



# *'Ike Wai*

*Securing Hawai'i's*

*Water Future*

## YEAR 2 ANNUAL REPORT

REPORTING PERIOD MARCH 1, 2017 TO JANUARY 31, 2018



## TABLE OF CONTENTS

I. 'Ike Wai Year 1 Annual Report Information	1
II. Overview	1
A. Vision, mission, and goals of the project	1
B. Coordination and interdependencies of multi-disciplinary research and education programs.	4
C. Brief summary of key accomplishments achieved during the reporting period	5
D. How accomplishments address the NSF criteria of intellectual merit and broader impacts.	9
E. Briefly describe any significant problems, novel opportunities, and/or changes in strategy during the reporting period	12
III. Research and Education Program	13
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	13
Goal 2: Develop a new data and modeling platform for Hawai'i volcanic hydrogeology	22
Goal 3: Education and Workforce Development	42
IV. Solicitation-Specific Project Elements	47
A. Workforce Development	47
B. Diversity	48
C. Partnerships	48
D. Collaborations	49
E. Sustainability	49
V. Broadening Participation	50
VI. Expenditures and Unobligated Funds	50
VII. Special Conditions	51
A. Response to External Evaluation Recommendations	52
VIII. Tabular/Graphic Representation of Progress to Date	53
Appendix A: Abbreviations and Hawai'ian Language Terms	54

## I. 'Ike Wai Year 1 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: March 1, 2017 to January 31, 2018

## II. Overview

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

**Vision:** Water resource management in Hawaii's 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.

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 by the end of Year 3

Objective 1.2: 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 Year 5

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 Yr. 3

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

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

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

Objective 2.4: Community Engagement

**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 UHH and UHM to address Hawai'i's water challenges.

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

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

Objective 3.3: Individual Professional Development: Create and implement individualized professional development plans for graduate students and postdocs, and Mentoring Cascade

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.

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

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

## **B. Coordination and interdependencies of multi-disciplinary research and education program.**

**Participating Units.** 'Ike Wai is a complex project with multiple internal and external participants. Two campuses, UH Mānoa (UHM) and UH Hilo (UHH) form the key institutions. 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), and the College of Social Sciences (CSS) for stakeholder engagement. At the UH System (UHS) level, Information Technology Services (ITS) provides senior leadership (PI, Jacobs) and the backbone for the database and data visualization. UHH houses education efforts in Data Science.

**Leadership.** In year 2, the Leadership Team includes the PI (Jacobs), 4 Co-Is (Bruno, Mougini-Mark, Platz and Turner) and 7 additional members: Darren Lerner (Interim Director WRRC), Greg Chun (Community Engagement Lead), Aly El-Kadi (Hydrological modeling), Kevin Kelly (Managing Director), Stephen Anthony (USGS Liaison), Roberto Pelayo (UHH - Data Science) and Velma Kameoka (Assoc. VC Research, UH Mānoa). Tom Giambelluca (Geography, UH Mānoa) will join the Leadership Team in Year 3 and will lead the effort to generate and disseminate very high value data products (rainfall, evapotranspiration, solar

radiation) data and maps with climate scenarios for research and decision making by water managers, farmers and state agencies.

### **Identification of interdependencies in the research program.**

The 'Ike Wai research endeavor comprises the intrinsically inter-dependent efforts of the Science Team (geophysics, biogeochemistry, hydrologic and economic modeling, sensor engineering, Hawai'ian studies), Cyberinfrastructure and Visualization teams. The research endeavor has matured in year 2 and interdependencies and integration are now becoming apparent. The degree of integration and enhanced level of project activity has allowed consistencies and reinforcements between sometimes radically different scientific approaches to emerge.

Examples:

- The Natural Energy Laboratory of Hawai'i Authority (NELHA ) wells will serve as a test location where a confluence of experimental techniques will be used to characterize a location. Down-well Remote Operating Platform (DROP) sensors (Garmire) will be deployed in the same location sampled by the microbial team (Frank), geochemistry (Lautze) and are upstream of subterranean groundwater discharge (SGD) locations (Dulai), this site also presents interesting opportunities for geophysics, e.g. 2D and 3D electrical resistivity tomography with our new Fullwaver-V system (Grobbe), or active/passive seismic studies with our new Z-land nodal system. These techniques will be used to study the top 1 km (maximum) and better characterize materials controlling SGD flow.
- Pumping simulations (Elshall) in Pearl Harbor benefit from UH HPC resources (Jacobs), and address land use change models (Bremer) which in turn (a) actively inform USGS and Honolulu Board of Water Supply (BWS) and (b) translate to location drivers for geophysics work (Grobbe)
- On the high-low water divide at Hualālai, geophysics activities provide information on the extension of the boundary north of the NW Rift Zone of the volcano (Grobbe), which in turn informs connectivity studies which can be used to validate models with well data (El Kadi, Lee) and with microbial studies (Frank) at selected sites
- Models of GW flow westwards from the summit of Mauna Loa volcano will be dramatically improved by gravity and other geophysics (e.g., seismics, MT, ERT or SP) depending on access on the SE extension of Hualālai's rift zone (Grobbe). Rain sensors and sampling for oxygen isotope data (Lautze) can confirm or refute model predictions by assessing whether high elevation water is indeed reaching the coast.
- The 'Ike Wai Science Gateway serves as the central location for data management, computation, analysis, visualization and dissemination of all data and data products generated by 'Ike Wai. It serves as the central integration point of the project.

### **C. Brief summary of key accomplishments achieved during the reporting period**

#### **Year 2 Capacity Building in Personnel**

We have completed our strategic hiring goals at UHM with several excellent early career faculty: Drs. Leah Bremer (economics), Harry Lee (groundwater modeling), and (both formerly from Stanford) Niels Grobbe (geophysics) (formerly from MIT). They now lead the economics, groundwater modeling, and geophysics

components, respectively. They join Dr. Nicole Lautze (geochemistry) who was hired in Year 1. All four of these new faculty have 50% FTE within WRRRC and meet regularly as part of WRRRC's engagement of water topics. At UHH, we have hired Drs. Travis Mandel (UW) and Grady Weyenberg (Univ. Kentucky) (data science education). We have also hired 4 postdocs: Drs. Eric Attias (geophysics), Ahmed Elshall (groundwater modeling), Francois Paquay (geochemistry), and Sheree Watson (microbiology).

### **Year 2 Capacity Building in Instrumentation and Sensing**

- Key equipment has been purchased to enhance our capacity in Audio-Magnetotellurics (AMT) and Magnetotellurics (MT), both active and passive seismics, Electrical Resistivity Tomography and Induced Polarization, and Self-Potential.
- We have designed and built a new version of the SGD "sniffer", which will be deployed at 4 rotating sites and a permanent reference site in the Kiholo aquifer.
- The 3rd iteration of the Downwell Remote Operating Platform (DROP) has been completed, and work is underway on the 4<sup>th</sup> iteration. DROP4 consists of a refinement of design to improve ease of deployment of the modules, ruggedization of the packaging, handling and miniaturization of the tether, and programming for the remote operation of the raspberry pi (rPi) embedded microprocessor. For activity 1.3.1, we have built and demonstrated fluorescence for organics detection (such as oils and other pollutants) which we have integrated into the DROP4 iteration.

### **Year 2 Research and Education Accomplishments**

#### **1) Geophysics**

- Three benchmark models have been used to develop synthetic simulations of the various geophysical methods that we will deploy. We have run >50 (A)MT forward simulations (Activity 1.1.1) and inversions (Activity 1.1.1 and 1.1.3) for these benchmark models. The simulations provide an increased understanding of the sensitivity of the AMT and MT signals to our structures of interest, the conductivity contrasts (e.g. between dikes, host rock, fresh water saturated, salt water saturated), dimensions of the structures of interest (e.g. width and depth of dikes, thickness of fresh water layer on top of salt water body), the lateral and vertical sensitivity and corresponding relevant acquisition parameters, etc.
- Permissions have been obtained to conduct geophysics 3 field experiments on Hawai'i Island: 2 major study sites traversing the high/low divide on Kona, and 1 coastal area (NELHA). As part of our continuing dialog with landowners to gain field access, we have developed geophysical one-pagers for the landowners, describing the details of each geophysical technique, the possible impact on their land, and what the technique can inform us on.
- Strong contacts have been established with the Hawai'i Volcano Observatory of the USGS on the Hawai'i Island, which are particularly important for the collection of gravity data across the high/low water divide on Hualālai and SE extension of the Hualālai Rift Zone, which may impede the water flow from Mauna Loa (to the east) towards the coast.

#### **2) Geochemistry**

- Permits to collect water samples have been obtained from Dept. of Fish and Wildlife (DOFAW) on

both Oahu and Hawai'i Island, and permit applications are pending to Natural Areas Resources Management (NARS) and Office of Mauna Kea Management (OMKM).

- Five precipitation collectors have been deployed in Pearl Harbor and 5 on Big Island. We collected and have lab analyses for major ions, trace metals, silica, and O H isotopes on ~120 samples (some duplicate samples) from 80 unique sites (both island). These comprise Hualālai: 55 wells, 12 springs, 5 precip collectors; and Pearl Harbor: 3 springs, 1 well (sampled at multiple depths) and 5 precipitation collectors. We established a new partnership with NELHA for space and alkalinity analyses.
- Microbial studies on Hualālai have sampled 118 unique sites with 15 organization (46 Anchialine Ponds, 12 Springs, 55 Wells, 1 SGD, 4 Reference samples). We spent 23 days in the field in Kona, to capture temporal variation in microbial community composition, and In Pearl Harbor sampled 7 sites with 1 organization (7 Springs).
- Twenty-nine coastal springs have been sampled under the SGD effort, measuring nutrients, stable isotopes of nitrate and water, as well as dissolved inorganic and organic carbon. We found that springs in the Kiholo aquifer have two different sets of properties, and in Keauhou there are 3 groups with different groundwater flow paths. Nutrient discharge was quantified within these groups.

### **3) Modeling**

- A three-dimensional conceptual model was created for the West Hawai'i area, encompassing six aquifer systems, including the primary Hualālai aquifer systems (Kīholo and Keauhou). The modeled area was extended beyond Kīholo and Keauhou aquifers to explore potential interconnectivity between aquifer systems. The conceptual model includes a physical barrier located between the low-water observation points and high-water observation points, running relatively parallel to the western coast.

### **4) Economics**

- Our first major cross-disciplinary, stakeholder-driven (USGS, HBWS), result is a GW simulation that addresses water salinity and pumping rates for different land use scenarios in Pearl Harbor. The finite element USGS PIWSC groundwater model of Oki [2005] has been used to simulate groundwater flow and chloride transport. The simulation optimization, developed by Elshall, estimates the maximum allowable withdrawal from various places in the aquifer without violating the sustainable yield constraints, representing the management objectives. These objectives, which were identified through stakeholder engagement, currently look at the reduction of salinization risk. We are currently working on the minimization of head-drop, conservation of spring discharge, and sustaining submarine groundwater discharge.

### **5) Cyberinfrastructure**

- The Computation and Storage platform setup is complete for the 'Ike Wai Science gateway. Key features are in production supporting data management, annotation, analysis, search and visualization. The gateway file browser and manipulations support several functions (upload, download, rename, copy, move and preview for supported data-types). A workflow for annotating data has been implemented to support minimal metadata creation, review, edit and approved products become available to the 'Ike Wai project members and accessible for search.

The gateway supports running computations on the UH High Performance Computer (HPC) cluster and the user interface allows researchers to launch and manage computational jobs and resulting data products. Internal search and discovery interfaces support free text, spatial, temporal and faceted querying of data annotations and data products and download.

- Two workflows that support microbial analysis and geophysical simulations have been deployed. Test applications with Mothur and QIIME related to environmental microbial community analysis workflows have been developed and tested with the UH HPC. The MARE2DEM application workflow for electromagnetic geophysics modeling has been developed and tested with the UH HPC.
- Rotzal (USGS) and the CI and Viz teams developed a prototype decision support application for calculating island recharge based on user defined land use types and two climate scenarios, based on stakeholder specifications. The prototype utilizes the 'IKE Gateway APIs for accessing serialized raster data and spatial search to return land-use recharge values back to the client for real-time recharge re-calculation. The prototype will be refined and improved with input from USGS, CWRM and water managers.

## **6) Education and Curriculum**

- The 'Ike Wai Undergraduate Scholars Program (3.1) is an academic-year program that includes a closely mentored research experience and monthly professional development workshops.
- Summer Bridge Programs (3.2) were developed and piloted at UHM (May 2017) and UHH (June-July 2017). The Mānoa curriculum covers Hawai'ian culture and community, geology, hydrology and careers. The Hilo curriculum focuses on mathematics and data science.
- Individualized Professional Development (IDP) and Mentoring Cascade (3.3) were developed based on best practices and existing models and implemented as designed. Both were revised during Year 2 based on graduate student and post-doc feedback.
- Cohorted Professional Development and 'Ike Wai travel grant programs (3.4) provided education and professional development training to our cohort of 'Ike Wai graduate students, post-docs, faculty and staff. Towards this end, we developed and implemented a series of workshops in pedagogy during Feb 2018, in partnership with educational specialists from the University of British Columbia. We also contracted professional facilitators from the COACH program, based at the University of Oregon, to run a series of workshops covering topics in mentoring, team building, leadership, strategic persuasion, negotiation, and launching a career in science in May 2017 and Jan 2018.
- Data Science capacity building at UH Hilo (3.5.) A certificate in Data Science was approved by the UH-Hilo's curricular review committees, and it will be available to students (along with 4 new Data Science courses) in Fall 2018.

## **Sustainability**

- Knowledge transfer from 'Ike Wai to regional Pacific island hydrogeophysical and groundwater studies. A geophysical proposal, with multi-disciplinary co-I's, submitted through WRRRC, for comparative studies on American Samoa and Saipan.
- 'Ike Wai has established strong contacts with the Hawai'i Volcano Observatory of the USGS,

enables future studies on volcanic-groundwater interactions in Hawai'i and other volcanic systems. Planning is underway for collaborative research proposals which exploit our new geophysical capabilities to investigate groundwater resources within volcanic islands.

- The CI Team is partnering with the Science Gateways Community Institute (SGCI) (<https://sciencegateways.org/>) to improve the usability, security and functionality of 'Ike Wai Gateway. The SGCI provides free expertise in key areas, community workshops and developer support.

#### **D. How accomplishments address the NSF criteria of intellectual merit and broader impacts.**

##### **Intellectual Merit:**

Modeling the 3-D structure of active Hawai'ian volcanoes, such as Hualālai, is a very challenging problem. Some geophysical attributes are known from the inspection of eroded examples on Oahu and Kauai - however new data is needed to probe depths in excess of 1 km. Improving this knowledge would be a significant scientific advance and provide crucial information to improve some of the existing USGS models with new structural data. These geophysics data are needed to validate or refute GW models and water geochemistry, and down-well sensors will help test if these models correctly predict salinity changes and/or biosignatures. Collectively, these approaches represent a novel synthesis of techniques which have a high potential to revolutionize our understanding of this volcano and, by implication, other basaltic oceanic islands. Similarly, through our combination of USGS GW models with the operational aspects of water policies and management (such as our pumping simulations in Pearl Harbor), advancing the science provides input on water policy and addresses the needs of the stakeholders. Some examples of results that exemplify the intellectual merit of Year 2 activities are as follows:

*Activities 2.2.5 through 2.2.8.* The West Hawai'i study area is geologically extremely complex, covering a large area that includes volcanic features with significant heterogeneities in hydrogeological data. The existence of geological structures, such as flow barriers, cause drastic drops in water levels across these structures, with challenging questions regarding their spatial distributions and hydrogeological characteristics. To create an accurate conceptual GW model for West Hawai'i, we have started to address many geological attributes and question in our study area, such as: 1) At what depth below the surface is flow negligible? 2) Where is the eastern boundary of the aquifer, and how much water enters through the boundary from Mauna Loa? 3) What spatial variations exist along the western boundary of the aquifer will these affect SGD? 4) Where are the interfaces between the freshwater and saltwater in the subsurface, particularly on both sides of the high/low water divide? 5) Can we differentiate between a measured water level/head in a well that is a perched layer vs. the aquifer? 6) What are the locations (including depth) and nature of barriers and low conductivity zones?

In Year 2 we recognized the unique contributions to GW models of geophysical surveys at specific location the need to collect well water data for chemical studies at sites such as across the high/low water divide, the value of SGD measurements to constrain the GW outflow from the western side of the aquifer, and water chemistry to determine the elevation at which the water fell as rain (thereby searching for barriers at the eastern side of the aquifer. We have found that, the water budget (input vs. output) does not

match and there a difference between recharge and SGD in the system, but we have not yet determined where the water goes. Is water, for example, trapped in such a structural complex (dikes)? Is water connected at all between the high side and the low side? If so, how? Via what paths (including at what depth)?

These research studies will provide fundamentally new insights into the internal structure of an active volcano based not only on geophysical data, but also knowledge of groundwater flow paths, SGD, water chemistry, and down-well sensing. These results provide data and models to stakeholder questions, such as the extent that pumping at specific wells can be sustained before salinity increases too rapidly, the supply of discharge to culturally-significant sites drop below acceptable limits, or questions related to changing rainfall and/or land cover are addressed.

