A Program Administered by the University of Hawai‘i System

Securing Hawai‘i‘s Water Future

‘IKE WAI

YEAR 3 ANNUAL REPORT

REPORTING PERIOD
FEBRUARY 1, 2018 TO DECEMBER 31, 2018

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RII Track-1: ʻIke Wai: Securing Hawaiʻi's Water Future
NSF Award Number: OIA-1557349
Award Start Date June 1, 2016
Principal Investigator: Gwen Jacobs
University of Hawaiʻi
Reporting Period: February 1, 2018 to December 31, 2018

II. Overview

A. Vision, mission, and goals of the project

Vision: Water resource management in Hawaiʻi'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 Hawaiʻi.

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

Goals: ʻIke Wai has the potential to be a transformational project for the University of Hawaiʻi, 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 Hawaiʻi. The specific goals of the ʻIke Wai project are:

> ***Goal 1:*** Collect new hydrological and geophysical data on the two study sites to address data gaps in our understanding of subsurface structure and flow.
>
> ***Goal 2:*** Develop a new data and modeling platform for Hawai'i volcanic hydrogeology, economic modeling and decision support.
>
> ***Goal 3:*** Establish an integrated set of pathways to train and develop a diverse cohort of students, post-doctoral, and faculty researchers at UHH and UHM to address Hawaiʻi's water challenges.

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

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

- Gwen Jacobs: PI
- Barbara Bruno: co-PI (Workforce & Education)
- Robert Pelayo: co-PI (UH Hilo Data Science)
- Helen Turner: co-PI Chaminade University
- Steve Anthony: United States Geological Survey (USGS) Liaison
- Greg Chun: Community Engagement
- Aly El-Kadi: Groundwater Modeling
- Tom Giambelluca: Geography; Climate & Rainfall
- Velma Kameoka: Manoa Assoc. Vice Chancellor for Research
- Kevin Kelly: EPSCoR Managing Director
- Nicole Lautze: Geochemistry
- Darren Lerner: Interim Director WRRC
- Punihei Lipe: Interim Director Inst. for Hawaiian Language Research & Translation (IHLRT)

B. Accomplishments achieved during the reporting period

Capacity Building in Personnel:

In response to recommendations from the NSF Reverse Site Visit Team we recruited a new postdoctoral scholar, Dr. Stephanie Barde-Cabusson, an expert in hydrogeophysics specializing in using seismic self-potential measurements. She joined the team in December 2018. Dr. Mouginis-Mark and Platz stepped down from their roles as Co-PI‘s on the project. Dr. Pelayo replaced Platz as Co-PI and Dr. Mouginis-Mark will be replaced in Year 4. Puniwai Lipe joined the Leadership Team in her role as Interim Director for the Institute for Hawaiian Language Research and Training (IHLRT). Francois Paquay left the project and his effort was replaced by a new graduate student reporting to Nicole Lautze. Steve Constable, Scripps Institute of Oceanography, UCSD joined the External Advisory Board to evaluate the marine geophysics work.

Capacity Building in Instrumentation and Sensing:

We completed the aquisition of a suite of hydrogeophysical equipment for Audio-Magnetotellurics (AMT) and Magnetotellurics (MT), both active and passive seismics, 2D and 3D Electrical Resistivity Tomography and Induced Polarization, and Self-Potential. These new instruments are now in use by project team members and will be maintained as an institutional resource at project end.

We completed a collaborative study with a novel set of marine geophysics sensors developed in Steve Constable‘s laboratory at Scripps Institute of Oceanograpy. The Porpoise system is a modification of the deep-towed fixed-offset Vulcan CSEM system that was previously developed by Steve Constable. Attias used this system in his CSEM survey of the nearshore marine geophysics environment at the Hualālai study site. This array is comprised of four Porpoise receivers that are towed at offsets of 250, 500, 750 and 1000 m. The Porpoise receivers are enclosed in buoyant PVC cases, which enables the receivers to be towed on the surface. A Porpoise receiver includes a 2 m inline electric field (E-field) dipole, main data logger package, an accelerometer, and a GPS timing pulse. GPS receivers mounted on top of each Porpoise unit, connected to a serial data logger that records time and location. An additional serial data logger records the Porpoise heading, pitch, and roll every second, using a compass/tiltmeter.

Key Research and Education Accomplishments in the reporting period:

1) Geophysics (Attias, Barde-Cabusson, Grobbe, Viti)

- **MT survey:** Palani Ranch: A 10 km, 2D magnetotelluric line acquisition survey was completed at Palani Ranch (Hawai‘i island) to study the high/low divide and its impact on the groundwater distribution, and high-level groundwater characteristics (Activity 1.1.2). A 1D MT forward modeling code with a 1D MT Bayesian inverse framework, was developed using the ‘R’ programming language and STAN. The Bayesian framework allows for uncertainty quantification (UQ) of the MT inversion results, as well as UQ of future hydrologic parameter inferences (Activities 1.1.1 and 1.1.3). Interpretations of the field data inversion results were compared to synthetic models. Alignment of both results indicate the location of a high/low divide structure (Activity 1.1.3).
- **CSEM Survey:** Marine Geophysics: Attias designed and executed (September 2018) a marine geophysics survey offshore the entire region parallel to the Hualālai aquifer (Activity 1.1.5), using several geophysical methods to acquire five types of marine datasets: (1) Controlled-Source Electromagnetic (CSEM), (2) High-resolution multi-beam (MBES) seafloor, (3) High-resolution MBES water-column, (4) Backscatter, (5) Magnetic. The survey encompassed 3 survey areas, 8 towlines parallel to the coastline, 3 perpendicular towlines, at an offshore range spanning from ~150 m to 4.5 km, with a total survey length of ~200 km in 8 days of survey. We achieved 95% of data recovery. The processing of the CSEM, MBES seafloor and Backscatter data have been completed.

2) Biogeochemical Tracers (Frank, Lautze, Watson, Tachera)

- **Geochemistry:** Seven precipitation collectors were deployed in Pearl Harbor and 18 on Hawai‘i Island. We worked with 20 different landowners and have obtained permits from Department of Fish and Wildlife (DOFAW) on both O‘ahu and Hawai‘i Island, Mauna Loa Observatory, and Office of Mauna Kea Management (OMKM).
- **Microbial communities:** Statistical analysis of the first microbial data set has yielded new information about flow paths and inter-aquifer flow in Hualālai. The distribution of microbial communities within the Hualālai aquifer showed areas of segregation across some aquifer boundaries, but no significant differences in populations between the high-level aquifer and basal aquifers in the Keauhou region. Populations were responsive to salinity levels and showed seasonal changes in community structures.

3) Modeling (El-Kadi, Lee and Okuhata)

- Four conceptual and numerical models of the Hualālai study site were developed, each designed to address specific management needs. 1) A three-dimensional West Hawai‘i Regional (WHR) model for six aquifer systems on western Hawai‘i Island, designed to incorporate incoming geochemical and microbial field data and to assess the overall water budget and aquifer interconnectivity. 2) A three-dimensional, density-dependent Keauhou basal aquifer (KBA) model for the basal groundwater of the Keauhou aquifer system, designed to answer water management questions and test the basal effects of various pumping scenarios for water managers. 3) Two 2D, density-dependent cross-sectional models through the Keauhou aquifer system. One model follows the magnetotelluric (MT) transect through Palani Ranch while a second model crosses through Kahalu‘u monitoring well. Both models aim to constrain model parameters and investigate local features
- Modeling results indicate 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 Hawai‘i County Department of Water Supply (HDWS) and has the potential to inform decision makers considering the location of surficial aquifer boundaries and the location of future wells on Hawai‘i Island

4) Economics (Bremer, Burnett, Wada, Elshall)

- A groundwater (GW) management optimization decision support model and framework was further developed and tested in the community. Team members collaborated with Sumida Farms to evaluate constraints to sustain and restore spring flow to their watercress farm, as well as develop a tradeoff curve between pumping and impacts on spring flow. They developed stakeholder-driven future land use scenarios representing futures of urban, agricultural, and conservation lands and are working with USGS to run these through their water balance model under the current and Representative Concentration Pathway (RCP) 8.5 mid-century climate scenarios.
- The team developed cost-effectiveness models for watershed conservation in collaboration with the Hawai‘i Island Department of Water Supply for the Hualālai aquifer. We began our assessment of groundwater dependent ecosystems in Hualālai to define and establish relevant constraints and outcomes to be evaluated using the KBA model in collaboration with the groundwater modeling team.

5) Cyberinfrastructure (Jacobs, Cleveland, Geis, McLean)

- We engaged the Science Gateways Community Institute to perform external reviews for cybersecurity and user experience to ensure best practices and improve usability.
- We improved the bioinformatic computational workflows to include Qiime2 workflows to analyze the first sampling dataset by Dr. Watson from Dr. Frank’s team.
- Rotzal (USGS), Cleveland and McLean refined a working decision support application for calculating island recharge based on user-defined land use types and two climate scenarios. The application was reviewed, refined and improved with input from USGS, Commission on Water Resources Management (CWRM) and water managers.
- Giambelluca‘s and the CI team automated a workflow to produce near real time gridded climate

products with rainfall estimates.

6) **Education and Curriculum (Bruno, Burns, Engel, Pelayo, Mandel, Weyenberg)**

- All graduate students and postdocs were paired with a professional development mentor, in addition to their research advisor, through the ʻIke Wai mentoring cascade. Following training, all created and/or revised an Individualized Development Plans (IDP) to guide their professional development (Activity 3.3). Data from the IDPs were collected, analyzed and presented at the American Geophysical Union (AGU) conference (Dec 2018) (Activity 3.7).
- Data have been analyzed for two education research articles on classroom COPUS observations and place-based teaching, and manuscripts are expected to be submitted to peer-reviewed journals by the end of Year 3. (Activity 3.7).
- Data Science capacity building at UH Hilo (Activity 3.5.) A UHH certificate in Data Science was completed in Fall 2018. Four new Data Science courses (8 total) have been created and approved for inclusion into the UHH course offerings.

C. Intellectual merit and broader impacts.

Intellectual Merit:

Modeling the 3-D structure and function of Hawaiian aquifers, such as Hualālai and Pearl Harbor is a very challenging problem given the complexity of the subsurface and relative paucity of data. Our four current groundwater models are a step forward and will be improved with the addition of needed data – specifically geophysical imaging, geochemical signatures and microbial community profiles. Collectively, this multidisciplinary approach involves an innovative synthesis of techniques which has great potential to revolutionize our understanding of these aquifers. Coupling the model simulations directly to stakeholder needs elevates this project to fulfill the goal of providing scientific knowledge to current managment issues as a collaborative process.

Achieving synergy and integration across multiple research efforts to address a common research question is a major project goal. This year we have significant results that demonstrate how the team is integrating their work. For example, recent results (**Dulai**) on coastal SGD and flowpaths using oxygen isotope measures in Hualālai suggest that there may be 5 distinct groundwater flow paths. Additional evidence suggests a deep SGD source in one part of the aquifer. A marine CSEM geophysics study (**Attias**) conducted off the coast of the aquifer revealed a corresponding area in the near shore indicative of SGD. The first results of the microbiome community analysis (**Frank, Watson**) show alignment with the 5 flow paths, but exhibit a complex inter-aquifer flow profile – with evidence for flow between some sectors - Kiholo-Keauhou, but not across other boundaries. Results also suggest that the high-low divide subsurface structure does not affect the distribution of microbes. No significant difference was found between microbial communities in the high aquifer and the basal aquifer. A recent Magnetotelluric survey (**Grobbe**) has provided some initial structural information about this geological feature. Each of these results contributes and helps to validate a better scientific understanding of this aquifer. This multi-faceted research approach is common to all projects in ʻIke Wai and challenges our young investigators to develop their collaborative skills.

These studies are providing new information based on geophysical data, knowledge of groundwater flow paths, SGD and water chemistry. The results provide data and models to address stakeholder questions, such as the rate 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:
Research projects in ʻIke Wai are designed to focus on specific stakeholder and community needs, so the benefit to the State is a direct outcome of the research project. These projects also serve as a model for sustaining the partnerships made between UH and the community into the future. For example, research by the Social Science team on pumping optimization studies in the Pearl Harbor aquifer focus on estimating maximum withdrawl without violating the sustainable yield constraints. The Pearl Harbor Groundwater modeling framework, provides information that can impact groundwater management decisions. Results have been presented and discussed with USGS, CWRM, and at multiple community meetings. The team evaluated the water quality and quantity needs of Sumida Farms, the largest watercress farm on the island to be incorporated into the modeling framework. Modeling results will help inform the farm owners on water availability in the future. In Hualālai, results indicate 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 by Hawaiʻi County Department of Water Supply (HDWS) and can inform decision makers on the location of future wells on Hawaiʻi Island. These results could inform CWRM on more accurate aquifer boundaries that better reflect the subsurface. ʻIke Wai's work linking watershed conservation to groundwater recharge and to the value of groundwater dependent ecosystems and water management in shaping these systems is providing substantial benefit to the community.

Advance discovery and understanding while promoting teaching, training, and learning.
Research activities in geophysics, geochemistry, traditional/historical knowledge and sensor development are involving significant numbers of graduate students and postdoctoral 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 ʻIke Wai. All ʻIke Wai faculty have active teaching loads and several (**Grobbe, Lee**) incorporated ʻIke related materials and concepts in classes.

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

Broaden dissemination to enhance scientific and technological understanding. The ʻIke Wai Science Gateway serves as the central location for data management, computation, analysis, visualization, and dissemination of all data and data products generated by the ʻIke Wai project. It serves as the central integration point of the project as well as the dissemination and access point for all data, models, and data products. An exemplar data product is high resolution (250-m) monthly gridded rainfall and estimated uncertainty maps from up-to-date, quality controlled, tabular rainfall data. The CI team and Giambelluca's team have developed an application to automate the production of these maps. The software system queries data from all known online sources, performs data screening, gap-filling, interpolation, and error analysis. The decision support tool developed by the CI team and USGS provides an interactive interface to study the effects of land use change on recharge. This tool will help water managers demonstrate and explain complex development and conservation scenarios.

The EPSCoR Website (**http://www.hawaii.edu/epscor/**) **and Facebook page** serve as the central location for information about the project, current results, student opportunities, and social media. In December of 2018, Maria Dumanlang was hired as a communications specialist to oversee project communications to include written and video news releases, social media engagement, and development of print and digital media.

D. Challenges, novel opportunites, and changes in strategy

Specific challenges: Gaining field access to geophysical study sites and wells has improved but gaps remain primarily with the Board of Water Supply on O'ahu and the high/low water divide on West Hawai'i. Agreements granting access to Kamehameha Schools property are very close to complete which will provide a large and important area for study.

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

Changes in strategy:

Three new efforts were initiated this year. The EAB recommended the development of a smaller Keauhou Basin Aquifer model for optimization studies by the social science team. Good progress was made on the model and the evaluation of modeling constraints to test. A novel marine geophysics survey was completed this year by Attias in collaboration with Steve Constable at Scripps Insitute. The project tested a new sensor array and collected significant data on the nearshore environment. Initial results indicate a large region along the coast with significant SGD, which aligns with results by Dulai. Age dating studies were initiated to help inform flow path and recharge predictions. These results will be used to validate modeling studies.

Faculty hiring update:

At UH Hilo, along with the two Data Science hires brought on in August 2017, one new faculty member (John Burns) was hired as an assistant professor in the Marine Science department starting in August 2018. Dr. Burns brings a computer vision and applied informatics expertise to the Data Science team. These three faculty continue to develop the UHH Data Science curriculum, as well as provide academic and summer research experiences for undergraduates.

New Faculty & Professional Staff Hires

Discipline	Status	Y1	Y2	Y3	Y4	Y5	Total
Hilo		0	2	1	1	0	4
Computer Science	Search Completed		8/17				
Mathematics	Search Completed		8/17				
Marine Science	Search Completed			8/18			
Economics/Business	Interviews Underway				8/19		
Manoa		2	1	0	0	0	3
Economics	Search Completed		7/17				
Geophysics	Search Completed		11/17				
Hydro Engineer	Search Completed		10/17				
System		2	1	0	0	0	3
Software Engineer	Search Completed	8/16					
Total Hires:		**4**	**4**	**1**	**1**	**0**	**10**

Table 1: Boxes indicate the timing for new hires with the total number of hires provided in the blue shaded lines. Dates are start dates for hires.

III. Research and Education Program

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

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

Objective 1.1: Image subsurface geologic structures and/or the location of groundwater in 3 to 4 target areas of Hualālai and Pearl Harbor aquifers systems using geophysical techniques. (Grobbe, Barde-Cabusson, Attias)

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

Results: Three benchmark models for the high/low divide have been developed. 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 in the study site. A 1D MT forward modeling code, as well as a 1D MT Bayesian inverse framework, was developed using the 'R' programming language and STAN (Activity 1.1.1 and 1.1.3). The Bayesian framework allows for uncertainty quantification (UQ) of the MT inversion results, as well as UQ of future hydrologic parameter inferences shown in Figure 1.

Forward synthetic MT modeling was performed to assist in the interpretation of our 2D MT field data inversion results. We have initiated campaign planning for our new ERT/IP nodal system and carried out synthetic test simulations. We initiated seismoelectric feasibility studies with coupled seismo-electromagnetic modeling software.

Outcomes: We developed 1D Bayesian (A) MT inversion software with capabilities for probabilistic inversions of our acquired MT field data (per station). Our code enables uncertainty quantification of the obtained MT inversion results, using different statistical approaches. It provides an estimate of the depth of investigation where there is a low spread in the probability histogram. The synthetic forward simulations (MT, ERT, ...) provide guidance for optimal field acquisition design and method selection and increases our understanding of different hydrogeological scenarios and the sensitivity of the methods to different subsurface features.

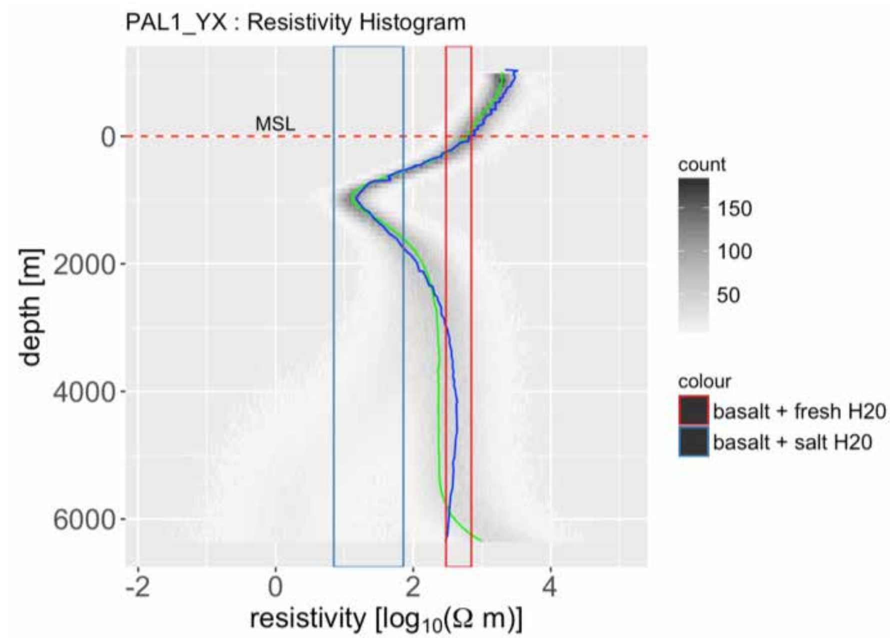


Figure 1: Example of a 1D Bayseian field data inversion result, The green line shows the median value of the probability distribution, the blue line displays the 1D result as extracted from the 2D smoothed Occam inversion, and the black-grey-white shades are histogram values representing the probability distribution, where darker grey/black colors represent a higher probability for that specific resistivity value to be the true value. The red box corresponds to literature values for fresh-water saturated basalts, and the blue box displays the literature range for salt-water saturated basalts

Risks and Mitigation Plan: We do not anticipate needing 3D MT forward modeling/inversion codes in the near future and have identified several 3D MT software packages. For self-potential inversions, we have a 2D SP inversion code available. We do not have a 3D SP forward modeling/inversion code in-house. However, we have identified potential collaborative partners that have a 3D SP inversion code available.

