



# *'Ike Wai*

*Securing Hawai'i's Water Future*

## YEAR 4 ANNUAL REPORT

REPORTING PERIOD

JANUARY 1, 2019 TO DECEMBER 31, 2019

Award Number: OIA1557349

PI/PD: Gwen Jacobs

June 1, 2016 to May 31, 2021



# TABLE OF CONTENTS

<b>I. 'Ike Wai Year 4 Annual Report Information .....</b>	<b>1</b>
<b>II. Overview .....</b>	<b>1</b>
A. Vision, mission, and goals of the project.....	1
B. Accomplishments achieved during the reporting period.....	2
C. Intellectual merit and broader impacts .....	6
D. Challenges, novel opportunities, and changes in strategy .....	8
<b>III. Research and Education Program .....</b>	<b>9</b>
A. <b>Goal 1.</b> Develop and validate improved conceptual models of subsurface water distribution and flow within and through Pearl Harbor and Hualālai aquifers systems (in order to develop a framework to sustainably manage groundwater resources in both regions).....	9
B. <b>Goal 2.</b> Develop a new data and modeling platform for Hawai'i volcanic hydrogeology, economic modeling and decision support.....	37
C. <b>Goal 3.</b> Education and Workforce Development Focus: Establish an integrated set of pathways to train and develop a diverse cohort of students, post-doctoral and faculty researchers at UHM and UHH to address Hawai'i's water challenges.....	71
<b>IV. Solicitation-Specific Project Elements .....</b>	<b>78</b>
A. Workforce Development .....	78
B. Diversity.....	78
C. Partnerships.....	79
D. Collaborations .....	81
E. Sustainability .....	82
<b>V. Broadening Participation.....</b>	<b>84</b>
<b>VI. Expenditures and Unobligated Funds.....</b>	<b>85</b>
<b>VII. Special Conditions.....</b>	<b>85</b>
<b>VIII. Response to External Evaluation Recommendations .....</b>	<b>85</b>
<b>IX. Tabular/Graphic Representation of Progress to Date .....</b>	<b>93</b>
<b>X. Appendix A: Abbreviations and Hawaiian Language Terms .....</b>	<b>95</b>

## I. 'Ike Wai Year 4 Annual Report Information

**RII Track-1:** 'Ike Wai: Securing Hawai'i's Water Future  
NSF Award Number: OIA-1557349

**Award Start Date:** June 1, 2016  
Principal Investigator: Gwen Jacobs University of Hawai'i

**Reporting Period:** January 1, 2019 to December 31, 2019

## II. Overview

### A. Vision, mission, and goals of the project

**Vision:** Water resource management in Hawai'i is sustainable, responsible and data-driven. Scientific, cultural and social dimensions to the problem of water security are integrated in a transparent, stakeholder-driven and rigorous water research enterprise in Hawai'i.

**Mission:** To ensure Hawai'i's future water security through an integrated program of research, education, community engagement and decision support.

**Goals:** 'Ike Wai has the potential to be a transformational project for the University of Hawai'i, the state, and for organized research units such as the University's Water Resources Research Center (WRRC). The project's promise is to be transformative *scientifically* in terms of the knowledge base of a critical resource, to transform capacity, in terms of the human, physical and computational capital to perform cutting-edge water research, and socially, to threshold a new level of partnership between the academic community and stakeholders in Hawai'i. The specific goals of the 'Ike Wai project are:

**Goal 1:** Collect new hydrological and geophysical data on the two study sites to address data gaps in our understanding of subsurface structure and flow.

**Goal 2:** Develop a new data and modeling platform for Hawai'i volcanic hydrogeology, economic modeling and decision support.

**Goal 3:** Establish an integrated set of pathways to train and develop a diverse cohort of students, post-doctoral, and faculty researchers at UHH and UHM to address Hawai'i's water challenges.

**Participating Units.** ‘Ike Wai is a complex project with multiple internal and external participants. Two campuses, UH Mānoa (UHM) and UH Hilo (UHH) are the key institutional participants. At UHM, the units include Water Resources Research Center (WRRC; for overarching water resource management), Hawai‘i Institute of Geophysics & Planetology (HIGP; for geophysics and geology), UH Economic Research Organization (UHERO; for water economics), Dept. Civil and Environmental Engineering (for groundwater modeling), Dept. Electrical Engineering (sensor development and deployment), the College of Social Sciences (CSS) for stakeholder engagement and the Laboratory for Advanced Visualization and Applications (lava.manoa.hawaii.edu), led by Jason Leigh, for visualization. At the UH System (UHS) level, Information Technology Services (ITS) provides senior leadership (PI, Jacobs) and the computing, data management, analysis and dissemination software infrastructure. UHH houses education efforts in Data Science across four participating departments: Computer Science, Mathematics, Marine Science and Economics and Business.

**Leadership.** In Year 3, the Leadership Team was reorganized to reflect new senior personnel joining the team. Punehei Lipe led the IHLRT and Tom Giambelluca led climate and recharge expertise. Peter Mouginis-Mark stepped down from his role as Co-PI and was replaced in Year 4 by Nicole Lautze. The Leadership Team now includes the following personnel:

- Gwen Jacobs: PI
- Barbara Bruno: co-PI (Workforce & Education)
- Helen Turner: co-PI Chaminade University
- Greg Chun: Community Engagement
- Aly El-Kadi: Groundwater Modeling
- Tom Giambelluca: Geography; Climate & Rainfall
- Velma Kameoka: Mānoa Assoc. Vice Chancellor for Research
- Kevin Kelly: EPSCoR Managing Director
- Nicole Lautze: Geochemistry
- Punihei Lipe: Native Hawaiian Affairs Program Officer and Interim Director Inst. for Hawaiian Language Research & Translation (IHLRT)

## **B. Accomplishments achieved during the reporting period**

### **Capacity Building in Personnel:**

In response to Site Visit recommendations, **Drs. Tom Giambelluca** and **Donald Thomas** (UHM) have joined the project as senior leaders and will lead identification and implementation of integrative activities across the program elements including publications and proposals. **Dr. Roberto Pelayo** (UHH) has taken a position at University of California Irvine but will remain involved with the project as an External Advisory Board member.

### **2019 Graduates:**

**Tamra Oyama** received her MS in Electrical Engineering from UHM and with multiple job offers, is now working for Hawaiian Electric.

**Taylor Viti** graduated with his MS from the Hawai'i Institute of Geophysics and Planetology (HIGP) at UHM. He is now working for Associate Dean Chip Fletcher on various aspects of sea-level rise in Hawai'i.

**Jared McLean** received his MS in Information and Computer Science from UH Mānoa and has been hired as a software engineer in the Cyberinfrastructure Group in Information Technology Services, UH System.

### **Awards and Recognition:**

**Niels Grobbe** has continued conducting hydrogeological feasibility studies using seismoelectric surface waves, for which he has won the Innovation Award at the SEG-ICEG 5th International Conference on Engineering Geophysics in the United Arab Emirates.

New UH Hilo faculty member **Grady Weyenberg** received his first NSF award (Award #: 1916496) for his project titled: *Collaborative Research: Principal Component Analysis over Tree Spaces and Its Applications to Phylogenomics*.

**Roberto Pelayo's** (UHH) educational and research track record was recognized as part of a series that honors a Latinx mathematician every day during Hispanic Heritage Month (<http://lathisms.org/october-9th-2019.html>><http://lathisms.org/october>).

Post doc **Ahmed Elshall** received an Outstanding Reviewer Award from Environmental Research Letters. He also published a feature article in the Multidisciplinary Digital Publishing Institute (MDPI) journal Water.

Post doc **Sheree Watson** received a 2019-2020 AAAS Science Technology Fellowship from the USGS, Director's Office of Science Policy Integrity.

**Diamond Tachera** (Graduate Student, UHM) received a UCAR Next Generation Fellowship for Diversity, Equity, and Inclusion. This fellowship for graduate students who intend to finish their Ph.D. in the atmospheric and related Earth system sciences and are committed to championing increased diversity, equity, and inclusion is based at UCAR in Boulder, Colorado.

MS Graduate student **Jared McLean** (UHM) received the Science Gateways Community Institute Young Professional of the Year 2019 award for notable achievement in the advancement of science gateways. Jason Leigh served as his thesis advisor.

UH Hilo undergraduate student **Alexa Runyan** won the Pacific Congress on Marine Science and Technology (PACON) award for the project involving the best use of technology, with a Pacific focus, for her project *“Creating Three-dimensional Models of Coral Reefs at Papahānaumokuākea Marine National Monument Using Structure-*

*From-Motion Software*". She presented this work at the 2019 UH Marine Option Program Symposium. John Burns, UHH served as her advisor.

UH Hilo undergraduate student **Lindsey Howells** received a \$900 travel award to present her poster "*Pepeiao: a machine learning tool for training environmental audio classifiers*" at the 2019 American Ornithology Meeting in Anchorage, AK. Grady Weyenberg, UHH is Lindsey's advisor.

## **Key Research and Education Accomplishments:**

### **1. Geophysics**

#### **Self-potential, ambient noise seismics, magnetotellurics, Kona, Big Island:**

Self-potential data (SP) at three study sites: 2 coastal areas, Queen Lili'uokalani Trust (QLT) and Natural Energy Lab Hawai'i Authority (NELHA), were acquired in Year 4 to study the dynamics of groundwater dependent ecosystems (Anchialine Ponds) and the flow and distribution of groundwater in these areas (Objective 1.1). The QLT survey has identified the major groundwater flow paths feeding into the Anchialine pond system (Objective 1.2). SP data was also conducted at Palani Ranch to study the high/low divide and its structural impact on fluid flow (Objective 1.2). This survey covered a major part of the same acquisition line as for which magnetotelluric data was acquired and inverted in Year 3. A total of 342, 226, and 145 measurements were performed at QLT, NELHA, and Palani Ranch representing ~ 13 km total survey length.

As part of his MS thesis work, graduate student Taylor Viti has further developed and tested a 1D MT Bayesian inversion framework that allows for uncertainty quantification (UQ). He has further customized this framework to explore inference of porosity and salinity values from the MT field data in order to extract hydrogeological parameters with sufficient accuracy, such that they can be used directly as input data for, or as a means to constrain or validate, the hydrological models.

**Self-potential (SP), ambient noise seismics, Schofield Dam, O'ahu:** SP and seismic surveys were conducted to study the nature of the high/low divide causing anomalous jumps in head levels at the so-called 'Schofield Dam', an important boundary condition for the Pearl Harbor aquifer models (Objective 1.1). Both data sets are currently being processed, and follow-up targeted 3D nodal-based Electrical Resistivity Tomography (ERT) and Induced Polarization (IP) studies will be deployed.

**Education:** Grobbs has established a new summer field school program: '*Hydrogeophysics in Volcanic Environments*', which was taught for the first time in 2019 (Objective 3.2). Five graduate students, including 1 mainland student, participated in the course that teaches the entire hydrogeophysical workflow: cultural and hydrogeological setting, hydrogeophysical theory, data acquisition design and field data acquisition, processing, inversion, and hydrogeological interpretations, as well as both oral and written communication skills. As part of this course, 385 SP-measurements were collected along 7680 m of profiles in the

relic stream valley of Makapu'u (O'ahu). Ambient seismic noise data was also collected over a 4-day deployment and the students conducted a small-scale 3D ERT/IP survey. The processed results not only served as support for the course, but are also about to be submitted for journal publication in *Water Resources Research*, in collaboration with all the participating students.

**Marine Geophysics CSEM Survey:** Postdoctoral scholar Eric Attias completed 2-D isotropic/anisotropic CSEM inversion models using data collected during his Year 3 marine geophysics survey offshore the entire region parallel to the Hualālai aquifer. A reduced to pole (RTP) total magnetic field profiles (Objective 1.1) that image the electrical resistivity as well as magnetic signature of submarine groundwater structures, which extend up to 4 km offshore of Kailua-Kona was also completed. These findings confirm Dr. Donald Thomas' (new sr. hydrogeology faculty member) drilling results (yet to be published) and contradicts previous USGS models, thereby, suggest a new model for land-to-sea transport mechanism of groundwater in volcanic settings. A paper describing the first evidence of large-scale submarine groundwater reservoirs offshore the island of Hawai'i will be submitted in May 2020.

## 2. Economics

A groundwater (GW) management optimization decision support model and framework was further developed, tested in the community, and results formalized for publication (Objective 2.3). Team members collaborated with Sumida Farms to evaluate constraints to sustain and restore spring flow to their watercress farm, as well as develop a tradeoff curve between pumping and impacts on spring flow. They developed stakeholder-driven future land use scenarios representing futures of urban, agricultural, and conservation lands and worked with USGS to run these through their water balance model under the current and Representative Concentration Pathway (RCP) 8.5 mid-century climate scenarios. These scenarios were evaluated in terms of changes in sustainable yield using the groundwater optimization model. Economic valuation of scenarios under several future water consumption scenarios was done using a groundwater replacement cost methodology. The team has one peer-reviewed article in second review and two to be submitted in February 2020. See Section 2.3.1 on p. 54.

## 3. Cyberinfrastructure

The CI team published and presented 4 'Ike Wai related conference papers related to decision support and streaming data infrastructure. See Section 2.1.4 on p. 37.

Cleveland and Arisdakessian, a graduate student in Dr. Frank's team, added bioinformatic computational workflows to include 16s, ITS and demultiplexing pipelines to analyze the sampling dataset by Dr. Watson from Dr. Frank's team.

Cleveland and McLean deployed a production decision support application for

calculating island recharge based on user-defined land use types and two climate scenarios (<https://recharge.ikewai.org>).

#### **4. Education and Curriculum**

In response to a site visit recommendation, the 'Ike Wai mentoring cascade was expanded to include faculty as mentees. New, untenured investigators can now request a senior, tenured faculty mentor from within or outside the 'Ike Wai project team (Objective 3.3).

Three geoscience education articles have been published on the topics of classroom observations at UH Mānoa, place-based teaching at UH Mānoa, and informal place-based geoscience education (Activity 3.3.1, p. 74). Two additional manuscripts on the topics of Individualized Development Plans and the Undergraduate Scholars Program have been drafted and are on track for submission in early 2020 (Activity 3.7.1, p. 77).

#### **5. Publications**

'Ike Wai researchers published 23 peer reviewed journal articles during 2019 seven of which received support form the project.

### **C. Intellectual Merit and Broader Impacts.**

Intellectual Merit: We will collect new geological, hydrological, and geophysical data at previously unavailable spatio-temporal resolution to provide actionable models of Hawai'i's aquifers, water flow, and transport processes (Objective 1). Geophysical imaging will provide new high-resolution 3D maps of geologic structures. Real-time down-well monitoring will support analysis of aquifer volume and hydraulic conductivity estimations. Flow and aquifer connectivity measurements will integrate three approaches: submarine GW Discharge (SGD) analysis, geochemistry and, innovatively, the use of microbial diversity as a GW tracer. We will create a transformative knowledge resource and modeling platform for water research and decision support (Objective 2). The 'Ike Wai Integrated Knowledge Environment (IKE) will be a data repository, support numerical modeling with High Performance Computing, and advanced data visualization, creating a decision support tool for our water enterprise. IKE will be populated with new data, previously untapped legacy/historical agency data, and indigenous Hawaiian knowledge. As an integral part of the field data collection, sensor fabrication, and data analysis, our education program will build an inclusive and diverse pipeline of future water researchers and policymakers (Objective 3). Our Pacific island culture and Hawai'i's pressing water issues frame multi-level efforts in diversity and community engagement that span these objectives. 'Ike Wai assembles a diverse team of hydrogeophysicists, modelers, volcanologists, engineers, visualization experts, social scientists, and educators, including seven strategic new faculty hires in the University of Hawai'i (UH) System. The three Objectives will be accomplished through five focal activities: (a) Develop new conceptual models of water distribution and flow within the aquifers that account

for Hawai'i's volcanic geology; (b) Identify fundamental data and knowledge gaps about water that will impact economic growth and development; (c) Develop tools to allow decision makers to make informed choices about water resource management; (d) Provide an inclusive STEM pipeline to develop diverse water scientists, data scientists, and policymakers; (e) Provide an improved model for volcanic island hydrology and water resources in Hawai'i that is extensible to other Pacific volcanic islands.

Broader Impacts: Hawai'i depends exclusively on local water. 'Ike Wai will provide data and models that address the grand challenge of water sustainability. A diverse workforce of data scientists and water researchers will work in concert with the community, government and business to inform decision makers with high-quality data and predictive capacity. The resulting new data-to-knowledge paradigms for volcanic island sustainability will be extensible to other Pacific locales. The project incorporates indigenous and local communities, and its robust, inclusive and diverse human capital pipeline of undergraduates, graduate students, postdocs and junior faculty will address water challenges at the academic and policy level.

**Advance discovery and understanding while promoting teaching, training, and learning.** Research activities in geophysics, geochemistry, traditional/historical knowledge and sensor development have involved fifteen graduate students and four post doctoral trainees. Each trainee position (including junior faculty) has an active role in a mentoring cascade and frequent professional development opportunities offered by the Education team (Bruno). Junior faculty are mentored both scientifically and in skills sets such as laboratory management, proposal writing, and navigation of university systems and the tenure process. Teaching is being actively promoted by 'Ike Wai. All UHH and most UHM 'Ike Wai faculty have active teaching loads and several (Grobbe, Lee) incorporated 'Ike Wai related materials and concepts in classes.

**Broadening participation of under-represented groups (See Section IV.B Diversity).** A key focus of 'Ike Wai has been partnering with Native Hawaiian-serving organizations to build pathways for Native Hawaiian and other diverse local students interested in STEM careers. Our active partners during this reporting period include Native Hawaiian Student Services (NHSS) and the Kapi'olani Community College (KCC) Native Hawaiian Advancement Office. These partnerships are already starting to bear fruit. Both of our Undergraduate Fellows (Highest Level of Scholars program) are graduating seniors who are applying to graduate school for Fall 2019, and both began their pathway toward STEM careers through our joint programs funded with KCC (See Activity 3.2.1 - summer bridge).

**Broaden dissemination to enhance scientific and technological understanding.**

The 'Ike Wai Science Gateway (Objective 2.1) serves as the central location for data management, computation, analysis, visualization, and dissemination of all data and data products generated by the 'Ike Wai project. It serves as the central integration point of the project as well as the dissemination and access point for all

data, models, and data products. An exemplar data product is high resolution (250-m) monthly gridded rainfall and estimated uncertainty maps from up-to-date, quality controlled, tabular rainfall data. The CI team and Giambelluca's team have developed an application to automate the production of these maps. The software system queries data from all known online sources, performs data screening, gap-filling, interpolation, and error analysis. The decision support tool developed by the CI team and USGS provides an interactive interface to study the effects of land use change on recharge. This tool will help water managers demonstrate and explain complex development and conservation scenarios.

The EPSCoR Website (<http://www.hawaii.edu/epscor/>) and Social Media (Objective 2.4): The addition of a communications director was instrumental in increasing the frequency and quality of public disseminations about 'Ike Wai research and education programs. In addition to our website and Facebook pages, the project's social media presence has expanded to include more content on Instagram, Twitter and LinkedIn. Internally University of Hawai'i (UH) News produced 12 EPSCoR-focused stories. News about the project was featured in UH and partner newsletters and Hawai'i EPSCoR was featured in a 30-minute Voice of the Sea episode – Native Forests - that aired in Hawai'i, American Samoa, Guam, Palau, the Federated States of Micronesia and the Marshall Islands.

#### **D. Challenges, novel opportunities, and changes in strategy**

**Specific challenges:** Right of entry (ROE) permits to two remaining field sites of interest are pending. On Hawai'i Island coastal access to Kamehameha Schools land has been approved and we are awaiting delivery of the ROE permits. This access will allow for the deployment of a SGD sniffer instrument and geophysical surveys at the north end of the hi-low divide. To gain access to state land in central O'ahu to conduct further geophysical studies 'Ike Wai leadership testified before the Agribusiness Development Corporation (ADC), the land management division of the Hawai'i Department of Agriculture, and was granted approval to conduct our research. We are now working with ADC to secure the permits.

**Novel Opportunities:** The Hawai'i Data Science Institute (HIDSI) was launched in January 2018, co-directed by Jason Leigh and Gwen Jacobs (<http://datascience.hawaii.edu>). The HIDSI is focused on data science research and training and hosts a seminar series and a series of hands on training workshops in basic data science and computational skills. 'Ike Wai team members are participating in the training workshops and seminar series. These events are shared with the 'Ike Wai Data Science team at UH Hilo via CyberCANOE. These activities will continue in Years 4 and 5.

**Faculty hiring update:** All of the faculty hiring proposed for the 'Ike Wai project was completed in Year 4 (Objective 3.5). UH Hilo completed its final faculty recruitment commitment with the hiring of Dr. Sukhwa Hong into the College of Business and Economics. Dr. Hong completed his post-doc at Virginia Tech and started as an Assistant Professor in Data Science and Business Administration at

UH Hilo on August 1, 2019. He joins three previous hires in the Data Science program, Grady Weyenberg (Mathematics), Travis Mandel (Computer Science) and John Burns (Marine Science).

These four faculty continue to develop the UHH Data Science curriculum, as well as provide academic and summer research experiences for undergraduates. Sukhwa's expertise is in text analytics (data mining on text-based data) and he is currently preparing new business analytics courses that will be submitted to the university approval this year.

New Faculty & Professional Staff Hires				Status	Y1	Y2	Y3	Y4	Y5	Total
<b>Hilo</b>					0	2	1	1	0	4
Computer Science	Travis Mandel	Hired			8/17					
Mathematics	Grady Weyenberg	Hired			8/17					
Marine Science	John Burns	Hired				8/18				
Economics/Business	Sukhwa Hong	Hired					8/19			
<b>Manoa</b>					0	3	0	0	0	3
Economics	Leah Bremmer	Hired				7/17				
Geophysics	Niels Grobbe	Hired				11/17				
Hydro Engineer	Jonghyun Harry Lee	Hired				10/17				
<b>System</b>					1	0	0	0	0	1
Software Engineer	Sean Cleveland	Hired			3/17					
<b>Total Hires:</b>					1	5	1	1	0	8

**Table 1:** Boxes indicate the proposed schedule for or new 'Ike Wai faculty hires with actual start dates in text. All of the proposed hires have been completed and 75% were on schedule.

### III. Research and Education Program

Here we describe the major accomplishments and research findings during the reporting period organized by the major goals or focus areas of the project, as put forth in the original proposal and approved strategic plan.

**Goal 1:** Develop and validate improved conceptual models of subsurface water distribution and flow within and through Pearl Harbor and Hualālai aquifers systems (in order to develop a framework to sustainably manage groundwater resources in both regions).

**Objective 1.1:** Image subsurface geologic structures and/or the location of groundwater in 3 to 4 target areas of Hualālai and Pearl Harbor aquifers systems using geophysical techniques.

**Activity 1.1.1:** Perform synthetic simulations of MT, gravity, ERT/IP, SP, and seismic geophysical techniques for 3 to 4 target areas in the Pearl Harbor and Hualālai aquifer systems in order to identify optimal field method(s). (Grobbe, Barde-Cabusson)

**Results:** We have further developed and tested our 1D MT forward modeling and Bayesian inversion code, using the ‘R’ programming language and STAN (Activity 1.1.1 and 1.1.3). We have expanded the software’s capabilities to not only invert for the 1D subsurface electrical resistivity distribution with uncertainty quantification (e.g., per station), but also to enable inference of hydrogeological parameters of interest, such as rock formation porosity and pore fluid salinity. Figure 1 shows the porosity and salinity estimation results, starting with a 1D bulk resistivity profile extracted from the 2D MT inversion result (Fig. 7, p. 16) for the Palani Ranch field data survey, at around 41 km along profile. The underlying physical model used in this Bayesian parameter estimation problem is Archie’s law (relating bulk resistivity, porosity, and fluid resistivity), which was originally developed for sedimentary environments, but demonstrated by e.g. Rai and Manghani (1981) to be applicable to Hawaiian basalts. Further details on the statistical model used for this parameter estimation problem can be found in (Viti, 2019, MS thesis, UH Mānoa). The ultimate goal would be to estimate these hydrogeological parameters with sufficient accuracy, such that they can be used directly as input data for, or as a means to constrain or validate, the hydrological models.

**Outputs:** 1D forward and inverse MT modeling code that uses the STAN software package. This code enables:

1D MT inversion results, i.e. the electrical conductivity distribution with depth, including Uncertainty Quantification (UQ) in a Bayesian framework,

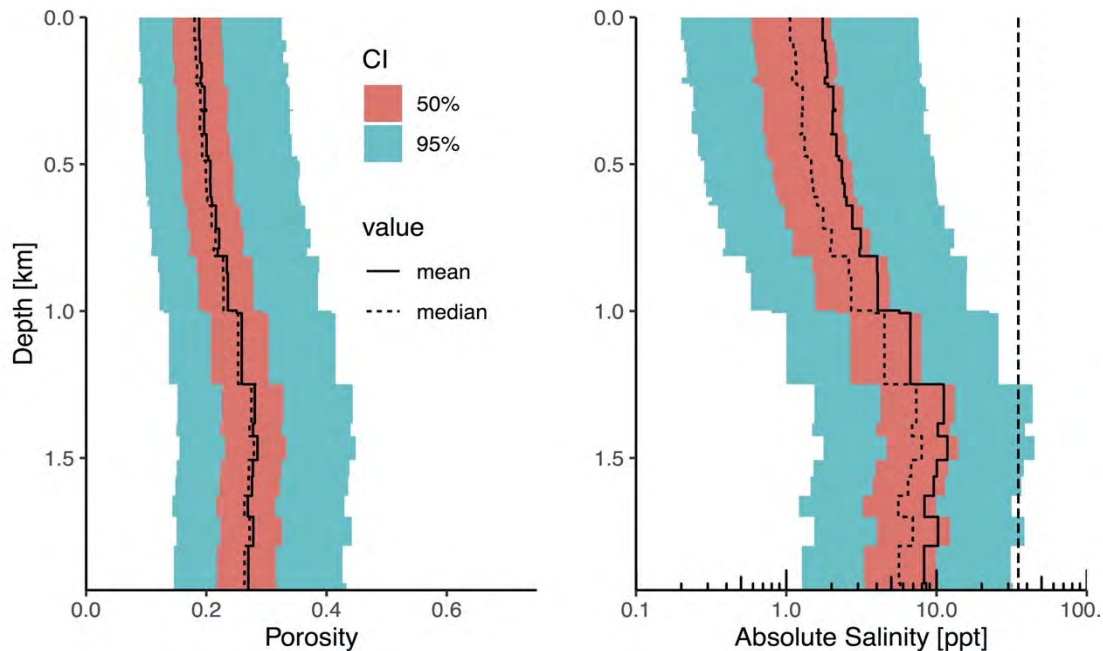
Hydrological parameter estimation, such as rock formation porosity, pore-fluid salinity (e.g., starting from electrical conductivity profiles obtained from MT data), including UQ.

**Publications and Papers:**

Viti, T., 2019, ‘A Magnetotelluric Investigation of Hawaiian Groundwater Systems in Kona, Hawai’i Island, Hawai’i, including Uncertainty Quantification’ (Viti, T. and Grobbe, N., 2020, to be submitted, Journal of Hydrology). MS graduate thesis.

Grobbe, N. and De Ridder, S.A.L., ‘Seismoelectric surface wave analysis for characterization of formation properties, using dispersive relative spectral amplitudes’, to be submitted in 2020.

**Outcomes:** Our code enables uncertainty quantification of 1D MT field data inversion results, with high flexibility and adaptability, e.g., allowing the use of different statistical modeling approaches and choices of priors. Furthermore, the code and its statistical framework is adaptable for hydrological parameter estimation problems, and we have already tested it for porosity and salinity estimation, a highly challenging inverse problem to uniquely solve; the importance of quantifying uncertainty during the interpretation stage and incorporation into hydrological models cannot be understated. The inferred 1D electrical conductivity distributions and hydrogeological parameters will serve as input parameters to



**Figure 1:** Posterior distributions of porosity (left) and absolute salinity (right), starting with a 1D bulk resistivity profile extracted from the 2D MT inversion result for the Palani Ranch field data survey, at around 41 km along profile. The vertical dashed line in the salinity plot indicates the salinity of seawater. Both the salinity and porosity distributions take on their maximum values between 1 km and 1.5 km, with the mean of salinity approaching seawater salinity.

hydrological models for the West Hawai'i aquifer system, and as a means to calibrate and validate hydrological modeling results. The MT data furthermore provides insight into the impact of the high/low divide on the groundwater system in Kona, and its hydrogeological properties.

**Activity 1.1.2:** Design geophysical survey, obtain land access permissions, and acquire field data. **(Grobbe, Barde-Cabusson)**

**Results:** Our geophysical study sites focus on three science questions (Q1-Q3):

1. What is the nature of the high/low divide (Hawai'i Island and O'ahu)?
2. What spatial hydrogeological variations exist along the western boundary of the Keauhou aquifer systems?
3. What are the characteristics of the valley fills on O'ahu and their impact on local hydrology? Field study sites are shown in Figure 2 below.

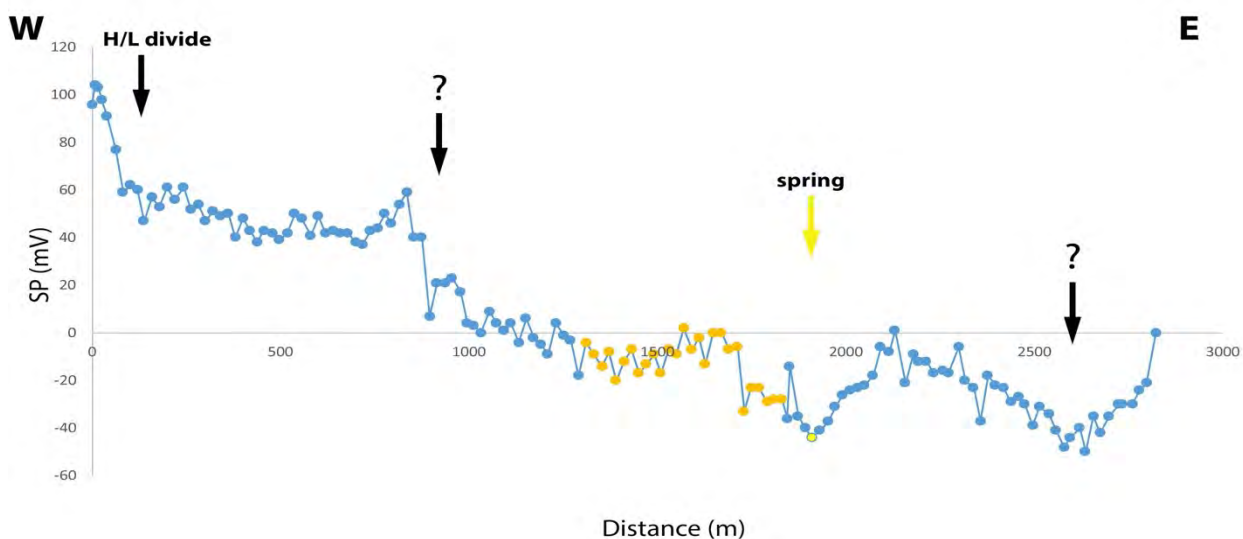
Below, we will display the results so far, focused on these 3 science questions.

Keauhou, Big Island:

Q1: *What is the nature of the high/low divide (Hawai'i Island and O'ahu)?*

At Palani Ranch, we acquired SP data along the lower portion of the MT profile previously acquired by Viti and Grobbe (middle of PAL2-PAL3 to PALB5-Fig. 7, p.16). The effect of the elevation variations on the SP signal, or so called

“topographic effect”, involves a constant linear SP/elevation relationship explained by a water table whose depth increases regularly with elevation in a homogeneous medium. In Figure 2, the left part of the plot corresponds to lower elevations. A global trend is observed with a decrease of the SP values with elevation (West to East). We note several jumps separating various sections of the plot, each section showing a similar trend. Those jumps can be interpreted as sudden variations of the water table depth and/or greater downward groundwater flow (vertical infiltration) associated to tectonic structures such as the high/low divide. The presence of multiple jumps could thus indicate multiple tectonic structures organized as a series of normal faults or perhaps a graben structure affecting the slope of Hualālai locally.



**Figure 2:** SP profile acquired in Palani Ranch, along part of the MT line. From East to West, the elevation is decreasing regularly and a typical inverse SP/elevation relationship is observed ( $-0.116$  mV/m calculated on the main trend with elevation information). The arrows highlight sharp variations of the SP signal possibly linked to sudden variation of the water table level. The westernmost variation correlates to the high/low divide proposed location and to the resistivity barrier highlighted at depth in the MT models. The four SP jumps could highlight the presence of multiple tectonic structures. Orange dots highlight a portion of the profile that was not linear in the field, producing some artifacts in the linear trend. Yellow dot marks a spring possibly guided by one of the tectonic structures.

Q2: What spatial hydrogeological variations exist along the western boundary of the Keauhou aquifer systems?

Self-Potential (SP) data collected at Queen Lili’uokalani Trust (QLT, Big Island) were referenced to the ocean and interconnected in order to create an SP map (Figure 3). The different colors of the map are interpreted as contrasts in the groundwater distribution. The blue zones (under 0 mV) observed on the map and connected to the QLT anchialine pond (white star), a groundwater dependent ecosystem of cultural significance, located at the coast, are interpreted as the most plausible groundwater flow directions feeding into the pond area.

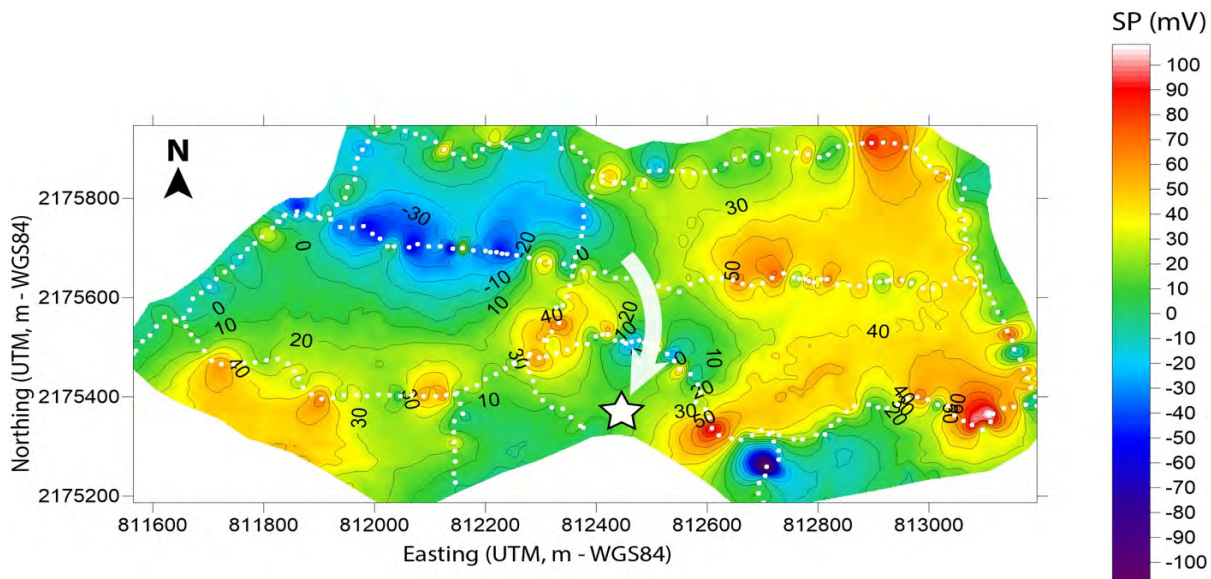
Subsequent SP data collection to extend this SP map to display a more regional

trend, will be carried-out at the end of January 2020, in order to confirm and further delineate, or rule out, the presence of a, or multiple, preferential groundwater paths from the mountain side to this anchialine pond. A journal paper including those geophysical results and cultural significance of anchialine ponds in the Hawaiian culture, is currently in preparation (*Barde-Cabusson et al., in prep.*).

Pearl Harbor, O’ahu:

Q1: What is the nature of the high/low divide (Hawai’i Island and O’ahu)?