#### **Broader Impacts:**

Through our research and training efforts, we will meet the pressing need of the State of Hawai'i for applying integrated research methods and thus produce the next generation of water professionals in our state. Importantly, these individuals will recognize both the interdisciplinary aspects of issues related to water research and the diverse perspectives associated with stakeholders, community interests, and the water professionals. Our work has far-reaching and broad applications, particularly in island environments and jurisdictions dependent on limited water resources. Certain activities directly meet Broader Impact criteria, including:

**Advance discovery and understanding while promoting teaching, training, and learning.** As detailed below in Broadening Participation Section V and Education section xxx, project is successfully integrating its research and education//training missions. Research activities in geophysics, geochemistry, traditional/historical knowledge and sensor development are involving significant numbers of graduate students and 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 and navigation of university systems and processes (Leadership Team). Teaching is being actively promoted by 'Ike Wai. All 'Ike Wai faculty have active teaching loads and several (e.g. Frank, Garmire, Lautze) incorporated 'Ike related materials and concepts in classes taught in Year 2 of the award. For example:

- (Lee), a new course (CEE 696: Optimization in Groundwater Engineering) has been designed and offered to 7 graduate students at UHM to learn how to perform mathematical optimization of groundwater supply linked with numerical groundwater flow and transport models. In the class, students have expanded their understanding of sustainable groundwater yield of Hawai'ian aquifers through hand-on modeling experiences and armed with relevant techniques for better aquifer management;
- (Frank) developed innovative place-based biology curriculum that integrates and highlights the research from 'Ike Wai to emphasize the importance of water and hydrological cycles on the evolutionary history of our islands and our organisms.

All 'Ike Wai participants with teaching roles are participating in workshops such as the Year 2 CoACh and pedagogy events that promote active learning and inquiry-based pedagogies. The development of new

Data Science certificate and degree programs at UH Hilo has progressed as planned in Year 2, and the courses and student projects (as well as new faculty research projects) in this curriculum will incorporate 'Ike Wai-related data sets and use cases.

**Broadening participation of under-represented groups. (see Section V).**

**Enhance infrastructure for research and education.** *Instrumentation infrastructure.* We have built new-to-Hawai'i capacity in hydrogeophysics and geophysics by selecting and purchasing equipment that is facilitating 3D data acquisition and processing and at the same time has low environmental footprint. Both the seismic (Fairfield Nodal Z-land systems) and ERT/IP systems (IRIS Fullwaver-V) that we have selected are nodal-based systems, ensuring great acquisition flexibility and optimal design for 3D acquisition in landscapes that can be affected by sharp topography. Our (Audio)-Magnetotelluric system ((A)MT) is inherently nodal-based, and the gravity and Self-Potential measurements are flexible and mobile. *Cyberinfrastructure:* The 'Ike Wai Gateway provides an advanced science as a service platform supporting all aspects of the project. *Partnerships with industry and government researchers and building University networks:* Partnerships with USGS, state BWS, CWRM, HDOH and national CI partners, TACC, Jetstream and ACI-REF provide additional support. and others. A product of the modeling team's research, numerical model calibration software (<https://github.com/jonghyunharrylee/pyPCGA/>) is currently used by researchers at the Technical University of Denmark and by engineers at US Army Engineer Research and Development Center - Coastal and Hydraulics Laboratory. By releasing the source code in a public domain repository, we expect active participation from many research groups at different institutions to improve the software and promote collaboration opportunities.

**Broaden dissemination to enhance scientific and technological understanding.** The 'Ike Wai Science Gateway serves as the central location for data management, computation, analysis, visualization and dissemination of all data and data products generated by 'Ike Wai. 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. The EPSCoR Website (<http://Hawai'i.edu/epscor>) and Facebook page serve as the central location for information about the project, current results, student opportunities and social media. A number of community and social media-based outreach efforts are underway. Examples include: (a) in partnership with Hawai'i Sea Grant and the College of Education Curriculum and Development Research Group we have produced and aired two episodes of Voice of the Sea (VoS) focused on 'Ike Wai research and engagement. This Voice of the Sea is a weekly educational documentary television show aired in Hawai'i on KFVE and throughout the Pacific region, with a 30,000 viewership in Hawai'i per episode and diverse viewers. VoS takes viewers "in the field" to learn in depth about the science and cultural and community importance of the research and findings of 'Ike Wai. (b) Thinktech Hawai'i is a weekly live TV broadcast, also available on YouTube, that focuses on technology and economic diversification in Hawai'i. 'Ike Wai co-PIs, investigators and leadership team members have been regulars on this show in year 2. (c) Bytemarks Cafe (Hawai'i Public Radio), Science Cafes and other HTDC efforts have been visited by 'Ike Wai team members. (d) Community engagement efforts on both islands extend to major landowners, water roundtables and cultural and environmental heritage sites.

**Benefits to society.** The 'Ike Wai project offers significant potential to benefit Hawai'i's community. Specifically, during Year 2, the combination of GW modeling and land use scenarios used to

generate models of permissible pumping rates for Pearl Harbor to maximize extraction while keeping salinity levels acceptably low. The consequences of these future pumping scenarios have already been presented to BWS managers, the USGS and other stakeholders. Year 2 results from the modeling team also strongly suggest that three separate structures (parallel to the “classic” high/low water divide) exist on Hualālai volcano. This modifies the current understanding of the subsurface structure being relied upon by BWS, and has the potential to inform decision makers considering location of future wells on Hawai‘i Island.

**E. Briefly describe any significant problems, novel opportunities, and/or changes in strategy during the reporting period.**

**Specific challenges:** 1) Gaining field access to geophysical study sites and wells has improved but gaps remain especially with BWS on Oahu and the high/low water divide on West Hawai‘i . Agreements granting access to KS property are very close to complete which will provide a large and important area for study. 2) Translating Hawai‘ian newspapers has failed to provide site-specific quantitative information and is not providing expected input data to GW models. These translations have provided a novel opportunity to build community relationships in study sites.

**Novel Opportunities:** Community engagement through translation of articles and other geocoded artifacts has greatly improved acceptance of the overall goals of the project, thereby facilitating field access for microbial and SGD studies.

**Changes in strategy:** 1) Implementing two EAB recommendations has yielded two of our most productive projects - the Pearl Harbor Pumping Optimization Model and the Recharge/ Decision support tool. Both of these projects leverage our collaboration between USGS scientists and our new postdocs and faculty. 2) We will deploy a broader range of geophysical techniques to accommodate different depth requirements related to GW models and SGD measurements. 2) We have expanded the cultural knowledge gained through newspapers articles to geocoded historical maps and documents. Using translations as a topic of discussion with local elders and community members has improved interest in the project and access to study sites.

**Faculty Hiring Update**

We are on schedule for the hiring of new faculty and professional staff with the addition of three new faculty at UH Mānoa and two data science faculty at UH Hilo. The Mānoa hires all have positions split 50/50 with the Water Resources Research Center and their home departments; Leah Bremmer in the University of Hawai‘i Economic Research Organization (UHERO), Niels Grobbe in the Hawai‘i Institute of Geophysics and Planetology (HIGP) and Jonghyun ‘Harry’ Lee in Civil and Environmental Engineering.

New UH Hilo faculty were hired into the Departments of Mathematics (Grady Weyenberg) and Computer Science (Travis Mandel). These new faculty have brought their expertise in mathematical statistics and the development of computational tools for data analysis (Weyenberg) and artificial intelligence and machine learning (Mandel) to develop new undergraduate curriculum for the Data Science program.

## New Faculty & Professional Staff Hires

Discipline	Status	Y1	Y2	Y3	Y4	Y5	Total
<b>Hilo</b>		0	2	1	1	0	4
Computer Science	Search Completed		8/17				
Mathematics	Search Completed		8/17				
Genomics / Marine Science	Interviews Underway						
TBD	Planned Search						
<b>Manoa</b>		2	1	0	0	0	3
Economics	Search Completed		7/17				
Geophysics	Search Completed		11/17				
Hydro Engineer	Search Completed		10/17				
<b>System</b>		2	1	0	0	0	3
Software Engineer	Search Completed	8/16					
Data Scientist	Planned Search						
<b>Total Hires:</b>		4	4	1	1	0	10

Table 1: The outlined boxes in the table indicate the proposed timing for new faculty and professional staff hiring for the 'Ike Wai project. The total number of hires for each participating institution is provided in the blue shaded line. The actual start dates for each hire are provided in the project year of hire.

### 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.

**A. 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).**

Significant progress has been made in geophysics, with the hire of Dr. Grobbs and the geophysics team. Collectively they have identified the geophysical equipment needs to meet the 'Ike Wai project goals and have initiated the purchases of various geophysical equipment sets. Dr. Grobbs is now enhancing our capacity in Audio-Magnetotellurics (AMT) and Magnetotellurics (MT), both active and passive seismics, Electrical Resistivity Tomography and Induced Polarization, and Self-Potential.

**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.*

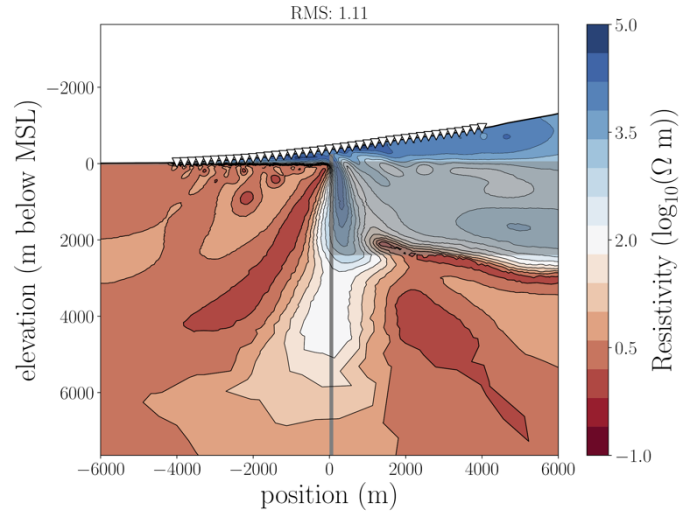


Figure 1: Geophysics field sites. Left - Two sites along the high/low water divide and the NELHA site. Right - Location of the Schofield Dam (SD) and Moanalua Valley (MV).

**Activity 1.1.1:** *Perform synthetic simulations of EM, gravity, 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).*

**Results:** Three major field sites selected for the Hualālai and Pearl Harbor aquifer systems (Hawai'i and O'ahu islands, respectively): Kona, Hawai'i (Big Island), Schofield dam area, O'ahu and Moanalua Valley, O'ahu (Fig. 1). We have run > 50 audio-magnetotelluric and magnetotelluric forward simulations and inversions for explaining the high/low water levels (well-heads) measured in Kona (Hawai'i) (Fig. 2) as well as at the Schofield Barracks (O'ahu). These simulations provide new knowledge on optimal field acquisition geometries (e.g., number of stations, station spacing, frequency bandwidth) for the types of structures and subsurface fluid distributions that we are dealing with. Moreover, crucial insight has been gained into the sensitivity and performance of the (A)MT data with respect to the kind of structures, geological electrical properties, and fluid distributions we are dealing with in Hawai'i.

Figure 2: MT inversion of a dike model, Hualālai, using a 200 m. site-spacing and an MT bandwidth of 100 s. - 1 kHz. The inversion result has a Root Mean Square error of 1.11. The water tables are based on well-data. The grey shaded areas represent part of the original model, i.e. the vertical dike intrusion at 0 m., and the fresh water zones to the left and right of the dike. The area above the grey zone consists of dry volcanic rocks, the area below of salt water saturated rocks. The elevation is in meters below mean sea-level. The red-white-blue colors represent the inverted resistivity values on a logarithmic scale, where blue is electrically more resistive and red is more conductive.



Key approaches, collaborators and software tools have been identified in Year 2. The (A)MT method has been studied in great detail, but we have not been able to study all geophysical techniques extensively using forward synthetic simulations. For the (A)MT simulations, we use the open-source software package Mare2DEM (developed by K. Key at Columbia University). It is 2D, adaptive finite-element modeling software capable of handling sharp topography. The code allows up to perform both forward modeling as well as inversion. For other geophysical simulations (e.g., gravity, seismic, ERT/IP, SP), we have identified the software packages that we will use for the data processing, forward modeling, and inversion, including alternative software options, for each of the methods we will deploy in the field. These are Gravity: Grav3D; Seismic: Seismic Unix, Madagascar, ProMAX, Paradigm software, MSNoise, fdelmodc, SpecFEM3D, JuMIT; Electrical Resistivity Tomography: Res2Dinv, Res3Dinv, E4D, BERT; Self-potential: own software (Julia-language), collaborations.

**Outcomes:** Key targets and geophysical questions have been identified related to possible groundwater flow-controlling structures on the Big Island based on the studies in Year 2 (see Fig. 3).

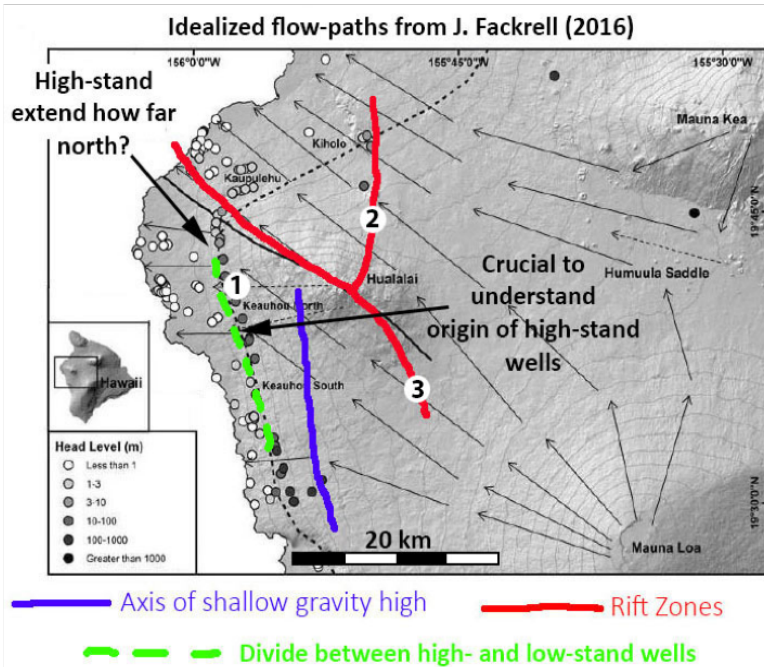


Figure 3: Hualālai aquifer modeling area, with some key hypothetical groundwater flow-controlling structures or interesting features highlighted with different colors. Geophysical studies will focus on testing which of these hypotheses is correct. The arrows do not represent the actual flow paths of the groundwater. They only show the potential source of the water samples in the mountains that are collected in the wells closer to the ocean, and do not represent the path that was taken. The various geophysical characterizations will inform the hydrological modeling on actual flow paths, e.g. via providing insights into flow-controlling

geological structures, or for example via Self-Potential estimation of Darcy flow velocities.

**Risks and Mitigation Plan:** Remaining risks are (1) We do not have 3D MT modeling and inversion software in-house. To mitigate this issue, we have identified collaborations to use their 3D MT software capabilities. (2) 3D active seismic inversion in basaltic environments may be challenging in terms of data quality, due to layering in the volcanic terrain. To mitigate this challenge, we have selected professional GUI based seismic data processing software and novel developments in the field of seismic scattering and imaging in strongly scattering media will be tested and investigated. (3) Self-Potential modeling software: we have in-house software and as we explore the modeling applications this software may need further in-house development.

**Activity 1.1.2:** Design geophysical survey, obtain land access permissions, and acquire field data.

**Results:** Preliminary geophysical field scouting trips to our Hualālai and Pearl Harbor study areas have been conducted. For the Hualālai aquifer, we have 3 permissions in place: 2 major study sites traversing the high/low divide, and 1 coastal area (NELHA). For O’ahu, we have initiated the permitting process for the Schofield dam area, as well as the Moanalua valley (and other valleys feeding into the Pearl Harbor aquifer) (Fig. 1). Based on our extensive synthetic forward modeling and inversion, we have carried-out geophysical survey designs for MT surveys on the 2 Hualālai study sites. We will start the actual MT field acquisition, together with gravity surveys on the Hualālai sites, in early March 2018. We have developed geophysical one-page summary documents describing the different multi-geophysical methods and their possible impact on the land/environment, that we have distributed to the different land owners.

**Risks and Mitigation Plan:** None needed, on track for Year 3.

**Activity 1.1.3:** *Model and invert newly obtained geophysical data*

**Results:** More than 50 MT inversions have been run on synthetic data with noise, together with our synthetic forward modeling efforts of Activity 1.1.1. An MT stochastic inversion approach is being explored in a Bayesian framework to investigate the uncertainties of the inversions, so far for the 1D case. This approach allows us to study the fully non-linear MT inverse problem. We will complete this stochastic inversion framework in Year 2 as an alternative inverse approach for the 2D problem as well and use the forward modeling code of Mare2DEM. We plan to test both inversion methodologies on collected MT field datasets. For Hualālai, we will carry-out 1D and 2D MT inversions on the field data that will be collected early March 2018.