Mitigation Plan: None, on track for Year 3.

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

Our geophysical study sites focus on three science questions:

1. What is the nature of the high/low divide (Hawai‘i Island and O‘ahu)?
2. What spatial hydrogeological variations exist along the western boundary of the Pearl Harbor aquifer systems?
3. What are the characteristics of the valley fills on O‘ahu and their impact on local hydrology?

Field study sites are shown in Figure 2 below.

Hawai‘i Island: 1) Palani Ranch and Queen Lili’uokalani Trust (QLT) to study the high/low divide and 2) QLT, Natural Energy Laboratory of Hawai’i Authority (NELHA), and Anaeho‘omalu Bay (A-bay) to study the spatial hydrogeological variations along the western boundary of the Hawai‘i Island aquifer systems. 3) O‘ahu: Schofield Dam to study an analogous high/low divide feature and Moanalua Valley to study the impact of valley fills on the hydrologic system (Fig. 2).

Results: We have carried out a 10 km, 2D magnetotelluric line acquisition survey at Palani Ranch to study the high/low divide and its impact on the groundwater distribution (Fig. 3).

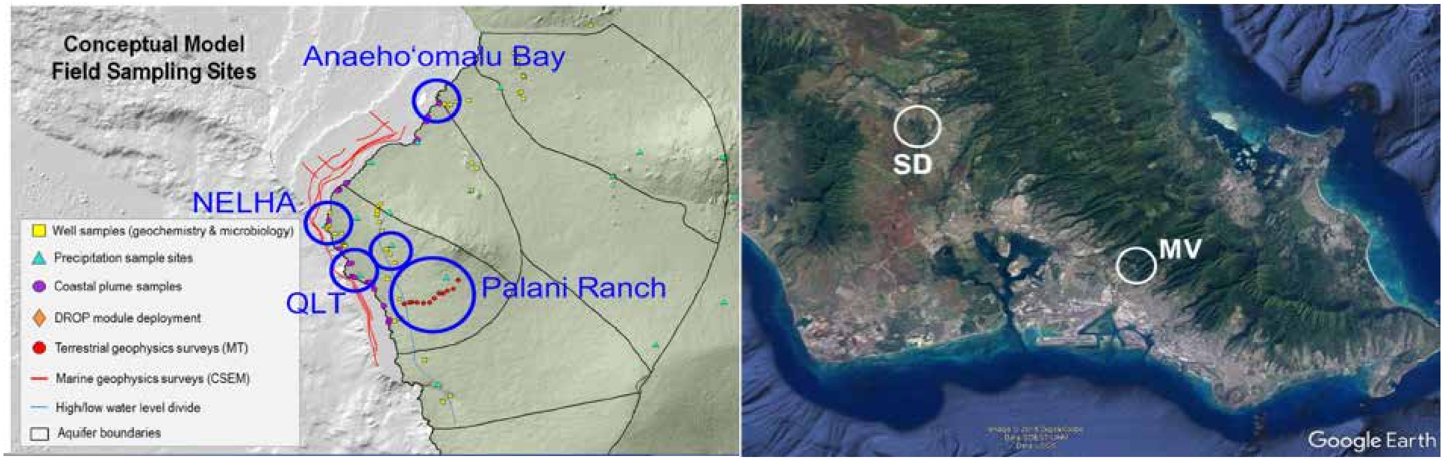


Figure 2: Geophysics field sites. Left - Two sites along the high/low water divide and 3 land-coastal sites (Western boundary of hydrologic modeling domain). Right - Location of the Schofield Dam (SD) and Moanalua Valley (MV).

Risk and Mitigation Plan: Land access. Geophysical land access remains challenging. We are still working on access to the Schofield Dam area, O'ahu (primarily military and private landowners), and A-bay, Hawai'i Island (a mixture of landowners). Various landowners have been contacted, and permitting procedures have started already for certain areas. Furthermore, the QLT high/low divide study has highly challenging field conditions, including steep topography, very dense vegetation, and fresh lava flows. We are actively exploring and initiating permitting procedures for alternative study sites that traverse the high/low divide and allow for geophysical investigations.

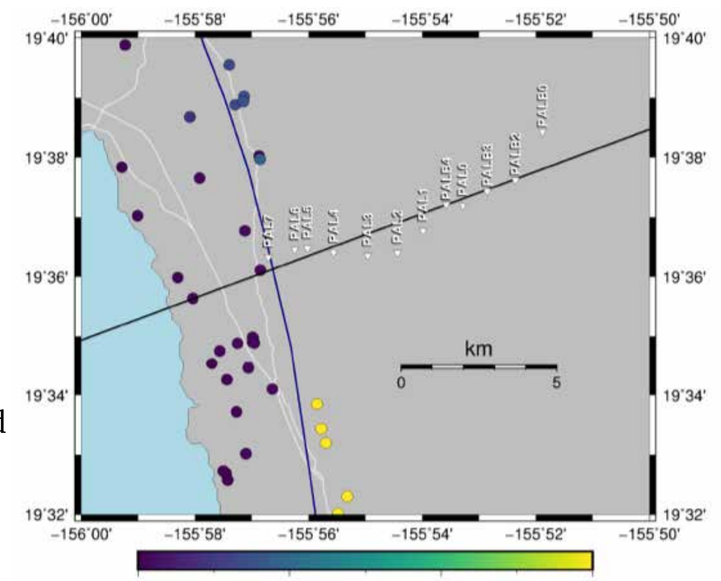


Figure 3: Magnetotelluric survey location. MT survey location (white triangles) with various well locations (colored circles) and the approximate location of the high/low divide in blue

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

Results: We have analyzed inversions of the collected Palani Ranch MT field data to obtain the electrical resistivity distribution of the subsurface: Comparisons of 1D and 2D inversion results show a close match, especially for the upper part of the subsurface (see e.g. Figure 1). Figure 4 displays the inversion result for the 2D inversion. The color scale represents electrical resistivity (logarithmic scale), where blue is electrically resistive and red is conductive. The dark blue colors correspond to literature values for dry basalt, light blue to fresh-water saturated basalt, and red to salt-water saturated basalt. According to the well data in the area (Fig. 3), the high/low divide is expected somewhere between station PALB5 and PAL 6. We can clearly observe a jump of the fresh/salt interface to shallower depths around this location, as well as an impact on the distribution of the freshwater. We have created a synthetic model containing a vertical, slightly dipping hydrogeologic barrier and its impact on the groundwater distribution that can possibly explain our field data inversion results (Figure 5 right). The synthetic model has the exact same acquisition parameters as the actual field data. We can see a similar inverted electrical resistivity distribution as observed in the field data inversion result (Fig. 5).

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

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

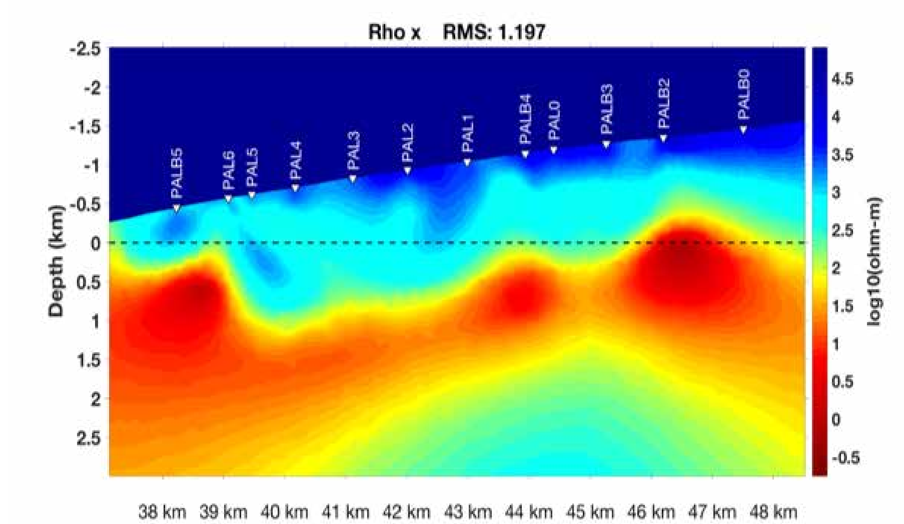


Figure 4: 2D MT smoothed Occam inversion result. The white triangles display the MT station locations The color scale represents electrical resistivity (logarithmic scale), where blue is electrically resistive and red is conductive. The dark blue colors correspond to literature values for dry basalt, light blue to fresh-water saturated basalt, and red to salt-water saturated basalt.

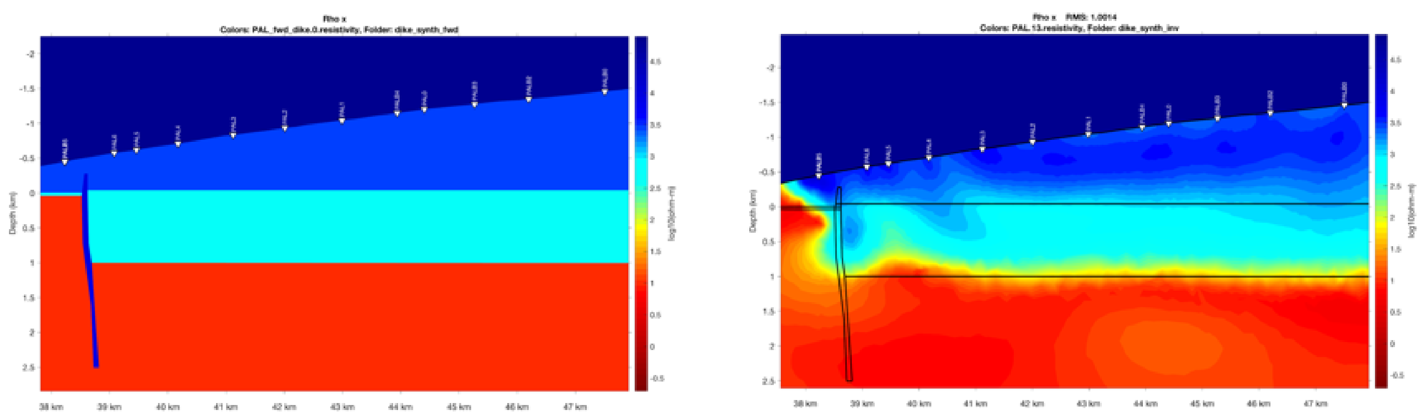


Figure 5: Synthetic model (left) and inversion result (right) for a vertical, slightly dipping hydrogeologic barrier and its impact on the groundwater distribution. The synthetic model has the exact same acquisition parameters as the actual field data. We can see a similar inverted electrical resistivity distribution as observed in the field data inversion result.

Results: This work will take place in the second half of Year 3, Year 4 and 5.

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

Activity 1.1.5. Marine Geophysics (Attias)

Results: Preliminary controlled-source electromagnetic survey (CSEM) pseudosections were constructed using a 1-D half-space forward modeling code and the electric field (E-field) data recorded by the Porpoise array. The pseudosections enables the visualization of lateral changes in the electrical resistivity across the offshore region of the Hualālai aquifer. The results show significant variability in the electrical resistivity along this area, with large scale resistivity anomalies located south of Kailua-Kona (Figure 6), indicative of submarine groundwater deposits that extend to ~500-600 m below the seafloor. Additionally, the high-resolution multi-beam seafloor and backscatter data acquired at this region exhibit an extensive heterogeneity in both seafloor bathymetry and texture. Next, 2-D isotropic/anisotropic CSEM inversions will be performed for all survey towlines (~200 km).

Risks and Mitigation Plan: None, 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. 7.

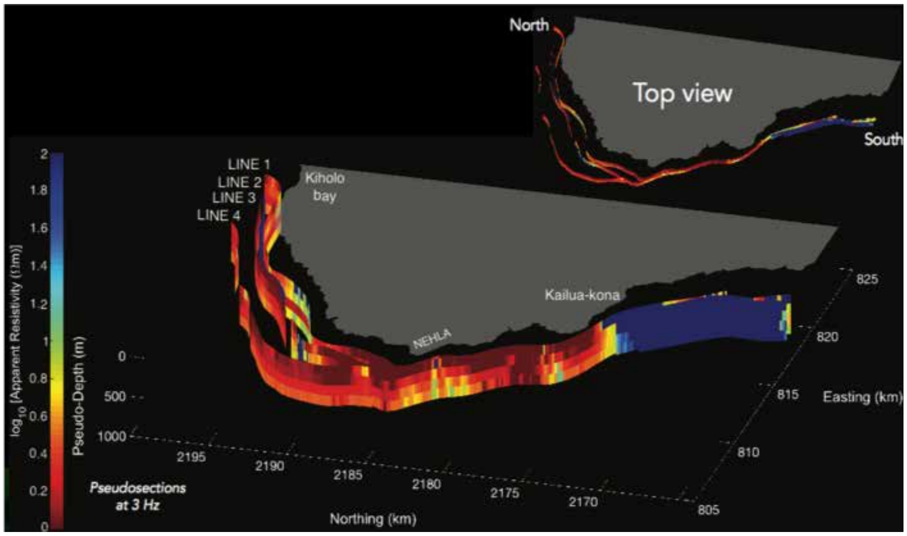


Figure 6: Marine geophysics: CSEM pseudosections of all in-line towlines, using the 3 Hz data from 4 Porpoise E-field receivers. Note the lateral variability in submarine electrical resistivity and the anomalous region south of Kailua-Kona.

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

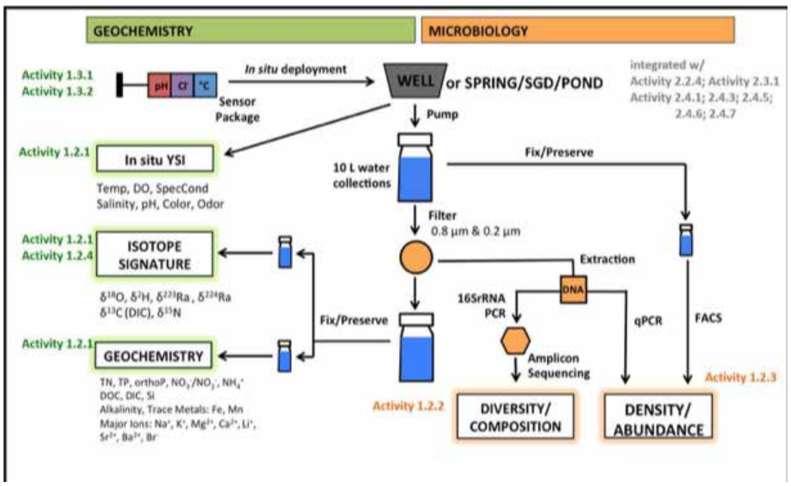


Figure 7: Schematic of sampling plan methodology for the geochemistry (in green) and microbial (in orange) investigations. Also shown are the connections between the these studies and the specific Activities within ʻIke Wai.

Results: We were granted permits from Departments of Fish and Wildlife (DOFAW) on both Oʻahu and Hawaiʻi Island. Permits are still needed for precipitation collectors on Kamehameha Schools land. Seven precipitation collectors in Pearl Harbor and 18 on Big Island have been deployed. In West Hawai'i we have data on the major ions, trace metals, silica, and O H isotopes for ~196 samples from 86 wells and 20 ponds; and 60 samples from 18 precipitation collectors. Fig. 8 shows the sample collection points. On Oʻahu 7 precipitation collectors have been deployed with 40 data points and 5 wells have been sampled. Graduate student Diamond Tachera is completing her second year focused on West Hawaiʻi groundwater chemistry; a new graduate student who will focus on Oʻahu is starting summer 2019.

Age dating: (Okuhata) Nine groundwater samples were collected in the Keauhou and Kīholo aquifer systems, in both basal and high-level groundwater systems (Fig. 8a) for age dating analysis. The water samples are being analyzed for tritium (3H) and helium (3He) concentrations.

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

Results: We sampled 129 unique sites with 31 organizations within the Hualālai aquifer. DNA from over 100 samples was extracted, archived and is being sequenced. Preliminary analysis from the first plate of microbial sequence data (741 samples encompassing data from May 2017-March 2018)

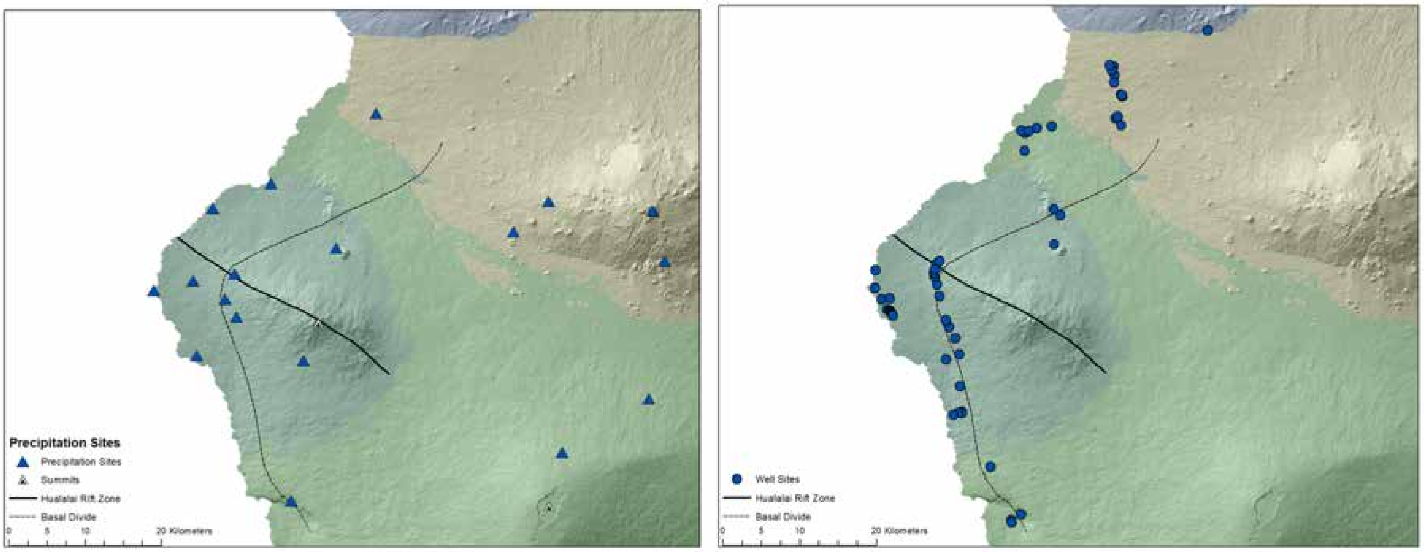


Figure 8: Geochemistry, wells, and access. a) Distribution of rainwater collectors. b) Distribution of Map of groundwater wells.

were analyzed based on taxonomic data and statistical analysis of Bray-Curtis and Weighted Unifrac distance clustering.