New land access has been obtained (Dole Fruit Company and Agriculture Development Corp. (ADC) lands on the island of O’ahu, to study the nature of the hydrogeological structures at Schofield Dam, which is considered an analog to the high/low divide on the Big Island, as well as its impact on the characteristics and distribution of the groundwater system feeding into the Pearl Harbor aquifer. Dole Fruit Company lands offers access to an area of about 15 square kilometers crossing the northern dam, characterized by important variations in hydraulic



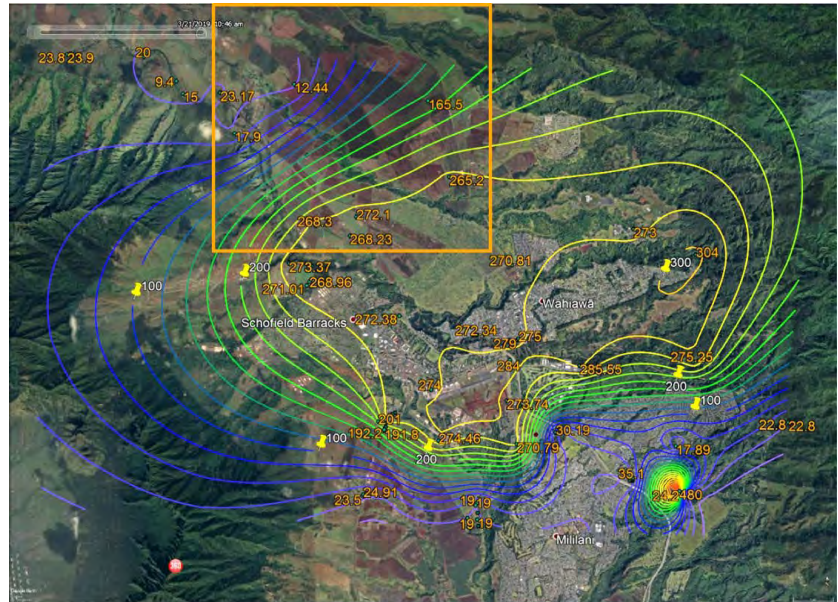
**Figure 3:** SP map created at Queen Lili’uokalani Trust, Big Island, displaying the most likely groundwater flow direction feeding into the anchialine pond area that is marked with the white star.

heads as observed in the wells distributed over the area (Figure 4).

SP and seismic geophysical surveys were designed to traverse and cover the full range of observed anomalous head levels in the area and acquired through November/December 2019 and are currently being processed (Figs. 5 & 6). We acquired 1884 SP measurements along ~ 38 km of profile (20 m spacing) to study the groundwater distribution and to determine the variations of the hydraulic heads levels between the wells. The seismic data acquired during a period of 18 days with 29 1-component nodes and 25 3- components nodes, will help us understand the nature of the structures causing those variations.

### Outputs:

- Keauhou, Big Island: [1] Self-Potential (SP) data collected at Queen Lili'uokalani Trust
- (Anchialine Ponds). SP map and hydrogeological [NG2] interpretation of the Anchialine pond area.
- SP data collected at Palani Ranch. Generated SP profile and joint-interpretation with MT profile at Palani Ranch.
- Pearl Harbor, O'ahu: [3] SP and ambient noise seismic geophysical survey data acquired at Dole Plantation Lands. A journal publication will be prepared once the SP data and Ambient Noise data have been processed.



**Figure 4:** Hydraulic heads interpolated from wells' information at the Schofield Dam. The yellow box indicates the location of Dole Fruit Co. lands where SP and seismic measurements were newly acquired in November/December 2019

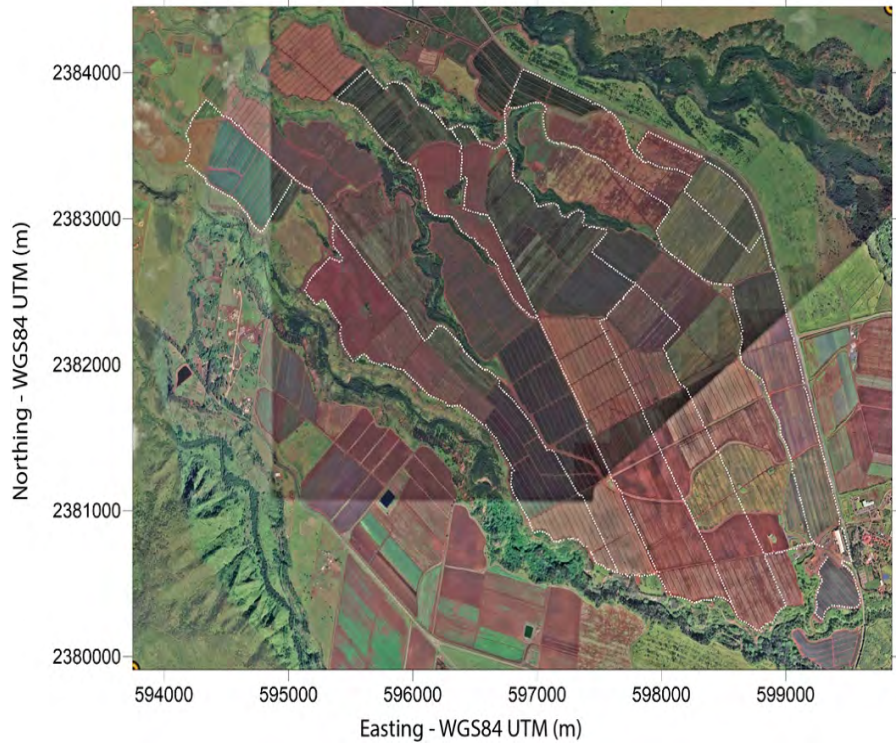
### Publications and Papers:

Grobbe, N. and Barde-Cabusson, S. (2019) 'Self-potential studies in volcanic environments: a cheap and efficient method for multiscale fluid-flow investigations'. International Journal of Geophysics, Article ID 2985824, 1-19, doi: <https://doi.org/10.1155/2019/2985824>.

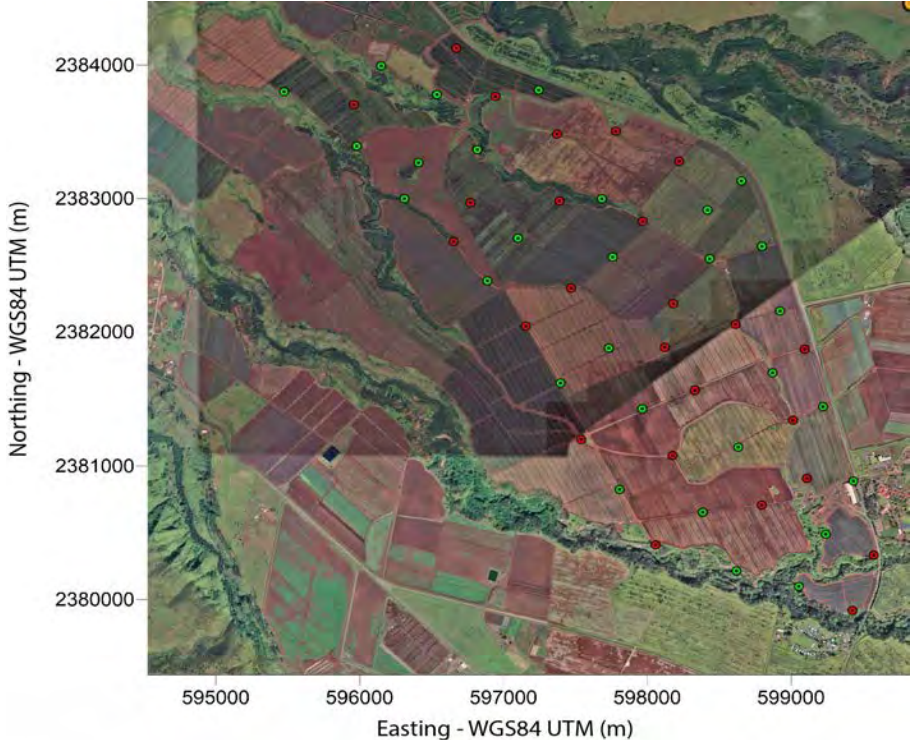
Barde-Cabusson, S., Finizola, A., and Grobpe, N. (2020, submitted) 'A practical approach for self-potential data processing, and elements of interpretation for volcanic and other environments'. In Prep.

Barde-Cabusson, S., Grobpe, N., et al., (tentative title): 'A self-potential study of a groundwater-dependent ecosystem (Anchialine pond), in Kona, West-Hawai'i, 2020, to be submitted.

**Outcomes:** Keauhou, Big Island: The self-potential data collected at the Anchialine pond area informs us on the subsurface fluid flow dynamics of this delicate groundwater-dependent ecosystem. It serves to identify the dominant and preferred groundwater flow paths feeding into this ecosystem, and any major anomalies in hydraulic conductivity, related to e.g. geological structures such as lava tubes. The site is located at the western boundary of the Keauhou aquifer system, Kona, Big Island, and our findings therefore provide information on this important boundary condition for the West Hawai'i groundwater modeling efforts (Q2). The SP results from Palani Ranch provide us with information on how the fluid flow paths are affected by the hydrogeological structure that makes up the high/low



**Figure 5:** White dots indicate the SP measurements, taken every 20 meters at Dole Fruit Company lands.



**Figure 6:** Seismic measurements. Green dots indicate 1-component seismic nodes and red dots refer to 3-component nodes across Dole Fruit Company lands

divide, and will be jointly interpreted with the MT data acquired along the same transect (Q1).

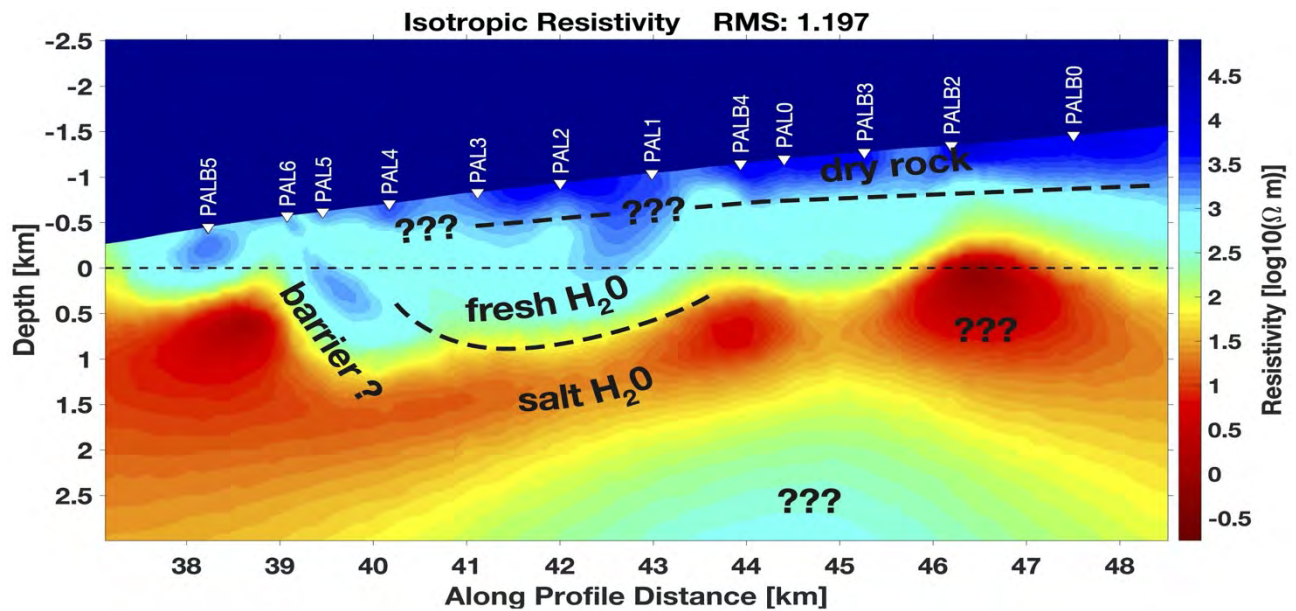
Pearl Harbor, O'ahu: The multi-geophysical studies (self-potential, ambient noise seismics) provide us with subsurface information necessary to understand the hydrogeological nature and impact of the high/low divide at Schofield Dam. This serves as an analogy to the high/low divide that we are studying on the Big Island (Kona), and enables comparison-contrast studies between the two sites (Q1). Furthermore, the Schofield dam forms an important hydrological boundary condition for the Pearl Harbor models, and the hydrogeophysical information will provide insight into the flow paths and groundwater distribution at this boundary, serving as important input data as well as a means to calibrate and validate hydrological models for the Pearl Harbor aquifer system.

**Activity 1.1.3: Model and invert newly obtained geophysical data. (Grobbe, Barde-Cabusson)**

**Results:** Keauhou, Big Island:

**Q1:** What is the nature of the high/low divide (Hawai'i Island and O'ahu)?

The inversion of the 2D magnetotelluric data collected at Palani Ranch, has been further fine-tuned and quality-controlled in conjunction with the 1D MT Bayesian inversion framework (Activity 1.1.1). Subsequently, we have carried out the most plausible hydrogeological interpretation given the available data for the study site, displayed in Figure 7. On the left, we can clearly identify the impact of the barrier on the distributions of fresh and saltwater. Furthermore, the contact between fresh and saltwater is clearly discernible, albeit within some transition zone, given the low-resolution characteristics of the magnetotelluric method, as is the transition



**Figure 7:** 2D inversion result, with the hydrogeological interpretations and inferred boundaries overlain.

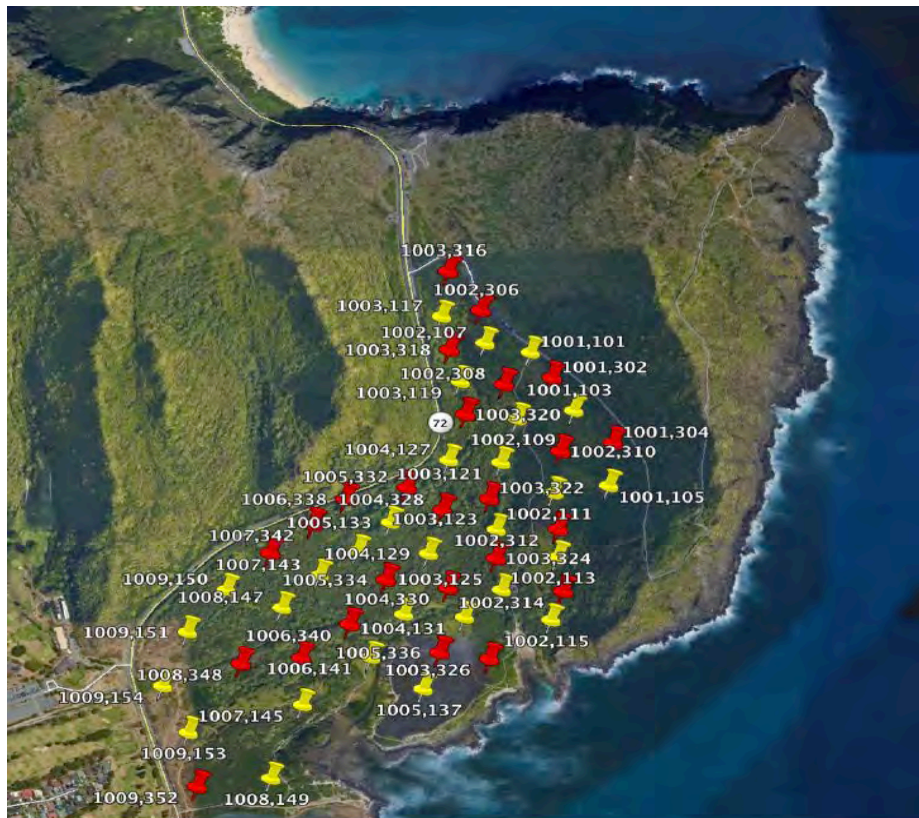
from unsaturated to fresh water saturated rock, especially on the right-side of the figure (higher topographic elevations). Our interpretation also displays several regions of interest that display features that we cannot readily explain given the available datasets.

Kaiwi Coast (Valley fill analog) O'ahu:

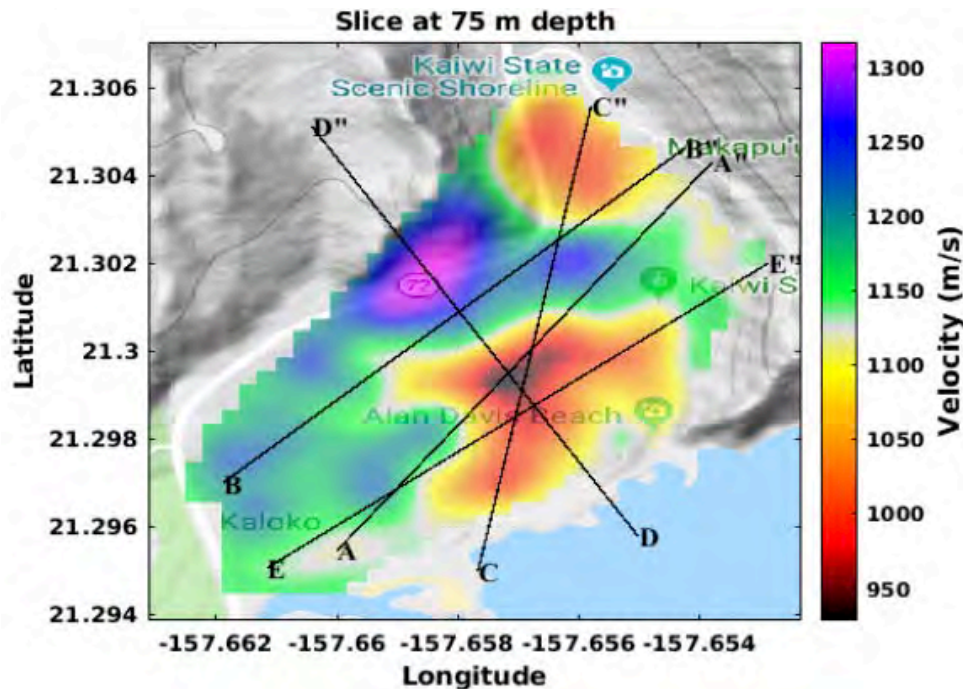
Q3: What are the characteristics of the valley fills on O'ahu and their impact on local hydrology?

As part of the new hydrogeophysics summer field school program at UH Mānoa, hosted for the first time in the summer of 2019, multi-geophysical data sets, including SP, ambient noise seismics, and a small, preliminary 3D ERT/IP survey, were acquired in an old stream valley on O'ahu, to study the role of valley fill vs. bedrock on groundwater flow. Figure 8 displays the acquisition geometry of the ambient noise data, with red pins corresponding to 3-component seismic nodes (3C; measures both the vertical and the two horizontal components of the ground particle motion) and yellow pins to 1-component seismic nodes (1C; measures only the vertical component of the ground particle motion).

Figure 9 shows an ambient noise surface wave tomography result obtained via cross-correlation interferometry and subsequent surface wave group velocity dispersion analysis of the recorded noise data (after pre-processing). This figure



**Figure 8:** Acquisition geometry of the ambient noise data. Red pins correspond to 3C nodes and yellow pins to 1C nodes.

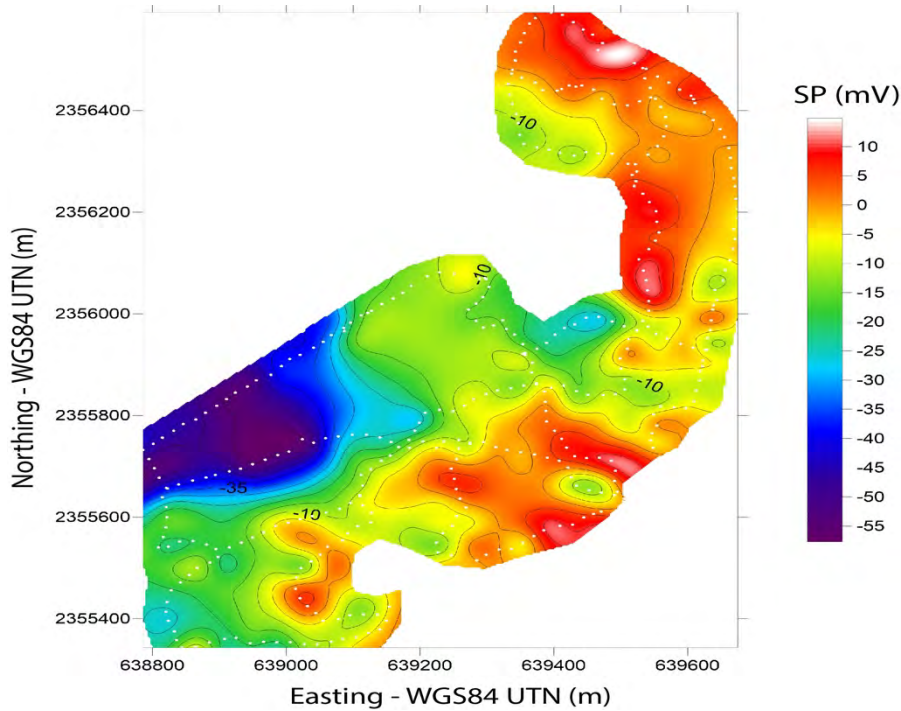


**Figure 9:** A- showing the shear wave velocities at 75 m. depth obtained via ambient noise surface wave tomography, in an old stream valley at the Kaiwi coast, Oahu. The results clearly highlight the variations between slower sediments and fluid filled formations, and the faster, underlying basaltic bedrock.

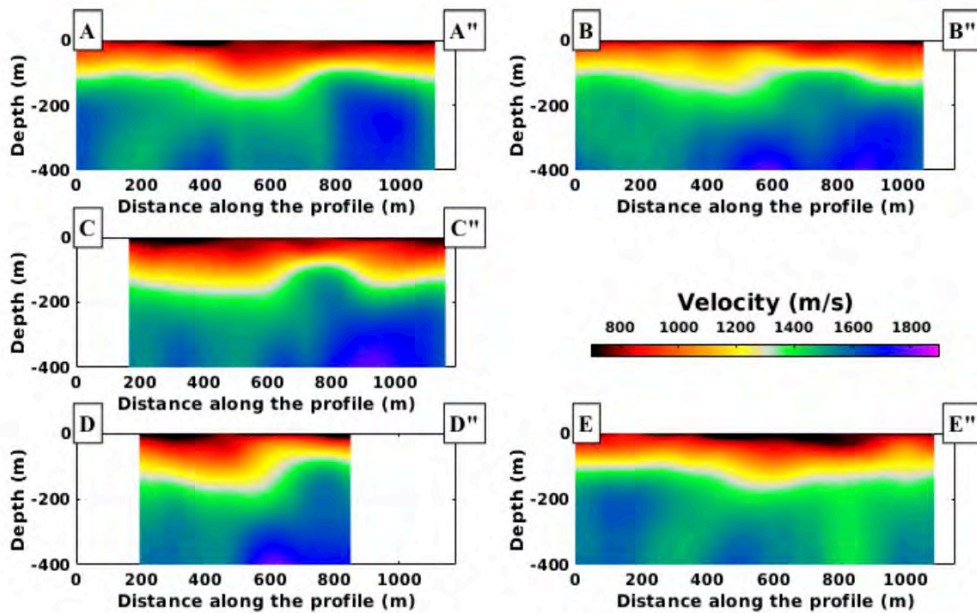
displays the seismic shear wave velocities at about 75 m. depth, with the colder colors corresponding to faster velocities, i.e. bedrock, and the warmer colors to slower velocities, i.e. sediments and most likely more water-saturated formations. We can clearly identify the contact between the deeper bedrock underlying the sediment infill of the old stream valley and coastal plain. Figure 11 shows vertical 2D depth slices (e.g., D-D'') obtained, via a Monte Carlo-type inversion using a neighborhood algorithm. These depth slices offer a different view on the geometry of the bedrock-sediment contact.

In addition, we have collected SP measurements covering the same area (Figure 10). Based on the gradients in SP values, and sharp contrast, we can observe that the old stream valley itself (red values in the top right) does not display much groundwater flow. Most of the fluids seem to be present and flow seems to occur, in the northwest of the figure (blue colors). These zones correspond nicely with the geographical location of the sediment-basaltic bedrock contact as identified in Figure 11. This suggests that the dominant flow seems to occur in the fractured bedrock.

It is important to realize that this stream valley seems less active than the stream valleys feeding into the Pearl Harbor aquifer systems, but these results seem to corroborate the hypothesis that on the leeward side of O'ahu, the bedrock is the dominant groundwater flow unit (the ridges of the valleys), as opposed to the alluvium fill of the valleys (which typically also contain zones of saprolite;



**Figure 10:** SP measurements of the Kaiwi coast, Oahu obtained during the hydrogeophysics summer field school program in 2019



**Figure 11:** displaying 2D depth inversions of the shear-wave velocities at Kaiwi coast, along the profiles indicated by the letters. We can recognize the contact and variations with depth between the sediments and the bedrock in the various profiles

weathered bedrock with low hydraulic conductivity). The results of this field school study are prepared for publication in the journal *Water Resources Research* (Grobbe et al., to be submitted).

**Outputs:** Keauhou, Big Island: inversion of the 2D magnetotelluric field data, as well as 1D Bayesian inversions and parameter estimations. Hydrogeological interpretation of the high-level aquifer system and the transitioning via the high/low divide to the low-level aquifer system

Kaiwi Coast, O'ahu: acquired multi-geophysical data sets, including SP, ambient noise seismics, and a small, preliminary 3D ERT/IP survey. Ambient noise surface wave tomography and Monte-Carlo-based depth inversions. Joint hydrogeological interpretation of this old stream valley on O'ahu.

***Publications and Papers:***

Lee, J., N. Grobbe, and P. and Kitanidis. Invited to a special issue in *International Journal of Environmental Research and Public Health*. "Large-Scale 3D Electrical Resistivity Tomography Using a Jacobian-Free Inverse Method." Submit late 2019

'A Magnetotelluric Investigation of Hawaiian Groundwater Systems in Kona, Hawai'i Island, Hawai'i, including Uncertainty Quantification' (Viti, T. and Grobbe, N., 2020, to be submitted, *Journal of Hydrology*). Viti, T. (2019) MS graduate thesis.

N. Grobbe, A. Mordret, S. Barde-Cabusson, L. Ellison, M. Lach, Y.-H. Seo, T. Viti, L. Ward, H. Zhang, A multi-hydrogeophysical study of an old stream valley at Kaiwi Coast (O'ahu, Hawai'i), using ambient noise surface wave tomography and self-potential data, *Water Resources Research*, To be submitted April 2020.

***Outcomes:***

Keauhou, Big Island: Insight into the impact of the high/low divide geological structure on the distribution of groundwater in West Hawai'i, Kona. Information on depth to the fresh/salt water interface, and an estimate of the depth of the aquifer system. Hydrological parameter estimates. All this information serves as input data, validation and calibration constraints to the hydrological models and conceptual models (Q1).

Kaiwi Coast, O'ahu: Understand the characteristics of the valley fills on O'ahu and their impact on local hydrology (Q3). This includes identification of the dominant groundwater flow paths (e.g. basaltic bedrock vs. valley fill) and comparison contrast studies between groundwater flow in stream valleys of the Ko'olau volcano and groundwater flow in the Pearl Harbor aquifer system (e.g., the Schofield dam area). This information serves to improve the conceptual models for O'ahu, as well as constrain hydrological models, particularly in light of providing an improved understanding of the role of chemically altered valley fills vs. bedrock flow on O'ahu.

**Activity 1.1.4:** Continuation of geophysical data acquisition based on key gaps identified from prior work. (**Grobbe, Barde-Cabusson**)

**Results:** The 2D MT interpretation from Palani Ranch on the southwestern slope of Hualālai Fig. 7, p. 16) identified several regions of interest that display features that we cannot readily explain given the available datasets. Plans to investigate include a 3D ambient seismic noise study of the high/low divide at Queen Lili'uokalani Trust later in 2020 (this site allows us to traverse the high/low divide significantly on both the high-level and low-level sides, as opposed to Palani Ranch which mainly focused on the high-level side due to access constraints).

Using the insights obtained from the SP and ambient noise seismic data about the dominant hydrogeological structures at Dole Plantation, we will design a targeted, 3D ERT/IP study for a more detailed understanding of these governing structures, and their impact on the groundwater system feeding into the Pearl Harbor watershed. The Schofield dam forms an important boundary condition for this watershed system and its accompanying water budget.

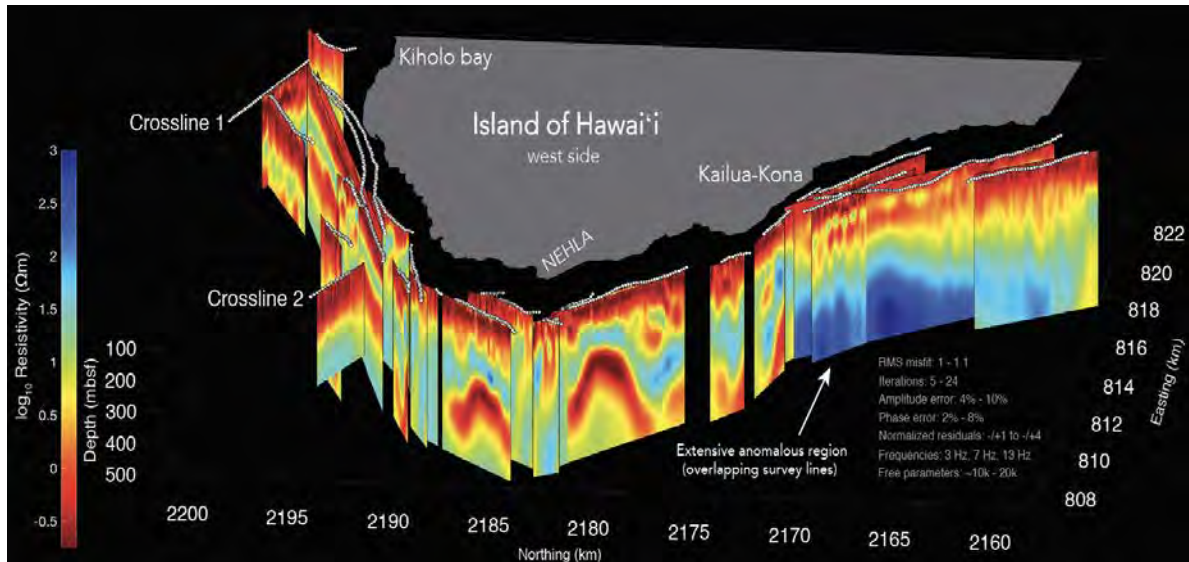
**Outputs:** SP profile collected at Palani Ranch (Fig. 2, p. 12)

**Outcomes:** The SP profile, in addition to the MT inversion results at Palani Ranch, provides a multi-physics insight into the groundwater system around the high/low divide, and zones of upwelling and infiltration of groundwater. The SP complements the information obtained from MT (primarily the distribution of subsurface fluids) in terms of providing insight into the flow dynamics of the groundwater system.

#### **Activity 1.1.5. Marine Geophysics (Attias)**

**Results:** The marine Controlled-source Electromagnetic Mapping (CSEM) geophysical method is sensitive to contrasts in bulk electrical resistivity, primarily controlled by porosity and pore fluid salinity. Therefore, submarine groundwater reservoirs will manifest as resistive anomalies embedded in a more conductive background because seawater occupies the pore space of the surrounding basalt. We completed 2-D isotropic (Fig. 12) and anisotropic CSEM inversion models, and the production of Reduction to Pole (RTP) total magnetic field profiles that image the electrical resistivity as well as magnetic signature of submarine groundwater structures, which extend up to 4 km offshore of Kailua-Kona. Additionally, the analysis of the MBES and backscatter data has been completed. Our results indicate the existence of substantial volumes of submarine groundwater reservoirs embedded in "layer-cake" formations (soil - low hydraulic conductivity; A'a flows driven fractured basalt - high hydraulic conductivity) exist offshore Kona between depths of ~130-500 mbsf, as indicated by co-located electrical and magnetic anomalies (*Attias et al., in prep*).

**Outputs:** 2-D isotropic and anisotropic CSEM inversion models; Production of RTP total magnetic field profiles; Electrical and magnetic signature of submarine groundwater structures. The results of this study were recently presented in (1) NSF 26th National Conference, and (2) at AGU Annual Meeting.



**Figure 12:** Fence diagram of 2-D CSEM isotropic inversion models for 26 survey lines. Blue shaded areas starting at ~130 mbsf represent resistive anomalies between ~50 - 1000  $\Omega\text{m}$ , associated with submarine groundwater in fractured basalt “layer-cake” structures. White circles denote Tx positions. Note the existence of a large-scale anomalous region south of Kailua-Kona, as indicated by the models of four overlapping survey lines.

### **Publications and Papers:**

Attias, E., D. Sherman, K. Ismail, D. Thomas, and S. Constable. Hawai'i groundwater transport mechanism revealed by marine electrical imaging. *Nature Geoscience* (to be submitted - May 2020).

Attias, E., D. Sherman, K. Ismail, B. Chase, B. Holz, K. Key, and S. and Constable. “First Evidence of Large-Scale Submarine Groundwater Reservoirs Offshore the Island of Hawai'i.” Submission Date: May 2020.

Attias, E., D. Sherman, and S. Constable. “Detection of freshwater plumes offshore Hawai'i using inversion modeling of controlled-source electromagnetic data”. *Geophysics* (to be submitted - July 2020).

Attias, E, et. al., “Volume Estimation of Submarine Groundwater Offshore the Island of Hawai'i Using CSEM, Hydrological, and Rock Physics Modeling.”, Submission Date: 2020

Attias, E, et. al., “Offshore Submarine Groundwater Imaging from Electrical and Magnetic 3-D Joint Inversion.”, Submission Date: Late 2021

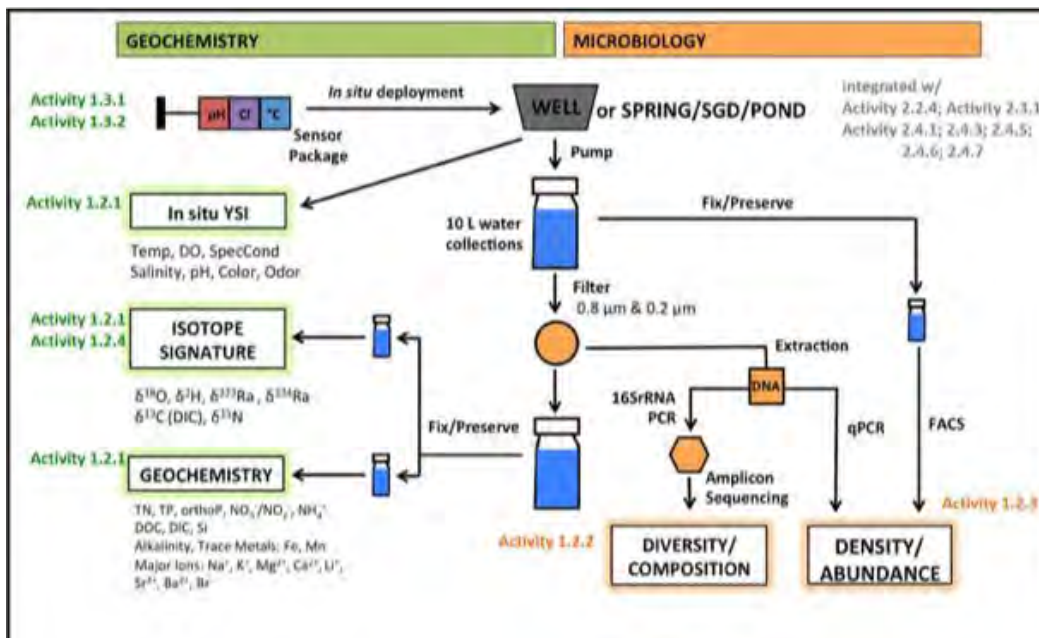
Attias, E., D. Sherman, K. Ismail, B. Chase, S. Holz, K. Key, and S. and Constable. “Detection of Freshwater Plumes Offshore the Island of Hawai'i from 2-D CSEM Inversion.”, Submission Date: Early 2021.

**Outcomes:** Our results indicate the existence of substantial volumes of submarine groundwater that are being transported in “layer-cake” formations (soil --> low hydraulic conductivity → barrier for freshwater transportation; fractured basalt -->

high hydraulic conductivity → transporting freshwater). These findings confirm Dr. Donald Thomas (new sr. hydrogeology faculty member) drilling results (yet to be published) and contradicts previous USGS models, thereby, suggest a new model for land-to-sea transport mechanism of groundwater in volcanic settings. This research captured the attention of the Wall Street Journal, who interviewed Dr. Attias for a video and a written article that they are currently working on. This article focuses on the potential of offshore groundwater to be used as a viable resource of freshwater, the technical complexities involved, and long-term implications.

**Objective 1.2:** Geochemistry, Microbial Tracers, and Submarine Groundwater Discharge (SGD): Map groundwater flow paths and improve estimates of connectivity and flux in the Pearl Harbor and Hualālai aquifer systems using integrated isotope, biogeochemical, and submarine groundwater discharge data by the end of Year 5.

The results we report here for Activity 1.2.2 and 1.2.3 are integrated across the tracers group (geochemistry, microbes, Fig. 13) as we synthesize our results in preparation for manuscripts and community stakeholder workshops, and reports.