As part of this activity, we have established contacts with the Hawai'i Volcano Observatory of the USGS (including Drs. Jim Kauahikaua and Don Swanson), on Hawai'i Island. This is particularly important for the interpretation of the gravity data across the high/low water divide on Hualālai. This discussion helps guide our future gravity field sites, which will extend northward in order to better constrain the groundwater models of subsurface flow (Activity 2.2.5). These discussions also made it clear that a key question for the groundwater models is the SE extension of the Hualālai Rift Zone, which may impede the water flow from Mauna Loa (to the east) towards the coast.

**Risks and Mitigation Plan:** None needed, on track for Year 3. A possible challenge could be the inversions of 3D field data, and we are reviewing the optimal software packages to assist us with these efforts (Activity 1.1.1.).

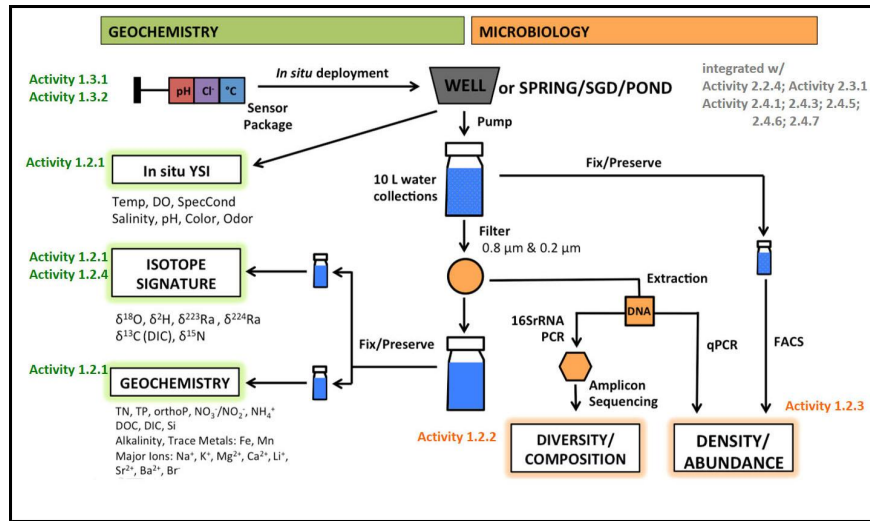
**Activity 1.1.4:** *Continuation of geophysical data acquisition based on key gaps identified from prior work.*

**Results:** None to date. Year 3 activity.

**Risks and Mitigation Plan:** None needed, on track for Year 3.

**Objective 1.2** 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 Year 5. These efforts are shown in Fig. 4.

Figure 4: Schematic of sampling plan methodology for the geochemistry (in green) and microbial (in orange) investigations. Also shown are the connections between these studies and the specific Activities within 'Ike Wai.



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

**Results:** We applied for and were granted permits from Departments of Fish and Wildlife (DOFAW) on both Oahu and Hawai'i Island. However, permits are still needed for deployment of precipitation collectors on some lands. We submitted permit applications to Natural Areas Resources Management (NARS) and Office of Mauna Kea Management (OMKM), which are pending. Five precipitation collectors in Pearl Harbor and 5 on Big Island have been deployed (with additional deployments planned for March 2018). We collected and have corresponding laboratory analyses for major ions, trace metals, silica, and O H isotopes on ~120 samples (some duplicate samples) from 80 unique sites (both islands). For Hualālai: these samples represent 55 wells, 12 springs, 5 precipitation collectors (Fig. 5a). In Pearl Harbor these samples represent 3 springs, 1 well (sampled at multiple depths) and 5 precipitation collectors. The geochemistry team established a new partnership with NELHA for space and alkalinity analyses. Postdoc and graduate student and undergraduate student hires have been completed in Year 2 (Dr. Francois Paquay (post-Doc), Diamond Tachera (grad student), Honour Booth and David Perriera (undergraduates).

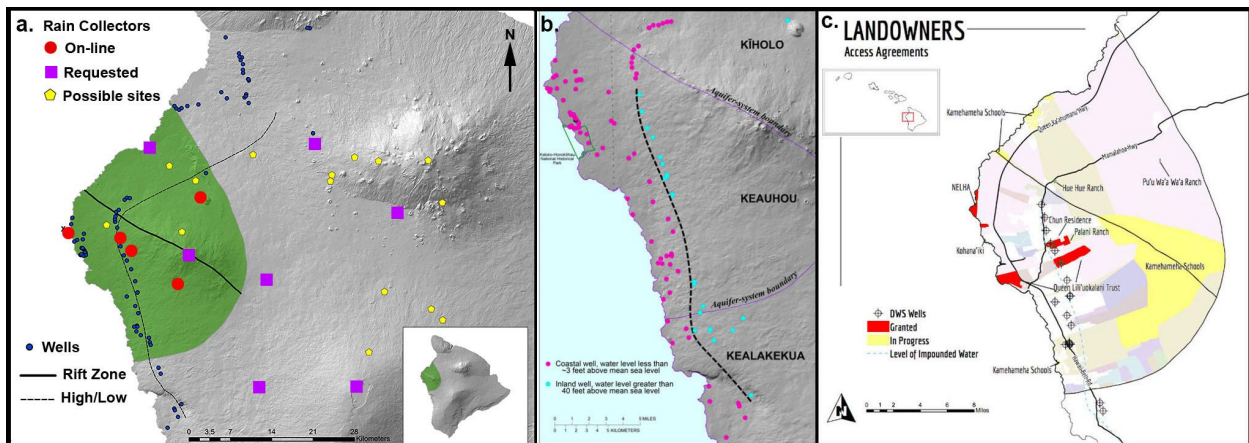


Figure 5: Geochemistry, wells, and access. a) Distribution of rainwater collectors. Red dots indicate where

we have already sampled, purple squares where permission is being sought, and small yellow symbols are potential sites. b) Distribution of Map of inland wells (blue) and coastal wells (pink) used for validating GW models. Available water level data suggest a cascading nature of the barrier with multiple drops in water levels in some locations. c) Landowner access obtained to date (red) and under negotiation (yellow).

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

**Results.** At Hualālai, we sampled 118 unique sites with 15 organizations (46 Anchialine Ponds, 12 Springs, 55 Wells, 1 SGD, 4 Reference samples). Twenty-three days were spent in the field in Kona, over the course of 3 field campaigns (May 2017, Aug 2017, and Nov 2017) to capture temporal variation in microbial community composition. In Pearl Harbor we sampled 7 sites with 1 organization (7 Springs), in a one-day field trip. one day was spent in the field in Pearl Harbor We established a new partnership with NELHA for space and nutrient analysis. Field samples collected: 125 sites. Archived samples: ~800 L of water filtered, archived 754 filters. Archived genomic DNA: 741 genomic DNA samples. Data sets archived on 'IKE = 3. Postdoc and graduate student hired: Dr. Sheree Watson (Post-Doc), Melanie Ku'i Keli'ipuleole (grad student), La'a Ali'ifua (undergraduate).

**Outputs:** List of target wells were identified for sampling; Identified well owners and obtained permissions to sample; Established a sampling schedule and plan in coordination with owners and research team; Acquired equipment and supplies needed to sample and have prepared labs for sample processing.

**Outcomes:** Personnel and supplies in place to move forward with efficient deployment and sampling of precipitation collectors, and sampling of wells. Developed detailed sampling plan to enable efficient sampling of wells with other project members. Development of sample plan ensures efficient sampling and that our data are comprehensive and mutually compatible to address science questions.

**Risks and Mitigation Plan:** **Geochemistry:** Continued access or lack thereof, limited by partner accessibility, downed or non-functioning wells, as a result sampling only occurred at the beginning of Year 2 (rather than during Year 1). This will be mitigated by an increase in the sampling schedule in Year 2 and additional efforts and focus on access agreements. We (Frank) plan to use geocoded cultural knowledge (location-specific insights from traditional and historical knowledge sources) to increase non-well GW site access and develop a community handout packet that shares information about findings to increase community buy-in. By establishing a methodology to correlate water age with groundwater source (from precipitation collectors) we will establish GW travel time (important for modeling). **Microbial diversity:** A potential risk is that microbes may be uniformly distributed and are not good tracers for groundwater connectivity. This concern will be mitigated by co-analyzing microbial and geochemical data to provide indicators or ecological clustering of groundwater conditions, and we will use quantitative indicator species/pathogens data (Activity 1.2.3.) to test source tracking and flow path hypothesis. Our novel application of molecular microbiological techniques may enhance understanding subsurface fluid connectivity and flow direction, and these data will provide important evidence on subsurface water quality, terrestrial subsurface biogeography, microbial dispersal, selection, and ecological habitat partitioning in the subsurface. Furthermore, we will have developed the largest GW microbial database in Hawai'i. **Risk Mitigation Plan:** None needed, on track for Year 3.

**Impacts:** Data will help answer question as to source location of groundwater (i.e. recharge location—measured by precip collectors), and GW flow paths, within which the question of connectivity across aquifer and other known boundaries (e.g., the high/low divide Hualālai, Schofield Dam) will be addressed.

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

**Results:** Primer design for quantitative study of indicator species: 25 targets. We developed modified protocols for analyzing cell density via qPCR (rather than flow cytometry now that instrumentation is no longer available) and are in the process of analyzing all samples. Quantification of cell density (via 16S & 18S qPCR): 22 sites analyzed (currently, in progress). Pathogenic targets identified = 25.

**Outputs:** Field samples collected: 125 sites. Archived samples: ~800 L of water filtered, archived 754 filters. Archived genomic DNA: 741 genomic DNA samples.

**Outcomes:** With the sampling completed so far in year 2 we are positioned for sequencing and bioinformatic analysis for 741 samples. Screened for 16S rRNA sequences has started to assess indications of potentially pathogenic organisms. This method provides a qualitative view of pathogen diversity, enabling us to more efficiently target pathogenic candidates for quantitative analysis and design appropriate and specific primers. In addition, in year 2 we started determining targets pre-emptively based on previous data from Frank's lab from related Hawai'i environmental systems. Both of these efforts establish a head start on year 3 goals.

**Risk and Mitigation Plan:** None needed, on track for Year 3.

**Activity 1.2.4:** *Link SGD to aquifer conditions at the two aquifer locations*

**Results:** (1) **Two SGD sensors deployed:** two sensors have been constructed and 4 deployment sites have been selected in Kona. Permits for deployment at two sites were obtained, two more are pending. **Risks and Mitigation Plan:** The delay in deployment is mitigated by discussions with stakeholders on obtaining permits and we are field testing the sniffers to fine tune them for deployment. We expect deployment with a few months delay. (2)

**Documented coastal salinity and SGD temporal trends:** 29 coastal springs were located and we characterized their salinity and groundwater discharge rates. The SGD Sniffer deployed 4 years ago in Kiholo Bay (supported by the prior RII Track I award cycle) was maintained and data was successfully collected. The data have been deposited in the 'Ike Wai Gateway. We conducted thorough analysis of this SGD time series, including seasonal and spectral decomposition of the data, and we examined the evolution of its filtered level and volatility (variation in the amplitude). In addition, we conducted regression analysis with the following predictors: coastal groundwater level, precipitation, tides, and sea level. Our work provides the longest high-resolution SGD record so far. Most importantly this research advances our understanding of SGD drivers and is the first step in predicting SGD in future land use and climate scenarios. (3) **Documented SGD nutrient flux and primary productivity:** In 29 coastal springs we measured nutrients, stable isotopes of nitrate and water, as well as dissolved inorganic and organic carbon. The water isotope data were used to identify springs with similar recharge altitude and groundwater flow paths. We found that springs in Kiholo aquifer belong to two different subsets, with different flow paths, and in Keauhou there are 3 subsets of springs with different groundwater flow paths. Within these groups nutrient discharge was quantified. **Mitigation Plan:** The associated coastal primary productivity at two sites will be determined with a few months delay due to sample analysis delay.

**Outcome:** The major outcome of year 2 was an increased understanding of total near-shore SGD in Hualālai: We surveyed existing literature and measured 5 additional springs to confirm literature values and fill in missing information. The magnitude of SGD closely matches the volume of recharge in Kiholo aquifer but only ~30% of

recharge emanates as near-shore SGD in the Keauhou aquifer. **Mitigation Plan:** None needed, on track for Year 3.

**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*

**Results:** We have completed the 3<sup>rd</sup> iteration, and are in the process of the 4<sup>th</sup> iteration, of the Downwell Remote Operating Platform (DROP), which is planned to culminate in a well test in March 2018 at 6 wells at the same NELHA where the geophysics and SGD work will be conducted using the deployment strategy illustrated in Fig. 6a. DROP4 consists of a refinement of design to improve ease of deployment of the modules, ruggedization of the packaging, handling and miniaturization of the tether (Fig. 6b), and programming for the remote operation of the raspberry pi (rPi) embedded microprocessor. A fluorescence sensor for organics detection (such as oils and other pollutants) has been built and demonstrated (Fig. 6c) and will be integrated into DROP4.

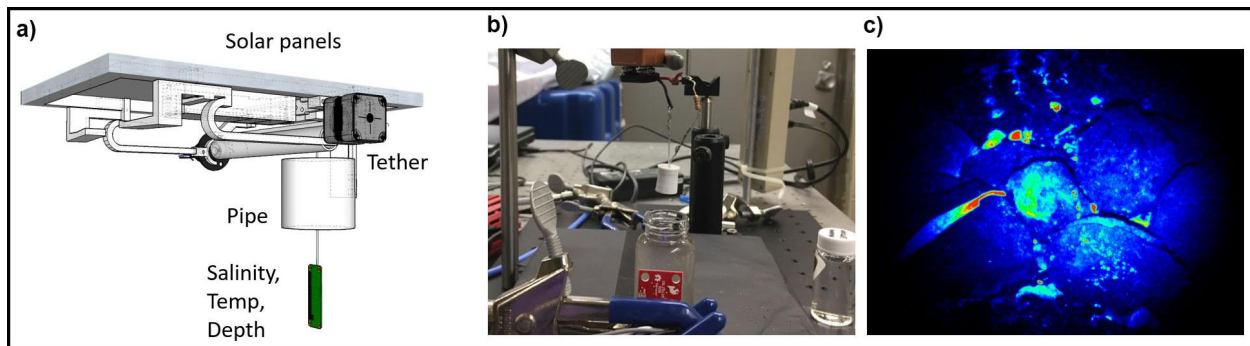


Figure 6: DROP3 and DROP4 development. a) Conceptual diagram of our developed deployment hardware. b) Testing ruggedization of sensor. c) Test image from organics sensor, which ultimately will be deployed to detect contamination in water.

Reducing the number of electronic components has been achieved by using the stepper motor as an accurate depth measurement tool as depth measurement is critical to the collected data. By employing smaller diameter nozzle outlets and water-safe plastics like PETG as well as multi-staging the prints and modifying the g-code, we are able to get much better encapsulation of the electronics.

Different tether management approaches have been tried because of limited well width and the different depths (and thus different total tether weight) which need to be measured. We have produced a novel mechanical design that allows a single stepper motor to both pull in the tether and ensure tether alignment while also keeping an accurate measurement of the amount of tether dispensed. To reduce the number of wires in the tether, we have switched to an I2C communications protocol. A challenge with going over long distances with I2C is that line capacitance will limit communication speed. However, we do not need rapid sampling (hourly, even daily would be a vast improvement). We will continue to investigate alternatives, but this approach appears to have

significant advantages in minimizing the tether diameter and allowing the tether spooler to be completely integrated at the wellhead.

**Outcomes:** 4th iteration of DROP sensor platform underway, 3rd iteration completed; component minimization and electronic encapsulation designs finalized; tether system optimized.

**Risks and Mitigation:** None, on track for Year 3.

**Activity 1.3.2:** *Perform pumping experiments*

**Results:** In order to calibrate our sensors in a controlled setting, we have decided to do pump testing with a test well of known hydraulic conductivity fabricated in the lab to simulate and ground truth our measurements. This approach helps in two regards. First, having a test well in the lab allows for more rapid iteration and testing of the module. Second, we can show agreement between a ground truth and the module measurements thereby improving the scientific outcomes of the effort. We have targeted the April – June 2018 timeframe to disseminate the current progress in the form of article submission and public release of code, designs, and procedures.

**Outcomes:** Pump test strategy designed and simulation of test well in lab defined as next step; public release of codes, designs and procedures targeted for April-June 2018.

**Risks and Mitigation Plan:** None, on track for Year 3.

## 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. **Mitigation Plan:** None needed, on track for Year 2.

**Activity 2.1.1:** Hire Professional Staff. In July of 2016 Jennifer Geis was hired as a software engineer to work on the development of the 'Ike Wai Gateway

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

**Results:** Computation and Storage platform setup is complete and gateway features are deployed. The gateway currently supports data management, annotation, analysis, search and visualization. The gateway file browser and manipulations support (upload, download, rename, copy, move and preview for supported data-types). A workflow for annotating data has been implemented to support minimal metadata creation, review, edit and approved products become available to the 'Ike Wai project members and accessible for search. The gateway supports computations on the University of Hawai'i HPC cluster and the user interface allows researchers to launch and manage computational jobs and resulting data products. Internal search and discovery interfaces support free text, spatial, temporal and faceted querying of data annotations and data products and download.

**Outputs:** Infrastructure is now able to support research and computation for the project; Researchers can manage data, run analysis and compute on the platform. **Risk Mitigation Plan:** None needed on track for Year 3.

**Activity 2.1.3:** Create training materials, documentation and train researchers on using the 'Ike Wai storage platform.