Bray-Curtis and UniFrac are standard ecological distance metrics that are used to compare microbial communities. Bray-Curtis is used to quantify the compositional dissimilarity between two different sites, based on counts at each site and doesn't make assumptions about genetic relationships within a community. UniFrac differs from dissimilarity measures like Bray-Curtis by including information on the relative relatedness of community members by incorporating phylogenetic distances between observed organisms and accounts for abundance of observed organisms.

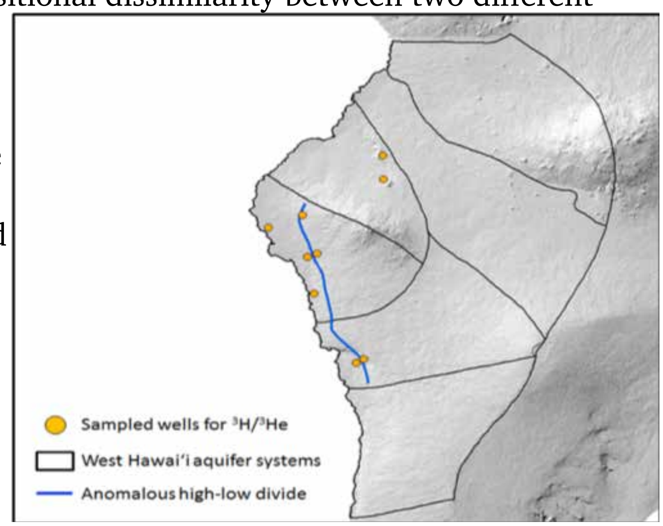


Figure 9: Sites of groundwater sampled for tritium (^3H) and helium (^3He) concentrations. Samples were primarily collected from the Keauhou and Kīholo aquifer systems and were split between basal and high-level groundwater systems

We used ANOSIM and permutational MANOVA tests on Bray-Curtis and Weighted Unifrac NMDS calculations to determine whether geophysical aquifer classifications show differences in phylogenetic or species diversity. Permutational multivariate analysis of variance is a non-parametric multivariate statistical test used to compare groups of objects and test the null hypothesis that the centroids and dispersion of the groups as defined by measured space are equivalent for all groups. A rejection of the null hypothesis means that either the centroid and/or the spread of the objects is different between the groups. ANOSIM is primarily employed to compare the variation in species abundance and composition among sampling units by comparing the mean of ranked dissimilarities between groups to the mean of ranked dissimilarities within groups. An R value close to "1.0" suggests dissimilarity between groups while an R value close to "0" suggests an even distribution of high and low ranks within and between groups.

Thirty-five days were spent in the field in Kona, over the course of 3 field campaigns (March 2018, August 2018, November 2018) to capture temporal variation in microbial community composition. Preliminary analysis, reveals that microbial community structure differs significantly over seasons in both Bray-Curtis and Weighted Unifrac analysis, suggesting the evolution of phylogenetically distinct communities over time (Fig.10) allowing us to carefully calibrate our conclusions about connectivity of water flow with respect to time. The structure of these groundwater community samples seem to be primarily driven by geochemical features, the strongest of which is salinity (Fig.11).

Permutational multivariate analysis of variance (PERMANOVA) analysis reveals significant differences in microbial communities structure from the high aquifer and the basal aquifer with p-values less than 0.001 for both distance metrics evaluated (Figure 11). However, because of the uneven sample sizes between the high and basal aquifer groups (due to the limited number of wells in the high aquifer), the results of the PERMANOVA conclude that there are differences in the mean and spread of variance between the two sample groups. Analysis of similarities (ANOSIM) tests reveal significant differences in communities clustered by Bray-Curtis (p=0.002), however, the R value is low (R=0.10) suggesting that the divide has a very small effect on the difference between the presence and absence of communities. Moreover, ANOSIM results based on Weighted Unifrac clustering shows no significant difference between microbial communities in the high aquifer and the basal aquifer. These statistical tests suggest that there is likely some connectivity in the water flow across the divide, which would account for similarities in phylogenetic relatedness of communities across the divide. Differences in geochemistry

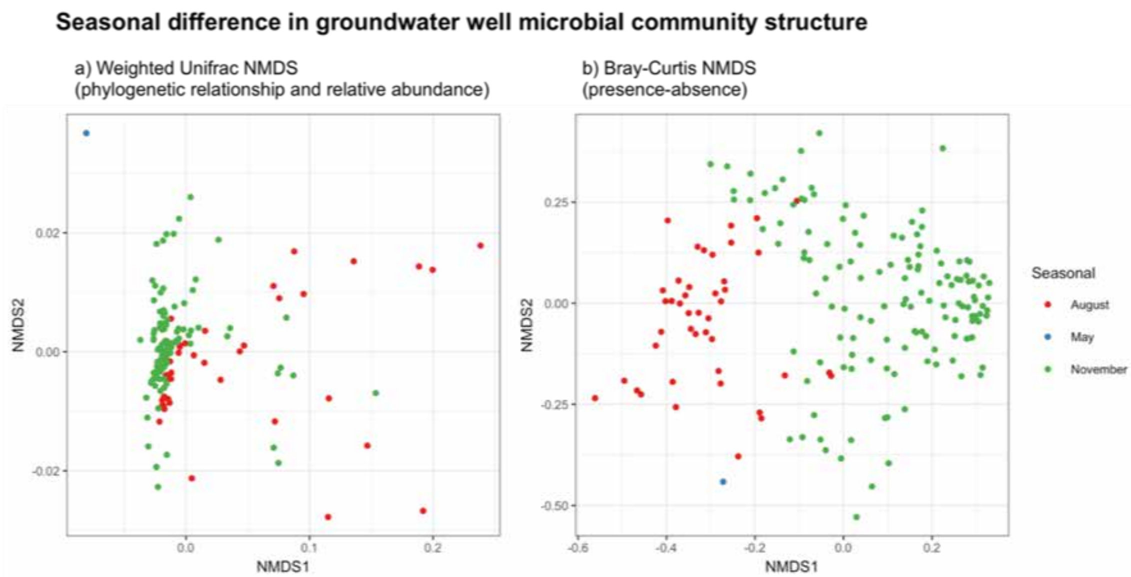


Figure 10: Non-Metric Multidimensional Analysis (NMDS) of 179 Hualālai groundwater well microbial communities. Sampling points are colored by season: Green = Winter samples (Nov 2017); Red = Summer samples (Aug 2017). a) NMDS based on Weighted Unifrac distance matrix which accounts for community abundance and phylogenetics relationships. b) NMDS based on Bray Curtis dissimilarities matrices.

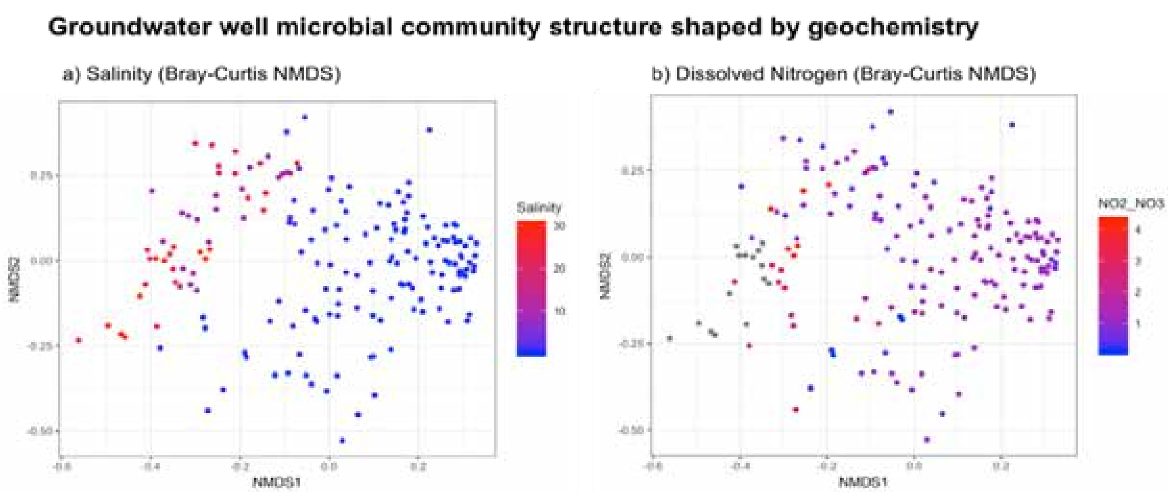


Figure 11: Non-Metric Multidimensional Analysis of 179 Hualālai groundwater well microbial communities based on Bray Curtis dissimilarity matrices colored by a) salinity or b) dissolved nitrogen concentration.

across the divide (Activity 1.2.1) are likely greater drivers for relative abundance differences in observed microbial community structure, rather than a complete separation between aquifers which would have resulted in isolated communities. ANOSIM analysis of microbial communities across aquifer boundaries based on Bray-Curtis dissimilarities matrices show significant differences in microbial community structure between Anaehoʻomalu and Kealakekua aquifers (p=0.001, R=0.85), Kealakekua and Waimea (p=0.001, R = 0.83), Kiholo and Waimea (p = 0.001, R = 0.724), Anaehoʻomalu and Kiholo (p=0.001, R = 0.541), Kealakekua and Kiholo (p = 0.001, R = 0.375) - which suggest that there is not much flow between these larger aquifer boundaries (Fig. 12). However, there was no significant difference in microbial structure between Keauhou and Kiholo (p = 0.236) based on presence absence of microbial communities. ANOSIM analysis based on Weighted Unifrac does show significant difference in communities between Keauhou and Kiholo (p = 0.005) however the R value is low (R = 0.19) and means that there is little difference in community structure, only relative abundance (which could be explained by differences in residence time or slightly different geochemistry). These analysis provide evidence that there is likely connectivity and fluid flow across the Keauhou - Kiholo boundary. Microbial community structure groups well with the 5 proposed flow paths based on recent data from Activity 1.2.4 (Dulai SGD data Figure 14). Microbial communities from each flow path are statistically significantly different than each other by ANOSIMS (with R values greater than >0.23) in almost every pair-wise comparison. In contrast, there were no significant differences observed between the blue and red flow paths - which suggests some flow between those two paths; as well has no significant difference between the green and orange, as well as purple and red paths.

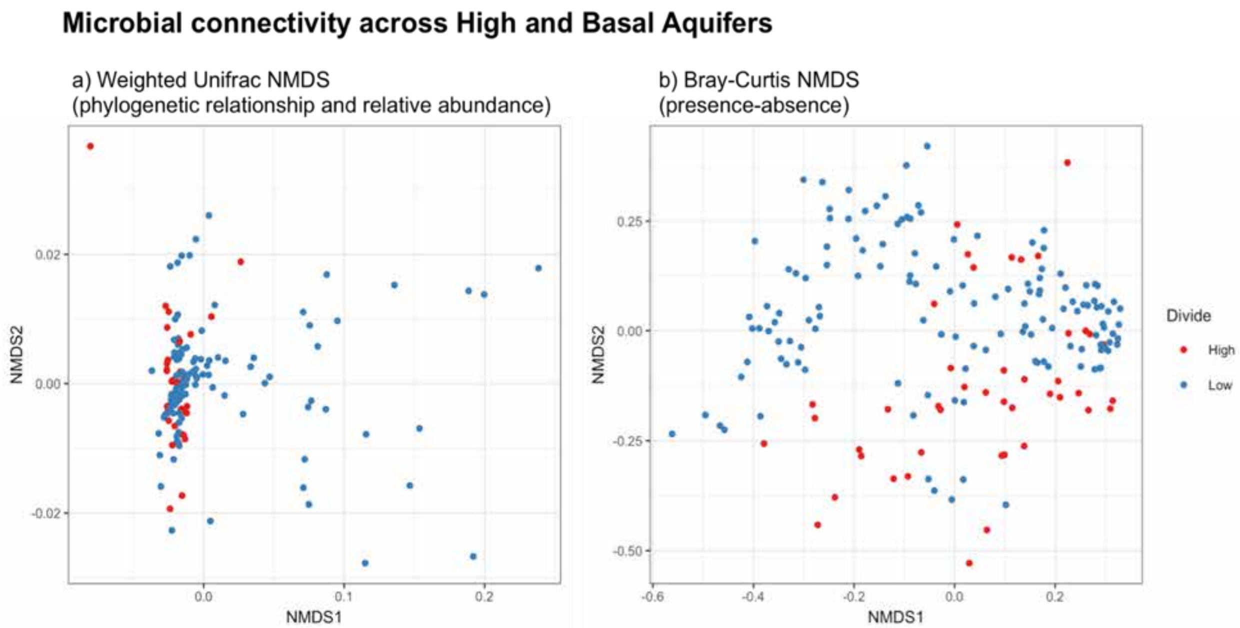


Figure 12: a) Field sampling sites and aquifer demarcations based on conceptual model. b) Non Metric Multidimensional Analysis of 179 Hualālai groundwater well microbial communities based on Bray Curtis dissimilarities matrices colored by aquifer classifications or b) hypothesized flow paths based on Dulai SGD isotopic analysis (Activity 1.2.4)

In Pearl Harbor, we sampled 41 unique sites with 8 organizations, in 12 one-day field expeditions. Personnel hired: Maria Petelo.

Outputs: Field samples have been collected from 170 sites within the Pearl Harbor and Hualālai aquifers. Based on initial results we both broadened but also more carefully selected samples for analysis in Y3 field work. Archived samples Y3: ~1,961 L of water filtered, archived 1560 filters. Archived genomic DNA: 1,406 genomic DNA samples. Data sets archived on 'IKE = 4. Microbial sequence data from 140 sample sites (17.9 Mbp) are archived within 'Ike Wai Gateway (Activity 4.2). Development of bioinformatic pipeline in the 'Ike Wai Gateway (Activity 4.2) has been established and used to analyze the first plate of sequence data. Bioinformatic analysis and of sequence data has been archived within the gateway (Activity 4.2). Preliminary integration of the molecular data with physico-chemical data (Activity 1.2.1) to look for correlations between community structure and nutrients as well as visualize large-scale special patterns. The is the largest database of groundwater microbial sequences in Hawai'i.

Outcomes: In the process of analyzing the initial suite of microbial sequence data through statistical code to test and verify hypothesis for use of microbes as tracers for groundwater connectivity. Preliminary assessments based on taxonomic data suggests consistencies with geochemical and geophysical data indicating connectivity across the high/low divide but distinctions across proposed flow paths.

Risks and Mitigation Plan: One risk is that microbes are uniformly distributed and are not good tracers for groundwater connectivity. However, preliminary data suggests this to be false and can be confirmed with statistical tests. We will mitigate this concern by analyzing microbes with geochemical data to provide indicators or ecological clustering of groundwater conditions. Even if our novel application of molecular microbiological techniques to understand subsurface fluid connectivity and flow direction proves ineffective 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.

Impacts: Data will help test hypotheses about the source location of groundwater (i.e. recharge location—measured by precip collectors), and address the question of connectivity across aquifer and

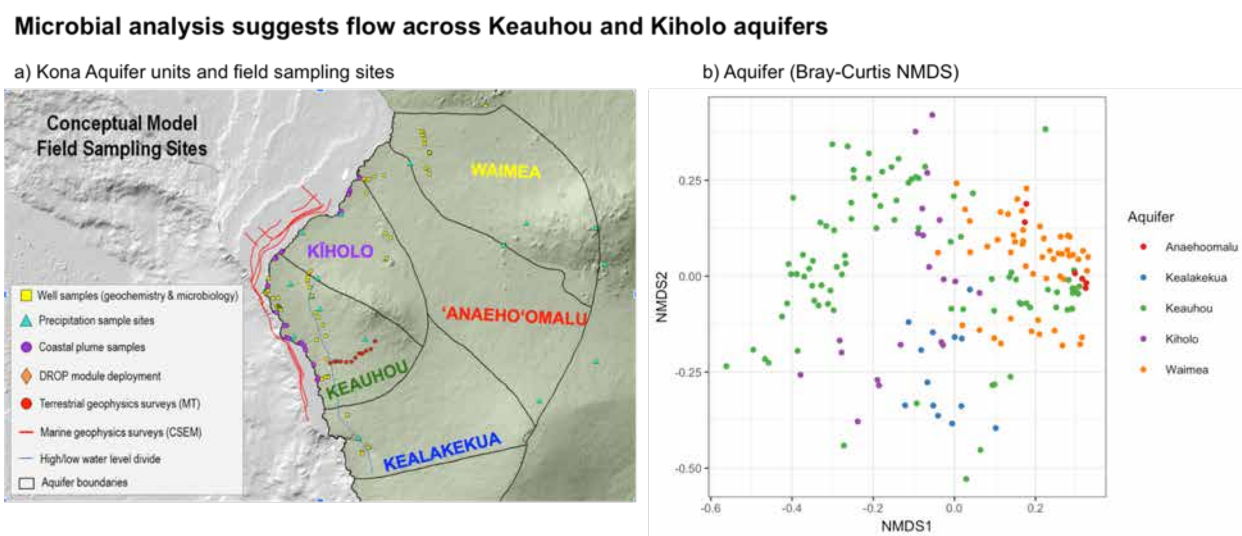


Figure 13: a) Field sampling sites and aquifer demarcations based on conceptual model. b) Non-Meteric Multidimensional Analysis of 179 Hualālai groundwater well microbial communities based on Bray Curtis dissimilaritie. Matricies colored by aquifer classifications or hypothesized flow plath base on Dulai SGD isotopic analysis (Activity 1.2.4)

other known boundaries with new information about GW flow paths.