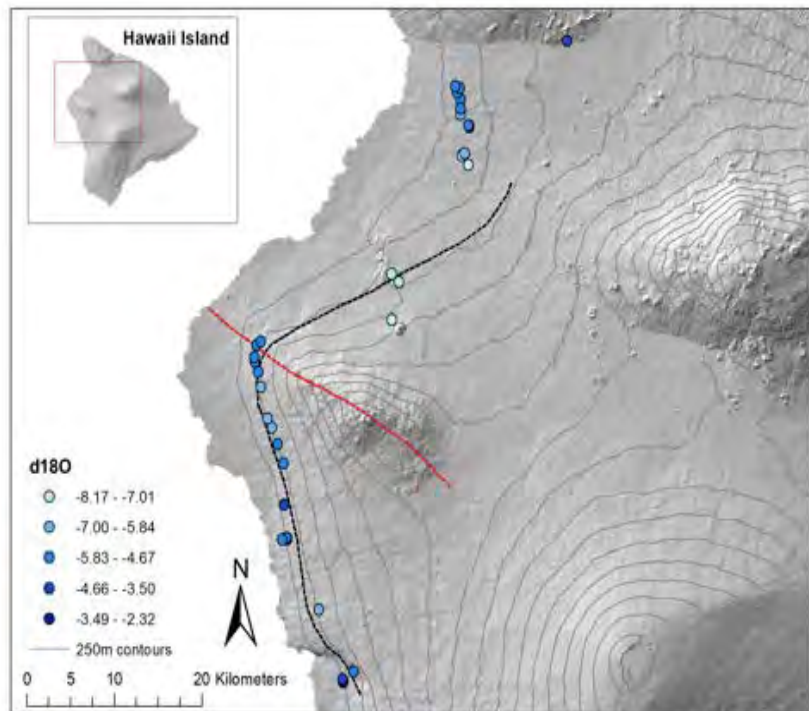


**Figure 13:** Schematic of sampling plan methodology for the geochemistry (green) and microbial (orange) investigations showing connections between these studies and the specific Activities within the strategic plan

**Activity 1.2.1:** Obtain geochemical data (major ions, trace elements, isotopes) to improve models of flow and connectivity. (**Dulai, Lautze, Tachera**)

**Results:**  $\delta^{18}\text{O}$  and  $\delta^2\text{H}$  vary spatially, possibly highlighting (the lack of) aquifer

boundaries (Fig. 14). North of the rift zone, isotopically light waters occur in Northern Kīholo and Southern Waikoloa possibly originating at higher elevations on Mauna Kea and/or Mauna Loa. Parker Ranch Deep well, located at the base of Kohala, is the most isotopically heavy. Wells in Lalamilo, Parker Ranch, and upper Waikoloa group together, possibly as a mixture of the isotopically light and heavy waters. South of the rift zone, spatial relationships do not seem to be as obvious as those north of the rift zone. Interestingly, Kahalu‘u, Keōpū, and wells along the rift zone (Hu‘ehu‘e and Makalei) plot together.



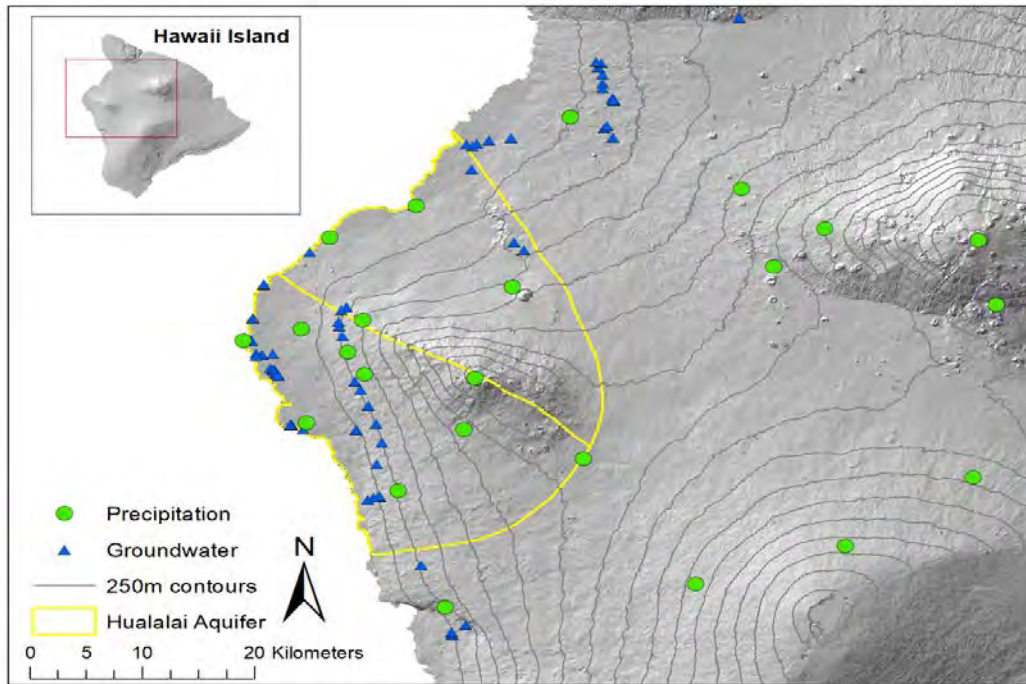
**Figure 14:** A map showing spatial variability of  $\delta^{18}\text{O}$  and  $\delta^2\text{H}$ .

More geochemical investigations might highlight if Kahalu‘u and Keōpū are thermally influenced, or if this is more of a seawater intrusion signature. Combining these results with those of the coastal geochemistry group to highlight aquifer boundaries (or the lack there of) is currently in process.

On O‘ahu, we deployed 13 precipitation collectors (8 in the Pearl Harbor aquifer and 5 elsewhere) and collected 42 data points. Second-year PhD student Diamond Tachera is researching the groundwater chemistry of West Hawai‘i.

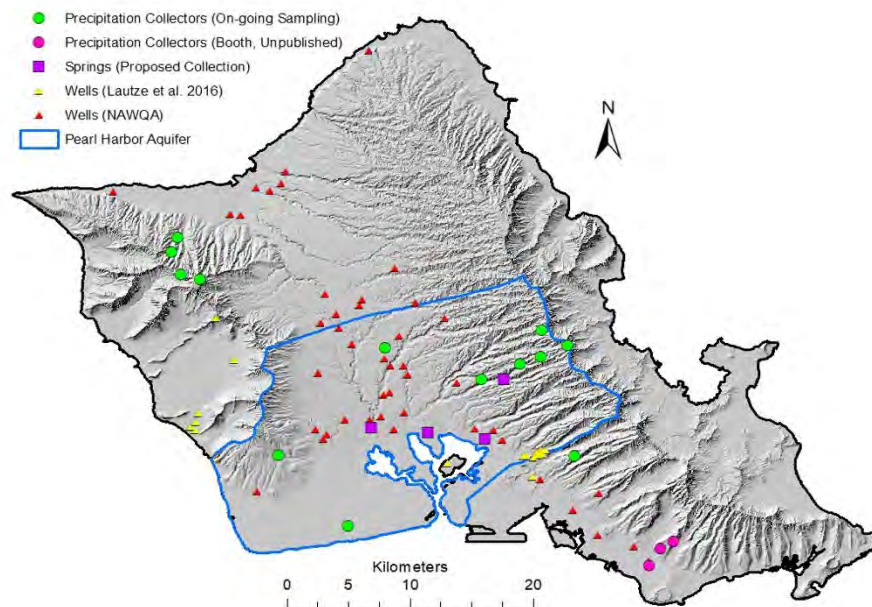
**Outputs:** On Hawai‘i Island, we deployed 22 precipitation collectors and made 3 sampling trips (March 2019, August 2019, and November 2019). There, we sampled 66 wells, 32 ponds, and 22 rain collector sites (Fig. 15). At the wells and ponds, we collected water samples to analyze major ions, trace metals, nutrients, and isotopes. We collected precipitation samples to analyze major ions and isotopes.

In February 2019, we obtained approval to deploy 4 rain collectors on Kamehameha Schools’ land on Hawai‘i Island. In March, Kamehameha Schools granted us an access permit. There, we deployed 2 rain collectors in August and 2 more in November. On O‘ahu, we deployed 13 precipitation collectors (8 in the Pearl Harbor aquifer and 5 elsewhere) and collected 42 data points. With the groundwater chemistry results, PhD candidate Tachera is preparing two papers for publication. Another paper focusing on the integration of precipitation and groundwater chemistry will be submitted in late 2020 or early 2021.



**Figure 15:** A map of the west part of Hawai'i Island highlighting the locations of precipitation collectors, groundwater sites, and the Hualalāi aquifer.

Figure 16 shows the sample collection points. From the Hawai'i State Department of Land and Natural Resources (DLNR), we obtained an extension for our access permit for the Mount Ka'ala Natural Area Reserve for another year. We also received permission to install two more collectors at Mount Ka'ala and now have four collectors there. Our permit to install and maintain collectors in the Ewa



**Figure 16:** A map of O'ahu Island with locations of precipitation collectors, springs (proposed collections sites), wells and the Pearl Harbor aquifer

Forest Reserve, which includes Manana Ridge, from DLNR has been expanded to include Tripler Ridge. In August, Mililani High School gave us permission to maintain one collector on its campus. In October, with the help of the Ko'olau Mountain Watershed Partnership, we installed a precipitation collector at Pu'u Waiawa on Kamehameha Schools' land (because this location is extremely remote, it is accessible only by helicopter). We made a request to install four collectors at Schofield Barracks.

**Publications and Papers:**

Diamond Tachera, Nicole Lautze, Henrietta Dulai, Chris Shuler, Don Thomas, *"Delineation of aquifer boundaries in West Hawai'i using Groundwater Chemistry"*, Hydrogeology Journal; June 2020

Diamond Tachera, Nicole Lautze, Henrietta Dulai, Giuseppe Torri, Don Thomas; *"Temporal Variation in O and H isotope values in Precipitation in the Western half of Hawai'i Island from 2017 to 2020"*, Hydrogeology Journal, December 2020.

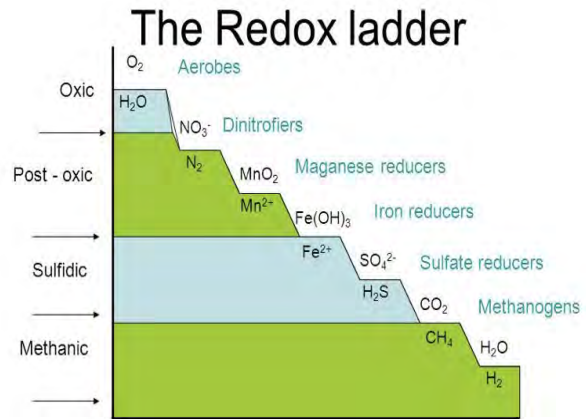
Diamond Tachera, Nicole Lautze, Henrietta Dulai, Giuseppe Torri, Don Thomas, *"Elucidating Groundwater Source and Flow Paths in West Hawai'i using O and H values in Precipitation and Wells"*, Hydrogeology Journal; June 2021

Theodore Brennis, Nicole Lautze, Robert Whittier; *"Examination of groundwater source and flow path in South Central O'ahu through O and H isotope analyses"*, Hydrogeology Journal; Spring 2021 (MS thesis)

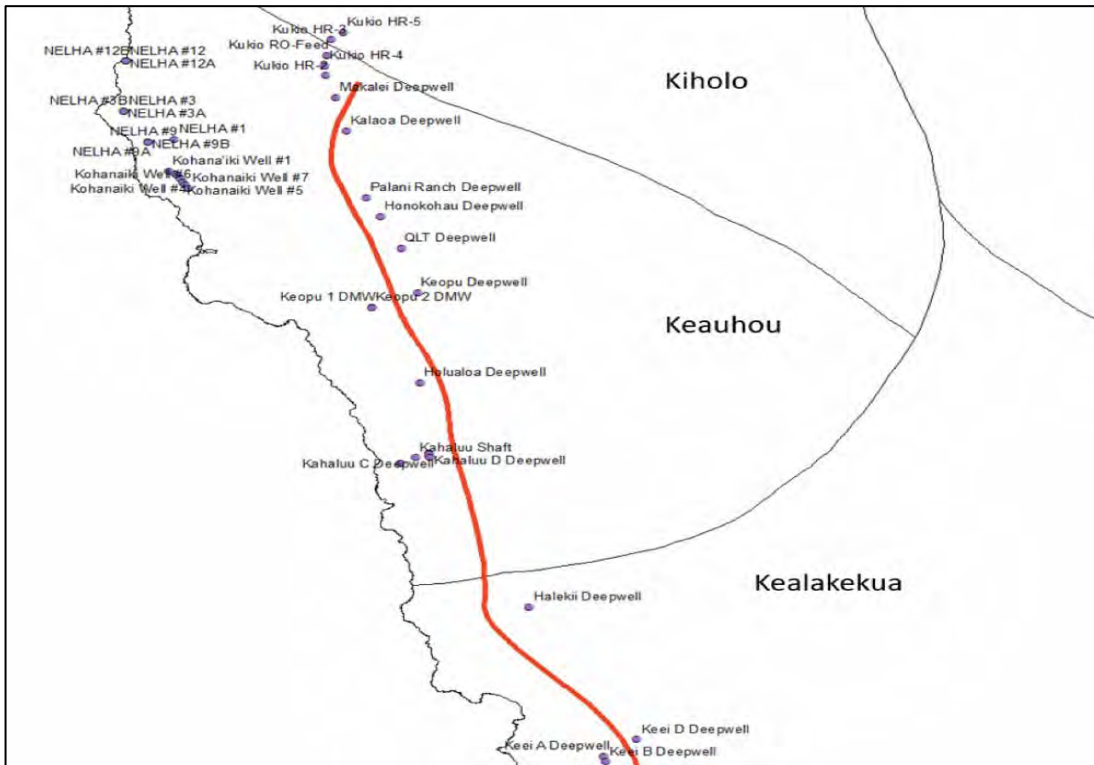
**Activity 1.2.2:** Characterize temporal and spatial distribution of microbial communities within wells at Pearl Harbor and Hualālai as a novel method for exploring water flow and source.

**Results:** Preliminary geochemistry results are presented here to set the context for our hypothesis regarding the use of microbial communities to indicate aquifer environments. PCA results indicate a difference in wells sampled with regard to location along the rift zone (Kukio Huehue Ranch wells) and corresponding nutrient geochemistry (P, Si). A few wells are also different with regard to concentrations of dissolved nitrogen (Kahaluu A, Kalaoa,  $\text{NO}_3+\text{NO}_2$ ). Based on these results we hypothesize that we will observe differences in our qPCR analysis for indicator genes (denitrifiers, sulfate reducers). We hypothesize that functional groups of Proteobacteria (denitrifiers, sulfate reducers) and corresponding groundwater geochemistry will provide information (depth, connectivity, and inputs of nutrients) about aquifers in the Hualālai watershed. Denitrification (oxic) and sulfate reduction (anoxic) are biogeochemical reactions that occur on opposite ends of a spectrum of oxygen concentrations in a redox reaction ladder (Figure 17.) and abundances of these groups of microbes can indicate oxygen available in their environment. Water samples from wells along the Kiholo and Keauhou aquifers were analyzed for abundances of genes (denitrification, nirS, and sulfate reduction, dsr) and dissolved nutrients (Figure 18).

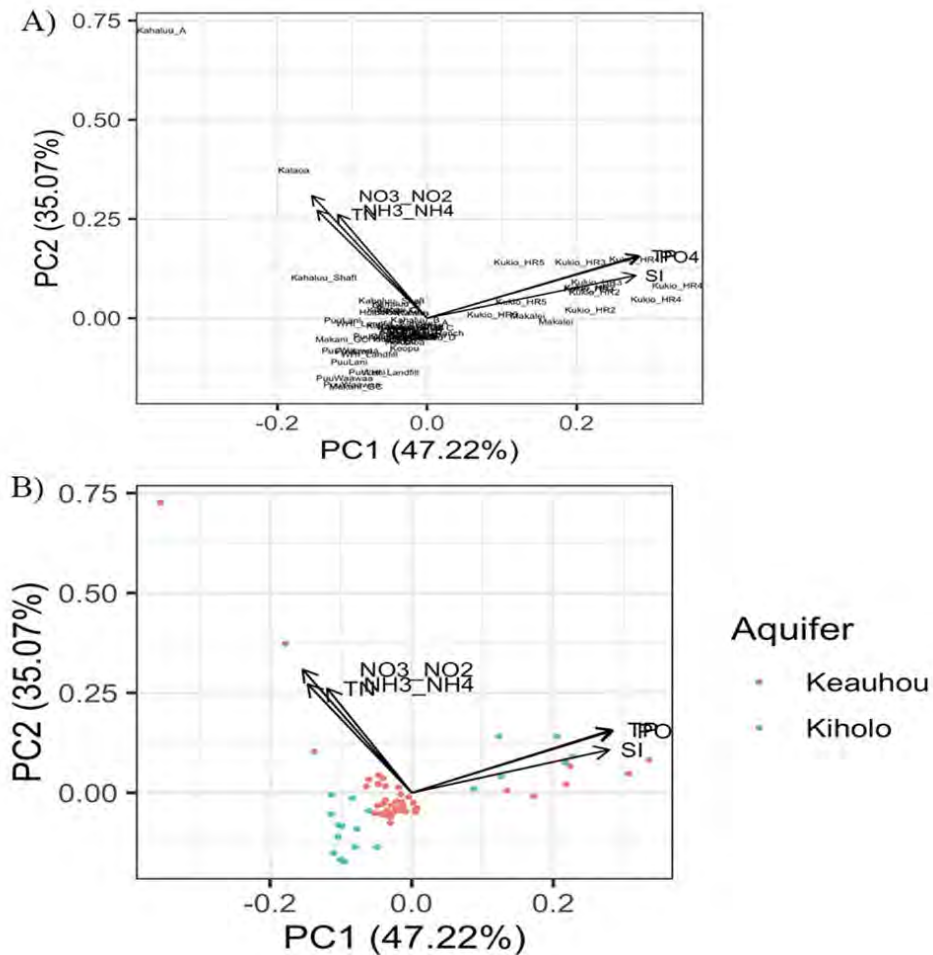
A principal component analysis (PCA) was performed to look for possible relationships amongst well samples and concentrations of dissolved nutrients (nitrite+nitrate, NO<sub>2</sub>\_NO<sub>3</sub>; orthophosphate, PO<sub>4</sub>; Ammonium, NH<sub>3</sub>\_NH<sub>4</sub>; Silica, Si; Total phosphate, TP; and Total nitrogen, TN) (Fig. 18). Almost half of the variation amongst wells observed in the PCA is explained by the concentrations of orthophosphate, total phosphate, and silica (PC1 47%) and differentiated wells in the Kiholo aquifer (Kukio Huehue Ranch wells) along increasing concentrations (Figure 19 PCA A). The second axis (PC2 35%) is explained by concentrations of nitrite+nitrate (NO<sub>2</sub>+NO<sub>3</sub>) and differentiated Kahaluu A and Kalaoa wells. The majority of the wells sampled are not differentiated from each other by dissolved nutrients and occur in the center of the PCA near the origin of the vectors. A second PCA colored response variables (wells) by aquifers (Keauhou and Kiholo) (Fig. 19 PCA B).



**Figure 17:** A visualization of the biogeochemical reactions that are mediated by microbes in relationship to available minerals and oxygen concentrations.



**Figure 18:** Map of the wells sampled in the Keauhou and Kiholo aquifers. The red line is the high/low divide. The line between the Kiholo and Keauhou aquifers indicates the rift zone.



**Figure 19:** Two PCA biplots with well ordinated as response variables against A) dissolved nutrients (nitrite+nitrate, NO<sub>2</sub>\_NO<sub>3</sub>; orthophosphate, PO<sub>4</sub>; Ammonium, NH<sub>3</sub>\_NH<sub>4</sub>; Silica, Si; Total phosphate, TP; and Total nitrogen, TN), and B) the same biplot but wells are colored by their location in aquifers in the Hualālai watershed

**Outputs:** Dissolved nutrient principal component analysis.

**Publications and Papers:**

Watson, Sheree J., Joseph A. Needoba, and Tawnya D. Peterson. 2019. "Widespread Detection of *Candidatus Accumilibacter Phosphatis*, a Polyphosphate-Accumulating Organism, in Sediments of the Columbia River Estuary." *Environmental Microbiology* 21 (4): 1369–82.

Kiana Frank, Sheree Watson, Cedric Arisdakesslan, Diamond Tachera, Nicole Lautze, Brytne Okuhata, Henrietta Dulai, Working title: *Integration of microbial and geochemical tracer studies to determine groundwater flow paths in West Hawai'i*, journal TBD, for submission in Spring 2020.

Cedric Arisdakesslan, Craig, Anthony, Sean Cleveland, *Bioinformatic 16S C-Maiki pipeline*, Journal TBD, in prep.

Sean Cleveland, Cedric Arisdakesslan, and others, *Web interface tool for pipeline use*, Journal TBD, in prep.

Kiana Frank, most of 'Ike Wai team, Gwen Jacobs, *Integrated paper addressing overall 'Ike Wai research questions*, planned for late 2020

Sheree J. Watson, Cédric Arisdakessian, Diamond Tachera, Brytne Okuhata, Maria Petelo, Ku'i Keliipuleole, Nicole Lautze, Henrietta Dulai, Kiana L. Frank, *Distributions of denitrifiers, and sulfate reducers reveal groundwater ecosystems*, ISME, June 2020

Sheree J. Watson, Cédric Arisdakessian, Diamond Tachera, Brytne Okuhata, Maria Petelo, Ku'i Keliipuleole, Nicole Lautze, Henrietta Dulai, Kiana L. Frank (potential community partners Keith Olsen, Pam Madden, Kimber Deverse, Darren Okimoto), *Biogeographical and biogeochemical drivers of microbial dynamics in groundwater ecosystems*, PNAS, December 2020.

Kiana L. Frank, Sheree J. Watson, Maria Petelo, Ku'i Keliipuleole, Diamond Tachera, Mana Purdy, Dena Sedar, Rebecca Most, Pamela Madden, Kila Ynigues, *Microbial biocultural restoration of anchialine pools in Kona, Hawai'i, Sustainability, Pacific Science, Traditional Management*, Spring or Fall 2020

Maria Steadmon, Cédric Arisdakessian, Diamond Tachera, Brytne Okuhata, Maria Petelo, Nicole Lautze, Henrietta Dulai, Kiana L. Frank, *Pathogen distributions of Hawai'i island freshwater ecosystems*, Journal TBD, Spring 2021 - COBRE

Sheree J. Watson, Jenny Engel, Henrietta Dulai, Leah L. Bremer, Kimberly M. Burnett, Ano'iolani Aga, John McHugh, Barbara Sumida, Maria Petelo, Ku'i Keliipuleole, Kiana Frank, *Microbial seasonal dynamics of Sumida watercress farms, Climate Change, Traditional Farming, or Sustainability*, February 2021

**Outcomes:** The microbe tracer team will plan to further integrate data with geochemistry, geophysics, and the hydrological modeling research that is on-going. We plan to discuss with the geochemistry and hydrological modeling group our microbe analysis and what can be revealed with regards to age dating, flowpath, source and circulation of groundwater within the Hualālai watershed.

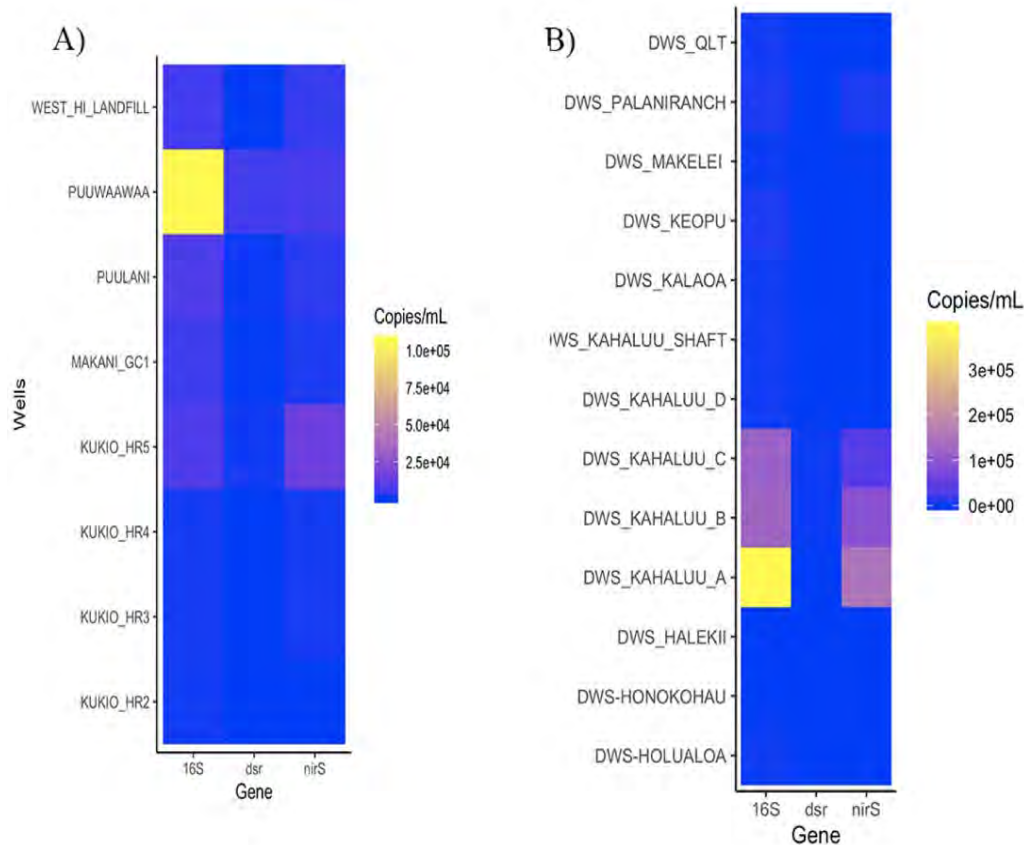
**Impacts:** Bioinformatic analysis of microbial communities indicated that we can utilize temporal and spatial distribution of microbial communities integrated with geochemistry to provide information regarding aquifer connectivity, and flow. Our analysis continues to characterize temporal and spatial distribution of microbial communities within wells in the Hualālai watershed as a novel method for exploring water flow and source.

**Activity 1.2.3: Quantify microbial water quality of well samples to identify pathogenic contaminants and microbial indicators for chemical contamination.**

**Results:** An overall abundance of bacteria and archaea groups were assayed by performing qPCR for the 16S rRNA gene, which is a conserved gene present in all members belonging to these microbial groups. A qPCR abundance number for 16S genes is a measurement of overall biomass in the environment. Abundances of 16S genes were highest in Kiholo wells at Pu'uwa'awa'a and Kukio Huehue Ranch 5 (Figure 20 A), although average biomass abundances were less in Kiholo compared to Keauhou. Biomass abundances were on average greater in the Keauhou wells specifically in the Department of Water Services Kahaluu wells (Figure 20 B).

Sulfate is ubiquitous in groundwater, with both natural and anthropogenic sources. Sulfate has been classified as a secondary contaminant in groundwater and there is great interest in the transport and fate of sulfate in subsurface environments in relation to biogeochemical processes affecting natural and contaminated system. Sulfate reduction reactions performed by sulfate reducing bacteria play a significant role in mediating redox conditions and biogeochemical processes for subsurface systems and also serve as the basis for innovative *in-situ* methods for groundwater remediation. To quantify the abundance of sulfate reducing bacteria across these systems as a proxy for sulfate reduction reactions, we measured abundances of the functional gene - dissimilatory sulfite reductase (*dsrA*). Abundances of sulfate reducing genes (*dsrA*) were very reduced across all samples assayed by qPCR in Kiholo (Figure 20 Heat Map A) and Keauhou (Figure B). The highest abundances of *dsrA* genes were observed in Kiholo at the Puuwa'awa'a well that also had the highest biomass (Figure 20 Heat Map A). Very low abundances of *dsrA* genes were observed in the Keauhou samples.

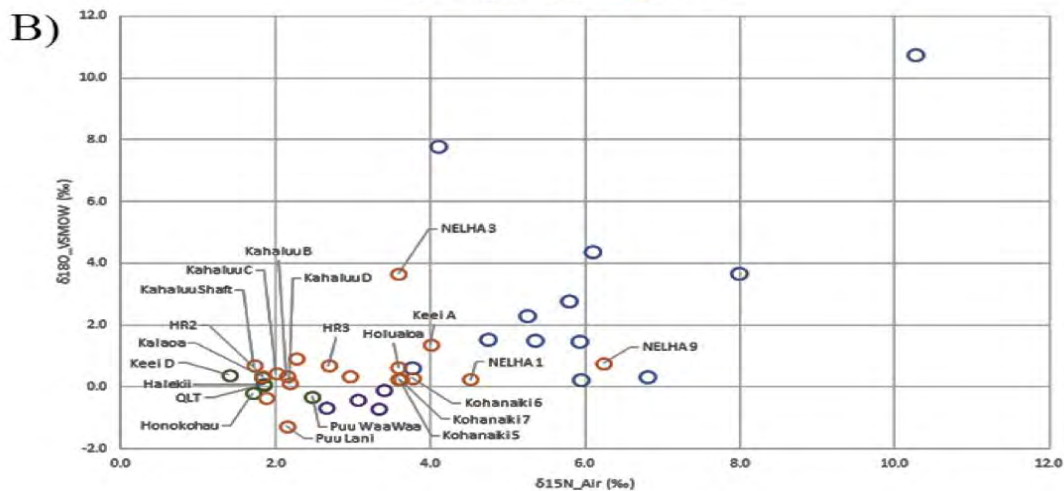
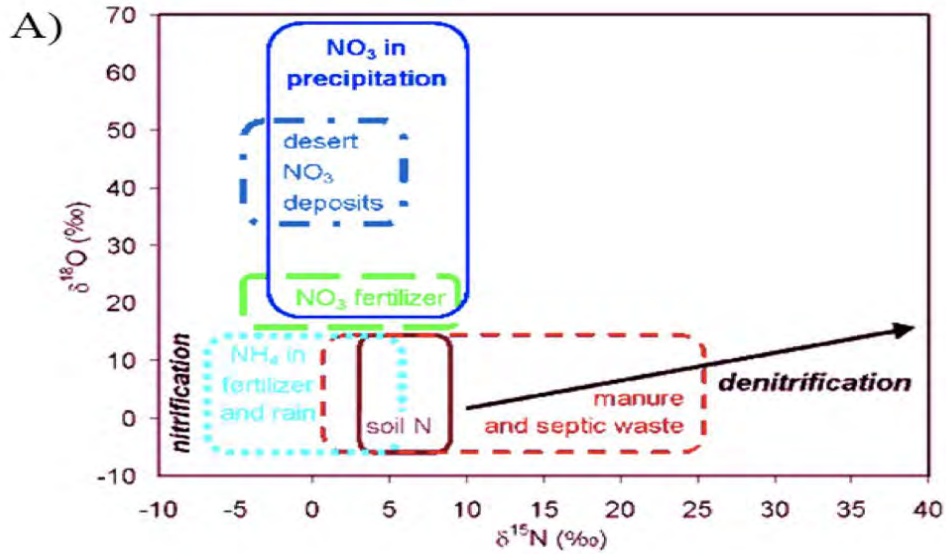
Nitrogen contamination of groundwater from wastewater disposal is a growing problem worldwide. Denitrification is the primary removal pathway of reactive nitrogen in aquifers. The presence of high levels of denitrifying bacteria in a given well can indicate areas of potential concern for nitrogen contamination. We assed the abundance of denitrifiers by quantifying the *nirS* gene. Denitrification (*nirS*) abundances were greatest in the Kahaluu wells in the Keauhou aquifer (Figure B). The Kukio Huehue Ranch 5 well in Kiholo had the highest abundances of *nirS*, but overall abundances of *nirS* were on average lower in Kiholo versus Keauhou samples as observed by the scale differences (Figure 20). An analysis of stable isotope ratios of  $^{15}\text{N-NO}_3^-$  and  $^{18}\text{O-NO}_3^-$  was done by Brtyne Okuhata as a proxy for potential  $\text{NO}_3^-$  sources in well water samples. Plotting  $^{15}\text{N-NO}_3^-$  and  $^{18}\text{O-NO}_3^-$  values provides indicative data regarding source and cycling of nitrogen in aquatic environments (Figure 21 A). Ponds, springs, and well stable isotope  $^{15}\text{N-NO}_3^-$  values were distributed evenly across the  $\text{NO}_3^-$  gradient. Anchialine pond values appeared to have the corresponding to the highest  $^{15}\text{N-NO}_3^-$  and  $^{18}\text{O-NO}_3^-$  isotope values (Figure 21 B). Well samples clustered in the lower quadrant and samples grouped together from wells in close proximity (Kahaluu Shaft, B, C, D). In addition, samples from the high (green circle) and low (orange circle) divide clustered together with little differentiation. The Kahaluu wells major source of  $\text{NO}_3^-$  was from  $^{15}\text{N-NO}_3^-$  and occurs in the range of sources from soil, manure and septic waste.



**Figure 20:** Abundances of indicator genes 16S rRNA (16S), denitrifiers (nirS), and sulfate reducers (dsr) assayed by qPCR for well samples in A) Kiholo, and B) Keauhou.

In addition to focusing on quantifying indicators of potential contamination utilizing qPCR and functional gene analysis, we also screened our extensive 16SrRNA sequence database against a reference database of human pathogenic bacteria including ~80 species in 40 genera from the Pathosystems Resource Integration Center (PATRIC). The data on pathogenic organisms from PATRIC contains National Institute of Allergy and Infectious Disease (NIAID), USA category A–C, emerging and re-emerging bacterial pathogens as well as resource transited from the National Microbial Pathogen Data Resource (NMPDR). OTUs classified to genera level in the reference pathogen database were screened out and aligned with the representative sequences of pathogenic species within the same genera using BLAST. Sequences with more than 99% identity and 98% coverage with the representative sequences were counted as a potential pathogen species, and the relative abundance of its population was calculated for each site.

**Outputs:** As reported above, a manuscript is being prepared with the integrated results for submission by Spring 2020. Quantitative microbial analysis results (qPCR) demonstrate an abundance difference in overall biomass (16S) and denitrifiers (nirS) with regard to samples from Keauhou (Kahaluu) wells. Kahaluu



**Figure 21:** A) Nitrogen sources of  $\text{NO}_3^-$  as identified by ratios of stable isotopes of  $^{15}\text{N}$  and  $^{18}\text{O}$ . B)  $\text{NO}_3^-$  stable isotope ratios of  $^{15}\text{N}$  and  $^{18}\text{O}$  for ponds, springs, and wells sampled in the Hualālai watershed.

wells were also differentiated in the PCA nutrient analysis with regards to increasing concentrations of dissolved N ( $\text{NO}_3 + \text{NO}_2$ ). Abundances of denitrifiers (nirS) appear to occur in wells that have higher concentrations of dissolved N in this preliminary analysis.

Quantitative microbial analysis results (qPCR) of all well samples were completed. Differentiation analyses using indicator genes 16S rRNA

**Publications and Papers:** As reported in Activity 1.2.1 above, a manuscript is being prepared with the integrated results for submission by Spring 2020.

**Outcomes:** The results reported here are preliminary and further work will identify and compare the microbial differences of denitrifiers amongst wells with

large abundances of nirS genes. The microbe tracer team will plan to further integrate data with geochemistry, geophysics, and the hydrological modeling research that is on-going. We plan to discuss with the geochemistry and hydrological modeling group what our microbe analysis can reveal with regards to age dating, flowpath, source and circulation within the Hualālai watershed.

**Impacts:** Preliminary results indicate microbial indicators (major metabolism genes) can provide information regarding water quality such as increased nutrient (N) inputs in groundwater aquifers. Work continues in the Frank lab by Cedric Arisdakesslan to utilize the large genetic database of microbes that has been produced by this project to analyze for pathogenic microbes. The temporal and spatial sampling survey performed by this project will produce the largest database of microbes in groundwater in Hawai'i and when integrated with geochemistry and geophysics will produce information for community stakeholders invested in water sustainability in the Hawaiian Islands.

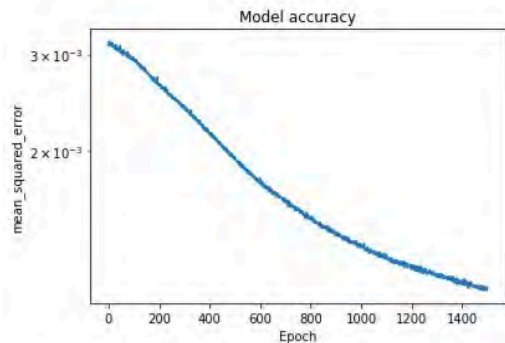
**Activity 1.2.4: Link SGD to aquifer conditions at the two aquifer locations. (Dulai and McKenzie)**

**Results:** (1) SGD sensor development: An upgraded version of the SGD Sniffer, an autonomous radon monitor, has been developed in years 1 & 2 of the project. In year 4 we tested the instrument and finalized its design. In addition, one of the two instruments was selected to be outfitted with wireless telemetry. Telemetry installation, which requires an upgrade of the software and some hardware parts is currently undergoing.