**Results:** The gateway now includes a comprehensive help section consisting of answers to frequently asked questions (FAQ) and a walkthrough that takes a new user from initial login through all the available actions in the system. Both the walkthrough and the FAQ sections include short videos showing each individual action. A general presentation on the features of the site has been made to the researchers and training is offered on demand as we find if we train before the researchers have an immediate need, the knowledge is forgotten and the training needs to be repeated.

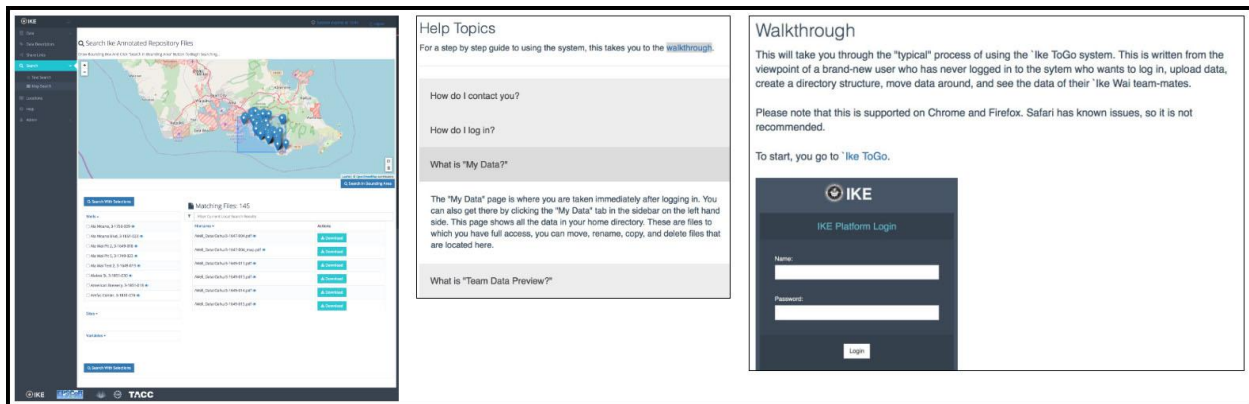


Figure 7. Screenshots showing examples from the 'Ike Gateway. Left: 'Ike gateway spatial search screenshot showing results of a bounding box query returning matching annotated data. Center: 'Ike gateway screenshot of the Help section. Right: 'Ike gateway screenshot of the Help Walkthrough.

The cyberinfrastructure team deployed two computational workflows that support microbial analysis and geophysical simulations. Test applications with Mothur and QIIME related to environmental microbial community analysis workflows have been developed and tested with the UH HPC. The MARE2DEM application workflow for electromagnetic geophysics modeling has been developed and tested with the UH HPC. In total 3 applications have been installed and two workflows are now supported in Year 2.

**Outcomes:** Researchers can run computational workflows on the platform. This allows the provenance of the computational parameters, inputs and outputs to be tracked and reproduced it necessary. **Risk Mitigation Plan:** None needed on track for Year 3.

**Activity 2.1.4:** 'Ike Visualization.

**Results: Prototype Decision Support Application.** The CI and Viz teams worked with USGS scientists to develop prototype decision support application for calculating island recharge based on user defined land use types. Recharge values are calculated based on two climate scenarios developed based on stakeholder specifications. The prototype utilizes the 'Ike gateway APIs for accessing serialized raster data

and spatial search to return land-use recharge values back to the client for real-time recharge re-calculation. The user can define different land use types interactively and view the resulting change in recharge estimates in real time. The design will scale to operate on regular laptops as well as take advantage of the large screen estate of CyberCANOEes. The prototype will be refined for usability and new feature addition through a set of user feedback sessions with users from USGS, CWRM and the BWS.

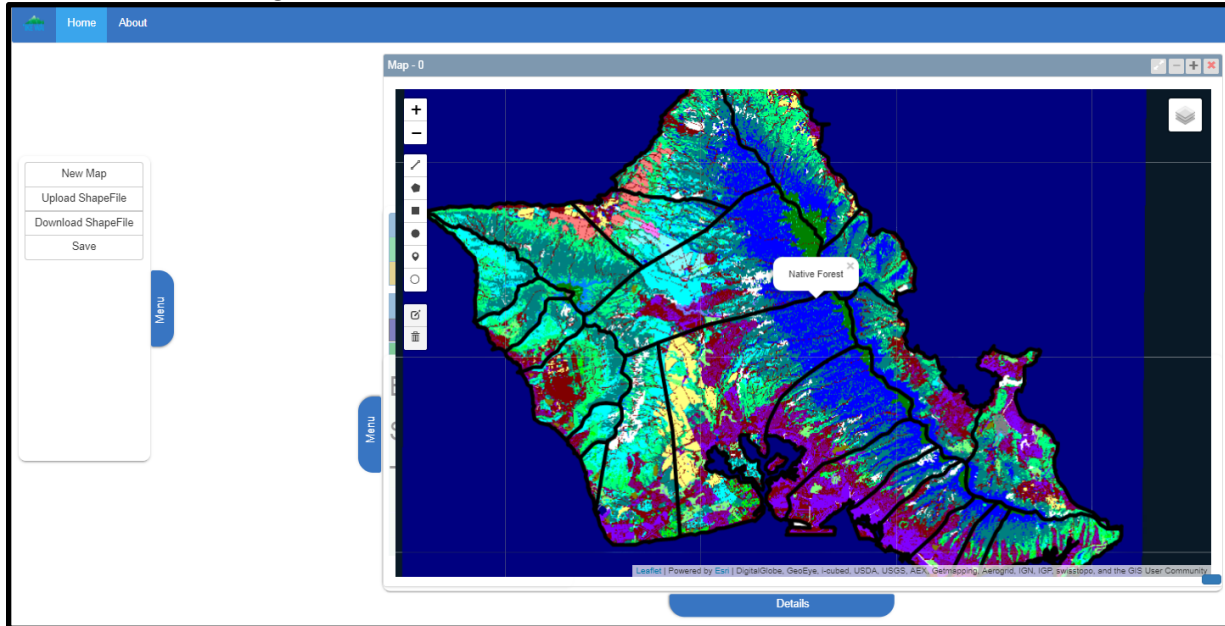


Figure 8. Prototype decision support application to calculate island recharge based on user defined land use types combined with climate scenarios.

**Outcomes:** A prototype decision support application that can be used to engage stakeholders. **Risks and Mitigation Plan:** None needed. On track for Year 3

**Activity 2.1.5:** ‘IKE Dissemination Platform. To date the CI team has focused on the internal users of the ‘Ike Wai Gateway to support data exchange between participants and computational workflows. As new data products are produced in Year 3 we will begin disseminating them to stakeholders and the larger community. Our new collaboration with the Science Gateways Community Institute is providing expert advice on how to identify and target specific user communities and tailor our products to different audiences. The Landuse/Recharge decision support tool prototype will be used as an example of the type of tools and products to be shared and as a way to engage our stakeholders in the further development of gateway features and data products.

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

**Activity 2.2.1:** Personnel & Training

**Personnel:** A data manager, Dr. Ouida Meier, was hired April 1 2017.

**Training:** The development team trained Jack Lam, a graduate student working on the visualizations in Spring 2017. On April 12, 2017 the cyberinfrastructure team and TACC hosted a day-long bioinformatics genomics data workshop at UH Mānoa. John Fonner (TACC) and Sean Cleveland (UH) presented with Rion Dooley (TACC), Joe Stubbs (TACC), Ron Merrill (UH), David Schanzenbach (UH) and Jennifer Geis (UH) assisting the 32 participants (30 from UH and 2 from Chaminade University) that attended. The workshop covered metadata and data organization, using the command line, R, Jupyter notebooks, some basic genomics processing software, creating computational workflows, and using the Agave ToGo software instance that is hosted on the UH infrastructure. The goal of the workshop was to allow the attendees to manage and analyze data more effectively and be able to apply the tools and approaches directly to their ongoing research.

#### **Activity 2.2.2: Data Store & Curation**

**Results:** In Year 2 the cyberinfrastructure team has completed implementation of an annotation/curation workflow in the 'IKE gateway allowing data to be minimally annotated for use and search/discovery. The cyberinfrastructure team has worked with 'Ike Wai team members imported and annotated the following data sets: (a) 4,757 Hawai'i water wells including 3,288 associated pumping logs and permit files, rendered discoverable and searchable to the 'Ike Wai project members.; (b) Shapefiles most often used in project GIS mapmaking (98 files in 11 sets); (c) Hawai'i Undersea Research Lab (HURL) submersible data, graphs, R script, process, maps (37 files in 7 sets); (d) Cleaned compilation of legacy stable isotope data from literature for main Hawai'ian islands, including site map (4 files, multiple formats); (e) Spreadsheet guidelines (Repository plus GitHub and example spreadsheets: 1 set, multiple formats); (f) 5,718 user uploaded files internal to 'IKE gateway users; note that these have not been annotated at this time; (g) SGD Legacy Chemistry dataset; (h) Rainfall atlas dataset; (i) Water quality data (<https://www.waterqualitydata.us/>) 4,418 water quality sites linked and data catalogued for Oahu.

The annotation of the above datasets also makes them discoverable and searchable to the 'Ike Wai research team within the 'IKE gateway. Location annotation where appropriate works with platform spatial search and discovery features.

#### **Activity 2.2.3: Collate historical and current data from diverse agencies**

**Hawai'i Water Well Data** - The Hawai'ian water well data is a legacy collection of scanned paper records from early siting, drilling, testing, and initial operation of water wells in the main Hawai'ian islands. Of interest to 'Ike Wai are initial readings of flow, salinity, depth, and records of pumping tests, site maps, and drilling logs. 'Ike Wai researchers are currently collecting water samples from a number of these same wells for water geochemistry, microbial community fingerprinting, and stable isotope tracking, all methods for inferring groundwater flows, so their original condition and hands-on observations are instructive. The drilling log component of early well records yield information about geological layers from core samples during the initial drilling process, and these are of interest to geological modeling. The well records were originally rescued by Nicole Lautze through a grant from the Department of Energy to document potential geothermal assets in Hawai'i.

**Hawai'i Undersea Research Laboratory (HURL) Data** - HURL datasets of interest are a selected set of submersible dives with conductivity, temperature, and depth measurements that were typically recorded regardless of the original project intent for which the submersibles were deployed at the time. These records which include over a dozen dives off of the Kona coast on the Big Island, uniquely provide an opportunity to locate intermittent and regular occurrences of deep (down to a few kilometers below sea level) freshwater: submarine groundwater discharge (SGD) spanning decades of exploration history. These can qualitatively inform understanding of freshwater flows through the island geology. An initial set was subjected to analysis and the results and code preserved; a project postdoc is expanding this analysis.

**Shapefiles** - Most of the research elements of the 'Ike Wai projects are making use of maps or geospatial data in one form or another. It is important therefore to provide a common set of base layers and other frequently used data layers, well-documented and kept updated by state and federal agencies, usable in multiple geospatial software platforms and for mapping use throughout the project's range of disciplines. Most of these shapefiles were obtained through the Hawai'i State Office of Planning.

**Rainfall Atlas Data Set** - The first holding in this legacy collection is quality controlled observations of meteorological data that draws on observations from 471 climate stations in Hawai'i within multiple meteorological networks. Measured parameters include rainfall, air temperature, relative humidity, wind speed, and radiation for a 25-year period (1990–2014). Rainfall is a critical element for 'Ike Wai researchers, including questions of groundwater storage and flow, and water age. Recent and predicted near-future shifts toward reduced rainfall quantity in Hawai'i are of great concern to water resource managers and the public. This dataset will be another candidate for eventual serialization within the platform. The origin of this dataset collection is a long-term effort by collaborator Tom Giambelluca and the current location of this data is here: <http://rainfall.geography.Hawai'i.edu/> Ingestion of this data into the 'Ike Wai Gateway is underway and dissemination of data products will be a major deliverable for Year 3.

**SGD Legacy Dataset** - The collections of coastal submarine groundwater discharge data, available from recent years and collected under other projects, are of strong interest to the 'Ike Wai research community examining freshwater discharges along the coast for understanding groundwater flows. These data were previously collected by Henrietta Dulai and collaborators. These also fit with a longer data record in the 'IKE repository of stable isotope values for H and O in water extracted from a detailed literature review by collaborator Robert Whittier working with Nicole Lautze.

**Water Quality Data** - The 'IKE platform is newly providing access to over 4,400 water quality observation sites in Oahu via a data link to the Water Quality Portal (<https://www.waterqualitydata.us/>) as a partner. The portal houses water quality data from USGS, EPA, and NWQMC - together, over 400 state, federal, tribal, and local agencies. 'IKE platform users can search for available data - provided, curated, and updated by the Water Quality Portal - through an active data link created within the 'IKE platform. This active repository linkage allows users to find water quality observations through the 'IKE platform's own search tools, including search by location through 'IKE's interactive map and bounding tool selection. This will help centralize access to water quality data resources for 'IKE platform users.

**Hawai'ian Translations.** The Institute for Hawai'ian Language Research and Translation (IHLRT) team has collected and translated relevant historic Hawai'ian language written articles focused on particular areas and types of water references relevant to 'Ike Wai researchers and to local community members deeply involved in water resource issues. The translations contain elements of natural history observation, including verbal-recorded and written observations of water quantity, quality, and unusual events. The cultural context of these observations is often related to traditional understanding and traditional practices of water management. In the 'IKE platform, English language translations link to an image of the original Hawai'ian language source as well as to metadata objects that locate the original story or article within a traditional land management unit (ahupua'a). Platform capability for creating shared links also makes it possible to link curated and cited translations and original sources within the platform to a publicly accessible interactive map outside of the platform.

**Outputs:** Dataset/files deposited = **18,316** [Datasets/files curated = 12,598 (comprising 8,045 well files and well metadata objects, and 4,553 other annotated files and metadata objects) plus 5,718 unannotated files available to team]. Additionally: Partners linked = 1 with Partner datasets linked = **4,418**.

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

**Risk Mitigation Plan:** None required on track for Year 3.

**Results:** As described in Activity 2.2.2, Multiple sources of legacy and historical data were recovered from diverse agencies in Year 2. Additional ongoing efforts include a sharing of data from a private hydrologist with extensive Hawai'i Island experience. Hawai'i Volcano Observatories (USGS) staff have provided files which are currently being reviewed for their content. Soil files from Honolulu County archives have also been received.

**Risks and Mitigation Plan:** None needed, on track for Year 3

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

**Results:** The IHLRT (Institute of Hawai'ian Language Research and Translation) team developed community relationships with Kona residents and gained valuable insight on what terms, plants, fish, and

place names were important for study. Two newspapers series were identified: *Nā Hoʻonanea o Ka Manawa* which ran from September 1923 – August 1924 and excerpts from *Nā Hunahuna No Ka Moʻolelo Hawaiʻi* September 1869 – May 1870. W. D. Alexander’s map of Hawaiʻi Island from 1901 (Fig. 9) was used as a reference to determine the traditional land names and divisions that would correlate within the context of the Hawaiʻian Language newspapers. A catalog of all ahupuaʻa, sections of land that would contain enough resources to sustain the amount of people living within the area, of the North Kona area was created. This catalog also listed water body terms within each section and was used to search the Hawaiʻian language digital repository for relevant search hits. These hits were used to create short summaries to identify water structures, use or management of water, or changes in land use that may affect water.

Members from the ʻIke Wai team held a series of discussions to review IHLRT’s translations and short summaries. The first and largest tabletop exercise reviewed fully translated articles and created water science responses. These responses provided collaborative insight into the article’s relevance to any of the water sciences within this project, created science questions or hypotheses that could be addressed from the translations, and additional key science terms that may relate to the article.

Figure 9: a) W.D. Alexander’s map of Hawaiʻi Island of 1901, red section denotes the enlarged section in b). b) Enlarged section of the 40 ahupuaʻa in North Kona.



**Outputs:** We identified 40 ahupuaʻa in North Kona (from Kiholo Bay to Keauhou). We placed 1361 place names, boundary points, and/or bodies of water within the 40 ahupuaʻa. Two ahupuaʻa (Puʻu Waʻawaʻa and Kaʻupulehu) place-based searches yielded 791 “hits” in the newspaper repository. Products of year 2 included 102 short summaries, 30 fully translated articles, 33 of 102 articles prioritized for full translation, and 1 interactive map at <http://purl.org/ihlirt/map>. In addition, in collaboration with the Education team, a Community Engagement Packet was compiled that includes two examples of full translations resulting from place-based searches.

**Outcomes:** We are creating a framework that engages water resource scientists and bridges two epistemologies to study water in Hawaiʻi. More importantly, we are giving back to the local communities of our study sites by providing the data, articles, and histories that were documented about their communities, by their elders from a century ago. One of the products poised to have an impact is an interactive map that will group articles related to water by ahupuaʻa and will link to a full translation and

a digital image of the original article. This could also potentially provide a timeline of resource management change over time.