Activity 1.2.3: Quantify microbial water quality of well samples to identify pathogenic contaminants and microbial indicators for chemical contamination. (Frank, Watson)

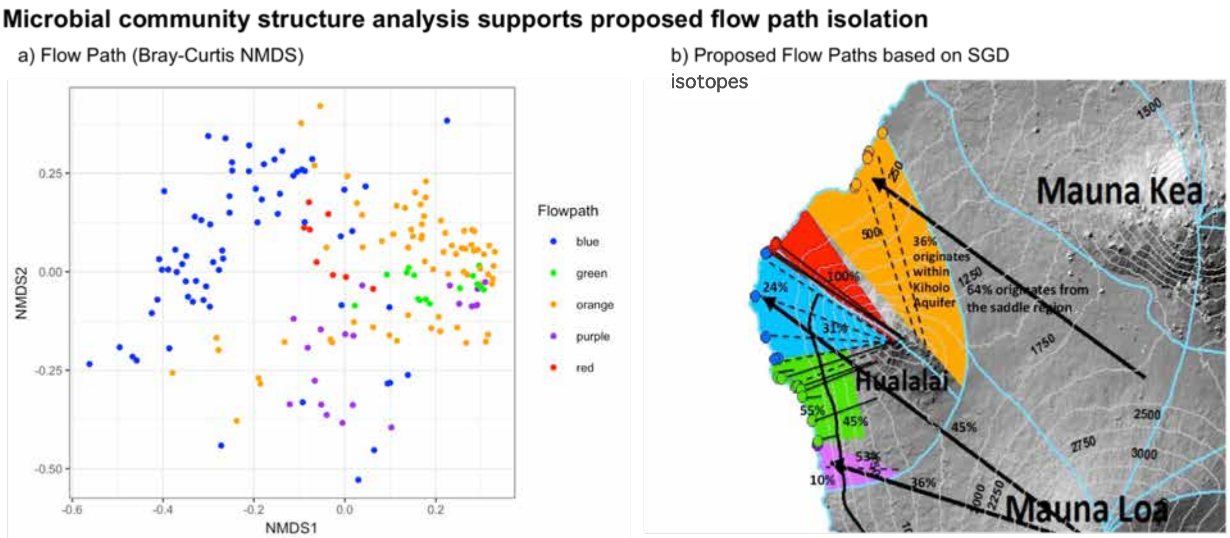


Figure 14: Non Metric Multidimensional Analysis of 179 Hualālai groundwater well microbial communities based on Bray Curtis dissimilarities matrices colored by hypothesized flow paths based on Dulai SGD isotopic analysis (Activity 1.2.4).

Results: Primer design for quantitative study of indicator species: 25 targets. Quantification of cell density (via 16S & 18S qPCR): 175 sites analyzed (currently, in progress – Fig.13). Pathogenic targets identified = 25. We have made progress towards developing a functional database from a reference database of human pathogenic bacteria based on the Pathosystems Resource Integration Center (PATRIC)50. Operational taxonomic units (OTUs) classified to genera level in the reference pathogen database will be screened out and aligned with the representative sequences of pathogenic species within the same genera using BLAST. Sequences with more than 99% identity and 98% coverage with the representative sequences will be counted as a potential pathogen species, and the relative abundance of its population will be calculated. α-diversity (within-sample species richness and species evenness) of the potential pathogenic pools (as well as the whole community) will be calculated using various diversity metrics (i.e., rarefaction, Chao1, Simpson, and Shannon) and weighted UniFrac distance.

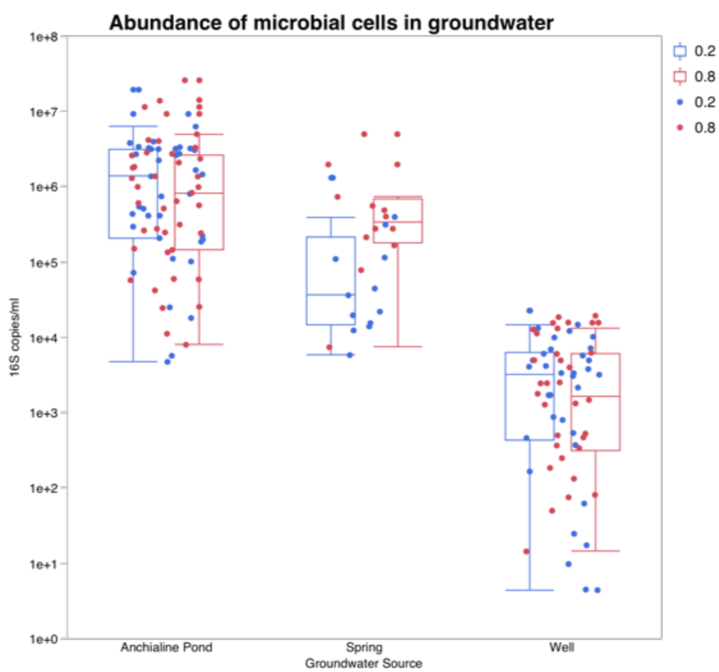


Figure 15: Abundance of microbial cells in groundwater measured by qPCR of 16S rRNA gene. No significant differences in abundance of cells between free-living (blue) and particulate bound (red) cells from different groundwater sources. Microbial abundance was lowest in groundwater wells, with an average of 4 x 10^3 copies 16S/mL compared to 2 x 10^5 copies 16S/mL in groundwater springs and 3 x 10^6 copies 16S/mL in anchialine ponds.

Outputs: Field samples have been collected from 170 sites within the Pearl Harbor and Hualālai aquifers. Based on initial results we both broadened but also more carefully selected samples for analysis in Y3 field work. Archived samples Y3: ~1,961 L of water filtered, archived 1560 filters. Archived genomic DNA: 1,406 genomic DNA samples.

Outcomes: Preliminary taxonomic analysis of 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.

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. (Dulai)

Results: (1) SGD sensor deployment: 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: (1) 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.

(2) **Documented SGD temporal trends and groundwater ages:** 12 SGD springs were sampled for hydrogen and oxygen isotopes of water analysis, 6 SGD groundwater samples were collected for C-14 of DIC, CFC and T/He analysis. (3) **Documented SGD pollutant flux:** In 12 coastal springs, we measured micropollutants as cesspool pollution tracers (Estrogen, Carbamazepine).

Outcome: The major outcome of year 3 was an increased understanding of long-term trends in H and O isotope signatures, groundwater ages, and increased understanding of pollution dispersion within the coastal aquifer and fluxes to the coastal ocean.

Mitigation Plan: Personnel will be devoted to prepare SGD Sniffer for and perform the field deployment.

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. (Garmire, Oyama)

Results: We have completed the fourth iteration (DROP4), and are in the process of the fifth iteration, of the Downwell Remote Operated Platform (DROP). DROP3 was deployed in a monitoring well at NELHA in June 2018 and collected data until August 2018. Upon retrieval, power and waterproofing issues included battery malfunction and water intrusion through the biofinder. The switch to the I2C protocol (complete) makes the sensors modular and easily added or removed. Changes from DROP3 to DROP4 include a more robust code with error handling, an improved motor system for the wire tether, and a different biofinder enclosure to accommodate a new LED and increased prevention of water intrusion. DROP5 will be using a stronger PV panel and two 5V batteries to provide ample power to charge the batteries and power the sensors during the night and cloudy weather. DROP5 will have modified sensor enclosures. Additionally, new materials are being tested for making the chassis water-resistant. Water resistant canvas and tarp material are being considered for DROP5. The DROP5 module will be deployed in May 2019 at five specifically chosen wells on the NELHA property. The well locations overlap with the geophysics areas and SGD monitoring sites. Figure 16 shows the overall

DROP3 module and two sensors.

Outcomes: The fourth iteration of the DROP sensor platform is completed and the fifth iteration is underway. Power management is being optimized and waterproofing for long periods with increased pressure being investigated.

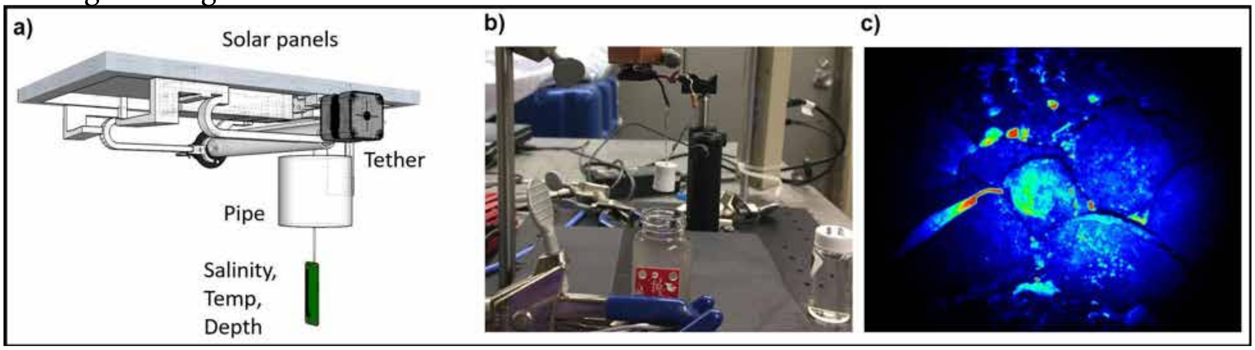


Figure 16: DROP3 and DROP4 development. a) Conceptual diagram of our developed deployment hardware. b) Testing ruggedization of sensor. c) Test image from organics sensor, which ultimately will be deployed to detect contamination in water.

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

Activity 1.3.2: Perform pumping experiments. (Garmire, Oyama)

Results: The original pumping experiment activity has been refined to insure rigorous testing of the salinity and biofinder sensors sensitivity and accuracy. The biofinder test will determine if bio contaminants can be identified or simply detected. Bio contaminant samples diluted up to one part per billion will be sampled using the biofinder. The salinity sensor has polymer resistor probes calibrated in fresh and varying concentrations of salt water. The salinity measurements will be cross tested against a commercial salinity sensor for sensitivity and accuracy. NELHA is interested in continuous monitoring of salinity data in 5 wells to determine if the amount of discharge released on the property by different companies correlates with the increased salinity values recorded by NELHA.

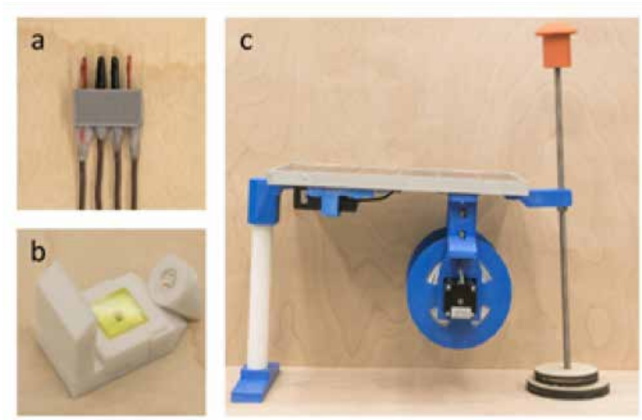


Figure 17: (a) Salinity sensor probes (b) Biofinder sensor with UV light source (c) DROP3 chassis with adjustable positioning for deployment on different well types

Outcomes: Sensitivity and accuracy determined for salinity and biofinder sensors; determine if there is a correlation between the discharge from companies on NELHA and the increase in salinity in the monitoring wells.

Risks and Mitigation Plan: Slightly delayed due to the modifications. 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.

Activity 2.1.1: Hire personnel: In December of 2018 the CI team added Alan Tsang to the project to work on gateway features at 0.2 full-time employment (FTE). (Cleveland, Geis, Jacobs)

Risk Mitigation Plan: None needed, activity complete.

Activity 2.1.2: Setup Computation and Storage platforms. (Cleveland, Geis, Jacobs)

Results: This activity was completed in Year 2.

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

Risk Mitigation Plan: None needed, activity complete.

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

Results: All ‘Ike Wai Gateway documentation and training materials are published on GitHub. Training efforts to date have been focused on individual members of the research teams. All participants will be trained on the gateway on demand. We find if we train before the researchers have an immediate need, sometimes the knowledge is forgotten and the training needs to be repeated. Deployment of science and bioinformatic computational workflows were updated to include Qiime2 workflows that support the latest analysis workflow from Dr. Frank’s team. Cleveland worked with

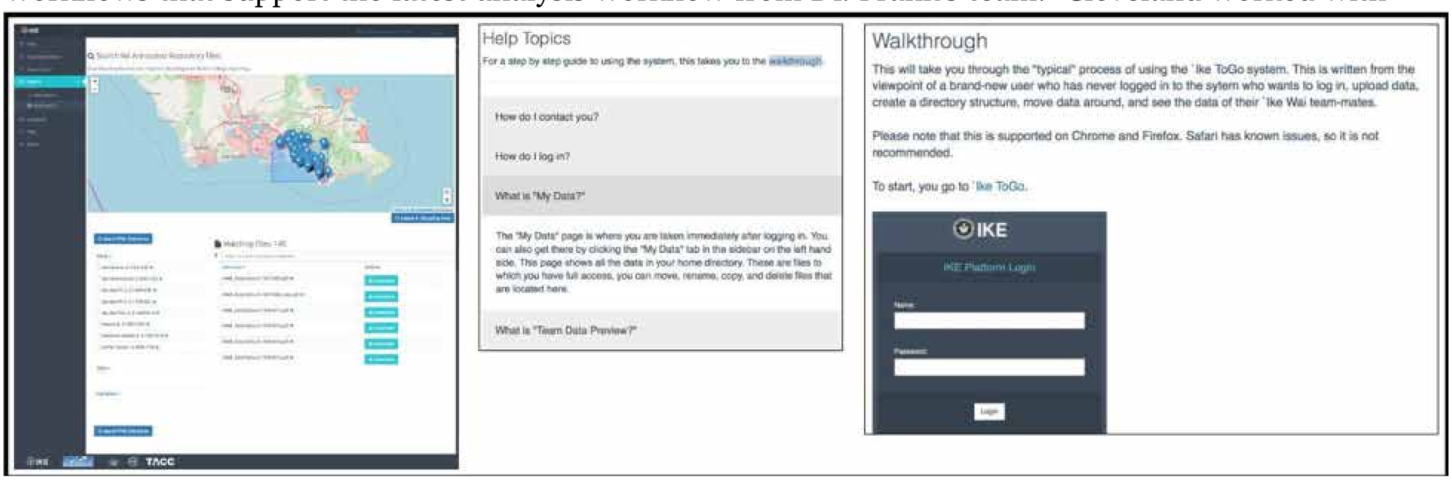


Figure 18: Left: ‘Ike Wai Gateway spatial search screenshot showing results of a bounding box query returning matching annotated data. Center: ‘Ike Wai Gateway screenshot of the Help section. Right: ‘Ike Wai Gateway screenshot of the Help Walkthrough.

the Hawai‘i Data Science Institute (HI-DSI) and the Texas Advanced Computing Center (TACC) to lead three training workshops at UH: 1) “Python Data Science Workshop” April 17-18 2018, 2) “Agave with Python for Compute and Analysis Workshop” April 19, 2018 and 3) “Agave with Containers for Compute and Analysis Workshop” on August 7-8th 2018.

Outcomes: The meta-genomic data analysis workflows have been used to analyze the first dataset from Dr. Frank’s group.

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

Activity 2.1.4: ʻIke Wai Visualization (Leigh, McLean, Cleveland)

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

Current features of the groundwater recharge decision support tool: Recharge visualization allows users to view the groundwater recharge rates based on interactive modifications. Users can select the metrics displayed in the details panel. Recharge rasters can be displayed as a gradient of values, a heat map of recharge difference or percent change. User defined areas can be drawn directly on the map and modified through the web interface. Data can be imported to and exported from a map as: ASCII or CoverageJSON file formats for land cover rasters and Shapefiles for user defined areas such as land

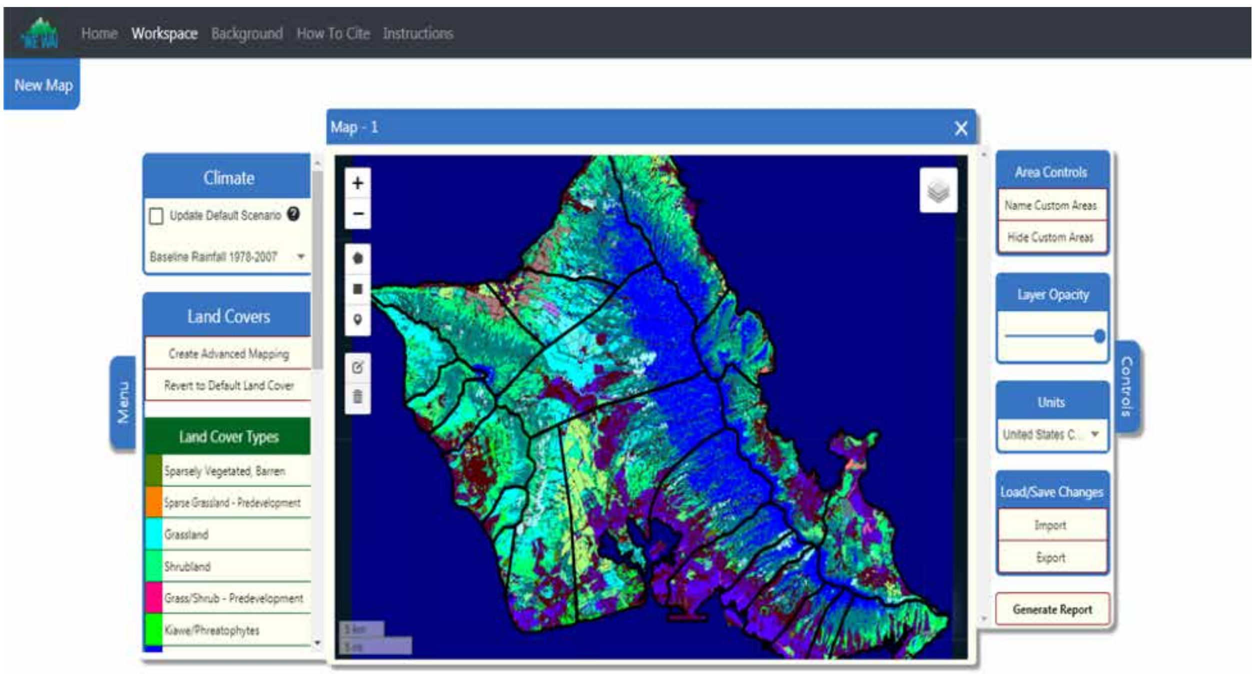


Figure 19: Hawaiʻi Groundwater Recharge decision support application that calculates island recharge based on user-defined land use types combined with multiple climate scenarios.

cover updates via a property containing the land cover type. The tool support data export of custom areas as a shapefile and land cover and groundwater recharge rasters in an ASCII or CoverageJSON format. Reports generated by the tool provide a comprehensive breakdown of metrics for: aquifers, aquifers excluding the caprock, custom areas, full island, and full island excluding caprock. Reports can be exported as a PDFs.

Outcomes: USGS recharge data was ingested into the ʻIke Wai Gateway to populate the decision support tool. The application was deployed on development and staging infrastructure at UH for USGS user review and feedback. Feedback sessions were held with USGS and stakeholders.

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

Activity 2.1.5: ʻIke Wai Gateway Dissemination. Development of dissemination platform.

Results: A decision support tool was developed in collaboration with USGS to disseminate recharge model outputs. Over 3,500 data files/datasets have been made ready for dissemination. We are designing a separate dissemination site to allow users from outside the ʻIke Wai project a simple search and visualization interface for all available data and data products. We plan to integrate dissemination of models and data via the community site, Hydroshare slated for roll-out in late spring 2019.