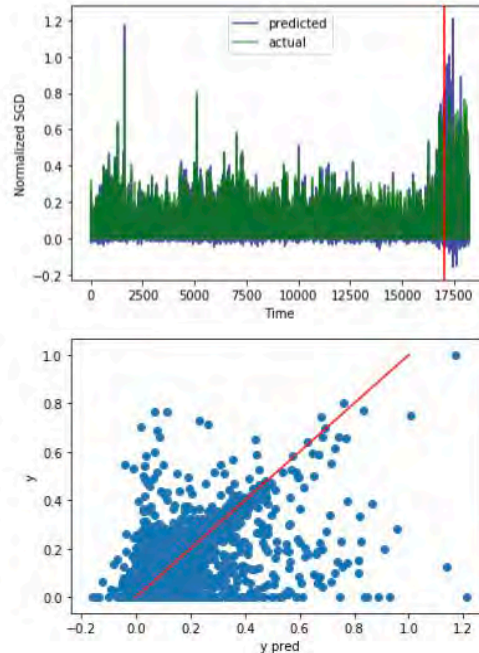
(2) SGD sensor deployment: Three deployment sites have been selected in Kona. Permits for deployment at all sites were obtained. We deployed 1 instrument at Queen Lili'uokalani Trust (QLT) anchialine pond in November 2019. This instrument is making hourly radon, salinity and temperature measurements. Data has to be retrieved manually. Deployment of an older SGD Sniffer at Kamehameha School (KS) is pending access coordination with KS personnel (the deployment crew needs to be accompanied by KS personnel). The upgraded SGD Sniffer awaiting outfitting with telemetry will be deployed at NELHA - all agreements with NELHA and site selection are completed. We anticipate deployment in March 2020.

(3) Data processing: Radon, temperature and salinity time series analysis is being automated by developing a code for automated data processing and SGD calculation in Python. In addition, time series analysis and deep learning methods have been developed to further evaluate seasonal trends and drivers of SGD as well as to predict SGD. These will be combined with rainfall patterns and analyzed for spatial and temporal correlations between precipitation and SGD.

## DNN Model Results



```
hist1b = model1b.fit(x_train1b, y_train1b,
epochs = 1500, batch_size = 6, verbose = 1)
```



**Figure 22:** Deep learning models (results from DNN shown) have been applied to analyze 4 years of SGD data collected in Kiholo Bay (2014-2017). Figures and data by Trista McKenzie PhD student on the SGD team in collaboration with Harry Lee from IW Modeling team

### ***Publications and Papers:***

McKenzie, Trista, Henrietta Dulai, and Jennet Chang. 2019. "Parallels between Stream and Coastal Water Quality Associated with Groundwater Discharge." *PLOS One* 14 (10): e0224513.

Taniguchi, Makoto, Henrietta Dulai, Kimberly M. Burnett, Isaac R. Santos, Ryo Sugimoto, Thomas Stieglitz, Guebuem Kim, Nils Moosdorf, and William C. Burnett. 2019. "Submarine Groundwater Discharge: Updates on Its Measurement Techniques, Geophysical Drivers, Magnitudes, and Effects." *Frontiers of Environmental Science & Engineering in China* 7: 141.

Hudson, Dulai et al: Groundwater recharge and discharge imbalance and its implications for coastal aquifer water budgets in Kona, Big Island, Hawai'i, to be submitted to *J. Hydrogeology*

Dulai et al. Geochemical trends in SGD on the Kona coast - in prep, *Marine Chemistry*

McKenzie, T., Dulai, H., Fuleky, P., Lee, J., Determination of submarine groundwater discharge dynamics using deep learning and long-term field measurements - data analysis in progress to be submitted to TBD

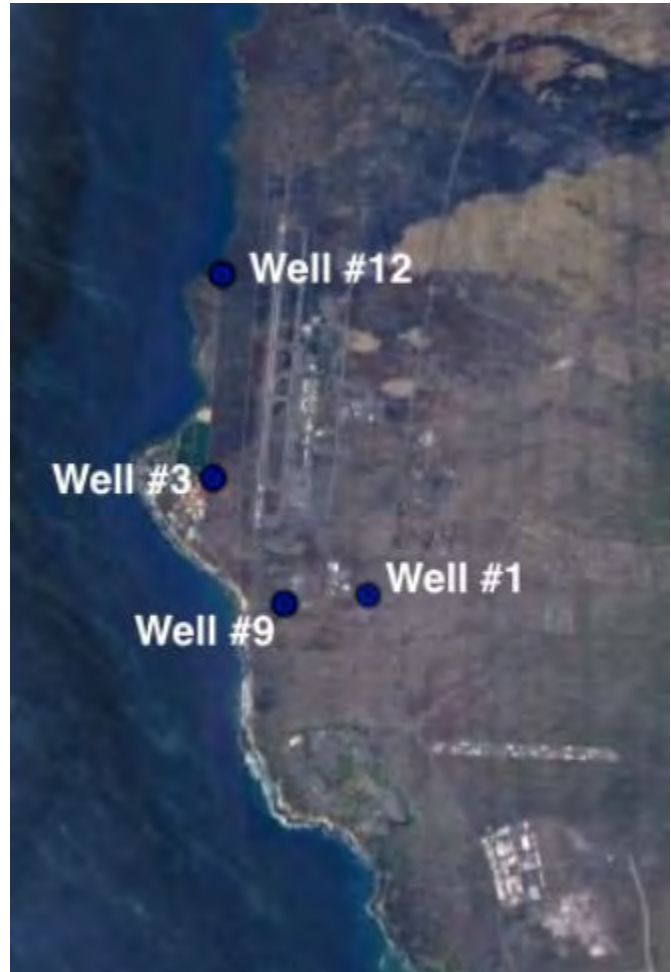
McKenzie, T., Dulai, H., Tachera, M. Dodge II, Michael, J. Jolly, et al. Temporal trends of submarine groundwater discharge and rainfall distribution inform groundwater flow paths in the Kiholo-Keauhou aquifer system - data to be collected, journal TBD

**Outcomes:** The new version of SGD Sniffer is perfectly suited for pond and nearshore coastal region monitoring. Deep learning methods predict SGD trends and can be used to predict SGD and therefore developed to run future scenarios of SGD to aid stakeholder pond management.

**Risks and Mitigation Plan:** (1) For telemetry, assistance from Brian Glazer's group at UH was requested and work is currently undergoing on installing telemetry. (2) The delay in deployment is mitigated by discussions with stakeholders on obtaining access for KS. (3) Trista McKenzie will be working to improve deep learning model accuracy and develop methods to fill in missing data.

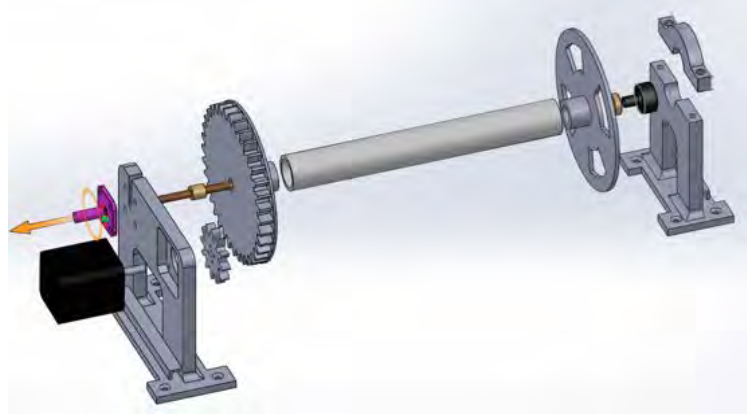
**Objective 1.3:** Produce datasets on physical and chemical parameters of groundwater by establishing novel sensor-based monitoring network in wells within targeted regions of the Pearl Harbor and Hualālai aquifer systems by the end of Year 3.

**Activity 1.3.1:** Build and deploy active well monitors. (Oyama)



**Figure 23:** location of NELHA Well 9 at Keahole Point, south of the Kailua-Kona

**Results:** We have completed the fifth iteration (DROP5) and have deployed this version of the module in well #9B at the NELHA (Fig. 23) in November 2019. DROP5 is using a stronger PV panel and 1 lithium ion battery to provide power to the sensors. The sensors were fitted to a PVC pipe rated for 410psi with drinking water standards. The PVC pipe fitting makes the sensor module more robust, and more aesthetically pleasing. DROP5 is



**Figure 24:** New chassis design with 3:1 gear system to increase torque

using a water-resistant canvas and more 3D printed elements to protect the electronics from the weather elements. The chassis is completely re-designed to include a gear system that increases torque (Fig. 24). The pieces are also printed on a higher resolution printer than previous modules, making all the 3D printed pieces extremely accurate and well fitted. The module has the capability to send data wirelessly to the Ike Wai Gateway and this was demonstrated in a laboratory setting before deployment. However, Wi-Fi is not available at the Well 9B site and therefore all the data will be stored as text files on the Raspberry Pi memory card. There is ample space for months of data to be stored. Originally the DROP5 module was to be deployed in well #1 and #9 to evaluate the salinity flow envelope on the NELHA property however, due to coupling issues in the wires for the 150ft depth of well, deployment in well #1 was not feasible.

**Outputs:** The DROP 5 module has been deployed at NELHA and is collecting data. The first data recovery will be in the first quarter of 2020. Limited test data was collected and deposited into the Ike Wai Gateway using a cell phone hotspot.

**Outcomes:** The development of the DROP sensors has been impacted by a number of issues including the transfer of the lead researcher, Dr. David Garmire, from UH Mānoa to the University of Michigan, physical complexity and variability of different well heads, and the graduation of MS student Tamra Oyama.

**Activity 1.3.2:** Perform pumping experiments.

**Results:** Success of a pumping experiment is dependent on validation of the sensor components of the DROP module. The in-house salinity sensor being developed was tested against a commercial salinity sensor from Atlas Scientific. The in-house salinity sensor, while showing accurate trends, was not precise or accurate enough for this application. The ground truthing experiment has shown interesting results in how inexpensive conductive polymers must be calibrated in order to be used in lieu of expensive platinum probes in the future. The commercial salinity sensor

was used in the DROP sensor module deployed in well #9B due to time restraints.

**Outcomes:** It was determined that the precision of the in-house salinity sensor was not adequate for the NELHA November 2019 deployment and thus a commercial salinity sensor was used instead.

**Risk and Mitigation Plan:** It is uncertain at this time what benefits future deployments of the DROP module will have on generating geochemical and water quality data that will contribute to constraining any of the hydrogeological models that have been developed by the modeling team. Discussions are underway with NELHA management to determine if the DROP module data can provide useful data to their ongoing well monitoring program.

## **Goal 2:** Develop a new data and modeling platform for Hawai'i volcanic hydrology, economic modeling and decision support

**Objective 2.1:** 'Ike Wai Gateway: Implement a fully featured data management, analysis, and visualization application based on the Agave software framework.

### **Activity 2.1.1:** Hire Professional Staff: (Cleveland, Geis, Jacobs)

In January of 2020 the CI team added Jared McLean to the project to work on gateway features. In January 2020 the CI team added Christopher Shuler to the project to assist researchers in documenting, annotating and publishing data products in the 'Ike Wai gateway.

### **Activity 2.1.2:** Setup Computation and Storage platforms.

**Results:** This activity was completed in Year 2.

**Outcomes:** Infrastructure is able to support research and computation for the project; Researchers can manage data, and run analysis and compute on the platform.

### **Activity 2.1.3:** Create training materials, documentation and train researchers on using the 'Ike Wai Gateway. (Cleveland, Geis, Jacobs)

**Results:** All 'Ike Wai Gateway documentation and training materials are published and updated on GitHub and YouTube. Training efforts to date have been focused on individual members of the research teams. All participants will be trained on the gateway on demand. We find if we train before the researchers have an immediate need, sometimes the knowledge is forgotten and the training needs to be repeated. Deployment of science and bioinformatic computational workflows were updated to include 15s, ITS and demultiplexing workflows that support the latest analysis workflow from Dr. Frank's team. Cleveland worked with the Hawai'i Data Science Institute (HI-DSI) and the Texas Advanced Computing Center (TACC) to lead two

training workshops at UH: 1) “Portable, Reproducible High Performance Computing in the Cloud” July 17 2019, 2) “Accelerated Reproducible Computing with Containers and Tapis” April 23-24, 2019

**Outputs:** All ‘Ike Wai Gateway documentation and training materials have been previously reported.

**Outcomes:** ‘Ike Wai researchers have used the gateway to upload data and annotate products. The meta-genomic data analysis workflows have been used to analyze the datasets from Dr. Frank’s group.

#### **Activity 2.1.4: ‘Ike Wai Visualization (Leigh, McLean, Cleveland)**

**Results: Decision Support Application.** The CI and Visualization teams continued their work with USGS scientists to deploy a production decision support application for calculating island recharge based on user-defined land use (Fig. 25).

#### **Current features of the groundwater recharge decision support tool:**

Recharge visualization allows users to view the groundwater recharge rates based on interactive modifications. Users can select the metrics displayed in the details panel. Recharge rasters can be displayed as a gradient of values, a heat map of recharge difference or percent change. User defined areas can be drawn directly on the map and modified through the web interface. Data can be imported to and exported from a map as: ASCII or CoverageJSON file formats for land cover rasters and Shapefiles for user defined areas such as land cover updates via a property containing the land cover type. The tool supports data export of custom areas as a shapefile and land cover and groundwater recharge rasters in an ASCII or CoverageJSON format. Reports generated by the tool provide a comprehensive breakdown of metrics for: aquifers, aquifers excluding the caprock, custom areas, full island, and full island excluding caprock. Reports can be exported as a PDFs.

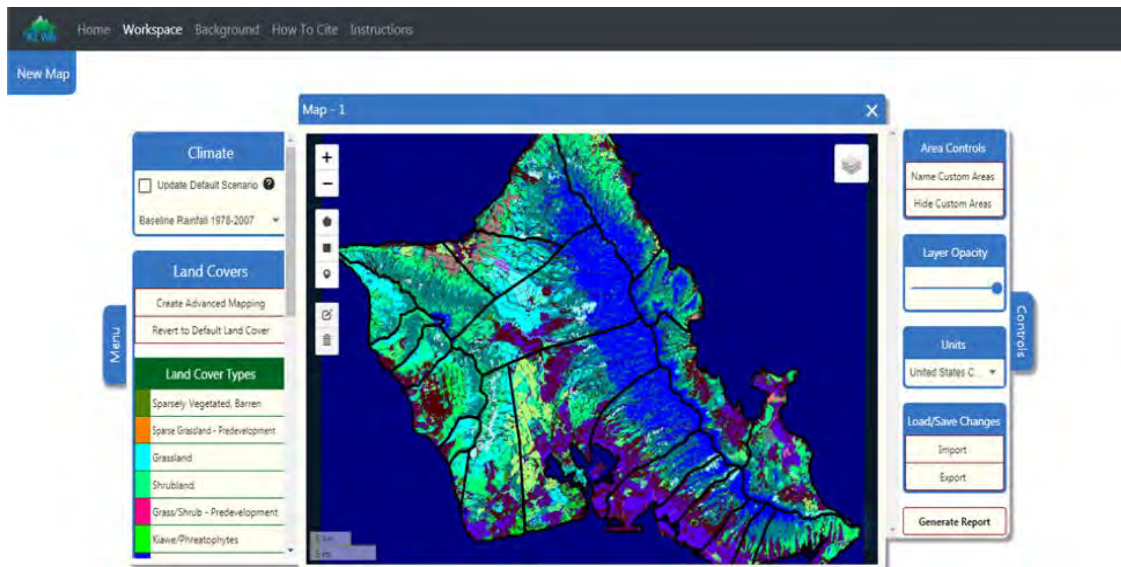
**Outputs:** Updates to the groundwater recharge decision support tool.

#### **Publications and Papers:**

Cleveland, Sean B., Jared H. McLean, Kolja Rotzoll, Scot K. Izuka, and Gwen A. Jacobs. 2019. “Enabling Real-Time User Interaction For Decision Support: Experiences Extending A Local Agave Platform Metadata Service.” In *Proceedings of the Practice and Experience in Advanced Research Computing on Rise of the Machines (learning)*, 8. ACM.

McLean J, Cleveland, S, Rotzoll, K Izuka, S Leigh, J and Jacobs G. 2019. “The ‘Ike Wai Groundwater Recharge Tool.” In *Science Gateways 2019*.

McLean, Jared, Sean B. Cleveland, Kolja Rotzoll, Scot K. Izuka, Jason Leigh, Gwen A. Jacobs, and Ryan Theriot. 2019. “The ‘Ike Wai Hawai‘i Groundwater Recharge Tool.”, Gateways 19, <https://osf.io/6u3yv/download>.



**Figure 25:** Hawai'i Groundwater Recharge decision support application that calculates island recharge based on user-defined land use types combined with multiple climate scenarios.

Dodge, M., Sean B. Cleveland, J. Mclean, and J. and Geis, "Processing Sensor Data in the Ike Wai", Submitted January 2020.

Geis, J., and S. B. and Cleveland. "Ike Wai Dissemination/Publication Paper, In Preparation for January 2020 Submission.

Longman, R., M. Lucas, T. Giambelluca, Cleveland, S, G. Mclean, A. Frazier, and M. Nullet. "Near-Real-Time Rainfall Mapping and Climate Data Portal of Hawai'i." In Preparation.

McLean, J., M. Lucas, S. B. Cleveland, and G. and Tom. "Hawai'i Precipitation Tool." In Preparation.

McLean, J., M. Lucas, S. Izuka, Kolja, and S. B. and Cleveland. "Hawai'i Groundwater Recharge Tool Software." In preparation for Spring 2020 Submission

**Outcomes:** USGS recharge data was ingested into the 'Ike Wai Gateway to populate the decision support tool. The application was deployed in production on infrastructure at UH. 70+ users have accessed the tool.

**Activity 2.1.5:** 'Ike Wai Gateway Dissemination. Development of dissemination platform. (Cleveland, Geis, Giambelluca)

**Results:** A decision support tool was developed in collaboration with USGS to disseminate recharge model outputs. Over 3,500 data files/datasets have been made ready for dissemination. We are developing a separate dissemination site from ikewai.org to allow users from outside the 'Ike Wai project a simple search and visualization interface for all available data and data products. We plan to integrate dissemination of models and data via the community site, Hydroshare,

slated for production rollout in late spring 2020.

A data platform is currently being developed to host all of the meteorological data compiled for the state of Hawai'i within the 'Ike Wai Gateway. The Hawai'i Climate Data Portal (HCDP) will host both daily and monthly rainfall data from over 1000 meteorological stations across the State spanning the period 1920 to present day. The HCDP will also host daily observations of other meteorological variables including, relative humidity, solar radiation, wind speed and many more. In addition to station-based climate data, the HCDP will host 100 years of Monthly rainfall maps and 30-years of daily rainfall maps, both of which will be updated in near-real-time. Users will have the ability to query specific data products, including quality controlled observations as well as serially complete versions of this data, for specified time periods. The expected Launch of a complete public facing version of the HCDP is the summer 2020.

**Objective 2.2:** Data Store Population: Aggregate, annotate, and store legacy, existing, and new scientific data.

**Activity 2.2.1:** Personnel & Training (Cleveland, Geis,)

**Training:** All research groups trained on annotating data using the 'Ike Wai platform. These users attended a training session or individual meeting that walked through the platform curation features and demonstrated how to curate and annotate project data products for large dissemination. All documentation and training materials on annotating data using the 'Ike Wai platform are published to github.com, youtube.com and within the gateway itself. Materials that educate and demonstrate the use of the 'Ike Wai platform for curating data products from the project have been integrated into the application as help document

**Activity 2.2.2:** Data Store & Curation (Cleveland, Geis, Jacobs)

**Results:** Over 261,000 files/data sets have been uploaded and ~3,600 have been curated. A data manager has been hired and has been meeting with groups and researchers individually to assist with uploading, curating, and annotating their data in the Gateway. New features make it easy for researchers to push their data and annotations to ikewai.org where everything is open and accessible to the public. Researchers can also push their annotations and links to the files to Hydroshare.org where they can obtain a DOI.

**Outputs:** 261,000 raw files and datasets, 3600 curated.

**Activity 2.2.3:** Collate historical and current data from diverse agencies. This update includes all new data collections added this year. (Cleveland, Geis, Jacobs, Giambelluca)

**Results:** Daily rainfall datasets: The 25 year legacy collection of quality controlled observations of meteorological data from 471 climate stations in Hawai'i within multiple meteorological networks (1990 - 2014) is updated with an additional five complete years (2015-2019) of rainfall data. Data from 132 additional climate stations (identified in 2.2.2) were also included in this dataset.

A 30-Year daily rainfall dataset has been quality controlled and uploaded to the 'Ike Wai Gateway portal.

Near-real-time rainfall data acquisition: Computer algorithms are developed for automated data collection from multiple public facing weather stations data streams, archived climate data API and from several private servers. Data are captured, quality controlled and made available through the 'Ike Wai Gateway portal.

Quality Control Machine Learning Algorithm: Data quality can be compromised for a number of reasons, including instrument malfunction, poor data collection practices, or manual errors made in the data processing phase. To address these concerns a comprehensive analysis of five unique Quality control, machine learning algorithms are tested to determine the most robust method for flagging erroneous values in the daily rainfall time series.

**Results:** The optimal Quality Control method is identified and is built into the automated data collection and processing system.

Gap-Filling Daily Rainfall Data: A detailed analysis of different gap-filling methods is conducted to determine the optimal method for infilling missing daily rainfall. Five computationally simple gap-filling approaches (Normal Ratio (NR), Linear Regression, Inverse Distance Weighting, Quantile Mapping and Single Best Estimator) are evaluated to, 1) determine the optimal method for gap-filling daily rainfall in Hawai'i, 2) quantify the error associated with filling gaps of various size and 3) to determine the value of gap filling prior to spatial interpolation.

**Results:** The optimal gap-filling methods is identified and a gap-filling algorithm based on these methods is built into the automated data collection and processing system. One major finding of this study is the identification of the added value that gap-filling daily rainfall has on the quality of spatial interpolation. As can be seen in Figure 26, where the results of spatial interpolation with and without gap-filled data is compared to a complete data set. On average, correlations are higher and errors are lower as a result of the fill.

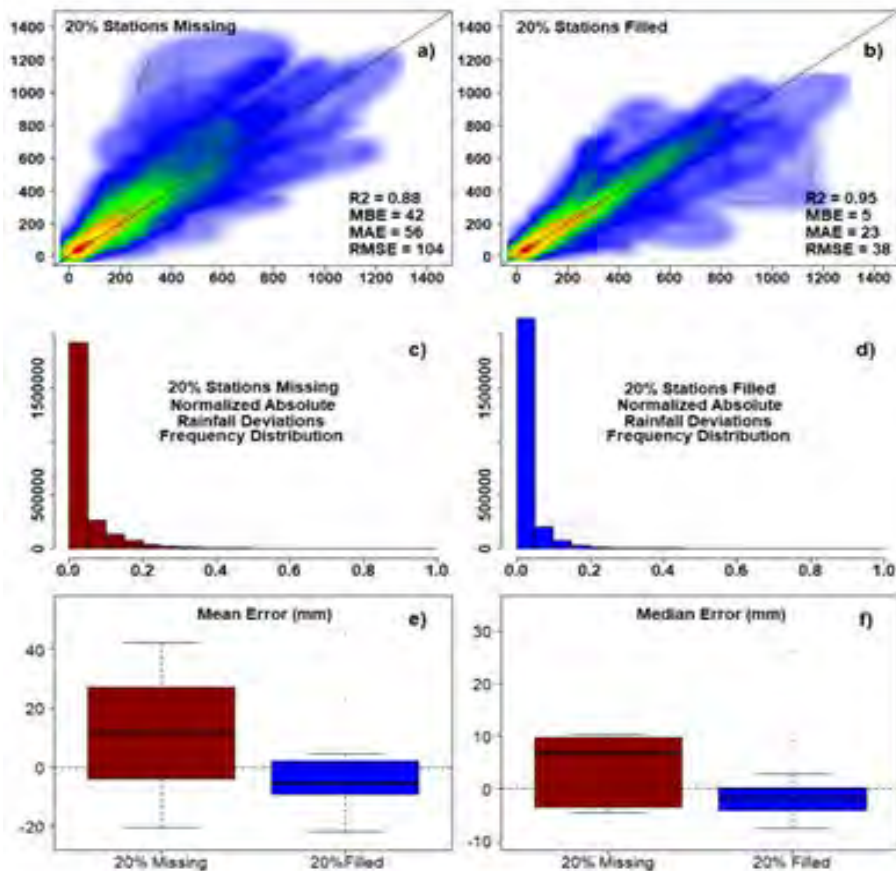
**Results:** A manuscript is submitted to the American Meteorological Societies "Journal of Applied Meteorology and Climatology" that describes the methods and results of the gap-filling analysis. This manuscript is developed in collaboration with senior researcher at the National Center of Atmospheric Research (NCAR), who is also an author.

**Results:** The 30-Year daily rainfall data set (described in 2.2.3) is completely gap-filled and is uploaded to the 'Ike Wai Gateway portal. Serially complete daily rainfall time series are necessary for numerous applications in the fields of

hydrology, resource management, and ecosystem modeling. Data users, who access the 'Ike Wai Gateway portal will now have access to both the observed and gap-filled data records for their analyses.

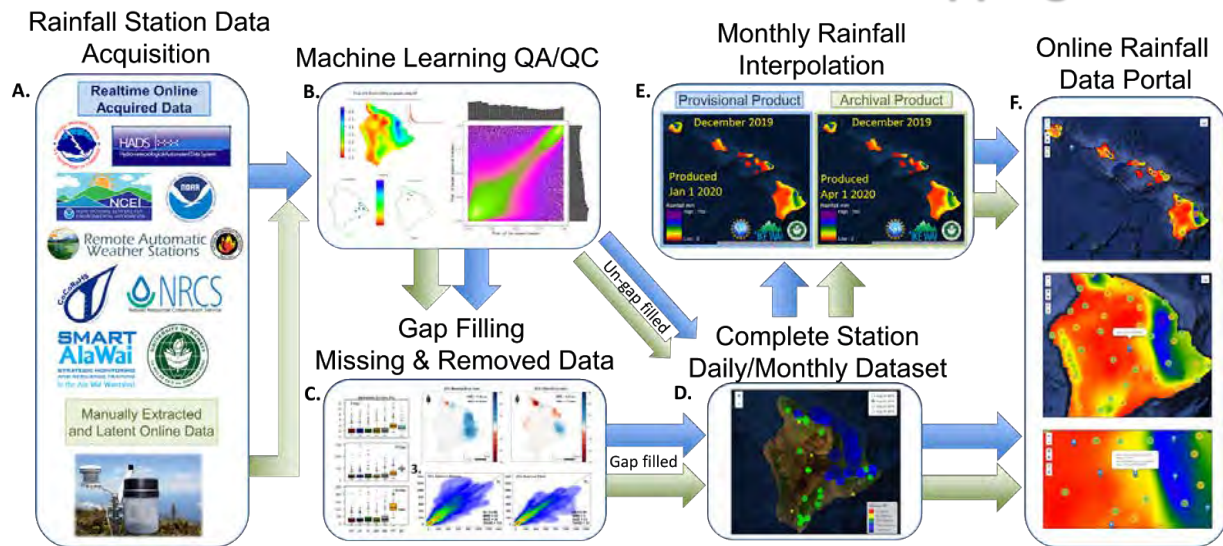
- Independent island(s) spatially climate aided cumulative monthly rainfall anomaly interpolation and conversation to cumulative monthly rainfall accumulation
- Kriging interpolation method validation and error assessment.
- Statewide rainfall mosaic of island(s) domains,
- Additional station data upload from manual and automatically sources when available and reproduction of same workflow above to produce increased quality map with additional data.

The end products, high resolution (250-m) monthly gridded rainfall and estimated uncertainty, are automatically generated soon after the end of each month. The up-to-date, quality controlled, tabular rainfall data will also be made available. The creation and ongoing production of rainfall estimates will facilitate the potential for further study into integration & application of this and similar other climate products into various other components of the Ike Wai project, such as economics, conservation planning, and groundwater balances and discharge.



**Figure 26:** 14-month composite of gridded estimates of observed rainfall (x-axis) compared with gridded estimates made with 20% of the observations missing a), and 20% of the observations filled b), frequency distributions of normalized absolute rainfall deviations for gridded estimates made with 20% of the observations missing c), and 20% of the observations filled d), mean e), and median f), deviations in rainfall between gridded estimates made with observed rainfall data and gridded estimates made with 20% of the data missing and 20% of the data filled.

# Automated Statewide Rainfall Mapping



**Figure 27:** A) Rainfall station data is collected from multiple sources and processed to daily totals with collection of online accessible data to make an immediate provisional product and after some data latency of weeks or months an additionally manually collected rainfall is used to produce an archival product. B) A custom random forest machine learning algorithm uses the 10 closest stations to estimate if an observed rainfall value is true or a data collection error. C) Data driven gap filling of removed and missing values using best available methods of normal ratio and inverse distance weighted to filling missing days of any station. D) Daily quality assured and raw and gap filled station data is produced for direct use and for interpolation (gap filled only) E) Gap filled monthly station values are used in a climate aided normal kriging creating 250m resolution surfaces of monthly rainfall anomaly, amount (mm) and respective standard errors. F) An online data portal will serve as the user interface for data interface, query, and download with station observation of daily and monthly rainfall amounts.

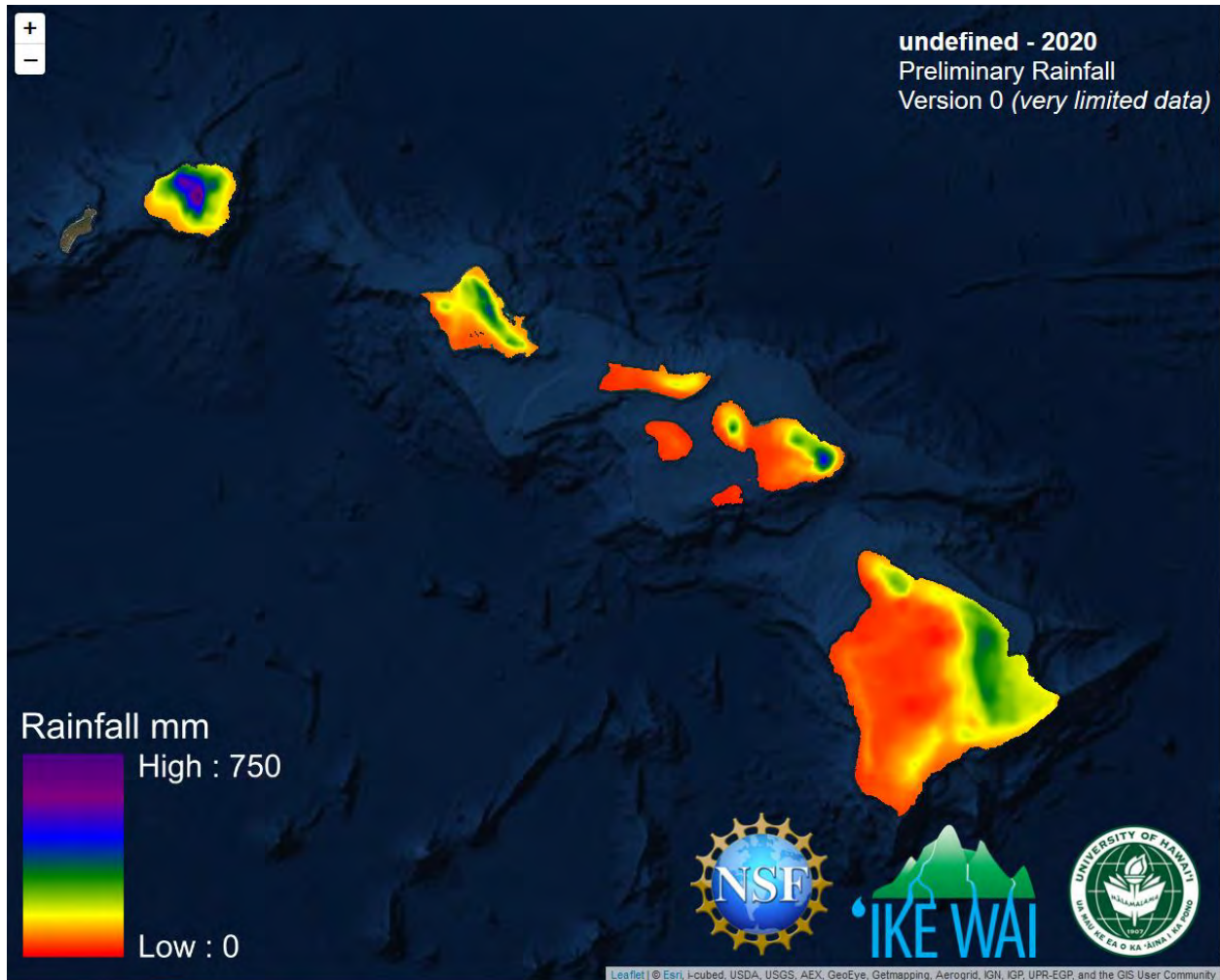
**Outputs:** Dataset/files deposited = 261,000 Datasets/files curated = 3,600

## Publications and Papers:

Longman, Ryan J., Abby G. Frazier, Andrew J. Newman, Thomas W. Giambelluca, David Schanzenbach, Aurora Kagawa-Viviani, Heidi Needham, Jeffrey R. Arnold, and Martyn P. Clark. 2019. "High-Resolution Gridded Daily Rainfall and Temperature for the Hawaiian Islands (1990–2014)." *Journal of Hydrometeorology* 20 (3): 489–508.

Newman, Andrew J., Martyn P. Clark, Ryan J. Longman, Eric Gilleland, Thomas W. Giambelluca, and Jeffrey R. Arnold. 2019. "Use of Daily Station Observations to Produce High-Resolution Gridded Probabilistic Precipitation and Temperature Time Series for the Hawaiian Islands." *Journal of Hydrometeorology* 20 (3): 509–29.

McKenzie, Marie M., Thomas W. Giambelluca, and Henry F. Diaz. 2019. "Temperature Trends in Hawai'i: A Century of Change, 1917–2016." *International Journal of Climatology* 39 (10): 3987–4001.



**Figure 28:** Example of provisional product of cumulative rainfall for Dec. 2019 produced Jan 1 2020

Alison Nugent, Ryan Longman, Clay Trauernicht, Mathew Lucas , Henry Diaz, & Thomas Giambelluca. *Fire and Rain: The legacy of Hurricane Lane in Hawai'i*, Bulletin of the American Meteorological Society, Accepted (December 2019)

Ryan Longman, Andrew Newman, Mathew Lucas & Thomas Giambelluca. *Characterizing the uncertainty and assessing the value of gap-filling daily rainfall data at multiple temporal resolutions in Hawai'i*, Journal of Applied Meteorology and Climatology, Proposed Submission (January 2020)

Ryan Longman, Oliver Elison Timm, Thomas Giambelluca & Lauren Kaiser. *A 20-year analysis of disturbance driven rainfall on O'ahu, Hawai'i*, International Journal of Climatology, Internal Review (Proposed submission March 2020)

McLean, J., GeoTIFF Visualization for Leaflet." Proposed Submission Spring 2020

Mathew Lucas, Ryan Longman & Thomas Giambelluca, *Quality control and quality assurance of daily rainfall data using machine learning: A method comparison*, In preparation

**Outcomes:** Annotated data is searchable and discoverable to the 'Ike Wai team.

**Activity 2.2.4.** Obtain historical land use data from Indigenous knowledge contained in Hawaiian newspapers and other cultural archives.