**Risks and Mitigation Plan:** None needed. On track for Year 3.

**Activity 2.2.5:** Develop and parameterize coupled conceptual models of GW flow and chemical transport.

**Results:** A preliminary three-dimensional conceptual model was developed for West Hawai'i, encompassing six aquifer systems including the primary Hualālai aquifer systems (Kīholo and Keauhou) (Fig. 10a). The modeled area was extended past the Kīholo and Keauhou because it is hypothesized that there is an interconnectivity between aquifer systems, thus allowing groundwater recharge to flow across aquifer boundaries. It is hypothesized that rain that falls on the slopes of Mauna Kea and Mauna Loa contribute to the Hualālai aquifers, therefore it is important that we extend the model area to properly simulate subsurface flow and the appropriate amount of recharge contributions. The conceptual model includes a physical barrier located between the low-water observation points and high-water observation points, running relatively parallel to the western coast. This barrier is treated as a vertical near-impermeable feature which extends down to the bottom of the aquifer (Fig. 10b-c). The conceptual model includes the Hualālai rift zone, modelled as a vertical structure of very low permeability, thus simulating the effect of dikes. Two extensions are added to the rift zone, one extending north and one extending south. It is known that ash and trachyte are layered within the volcanics, but their depth and extent are unknown. This preliminary conceptual model does not include those features because of their uncertainty but can easily be incorporated as more data is obtained.

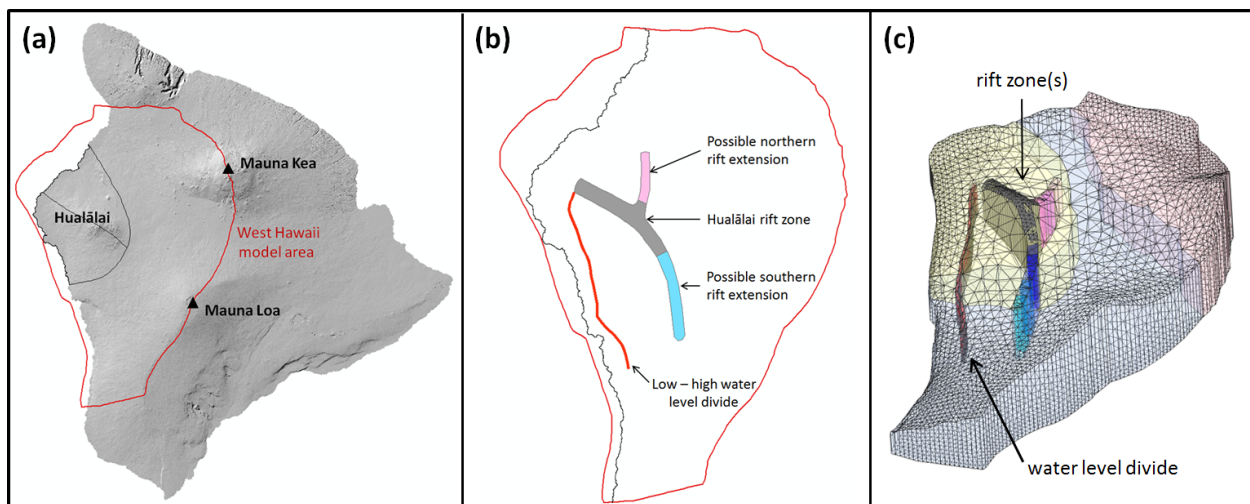


Figure 10. (a) Groundwater model boundary (red) encompassing the Hualālai aquifer system (Kīholo and Keauhou) and extending out to four additional aquifer systems (Waimea, Anaeho'omalū, Kealakekua, Kaapuna). It is likely that water that falls as rain on Mauna Kea and Mauna Loa contributes to the Hualālai aquifer system. (b) General hypothesized geologic structures that may impact subsurface flow. The Hualālai rift zone is relatively well accepted due to surficial geologic features, but the north and south extension of the rift zone are unknown. The low - high water level barrier is estimated based on observed

*water level measurements, but it is unknown how the barrier was formed. (c ) 3D conceptual model of hypothesized main geologic structures affecting groundwater flow.*

**Output:** We developed a conceptual model of West Hawai'i that can be modified/updated based on new findings (i.e., inclusion of ash layers, extent of rift zones, placement of barrier).

**Outcomes:** The primary outcome from this conceptual model is a better representation of the subsurface geology based on legacy data, drilling logs, and previous research. These conceptual models will help guide the validation process of the numerical models, which will in turn help in guiding the field work to reduce assessment uncertainties.

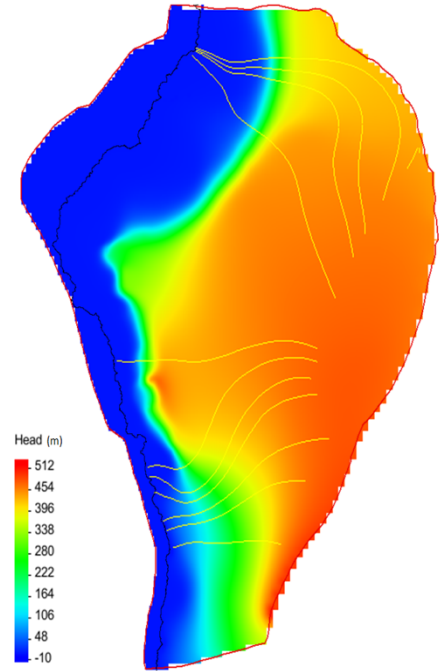
**Risks and Mitigation Plan:** Our key concern is that the GW models are only "calibrated" by well data, and the wells are preferentially located toward the western side of the volcano. The risk is that we know (by analogy with older, eroded, Hawai'ian volcanoes) that the subsurface structure (e.g., distribution of dikes, different layers of lava flows and/or ash) can be spatially and vertically highly variable. Without this 3-D knowledge of the eastern side of Hualālai volcano our GW models may be too simplistic. Thus, our mitigation plan is to collect geophysical data in places such as the SE rift zone of Hualālai to resolve structure down to ~1 km depth. It is also possible that geochemical data will help constrain these models; e.g., oxygen isotope data will tell us if water from high on the west flank of Mauna Loa can reach the coast, or if there is a subsurface barrier (dike?) that prevents this flow.

**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.

**Results:** Using the conceptual model described in Activity 2.2.5, preliminary numerical models were developed for the West Hawai'i area. The numerical simulation programs, MODFLOW and FEFLOW, were used in the development process, utilizing available data in model calibration. A refined FEFLOW model was used to confirm the results based on the coarser-grid MODFLOW model. Calibration data includes 132 pumping wells reported from 1970-2017 and 207 observed water levels measured from 1947-2013. The MODFLOW numerical model was then optimized using an automatic inverse modeling approach, which is described in Activity 2.2.7. Using the best optimized model, groundwater flow paths were simulated and were nearly similar to the results from previous isotopic research conducted by Fackrell et al. (2016). The flow paths were initiated on the eastern side of the study area and flow to the coast line on the western side of the study area (Fig. 11). The flow paths travel across aquifer boundaries, indicating interconnectivity between the aquifer systems.

Figure 11. MODFLOW Simulated head levels for the West Hawai'i study area calibrated with 207 observed head levels measured from 1947-2013. Simulated groundwater flow paths (yellow lines) indicate the potential travel through the modeled area. Flow paths travel across aquifer boundaries, suggesting interconnectivity between aquifer systems.

The density dependent numerical model SEAWAT was used in the simulations. The 2D model crosses through Kiholo aquifer, extending up the slope of Hualālai. The 2D model grid was refined down to one meter cell size surrounding the coastal boundary (Fig. 12a). The refined grid eliminated numerical errors that would occur in large sized model grids, thus resulting in a defensible calibration. Results of calibration are useful in constraining values needed for a larger scale multidimensional areas. The model also helps in carefully setting ocean boundary conditions based on values of submarine groundwater discharge. Finally, the 2D model presented the opportunity to calibrate transient data, which would typically take a longer time to complete with a large-scale model. The results from the 2D model can thus be used to refine parameter values and enhance calibration for the larger 3D model.



The transient simulation water results at a monitoring well shown in Figure 12b, where good match can be shown between measured and simulated results. Reasonable salinity results were also obtained.

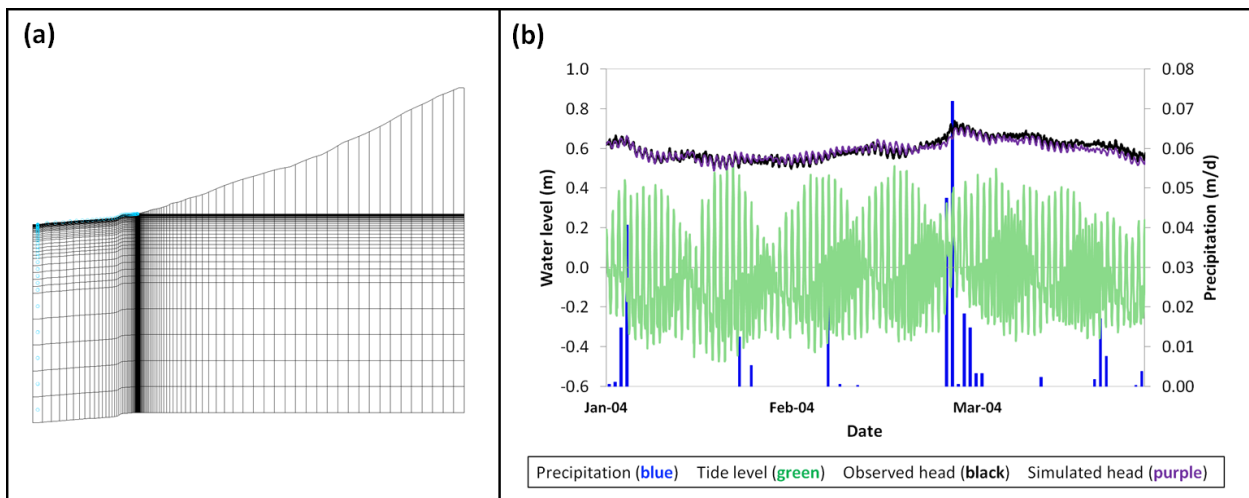


Figure 12. (a) 2D computational grid through Kiholo aquifer, refined down to one meter cell size. (b) SEASWAT simulated transient water level against observed water level from Kiholo well, tidal fluctuations,

*and precipitation.*

**Outputs:** Efforts include developing a 3D preliminary numerical groundwater model with simulated head levels and flow path lines. The model is a useful tool in assessing scenarios for geological site features and guiding the field data collection process. The models will be improved as new data is collected. We also developed a refined density-dependent preliminary numerical groundwater model to assess transient, near-shore conditions.

**Outcomes:** The primary outcome from this numerical groundwater model was the identification of structures needed to match observed head levels. The nature and extent of these structures are unknown, but this model informs us that the drastic head difference cannot be obtained with simple homogeneous lava flows. These findings will help guide field work teams by proposing potential sample locations. It would be ideal to conduct geophysical surveys across the predicted structures in order to properly identify their existence and to determine the actual hydraulic conductivity. Specifically, geophysical and geochemical techniques and sensor technology are needed to identify aquifer bottom where flow is negligible, eastern boundary location and condition, location of the freshwater-saltwater interface, location of the water table (especially in areas where no wells exist), perched layers, water flow path and Darcy's fluxes, and location and nature of barriers or low conductivity zones. Geophysical approaches to address the assessment of controlling geological structures are described in Activity 1.1.1.

**Risks and Mitigation Plan:** The models developed are currently on schedule, so a risk mitigation plan is not necessary. However, it is crucial to conduct geophysical surveys and analyze geochemical samples in order to properly model the aquifer systems during Years 3 to 5. These are just preliminary models, which need to be calibrated 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.

**Results:** The preliminary numerical MODFLOW model described in Activity 2.2.6 was calibrated by using currently available observed water levels through an automatic inverse modeling approach. The approach has been developed to perform computationally prohibitive calibration of 3D refined numerical model that will utilize hydro-geophysical and geochemical datasets to be collected in coming years. The approach can handle millions of unknown model parameters and observations linked with multiphysics simulation models for joint hydro-geophysical and geochemical inversion. The inverse modeling code, written in Python by a member of the modeling team (Dr. Lee), has been released in a public domain repository (<https://github.com/jonghyunharrylee/pyPCGA> and will be made public by mid-March with a general groundwater inverse modeling example).

The estimated hydraulic conductivity parameters identified structures of lower hydraulic conductivity following the divide of low-level and high-level water elevations (Figure 13a). A good match has been achieved between measured and estimated water level values (Figure 13b). However, the calibrated

hydraulic conductivity values are lower than expected based on previous research studies. These lower than expected values are probably representing effective values reflecting the existence of geological structures yet to be identified. This issue will be further assessed with new data based on future field work.

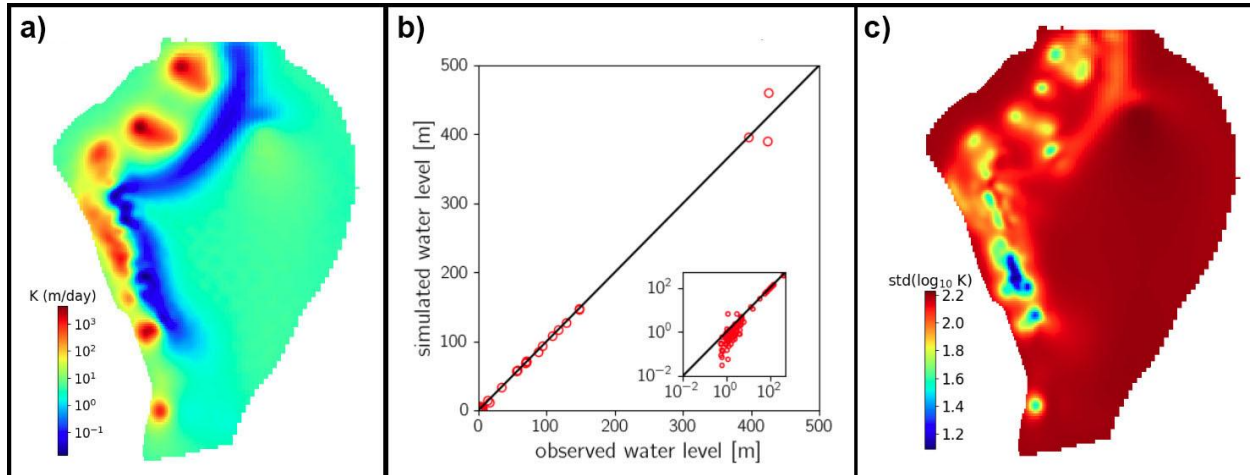


Figure 13. (a) Calibrated hydraulic conductivity with preliminary numerical groundwater model. (b) estimated vs. measured water level data with root mean squared error (RMSE) = 4.6 m; inset plot of data match in log-log scale indicates a good match in the low water level region. (c) Uncertainty map for calibrated hydraulic conductivity. High uncertainty prevails where calibration data are not available.

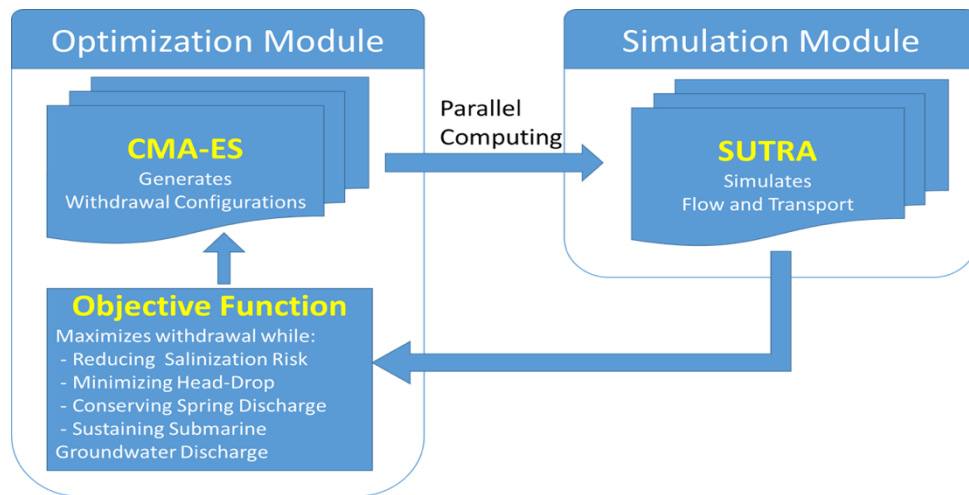
**Outputs:** A preliminary numerical groundwater model was calibrated to match 207 observed head levels through a computationally efficient inverse scheme. The inverse modeling code was released in a public domain repository (<https://github.com/jonghyunharrylee/pyPCGA>). The code was designed to link flow and reactive transport numerical simulation models with geophysics numerical simulation models and incorporate future geophysical and geochemical observations to better estimate hydrogeophysical model parameters in high performance computing environment.

**Outcomes:** The primary outcome from the model parameter estimation was the identification of distributed hydraulic conductivity parameters in the preliminary numerical groundwater model that reproduce currently available observations. During the calibration step, we have created an uncertainty map (Figure 13c) of estimated hydraulic conductivity to support future geophysical survey and geochemical data collection plans. New data with updated conceptual model and numerical groundwater model will be provided into our calibration tool to better characterize subsurface structures with reduced uncertainty.

**Risks and Mitigation Plans:** Activity 2.2.7 is also on schedule.

**Activity 2.2.8:** Apply modeling tools to specific, pressing questions advanced by the hydrology community and stakeholders.