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

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

Activity 2.2.1: Personnel & Training

Training: 5 (out of 10) research groups trained on annotating data using the ʻIke Wai platform. These users attended a training session that walked through the platform curation features and demonstrated how to curate and annotate project data products for large dissemination. All documentation and training materials on annotating data using the ʻIke Wai platform are published to github.com and within the gateway itself. Materials that educate and demonstrate the use of the ʻIke Wai platform for curating data products from the project have been integrated into the application as help document

Risk Mitigation Plan: None needed, on track for Year 4.

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

Results: Over 44,000 files/data sets have been uploaded and 3,500 are curated. Waterqualitydata.us Hawaiʻi water data has been linked into the gateway as a partner dataset. Hawaiʻi water quality site from the waterqualitydata.us site will be cataloged and geo-referenced in the gateway for discovery in the aggregated search interface of partner and project data. This improves the discovery of water-related data for Hawaiʻi by aggregating data in a single location.

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

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

Rainfall Atlas Data Set (Giambelluca) This legacy collection consists of a 25 year record of quality controlled observations of meteorological data from 471 climate stations in Hawaiʻi within multiple meteorological networks (1990 - 2014). Measured parameters include rainfall, air temperature, relative humidity, wind speed, and radiation. Rainfall is a critical element for ʻIke Wai researchers, including questions of groundwater storage and flow, and water age. Recent and predicted near-future shifts toward reduced rainfall quantity in Hawaiʻi are of great concern to water resource managers and the public. This dataset will be another candidate for eventual serialization within the ʻIke Wai Gateway. The origin of this dataset collection is a long-term effort by Tom Giambelluca and his team. Currently, these data can be accessed at: https://doi.org/10.6084/m9.figshare.c.3858208

As part of this effort, the team is developing a system to automatically update the existing climate data set, and to automatically process incoming data to produce near-real-time gridded climate products, beginning with monthly rainfall. The system queries data from all known online sources, performs data screening, gap-filling, interpolation, and error analysis. The workflow for this system is shown in Figure 20.

Workflow for near-real-time high-resolution rainfall map production:

- Automated data collection from multiple public facing weather station data streams and archived climate data API.
- Combination of all stations from all data sources, calculation of daily and monthly rainfall totals, and removal of duplicate records.
- Automated data quality check and removal for wrong (negative), unverified probabilistically high and unsupported adjacent unlikely values.
- Optimized CDF correlation matched data gap filling.

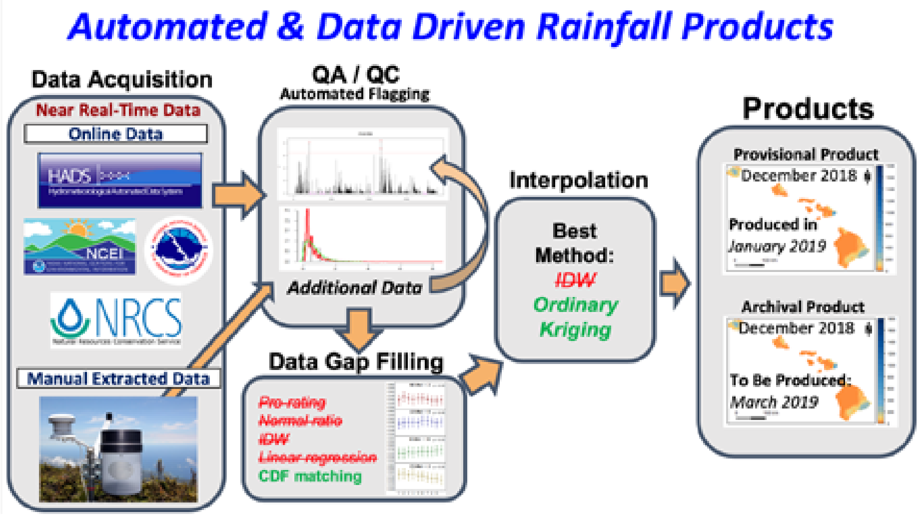


Figure 20: Workflow of automated high-resolution rainfall map production with additional data augmentation for production of near-real-time provisional and high-quality archival rainfall products

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

The end products, high resolution (250-m) monthly gridded rainfall and estimated uncertainty, are automatically generated soon after the end of each month. The up-to-date, quality controlled, tabular rainfall data will also be made available. Figure 21 shows the January 2019 rainfall product, produced by this system on February 1, 2019.

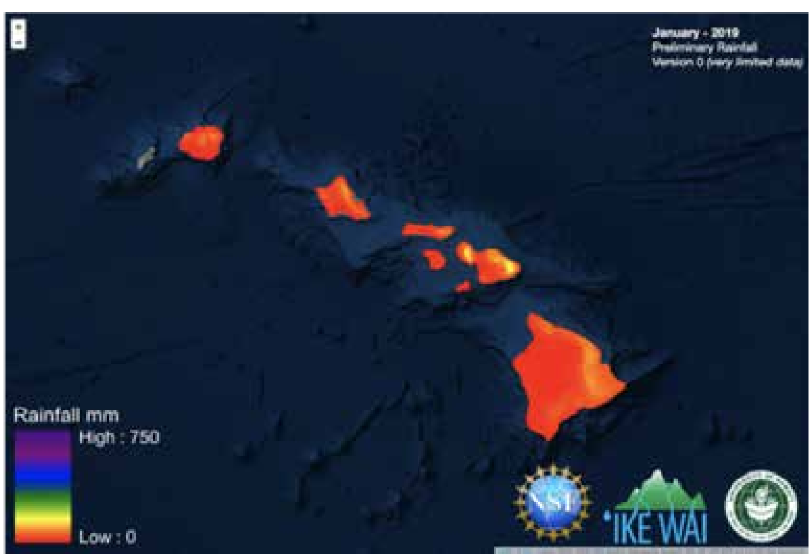


Figure 21: Automatically generated 250-m resolution monthly rainfall map of the Hawaiian Islands for January 2019.

SGD Legacy Dataset - The collections of coastal submarine groundwater discharge data, available from recent years and collected under other projects, are very valuable for examining freshwater discharges along the coast. These data were previously collected by Henrietta Dulai and collaborators. In adition to there is a detailed data record in the repository of stable isotope values for H and O in water from a detailed literature review by collaborator Robert Whittier working with Nicole Lautze. Preliminary CSEM results derived from the marine offshore survey suggests that submarine groundwater accumulations extend to about 2-3 km from the coastline.

Water Quality Data - The ʻIke Wai Gateway provides access to over 4,400 water quality observation sites on Oʻahu 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. Users can search for available data - provided, curated, and updated by the Water Quality Portal - through an active data link created within the ʻIke Wai Gateway. This active repository linkage allows users to find water quality observations through the Gateway's own search tools, including search by location through the interactive map and bounding tool selection. This feature helps centralize access to water quality data resources for ʻIke Wai Gateway users.

Hawaiian Translations - The Institute for Hawaiian Language Research and Translation (IHLRT) team has collected and translated relevant historic Hawaiian language written articles. 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 ʻIke Wai Gateway, Files of English language translations paired side-by-side to an image of the original Hawaiian language source are stored in the ʻIke Wai Gateway. Data descriptors with metadata are linked to each file. Creating shared links allows linkage of curated translations and original sources within the Gateway to a publicly accessible interactive map.

Outputs: Dataset/files deposited = 44,000 Datasets/files curated = 14,500

Outcomes: Annotated data is searchable and discoverable to the ʻIke Wai team.

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

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

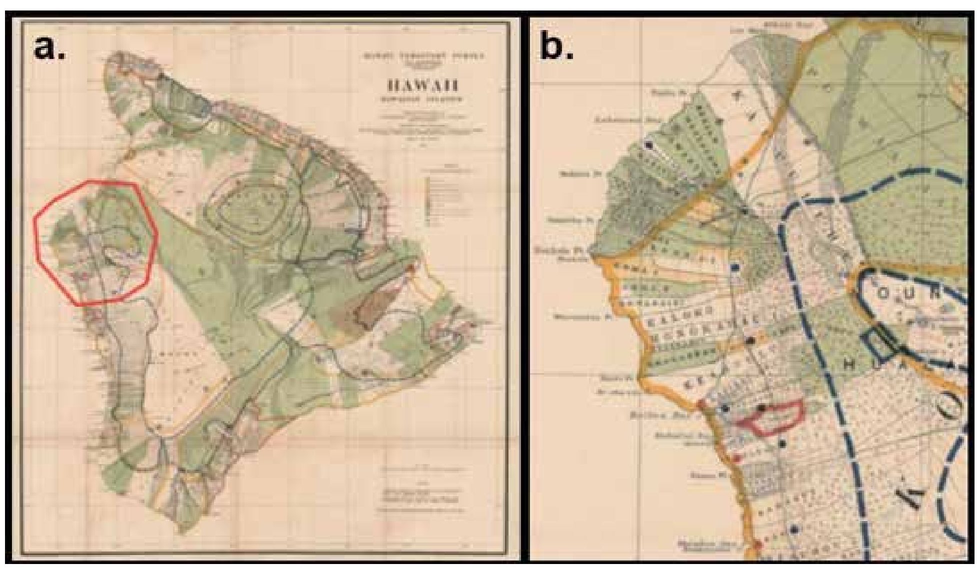


Figure 22: a) W.D. Alexander's map of Hawaiʻi Island of 1901, red section denotes the enlarged section in b). b) Enlarged section of the 40 ahupuaʻa in North Kona.

Results: The IHLRT (Institute of Hawaiian Language Research and Translation) team developed community relationships with Kona residents and gained valuable insight on location of place names. Two newspapers series were translated: Nā Hoʻonanea o Ka (September 1923 - August 1924) and excerpts from Nā Hunahuna No Ka Moʻolelo Hawaiʻi (September 1869 - May 1870). Community engagement meetings were conducted to review content and place names. The W. D. Alexander's map of Hawaiʻi Island from 1901 (Fig. 22) was used as a reference locate possible areas of previously known place names.

Dr. Jenny Engels from the Education team was PI on a side project entitled Groundwater Sustainability for Small Farmers of Oʻahu. This was a case study of the groundwater around the Sumida Watercress

Farm in Kalauao, ʻEwa, Oʻahu. The was to provide the small farmer historical and current data of water quality and springwater production which might be useful in advocating additional controls on groundwater pumping. Outputs: Products of Year 3 included 45 fully translated articles, including the complete series of Nā Hoʻonanea o Ka Manawa and excerpts from Nā Hunahuna No Ka Moʻolelo Hawaiʻi. Nā Hoʻonanea o ka Manawa has been selectively distributed to local Kona community members in both digital and hard copy drafts to assist our team in content review and revisions. Three digital storyboards were created. for Nā Hoʻonanea o ka Manawa (http://arcg.is/09fCer) and Nā Hunahuna No Ka Moʻolelo Hawaiʻi (http://arcg.is/1W9nW9) provide images of the digitized newspaper article followed by English translations and citation alongside the Hawaiʻi Island map of 1901 to provide spatial context. The third digital storyboard Water Stewardship in Puʻuloa (Pearl Harbor) Aquifer (http://arcg.is/19OzPb) provides a visual report of the research, data, and collaboration on the project.

Outcomes: We are building a reciprocal relationship with the communities by providing the data, articles, and histories that were documented about their communities, by their elders from a century ago. The conversations the IHLRT team has had with the community have been invaluable in understanding the content of the translated articles. Digital and hard copy drafts of the translations have been distributed to community members in appreciation for giving their time and space to do research. The digital storyboard will be made available to the public on our website in Year 4.

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. (El-Kadi, Lee, Elshall)

Results: Three conceptual models were developed to assess the West Hawaiʻi groundwater systems. They vary in size and have different degrees of refinement: the West Hawaiʻi regional (WHR) model, Keauhou basal aquifer (KBA) model, and two-dimensional cross-sectional models within the KBA model (Fig. 23 and 24). Each model was developed to answer different research and management questions and accommodate the field datasets which are spatially and temporally variable.

West Hawaiʻi Regional (WHR) model: WHR is a steady state three-dimensional model that encompasses the six western aquifer systems (Waimea, ʻAnaehoʻomalu, Kīholo, Keauhou, Kealakekua, and Kaʻapuna) and extends further offshore (Fig. 24). The larger area is modeled to assess the overall water budget and aquifer interconnectivity, to test the hypothesis that groundwater flows across aquifer boundaries and is potentially recharged from as far as Maunakea and Maunaloa. The model is designed to accommodate geochemical and microbial groundwater data, which extends from Waimea down to Kealakekua, and isotopic precipitation data, which extends out to Mauna Kea and Mauna Loa.

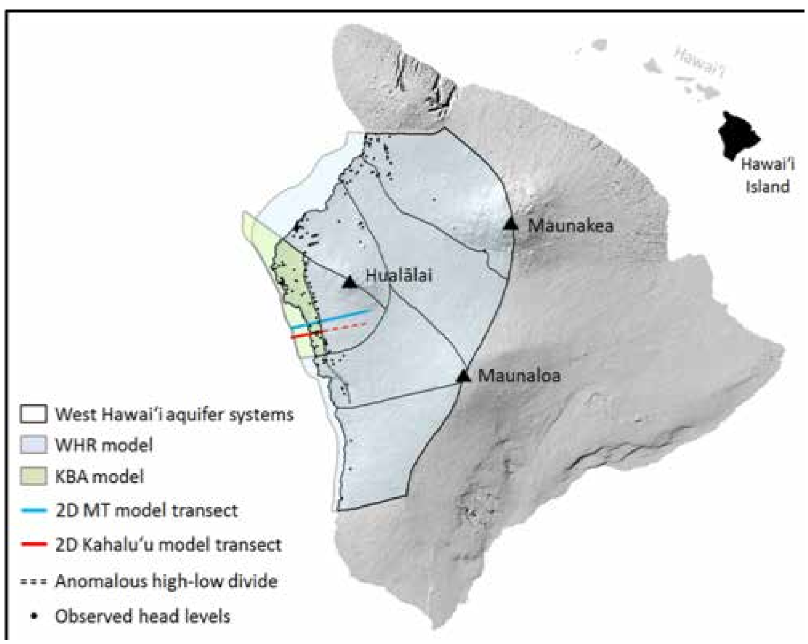


Figure 23: West Hawaiʻi study area encompassing six aquifer systems

Surficial aquifer boundaries designated by the Department of Land and Natural Resources (DLNR) are not assigned as physical boundaries, thus the WHR model assumes that groundwater recharged across Hualālai and the western slopes of Mauna Kea and Mauna Loa is able to flow across such boundaries. Groundwater is also allowed to flow across the coastal boundary, exiting the aquifers as submarine groundwater discharge. The model also assumes that groundwater flow is negligible around 2 km below ground elevation. Previous seismic research suggests that porosity drastically declines starting at such an elevation, evidenced by an increase in seismic velocity and density (Oki, 1999). This model is not density-dependent, and therefore does not accurately simulate the nearshore area, where a freshwater lens exists combined with a mixing zone. However, the model is still useful in quickly assessing the overall water and chemical budgets of the area. The model is also able to simulate flow path lines covering the area and assessing aquifer interconnectivities. Various chemical tracers and age can be also simulated by the model. Currently, we are extending the formulation to include a sharp interface between the freshwater and saltwater zone using USGS MODFLOW-SWI package. Data

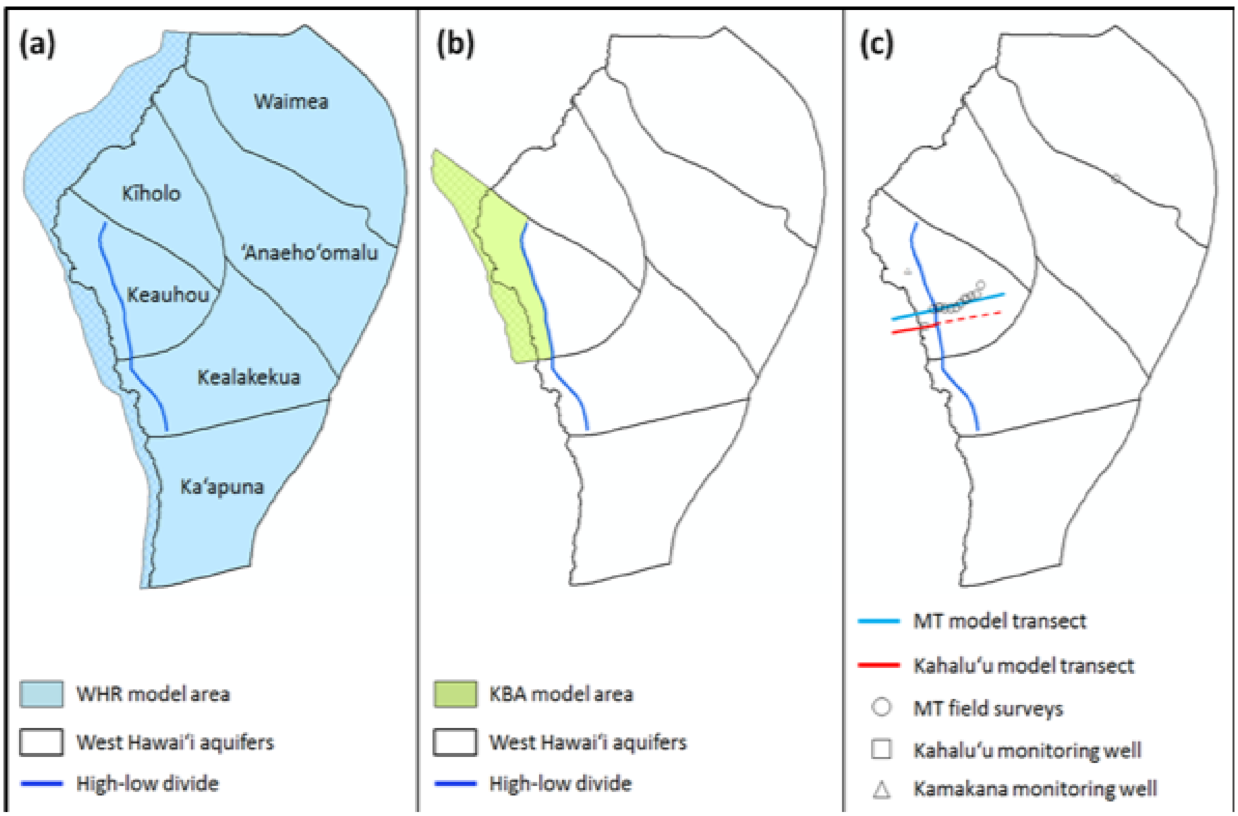


Figure 24: (a) West Hawaiʻi Regional (WHR) groundwater model encompassing six aquifer systems. WHR is a three-dimensional, freshwater groundwater model that extends offshore (hatched area) to accommodate submarine groundwater discharge. (b) Keauhou basal aquifer (KBA) groundwater model, focusing on the shallow groundwater of Keauhou. KBA is a three-dimensional, density-dependent model that also extends offshore (hatched area). (c) Two-dimensional cross-sectional models developed within the Keauhou aquifer system. The MT model transect approximately follows the transverse section of the magnetotellurics (MT) field surveys conducted on Palani Ranch land. The Kahaluʻu model transect aligns with the Kahaluʻu monitoring well, where transient water level and salinity data sets are available.

available for model calibration includes observed hydraulic head levels and pumping withdrawal rates reported by the Commission on Water Resources Management (CWRM). Groundwater recharge was calculated by the USGS as an annual average (Engott, 2011).