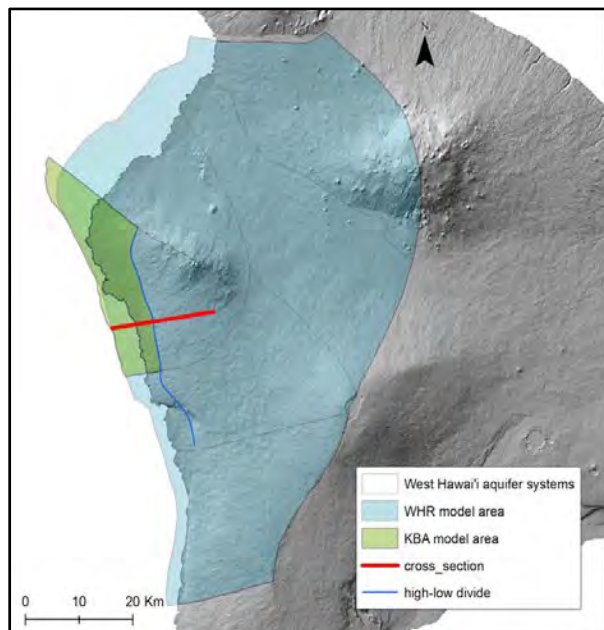
**Results:** No additional progress was made on this component of the project. Graduate student Kilika Bennet withdrew from the university without graduating in the summer of 2019. There are no plans to pursue further translations however the Community Outreach and Hawai'i Island science teams have continued discussions with community members about various aspects of the 45 fully translated articles. These include the complete series of Nā Ho'onanea o Ka Manawa and excerpts from Nā Hunahuna No Ka Mo'olelo Hawai'i.

**Outcomes:** The Hawaiian newspaper translations and storyboards produced under this component of the project were instrumental in building trust relationships with many community members and organizations both on Hawai'i Island and O'ahu. The conversations between community members and the 'Ike Wai researchers have been invaluable in understanding the content of the translated articles.

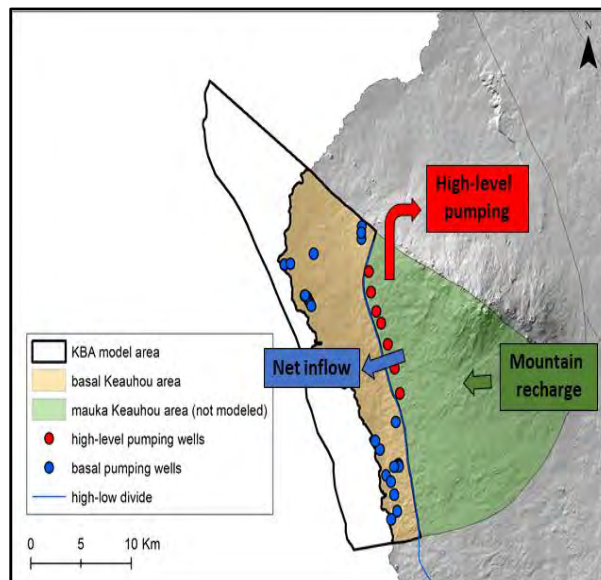
**Activity 2.2.5:** Develop and parameterize coupled conceptual models of GW flow and chemical transport. (El-Kadi, Lee)

**Results:** Three conceptual models, which vary in size, were developed to assess the West Hawai'i groundwater systems (Fig. 29). The West Hawai'i Regional (WHR) model encompasses six aquifer systems to assess aquifer interconnectivity and associated inter-aquifer flows. The Keauhou Basal Aquifer (KBA) model focuses on the basal groundwater of Keauhou, while still incorporating high-level pumping, to assess water management scenarios (Fig. 30). The 2D Cross-Sectional model (Section 2.2.7) aligns with the MT surveys through Palani Ranch, which is aimed at integrating MT results with hypothetical hydrogeological scenarios. All three models are continuously being improved upon as more information becomes available.

**Outputs:** We have continued to update the three conceptual models for West Hawai'i to accommodate different data sets. The KBA and 2D cross-sectional model have been modified based on new findings and are being used to develop numerical groundwater models (Section 2.2.6.).



**Figure 29:** Spatial variation between the three conceptual groundwater models developed



**Figure 30:** Conceptual design of how high-level pumping and mountain recharge is considered in the KBA model.

### ***Publications and Papers:***

Battistel, Maria, Muhammad Muniruzzaman, Felix Onses, Jonghyun Lee, and Massimo Rolle. 2019. “*Reactive Fronts in Chemically Heterogeneous Porous Media: Experimental and Modeling Investigation of Pyrite Oxidation.*” *Applied Geochemistry: Journal of the International Association of Geochemistry and Cosmochemistry* 100 (January): 77–89.

Ghorbanidehno, Hojat, Jonghyun Lee, Matthew Farthing, Tyler Hesser, Peter K. Kitanidis, and Eric F. Darve. 2019. “*Novel Data Assimilation Algorithm for Nearshore Bathymetry.*” *Journal of Atmospheric and Oceanic Techn*

Lee, J., and S. Lee. “Adaptive Enriched Galerkin Finite Element Method for Density-Driven Groundwater Flow in Coastal Aquifers.”, In preparation to *Advances in Water Resource* targeted in December 2019.

Giron, G. B. and El-Kadi. “Preferential Density-Dependent Flow and Transport at Local Scale Geological Variability.” In preparation.

El-Kadi, A. L. Has not started. “Preferential Density-Dependent Flow and Transport at Regional Scale Geological Variability.” TBD

***Outcomes:*** The different conceptual models allow us to realistically work with the different data sets being collected and allow us to focus on different research and management questions.

**Activity 2.2.6:** Based on model conceptualization, develop and apply suitable

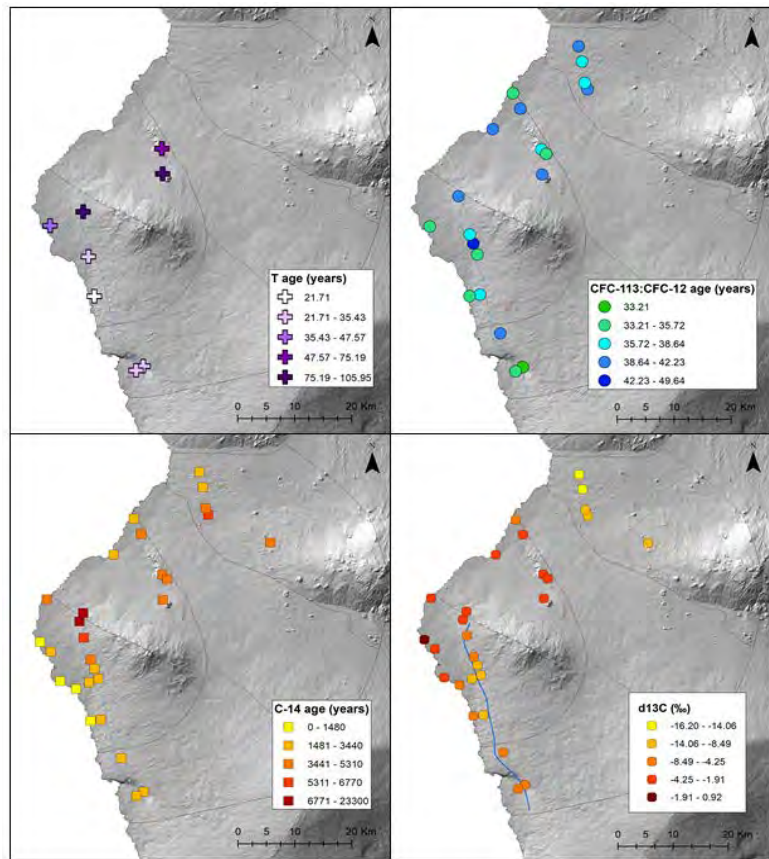
numerical groundwater models for use in developing comprehensive schemes for sustainable water use in West Hawai'i. (El-Kadi, Lee)

**Results:** Using the conceptual models in Activity 2.2.5, numerical models are continuously being improved upon for the West Hawai'i area. The numerical simulation program SEAWAT for density-driven groundwater flow was used in the development process of the KBA model, utilizing available data in model calibration.

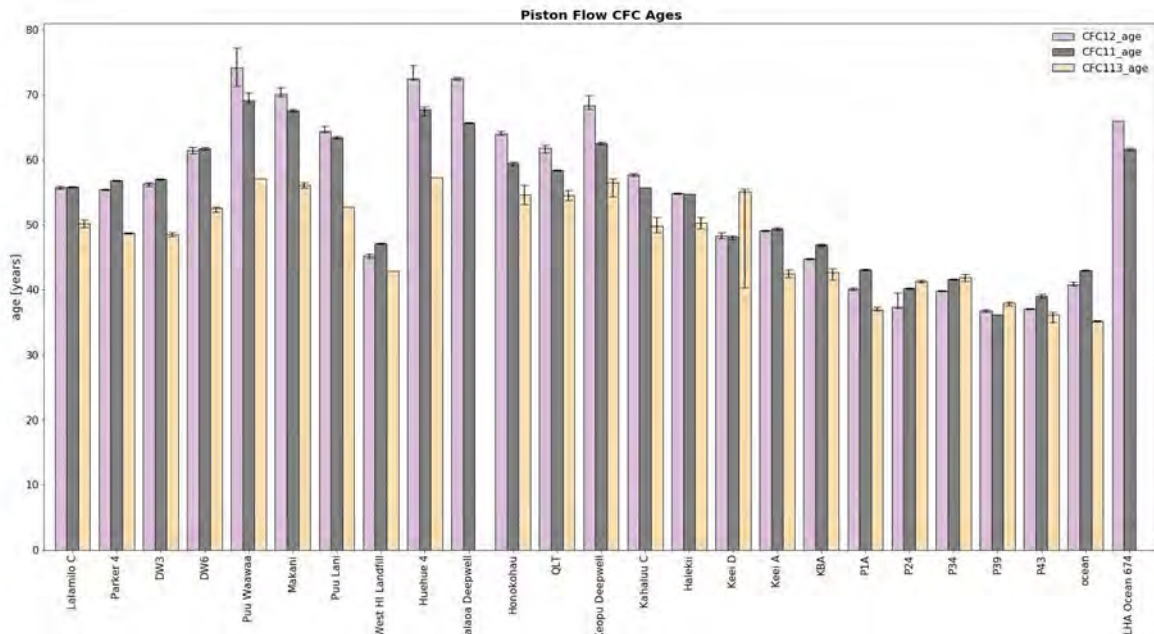
Graduate student Brytne Okuhata initiated groundwater age sampling to supplement the WHR groundwater model calibrations. Water samples from pumping wells, monitoring wells, and submarine groundwater discharge plumes were analyzed for groundwater ages. The samples were collected across five different aquifers and within both the basal and high-level groundwater systems. Eight samples were analyzed for tritium ( $^3\text{H}$ ), twenty samples were analyzed for chlorofluorocarbons (CFCs) and sulfur hexafluoride ( $\text{SF}_6$ ), and thirty samples were analyzed for radiocarbon ( $^{14}\text{C}$ ) (Fig. 31). To supplement  $^{14}\text{C}$  results,  $\delta^{13}\text{C}$  values were also measured in all  $^{14}\text{C}$  samples. Radiocarbon results represent the average age of older groundwater since it is naturally produced in the atmosphere. Tritium and CFC results represent the age of young groundwater since T and CFC were anthropogenically introduced in the 1900s. Three different CFC compounds (CFC-12, CFC-11, CFC-113) were measured in each sample, from which an independent apparent age can be calculated (Fig. 32). Since each CFC compound was released and decayed at different rates, the three different ages can be compared to one another to refine an age. The displayed age results are preliminary, which have not been adjusted for groundwater mixing.

Three different CFC compounds (CFC-12, CFC-11, CFC-113) were measured in each sample, from which an independent apparent age can be calculated (Fig. 32). Since each CFC compound was released and decayed at different rates, the three different ages can be compared to one another to refine an age. The displayed age results are preliminary, which have not been adjusted for groundwater mixing.

**KBA pumping scenarios:** The model was manually calibrated (Fig. 33) using reported head levels (obtained from the Commission on Water Resource Management (CWRM)) as well as measured salinity, nitrate+nitrite (further referred to as N), and phosphate (further referred to as P) compiled by the 'Ike Wai



**Figure 31:** Preliminary groundwater ages for measured T, CFC-113:CFC-12 ratios,  $^{14}\text{C}$  and  $\delta^{13}\text{C}$ .

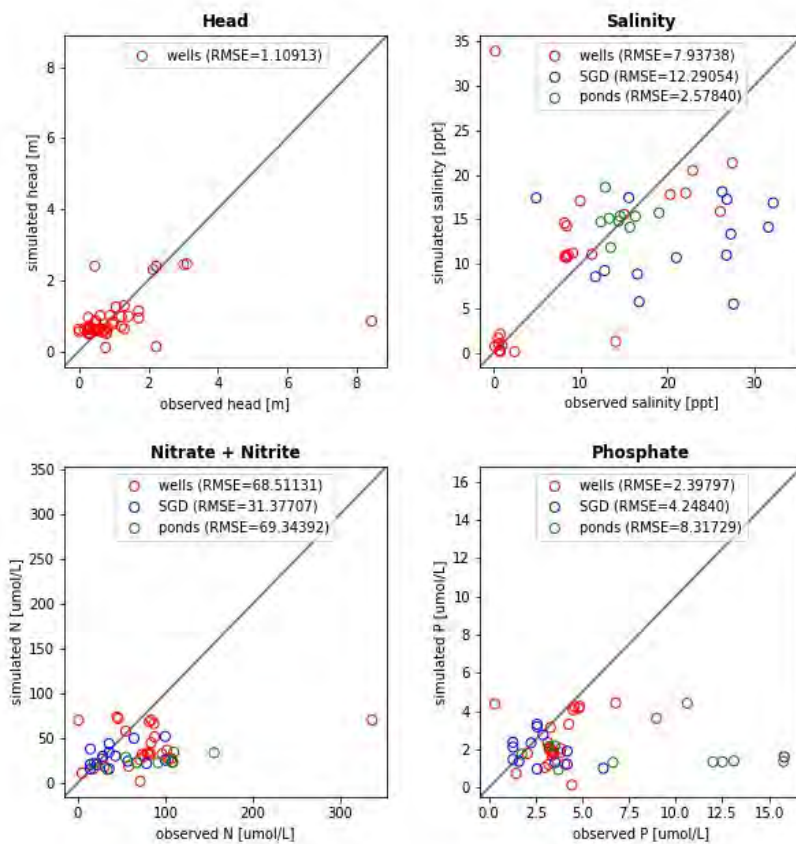


**Figure 32:** Piston flow ages determined independently from three different CFC compounds (CFC-12, CFC-11, CFC-113). Samples are organized from north to south wells. If the three ages agree, then you can assume the groundwater sample follows a piston flow model.

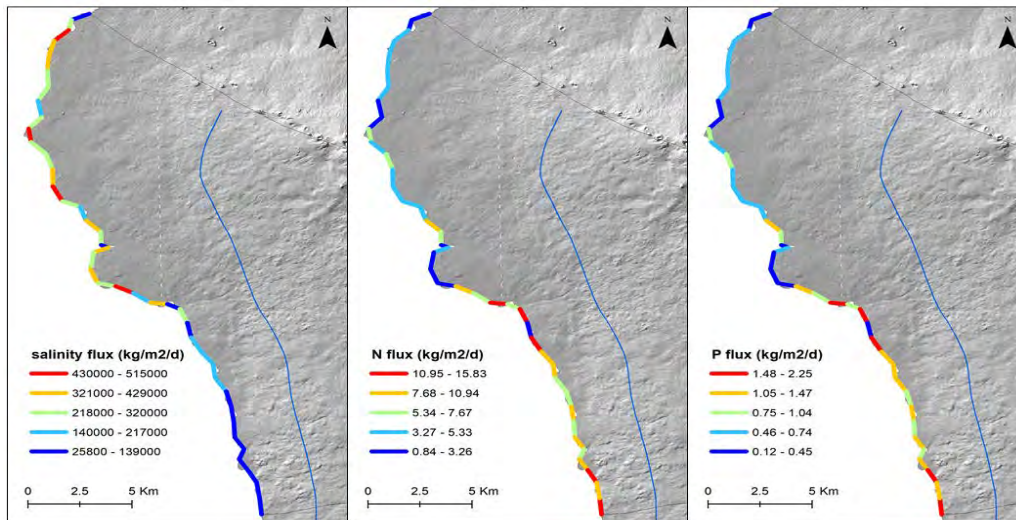
team. Salinity, N, and P fluxes across the coastal interface were computed to assess how the discharges may vary at computed to assess how the discharges may vary at different locations along the coast (Fig. 34). Two preliminary water management scenarios were completed using the calibrated KBA model, where the baseline results were set as the starting conditions for the scenario runs. The first scenario reduced the net inflow from the mauka regions by 75%. To do this, the eastern flux boundary condition was reduced from 185,000 m<sup>3</sup>/d to 46,250 m<sup>3</sup>/d. The value of 75% was arbitrarily selected, representing a reduction potentially simulating a decrease in groundwater recharge or an increase in high-level pumping rates. The second scenario removed all on-site sewage disposal systems (OSDS) from the model. In addition to such a removal, N and P concentrations originally assigned to the eastern boundary condition were reduced to 57.12 umol/L and 2.26 umol/L, respectively. Since the sustainable coastal ecosystems are of interest to 'Ike Wai and the community, the simulated concentrations along the coast were compared between the baseline model and the two scenarios (Fig. 35).

**Outputs:** A baseline KBA model was developed and preliminary water management scenarios were executed. The baseline model will be used to test realistic water management scenarios developed by the social/management teams. Results from the model will also be utilized by the social team to assess the impacts these scenarios have on coastal ecosystems.

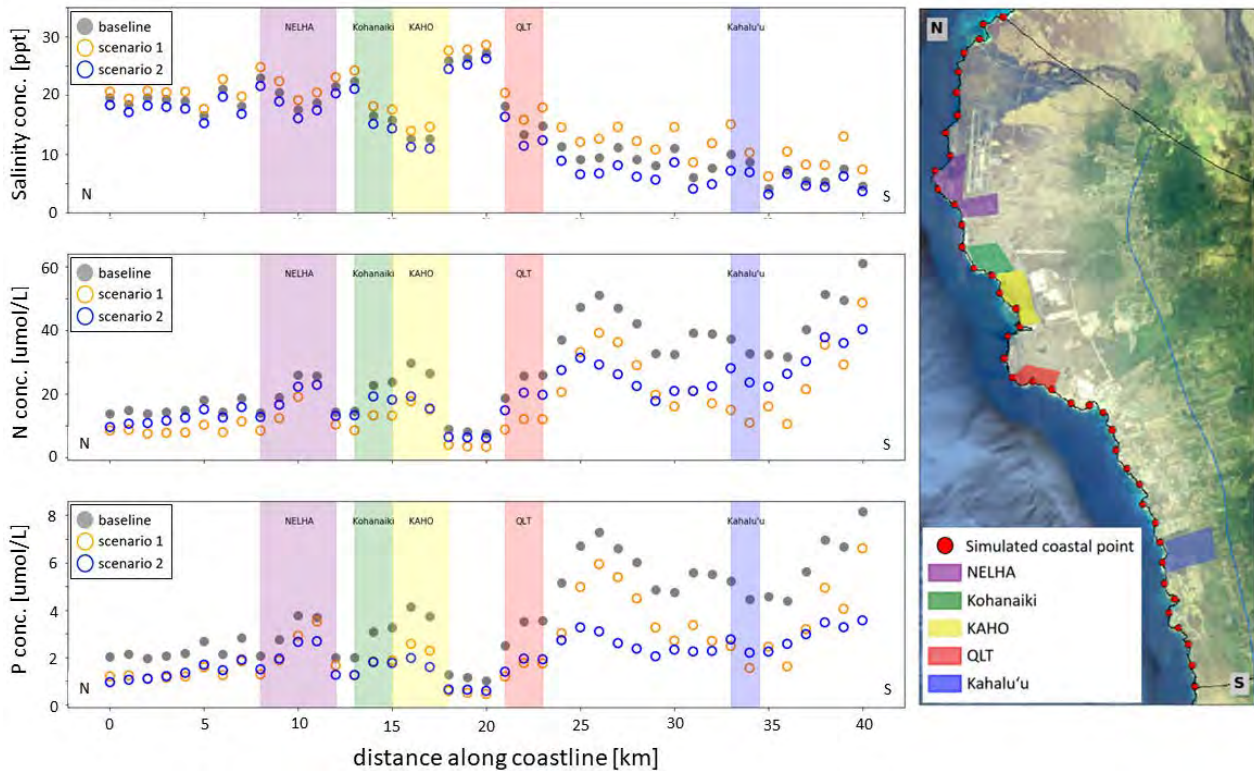
**Outcomes:** The KBA model integrates efforts from the modeling and management teams to assess pumping scenarios for water management purposes. Various scenarios developed by water managers can be simulated with this model to predict how the aquifer (and coastal ecosystems) may respond.



**Figure 33:** KBA baseline model calibration plots for head, salinity, nitrate+nitrite, and phosphate. Modeled head results are calibrated against measured head levels obtained from CWRM. Salinity, N, and P results are calibrated against data collected from wells, SGD, and anchialine ponds by the 'Ike Wai team.



**Figure 34:** Simulated baseline salinity, nitrate+nitrite, and phosphate fluxes along the coastline of the Keauhou aquifer. Values represent an outflux from the aquifer to the ocean.



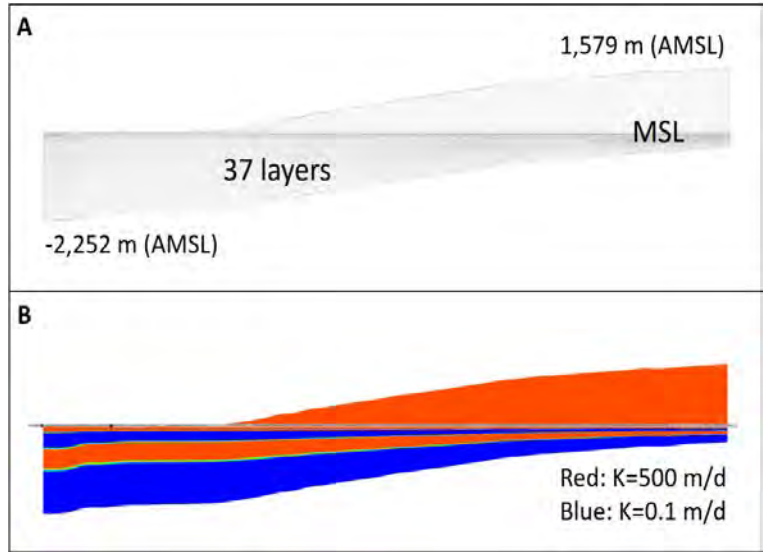
**Figure 35:** Comparison of salinity, N, and P concentrations along the Keauhou coastline simulated in the baseline, scenario 1, and scenario 2 models. Each plotted point correlates to a red marker location on the map to the right, where the plot moves from north (the edge of Kiholo Bay) to south (the edge of Kealakekua). Areas of importance along Keauhou’s coastline were highlighted.

**Risks and Mitigation Plan:** Groundwater ages will need to be further analyzed and refined in order to be included in the WHR model. The ages (specifically the CFC ages) rely on realistic estimates of groundwater recharge elevations, which are determined by the water isotopic compositions. Current models are preliminary with a manual calibration, which need to be recalibrated systematically against more data sets and ground- truthed with better subsurface structure identification.

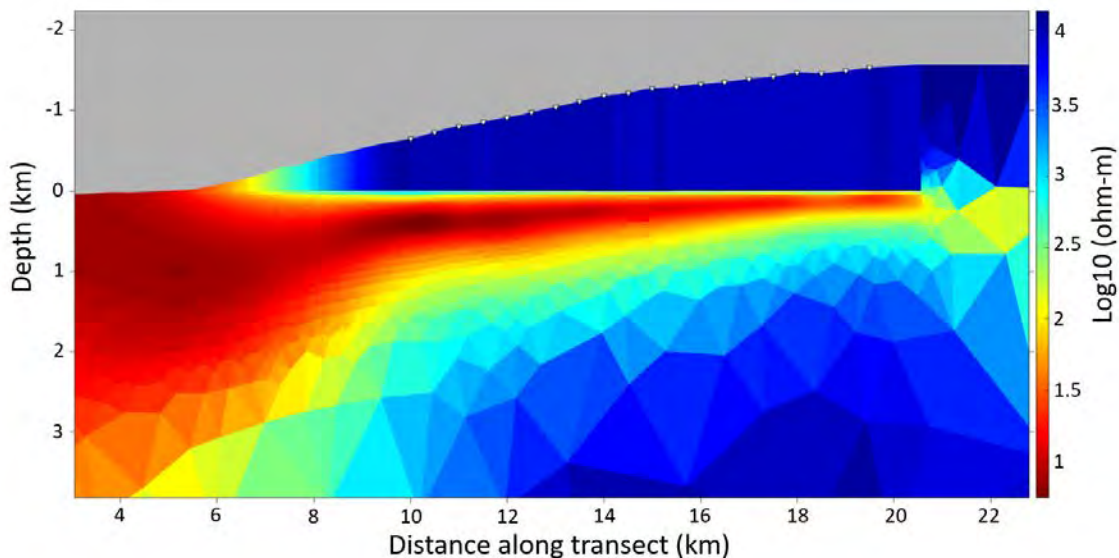
**Activity 2.2.7:** Estimate model parameters, their spatial distribution, and boundary conditions by direct measurements or through inverse methods. (El-Kadi, Lee)

**Results:** The hydraulic conductivity distribution of the WHR and KBA models were previously optimized using an inverse modeling code developed by the modeling team and the USGS PEST software (as described in Year 3 report). As new data is analyzed and refined, the WHR model will be further optimized to include groundwater age (see Section 2.2.6). The KBA model will be further optimized to include salinity data sets. This section outlines the progress in the effort to integrate geophysical and hydrological data in model calibration through full cooperation between the Modeling and the Geophysical Teams.

To investigate how geophysics surveys can improve the estimation of underlying subsurface structure, especially in field sites where only a few groundwater monitoring wells are available (e.g. Palani Ranch) a 2D cross-sectional model was designed in the model SEAWAT to test several hypothetical hydraulic conductivity scenarios in a density-dependent environment. Currently, three scenarios are being studied representing different geological models: (1) a case of homogeneous system with a barrier placed along the high-low divide, (2) the model area is divided to two zones of contrasting conductivities separated along the location of the divide, and (3) the subsurface is comprised of layers of contrasting conductivities. The latter case is shown in Figure 36. The approach adopted includes (1) using the model SEAWAT to simulate the density dependent flow for the respective geological model, (2) utilizing all input data, including conductivities, and the simulated heads and salinities to estimate synthetic electrical resistivities (Figure 37), and (3) attempting to recover hydrogeological properties by



**Figure 36:** 2D cross-sectional model of conceptual geologic structures. (A) 2D model grid, (B) A stratified scenario, where hydraulic conductivity (K) values are divided into four layers. Red layers are assigned a K value of 500 m/d and blue layers are assigned a K value of 0.1 m/d.



**Figure 37:** Preliminary estimation of electrical resistivity from synthetic MT survey using the layered hydraulic conductivity scenario and associated hydraulic head and salinity through SEAWAT . The inversion was carried out by MS graduate student T. Viti from the geophysics team using MARE2DEM inversion code.

converting the results through petrophysical relationships in step 2. Finally, data will be perturbed to assess parameter uncertainty under scarcity of both hydrogeological and geophysical data. We performed steps 1 and 2 and confirmed from our preliminary results that the electrical resistivity field can be estimated reliably with many MT surveys. However, identifying the hydraulic conductivity field and fresh/salt water separately will require additional hydrogeological information or accurate petrophysical relationships.

**Outputs:** A 2D cross-sectional model was developed and multiple hydrogeologic scenarios were simulated. The results from one of the scenarios (layered hydraulic conductivities) were passed along to the geophysics team to perform a preliminary synthetic electrical resistivity inversion. MS graduate student completed his studies in December 2019 and is currently employed in the office of the Associate Dean of SOEST at UH Mānoa.

**Publications and Papers:**

Y. Seo, M. Rolle, P. K. Kitanidis, J. Lee, *Upscaling of large-scale hydraulic conductivity fields with a spectral method*, Water Resources Research, Submit Spring 2020.

J. Lee, S. Lee, *Adaptive Enriched Galerkin finite element method for density-driven groundwater flow in coastal aquifers*, Advances in Water Resources, Submit Spring 2020.

B. Okuhata, A. El-Kadi, H. Dulai, J. Lee, D. Thomas, B. Popp, *Assessment of West Hawai'i groundwater ages using a multiple tracer approach*, Applied Geochemistry, Submit Fall 2020.

Y. Seo, T. Viti, B. Okuhata, N. Grobde, A.I. El-Kadi, J. Lee, *MT-informed subsurface characterization*, Journal of Hydrology, Submit Fall 2020.

B. Okuhata, A. El-Kadi, H. Dulai, J. Lee, L. Bremer, K. Burnett, C. Wada, *Management of the Keauhou Basal Aquifer to assess nutrient transport to coastal ecosystems*, PLOS One, Submit Spring 2021.

B. Okuhata, A. El-Kadi, H. Dulai, J. Lee, D. Thomas, *An improved groundwater model for West Hawai'i by integrating modeling and age dating*, Journal of Hydrology, Submit Fall 2021

**Outcomes:** The 2D cross-sectional model integrates efforts from the Modeling and Geophysics teams to characterize subsurface structures. Since well logs are not available to ground-truth the MT surveys conducted through Palani Ranch and other locations, the synthetic scenarios provide the teams with an idea of how certain hydrogeologic parameters will affect electrical resistivity results.

**Risks and Mitigation Plans:** The graduate student from the geophysics team successfully graduated with his master's degree, but the additional two scenarios (as well as future scenarios) will need to be modeled for electrical resistivity estimation and associated conversion to hydraulic conductivity field. The modeling team will therefore work with the already-developed MARE2DEM code to run future model scenarios. Since the built-in inversion in MARE2DEM is time-

consuming and does not provide estimation uncertainty, the fast inversion code developed by the modeling team has been set up for stochastic electrical resistivity estimation as in

[https://nbviewer.jupyter.org/github/jonghyunharrylee/pyPCGA/blob/master/examples/mare2dem\\_MT/inversion\\_mare2dem.ipynb](https://nbviewer.jupyter.org/github/jonghyunharrylee/pyPCGA/blob/master/examples/mare2dem_MT/inversion_mare2dem.ipynb).

**Activity 2.2.8:** Apply modeling tools to specific, pressing questions advanced by the hydrology community and stakeholders for the Pearl Harbor Aquifer. (**Bremer, Burnett, Wada**)

**Results:** A collaboration with the USGS Pacific Islands Water Science Center (PIWSC) to develop a simulation optimization methodology to estimate sustainable yield in Hawai'i under different land- use and climate change scenarios was completed. The finite element USGS groundwater model of Pearl Harbor [Oki, 2005] was used to simulate groundwater flow and chloride transport. The simulation optimization scheme estimated the maximum allowable withdrawal in the Pearl Harbor aquifer without violating the sustainable yield constraints, which state our management objectives which are: the reduction of salinization risk, minimization of drawdown and conservation of spring discharge. The USGS Hawaiian Water Budget Model (HWBM) was used to generate recharge maps due to different climate change and land-use scenarios. The study involved using the simulation optimization procedure to evaluate sustainable yield given (i) different spring discharge thresholds, (ii) the impact of climate change, and (iii) the effect of watershed restoration and development scenarios. These are each detailed in objective 2.3.

**Outputs:**

Framework for calculating sustainable yield that includes important components of the Hawai'i state water code.

Maps of optimal pumping across Pearl harbor Aquifer under varying climate and land use scenarios.

Recommendations for updating sustainable yield in Pearl Harbor Aquifer.

**Publications and Papers:**

Bremer, L., A. Elshall, C. Wada, L. Brewington, J. Delevaux, and K. Burnett, "Climate and Land Cover Change Effects on Groundwater Sustainable Yield in a Highly Stressed Aquifer in Hawai'i.", Submission date: March 2020.

Kimberly M. Burnett, Ahmed S. Elshall, Christopher A. Wada, Aida Arik, Aly El-Kadi, Leah L. Bremer, "Incorporating historical spring flow protection into groundwater management: A case study from Pearl Harbor Aquifer, Hawai'i", Journal of the American Water Resources Association, Targeted Submission March 2020

**Outcomes:**

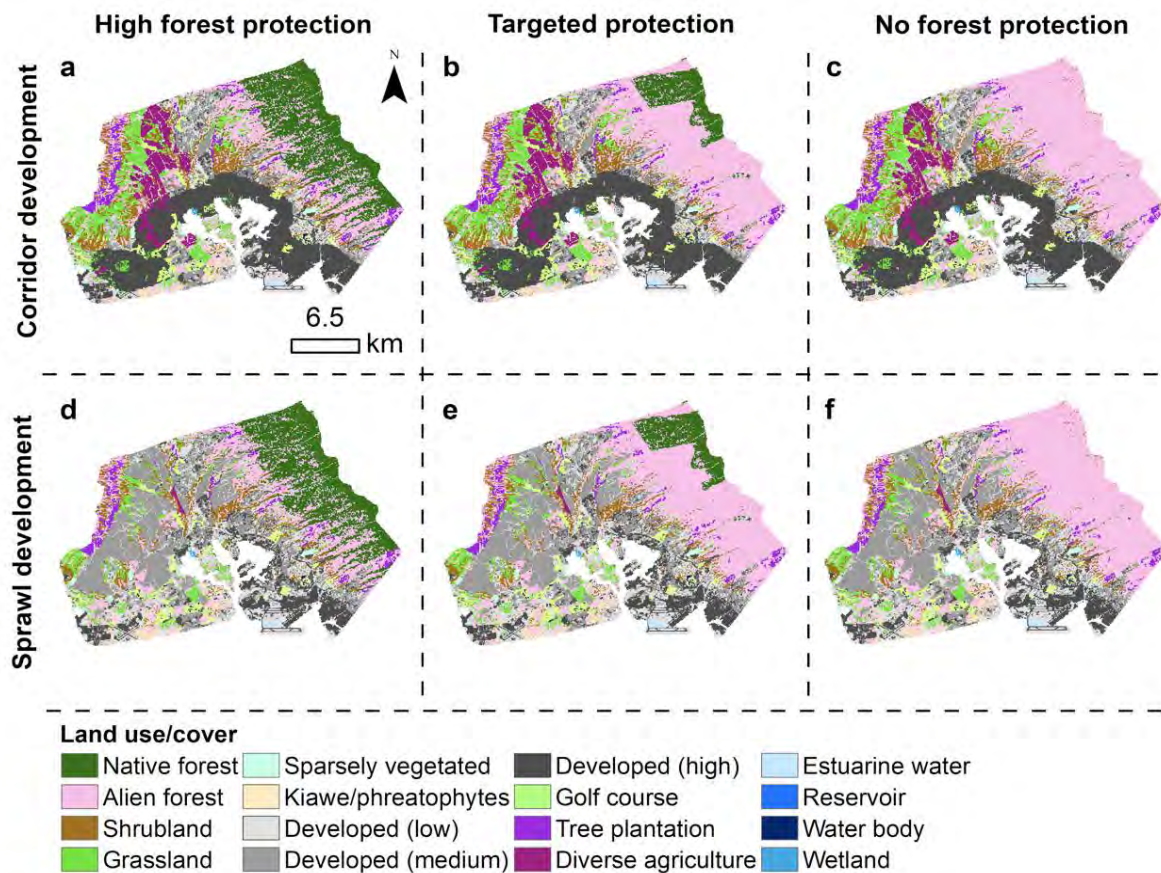
Sustainable yield estimates that include component of the state water code.

Improved coordination between groundwater modeling and groundwater management in Hawai'i.

**Objective 2.3:** Use economic modeling to forecast water availability and qualify economic impacts of aquifer utilization.