**Results:** During the reporting period, the modeling team and the social science-economics team collaborated with the USGS Pacific Islands Water Science Center (PIWSC) to develop a simulation optimization procedure to estimate sustainable yield in Hawai'i. The finite element PIWSC groundwater model of Pearl Harbor [Oki, 2005] was used to simulate groundwater flow and chloride transport in our study site. The simulation optimization estimates the maximum allowable withdrawal in the aquifer without violating the sustainable yield constraints, representing the management objectives. These objectives, which were identified through stakeholder engagement, are reduction of salinization risk, minimization of head-drop, conservation of spring discharge, and sustaining submarine groundwater discharge. So far, we have included salinity and head-drop constraints in the simulation optimization procedure. Including spring discharge and submarine groundwater discharge is still work in progress. The USGS SUTRA code [Gingerich and Voss, 2005] was used to simulate groundwater flow and chloride transport. The optimization algorithm is covariance matrix adaptation evolution strategy (CMA-ES) [Hansen et al., 2003]. CMA-ES is a stochastic derivative-free algorithm for numerical optimization that is readily amenable to parallel computation [Elshall et al., 2015]. Figure 14 shows a schematic diagram of the simulation optimization procedure. The simulation optimization run was for 50 years, from 2016 to 2065. Initially we clustered the pumping wells into 20 pumping clusters based on distance yielding 20 decision variables. Then clusters were identified through stakeholder engagement to identify relevant pumping wells that need to be included as decision variables. The optimal solutions for these two test runs give a maximum allowable withdrawal of 179 mgd and 206 mgd, respectively. This indicates that shutting down one of the navy wells near the coast in Ewa area of Oahu can increase the maximum allowable withdrawal. Figure 20 and 21 show the initial withdrawal conditions and the optimal solution



for the first test run, respectively. The initial withdrawal conditions, are the current withdrawals, which are average withdrawals for the period of 2001 to 2015. The total current withdrawal is 116 mgd.

Figure 14 A schematic diagram of the simulation optimization procedure

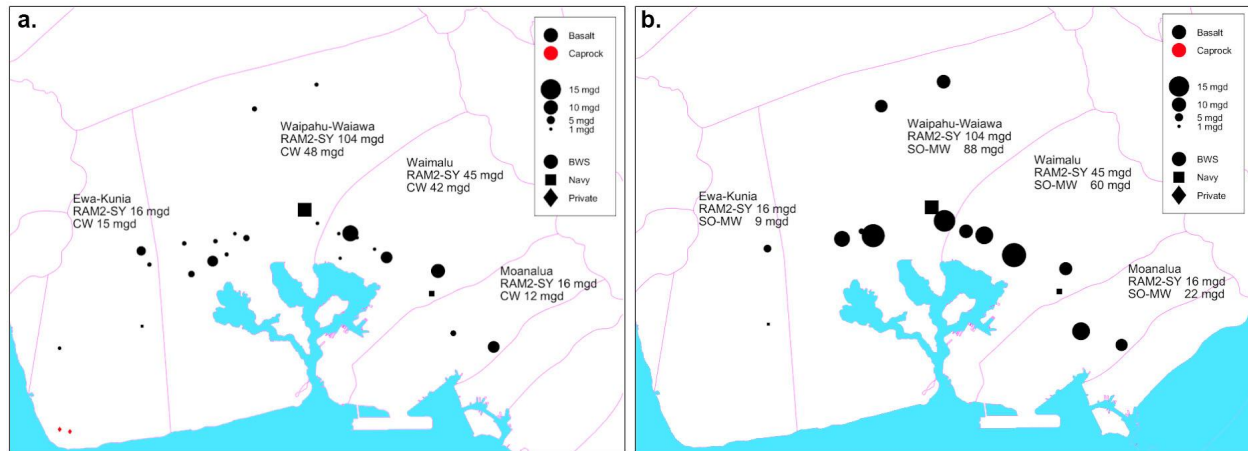


Figure 15. a) Map showing current withdrawal with 24 decision variables (22 BWS wells and 2 private wells) and 3 navy wells. The current withdrawal (CW) and the RAM2 model sustainable yield (RAM2-SY) estimates are shown for each aquifer unit. Note that RAM2 is an analytical function model that is currently being used to estimate sustainable yield in Hawai'i. Pumping wells with withdrawal less than 1 mgd are not shown on the map. b) Maximum allowable withdrawals for the test run of excluding the navy wells from the decision variables. The simulation optimization maximum withdrawal (SO-MW) and RAM2 model sustainable yield (RAM2-SY) estimates are shown for each aquifer unit. Pumping wells with withdrawal less than 1 mgd are not shown on the map.

**Outputs:** The main output is a flexible simulation optimization code for estimating sustainable yield using high performance computing environment. The code is generic enough to account for various management strategies and future feedback from stakeholders.

**Outcomes:** Our preliminary test runs show a success in implementing the simulation optimization approach. Increasing the time step from 10 to 180 days reduces simulation optimization runtime from 16 to 2 days, while maintaining good numerical accuracy with comparable solution to that with a 10-day time step. The results indicated that withdrawal dependent penalty is a stable objective function. Finally, accounting for head-drop is an important criterion to avoid depleting the aquifer. Such outcomes are significant towards addressing future runs in response to stakeholder' demands.

**Risks and Mitigation Plan:** Decisions in groundwater management are difficult because our scientific knowledge about complex groundwater systems is uncertain. As this uncertainty analysis is not part of the 'Ike Wai proposal, we are seeking additional funding to address this component under the USGS National Competitive Grants Program for fiscal year 2018. In addition, we are considering conducting a basic uncertainty analysis to understand the variability of the solution.

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

**Activity 2.3.1:** Develop three land-use scenarios under three different conditions: current or business as usual, increased development and green. (Based on the stakeholder engagement process)

**Results:** Based on BWS input we have developed three land-use scenarios for the Pearl Harbor aquifer based on potential futures of urban, agricultural, and conservation lands. These scenarios are: 1) business as usual (current trajectory); 2) high development (increased urban development, low forest conservation, low agricultural protection); and 3) green (no further development, high forest conservation, high agricultural protection). We are working closely with USGS and in year 2 started a new collaboration with Pacific RISA to ensure these scenarios are well-designed and suited for calculating recharge estimates. These recharge estimates will then serve as inputs to the groundwater modeling optimization framework. In addition to land-use scenarios, we have developed a case study for spring protection (a spring protection scenario) focused on protecting the high cultural and economic value of spring-dependent watercress production in the Pearl Harbor aquifer. Finally, we have identified RCP 8.5 mid-century as an appropriate climate change scenario to consider. We have also developed land-use scenarios for Hualālai, focusing first on watershed conservation scenarios, collaborating closely with the Hawai'i Community Foundation, the Department of Water Supply on Hawai'i, and three watershed partnerships. In this study site the key stakeholder interest from the Department of Water Supply is to target investments in watershed conservation and restoration for cost-effective recharge benefits.

**Outputs:** 3 land-use scenarios developed for Pearl Harbor (see Figure 16); 3 land-use scenarios in development for Hualālai (completed by end of Q1, year 3); 1 climate change scenario identified; 1 spring scenario identified; 1 SGD scenario identified; 1 framework for watershed investment targeting developed for Hualālai.

**Outcomes:** As described above, the major outcome of developing these scenarios is a concrete framework to integrate these scenarios into the Pearl Harbor optimization groundwater management framework and into management plans for Hualālai.

## Pearl Harbor Land-Use Scenarios

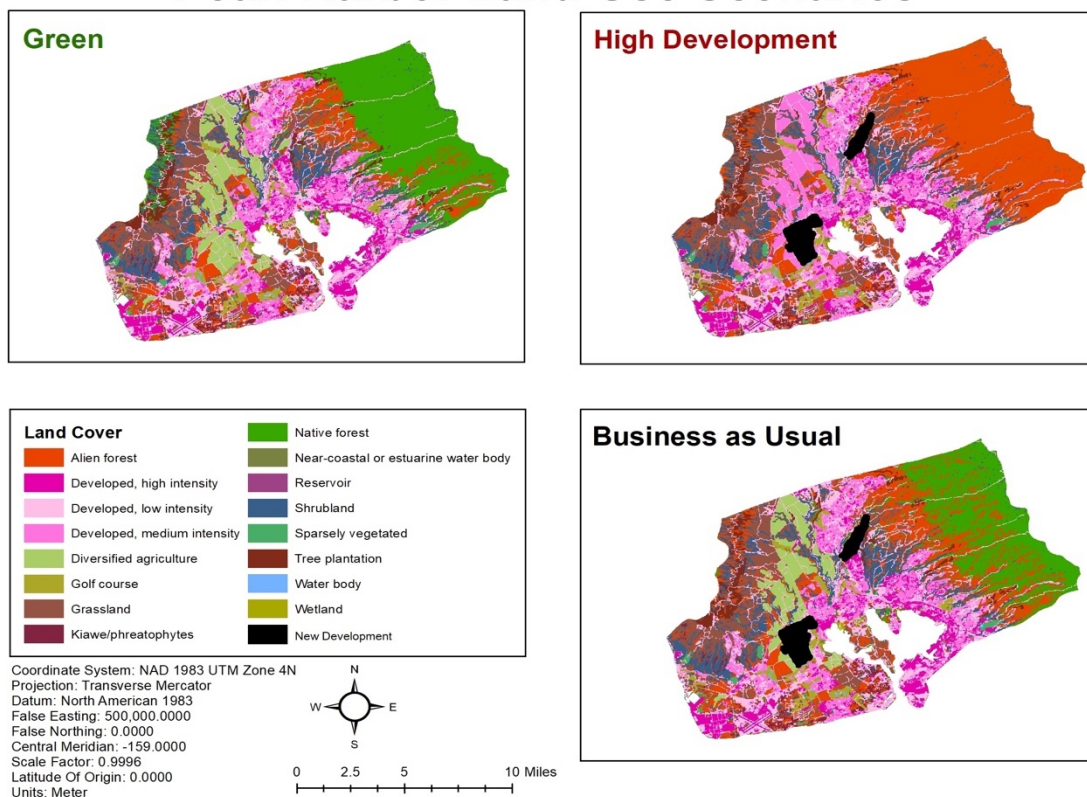


Figure 16. Land-use scenarios developed for Pearl Harbor aquifer. In scenario (1) “Business as usual” (lower right) urban expansion proceeds according to planned and projected developments and management of agricultural and conservation lands proceeds according to existing plans; in scenario (2) “Green” (upper left), no new urban expansion occurs, all native forests within watershed partnerships are conserved and agricultural lands are preserved; in scenario (3) “High development” (upper right) all agricultural areas are converted to urban development and all native forests are invaded by alien species. These are initial land use scenarios created based on existing plans and a first round of stakeholder engagement. The scenarios will be iterated on with stakeholders and completed by the end of Year 2.

**Risks and mitigation plan:** None needed. On track for Year 3.

**Activity 2.3.2:** Use economic analysis to maximize the net present value (NPV) of social welfare that can be attributed to water use over time (Evaluate economic and management implications of scenarios).

**Results:** Working closely with the groundwater management team, we have developed a groundwater optimization framework in Pearl Harbor which allows us to evaluate the economic and management implications of the scenarios described above (land use, climate, and spring/SGD protection). Through an iterative process with CWRM, BWS, and USGS, we have refined which wells to include in the optimization

for maximum utility to the decision makers. Elshall included optimization for a salinity and head drop constraint (**see activity 2.2.8**). In Year 2 we started to gather data on pumping costs that will be easily integrated into the framework described above and allow us to use economic analysis to maximize the NPV of social welfare that can be attributed to water use over time. This involves gathering and cleaning data from multiple sources and conducting an econometric analysis of the pumping costs under different head levels and electricity (energy prices). Also in Year 2 we progressed in gathering cost data for watershed conservation, which together with the pumping costs will allow us to calculate the NPV of watershed conservation.

**Outputs:** 1 salinity constraint incorporated into the optimization framework; 1 head-drop constraint incorporated into the optimization framework; 30 pumping wells identified for use in analysis (based on stakeholder feedback); Cost data obtained for 33 primary pumping wells in Pearl Harbor; Cost data obtained for 15 booster pump stations in Pearl Harbor; Combining legacy watershed conservation cost data from 6 management sites on Hawai'i Island and 1 site on Maui (in progress); Obtaining current and projected watershed conservation cost data from 3 watershed partnerships on Hawai'i Island (in progress); Methods (4) defined to evaluate the economic and management implications of scenarios (i) pumping cost estimation, (ii) watershed restoration cost estimation, (iii) watershed restoration benefit estimation (GW recharge tied to changes in pumping costs), and (iv) market value of spring-dependent agriculture compared with changes in pumping costs.

**Outcomes:** These data and methods have been utilized in the GW-management model to operationalize managing water for the public trust in Hawai'i.

**Risks and mitigation plan:** One risk is that we will experience delays in getting recharge estimates from USGS. To mitigate this, we have developed a plan B approach to estimating GW recharge using a statistical model of evapotranspiration (published in Bremer et al. in press and Wada et al. 2017) translated to water balance approach.

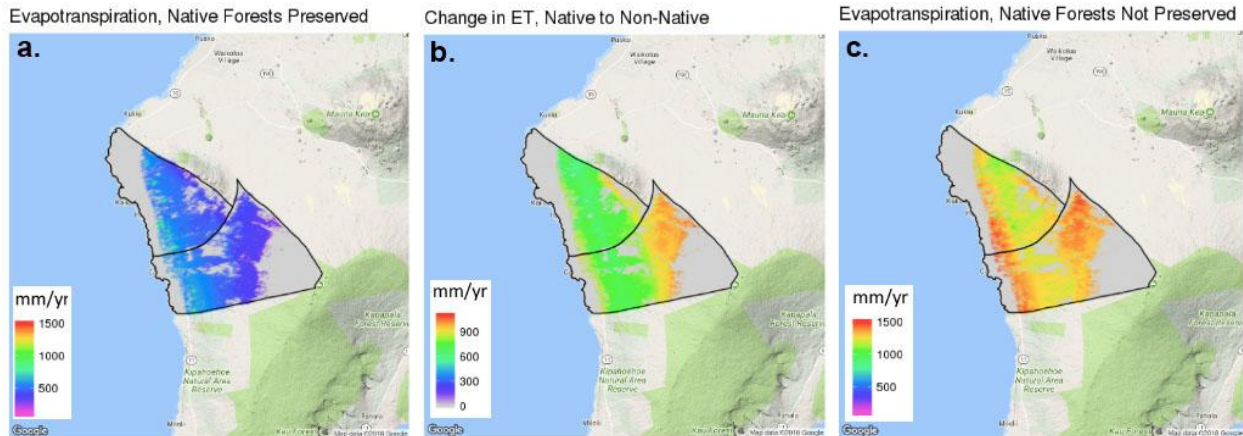
**Activity 2.3.3:** Incorporate energy costs into consideration of water stress scenarios (Added: Spatial analysis of watershed restoration investments).

**Results:** A new collaboration was developed in Year 2 with the Hawai'i Community Foundation and Department of Water Supply on Hawai'i Island to conduct a spatial analysis of the most cost-effective areas to invest in watershed protection and restoration for groundwater recharge. These cost-effectiveness maps are a type of scenario and also are key to evaluating the NPV of watershed conservation and of water use in the Hualālai aquifer. In year 2 we developed an approach to model changes in Evapotranspiration with land-use change (**see activity 2.3.1**) that can be utilized in Pearl Harbor aquifer. We collected pumping cost and energy price data for the Pearl Harbor aquifer. Together with head level data, this information allows us to estimate an energy requirement function for pumping. Future energy price scenarios (to be completed in year 3) will be included in future groundwater optimization simulations via the energy requirement function. Objectives such as cost-minimization can then be integrated into the objective function.

**Outputs:** Maps of ET created for forest protection, Fig. 17; Cost data collected (in progress); 3 stakeholder meetings.

**Outcomes:** Newly generated information on changes in ET with watershed conservation and an approach to estimate a pumping cost function that allows for future energy price scenarios.

**Risks and mitigation plan:** None needed. On track for Year 3.



*Figure 17. Spatial analysis of the Kona Coast, currently in progress, is focused on the question of the most cost-effective ways to invest in watershed conservation for increased groundwater recharge. Changes in evapotranspiration are based on differences in modeling parameters in native vs. non-native forest types, which have different stomatal conductances.*

**Activity 2.3.4:** Develop institutional capacity in the economics of water:

Results: Dr. Leah Bremer began work on July 1, 2017 and has been integrated into the social science/economics team. She brings experience linking ecological and economic value in ecosystem services and spatially targeting watershed investments as well as integrating ecosystem services into the optimization framework.

**Objective 2.4.** Community Engagement.

**Activity 2.4.1:** Agency Outreach.

In Year 2 we finalized agency agreements with Hawai'i County Department of Water Supply and the Natural Energy Laboratory of Hawai'i (NELHA) providing access to 10 sampling wells and laboratory use for processing field samples. (Landowner agreements providing access to other sites in West Hawai'i County are covered in 2.4.5.) For Pearl Harbor Aquifer, we secured a research permit with the State of Hawai'i Division of Forestry and Wildlife (DOFAW) to deploy several precipitation collectors in the watershed areas that recharge the aquifer. Upon the hiring of our project geophysicist in Nov 2017 the field sampling plan for this study site has been updated and we are currently preparing a second DOFAW permit request to

conduct geophysical studies on State lands in the region and have identified the Department of Army and the Hawai'i State Department of Agriculture as additional agencies to approach to secure access. Additionally, we are still trying to secure an agreement with the Honolulu Board of Water Supply (BWS) for access to well sampling sites in the Pearl Harbor Aquifer. We are seeking additional meetings with the Honolulu Board of Water Supply to do the same. **Mitigation Plan:** The Pearl Harbor Pumping optimization work provides an opportunity to refocus the conversation with BWS from one of needing something from them to one of how the tools that we are developing can be improved with better data. Our request to meet regarding this work is intended to also lay the foundation for negotiating access. We are also using a multi-pronged approach by having several project team members seek their cooperation.