Keauhou Basal Aquifer (KBA) model: KBA is a transient, three-dimensional, multi-specious, density-dependent model that focuses on the basal groundwater of Keauhou aquifer (Fig. 25). This model was designed to answer water management questions, specifically how the basal aquifer will respond to changes in groundwater withdrawals from major pumping wells. The freshwater lens is very thin and head levels are low in the basal aquifer. The grid layers need to be drastically refined to simulate the thin freshwater lens transitioned to the underlying saltwater. The eastern boundary is set at the high-low divide, located immediately before the drastic increase in head levels. Since the KBA model is designed to focus on water management questions, it is important to include the major pumping wells located east of the high-low divide, which does not fall within the modeled area. The eastern boundary was set as a flux boundary condition to account for the groundwater recharge and pumping that occurs in the high-level Keauhou aquifer. The net inflow at the boundary was determined by accounting for the rate of groundwater discharge over the area of the high-level aquifer and the pumping rates from high-level wells. The total pumping was removed from the mauka flow, and the remaining value was added to the KBA model as a net boundary inflow (Fig. 25).

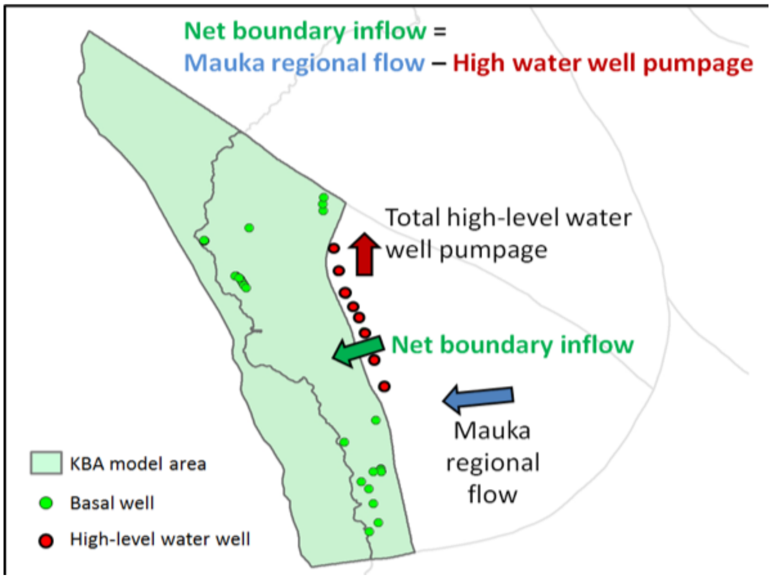


Figure 25: The KBA area model with a boundary condition accommodating for flow and high-level pumping rates east of the high-low divide. A primary goal of the KBA model is to assess how pumping from basal and high-level wells may affect the water levels in the basal aquifer. To do so, withdrawal from major pumping wells in the high water area must be accounted for in estimating the boundary inflow.

The model assumes that groundwater does not flow to/from adjacent aquifer systems (i.e., Kīholo and Kealakekua), therefore the northern and southern boundaries are set as no-flow boundary conditions. Such an assumption was acceptable based on water budget calculations involved the WHR model.

2D Cross-Sectional models: Two-dimensional cross-sectional models were developed to model strictly mountain-ocean flow conditions where three dimensional effects are not significant. They are useful in investigating local features and boundary conditions, and in constraining various flow and transport parameters. With the smaller-size model, the grid could be further refined and detailed geological features included, such as aquifer stratification and details of the high-low water flow barrier. The MT transect follows the general path of the magnetotellurics (MT) field surveys conducted through Palani Ranch within Keauhou. Hydrogeological modeling for that cross-section is an important step towards integrating geophysical results into the geological model of the area. A discussion of an approach for such an integration has been initiated between the modeling and geophysical teams. The Kahaluʻu model transect crosses through Kahaluʻu monitoring well where detailed transient salinity and water level exist. In addition to the nature of the barrier and the potential existence of a no-flow condition at the bottom, there is a need to investigate the overall sharp and shallow freshwater-saltwater interface and the potential occurrence of deep freshwater flow. The models were extended across the flow barrier and to the ocean and various boundary conditions were tested. To test suitability of the 2D assumption, we projected nearby observation wells on the cross section location and calibrated the model based on these observation data.

Output: We created three conceptual models within the West Hawaiʻi area to accommodate different types of data sets, to answer different research and management questions. The models utilize the same observed head and pumping data, but have different assumptions regarding boundary conditions and density-dependent flow. The conceptual models can be modified based on new findings as field data arrives and are used to develop the numerical groundwater models described in Section 2.2.6.

Outcomes: The three different conceptual models allow us to refine model development to address specific questions as well as needs of other team members. By developing multiple models, we can customize our work and refine our understanding of different groundwater processes and controls. The WHR model can assess aquifer interconnectivity; the KBA model can assess pumping effects on the basal aquifer; and the cross-sectional models can refine subsurface structures and hydrologic parameters (porosity, permeability, storage coefficients, etc.) that have the most influence on groundwater flow.

Risks and Mitigation Plan: Our key concern is the lack of data available to develop the conceptual models. The primary dataset utilized to conceptualize the West Hawaiʻi aquifer systems is the observed head levels from existing wells. However, the wells are predominantly only located along the coastline, therefore a large area of the WHR model area has no data to work with (Fig. 23). Due to the lack of available data, the conceptual models are highly simplified, especially the eastern slope of Hualālai extending out to Mauna Kea and Mauna Loa. Data is not existent regarding high water levels throughout the saddle region and the way groundwater movement is affected by the interfingering of lava flows between all three volcanoes. Salinity data are sparse and may reflect uncertainty in modeling results. The geochemical, microbial, and geophysical field work is intended to help clarify these uncertainties and constrain the conceptual models.

Activity 2.2.6: Based on model conceptualization, develop and apply suitable numerical groundwater models for use in developing comprehensive schemes for sustainable water use in West Hawaiʻi.

Results: Using the conceptual models described in Activity 2.2.5, preliminary numerical models were developed for the West Hawaiʻi area. The numerical simulation programs, MODFLOW, SEAWAT, and FEFLOW, were used in the development process, utilizing available data in model calibration. The WHR, KBA, and 2D numerical models were each applied to different aspects of sustainable water research.

WHR groundwater age simulations: A numerical FEFLOW version of the WHR model was used to simulate average groundwater ages, with results that are displayed in Fig. 26. Groundwater reaching the basal wells in displayed younger ages, indicating that the basal groundwater is locally recharged. In contrast, groundwater reaching the high-level wells in Keauhou and wells in Waimea displayed older ages. As previously determined from model simulations in Year 2, groundwater particles travel across aquifer boundaries, indicating interconnectivity between aquifer systems. Particles in the northern aquifers (Waimea and ʻAnaehoʻomalu) are generally sourced from the slopes of Mauna Kea, traveling the farthest distances. Particles in the Hualālai and southern aquifers (Kīholo, Keauhou and Kealakekua) generally travel shorter distances, sourced from the highly recharged area east of the high-low divide (Fig. 26, inset). Flow paths in Waimea extend far distances to Maunakea leading to an older groundwater in this area. The flow paths through Hualālai, however, are relatively short and primarily remain within aquifer boundaries. The short flow paths and old ages suggest a relatively lower velocity, where water is stored or slowed within the aquifer before reaching the wells. Groundwater ages can be connected to aquifer size, which is important in developing sustainable water use strategies. Field samples have been collected for age evaluation and results will be used in further calibrating the model.

KBA pumping scenarios: A numerical SEAWAT model was developed for KBA and reasonably calibrated against water level data.. A number of water management scenarios were implemented to assess how different basal and high-level pumping rates would affect the basal aquifer regarding water levels, salinity, and various water budget elements, including submarine groundwater discharge (SGD). The elements of the water budget are shown in Fig 27, including: (1) direct recharge over the KBA area, (2) net mauka-boundary flow, (3) inland SGD flow, (4) total basal well pumping, and (5) SGD flow to the ocean. In Scenario 1, the pumping rates were doubled at active wells in both the basal and high-level aquifers. In Scenario 2, the pumping was also doubled, but pumping was ceased from the basal aquifer and all the pumping demand was restricted to high-level wells. To meet the increase in demand, the net mauka flow was reduced by 16 and 50%, respectively for the two scenarios. The results were sensitive to the resulting net mauka flow and showed a larger decrease in SGD flowing out of the aquifer system (see the table in Fig. 27). A larger decline in head and an increase in salinity were also observed for Scenario 2 compared to Scenario 1 (results are not shown here). Under all assumptions and data used in the model, it was concluded that Scenario 1 is superior to Scenario 2.

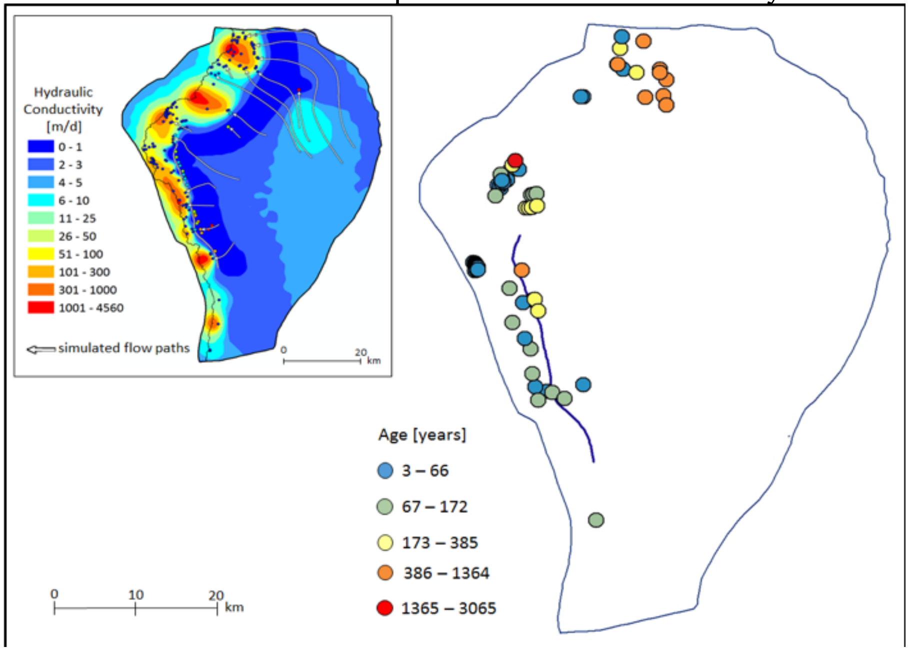
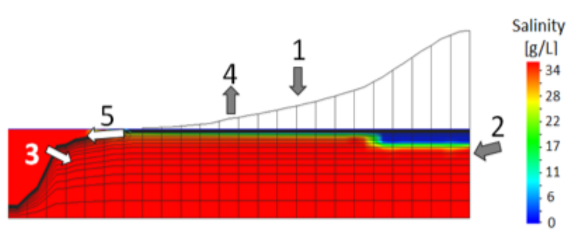


Figure 26: Simulated groundwater ages at observation wells. Basal wells in the Keauhou aquifer display younger ages while the high-level wells display relatively older ages. Inset map displays optimized hydraulic conductivity values and simulated groundwater flow pathlines. Simulated ages are consistent with such pathlines



	Baseline Value (m³/day)	Scenario 1		Scenario 2	
		Value (m³/day)	Change (%)	Value (m³/day)	Change (%)
1. Recharge (in)	174,000	174,000	0	174,000	0
2. Net mauka boundary flow (in)	120,000	101,000	-16	61,000	-50
3. SGD in	134,000	137,000	+2	108,000	-19
4. Basal wells (out)	22,000	44,000	+100	0	-100
5. SGD out	406,000	368,000	-9	364,000	-15

Figure 27: Preliminary water budget scenarios using the KBA model compared to the baseline case. In both scenarios, higher pumping withdrawals from the high-level aquifer will lead to a lower net mauka boundary inflow (as explained in Fig. 26). The inset figure displays salinity distribution for a cross-section of the KBA area with the numbers 1 through 5 referring to inflow and outflow fluxes as listed in the table below the cross sectional figure. Percent changes are relative to the baseline values.

2D model simulations: The 2D cross section models depicted in Fig. 4 were simulated by using the density-dependent SEAWAT model. The calibrated model predicted acceptable results for water levels. However, the model failed to predict accurate vertical salinity profiles, as can be seen in Fig. 28. A thin freshwater lens and sharp interface between freshwater and saltwater were field observed in the two wells, which did not correspond well with the simulated profiles. The sharp interface profiles have been also confirmed by Oki (2018). The average simulated depth of the freshwater lens was about 40 and 50 m (i.e., depth at the 50% relative salinity), whereas the respective measured values were only 16 and 18 m. The simulated values are much closer to the Ghyben-Herzberg ratio of 40:1 considering that average water level is around one meter. Efforts to reach a closer match necessitate the use of a very small storage coefficient that is outside conventional values for aquifer material.

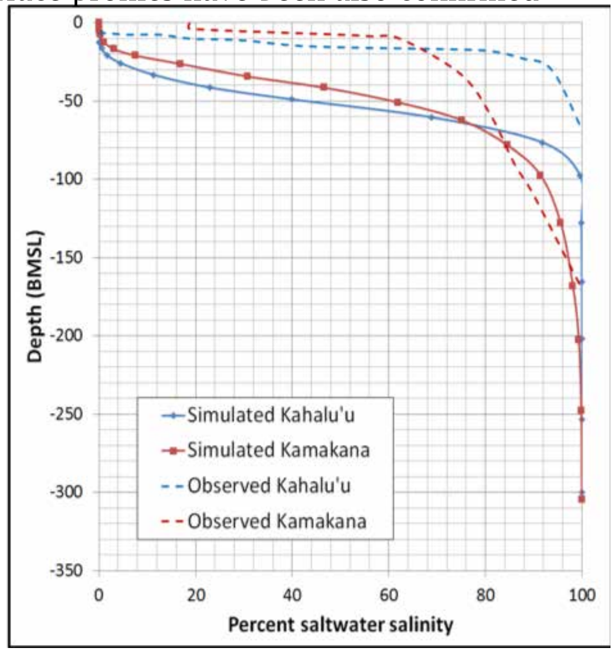


Figure 28: Observed vs simulated vertical salinity concentration profiles s in the Kahalu'u and Kamakana monitoring wells. Average freshwater lens is estimated at the 50% saltwater salinity.

Outputs: Three different numerical groundwater models were developed. Water levels, flow paths, salinity concentrations, and average groundwater ages were simulated for preliminary analyses of the aquifer systems. Example management scenarios were developed for one of the models (the KBA model) as an illustration of the procedure. The KBA model is available for application by the Social team for addressing aquifer management to meet stakeholders' needs.

Outcomes: The WHR model simulated average groundwater ages in observation wells, which provide preliminary estimates of what to expect from field results. The large range of ages informs us that multiple age tracers should be used in order to capture the different expected ages. The KBA model integrates efforts of the modeling and management teams for analyzing how pumping from high-level wells affects the basal aquifer system. All of these numerical models can be further utilized to refine sustainable water use scenarios and research.

Risks and Mitigation Plan: It is crucial to complete geophysical surveys and analyze geochemical samples in order to improve on model calibration and validation to properly model the aquifer systems during Years 4 to 5. Compiled field data includes groundwater samples for apparent age estimation in order to properly calibrate the WHR model. By combining apparent ages with estimated travel distances (from isotopic analysis), we can estimate seepage velocities and effective porosities. Current models are preliminary in nature, 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. (El-Kadi, Lee)

Results: Three preliminary models were calibrated in parallel with the conceptual modeling development, as described in Activity 2.2.5 and Activity 2.2.6. Currently available observed water levels and salinity data sets were used to calibrate hydraulic conductivity distribution of each model using a previously developed inverse modeling code and USGS PEST software. The optimized hydraulic conductivity coverage calibrated from the WHR numerical model was used as the initial condition for the KBA model. The KBA model was then further optimized with the new model assumptions (mainly the consideration of density-dependent flow) Fig. 29 illustrates the optimized hydraulic conductivity values, which are drastically increased in the KBA model (max 14,000 m/d), compared to the WHR model (max 3,065 m/d), but varied layer by layer. Since transmissivity was not averaged over all of the layers, the thinner upper layers calibrated higher hydraulic conductivities while thicker bottom layers had lower values. The size of the overall modeled aquifer has a significant effect on calibration results.

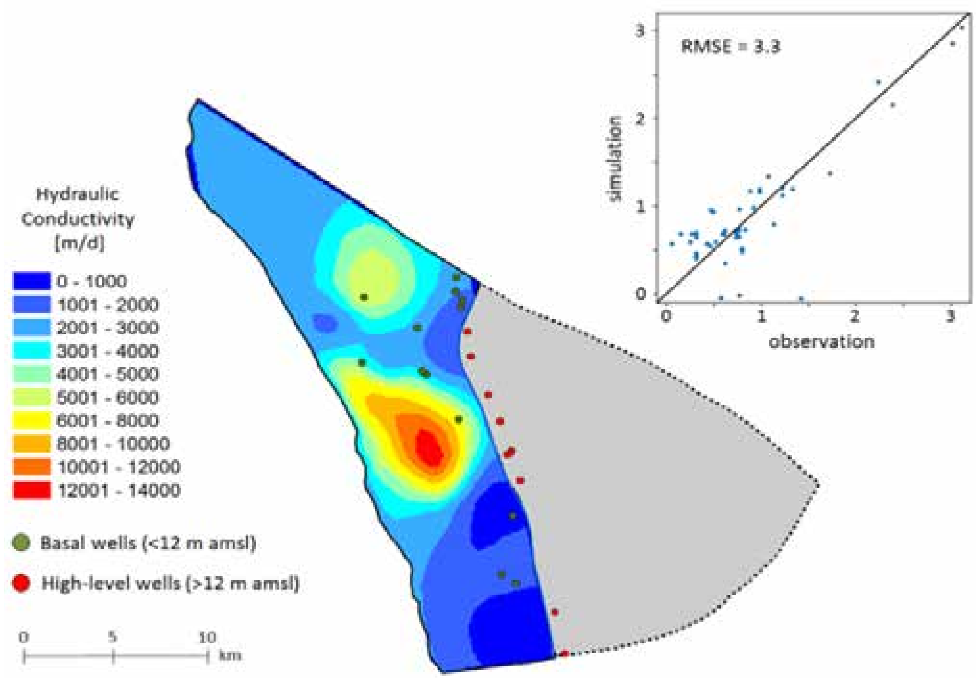


Figure 29: Optimized hydraulic conductivities of the top layer of the Keauhou basal aquifer. Values are refined based on updated model assumptions. Note the higher conductivity values calibrated by the model (compared to WHR, Fig. 24) do not represent average transmissivity over all of the modeled layers.