**Activity 2.3.1:** Develop site-specific land-use scenarios (Based on the stakeholder engagement process) (**Bremer, Burnett, Wada**)

**Results:** Pearl Harbor Aquifer: Land use and climate scenarios: Based on input from stakeholders including the State Office of Planning, the City and County of Honolulu Department of Planning, the Department of Forestry and Wildlife, and the Ko'olau Watershed Partnerships, six finalized scenario maps were created representing broad potential future land use changes over the next 30-years within the Pearl Harbor aquifer in urban, agricultural, and conservation lands (Fig. 38). Details on the specific land use changes represented by the scenarios were provided in the last report. The scenarios were then used to evaluate how groundwater recharge, sustainable yield, and groundwater management costs may change under a range of possible land-use and climate futures in the Pearl Harbor aquifer, and how this

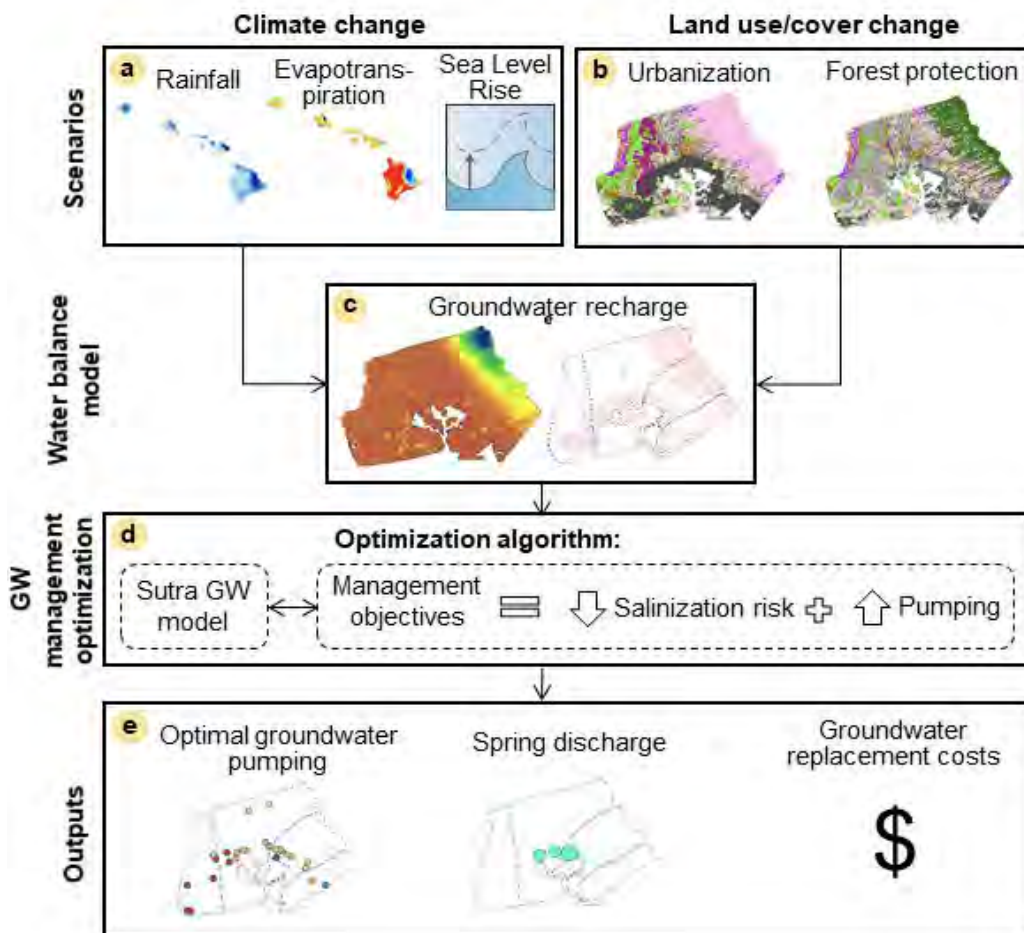


**Figure 38:** Pearl Harbor land use scenario matrix

changes estimates of sustainable yield and groundwater management recommendations.

During year 4, we finalized a systematic framework to link land use and climate scenarios to a groundwater optimization modeling and economic valuation framework (Fig. 39). Once the land use scenarios were created (Fig. 38), we collaborated with USGS who ran the scenarios through the Hawai'i Water Balance Model under current (1978-2007) and RCP 8.5 2041-2069 climate projections. These recharge projections were then linked to the optimization modeling framework described in the modeling section above to estimate sustainable yield under these scenarios as well as replacement costs. We provide an overview of economic methods and results of our analyses in section 2.3.2.

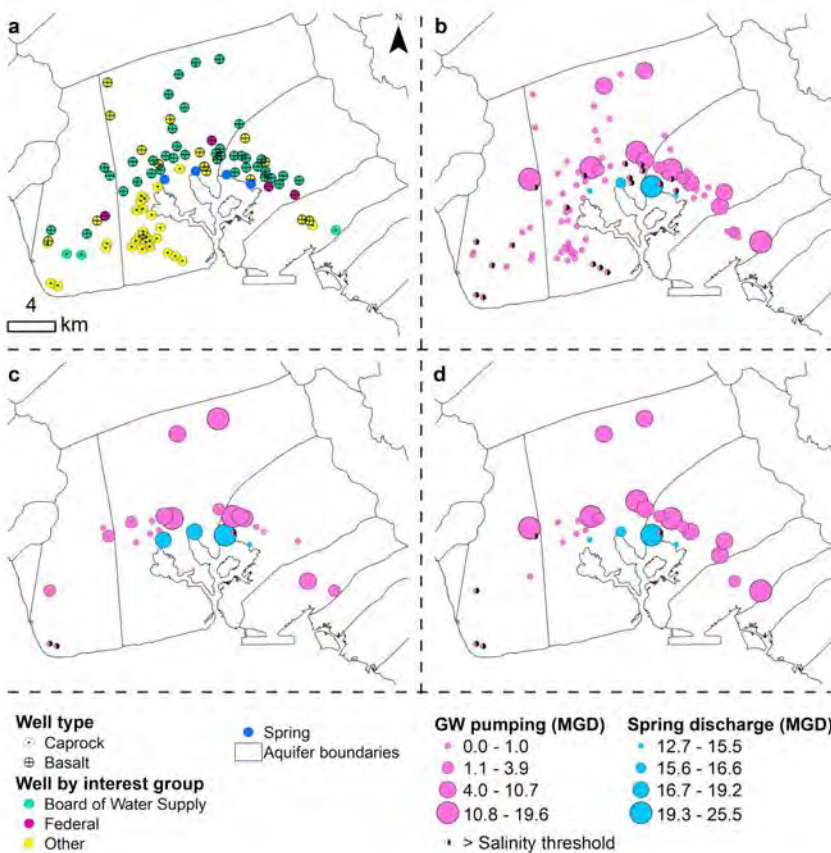
*Spring scenarios:* We completed the integration of a spring discharge constraint into our modeling framework in Pearl Harbor. We constructed an in-depth case study with Sumida watercress farm to develop a spring constraint to identify tradeoffs in pumping and spring flow. We are finishing a digital storyboard describing the history and social, ecological, and economic values of Sumida Farm.



**Figure 39:** Conceptual framework for analysis of land use and climate scenarios in terms of groundwater recharge, sustainable yield, replacement costs, and spring discharge.

We are revising a manuscript for publication in PLOS ONE.

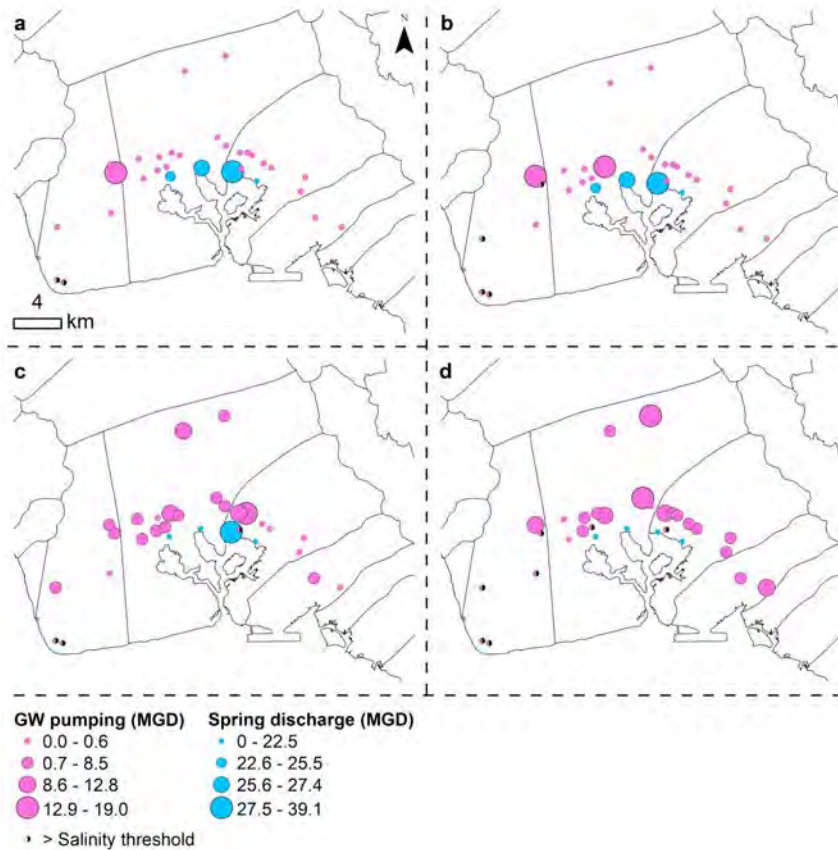
Optimal maximum allowable withdrawal was estimated under the two scenarios of excluding and including the federal wells in the decision set. Over a 50-year period with salinity, drawdown and current levels of spring discharge constraints, the optimal maximum allowable withdrawal is 124 mgd with the exclusion of federal wells from the decision set (Fig 40). For comparison, the current withdrawal rate of 117 mgd is already near the estimated optimal maximum, while the current designated sustainable yield value of 182 mgd using RAM2 is notably higher. When federal wells were included in the set of decision variables, the optimal solution increased slightly to 127 mgd (Fig 40).



**Figure 40:** Conceptual framework for analysis of land use and climate scenarios in terms of groundwater recharge, sustainable yield, replacement costs, and spring discharge.

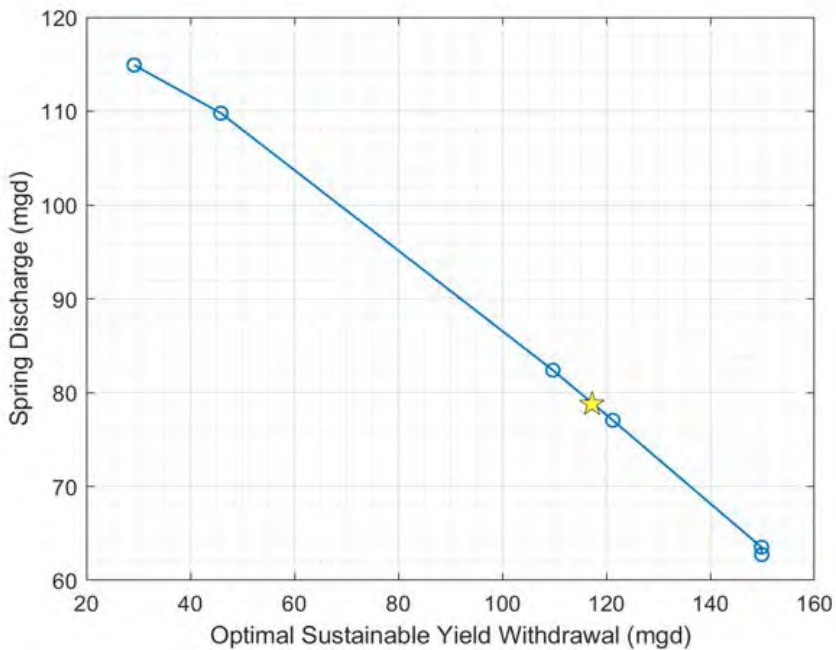
Given the requirements of the state water code, the next step was to incorporate spring discharge in the simulation optimization code. The most aggressive constraint would be to require maintenance of spring discharge at the level that existed prior to the development of the aquifer. We then defined additional constraints as different percentages of that pre-Development discharge level. We used the second scenario of including the federal wells as decision variables. Our simulation optimization results suggest that estimated optimal maximum allowable withdrawal falls from 127 mgd to between 29-150 mgd, depending on the severity

of the spring discharge constraint (Fig. 41). Given that the current withdrawal rate from the Pearl Harbor aquifer is 117 mgd, which is more than twice that required to restore 80% of the pre-development spring flow or higher, imposing such a strict constraint is likely not feasible. We therefore estimated a “tradeoff curve” to illustrate different combinations of spring discharge constraints and optimal maximum allowable withdrawal estimates (Fig. 42).



**Figure 41:** Simulation optimization results with the addition of the spring discharge constraints. (a) 100% pre-development spring flow (b) 80% pre-development spring flow (c) 60% pre-development spring flow (d) 40% pre-development spring flow

Hualālai Aquifer: Land use scenarios: We developed forest protection and restoration scenarios for the Kona area in collaboration with the Hawai‘i County Department of Water Supply. Results are described in detail in Activity 2.3.3. We also have begun working with the stakeholders including cesspool working group to develop future development and wastewater treatment scenarios for the Keauhou region. Understanding the influence of future development and wastewater treatment (e.g. cesspool upgrades) was identified as a key information need by stakeholders in the region. The social science team has been working closely with the groundwater modeling team to develop a methodology to link these scenarios to the KBA model and then to groundwater dependent ecosystems. We are also working closely with a team of marine ecologists to link outputs of the KBA modeling of the development-wastewater scenarios for nearshore water



**Figure 42:** Estimated spring discharge-SY tradeoff curve. Current pumping within the Pearl Harbor aquifer (117 mgd, marked with a star) allows for approximately 77 mgd of total spring discharge given optimum withdrawal. The circle markers from the lowest to the highest spring discharge (mgd) represent the simulation optimization results for the cases of no spring discharge constraint, 40% pre-development spring discharge constraint, current level of spring discharge constraint, 60% pre-development spring discharge constraint, 80% pre-development spring discharge

quality and dependent coral reef ecosystems (following a methodology outlined in Delevaux et al. 2019). This analysis will be useful to the cesspool working group and others to begin to evaluate how future development and cesspool upgrades might affect the coastal environment and groundwater dependent ecosystems (GDEs). We also successfully obtained a follow up grant through the Water Resources Research Center grant program to evaluate how development, climate, and forest management scenarios will influence groundwater quality and quantity and how this will influence limu (marine algae) and other groundwater dependent ecosystems.

Groundwater dependent ecosystems, including anchialine pools, fish ponds, and nearshore ecosystems are highly valued by communities, resource managers, and, recently, have been highlighted as important public trust resources which require protection. Despite recognition of the high value of these systems, particularly in the Kona area, there has been little research documenting this. A social science graduate student thus conducted and transcribed 16 key informant interviews with groundwater-dependent ecosystems (GDE) managers and cultural practitioners to better understand the economic, social, and cultural values of these systems. The interview transcripts have been provided to the interviewees and our team is writing these interviews up as a manuscript that combines information from management documents, peer-reviewed literature, oral histories, interviews, and Hawaiian newspapers on the use and value of these systems. This information will help to evaluate the impact of land use and climate change on these systems.

## ***Outputs:***

### Pearl Harbor Aquifer:

*Land use scenarios:* We developed forest protection and restoration scenarios for the Kona area in collaboration with the Hawai'i County Department of Water Supply: Created six land use scenario maps

Developed new sustainable yield estimates under these scenarios, as well as replacement costs, under six land use scenarios.

Develop a spring constraint to identify tradeoffs in pumping and spring flow using an in-depth case study with Sumida watercress farm.

### Hualālai Aquifer:

*Land use scenarios:* Forest protection and restoration scenarios were developed for the Kona area in collaboration with the Hawai'i County Department of Water Supply.

Received a Water Resources Research Center grant to evaluate how development, climate, and forest management scenarios influence groundwater quality and quantity and its impact on limu (marine algae) and other GDEs.

16 key informant interviews with GDE managers and cultural practitioners

## ***Publications and Papers:***

Elshall, A., K. Burnett, L. Bremer, C. Wada, A. Arik, G. Chun, and A. El-Kadi. "Groundwater Sustainable Yield: A Review of the Interactions between Science and Policy." Submitted December 2019.

Elshall, A. "The Spatial Dependency Concern: Are Lumped Empirical Models Sufficient for Estimating Groundwater Sustainable Yield in the Hawaiian Islands or Do We Need Distributed Mechanistic Models?", Submission Date: Late 2019.

Bremer, L., L. Brewington, A. Elshall, and C. Wada. Target, "Pearl Harbor Watershed Restoration LULC and Climate Scenarios.", Submission Date: February 2020.

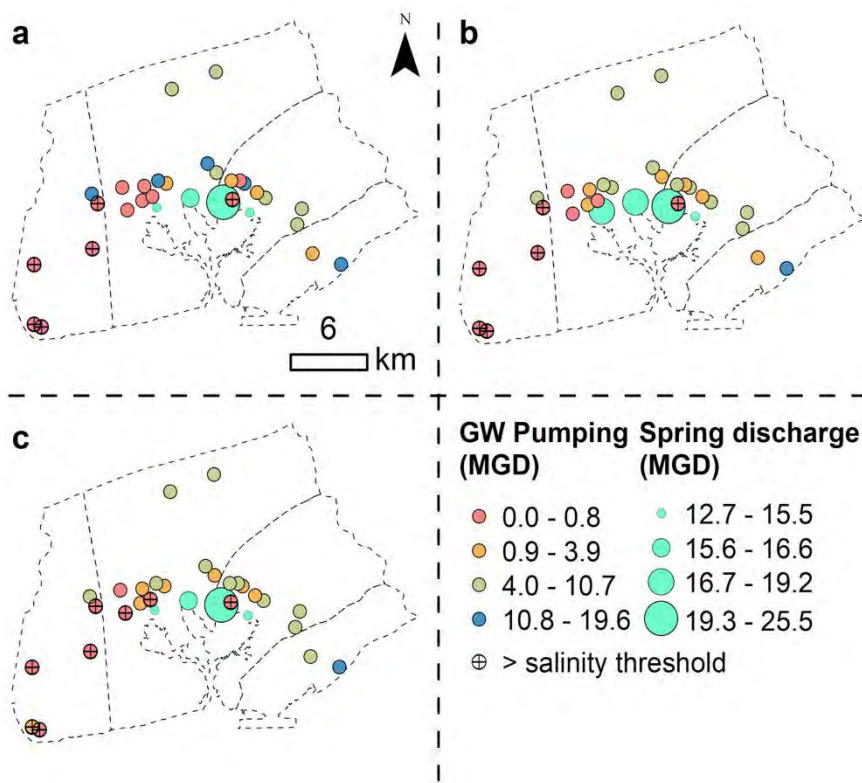
Gibson, V., L. Bremer, K. Burnett, A. Aga, and K. Bennett. Target Submission Date: February 2020. "Overview of Uses and Values of GDEs."

Bremer, L., J. Delevaux, K. Burnett, C. Wada, B. Okuhata, and H. Dulai. "Kona Case Study - Pumping, Cesspool, Climate Scenarios - Links to Coral Reefs", Submission Date: late 2020.

***Outcomes:*** The Hawai'i County Department of Water Supply will use this research to inform location and magnitude of watershed conservation surrounding their managed aquifer units of interest. This research was co-designed and co-produced with DWS with the intention of using the results to inform an RFP (request for proposals) process that will begin later this year. Through this process, research results from Ike Wai will inform water and watershed management in the Kona area.

**Activity 2.3.2:** Evaluate economic and management implications of scenarios.  
**(Bremer, Burnett, Wada)**

**Results:** Pearl Harbor Aquifer: As described in the Year 3 report, through an iterative process with CWRM and USGS, we refined the set of wells to include in the optimization. Elshall included optimization for a salinity and head drop constraint and recently completed integration of a spring constraint and incorporation of land use and climate scenarios (see activity 2.2.8). Figure 43 shows the spatial distribution of maximum SY with all springs restored to pre-industrial levels, indicating a major tradeoff between pumping and spring protection. Results from this analysis can inform decision-making around location and magnitude of groundwater withdrawals in the Pearl Harbor aquifer.



**Figure 43:** Optimal pumping under current (a), RCP 8.5 mid century rainfall (b), and RCP 8.5 mid century rainfall + 0.5 m of sea level rise projections.

Following the framework described above (Fig. 39), we estimated groundwater replacement costs of land use and climate (RCP 8.5 mid century rainfall projections and 0.5 meters of sea level rise) scenarios based on demand projections developed by the Honolulu Board of Water Supply (HBWS, 2016), which serves roughly one million customers on O’ahu, including those residing in the regions overlying and surrounding the Pearl Harbor aquifer. Demand projections were driven by two primary factors: (1) population growth and (2) changes in per capita demand. In their moderate demand growth scenario, HBWS assumed that population

continues to grow through 2040, while per capita demand for each customer declines over time. In their high demand growth scenario, they assumed that per capita demand remains constant over time for the existing population, while per capita demand declines for new future users. Although demand projections were tied to land use districts rather than aquifers, we assumed that the Pearl Harbor aquifer will continue to supply surrounding districts in the future, including the Primary Urban Center, Ewa, Central O’ahu, and East Honolulu. In 2012, the base year for the projections, demand for the four districts of interest totaled 112.2 mgd. The aggregated projected demand in 2040 was 123.8 and 132.3 mgd for the moderate and high demand growth scenarios respectively. These values correspond to average annual demand growth rates of 0.35 and 0.59 percent. Assuming that the rate of demand growth remains constant, we extended the projections to year 2070, which resulted in final-period demands of 137.6 (moderate growth) and 157.8 mgd (high growth).

For each land use and climate scenario, we then calculated the year 2070 shortfall under each of the demand growth assumptions (moderate and high) as the difference between the sustainable yield estimate generated by our simulation optimization model and the final-period demand projection. In the cases where estimated sustainable yield exceeded projected demand, expected shortfall in 2070 was zero. Replacement costs in year 2070 were then calculated by multiplying the estimated shortfall for each land use and climate scenario by \$9 per thousand gallons, in accordance with a recent estimate of the unit cost of desalination in Maui, Hawai’i (MCDWS, 2019). Note that the estimated replacement cost for each scenario is the cost of bridging the gap between sustainable yield and demand using desalination in year 2070, i.e., not aggregated over the 50-year planning period. Results are summarized for each scenario in Table 2.

We found that groundwater recharge declined by 15% (from 201 MGD to 170 MGD) under RCP 8.5 mid-century rainfall projections compared with current rainfall conditions, assuming constant baseline land use (Table 2). Reductions in recharge with climate change occurred across the landscape, with the exception of golf courses where recharge increased slightly (due to assumed increases in irrigation), but reductions were greatest in forested high elevation areas.

Groundwater modeling results indicated that groundwater SY was highly sensitive to reductions in recharge as well as sea level rise, but that optimization substantially increased SY across climate scenarios (Table 2; Fig. 43). Under *current climate and land use*, optimizing pumping increased sustainable yield by 49 MGD from 103 MGD to 154 MGD compared with current pumping distribution. The value of optimization in this case depended on the growth demand assumptions (~\$114 million under moderate growth and \$161 million under high growth), as there was no water supply shortfall under the moderate demand optimized scenario (Table 2). Optimizing pumping under RCP 8.5 mid century rainfall projections with and without sea level rise, increased SY by 30 MGD and 45 MGD respectively. Even with optimization, the costs of replacing water under climate change compared to under the current climate are high and estimated at ~112

Scenario	Recharge (mm/year; MGD)	Sustainable Yield (MGD)	Spring Discharge (MGD)	Replacement Cost (\$M/yr) - Moderate Demand	Replacement Cost (\$M/yr) - High Demand
Current land use, current rainfall, NO SLR; not optimized	553 (201)	103	78.2	114	180
Current land use, current rainfall, NO SLR; optimized	553 (201)	152	56.6	0	19
Current land use, RCP 8.5 rainfall, NO SLR; not-optimized	466 (170)	93	69.9	146	213
Current land use, RCP 8.5, NO SLR; Optimized	466 (170)	127	62.4	35	101
Current land use, RCP 8.5 rainfall, SLR not optimized	466 (170)	63.1	78	245	311
Current land use, RCP 8.5 SLR optimized	466 (170)	109	79.6	94	160
Corridor, high forest, RCP 8.5 rainfall, no SLR	462 (168)	125	63	41	108
Corridor, targeted forest, RCP 8.5, no SLR	442 (161)	116	63.5	71	137
Corridor, no forest, RCP 8.5, no SLR	434 (158)	113	53.8	81	147
Sprawl, high forest, RCP 8.5, no SLR	459 (167)	121	63.2	54	121
Sprawl, targeted forest, RCP 8.5, no SLR	439 (160)	115	62.1	74	141
Sprawl, no forest, RCP 8.5, no SLR	432 (157)	113	54.2	81	147

**Table 2:** Recharge, SY, spring discharge, and replacement costs (under two growth assumptions of select scenarios).

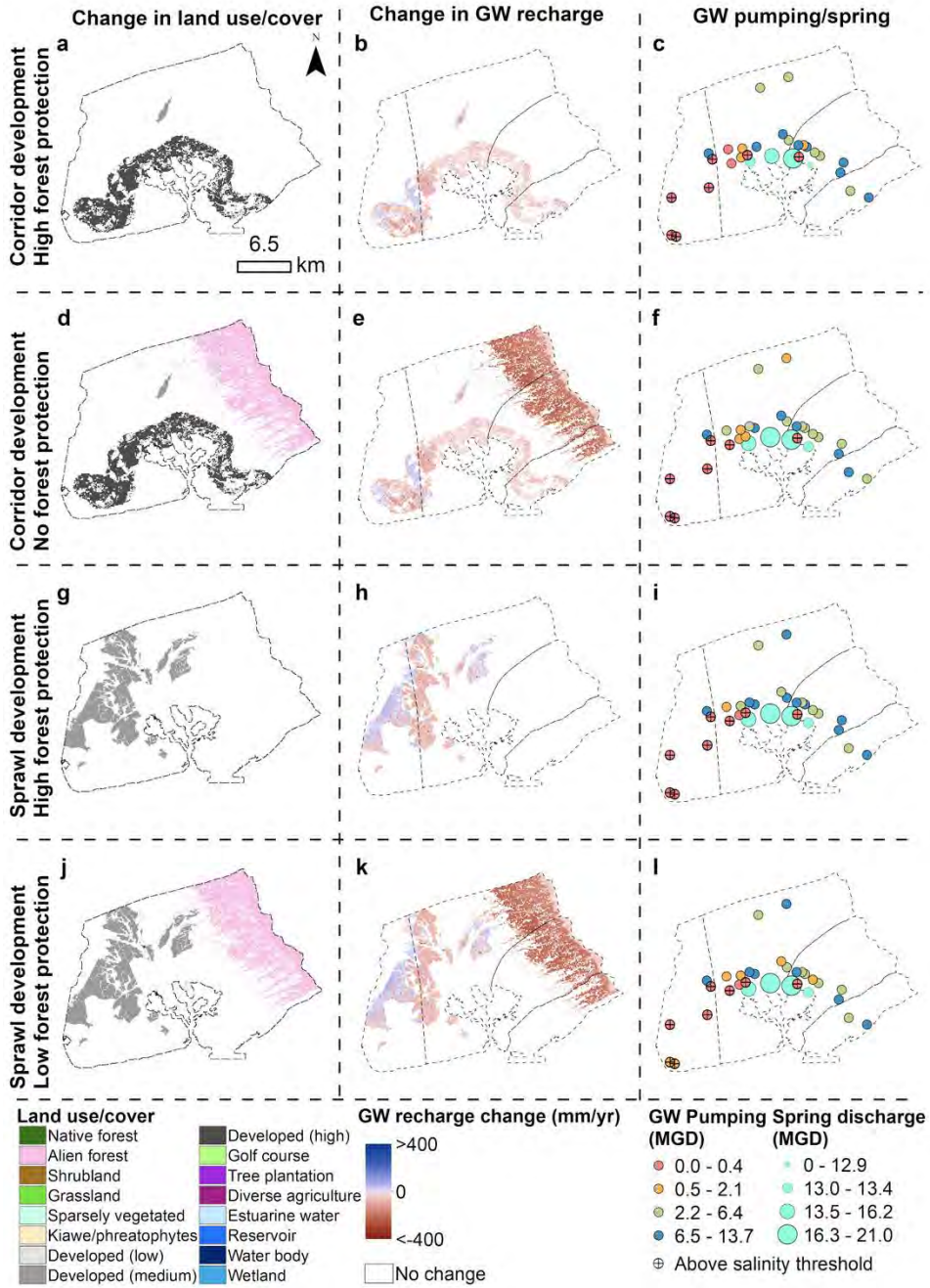
million and ~\$151 million with and without sea level rise.

The degree of forest protection was the most important land use signal for changes in recharge and sustainable yield under both climate scenarios. Under RCP 8.5 mid century, *high forest protection* and *targeted forest protection* prevented the loss of 10 MGD and 7 MGD in recharge respectively, compared with *no forest protection*. In contrast, development patterns resulted in little difference in overall recharge, but shifted the location of an overall small decline in recharge (2 MGD).

This translated into increases in optimized SY estimates by 9-12 MGD for high forest protection and by 2-3 MGD for targeted forest protection respectively. Though high for both development scenarios, the difference in SY and associated value of forest protection was higher under corridor development (\$10 million USD for *targeted protection* and \$39 million USD for *full protection*) than sprawl development (\$6 million USD for *targeted protection* and \$33 million USD for *full*

protection). This was due to lower SY under sprawl development for *full forest protection* and *targeted forest protection*, but equal SY under *no forest protection*. In addition to the aquifer wide SY reported here, the optimal spatial allocation of pumping shifts under different land use scenarios. (Fig. 44).

Kiholo Aquifer: Using a simplified representation of the Kiholo aquifer in West Hawai'i, we developed a mountain-to-sea resource management framework that



**Figure 44:** Optimal pumping under varying land use scenarios assuming RCP 8.5 mid century rainfall, but no sea level rise.

links upstream watershed conservation activities, groundwater management decisions, and the health of a nearshore algal species. Our results suggest that optimal investment in forest conservation can largely offset (up to ~75%) losses in net present value resulting from reductions in groundwater pumping that would otherwise be required to maintain growth of the nearshore marine species. Sensitivity analysis indicated that optimal management outcomes are most sensitive to changes in water demand growth and salinity parameters. Given the coarseness of the data used and the many simplifying assumptions, the objective of this activity was to outline an integrated approach that can later be adapted to the larger study region using more complex models. This was published in a high impact economic journal (Wada et al. 2019).

We updated an analysis of watershed conservation costs in Kona (see Activity 2.3.3) that we combined with recharge modeling to generate management recommendations for Hawai'i DWS on cost-effective watershed investments. This was published as a technical report for the Department of Water Supply (Bremer et al. 2019). This information will be run as a scenario in the KBA analysis to evaluate the economic benefit in terms of avoided pumping restrictions and/or impacts to GDEs. We are also working to evaluate the costs and benefits of cesspool upgrades in terms of impacts on the nearshore environment and GDEs.

**Outputs:** Pearl Harbor Aquifer: Developed estimates of groundwater replacement costs of land use and climate scenarios based on demand projections developed by the Honolulu Board of Water Supply.

Hualālai Aquifer: Net present value analysis of the impact of groundwater pumping on watershed conservation activities, groundwater management decisions, and the health of a nearshore algal species

***Publications and Papers:***

Wada, Christopher A., Sittidaj Pongkijvorasin, and Kimberly M. Burnett. 2019. "Mountain-to-Sea Ecological-Resource Management: Forested Watersheds, Coastal Aquifers, and Groundwater Dependent Ecosystems." *Resource and Energy Economics*, December, 101146

Delevaux, Jade M. S., Kostantinos A. Stamoulis, Robert Whittier, Stacy D. Jupiter, Leah L. Bremer, Alan Friedlander, Natalie Kurashima, et al. 2019. "Place-Based Management Can Reduce Human Impacts on Coral Reefs in a Changing Climate." *Ecological Applications: A Publication of the Ecological Society of America* 29 (4): e01891.

Hayes, Tanya, Tara Grillos, Leah L. Bremer, Felipe Murtinho, and Elizabeth Shapiro. 2019. "Collective PES: More than the Sum of Individual Incentives." *Environmental Science & Policy* 102 (December): 1–8.

Pongkijvorasin, S., K. Wada, and K. and Burnett. "Optimal Multi-Instrument Management of Interrelated Resources and a Groundwater Dependent Ecosystem", Submitted, waiting for first reviews.

**Outcomes:** The groundwater optimization work in Pearl Harbor and watershed

conservation analyses from the Kona area can directly influence water and watershed management in these areas. The research was co-designed and co-produced with the relevant agencies (Departments of Water Supply, Board of Water Supply, Commission on Water Resource Management, Department of Land and Natural Resources, the Watershed Partnerships, and the State and County Departments of Planning) to ensure these results would be the most useful for informing policy and decision making in these management units. The economic analyses are providing water managers and conservations specialists with new insights based on new modeling scenarios.

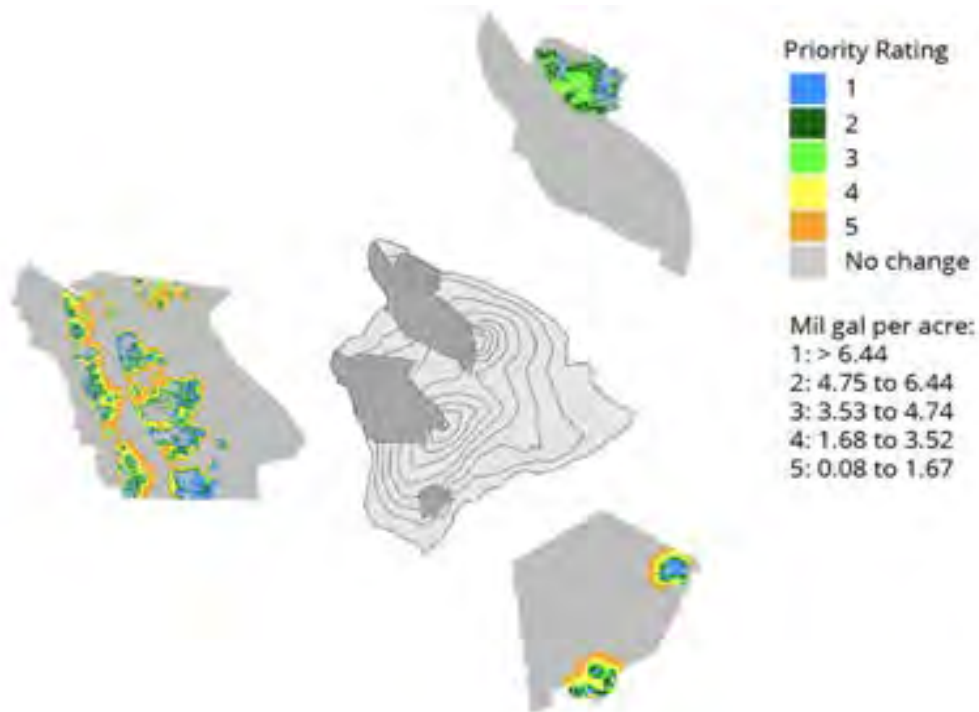
**Activity 2.3.3: Spatial analysis of watershed investments. (Bremer, Burnett, Wada)**

**Results:** We completed a second iteration of a spatial analysis of watershed investments in collaboration with Hawai'i County Department of Water Supply (can provide UHERO link; Bremer et al. 2019). This included an analysis of the most cost effective areas for investments in watershed protection and restoration. To do so, we coupled a land use change model with a statistical water balance model to evaluate potential benefits in three priority study areas, including Kona.

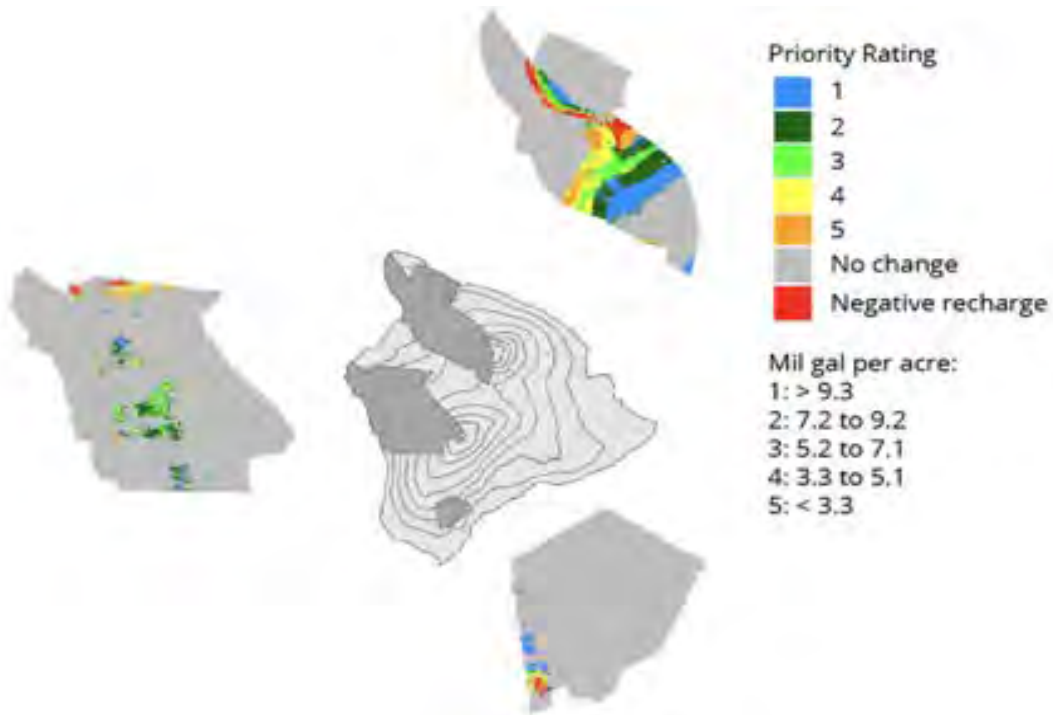
To produce the maps, we dynamically modeled counterfactual scenarios of invasive forest and grassland spread in the absence of conservation activities and calculated the change in evapotranspiration and recharge using a statistical model developed by our team (see Wada et al. 2017). We additionally modeled reforestation benefits in areas suitable for reforestation with native species. We produced priority investment maps based on which areas would result in the greatest avoided loss of recharge or increase in recharge in the case of reforestation (Figure 45 and 46). We also gathered watershed conservation costs and overlaid these to create maps of cost effectiveness (shown in last years report for avoided loss of recharge only). DWS expressed interest in us focusing on benefits rather than costs of reforestation given that the costs will be so variable.