**Activity 2.4.2:** Establish Water Resources Advisory Committee (WRAC). We have extended our outreach to multiple stakeholder groups and has developed positive working relationships with CWRM, USGA, DWS, water professional groups, and multiple landowners. Central to this was the Water Governance Study we conducted simultaneously with our outreach to identify decision-support needs (**See Activity 2.4.3**). As a result, the need to establish the WRAC has been reconsidered and found to be unnecessary. **Mitigation Plan:** None needed; activity deleted.

**Activity 2.4.3:** Identify stakeholder decision-support needs. Established relationships and collaborations with the Commission and Water Resource Management (CWRM), United States Geological Survey (USGS), the Hawai'i County Department of Water Supply (DWS), and the Honolulu Board of Water Supply (HBWS) that include data sharing, technical consultation, and use of their wells as sampling sites remain in place. During the second quarter of 2017, we completed our agency interviews in partnership with Ulupono Initiative, in total more than 15 semi-structured interviews. Our objective was twofold: (1) to identify research and decision-support needs of water management agencies, and (2) to better understand the governance structure and interactions of the agencies and entities within the water management network. During Year 2, we held two separate roundtable discussions consisting of water professional and large landowners, all of which were identified as having extensive knowledge of the water governance network including former water managers, landowners, developers, and water professionals.

Through our agency and stakeholder discussions, we identified the need for more scientific research to better inform sustainable yield as being a critical groundwater management mechanism. We conducted a comprehensive literature review of sustainable yield, to better contextualize the way in which sustainable yield policy is operationalized in Hawai'i. **Mitigation Plan:** None needed, on track for Year 3.

**Activity 2.4.4:** Establish Interagency Data Committee. As our relationships with stakeholders have matured and in response to recommendations from our EAB, we have identified key thought leaders in the community to guide the population of this important committee. Steve Anthony, USGS and Tom Giambelluca, UH Mānoa will guide the PI in identifying and recruiting key stakeholders to this committee from the BWS, CWRM, HDOH, USGS, Hawai'i Community Foundation, NOAA, Department of Fish and Wildlife and others. This group will convene monthly in Year 3 to set the standards for data sharing and access for the 'Ike Wai project. Once data sharing agreements are in place, the committee will meet quarterly. **Mitigation Plan:** None needed, on track for Year 3.

**Activity 2.4.5.** Negotiate, document, and manage landowner agreements. Landowner agreements in the Hualālai Aquifer providing access to wells, geophysics study areas, and precipitation collector sites have

been secured with, Queen Lili'uokalani Trust, Palani Ranch, Huehue Rannh, Pu'uwa'awa'a Ranch, Na Pu'u Water Company, Kapaopalapala (Chun residence, University of Hawai'i- Office of Maunakea Management, University of Hawai'i- Hawai'i Community College at Palamanui. All of these agreements are in addition to the agency agreements described in **Activity 2.4.1**.

An access agreement is still being developed with Kamehameha Schools, which includes access to Oahu lands. See Fig. 5c.

Regarding the Pearl Harbor Aquifer, as described in **Activity 2.4.1** landowner access agreements are being pursued with the Department of the Army and the Department of Agriculture.

**Mitigation Plan:** None needed for the Hualālai Aquifer or Pearl Harbor.

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

Strategic partnerships continued in Year 2 with the Ulupono Initiative, Hawai'i Community Foundation, Moanalua Gardens Foundation (MGV), and Hui Look. Community engagement lead Chun has been invited to join the MGV Board of Directors and will focus on sharing 'Ike Wai data and research findings as they develop with the place-based curriculum development work MGV does with the Hawai'i's State Department of Education. Kona and Waimea Water Roundtables will be scheduled as data and findings emerge. In Year 2 we also established a new partnership with the USDA Forest Service who is conducting a stewardship network mapping project (STEWMap) in the South Kohala/North Kona which overlaps with the Hualālai Aquifer, as well as with Hui Loko is a network of community Kona-based fishpond practitioners who are caretakers of coastal ponds, springs and aquatic resources. This network is fostered and facilitated by The Nature Conservancy and is a subgroup of a larger state network Hui Mālama Loko l'a that is facilitated by the NGO Kua'āina Ulu Auamo. Relationships and partnership with this organization has helped to facilitate access to 50% of the sites currently sampled in Kona. Researchers also share and disseminate data through their outreach pipelines. In the Pearl Harbor Aquifer, Community Engagement lead Chun was able to secure an 'Ike Wai Scholar who is assisting with identifying community-based groups conducting resource management and education programs in the study site. This information is being used to develop our outreach plan for Pearl Harbor. In total, more than 60 entities were identified through this process. **Mitigation Plan:** None needed, on track for Year 3.

**Activity 2.4.7.** Conduct General Education and Disseminate Information. The field team is scheduled to conduct sample collection in the Hualālai Aquifer during the period March 11-23, 2018. A project update to the community is being scheduled during their stay. During Year 2 the following briefings have been performed: Hawai'i Leeward Planning Conference, Kona Round Table; Honolulu and Kona Science Cafes, Think Tech Hawai'i, Hawai'i Freshwater Initiative. During Year 2 the following written dissemination materials have been developed or updated: Project Executive Summary (One-pager) - used for general project overviews and as a leave behind, Geophysics Informational Handout for Landowners. General dissemination has been via the 'Ike Wai website and social media channels, as well as the subject of a 'Voice of the Sea' one-hour documentary.

**Goal 3: 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.**

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

**Activity 3.1.1:** Undergraduate Research. During Year 1, 22 undergraduate Scholars were trained to conduct research at UH Mānoa and UH Hilo in this academic-year program. The UH Mānoa projects focused on water science, whereas UH Hilo projects focused on data science. Scholars delivered poster presentations on their research results at an 'Ike Wai symposium held in Hilo in April 2017. During Year 2, 23 undergraduate Scholars were trained at UH Mānoa and UH Hilo. Also during Year 2, the water science undergraduate Scholars program was expanded to include UH Hilo students. Website portals to accept Scholars applications have been updated and revised, and we are currently accepting applications for Year 3. A conference presentation on the undergraduate Scholars Program will occur in July 2018 at the Earth Educators Rendezvous, the premier conference venue for geoscience education. The 'Ike Wai undergraduate scholars are highly diverse. Our success in meeting our demographic targets is due in part to recruiting partnerships that were developed during Year 1 and strengthened during Year 2 with Native Hawai'ian-serving programs, particularly Kapi'olani Community College's Native Hawai'ian Advancement Office and UH Native Hawai'ian Student Services. We anticipate student diversity will remain high in our Year 3 cohort of undergraduate scholars. **Mitigation Plan:** None needed. Our number of scholars during Year 2 is slightly less than the number stated in the strategic plan(23 vs 30), but that was a conscious decision to invest more resources in fewer students.

**Activity 3.1.2:** Undergraduate Professional Development (PD). During Year 1, in accordance with what was proposed, we did a soft roll out of the 'Ike Wai Undergraduate Scholars program, limited to research opportunities (no PD). As noted in our Year 2 strategic plan, we have developed and are currently implementing a series of eight PD workshops. All workshops are run in partnership with Native Hawai'ian Student Service and incorporate a culture/science focus. Workshop topics include traditional Hawai'ian land divisions, water-related place names within ahupua'a, translating Hawai'ian language newspaper articles with a focus on fresh water, water use and management in traditional Hawai'ian culture, the role of water-related laws in today's state agencies, and forecasting future directions for water use in Hawai'i. Four of eight workshops have been delivered during the reporting period, with the remaining four to be delivered in Spring 2018. The final professional development workshop will be a student symposium on May 4, 2018 where student research projects will be presented in poster form. Two of four community outreach events were conducted in Fall 2017 ('Ike Wai booths at SOEST Open House and the Kapi'olani Community College STEM Expo, which reached an estimated 7000 participants), and two more will occur in Spring 2018. **Mitigation Plan:** None needed, on track for Year 3.

**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. A summer bridge program between Kapi'olani Community College (KCC) and UH Mānoa has been developed based on 'Ike Wai research

covering four main content areas: (1) Hawaiʻian culture and community; (2) Geology; (3) Hydrology; and (4) Careers. The Year 1 teaching team (recruited in Spring 2017) included ʻIke Wai graduate students and faculty in geoscience, social science, engineering and Hawaiʻian language. Our KCC partners recruited 25 students, with diverse majors ranging from Hawaiʻian studies to various STEM disciplines, and 5 peer mentors who serve as teaching assistants. The summer bridge program was first implemented in May 2017 and interested summer bridge students and mentors were recruited into the ʻIke Wai Undergraduate scholars program and SOEST majors. The Year 1 program was rigorously evaluated and revised based on feedback received. The Year 2 summer bridge program will be implemented in May 2018, and the teaching team is currently being recruited. Our KCC partners are currently recruiting students and peer mentors for the Year 2 program. **Mitigation Plan:** None needed, on track for Year 2.

**Activity 3.2.2:** Hilo Summer Bridge for rising freshmen and sophomores. In Summer 2017, Pelayo spearheaded the development and implementation of the Hilo Summer Bridge program. For 5 weeks in June - July 2017, nine high school and UH-Hilo students participated in the intensive bridge experience, which gave them a credit-bearing Mathematics course (PreCalculus or Calculus 1, depending on skill level) and an Introduction to Data Science course. Both of these courses were taught in the new Data Science classroom on the UH-Hilo campus, which includes a cyberCANOE interactive panel. A flipped classroom approach, paired with utilizing the online assignment portal MyMathLab on the cyberCANOE, allowed both the PreCalculus and Calculus 1 courses to be taught in parallel. The Introduction to Data Science course, which was taught by Drs. Mike Peterson and Keith Edwards from the UH-Hilo Computer Science department, served as the basis for the newly developed CS 171 - "Data Science Fundamentals in R" course, which is now a part of the Data Science certificate program at UH-Hilo. **Mitigation Plan:** None needed, on track for Year 3.

**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 post-docs.* **Results:** During the reporting period, the education team revised the IDP template based on the pilot phase conducted in Year 1. Based on feedback in Year 1, a new module on Place/Culture was added to better align the IDP template with the important Hawaiʻian cultural aspects of the ʻIke Wai project. To create space for this new module, two previous modules (oral communication and writing/publishing) were combined into a single module (communication). Developing an IDP begins with a self-assessment of existing job-related skills and experiences, and then continues with a reflection activity on the additional skills/experience needed to achieve their professional goals. The next step is to create a IDP with concrete, measurable milestones and timelines, which serves as a personal action plan for professional development. Because career goals can change, IDPs are now reviewed and revised each semester. Training sessions are held once per semester to provide guidance to incoming ʻIke Wai graduate students and post-docs on how to create an effective IDP. All graduate students and postdocs are required to complete an IDP within 60 days of hire. To date, we have 100% compliance: 12 students/postdocs have completed IDPs, with 3 additional IDPs in active development for new hires, to be completed Spring 2018. All current graduate students who were part of the pilot program in Year 1 have revised their IDP for Year 2 (there were no post-docs hired in Year 1). 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. **Risks and Mitigation Plan:** None needed, on track for Year 3.

**Activity 3.3.2: Mentoring Cascade. Results:** During the reporting period, the education team revised the structure of the mentoring cascade (or layered mentoring network) based on lessons learned and feedback received in Year 1. All 'Ike Wai graduate students and postdocs participate in the mentoring cascade as mentees: all 15 currently active (plus 2 previous) graduate students and postdocs have selected PD mentors from a list of 'Ike Wai faculty and staff members outside their research group/field. These PD mentors are not research advisors: their role is to coach the student in completing their IDPs (see Activity 3.3.1) by providing their additional experience, knowledge, and resources. Requiring the mentor to be from a different research field both provides a fresh, outside perspective and promotes communication and interaction among the various 'Ike Wai research groups. A training workshop was held in August 2017 to train new mentors in effective ways to provide feedback and support to their mentees to assist them as they develop their IDPs. A key outcome of having mentors provide such feedback to students/postdocs was more realistic self-assessments and IDPs. Thereafter, mentors meet each semester to discuss challenges and successes share best practice (next meeting: March 2018). In addition, STEM mentoring experts are invited to Hawai'i to lead workshops on successful mentoring. During the reporting period, two workshops were provided by Dr. Becky Packard of Mount Holyoke (April 2017) and Dr. Geri Richmond of COACH (January 2018) (see Activity 3.4.1). These workshops were both well attended and found to be highly beneficial by external evaluators. Plans are currently on track to expand mentoring cascade to undergraduate mentees, who will be mentored by 'Ike Wai graduate students, as scheduled during Year 3. **Mitigation Plan:** None needed, on track for Year 3.

**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: Cohorted Professional Development (PD) Training. Results:** One Ph.D. scientist-educator joined the education team (part time) in Dec 2017 to replace the previous professional development coordinator (who left the 'Ike Wai project to accept a tenure-track position; this attests to the valuable training that education team members receive). The pedagogy training plan devised in Year 1 was revised as scheduled during Year 2, based on feedback received from instructional faculty. Two pedagogy workshops were conducted by External Consultant Dr. Sarah Sherman of the Carl Weiman Science Education Institute in Feb 2018, including one on Metacognition (aimed primarily at Faculty) and one on Teaching & Learning fundamentals (for graduate students and postdocs). In addition, 4 half-day professional development workshops were conducted by professional facilitators Dr. Jane Tucker and Nancy Houfek from the renowned COACH program in May 2017 on topics such as Team Science, Strategic Persuasion and Leadership. An additional 3 half-days of professional development workshops were conducted in Jan 2018 by COACH founder Dr. Geri Richmond on topics including Successful Mentoring, Launching a Successful Career in Science, the Art of Effective Negotiation, Women in Academic Leadership, and a miscellaneous Q&A session. Additional "in-house" Professional Development workshops have or will be delivered in place-based research (Feb 2018) and mentoring (March 2018). Outcomes of these workshops include increased awareness among faculty, postdocs and graduate students of effective teaching and learning methods, tools and approaches for increasing student engagement, and increased leadership and communication skills. In addition, a peer-reviewed publication

on pedagogy was published in April 2017, slightly ahead of the schedule outlined in the strategic plan: B. C. Bruno, J. L. Engels, G. Apuzen-Ito, J. Gillis-Davis, H. Dulai, G. Carter, C. Fletcher, D. Bottjer-Wilson. *Two-stage exams: a powerful tool for reducing the achievement gap in undergraduate oceanography and geology classes*, *Oceanography*, vol. 30, p. 198-208, 2017. <https://doi.org/10.5670/oceanog.2017.241>

**Risks and Mitigation Plan:** None needed, on track for Year 3.

**Activity 3.4.2:** *'Ike Wai Travel Grants (formerly called EDventures mini-grants).* EDventures (or Educational Venture Capital) was a program developed by the NSF-funded Center for Microbial Oceanography: Research and Education (C-MORE) to encourage students and post-docs to write proposals by providing a tangible reward: funding for conferences or other educational opportunities. Based on this model, the 'Ike Wai travel grant program was developed and rolled out on schedule during Year 2. During the reporting period, a Request for Proposals was established and a three-person panel (including one graduate student or post-doc) was formed. The panel reviews each proposal and provides both positive and constructive feedback. There are three review cycles each year. Proposals that are not initially awarded funding may be revised based on feedback provided and resubmitted during the same review cycle; this is consistent with the training focus of the program. Training is obtained in multiple ways, through (1) writing the proposal; (2) revising the proposal, if needed; (d) participating in the conference or other proposed educational activities (if funded); and/or (4) by serving on peer review panels.

**Risks and Mitigation Plan:** None needed, on track for Year 3

**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.* Beginning in August 2017, Dr. Grady Weyenberg and Dr. Travis Mandel joined the UH-Hilo faculty as tenure-track assistant professors. Dr. Weyenberg, who is currently housed in the UH-Hilo Mathematics department, has been lending his expertise in Statistics to develop the curriculum for the newly created course Math 271 - "Applied Statistics with R". Dr. Mandel, who is currently housed in the Computer Science department, has helped formulate the curriculum for two newly developed Data Science courses: CS 172 - "Python for Data Analysis" and CS 272 - "Machine Learning for Data Science".

In September 2017, an advertisement for the position of "Assistant Professor of Data Science in Biology or Marine Science" was posted, with evaluation of applications beginning in mid-December. This new hire is expected to be an expert in Genomics/Bioinformatics or Physical Oceanography and contribute at least two new Data Science courses to the overall curricular efforts. Both the Marine Science and Biology departments at UH-Hilo are very popular and have faculty supportive of creating courses that can be cross-listed as Data Science courses that will count towards the certificate and eventual B.S. An offer is expected to be made in March 2018, with the new tenure-track position beginning in August 2018.