The inverse modeling code written in Python has been uploaded in a public domain repository and updated with many examples including groundwater pumping history identification, geothermal aquifer characterization, and tracer tomography. In a collaboration with the geophysics team, MT and ERT-based hydraulic conductivity identification methods have been developed in the code with an example of synthetic high-resolution resistivity estimation in a 2D cross-section aquifer.

Outputs: Three preliminary models were calibrated to match observed head levels at 207, 56 and 22 well locations in WHR, KBA and 2D Cross-Sectional models, respectively. Transient groundwater level observations due to tides were used for preliminary 2D Cross-Sectional model calibration. The preliminary calibration was performed using a computationally efficient inverse modeling code the team has developed and maintained for high-dimensional hydraulic conductivity field identification in a public domain repository (https://github.com/jonghyunharrylee/pyPCGA). The repository has been updated with six Jupyter Notebook examples to illustrate how different types of information from hydrogeological, geochemistry and geophysical data could improve subsurface characterization with uncertainty reduction.

Outcomes: The primary outcome from the model calibration was the identification of hydraulic conductivity distribution and boundary conditions in the preliminary models that reproduce currently available observations. New tracer and geophysics data with our multi-purpose models will be utilized 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 for the Pearl Harbor Aquifer. (Elshall, Bremer, Burnett, Wada)

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

We estimated the pre-development spring discharge and cross-validated the model simulation with the earliest available spring discharge data from literature. We developed and tested various spring discharge objective functions. Figure 30 shows that the optimal solution to restore the predevelopment spring discharge without violating the sustainable yield constraints of salinity and drawdown.

We added a module to the simulation-optimization code to account for different recharge scenarios. Given preliminary recharge maps, we quantified the optimal groundwater withdrawal under current and future climate, given two development scenarios crossed by three watershed conservation scenarios. Figure 31 shows the preliminary sustainable yield estimates for a dry future climate scenario given six land use scenarios.

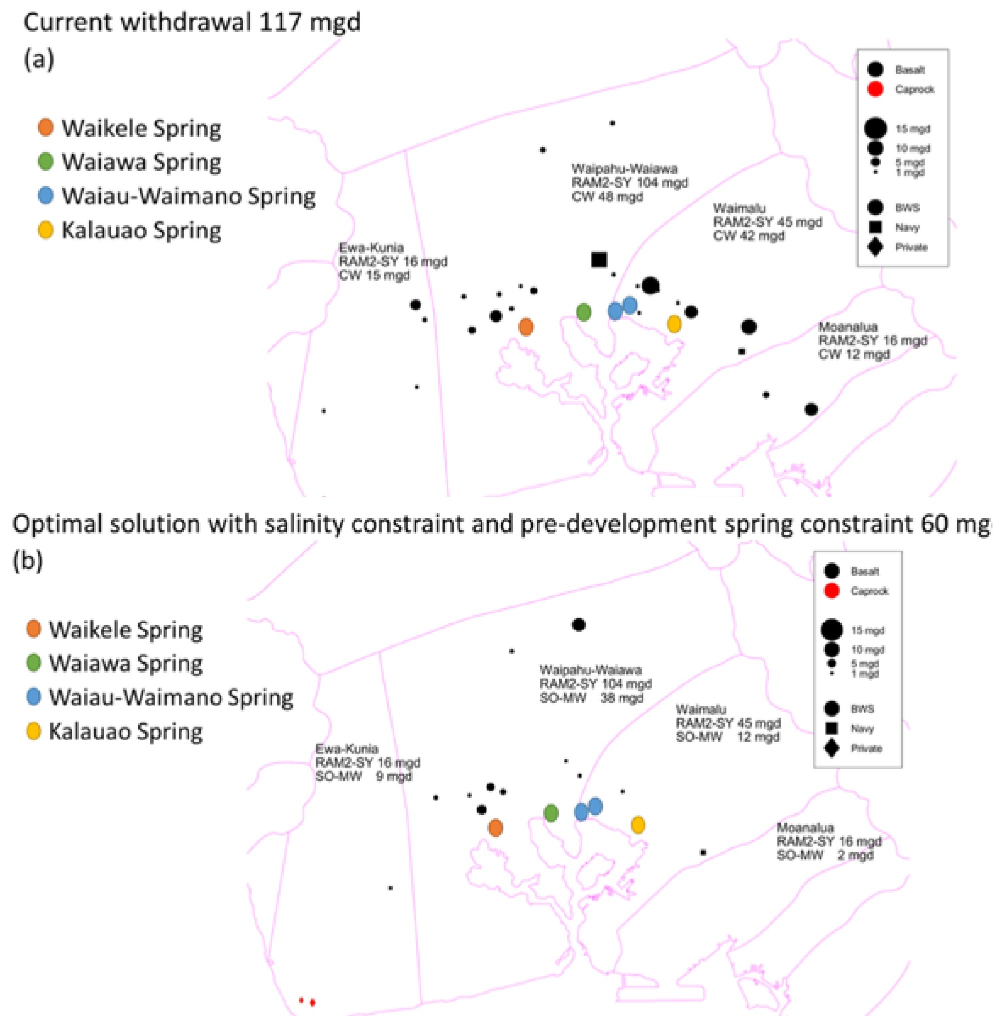


Figure 30: a) Map showing current withdrawal. The current withdrawal (CW) and the RAM2 model sustainable yield (RAM2-SY) estimates are shown for each aquifer unit. Note that RAM2 is a lumped analytical function model that is currently being used to estimate sustainable yield in Hawai‘i. Pumping wells with withdrawal less than 1 mgd are not shown on the map. b) Maximum allowable withdrawals to restore the pre-development spring discharge. 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 a high performance computing environment..

Outcomes: The developed method accounts for withdrawal spatial distribution and groundwater discharge for ecosystem services. Thus, the method overcomes the limitation lumped RMA2, which is currently being used to estimate sustainable yield in Hawaiʻi.

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 ʻIke Wai proposal, we are seeking additional funding to address this component under the USGS National Competitive Grants Program for fiscal year 2019.

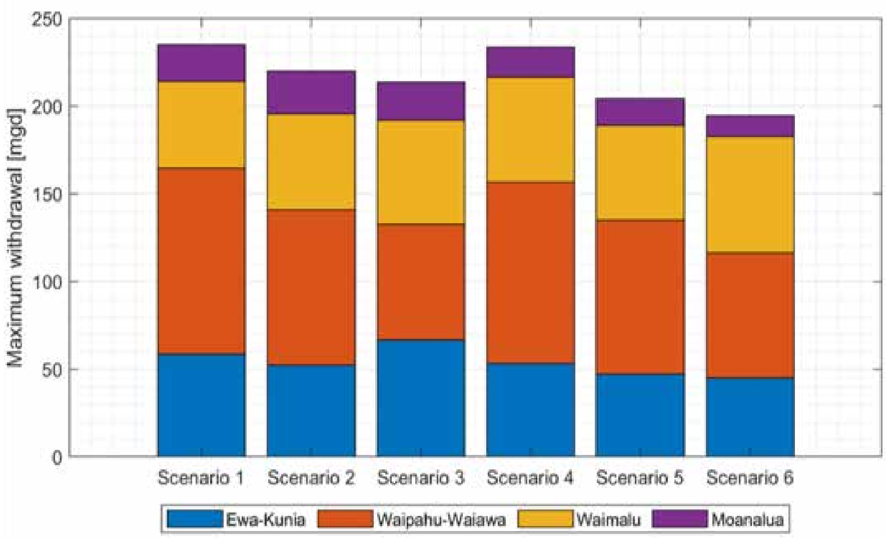


Figure 31: Preliminary sustainable yield estimates for the four aquifer units for a dry future climate scenario given six land use scenarios. Scenario 1 to 3 are high level, targeted and no watershed restoration scenarios, respectively, under dense development along a 1-mile radius corridor of the planned rail system. Scenario 4-6 are are high level, targeted and no watershed restoration scenarios, respectively, under urban sprawl following historical development patterns.

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

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

Results: **Pearl Harbor Aquifer:** *Land use and climate scenarios*: Based on input from stakeholders including the State Office of Planning, the City and County of Honolulu Department of Planning, the Department of Forestry and Wildlife, and the Koʻolau Watershed Partnerships, six finalized scenario maps were created representing broad potential future land use changes over the next 30-years within the Pearl Harbor aquifer in urban, agricultural, and conservation lands. The objective of the scenarios is to evaluate how groundwater recharge may change under a range of possible land-use and climate futures in the Pearl Harbor aquifer, and how this changes estimates of sustainable yield and groundwater management recommendations.

Urban and agricultural lands: Two simplified urban scenarios were considered: 1) dense development along a 1-mile radius corridor of the planned rail system (referred to as corridor development); and 2) urban sprawl following historical development patterns (Fig. 32). In corridor development, all future urban growth occurs as dense development along a 1-mile rail corridor and all existing agricultural lands are preserved, while in urban sprawl, all currently used agricultural lands (except those designated as Important Agricultural Lands) are converted to suburban style development. Both scenarios include the two major planned developments, Koa Ridge and Hoʻopili. These scenarios are roughly based on scenarios developed by Calthorpe Associates (2013) as part of Transit Oriented Development (TOD) planning. These scenarios are meant to represent simplifications of the range of possible futures of urban and agricultural lands.

Conservation lands: Within areas designated as conservation lands, the major potential land cover change is invasion of existing native forest by non-native species, potentially resulting in a conversion to non-native forest cover. The current USGS recharge estimates are based on higher water use of non-native forest versus native forest. With input from the Division of Forestry and Wildlife and the watershed partnerships, we created three future forest cover scenarios: 1) high protection (all native forest are protected); 2) targeted protection (all native forest in existing and planned fences and management areas are protected); and 3) no protection (no forests are protected). We modeled non-native forest spread outside of these protected areas as increasing at a rate of 5% per year, which

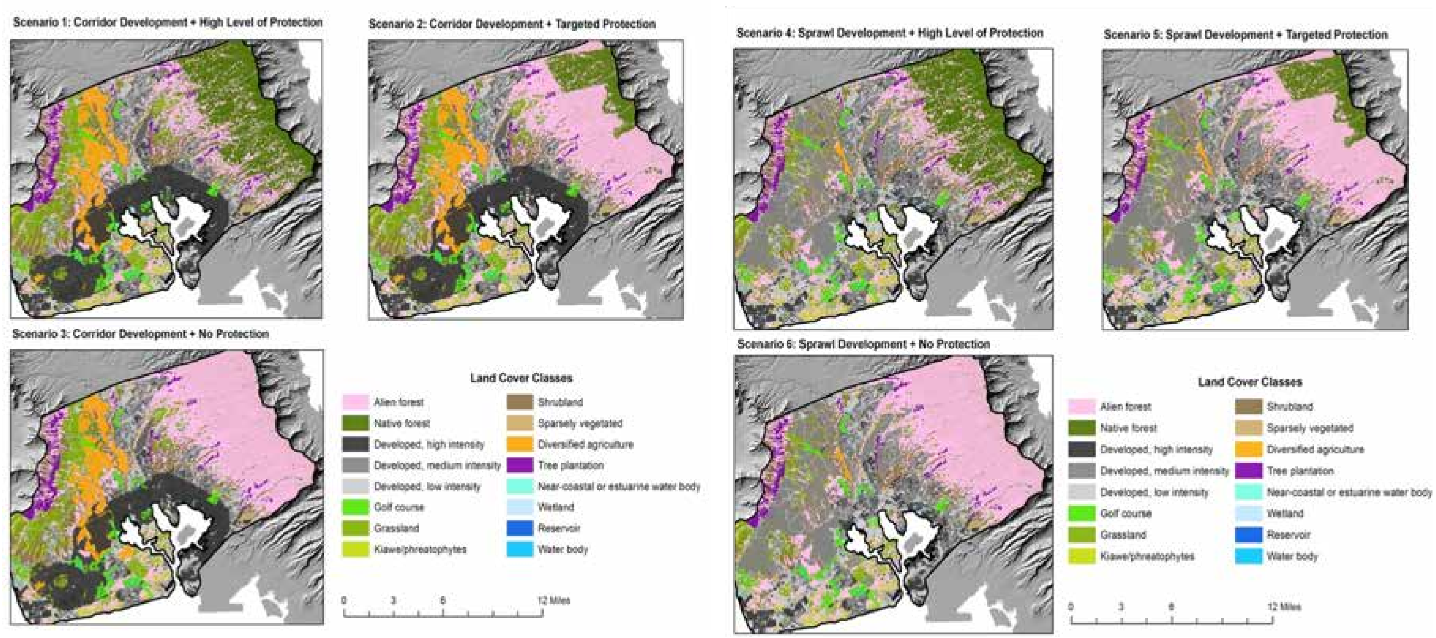


Figure 32: Development and conservation scenarios for the Pearl Harbor Aquifer

resulted in near complete conversion in 30 years without protection. Each of the conservation lands scenarios are crossed with corridor and sprawl development.

Integration of land use and climate change scenarios into the PH optimization model:

Working with the USGS, we have preliminary runs of our scenarios through the USGS water balance model (see Figure 33 below). These updated recharge rasters are being integrated into the optimization model (see Activity 2.3.2 below) in order to calculate the NPV of varying future land use and climate scenarios using a replacement cost methodology described in Activity 2.3.2.

Spring scenarios: We have made progress in integrating a spring discharge constraint into our modeling framework in Pearl Harbor. We developed an in-depth case study with Sumida watercress farm to develop a spring constraint and identify tradeoffs in pumping and spring flow. We are collaborating with IHLRT to produce a holistic understanding of Sumida Farms under current and past conditions and to provide information relevant to their future. We conducted several stakeholder interviews with the Sumidas and the Commission on Water Resources Management. In addition to the economic values associated with crop production, we encountered other values relevant to community in Hawaiʻi and the public trust doctrine. The following quotes are from an interview with the Sumida family:

Natural heritage/sense of place: *"There's a big emotional attachment to this spot here cause we grew* *up here, our parents worked here, and even our kids, even though they didn't really grow up here on the farm, they're starting to realize that they also have a strong tie to the farm."*

Community/ existence value: *"Yeah, besides the value of the crop, it has social value... even that shack! If we were to tear down that shack over there, the outrage!"*

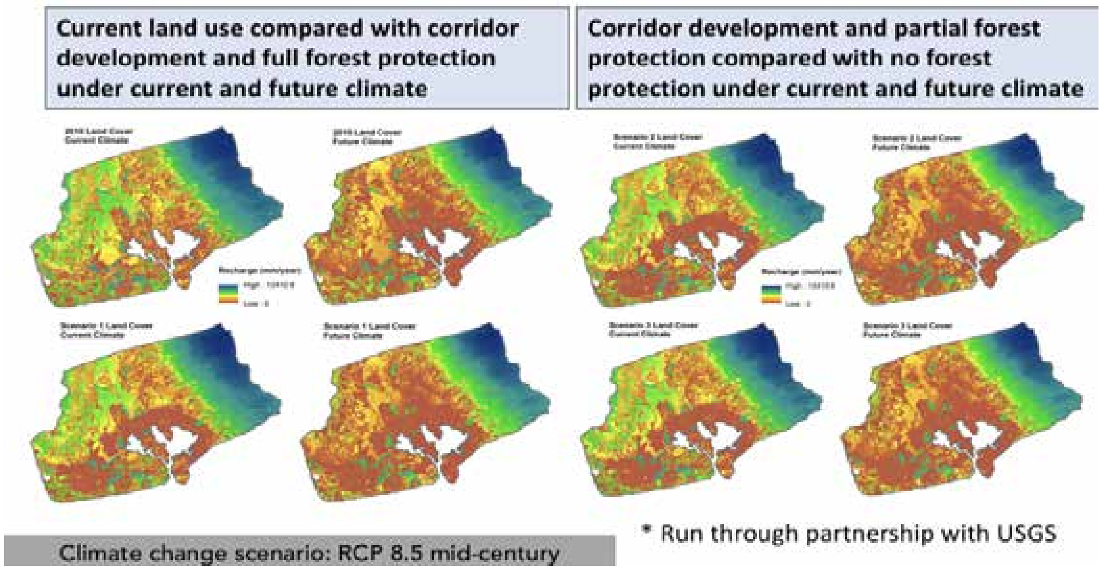


Figure 33: Subset of recharge estimates generated by USGS water balance model. A total of 12 scenarios were run (6 land use scenarios and 2 climates (current and RCP 8.5 mid century).

Figure 34: John and Barbara Sumida, Community Partners

We are working to incorporate the value of this farm into our optimization framework as a constraint. Thus far, we identified a spring-related constraint in the literature (McHugh et al. 1987):≥ 1,000,000 gallons/acre/day spring flow, Chloride ≤ 1,000 ppm which aligns with the information provided to us by the Sumidas during the interview:

"Our dad told us at one time there was about 10 million gallons of fresh water coming through the land per day then down to about 5 millions gallons per day. I don't know how he measured it, but when he was running the farm he had about 10 million gallons. Towards the 90's, his guess was about 5 million. He estimated by looking around and seeing where it wasn't growing as well as it used to. Eyeball calculation."

This case study will be used to communicate the broader importance of understanding the tradeoffs between pumping and spring flow in the PH aquifer and beyond. This tradeoff curve was shown to a CWRM representative who responded that this was exactly the right way to look at this and that this type of tradeoff analysis is critical to their ability to make decisions.

Kona: We have completed the literature review of the economic, social, and cultural values of GDEs in Kona, which included the review of 42 articles, reports, and archival documents and have a completed analysis of the Hawaiian newspaper translations that are related to GDEs. ʻIke Wai co-sponsored a workshop on GDEs with CWRM in November 2018 . The symposium focused on: traditional and customary practices, historic and current biota in GDEs adaptive saltwater tolerances current data on water-level changes, salinity fluctuations, and SGD Information on the symposium can be found here: http://accord3.com/pg1028.cfm A graduate student is conducting key informant interviews with GDE managers to understand their current values and engage the community in our analysis. 15 interviews will be completed by the end of February 2019 and a publication submitted on the value of GDEs in Kona submitted by December 2019.

We are also selecting key species/ecosystems of interest to focus our modeling (with the KBA model) study on. Key species of interest to community members include the endemic red shrimp (‘opae ula), mullet, and several native algal species. We are working with a graduate student to determine their nutrient, salinity, and other ecological tolerances to be able to project how various scenarios of pumping, climate change, and land management will affect these species and ecosystems, which we have identified as important culturally and economically.

Outputs:

KONA: Review of GDEs completed; stakeholder interviews summarized (stakeholder interviews to be completed by March 2019 and summarized by May 2019)

PH: Key stakeholder interviews transcribed; spring scenarios defined.

Outcomes:

KONA: Review of GDEs and information gathered from stakeholder interviews will be used to define GDE scenarios for eventual inclusion in the KBA model (Activity 2.2.6) in Year 4 (in progress for completion by Year 3 end)

PH: Defined spring scenarios integrated into the Pearl Harbor optimization model (Activity 2.2.5b).