These results stand on their own as providing an important benefit to society and DWS who will use this as part of their RFP process but also are an important sensitivity analysis for our KBA modeling study. Specifically, we will look at how future watershed restoration pathways affect the influence of pumping on GDEs of interest.

**Outputs:** Completed priority investment maps to identify areas with the greatest avoided loss of recharge or increase in recharge in the case of reforestation.



**Figure 45:** Avoided loss of groundwater recharge with watershed protection from invasion of non-native forest and non-native grassland (in millions of gallons per acre) assuming 10% higher fog capture efficiency of intact native forest. Blue=highest priority.



**Figure 46:** Aggregated change in recharge with reforestation of non-native grasslands over 50 years (in millions of gallons per acre). Blue = highest priority.

### ***Publications and Papers:***

Bremer, Leah L., Christopher A. Wada, Sarah Medoff, Jonathan Page, Kim Falinski, and Kimberly M. Burnett. 2019. "Contributions of Native Forest Protection to Local Water Supplies in East Maui." *The Science of the Total Environment* 688 (October): 1422–32.

Jennifer L. Engels, Sheree Watson, Henrietta Dulai, Kimberly M. Burnett, Christopher A. Wada, 'Ano'ilani Aga, Nathan DeMaagd, John McHugh, Barbara Sumida, Leah L. Bremer, *Collaborative research to support urban agriculture in the face of change: the case of the Sumida watercress farm near Pearl Harbor, O'ahu*, PLOS One, Submitted 2019.

Engels, J.L., S. Watson, H. Dulai, K.M. Burnett, L.L. Bremer, A. Aga, N. DeMaagd, C.A. Wada, J. McHugh, B. Sumida. "Collaborative Research to Assess Resilience of Urban Green Infrastructure: The Case of the Sumida Watercress Farm near Pearl Harbor, O'ahu." Submitted 2019.

Sittidaj Pongkijvorasin, Christopher A. Wada, and Kimberly M. Burnett, *Optimal multi-instrument management of interrelated resources and a groundwater dependent ecosystem*, Journal of Environmental Management, Submitted

Leah L. Bremer, Ahmed S. Elshall, Christopher A. Wada, Laura Brewington, Jade Delevaux, Kimberly M. Burnett, *Climate and land cover change effects on groundwater sustainable yield in a highly stressed aquifer in Hawai'i*, Environmental Research Letters, Submit March 2020

Bremer, L., N. DeMaagd, C. Wada, and K. Burnett. Submitted. "Cost-Effective Watershed Restoration on Hawai'i Island.", Submission Date: TBD.

**Outcomes:** The primary outcome associated with activity 2.3.3 are the maps and spatial data layers provided to the Hawai'i Department of Water Supply in order to inform their Request for Proposals process for increased watershed protection projects. DWS plans to begin this RFP process later this year, and will use the results from activity 2.3.3 to make decisions regarding size, scope, and location of future watershed conservation.

### **Objective 2.4. Community Engagement.**

#### **Activity 2.4.1: Agency Outreach.**

'Ike Wai researchers are using early results to address specific concerns of water management stakeholders. The modeling team manually calibrated the KBA model using reported head levels (obtained from the Commission on Water Resource Management (CWRM) Section 2.2.6) as well as measured salinity, nitrate+nitrite (further referred to as N), and phosphate (further referred to as P) compiled by the 'Ike Wai (Fig. 33). Two preliminary water management scenarios were completed using the calibrated KBA model, where the baseline results were set as the starting conditions for the scenario runs.

2.3.2 management scenarios: The set of wells used in the Pearl Harbor pumping optimization model by Eshall in Year 3 was refined to include integration of a spring constraint and incorporation of land use and climate scenarios (see activity 2.2.8). The results show the spatial distribution of maximum SY with all springs restored to pre-industrial levels, indicating a major tradeoff between pumping and spring protection. Results from this analysis can inform decision-making around location and magnitude of groundwater withdrawals in the Pearl Harbor aquifer.

**Outcomes:** A stakeholder workshop is planned for February 2020 where 'Ike Wai researchers will share the results of their research in 5 minute lightning talks. Water management and policy from across the state will have an opportunity to highlight their most pressing water issues and together the workshop participants will identify future research opportunities. This workshop is focused on the long-term sustainability of 'Ike Wai research and strengthening the capacity of the WRRC.

**Activity 2.4.2-2.4.4:** These activities were combined with Activities 2.4.5 - 2.4.6.

**Activity 2.4.5:** Negotiate, document, and manage landowner agreements.

'Ike Wai entered into three additional land access agreements in Year 4 all focused on geophysical survey access around the Schofield Dam area in central O'ahu. Self-potential surveys have been completed on the Dole Fruit Co. land and we are awaiting our right of entry permit from the Agricultural Development Corporation, a quasi-state agency that manages state agricultural land and infrastructure. The Department's board of directors approved the permit in October 2019. A visit to the Kamanui was made in October and a survey plan is being developed for that property. Additional interaction is needed to secure access to wells on Kamehameha Schools and Honolulu Board of Water Supply properties. We are continuing to work with the Hawai'i Agricultural Research Center that owns lands in central O'ahu and has strong relationships with other landowners and private water system operators in the region.

No new Agency Agreements were formalized in Year 4 on Hawai'i Island but we have secured field access from Kamehameha School (KS) to secure field access for the deployment of precipitation collectors and a stationary marine sniffer in West Hawai'i. KS has approved our request in concept, but due to unforeseen circumstances (e.g. coral bleaching events), right-of-entry permits have been delayed but should now be in process.

**Mitigation Plan:** Depending on the results of initial geophysical surveys on Hawai'i Island we will prioritize seeking access to Parker Ranch and/or Queen Emma Land Co. properties. Regarding O'ahu geochemical data collection, securing the cooperation of the Honolulu Board of Water Supply may require engaging the State Science and Technology Committee to exert their political influence.

**Activity 2.4.6:** Develop Strategic Community Partnerships.

We continue to strengthen our existing relationships through individual and small

group outreach. The geochemical field team conducted a community update on August 7, 2019 at NELHA that was well received.

As the focus of the project turns more to sustainability we are developing strategies to insure the continuation of partnerships that have been developed and nurtured under 'Ike Wai. Towards that goal planning for a Stakeholder Workshop began in late 2019. Under the leadership of 'Ike Wai climate researcher and WRRC Director Tom Giambelluca, the workshop is an opportunity for community partners to convey their water management concerns and research needs, and for the science community to showcase their capabilities for conducting management-relevant research. The workshop is scheduled for February 20, 2020 at the East-West Center on the UH Mānoa campus.

<b>Section A: Agreements in Place or Pending</b>				
<b>Landowner</b>	<b>Entity Type</b>	<b>Status</b>	<b>Agreement Coverage</b>	
<b>Hawai'i Island</b>				
Division of Forestry and Wildlife Maunakea Management	State	Application Approved	Precipitation Collector	
Division of Forestry and Wildlife Pu'u Wa'a Wa'a Sanctuary	State	Application Approved	Precipitation Collector	
Hawai'i Department of Water Supply (DWS)	County	Agreement Executed 2/1/18	Well Sampling	
Hawai'i Water Services	Private	Access Granted	Well Sampling	
Kamehameha Schools (KS)	Private	Application being processed by KS	Geophysical Surveying, Well Sampling, Precipitation Collector, Buoy deployment	
Kapaopalapala (Chun residence)	Private	Agreement Made	Geophysical Surveying, Precipitation Collector	
Kiholo Bay	Private	Access Granted	Precipitation Collector	
Kohana'iki	Private	Access Granted	Geophysical Surveying, Well Sampling, Precipitation Collector, Buoy deployment	
Napu'u Water Services Private Access granted	Private	Access Granted	Well Sampling at Puu Waa Waa Ranch	
NOAA Earth System Research Laboratory, Global Monitoring Division	Federal	Application Approved	Precipitation Collector	
Natural Energy Laboratory of Hawai'i Authority (NELHA)	State	Agreement Executed 8/17/17	Lab/storage Space Rental for Well Sampling, Buoy Deployment, and Precipitation Collector	
Office of Mauna Kea Management	State	Access Granted	Precipitation Collector	
Palamanui	Private	Access Granted	Precipitation Collector	
Palani Ranch	Private	Agreement Executed 6/30/17	Geophysical Surveying, Well Sampling, Precipitation Collector	
Pu'u Wa'a Wa'a Ranch Private	Private	Agreement Executed 5/25/17	Geophysical Surveying, Well Sampling, Precipitation Collector	
Queen Lili'uokalani Trust (QLT) Private Executed 8/9/17	Private	Agreement Executed 8/9/17	Geophysical Surveying, Well Sampling, Precipitation Collector, Buoy deployment	
<b>O'ahu</b>				
Agricultural Development Corp. (Hawaii Dept. of Agriculture)	State	Approved by Board 10/9/19; Awaiting Permit	Geophysical Surveying	
Dole Fruit Company	Private	Access Granted 9/13/19	Geophysical Surveying	
Kamananui Ranch	Private	Access Granted 9/10/19	Geophysical Surveying	
Kamehameha Schools (KS)	Private	Application being processed by KS	Geophysical Surveying, Well Sampling	

**Table 3:** List of current access agreements

**Activity 2.4.7** (Previously 3.4.2): Conduct general education and disseminate information

**Results:** In addition to continuing dissemination of project information, current results and student opportunities through the EPSCoR website ([www.hawaii.edu/epscor](http://www.hawaii.edu/epscor)) and Facebook page ([www.facebook.com/HawaiiEPSCoR](https://www.facebook.com/HawaiiEPSCoR)), Hawai'i EPSCoR has also expanded the project's social media presence to include more content on Instagram ([www.instagram.com/hawaiiepscor](https://www.instagram.com/hawaiiepscor)), Twitter ([twitter.com/HawaiiEPSCoR](https://twitter.com/HawaiiEPSCoR)) and LinkedIn ([www.linkedin.com/company/19154853](https://www.linkedin.com/company/19154853)).

Facebook fans span 10 countries across 53 cities. There were more than 1,800 impressions on Twitter. Twelve news articles and 2 video news releases about Hawai'i EPSCoR published by University of Hawai'i (UH) News in 2019.

Hawai'i EPSCoR stories were shared in various newsletters including UH School of Ocean and Earth Sciences and Technology, UH Native Hawaiian Place of Learning Advancement Office, Natural Energy Laboratory of Hawai'i Authority, the American Geophysical Union.

In addition, Hawai'i EPSCoR was featured in a 30-minute Voice of the Sea episode – Native Forests that aired in Hawai'i, American Samoa, Guam, Palau, the Federated States of Micronesia and the Marshall Islands. Project researchers Giambelluca, El-Kadi and Lee were featured in a special New Year documentary (<http://www.jibs.co.kr/tv/regularProgram/viewRegularProgramReplay?channellid=246>) that aired on JIBS, a TV station in Jeju, South Korea.

#### **Outputs:**

- UH researcher earns international recognition for innovation in geophysics
- UH data science institute awarded \$1M National Science Foundation grant
- UH Hilo students apply data science to reef research
- Voices of the Sea – Native Forests
- Record-breaking survey investigates Alaskan ocean trench
- Machines vs. the human eye: UH Hilo students learn and apply data science skills to reef study
- Sumida Farm, UH researchers collaborate on water sustainability
- Project STEMulate Summer Bridge at UH Maui College
- Three artists and a scientist from UH Hilo create modern 3D work of art, now on exhibit at Honolulu art show
- Ocean sensors help UH researchers understand Hawai'i Island aquifers
- UH renews focus on sustainability and resilience initiative
- UH student-developed sensor could revolutionize well-water monitoring
- UH Mānoa researchers advance nuclear nonproliferation and education
- Season 2 #BOSSdancefriends

**Goal 3:** Establish an integrated set of pathways to train and develop a diverse cohort of students, post-doctoral, and faculty researchers at UHH and UHM to address Hawai'i's water challenges.

**Objective 3.1:** 'Ike Wai Undergraduate Scholars Program: Undergraduate research and professional development.

**Activity 3.1.1:** Undergraduate Research. (Bruno, Pelayo, UHH Faculty)

**Results:** During the reporting period, 17 undergraduate Scholars were trained to conduct research at Kapi'olani Community College (KCC), UH Mānoa and UH Hilo. The O'ahu (UH Mānoa and KCC) projects focused on water science; Hilo projects focused on data science. Website portals to accept Scholars applications have been updated and revised, which led to a highly diverse applicant pool. Our success in meeting our demographic targets is due in part to recruiting partnerships that were developed during Years 1 and 2 with Native Hawaiian-serving programs, particularly KCC's Native Hawaiian Advancement Office and UH Native Hawaiian Student Services.

The 10 O'ahu-based Scholars were hired at three levels: 5 Trainees, 3 Interns and 2 Fellows. The 5 trainees participated in a group research project at KCC in Spring 2019 through SCI 295, a course team-taught by Dulai and Watson. The class consisted of lectures and discussions on water resources and their cultural relevance and current issues, as well as hands-on field and laboratory training in hydrology and water quality testing.

The 3 Interns and 2 Fellows each had their own closely mentored individual research project. The Fellows are seniors who served as research interns in prior years. As Fellows, they serve as peer mentors and role models for the Interns and Trainees. Both fellows graduated during the reporting period and are currently in graduate school, pursuing Masters degrees in Urban Planning (Booth) and Marine Biology (Keliipuleole). One intern (Dasalla) co-authored a paper in 2019 (published in Oceanography) and another (Heu) is actively preparing a manuscript targeted for publication in 2020.

During the next reporting period, this Undergraduate Scholars program will be transformed into the 'Ike Wai Internship program. The academic research experiences will be replaced by internships with government agencies and private businesses, as discussed below in Activity 3.6

The 7 Hilo-based Scholars participated in Data Science research with UHH faculty members. These projects spanned various subdisciplines in Data Science, including Machine Learning, Visualization, and Statistics. This academic-year research experience culminated in a research symposium open to the UHH campus. The 2019 'Ike Wai Data Science Research Symposium showcased the 7 students' work via a lightning talk and poster presentation and served as an opportunity to

advertise the UHH Data Science program.

***Publications and Papers:***

Engels, Jennifer, Barbara Bruno, Noelle Dasalla, and Daniela Böttjer-Wilson. 2019. "Class Observations from the University of Hawai'i at Mānoa Highlight the Need for Active Learning Strategies to Support Diverse Students in Large Classes." In *Fifth International Conference on Higher Education Advances*.  
<https://doi.org/10.4995/HEAD19.2019.9547>.

Bruno, B. C., C. Heu, and G. Weyenberg. In preparation (target 2020). "Comparing REU Student Vs. Advisor Ratings of Student Performance Indicates Low Student Self-Efficacy."

**Activity 3.1.2: Undergraduate Professional Development (PD). (Bruno, Jacobs, Cleveland)**

**Results:** A wide range of undergraduate professional development (PD) was offered during the reporting period, including: field work opportunities; presentation skills training and delivery; and a variety of workshops on 'soft skills'. In January 2019, seven undergraduates (including all 5 trainees) had the opportunity to participate in fieldwork at Kona, Hawai'i Island. The trainees analyzed the samples collected during this fieldwork during Spring 2019. These students presented their research results through poster presentations at the May 2019 Student Undergraduate Research Fair (SURF) at KCC. Also in May 2019, all 5 interns and fellows presented their research in the form of lightning talks. The venue was the career networking mixer, held on the final day of the O'ahu summer bridge program. In this way, they shared their research with both geoscience professionals (prospective employers) and KCC students in the summer bridge program. Workshops were held throughout the year to encourage and support students as they apply for internships, fellowships and scholarships, including REU programs and graduate fellowships. Due to its fortuitous location in Honolulu, many of our students had the opportunity to attend the 2019 national meeting of the Society for the Advancement of Chicanos and Native Americans in Science (SACNAS).

**Objective 3.2: Summer Bridge Programs: Attract early undergraduates to 'Ike Wai-related STEM fields by developing and implementing summer bridge programs.**

**Activity 3.2.1: O'ahu Summer Bridge for rising sophomores. (Bruno)**

**Results:** In May 2019, we developed and delivered a field-based summer bridge program between the Kapi'olani Community College (KCC) Native Hawaiian Advancement Office and UH Mānoa based on 'Ike Wai research covering four main content areas: (1) Hawaiian culture and community; (2) Geology; (3) Hydrology; and (4) College/ Careers. The teaching team (recruited and trained in Spring 2019) included 'Ike Wai students and faculty. Our partners at KCC's Native Hawaiian Advancement Office recruited 25 students, with diverse majors ranging from

Hawaiian studies to various STEM disciplines, and 5 peer mentors who served as teaching assistants. The peer mentors were all program alumni and many were 'Ike Wai Scholars. The summer bridge program is part of a pathway through which we recruit KCC students into undergraduate 'Ike Wai programs and SOEST majors. Our KCC partners are currently recruiting students and peer mentors for the Year 4 (May 2020) program.

**Activity 3.2.2: Hilo Summer Bridge for rising freshmen and sophomores. (Pelayo, UH Hilo faculty)**

**Results:** In summer 2019, Pelayo again implemented the curriculum for the Hilo Summer Bridge program. For five weeks in July - August 2019, eight rising and continuing UHH students earned credit-bearing courses in Mathematics and Computer Science courses: Math 241 (Calculus 1) and CS 171 (Data Science Fundamentals in R). A flipped classroom approach, paired with utilizing the online assignment portal MyMathLab on the CyberCANOE, allowed for increased student involvement and engagement in the Mathematics course. The Data Science Fundamentals in R course was again taught by Edwards and Peterson from the UHH Computer Science department. A major deliverable of this Data Science course was a final presentation on a Data Science technique, which was delivered in the Hilo Data Science Research Symposium in early August 2019.

Parallel to the Bridge program was the Hilo Data Science Research program, which included 14 students in a cross-disciplinary research project meant to unify the expertise of faculty members Burns, Weyenberg, and Mandel. The research theme was the comparison of coral reef disease prevalence using in-situ vs. digital data collection methods. Both of these techniques are utilized within the Marine Science community, and it is unclear which is a more reliable or efficient methodology. The Research program was structured with a "wet" component, which included data collection from experienced student divers, and a "dry" component, which focused on computational and statistical analyses of the data. The student participants had diverse academic backgrounds, coming from Marine Science, Computer Science, and Mathematics. The Marine Science, Machine Learning, and Statistical expertise from Burns, Mendel, and Weyenberg, respectively, led to a powerful experience that produced a submitted manuscript.

**Publications and Papers:**

Burns, Mendel, and Weyenberg, "A Comparison of the Diagnostic Performance of In-Situ and Digital Image-based Assessments of Coral Health and Disease.", *Frontiers in Marine Science*, Submitted 2019.

Mandel, T. S., and A. I. El-Kadi. "Using Artificial Intelligence and Machine Learning to Develop Systems to Automatically Segment Land Cover Types from Existing Imagery." in progress.

**Objective 3.3: Individualized Professional Development: Create and**

implement individualized professional development plans for graduate students and postdocs, and Mentoring Cascade.

**Activity 3.3.1:** Individualized Development Plan (IDP) for graduate students and postdocs. (Bruno, Eason)

**Results:** Training sessions were held each term for all incoming 'Ike Wai graduate students and postdocs on how to create an effective IDP. All graduate scholars and postdocs are required to complete an IDP within 60 days of hire. As of Dec 2019, all 13 active (new and continuing) graduate students and postdocs had completed IDPs, for a running total of 23 graduate students and postdocs with IDPs over the course of the project. A key outcome of this self-assessment of job-related skills/experience and career goals is enhanced awareness of the additional skills and experience needed to obtain their professional goals. A manuscript on the 'Ike Wai IDP program is in progress (see Activity 3.7). At the invitation of the Graduate Dean, we presented our IDP program as a model for graduate mentoring at a workshop for graduate chairs campus-wide. Two academic units – the Communication and Information Sciences Interdisciplinary PhD Program & the College of Education – were interested in utilizing this approach, and we have been supporting them as they roll-out their pilot programs.

**Activity 3.3.2:** Mentoring Cascade. (Bruno, Eason)

**Results:** All 'Ike Wai graduate students and postdocs participated in the mentoring cascade as mentees. All 13 active (plus 10 previous) graduate students and postdocs have selected PD mentors from a list of 'Ike Wai faculty and staff members outside their research group/field. New mentors and mentees were trained on the IDP process, and a mentoring workshop was held in October 2019 to discuss effective ways to provide feedback and support to their mentees as they develop their IDPs, navigate academia, and make future career plans.

In response to a site visit recommendation, the 'Ike Wai mentoring cascade was expanded to include faculty as mentees. New, untenured investigators can now request a senior, tenured faculty mentor from within or outside the 'Ike Wai project team. All 9 new faculty were contacted during Fall 2019 with an invitation to be paired with a mentor. The Education Director held individual consultations with the 6 faculty who accepted the offer, to gain a better understanding of their mentoring needs. Following the consultations, names of prospective mentors were suggested and mentoring pairs are in the process of being set up.

**Objective 3.4:** Cohorted Professional Development: Develop and implement a series of education and training workshops for 'Ike Wai Graduate Students, Postdocs, Faculty and Staff.

**Activity 3.4.1:** Cohorted Professional Development (PD) Training. (Bruno, Eason)

**Results:** During the reporting period, we offered 11 workshops to 'Ike Wai

Graduate Students, Postdocs, Faculty and Staff. External Consultant Dr. Sarah Sherman of the Carl Wieman Science Education Institute conducted two pedagogy workshops in February 2019 (funded through Bruno’s IUSE Geopaths grant), including Motivating Students (aimed primarily at Faculty) and Managing Difficult Situations (for graduate students and postdocs). Outcomes of these workshops included increased awareness among faculty, postdocs and graduate students of effective teaching and learning methods, tools and approaches for increasing student motivation, and improved classroom management skills. Also for faculty, a proposal development workshop led by The Implementation Group (TIG) was held in Spring 2019, and two workshops on applying to the NSF GRFP were held for graduate students and advanced undergraduates. In-house workshops for graduate students and postdocs included two data science workshops (two half-days each, Introduction to Programming, and Data Wrangling) developed in coordination with the Hawai’i Data Science Institute in Spring 2019. Additional 2019 workshops focused on data management skills (in particular, training on the ‘Ike Wai Gateway), developing and presenting scientific posters, and two workshops focused on Hawaiian language and cultural topics.

***Publications and Papers:***

Eason, D. E., B. C. Bruno, and B. Böttjer-Wilson, “Individual Development Plans (IDPs): An Underutilized Advising Tool in the Geosciences”, In preparation, Submit Late 2020

**Objective 3.5:** Data Science: Establish two academic programs at UH Hilo in Data Science, a certificate and a BA in data analytics.

**Activity 3.5.1:** Initiate Strategic Faculty Hires in Data Science. **(Pelayo)**

**Results:** Dr. Sukhwa Hong joined the UHH faculty as a tenure-track assistant professor in the College of Business and Economics (CoBE). Dr. Hong successfully completed his PhD in Business from Virginia Tech during Summer 2019, shortly before joining the UHH faculty and the ‘Ike Wai team. In one of his first contributions to the Data Science curriculum, Dr. Hong oversaw the creation of two new Data Science courses within CoBE, as well as a significant modification to an existing course. See Activity 3.5.2 for details on these three courses.

Dr. Hong’s hire concludes the planned faculty hires for the Data Science program at UHH. The cross-department and cross-college composition of the Data Science faculty (Mathematics, Computer Science, Marine Science, and CoBE) was deliberate and is considered to be a strength of the Data Science program. Unlike other Data Science programs throughout the country, the UHH Data Science program is proudly cross disciplinary and appeals to students from numerous departments with varying mathematical and computation skill sets.

**Activity 3.5.2:** Develop a Data Science Pathway. **(Pelayo, UH Hilo faculty)**

**Results:** The UHH Data Science Education advisor Board includes ‘Ike Wai Hires Burns, Weyenberg, Mandel, and Hong, as well as existing faculty members Drs. Edwards and Peterson from Computer Science. With the newly added expertise of Dr. Hong in CoBE, the following significant changes were introduced into the Quantitative Business Administration course catalogue: QBA 200 (Introduction to Business Analytics) and QBA 465 (Text Mining and Social Media Analytics). Along with this, the existing course QBA 36A, a required course for Business majors, obtained a major overhaul; its name was changed from Management Information Systems to Business Analytics and its content was modified to align with the goals of the Data Science efforts at UHH.

Several existing Data Science courses were modified to be more beneficial to students. In particular, almost all courses created in the last 3 years as part of the ‘Ike Wai grant were cross-listed with a new DATA course. This DATA curricular alpha will improve the transition to a new B.S. in Data Science and signal to employers that students completing these courses have had significant Data Science training. Two Data Science courses were also submitted for General Education approval (in the Quantitative Reasoning category), which will increase the attractiveness of these course offerings.

The Data Science Education Advisory Board is working with the Vice Chancellor for Academic Affairs to submit an Authorization to Plan (ATP), the primary step in developing the Data Science B.S. Degree.

While Pelayo has formally left UHH and the ‘Ike Wai project, he continues to consult with the Data Science Education Advisory Board on crafting the curriculum to be attractive to students and relevant to Data Science jobs and graduate programs.

### **Outputs:**

#### **Publications and Papers:**

Adolf, Jason E., John Burns, Judy K. Walker, and Sydney Gamiao. 2019. *Near Shore Distributions of Phytoplankton and Bacteria in Relation to Submarine Groundwater Discharge-Fed Fishponds, Kona Coast, Hawai‘i, USA*, Estuarine, Coastal and Shelf Science 219 (April): 341–53.

Fukunaga, Atsuko, John H. R. Burns, Brianna K. Craig, and Randall K. Kosaki. 2019, *Integrating Three-Dimensional Benthic Habitat Characterization Techniques into Ecological Monitoring of Coral Reefs*, Journal of Marine Science and Engineering, 7 (2): 27.

Magel, Jennifer M. T., John H. R. Burns, Ruth D. Gates, and Julia K. Baum. 2019. *Effects of Bleaching-Associated Mass Coral Mortality on Reef Structural Complexity across a Gradient of Local Disturbance*, Scientific Reports 9 (1): 2512.

Chong, Rylan C., H. Turner, and M. Speck, “Module and Kemp Instructional Design Approaches to Integrate STEM Issues and Public Policy into Data Science Curricula at a Native Hawaiian and Pacific Islander-Serving Institution.” In.

**Objective 3.6: Business and Community: Connect ‘Ike Wai to business and community.**

**Activity 3.6.1: Engage with Stakeholders. (Bruno, Pelayo, Chun)**

**Results:** The ‘Ike Wai Community Engagement Packet (created during the last reporting period) contains a primer on the project, maps of study sites and Hawaiian translations, and ethical research standards rooted in the Hawaiian culture. This must-read resource continues to drive our stakeholder engagement. As noted above under Objective 3.1, during the next reporting period, the Undergraduate Scholars program will be transformed into the ‘Ike Wai Internship program. The academic research experiences will be replaced by internships with government agencies and private businesses. To lay the groundwork for this program transformation, during the current reporting period, relationships were established with a range of potential host sites, including Hawai‘i Volcanoes Observatory, Papahānaumokuākea Marine National Monument, Honolulu Board of Water Supply, Hawai‘i Dept. of Health, Stormwater Quality Branch of the Department of Facility Maintenance at the City and County of Honolulu.

**Objective 3.7: Educational Research**

**Activity 3.7.1: Geoscience Educational Research. (Bruno, Eason)**

**Results:** Three geoscience education articles were published during the reporting period. The topics are: (1) Measuring active pedagogical techniques at UH Mānoa based on the Classroom Observation Protocol for Undergraduate STEM (Engels et al); (2) Fostering place-based geoscience teaching at UH Mānoa (Böttjer-Wilson et al); and (3) Designing and evaluating informal geoscience educational material for place-based education (Bruno et al). Two of these publications were led by former members of the ‘Ike Wai geoscience education research team (Böttjer-Wilson, Engels) after they left, attesting to the success of this EPSCoR grant in establishing robust, continuing collaborations. Two additional manuscripts on the topics of Individualized Development Plans (Eason et al) and the Undergraduate Scholars Program (Bruno et al) have been drafted and are on track for submission in early 2020.

**Outputs:**

**Publications and Papers:**

Bruno, Barbara C., and Anne Wallace. 2019, *Interpretive Panels for Geoheritage Sites: Guidelines for Design and Evaluation*, *Geoheritage* 11 (4): 1315–23.

Böttjer-Wilson, Daniela, and Barbara C. Bruno. 2019. “Place Matters! Fostering Place-Based Geoscience Teaching at the University of Hawai‘i at Mānoa.” In *Fifth International Conference on Higher Education Advances*.  
<https://doi.org/10.4995/HEAD19.2019.9237>. *ology* 36 (4): 699–715.

Eason, D.E., B.C. Bruno, D. Böttjer-Wilson, *Individual Development Plans (IDPs): An underutilized advising tool in the geosciences*, *GSA Today* (manuscript #: G3GW;

submitted Jan 2020)

Bruno, B. C., C. Heu, and G. Weyenberg. "Comparing REU Student Vs. Advisor Ratings of Student Performance Indicates Low Student Self-Efficacy.", In prep., Submission Date: late 2020.

## IV. Solicitation-Specific Project Elements

**A. Workforce Development:** Workforce development efforts during the reporting period have focused on research and professional development training for undergraduates (Objectives 3.1- 3.2), graduate students and postdocs (Objectives 3.3-3.4) and faculty/staff (Objectives 3.4-3.5). The goals, objectives and activities associated with these workforce development programs are detailed immediately above in Section III. A key part of faculty-level workforce development is establishing and filling new tenure-track positions at UH Mānoa and UH Hilo to build capacity in water science and data science, respectively. This brings new expertise into the UH system, enabling the creation of new undergraduate and graduate training programs and ultimately resulting in the development of a diverse, local workforce equipped to tackle pressing challenges such as ensuring Hawai'i's future water security. During this reporting period, we filled the 7th and final tenure-track faculty position by hiring Sukhwa Hong, in the College of Business & Economics at UH Hilo. (See Faculty Hiring Update on p. 8).

**B. Diversity:** Broadening participation is integral to the 'Ike Wai research and education missions. We set ambitious demographic targets (both in terms of gender equity and ethnicity). For undergraduates, our goals are 75% women and 50% underrepresented minorities (URM), including 25% Native Hawaiians and Pacific Islanders (NHPI). On O'ahu, we have far exceeded the NHPI and URM targets, with 100% of undergraduates served during the reporting period being URM, including 85% NHPI (including summer bridge participants). Additionally, 50% of undergraduates are women. Much of our success in broadening participation can be attributed to a well-established partnership with the Kapi'olani Community College Native Hawaiian Advancement Office.

For graduate students and post-doctoral researchers, our targets were 50% women and 25% URM. Our current graduate/postdoc cohort comprises 47% female and 53% URM. These hires were broadly advertised through local and national minority-serving organizations, including UH Native Hawaiian Student Services, Institute of Broadening Participation, Society for Advancement of Chicanos and Native Americans in Science (SACNAS), the American Indian Science and Engineering Society (AISES) and the NSF Science and Technology education and diversity listserv.

Our commitment to diversity is reflected in our core values and the demographic makeup of the leadership team, which is 60% female and 20% URM. We are actively mentoring and supporting women faculty, in addition, we support the dissemination and advancement of Native Hawaiian cultural insights and

traditional/historical knowledge both within and beyond the ‘Ike Wai project (see Recommendations: Cultural Awareness, p. 93)

Project Role	Total Participants	% Female	% URM
Faculty participant (or equivalent)	27	33%	37%
Graduate student	14	57%	43%
Non-technical support staff	4	100%	100%
Post Doc	5	40%	40%
Technical support staff	9	22%	22%
Undergraduate student	20	70%	45%
Leadership	15	47%	20%
Combined	79	49%	42%

The ‘Ike Wai project was well represented at the Society for the Advancement of Chicanos and Native Americans in Science (SACNAS) national conference, which was held for the first time in Hawai‘i. “Cross-Disciplinary Applications of Data Science,” a session organized by Co-PI Pelayo, featured three talks (by

‘Ike Wai Hilo faculty Pelayo, Weyenberg, and Burns) on curricular development, machine learning, and coral health. A fourth talk by graduate student Dylan Kobayashi (of Dr. Jason Leigh’s lab) discussed the research uses of the CyberCANOE visualization platform and a fifth talk by Sheree Watson during the “Harnessing Ecology and Evolution to Answer Applied Questions in Hawai‘i and Beyond” session discussed groundwater microbial communities revealing aquifer features. In the exhibit hall, ‘Ike Wai students, staff and faculty (led by Dumanlang) collaborated on a joint EPSCoR booth with teams from five EPSCoR jurisdictions from across the nation.

**C. Partnerships:** We have developed strategic partnerships with over 25 different entities, including local foundations with missions focused on island sustainability, resiliency and land stewardship, state agencies and key landowners and community forums. These partnerships provide two important benefits to the project, 1) a direct and trusted connection between our project activities and the potential benefits and impacts on the community and 2) access to land for study sites and wells and to current and legacy data important to our work. These partnerships include:

- **Department of Fish and Wildlife (DOFAW)** - Land owner; study site access and data sharing.
- **Hawai‘i Community Foundation** – There are opportunities to develop an ongoing strategic partnership with HCF, one proposal is for collecting existing water legacy data in the State not included in agency data and the second is to develop a methodology for determining ROI on watershed conservation. These are unanticipated opportunities arising post-award.
- **Hawai‘i County Department of Water Supply (HDWS)** - Well owner and operator; study site access and data sharing
- **Hawai‘i Department of Health** - ‘Ike Wai Internship partner
- **Hawai‘i Volcanoes Observatory** - ‘Ike Wai Internship partner

- **Hawai'i Water Service (HWS)** - Land/well owner; study site access and data sharing.
- **HI-SEAS** - Land owner; study site access and data sharing.
- **Honolulu Board of Water Supply** - O'ahu well access, 'Ike Wai Internship partner
- **Hualālai Resort** - Land owner; study site access and data sharing.
- **Huehue Ranch** - Land/well owner; study site access and data sharing.
- **Hui Aloha Kiholo** - Study site access and data sharing
- **Hui Loko** - Landowner study site access and data sharing.
- Department of Hawaiian Homelands community of Kailapa, and the Richardson School of Law (University of Hawai'i): collaboration initiated to assess water resources as part of the Māhukona aquifer system.
- **Kamehameha Schools (KS)** - Landowner; Study Site access.
- **Ka'onohi Farms** - Land owner, study site access and data sharing
- **Ka'ūpūlehu Marine Advisory Council** - Study site access and data sharing
- **Kohnana'iki Resort (KR)** - Land/well owner; study site access and data sharing.
- **Makani Golf Club (MGC)** - Land/well owner; study site access and data sharing.
- **Mauna Loa Observatory (MLO)** - Land owner; study site access and data sharing.
- **Moanalua Gardens Foundation (MGF)** - Land stewardship organization that conducts place- based education in the Moanalua Valley on O'ahu that abuts our Pearl Harbor Aquifer study site
- **Napu'u Water Inc. (NW)** - Land/well owner; study site access and data sharing.
- **Natural Energy Lab of Hawai'i (NELHA)** - Land/well owner; study site access and data sharing.
- **The Nature Conservancy** - Land owner; study site access and data sharing
- **Office of Mauna Kea Management (OMKM)** - Land owner; study site access and data sharing.
- **Palani Ranch (PaR)** - Landowner; study site access and data sharing.
- **Papahānaumokuākea Marine National Monument** - 'Ike Wai Internship partner
- **Pu'u Wa'awa'a Ranch (PWR)** - Land/well owner; study site access and data sharing.
- **Queen Lili'uokalani Trust (QLT)** - Land/well owner; study site access and data sharing.
- **Stormwater Quality Branch of the Department of Facility Maintenance at the City and County of Honolulu** - 'Ike Wai Internship partner

- **Sumida Farms** - Land owner, study site access and data sharing
- **Ulupono Initiative** - A private social impact investment firm who is providing additional funding to expand the scope of our agency outreach to include an assessment of the water management system in Hawai'i.
- **West Hawai'i Landfill (WHL)** - Land/well owner; study site access and data sharing.