**Risks and Mitigation Plan:** None needed, on track for Year 3

**Activity 3.5.2:** *Develop a Data Science Pathway.* Pelayo formed a campus-based Data Science Education Advisory Board, which was charged with developing several new courses and a certificate program at UH-Hilo. This advisory board consists of Pelayo, Mandel (new 'Ike Wai hire in CS), Weyenberg (new 'Ike Wai

hire in Mathematics), Dr. Mike Peterson (faculty in CS), and Dr. Keith Edwards (chair of CS department). This group created four new courses and a Data Science certificate program that will be open to UH-Hilo part-time and full-time students starting in Fall 2018. The four new courses are CS 171 - Data Science Fundamentals in R; CS 172 - Python for Data Analytics; Math 271 - Applied Statistics in R; CS 272 - Machine Learning for Data Science. These four courses, along with six other credits (i.e., approximately two courses) of existing UH-Hilo data-intensive courses are required for the Data Science certificate. Furthermore, the alpha DSCI (for Data Science) has been created. In future years, along with the development of more Data Science and the B.S., all Data Science courses will be cross-listed with the DSCI alpha.

**Risks and Mitigation Plan:** None needed, on track for Year 3.

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

**Activity 3.6.1:** Engage with Stakeholders. We have made great strides in building trust and connecting to communities. The 'Ike Wai Community Engagement Packet created 2/2018, contains a primer on the project, maps of study sites and Hawai'ian translations and other geo-coded information. This is a must-read resource to 'Ike Wai students and faculty.

AGU/Lockheed. AGU submitted a proposal to Lockheed Martin to fund undergraduate scholarships for underrepresented community college and university undergraduates interested in pursuing earth science majors. Hawai'i was included as one of 3 locations nationwide to pilot the program, and I was named as local coordinator. Proposal is pending.

USGS – Bruno is working with Steve Anthony & Eleanor Snow (National Youth and Education in Science Program Manager at USGS headquarters) in the hopes of setting up summer internships for 'Ike Wai undergrads and grads

SACNAS – Hawai'i's hosting the 2019 meeting and this will be a superb venue to showcase 'Ike Wai.

## **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 post-docs (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. To date, 5 of 7 tenure-track faculty positions have been filled. The remaining two positions are in data science and are on track to be filled in project years 3 and 4, in accordance with the strategic plan (See Faculty Hiring Update on p. 13).

### **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) and are fully committed to attaining them by the end of the project period. For undergraduates, we are striving for 75% women and 50% underrepresented minorities (URM), including 25% Native Hawai'ians and Pacific Islanders (NHPI). We are making excellent progress toward these targets, as our undergraduate Scholars cohort includes 47% women and 63% URM (including 50% NHPI). We have established a recruiting partnership with several programs to reach out to Native Hawai'ian undergraduates to join our summer bridge and undergraduate Scholars programs, including the Kapiolani Community College Native Hawai'ian Advancement Office and UH Native Hawai'ian Student Services. Our success with recruiting URM clearly indicates that these partnerships have been effective. Looking ahead to Year 3, we will direct more effort to recruiting more women.

For graduate students and post-doctoral researchers, our targets are 50% women and 25% URM. Our current graduate/post-doc cohort comprises 53% female and 47% URM. These hires were broadly advertised through local and national minority-serving organizations, including UH Native Hawai'ian 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 make-up of the leadership team, which is 33% female and 33% URM. We are actively mentoring and supporting women faculty, in addition, we support the dissemination and advancement of Native Hawaiʻian cultural insights and

Role In Project	# of Individuals	% Female	% URM
Faculty	17	41%	6%
Staff	12	58%	25%
Postdocs	4	25%	25%
Graduate students	11	64%	55%
Undergraduate students	38	47%	63%
RII Leadership Team	9	33%	33%
<b>Overall Total</b>	<b>91</b>	<b>47%</b>	<b>42%</b>

traditional/historical knowledge both within and beyond the ʻIke Wai project. For example, IHLRT has offered oleo Hawaiʻi(Hawaiʻian language) workshops to a diverse group of faculty, staff, students and administrators during year 2.

Table 2: Breakdown of gender and ethnicity of ʻIke Wai participants by project role.

### **C. Partnerships**

We have developed strategic partnerships with ten different entities, including local foundations with missions focused on island sustainability, resiliency and land stewardship, state agencies and key land owners 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.

- The 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 Hawaiʻi.
- Hawaiʻi 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.
- Moanalua Gardens Foundation (MGF) - Land stewardship organization that conducts place-based education in the Moanalua Valley on Oʻahu that abuts our Pearl Harbor Aquifer study site.
- Kamehameha Schools (KS) - Landowner; Study Site access.
- Hawaiʻi County Department of Water Supply (HDWS) - Well owner and operator; study site access and data sharing
- Natural Energy Lab of Hawaiʻi(NELHA) - Land/well owner; study site access and data sharing.
- Kohnanaʻiki Resort (KR) - Land/well owner; study site access and data sharing.
- Queen Liliʻuokalani Trust (QLT) - Land/well owner; study site access and data sharing.

- Palani Ranch (PaR) - Landowner; study site access and data sharing.
- Hui Loko Landowner study site access and data sharing.

#### **D. Collaborations**

We continue our collaborations with the USGS Pacific Islands Water Science Center and the other with the Texas Advanced Computing Center. These collaborations will continue throughout the duration of the project. Our collaborators provide expertise, technical advice and deep knowledge of the respective subject areas

- U.S. Geological Survey: Key members of the USGS Pacific Islands Water Science Center, listed below provide in depth advice on water-balance and groundwater modeling in Hawai'i. Our teams met to engage in table top exercises on both study sites on 5 different occasions and Director Steve Anthony, serves on our 'Ike Wai leadership team. The USGS has been assisting with the development of a user-friendly, map-based web-interface/database system to allow stakeholders to evaluate the effects of land-cover and climate change on groundwater recharge for the island of O'ahu. More specifically, the USGS will be providing GIS datasets of groundwater recharge for selected land cover and climate conditions. The USGS is also assisting with the conceptual development of the web interface/database system. Finally, the USGS has been providing feedback on our optimization modeling of groundwater withdrawals from the Pearl Harbor aquifer. The USGS team is the lead science organization in the state focused on water issues and their input and advice has been extremely valuable to our project.
- Texas Advanced Computing Center (TACC): The CI team of 'Ike Wai collaborates with members of TACC on the development of the AGAVE software platform that will be used to support data storage, management and sharing. Our teams met monthly via teleconference to collaboration on the design, architecture and implementation of the 'Ike Wai platform. The TACC team (Stubbs, Fonner and Dooley) visited for a week in April to co-lead a workshop for the UH community and for a week long face-to-face working session on the platform. Dan Stanzione, Director of TACC serves on our external advisory board.

#### **E.Sustainability**

Continued funding beyond the five-year duration of this award is essential for our continued engagement with the community. . Several proposals have been submitted during Year 2 that leverage, extend and sustain 'Ike Wai. These include:

**Grobbe:** A geophysical proposal, with multi-disciplinary co-I's, submitted through WRRRC to USGS, for comparative studies on American Samoa and Saipan (\$250,000)

**Frank:** Investigator on C-MAIKI (Center for Microbiome Analysis Island Knowledge and Integration), an NIH P20 COBRE submitted in Year 2. This COBRE proposes an *Integrative Center for the Earth's Microbiome and Human Health*. (PI: M. McFall-Ngai, Co-PI: E.Ruby, JI: **K.Frank**, M.Medeiros, F.Reed, G.Bennett, J.Yew)

**Lautze:** Received a Hawai'i Department of Health award via WRRRC study groundwater in S and SE Oahu using chemistry, geodesy, and gravity (\$80,000).

**Elshall:** Submitted pre-proposal to the USGS under National Competitive Grants Program for fiscal year 2018

Institutionalization of all 'Ike Wai faculty hires is a commitment of the University of Hawai'i to the project and its goals. WRRRC's funding of 50% of 3 new faculty hires in the first year and a fourth hire whose WRRRC support will begin in the first year following the current cooperative agreement, provided a foundation for commitments to hire and the future permanent support (post 'Ike Wai) of this cluster of four new faculty hires at the University of Hawai'i at Mānoa. This initiative also resulted in increasing the interdisciplinary research focus of the Mānoa campus by developing these 4 as joint hires between diverse Colleges/Schools (WRRRC, School of Ocean and Earth Science and Technology, College of Engineering and the College of Social Science). Based on this initiative additional interdisciplinary cluster hires are underway. At UH Hilo, four new faculty will be recruited and retained beyond the award period to form the core of the Data Science Program. Two hires are complete, the third is underway and the fourth faculty search will commence in Year 4.

#### **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 two. Women are represented in 'Ike Wai, and recognitions of female 'Ike Wai scientists in year 2 include a national award for Clean Energy Education and Empowerment (Lautze) and teaching excellence (Frank). Native Hawai'ians are participating in 'Ike Wai at all of these levels, with particular highlights in year 2 being recognition of 'Ike Wai faculty Frank (a Mellon Fellow), with an UH Leadership in Sustainability award and Frank's selection as an NIH COBRE junior investigator. In addition, the participation of NHPI in Summer Bridge and 'Ike Wai Scholars programs in year 2 and the inclusion of best practices (such as summer bridge programs and paid internships) for increasing participation of URM have been implemented in the Education program during year 2. Research and curriculum activities that privilege Hawai'ian and Pacific epistemologies are also central to 'Ike Wai with the goal of increasing relevance of and engagement in water research for NHPI. In year 2 these have been exemplified by the synthesis between historical/traditional knowledge (Nogelmeier, Aga) and the community engagement/legacy data set activities of the geochemistry and microbial ecology teams (Frank, Lautze).

#### **VI. Expenditures and Unobligated Funds**

The 'Ike Wai has been awarded \$7.633M in the first two years of the project's cooperative agreement. As of December 31, 2017, total funds expended are \$4,125,210 or 54.04% of available funding. There are current outstanding purchase orders of \$369,849 and encumbrances of \$1,480,851 (salary, fringe, contracts, indirect costs). Together, these committed expenses of \$5,975,909 represent 78.3% of all available funds.

Our rate of spending will increase significantly during the period January-May 2018 now that all of our faculty hiring has been completed and these researchers begin to draw salary, order equipment, and stage field expeditions. Orders are now being placed for geophysical equipment (\$368k / 4.8% of available funds) and new faculty are accessing Travel and Material & Supply funds to stage field expeditions. Additional travel will be used to participate in our Reverse Site Visit (10 travelers) in April and PD/PA meeting in May (3 travelers).

Our budget projections/encumbrances indicate that we will have spent over 85% of total available funds by May 31, 2018

## VI. Special Conditions

Two Programmatic Terms & Conditions were specified, both have been achieved in Year 1 and Year 2.

1. *Place a USGS expert on our EAB.* Response: Dr. Cliff Voss has served on our External Advisory Board for our Year 1 and Year 2 meetings. His input has been transformative for the project. In addition to attending our EAB meeting he has spent an additional week in one on one meetings with our young investigators.
2. *Move the hydrological modeling hire from the proposed Year 2 to Year 1.* Response: Harry Lee was hired into this position in Year 2.

## VII. Response to External Evaluation Recommendations

### **Recommendation 1: Create a systematic process that supports communication among project teams.**

*Recommendation:* Add dependencies with hard deadlines that cross project focus areas to project timelines and schedule means for sharing communication internally, such as a project newsletter and regular update letters from the director and administrator.

*Response:* This process has been initiated for both the strategic plan and project management timeline and is ongoing. Identification of dependencies occur throughout current strategic plan. All-hands meetings occur monthly bi-weekly started in March 2017. Project newsletter will start in Fall 2018; (iii) social media and website efforts to bolster internal communications are ongoing, in particular an ‘EPSCoR calendar’ was added last year to the website so that all are aware of upcoming deadlines and opportunities; (iv) meeting minutes/notes will be summarized in a bi-weekly digest to all-hands starting in Fall 2017. On the alternate weeks, and ad hoc as needed, the PI/PD is sending out regular team updates by email to all-hands.

**Recommendation 2: Develop a detailed tactical plan for communicating and engaging with stakeholders, agencies and other communities.** A comprehensive plan should: a) Reflect the variety of audiences and communicating/engagement goals; b) Have clear messaging with a timeline detailing outreach activities and identifying specific groups/individuals; c) include training for all ‘Ike Wai participants on relevant local history as well as the cultural and environmental perspectives and concerns of Native Hawai’ians.

*Response:* An intentional Community Engagement Plan (CEP) has been implemented throughout Year 2. The goals of the CEP are clearly stated in our strategic plan (Objective 2.4). The plan has been incorporated into the project timeline and is regularly reviewed at Leadership Team meetings. CE activities include over two dozen community engagement meetings with high priority organizations partners across 22 agencies/organizations on multiple islands. ‘Ike Wai participants included variously the CE lead (Chun), the PI Jacobs, science team members (e.g., Lautze, Burnett, Mouginis-Mark), and USGS partners, reflecting

the CE operating principle that the whole 'Ike Wai endeavor needs to be involved in stakeholder conversations. Training and exposure for 'Ike Wai participants in community engagement goals and processes is ongoing. Examples of these activities include:

- Liaison activities between education and CE teams, incorporating stakeholder perspectives and engagement techniques into undergraduate, graduate and post-doc training activities in Year 2;
- All-hands meetings are a vehicle for candid discussions of stakeholder perspectives, allowing team members at all career stages to be exposed to the processes and complexities of CE in Hawai'i, particularly with reference to water politics and Hawai'ian community viewpoints.

**Recommendation 3: Focus Professional and Workforce Development:** We take full advantage of our CyberCANOE and web-based video conferencing to include team members at different locations. Many of our students are not yet ready to enter the workforce and we plan to initiate internship opportunities with grad students. Our current recruitment strategies for grads and under grads will be reviewed and revised.

**Recommendation 4: Revisit Strategic Planning and Core Project Values:** We recognize and welcome the recommendation that we revisit our core values. Our team has expanded with new faculty and adjusting to the University, their new departments and the project has been a challenge for some. In each team meeting time is allotted for the Hawai'ian Studies team to discuss those places under review from the standpoint of historical and cultural significance. The project has incorporated aspects of both Western and Hawai'ian thought into the proposed conflict management plan currently discussed by the Leadership Team in the context of the Team Science agreement. *Hooponopono* ('to put to rights') is a Hawai'ian conflict resolution system founded on a process of reflection, acknowledgement, cooperation and release from obligation.

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

	Y1	Y2	Y3	Y4	Y5
<b>GOAL 1: Collect new hydrological and geophysical data on the two</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	●	●			
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				
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				
Activity 1.3.1	●	●			
Activity 1.3.2	●	●			

	Y1	Y2	Y3	Y4	Y5
<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	●	●			
Activity 3.4.2	●	●			
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		●			

	Y1	Y2	Y3	Y4	Y5
<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	●	●			

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

## Appendix A: Abbreviations and Hawai'ian Language Terms

AGU	American Geophysical Union
CI	Cyberinfrastructure
CKAN	Comprehensive Knowledge Archive Network
COACH	Council of Academic Chemists
COE	College of Engineering
CSS	College of Social Sciences
CWRM	Commission on Water Resource Management
CWSEI	Carl Wieman Science Education Initiative
DLNR	Department of Land and Natural Resources
DROP	Down-well Remote Operating Platform
EPA	Environmental Protection Agency
FWAC	Fresh Water Advisory Council
G&G	Geology and Geophysics
HBWS	Honolulu Board of Water Supply
HCF	Hawai'i Community Foundation
HDOA	Hawai'i Department of Agriculture
HDOH	Hawai'i Department of Health
HDWS	Hawai'i County Department of Water Supply
HFWI	Hawai'i Fresh Water Initiative
HIGP	Hawai'i Institute of Geophysics & Planetology
HLPC	Hawai'i Leeward Planning Commission
HPC	High Performance Computing
HSSTC	Hawai'i Science & Technology Committee
HVO	Hawai'i Volcano Observatory
ICS	Information and Computer Sciences
IDC	Interagency Data Committee
IDP	Individual Development Plan
IHLRT	Institute of Hawai'ian Language Research and Translation
'IKE	Integrated Knowledge Environment
ITS	Information Technology Services
KCC	Kapiolani Community College
KS	Kamehameha Schools
KR	Kohnana'iki Resort
LT	Leadership Team
NELHA	Natural Energy Laboratory of Hawai'i Authority
NPV	Net Present Value
PaR	Palani Ranch
PBRC	Pacific Biomedical Research Center
PIWSC	USGS Pacific Islands Water Sciences Center
PR	Parker Ranch

QLT	Queen Lili'uokalani Trust
RHBFSF	Red Hill Bunker Fuel Storage Facility
S&T	Science and Technology
SG	UH Sea Grant
SGD	Submarine Groundwater Discharge
SOEST	UH Mānoa School of Ocean and Earth Science and Technology
SST	Science & Technology Thrusts
ST	Sustainable Yield
TACC	Texas Advanced Computing Center
USGS	US Geological Survey
UH	University of Hawai'i
UHERO	UH Economic Research Organization
UHH	University of Hawai'i Hilo
UHM	University of Hawai'i at Mānoa
UHS	University of Hawai'i System
UI	Ulupono Initiative
WFD	Workforce Development
WMP	Water Master Plan
WR	Waiki'i Ranch
WRAC	Water Resources Advisory Council
WRRC	UH-Water Resources Research Center

#### **Hawai'ian 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