#### D. Collaborations:

During the reporting period 'Ike Wai researchers were involved in 11 collaborations across 16 institutions and 22 external collaborators. Five new collaborations were started in Year 4:

- **University of Gothenburg:** Graduate student Trista McKenzie is applying machine learning algorithms such as artificial neural networks to a global carbon in submarine groundwater discharge (SGD) data set to learn more about the drivers of carbon fluxes in global SGD.
- **Boise State University and University of Southern Florida:** Niels Grobde and Stéphanie Barde-Cabusson conducted geophysical surveys using 3 different methodologies in Idaho. In addition to learning about various equipment in the field, the survey site is similar to karst environments found around Pearl Harbor.
- **University of Hawai'i - Hilo:** Grady Weyenberg and John Burns partnered with a colleague in the Tropical Conservation Biology and Environmental Science (TCBES) program at UH Hilo to analyze coral reef survey data from Papahānaumokuākea Marine National Monument.
- **University of Guam:** Gwen Jacobs and the Cyberinfrastructure team is working to provide access for University of Guam faculty to the University of Hawai'i high performance computing cluster for bioinformatics. The UH CI team will set up accounts for UoG researchers, provide training/onboarding and will monitor the data transfers on the Guam/HI links.
- **Texas Advanced Computing Center (TACC): The Cyberinfrastructure team started working on Project Tapis: Next Generation Software for Distributed Research.** Tapis will be a new platform for distributed computational experiments that leverages NSF's investments in the Agave, Abaco and CHORDS projects. Working alongside a diverse set of domain researchers to drive real-world use cases, Tapis will be the underlying cyberinfrastructure for computational workflows and science gateways (such as the Ike Wai Gateway).

During Year 4 'Ike Wai researchers continued working on the following three collaborations:

- **Hawai'i Department of Water Supply:** Kimberly Burnett, Christopher Wada, Gregory Chun, Sarah Medoff, and Leah Bremer helped create maps of priority areas

for watershed investments based on groundwater recharge and economic modeling. These maps will be used in future RFPs for services by the agency.

- **East West Center:** Leah Bremer, Kimberly Burnett, Christopher Wada worked with Pacific Risa to share ideas on developing land cover scenarios for the Pearl Harbor aquifer. This collaboration has identified synergies between our work and a Pacific Risa - USGS collaboration on Maui.
- **Scripps Institution of Oceanography, University Malaysia Terrengganu, and Frontier Geosciences (N. Vancouver):** This CEM Marine CSEM study offshore Kailua-Kona has identified high resistivity deposits of low salinity water in the offshore subsurface. The team is currently working on a number of publications as a result of this work. See Activity 1.1.5.

The following collaborations ended in Year 4:

- **Science Gateways Community Institute:** Over a period of about 6 months, Gwen Jacobs and Jennifer Geis have collaborated with the Science Gateways Community Institute (SGCI) in which they performed a usability analysis on our 'Ike Wai Science Gateway and provided recommendations for how it can be improved.
- **University of Oregon-COACH:** Barb Bruno ended her collaboration with COACH as 'Ike Wai has transitioned from career building workshops to building a local internship program for student participants.
- **Bishop Museum, UH Mānoa, UH Hilo:** John Burns worked with partners to understand environmental stressors on deep reefs to support management of Papahānaumokuākea Marine National Monument.

## E. Sustainability

Continued funding beyond the five-year duration of this award is essential for expanding the scope of our water resources research and our continued engagement with the community. During the award period, a record number of 54 proposals were submitted by 'Ike Wai faculty totaling \$63,849,598. Eight 'Ike Wai new investigators submitted 18 proposals totaling \$15,371,810 and a total of 18 proposals were submitted to NSF (\$33,247,683).

Thirteen new awards were made in 2019 totaling \$3,451,288 and increments for 21 existing awards were received totaling \$8,399,462. Seven of the new awards totaling \$3,092,417 were from NSF including two from new faculty:

- Grady Weyenberg (UHH) is the PI of a project titled: *Collaborative Research: Principal Component Analysis over Treespaces and its Applications to*

*Phylogenomics* (\$118,807)

- Leah Bremmer (UHM) is a co-PI on a project titled: *CoPe EAGER - Identifying Multiple Values for Beaches and Coastlines Under Sea Level Rise* (\$299,095)

Two other new 'Ike Wai faculty also received new awards in Year 4:

- Jonghyun Harry Lee is a co-PI on a Sandia National Laboratory project titled *Deep Learning Applications for Image Reconstruction and Analysis in Earth Sciences* (\$25,000)
- Niels Grobbe (UHM) received a grant from the Society of Exploration Geophysicists for his summer hydrogeophysics class (\$5,000)

PI Name	Campus Name	Award Sponsor	Amount
Leah Lodge Bremer	UH Mānoa	National Science Foundation	\$ 299,095
Niels Grobbe	UH Mānoa	Society of Exploration Geophysicists	\$ 5,000
Jonghyun Lee	UH Mānoa	Sandia National Laboratories	\$ 25,000
Grady Weyenberg	UH Hilo	National Science Foundation	\$ 118,807
TOTAL			\$ 447,902

**Table 4:** New 'Ike Wai investigators received four new awards in Year 4 including 2 from NSF.

Jacobs, Cleveland and Leigh received two awards that provide new funding for High Performance Computing and continued support for the Ike Wai Gateway in collaboration with TACC.

- NSF OAC #1931575: Collaborative Proposal Project Tapis: Next Generation Software for Distributed Research PI: Jacobs, Co-I Cleveland (\$997,212)
- NSF CNS: #1920304: MRI Acquisition: High Performance Computing Cluster for Data Intensive Research. PI: Jacobs, Co-I Leigh (\$700,000)

The remaining new 7 awards are:

- Matthew Platz, Excited and Ground State Hydrogen Migration, \$393,775, NSF
- Matthew Platz, MRI: Acquisition of Single-Crystal X-ray Diffractometer, \$264,849, NSF
- Matthew Platz, Pushing Health Profession Students Past the Chemistry Barrier, \$20,000, UH Foundation
- Anupam Misra, In-situ Vent Analysis Divebot for Exobiology Research, \$113,041, SETI Institute
- Henrietta Dulai, GP-IMPACT: Project EPIK - Earth, Planets, Ike, and Kuleana - Preparing the Next Generation of Diverse Geoscientists in Hawai'i, \$318,679, NSF
- Jason Leigh, Development of HAVEN Table for HECO, \$100,604, Hawaiian Electric Co.
- Kimberly Burnett, Bio-Economic Models for Protection Against Miconia Invasion Project, \$95,186, County of Maui Dept. of Water Supply.

## V. Broadening Participation

Recruitment of women and under-represented groups into 'Ike Wai roles at the undergraduate, graduate, post-doctoral and faculty roles have continued successfully in year four. As reported in Section B: Diversity (p. 79) we are striving for a participation profile for undergraduates of 75% women and 50% underrepresented minorities (URM), including 25% Native Hawaiians and Pacific Islanders (NHPI) and Graduate and Postdoctoral participants of 70% women and 25% URM.

We have seen excellent progress toward these targets, as our current undergraduate Scholars cohort includes 70% women and 45% URM (including 25% NHPI).

When we include participants in the Summer Bridge program, our total undergraduate population served included 55% women and 76% URM, including 67% NHPI). Our graduate/postdoc cohort comprises 53% female and 42% URM. Demographic data sorted by participating campus (Table 5) shows consistent success in the engagement of women and URMs at all campuses. The low personnel count at the UH System level with no new hires planned will make it difficult to improve diversity figures at that unit.

<i>Institution or RII Track-1 Totals</i>	<i>Category</i>	<i>Total individuals in category</i>	<i>Male</i>	<i>Female</i>	<i>% Female</i>	<i>URM</i>	<i>% URM</i>	<i>Native Hawaiian</i>	<i>% Native Hawaiian</i>
<b>UH System</b>	Faculty participants	2	1	1	50%	0	0%	0	0%
	Technical support staff	3	2	1	33%	0	0%	0	0%
	Non-technical support staff	2	0	2	100%	2	100%	0	0%
	Post docs	0	0%	0%					
	Graduate students	0	0%	0%					
	Undergraduate students	0	0%	0%					
	RII Leadership Team	4	1	3	75%	1	25%	0	0%
<b>UH Manoa</b>	Faculty participants	19	11	8	42%	8	42%	2	11%
	Technical support staff	5	4	1	20%	1	20%	1	20%
	Non-technical support staff	2	0	2	100%	2	100%	1	50%
	Post docs	5	3	2	40%	2	40%	0	0%
	Graduate students	14	6	8	57%	6	43%	3	21%
	Undergraduate students	8	4	4	50%	5	63%	4	50%
	RII Leadership Team	10	6	4	40%	1	10%	1	10%
<b>UH Hilo</b>	Faculty participants	6	6	0	0%	2	33%	0	0%
	Technical support staff	1	1	0	0%	1	100%	0	0%
	Non-technical support staff	0	0	0	0%	0	0%	0	0%
	Post docs	0	0%	0%					
	Graduate students	0	0%	0%					
	Undergraduate students	12	2	10	83%	4	33%	1	8%
<b>RII total</b>	Faculty participants	27	18	9	33%	10	37%	2	7%
	Technical support staff	9	7	2	22%	2	22%	1	11%
	Non-technical support staff	4	0	4	100%	4	100%	1	25%
	Post docs	5	3	2	40%	2	40%	0	0%
	Graduate students	14	6	8	57%	6	43%	3	21%
	Undergraduate students	20	6	14	70%	9	45%	5	25%
	RII Leadership Team	15	8	7	47%	3	20%	1	7%
<b>Program Total</b>	<b>All Participants</b>	<b>79</b>	<b>40</b>	<b>39</b>	<b>49%</b>	<b>33</b>	<b>42%</b>	<b>12</b>	<b>15%</b>
External Advisory Board (EAB)		9	6	3	33%	0	0%	0	0%

Table 5: 'Ike Wai demographic data by participating campus

## VI. Expenditures and Unobligated Funds

The 'Ike Wai has been awarded \$16,000,000 in the first four years of the project's cooperative agreement. As of December 31, 2019, total funds expended were \$13,728,430.

Remaining funds at the end of the reporting period (12/31/19) were \$2,271,570 total cost.

There are projected expenditures of \$1,502,319 through 5/31/20 comprised of salary, fringe benefits, supplies, travel and participant support costs.

We anticipate no more than \$769,251 (total cost) carry forward by the end of Year 4 which is 19.2% of the Year 4 budget of \$4,000,000.

## VII. Special Conditions

Two Programmatic Terms & Conditions were specified in Amendment #002 (1841642) - Update to Cooperative Agreement (CA) issued September 14, 2018.

**1. Hiring of Faculty and other Key Personnel:** Because of the need to develop institutional capacity in hydro-engineering (Aim 2.2.c), the awardee will accelerate the hiring of a faculty member at UHM with computational hydrogeology expertise, with the objective of this new member being an active participant on the project by the beginning of Year 2. A schedule for the hiring search will be included in the project's Strategic Plan and its outcome reported on in the Annual Report. NSF EPSCoR must first approve any changes.

**Actions:** Completed in Year 2 with the hire of Dr. Niels Grobbe

**2. External Advisory Committee Membership:** The awardee will arrange for a representative from the US Geological Survey with knowledge of this agency's past and current hydrological modeling of Hawaiian aquifers to serve as a member of the project's External Advisory Committee.

**Actions:** Dr. Cliff Voss has served on our External Advisory Board since Year 1. In addition to attending our EAB meeting Dr. Voss is now an affiliate faculty member of the Water Resources Research Center (WRRC) and spends additional days in Hawai'i in one on one meetings with our young investigators.

## VIII. Response to Recommendations

### 1. External Evaluator Recommendations

'Ike Wai has been fortunate to receive constructive feedback throughout the course of the project. Recommendation made by the Reverse Site Visit panel in April 2018, Site Visit panel in September 2019 and our External Evaluators in January 2020 fall

into seven programmatic areas of improvement.

1. Hydrology Expertise
2. Project Integration
3. Field Site Access
4. Economic Modeling
5. Sustainability
6. Faculty Mentoring
7. Cultural Awareness

### Hydrology Expertise

**RSV Recommendation 1:** The project would be significantly strengthened by the addition of hydrogeology expertise to integrate and complement the new and existing faculty. Expertise should be brought in directly to the project through the hire of a new faculty member or post-doc, as well as through expert, external advice (through an advisory board or similar). Submit a plan for including hydrology expertise other than through partnerships and collaborations.

**Response:** Dr. Stephanie Barde-Cabusson who joined the 'Ike Wai team in January 2019. Dr. Barde-Cabusson is a hydrogeologist with expertise in near surface geophysics (geolectrical methods), soil temperature measurements, and field geology.

Since arriving Stephanie has led two self potential field surveys on Queen Lili'uokalani Trust land along the Kona coast and at the Dole Fruit Co. property on central O'ahu. She has participated in an MT survey on Hawai'i Island and has assisted Niels Grobde with his summer geophysics course and MT field work at Palani Ranch on Hawai'i Island.

**SV Recommendation 1:** Submit an updated plan for strengthen on-site hydrogeology expertise other than through partnerships and collaborations.

**Response:** We have addressed this issue by recruiting Dr. Donald Thomas and Dr. Thomas Giambelluca, both with extensive research experience to join the team. In cooperation with Dr. El-Kadi who leads the modeling team, Thomas and Giambelluca will lead the effort towards the full integration of numerical modeling utilizing hydrological, geochemical, microbiological, and geophysical data. All senior members of the hydrogeological research team are active in acquiring major grants, publishing manuscripts, advising graduate and undergraduate students, and mentoring young researchers. They serve on the 'Ike Wai Leadership Team.

Towards a sustainable hydrogeology program at the University of Hawai'i, Drs. Thomas and Giambelluca will develop a working relationship with stakeholders to demonstrate the value of supporting hydrogeologic research. Giambelluca, who was recently appointed Director of WRRRC, is currently organizing an 'Ike Wai-WRRRC stakeholder workshop dealing with identifying and connecting water resources management needs with the University's water science expertise. Presentations will cover the most important water management questions (research needs) and researchers' capabilities and research interests.

Source	Recommendation
<b>Hydrology Expertise</b>	
Reverse Site Visit Recommendation 1	Addition of hydrogeology expertise to integrate and complement the new and existing faculty.
Site Visit Recommendation 1	Strengthen on-site hydrogeology expertise other than through partnerships and collaborations.
<b>Project Integration</b>	
Reverse Site Visit Recommendation 2	The panel saw the activities of the project to be separated and not well integrated together. a. Prepare and submit flowcharts that integrate and detail specific scientific, historical, and community inputs and how the data produced from those inputs can be fed into models that lead to specific outcomes answering specific questions of 'Ike Wai. b. Outline the roles and responsibilities of each faculty member in these flowcharts. c. Produce a timeline by which each components of the flowchart can be achieved.
Reverse Site Visit Recommendation 4	Present a plan of potential ways that UH Hilo and UH Manoa could better integrate given the relative strengths of each campus in the 'Ike Wai project.
Site Visit Recommendation 3	Provide potential activities between UH Hilo and UH Manoa to integrate data science training with hydrological information derived from the research.
External Evaluator 1	Communicate to Integrate: Facilitate structured and intentional communication activities that encourage cross-project collaboration.
External Evaluator 2	Incentivize Integration
<b>Field Site Access</b>	
Reverse Site Visit Recommendation 3	Access to Field Research Sites: Outline a clear strategy to obtain access to required wells and integrate the strategy with the research plan outlined in recommendation 2.
<b>Economic Modeling</b>	
Reverse Site Visit Recommendation 5	Economic Modeling: Develop a plan to fully integrate hydrologic and economic models as originally proposed and presented in the Strategic Plan (Goal 2).
<b>Sustainability</b>	
Reverse Site Visit Recommendation 6	Long-term Sustainability: Produce an outline that is centered around long-term planning for formal education and research in Hydrology at the UH system.
<b>Faculty Mentoring</b>	
Site Visit Recommendation 2	Develop a mentoring plan for the early career faculties.
<b>Cultural Awareness</b>	
Site Visit Recommendation 4	All faculty and staff participants be required to read the Community Engagement Packet and share a cultural experience visiting the educational 'auwai.

**Table 6:** Recommendations from 3 project reviews are summarized and grouped into 7 programmatic themes. The full recommendation and a response to each is provided in the narrative.

### Project Integration:

**RSV Recommendation 2:** The panel saw the activities of the project to be separated and not well integrated together. This issue is significant and could potentially put the project at risk of not achieving its goals. Further- more, the project has brought in several new faculty who bring in new strengths and expertise to the project that could not have been envisioned at the time of either the project development or at the strategic planning stage. To this end, the following is requested:

- a. Collaboratively, prepare and submit flowcharts that integrate and detail specific scientific, historical, and community inputs and how the data produced from those inputs can be fed into models that lead to specific outcomes answering

specific questions of 'Ike Wai.

**Response:** Our strategy is to engage these faculty in additional activities that are closely aligned with their individual academic goals. Face-to-face interaction is essential to build new collegial relationships, so we have implemented a set of activities to promote engagement in three key areas: collaborative research, curriculum development and data science skills training.

Collaborative Research: Successful collaborative research projects in Data Science require a shared interest in the problem and access to the data or data sets that are suitable for the project. While many of the data sets generated from the 'Ike Wai project are not suitable for a data science project there are however, several areas of potential collaboration.

Curriculum Development: UHH, UHM and Chaminade University are building data science programs at their institutions - focused on both degree and certificate programs. The Hawai'i Data Science Institute (HIDSI) serves as a central entity to convene discussions of best practices and sharing curriculum materials. We are focused on acquiring and hosting two types of materials: 1) Jupyter notebooks with exercises and 2) curated data sets, especially those with Hawai'i specific data. In addition, the Hawai'i Data Science Institute (HIDSI) will host an annual **Data Science Workshop in Spring 2020** for faculty teaching data science courses. Opportunities to meet and share best practices and materials will help to build those relationships.

Data Science Skills Training: The Hawai'i Data Science Institute (HIDSI) offers hands-on training workshops in a variety of data science and advanced cyberinfrastructure skills. These workshops are hosted at UH Mānoa in the Data Science Institute and broadcast to participating campuses via CyberCanoe. HIDSI faculty, professional staff and industry representatives lead the workshops.

**External Evaluator Recommendation 1:** Communicate to Integrate: Effective and frequent communication is core to improving collaboration and integration across projects. In past years, internal communication among 'Ike Wai teams was identified as a challenge by external evaluators and 'Ike Wai leadership conveyed that they have made concerted efforts in this area. If it has not already done so, the external evaluation team recommends that 'Ike Wai leadership facilitate structured and intentional communication activities that encourage cross-project collaboration. For example, in lieu of delivering project updates at All Hands Meetings, team leads might be encouraged to report on their group's needs and/or how other teams may be able to assist them.

**Response:** We acknowledge the challenges of internal communications across islands and are continuing to work to provide additional face-to-face time between the UHH and UHM faculty including, for example, at the External Advisory Board meeting in February 2020.

**External Evaluator Recommendation 2:** Incentivize Integration: Improved communication and/or engaging in new strategies that expose team members to collaboration opportunities may address, but will not solve the integration issue.

Reasons for this include the complexity of the work as well as gaps in leadership identified by the EAB, specifically physical hydrogeology.

Given the complexity of the 'Ike Wai project and the persistent challenge of integration across teams, the external evaluation team recommends that 'Ike Wai leadership identify and promote opportunities for integrated projects. An example of one such opportunity might be to improve how the IKE Platform functions to display time-series, as recommended by the EAB.

Additionally, we recommend 'Ike Wai leadership consider incentivizing integration among 'Ike Wai activities. An example of an incentive could be to provide funding or an equally persuasive motivator to conduct activities intentionally designed to integrate work across teams, as suggested by an 'Ike Wai faculty member.

**Response:** We have been working to identify specific areas of collaboration that align with individual faculty needs and interests. In our Site Visit response examples of possible projects were identified including:

- Analysis of microbiome data set: (Kiana Frank, Grady Weyenberg)
- Automated QA/QC and analytics for sensor data streams: (Travis Mandel, Tom Giambelluca, Matt Lucas, Sean Cleveland, Brian Glazer, Grady Weyenberg)
- Data Visualization: (Jason Leigh, John Burns)
- Education & Training: (Barb Bruno, Grady Weyenberg)

Collaborations are already underway. Jason and John have a longstanding collaboration between their labs focused on data visualization - specifically 3-D immersive techniques and virtual reality. They actively collaborate on visualization techniques as well as sharing and using extensive 3-D data sets. They have collaboratively taught a cross-campus Data Visualization course for both UHH and UHM students. The coral health data that Burns has generated is used in Leigh's lab for training and demonstrations in the Destiny virtual environment. Leigh, Burns, and Bob Pelayo (formerly UHH, now at UC Irvine) have co-authored a paper on the use of the CyberCANOE for research purposes. They will continue this work in writing a manuscript about the pedagogical uses of this transformative technology. All three have significant experience in adapting curricula to leverage the CyberCANOE platform. Bruno and Grady Weyenberg are collaborating on analyzing survey data from 'Ike Wai participants, on both the student and faculty end, to identify and improve 'Ike Wai's programs and initiatives targeting improved retention and student researcher recruiting.

### **Field Site Access:**

**RSV Recommendation 3:** Access to Field Research Sites: While good progress has been made in securing land access for field research, it is unclear if sufficient land access is available, or likely to be obtained, to complete the research tasks. Outline a clear strategy to obtain access to required wells and integrate the strategy with the research plan outlined in recommendation 2 above.

**Response:** A comprehensive review of progress to research sites on Hawai'i Island and O'ahu is provided in Activity 2.4.1: Agency Outreach and Access Agreements on p. 67. Our priorities are to secure right-of-entry permits for Hawai'i Island sites from Kamehameha School (KS) for water sampling, SGD sniffer deployment, and geophysical work. On O'ahu we are working to secure right-of-entry permits from the state's Agribusiness Development Corporation that were approved by the Department of Agriculture Board of Directors at their December 11, 2019 meeting.

### **Economic Modeling:**

**RSV Recommendation 5. *Economic Modeling:*** The project does not appear to be currently performing the research activities in economic modeling related to Goal 2. Develop a plan to fully integrate hydrologic and economic models as originally proposed and presented in the Strategic Plan (Goal 2).

**Response:** In Year 3 The team developed a comprehensive plan to integrate the hydrologic (groundwater) models with economic models for the Pearl Harbor study site and has developed a similar plan for the Keauhou Basin model as described in Objective 2.3 of the annual report. In both cases a focus on direct linkages between the output of the hydrological model and economic model has improved the outputs of the work and provided an avenue for feedback from community stakeholders.

During Year 4 the team finalized a systematic framework to link land use and climate scenarios to a groundwater optimization modeling and economic valuation framework (See Section 2.3.1). Subsequent impacts to recharge projections were then linked to the optimization modeling framework to estimate sustainable yield as well as replacement costs (See Section 2.3.2).

### **Sustainability:**

**RSV Recommendation 6. *Long-term Sustainability:*** The RSV panel noted that there was a lack of clarity of the long-term sustainability of the 'Ike Wai project beyond the scope of this award. Produce an outline that is centered on long-term planning for formal education and research in Hydrology at the UH system.

**Response:** We have previously reported on progress towards sustainability of 'Ike Wai educational and research programs through alliances with key campus institutes and centers. The Water Resources Research Center (WRRC) partners with SeaGrant, Institute of Sustainability and Resilience, and the Hawai'i Data Science Institute.

**Sustainability of Computational Resources:** The Cyberinfrastructure team was awarded 2 NSF grants during the reporting period that continue to build computational resources at UH. These include Project Tapis: Next Generation Software for Distributed Research (\$997k) and an MRI award (\$700k) to support the High Performance Computing cluster.

Sustaining 'Ike Wai Research Activity: In addition to system-wide proposal writing workshops, 'Ike Wai leadership has been offering proposal development assistance to our new faculty. In Year 4 eight young investigators submitted (as PI or co-PI) 18 proposals valued at \$15,371,810. To date four of those proposals have been funded:

- Leah Bremer (Co-PI), NSF, \$299,095: *CoPe EAGER - Identifying Multiple Values for Beaches and Coastlines Under Sea Level Rise*
- Grady Weyenberg (PI), NSF, \$118,807: Collaborative Research: *Principal Component Analysis over Treespaces and its Applications to Phylogenomics*
- Jonghyun Harry Lee (Co-PI), Sandia National Laboratories, \$25,000: *Deep Learning Applications for Image Reconstruction and Analysis in Earth Sciences*
- Niels Grobbe (PI), Society of Exploration Geophysicists, \$5,000: *Hydrogeophysics in Volcanic Environments - Summer School Program*

### **Faculty Mentoring:**

**SV Recommendation 2:** Develop a mentoring plan for the early career faculties, perhaps similar to the two-tiered mentoring approach currently used for graduate students, where a senior faculty mentor assists with balancing the different demands on a tenure-track faculty member, providing guidance on effective proposal development and assuring good progress towards a positive tenure decision. The plan should include HI EPSCoR, departmental, and institutional efforts.

**Response:** Our 'Ike Wai early career, tenure-track faculty each have a unique situation. They represent two campuses (Hilo and Mānoa), several departments, three faculty tracks (instructional, specialist, research) and two levels of appointment (assistant and associate). Their vastly differing job duties and expectations range from minimal teaching to full teaching loads, from minimal research activity to developing robust, externally funded research programs. Moreover, some faculty are assigned or offered a mentor by their department chair upon appointment, while others are expected to proactively seek out their own mentors on an as-needed basis. Clearly 'Ike Wai has an important role to play in ensuring all faculty receive appropriate mentoring so that they can thrive. We are also cognizant that each faculty is in a unique situation, and some already have mentors, so any mentoring plan must be flexible (tailored to each faculty's needs) and opt-in on an as-needed basis.

As per the recommendation, the 'Ike Wai mentoring cascade has been expanded to include faculty as mentees. New, untenured investigators can now request a senior, tenured faculty mentor from within or outside the 'Ike Wai project team. All 9 new faculty were contacted during Fall 2019 with an invitation to be paired with a mentor. The Education Director held individual consultations with the 6 faculty who accepted the offer, to gain a better understanding of their mentoring needs. Following the consultations, names of prospective mentors were suggested and

mentoring pairs are in the process of being set up.

In 2020 we will also resume monthly office hours for grant writing assistance that were piloted in award year 3. Co-PI Turner will again lead these grant writing sessions. She will provide general support and mentoring and (with co-PI Bruno) will act as a recruiter for specific expertise from the wider UH faculty to assist with individual proposals in specific domain areas. Through the 'Ike Wai senior leadership, senior UH faculty, and resources such as our External Advisory Board, we have the opportunity to vertically integrate a junior faculty draft proposal into review by senior and seasoned researchers in the field. We will recruit these internal and external reviewers as draft proposals start to be generated.

### **Cultural Awareness:**

**SV Recommendation 4:** Present a plan in which all faculty and staff members who participate in the 'Ike Wai project be required not only to read the Community Engagement Packet but that they share a cultural experience visiting the educational 'auwai.

**Response:** We continue to implement the activities outlined in our strategic plan Objective 2.4: Community Engagement. During the last quarter of 2019 'Ike Wai leadership worked with participants to identify opportunities to work with key UH faculty community members to better understand and respond to native Hawaiian perspectives, especially as they apply to our research and education programs.

Effective January 2020, we will dedicate one all-hands meeting per quarter (4 per year or 33% of meetings) to community engagement training. Our first all-hands training will be in the first quarter of 2020. An all-hands workshop with the Edith Kanaka'ole Foundation, a Hawaiian cultural-based non-profit organization established in 1990 to maintain and perpetuate the teachings, beliefs, practices, philosophies and traditions of the late Luka and Edith Kanaka'ole, is being planned for the first quarter of 2020. Future workshops will include a review of the Community Engage Handbook with its authors, Dr. Rosie Alegado, a native Hawaiian professor of oceanography, and Katy Hintzen, a specialist with the UH Sea Grant College Program.

In addition, we will dedicate at least one graduate student/postdoc meeting per semester (2 per year or 33% of meetings) to community engagement training. Graduate students and post-docs are being actively engaged in selecting meeting topics. Among options being discussed are compiling a list of common Hawaiian language terms encountered in the 'Ike Wai project, in the field and the community, and their English translations. Information like this will be added to the 'Ike Wai community engagement packet and serve as a resource for all team members.

Finally, all 'Ike Wai team members will be expected to participate in a minimum of two activities of their own choosing to develop their cultural competency, engage with place, and/or engage with the community. All participants will self report to the project administrator and updates will be provided in future annual and final

reports. The 'Ike Wai Communications Officer will provide a list of opportunities on O'ahu and Hawai'i island that provide a range of opportunities and flexible time commitments. Already several project participants have participated in Aloha 'Āina Fridays, Mānoa campus-based activities exploring the rich history of Hawaiians on that campus.

## IX. Tabular/Graphic Representation of Progress to Date

	Year 1	Year 2	Year 3	Year 4	Year 5
<b>GOAL 1: Collect new hydrological and geophysical data on the two study sites to address data gaps in our understanding of subsurface structure and flow.</b>					
Objective 1.1	Image subsurface geologic structures and/or the location of groundwater in 3 to 4 target areas of Hualālai and Pearl Harbor aquifers systems using				
Activity 1.1.1	●	●	●	●	
Activity 1.1.2	●	●	●	●	
Activity 1.1.3	●	●	●	●	
Activity 1.1.4	●	●	●	●	
Activity 1.1.5	○	○	●	●	
Objective 1.2	Map groundwater flow paths and improve estimates of connectivity and flux in the Pearl Harbor and Hualalai aquifer systems using integrated isotope, biogeochemical, and submarine groundwater discharge data by the end year 5				
Activity 1.2.1	●	●	●	●	
Activity 1.2.2	●	●	●	●	
Activity 1.2.3	●	●	●	●	
Activity 1.2.4	●	●	●	●	
Objective 1.3	Produce datasets on physical and chemical parameters of groundwater by establishing novel sensor-based monitoring network in wells within targeted regions of the Pearl Harbor and Hualalai aquifer systems by the end of Year 3.				
Activity 1.3.1	●	●	●	●	
Activity 1.3.2	●	●	●	●	

●	On schedule / completed
●	Delays - mitigation underway
●	May not be completed by the next reporting period.
○	Not Started / Completed

	Year 1	Year 2	Year 3	Year 4	Year 5
<b>GOAL 2: Develop a new data and modeling platform for Hawaii</b>					
Objective 2.1	IKE Platform: Implement a fully featured data management, analysis, and visualization application based on the AGAVE software framework.				
Activity 2.1.1	●	●	○	○	
Activity 2.1.2	●	●	○	○	
Activity 2.1.3	●	●	●	●	
Activity 2.1.4	●	●	●	●	
Activity 2.1.5	●	●	●	●	
Objective 2.2	Data Store Population: Aggregate, annotate and store legacy, existing and new scientific data.				
Activity 2.2.1	●	●	●	●	
Activity 2.2.2	●	●	●	●	
Activity 2.2.3	●	●	●	●	
Activity 2.2.4	●	●	●	○	
Activity 2.2.5	●	●	●	●	
Activity 2.2.6	●	●	●	●	
Activity 2.2.7	●	●	●	●	
Activity 2.2.8	●	●	●	●	
Objective 2.3	Use economic modeling to forecast water availability, and qualify economic impacts of aquifer utilization.				
Activity 2.3.1	●	●	●	●	
Activity 2.3.2	●	●	●	●	
Activity 2.3.3	●	●	●	●	
Objective 2.4	Community Engagement				
Activity 2.4.1	●	●	●	●	
Activity 2.4.2	●	●	○	○	
Activity 2.4.3	●	●	●	●	
Activity 2.4.4	●	●	●	○	
Activity 2.4.5	●	●	●	●	
Activity 2.4.6	●	●	●	●	
Activity 2.4.7	●	●	●	●	

	Year 1	Year 2	Year 3	Year 4	Year 5
<b>GOAL 3: Education and Workforce Development: Establish an integrated set of pathways to train and develop a diverse cohort of students, post-doctoral and faculty researchers at UHM and UHH to</b>					
Objective 3.1	'Ike Wai Scholars Program: Undergraduate research and professional development.				
Activity 3.1.1	●	●	●	●	
Activity 3.1.2	●	●	●	●	
Objective 3.2	Summer Bridge Programs: Attract early undergraduates to 'Ike Wai-related STEM fields by developing & implementing summer bridge programs.				
Activity 3.2.1	●	●	●	●	
Activity 3.2.2	●	●	●	●	
Objective 3.3	Individual Professional Development: Create and implement individualized professional development plans for graduate students and postdocs, and Mentoring Cascade.				
Activity 3.3.1	●	●	●	●	
Activity 3.3.2	●	●	●	●	
Objective 3.4	Cohorted Professional Development: Develop and implement a series of education and training workshops for 'Ike Wai Graduate Students, Post-docs, Faculty and Staff, and establish an EDventures mini-grant program.				
Activity 3.4.1	●	●	●	●	
Objective 3.5	Data Science: Establish two academic programs at UH Hilo in Data Science, a certificate and a BA in data analytics.				
Activity 3.5.1	●	●	●	●	
Activity 3.5.2	●	●	●	●	
Objective 3.6	Business and Community: Connect 'Ike Wai to business and community.				
Activity 3.6.1	○	●	●	●	
Objective 3.7	Education Research.				
Activity 3.7.1	○	○	●	●	

## X. Appendix A: Abbreviations and Hawaiian Language Terms

A-bay	Anaehoʻomalū Bay	ICS	Information and Computer Sciences
AGU	American Geophysical Union	IDC	Interagency Data Committee
AMT	Audio-Magnetotellurics	IDP	Individual Development Plan
BWS	Board of Water Supply (Honolulu)	IHLRT	Institute of Hawaiian Language Research and Translation
CI	Cyberinfrastructure	IKE	Integrated Knowledge Environment
CKAN	Comprehensive Knowledge Archive Network	ITS	Information Technology Services
COACH	Council of Academic Chemists	KBA	Keauhou Basal Aquifer
CoBE	College of Business and Economics	KCC	Kapiʻolani Community College
COE	College of Engineering	KS	Kamehameha Schools
CSEM	Controlled-source Electromagnetic	KR	Kohnanaʻiki Resort
CSS	College of Social Sciences	LT	Leadership Team
CWRM	Commission on Water Resource Management	MGF	Moanalua Gardens Foundation
CWSEI	Carl Wieman Science Education Initiative	MT	Magnetotellurics
DLNR	Department of Land and Natural Resources	NELHA	Natural Energy Laboratory of Hawaiʻi Authority
DOFAW	Department of Fish and Wildlife	NPV	Net Present Value
DROP	Down-well Remote Operating Platform	OMKM	Office of Mauna Kea Management
EAB	External Advisory Board	PaR	Palani Ranch
EPA	Environmental Protection Agency	PBRC	Pacific Biomedical Research Center
FWAC	Fresh Water Advisory Council	PIWSC	USGS Pacific Islands Water Sciences Center
G&G	Geology and Geophysics	PR	Parker Ranch
GDE	Groundwater-Dependent Ecosystems	QBA	Quantitative Business Administration
GW	Groundwater	QLT	Queen Liliʻuokalani Trust
HCF	Hawaiʻi Community Foundation	RHBFST	Red Hill Bunker Fuel Storage Facility
HDOA	Hawaiʻi Department of Agriculture	S&T	Science and Technology
HDOH	Hawaiʻi Department of Health	SGCI	Science Gateways Community Institute
HDWS	Hawaiʻi County Department of Water Supply	SEI	Science Education Initiative (University of British Columbia)
HFWI	Hawaiʻi Fresh Water Initiative	SG	UH Sea Grant
HIGP	Hawaiʻi Institute of Geophysics & Planetology	SGD	Submarine Groundwater Discharge
HLPC	Hawaiʻi Leeward Planning Commission	SOEST	UH Mānoa School of Ocean and Earth Science and Technology
HPC	High Performance Computing	SST	Science & Technology Thrusts
HSSTC	Hawaiʻi Science & Technology Committee	ST	Sustainable Yield
HVO	Hawaiʻi Volcano Observatory	TACC	Texas Advanced Computing Center
		USGS	US Geological Survey
		UH	University of Hawaiʻi
		UHERO	UH Economic Research

Organization			
UHH	University of Hawai'i Hilo	WHR	West Hawai'i Regional
UHM	University of Hawai'i at Mānoa	WMP	Water Master Plan
UHS	University of Hawai'i System	WR	Waiki'i Ranch
UI	Ulupono Initiative	WRAC	Water Resources Advisory Council
URM	Underrepresented Minorities	WRRC	UH-Water Resources Research Center
WFD	Workforce Development		

### Hawaiian Language Terms

'auwai	Path water flow
'Ike Wai	'Ike, meaning knowledge, Wai, meaning water
kapunalu'u	Spring dived for
moku	Large district land division mo'olelo Stories or history
'oiwi	Native son
Pono	What is right
po'e	People
'āina	Land
Wai	Water