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

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

Results:

Pearl Harbor: Through an iterative process with CWRM and USGS, we refined the set of wells to include in the optimization. Elshall included optimization for a salinity and head drop constraint and is currently working to also integrate a spring constraint and incorporate land use and climate scenarios (see activity 2.2.8). Figure 35 shows the spatial distribution of maximum SY with all springs restored to pre-industrial levels, indicating a major tradeoff between pumping and spring protection. Updated maps will be available in the next month and will be submitted to publication by May 2019.

We start with current withdrawals (117 mg) (column 1, table 2 then assume various growth in consumption rates and use this to calculate potential future consumption needs in 50 years (column 3). Each scenario is then associated with a maximum sustainable yield based on the optimization model outputs (with the objective to identify the maximum withdrawal without violating salinity and head drop constraints; column 4). From this a shortfall, we can calculate where maximum SY is less than the consumption needs (column 5). We then assume a unit replacement cost based on desalination and/or other groundwater alternative(s) (column 6), which translates to total replacement costs (column 7).

Replacement costs for different land use scenarios can then be compared to estimate potential benefits of watershed investment decisions. For example, the difference between groundwater replacement costs for targeted forest protection and no forest protection represents the benefit (avoided cost) generated by targeted native forest protection.

Kona: We completed an analysis of watershed conservation costs in Kona which we combined with recharge modeling to generate management recommendations for Hawaiʻi DWS on cost-effective watershed investments. This information will be run as a scenario in the KBA analysis to evaluate the economic benefit in terms of avoided pumping restrictions and/or impacts to GDEs. We began to

Current withdrawals (mgd)	Consumption growth rate	Consumption in 50 years (mg	MSY from optimization simulation (m	Shortfall (mgd)	Unit replacement cost ($/tg)	Total replacement cost ($/yr)
Scenario 1 (RCP 8.5; corridor development + high level of forest protection)						
117	1.00%	193	260	0	8	$0
117	1.50%	248	260	0	8	$0
117	2.00%	318	260	58	8	$169,360,000
Scenario 6 (RCP 8.5; sprawl development + no forest protection)						
117	1.00%	193	240	0	8	$0
117	1.50%	248	240	8	8	$23,360,000
117	2.00%	318	240	78	8	$227,760,000

Table 2: framework for calculating future groundwater replacement costs of each scenario.

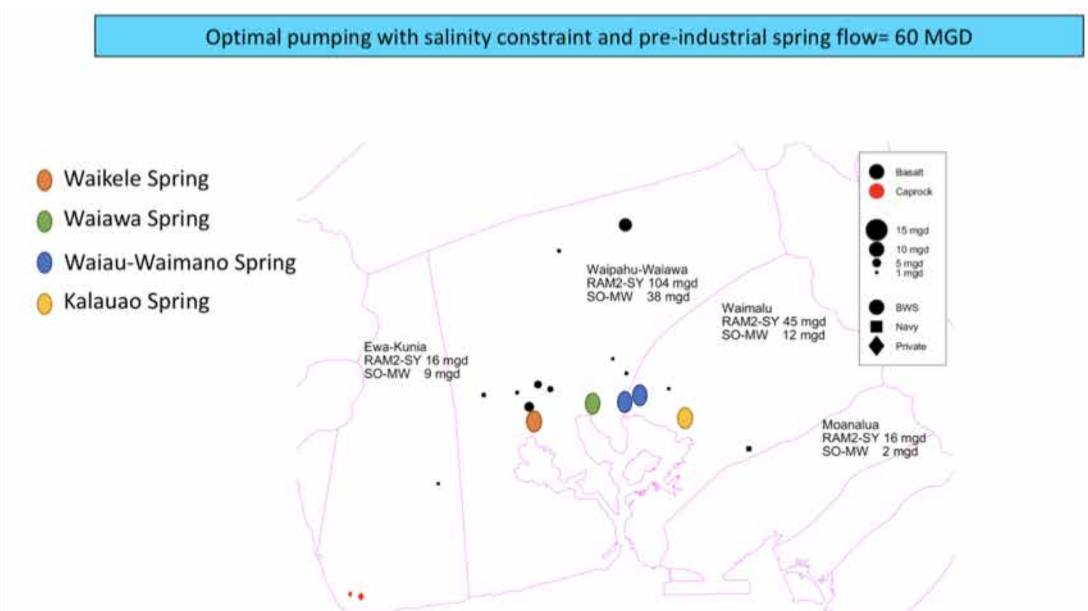


Figure 35: Maximum allowable pumping with spring constraints at pre-industrial levels. This would require pumping to be halved, which represents an important tradeoff. Further analyses are refining this tradeoff.

estimate a water demand function for Kona using billing data from ~8,000 households supplied by the Hawaiʻi DWS system. We exploit the difference in the price of water between homes with cesspools and homes with sewer connections to estimate a residential water demand curve. Preliminary results from a propensity score matching approach suggest the price elasticity of demand for water (i.e. the responsiveness of water users to changes in price) in Kona is -0.315. With this number, we can estimate the total change in water use if all homes currently on cesspools in Kona were converted to sewer. We estimate this to be a reduction of about 8 million gallons per month.

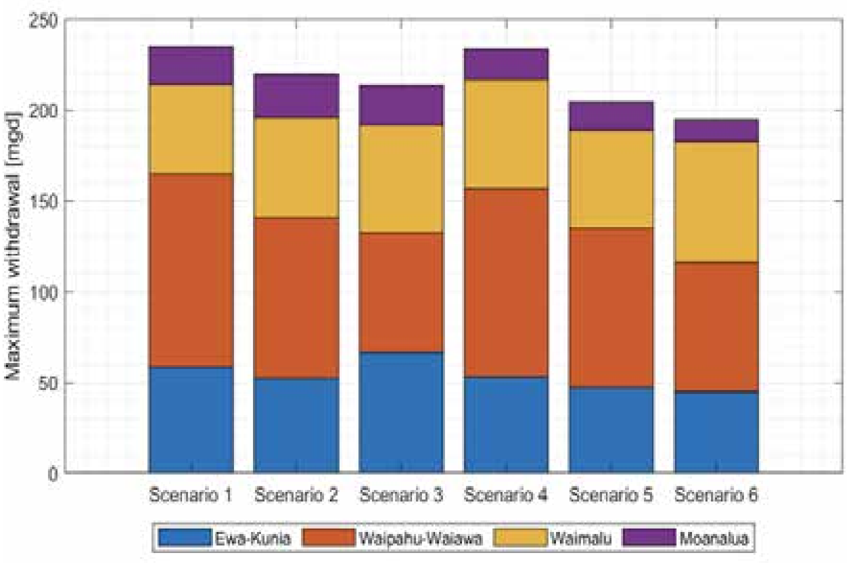


Figure 36: Preliminary results of maximum allowable withdrawal given varied recharge under different land use scenarios given salinity and head drop constraints. Note, current climate results shown only.

The benefits of converting homes with cesspools are twofold: first, the change in infrastructure will lead to wastewater being more thoroughly treated before it is discharged. Additionally, this conversion is likely to reduce overall water use due to the increased cost of sewer imposed on customers. How much consumption is reduced depends on consumers' sensitivity to water prices.

We are working with the modeling team to integrate the economic analysis into the KBA groundwater model. The integrated model will then be used to estimate the corresponding effect of cesspool conversion on water quality, both at drinking wells and along the coast. Because a one-time conversion of the ~6,500 cesspools in Kona is cost-prohibitive, our results will help to prioritize conversions and inform a more pragmatic long-term strategy.

Outputs:

KONA: Water demand function estimated using household billing data.

PH: Maps of maximum allowable pumping under defined spring scenarios (Activity 2.3.1) from simulations using GW model (Activity 2.2.5b).

Outcomes:

KONA: Estimated demand function will be used to evaluate welfare (net present value) implications of protecting GDEs in Year 4.

PH: Decision makers have information on optimal pumping under varying constraints, including established spring constraints. At least 1 presentation delivered to decision makers on optimal pumping under varying constraints.

Risks and Mitigation Plan: One risk is delays in getting recharge estimates from USGS. We have developed a plan B approach to estimating GW recharge using a statistical model of evapotranspiration (published in Bremer et al. 2018 and Wada et al. 2017) translated to water balance approach.

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

Results: We completed a study in collaboration with Hawaiʻi Island DWS, several watershed partnerships, and Hawaiʻi Community Foundation to produce cost effectiveness maps of watershed investments. To produce the maps, we dynamically modeled counterfactual scenarios of invasive forest spread in the absence of conservation activities and calculated the change in evapotranspiration and recharge using a statistical model developed by our team (see Wada et al. 2017). We produced priority investment maps based on which areas would result in the greatest avoided loss of recharge (Figure 38). We also gathered watershed conservation costs and overlaid these to create maps of cost effectiveness (Figure 39). We have presented this information through formal presentations and technical reports to the Hawai‘i Community Foundation, DWS, and watershed partnerships and are now working on expanding the areas and including the benefits of restoration of pasture areas.

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

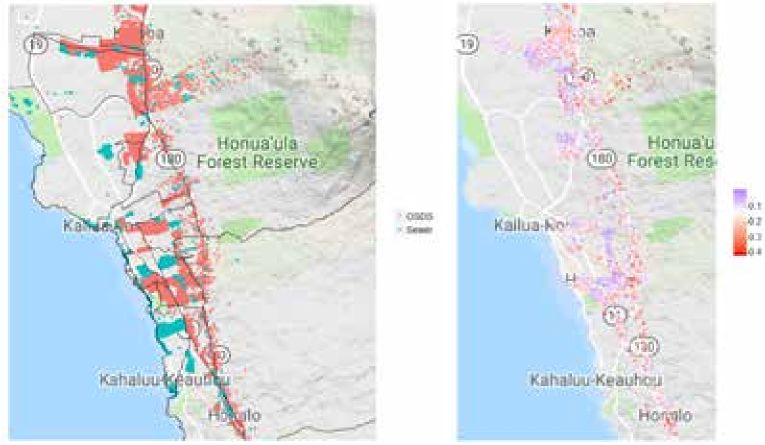


Figure 37: Left : Distribution of sewer and cesspools in Kona, Right: Predicted change in water use after switching to sewer from cesspools.

Outputs

KONA: Results from recharge benefit analysis highlight potential priority areas for decision makers and serve, together with documented conservation costs, as input for the cost-effectiveness analysis to be

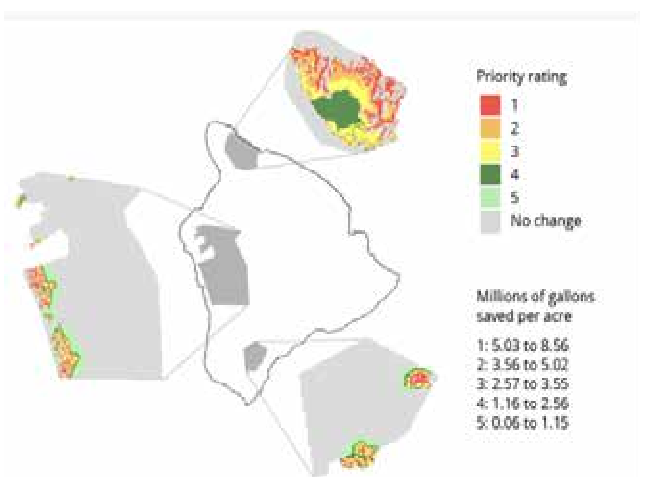


Figure 38: Priority maps in DWS priority areas based on groundwater recharge protected.

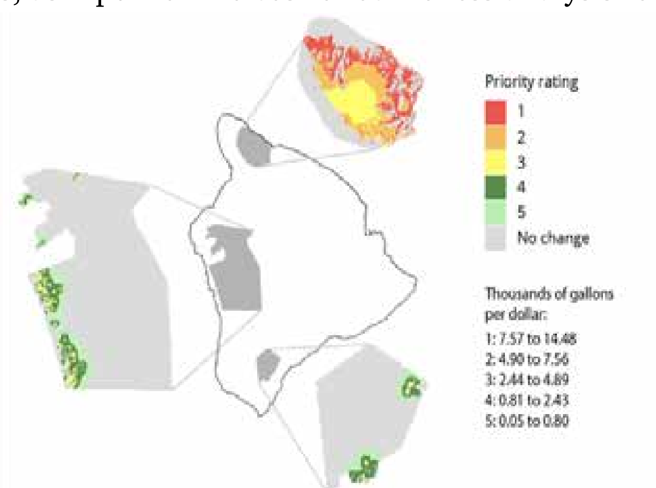


Figure 39: Priority maps in DWS priority areas based on cost-effectiveness.

completed in Year 4. Maps of recharge benefits under varying watershed conservation investments are completed; watershed conservation costs documented.

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 4.

Objective 2.4. Community Engagement.

Activity 2.4.1: Agency Outreach and Access Agreements. (Chun)

No new Agency Agreements were formalized in Year 3 but after two years of effort progress was made in securing field access for deployment of precipitation collectors on Kamehameha School (KS) land in West Hawai‘i. KS has approved our request in concept which now needs to be finalized in the form of a right-of-entry. The Social Science Team also secured extramural funding from the Hawai‘i County Department of Water Supply to expand their economic modeling in West Hawai‘i to include watershed protection investments. We also began outreach to land owners and potential collaborators in the Kunia sector of the Pearl Harbor aquifer and have secured the cooperation of the Hawai‘i Agricultural Research Center that owns lands and has strong relationships with other landowners and private water system operators in the region. They have volunteered to assist with us introductions. After pursuing multiple pathways still no progress has been made in securing an agreement with the Honolulu Board of Water Supply. This has hindered geochemical data collection in the Pearl Harbor aquifer.

Mitigation Plan: Geochemical data collection on O’ahu, and geophysical data collection on both O’ahu and in West Hawai’i, are behind schedule. Regarding O’ahu geochemical data collection, securing the cooperation of the Honolulu Board of Water Supply may require engaging the State Science and Technology Committee to exert their political influence. Regarding the geophysics, field work plans for both regions remain incomplete before we can request access and need to be given priority.

Activity 2.4.2: Establish Water Resources Advisory Committee (WRAC). (Chun) Per our Year 2 report this activity was combined with Activity 2.4.3 and was deleted as a stand-alone activity.

Activity 2.4.3: Identify stakeholder decision-support needs. (Chun, Lautze, Burnett) This activity was combined with the development of the landuse/recharge decision support tool in collaboration with USGS. USGS and the ‘Ike Wai team participated in three stakeholder review meetings to discuss improvements to the tool. Review and feature refinementment will continue in Year 4.

Activity 2.4.4: Establish Interagency Data Committee. (Chun, Lautze, Burnett, Jacobs) Key stakeholders provided advice and feedback to ‘Ike Wai team members as part of their projects. The Social Science Team meets regularly with CWRM and DWS as part of their modeling efforts. Data sharing agreements are in draft form.

Activity 2.4.5. Negotiate, document, and manage landowner agreements. (Chun) Landowner agreements in the Hualālai Aquifer have been secured with, Queen Lili’uokalani Trust, Palani Ranch, Huehue Ranch, 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 O‘ahu 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. (Chun)

We continue to strengthen our existing relationships through individual and small group outreach. A community update was conducted by the geochemical field team on August 7, 2019 at NELHA that was well received. A new collaboration has been developed by the field team with Sumida Farms on O'ahu where water sampling is occurring. Sumida Farms is an urban agricultural enterprise nearly 100 years old that grows watercress which is highly dependent on spring fed sources in the Pearl Harbor aquifer. This data will be used to inform both the hydrological and economic models being developed for Pearl Harbor.

Mitigation Plan: None needed.

Activity 2.4.7. Conduct General Education and Disseminate Information. (Frank, Chun, Aga)

Results: During Year 3 team member made presentations to multiple community groups, meetings and agencies including: EPSCoR State Conference, Kaʻūpūlehu Marine Advisory Council Meeting, Hawaiʻi Conservation Conference, ʻIke Wai update at the Natural Energy Laboratory of Hawaiʻi Authority (NELHA), Water Resources Research Center (WRRC) seminars, Kiholo Fishpond Community workday presentations, and Commission on Water Resource Management (CWRM) Symposium. Written dissemination materials that 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, Geochemical Tracer Team coloring book to contextualize summary data for stakeholders (Figure 40). General dissemination has been via the ʻIke Wai website and social media channels (instagram: @hawaiiEPSCoR, @labhuiofrank, #ikewaiEPSCOR Youtube: #BOSSdancefriends), as well as the subject of a 'Voice of the Sea' one-hour documentary.

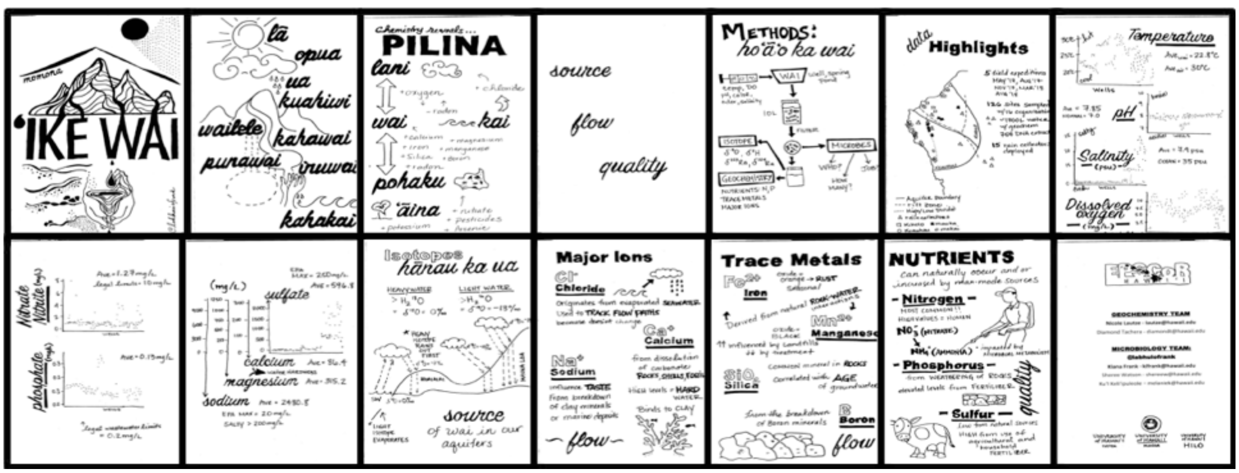


Figure 40: Geochemical tracer team coloring book that contextualized the collected data to date in Y3 for the community and links into the Hawaiian world view.

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

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

Activity 3.1.1: Undergraduate Research. (Bruno, Pelayo)

Results: During Year 2, 23 undergraduate Scholars were trained to conduct research at KCC, UH Mānoa and UH Hilo. The Oʻahu (UH Mānoa and KCC) projects focused on water science, UH Hilo projects focused on data science. Website portals to accept Scholars applications have been updated and revised, which led to a highly diverse applicant pool. Our success in meeting our demographic targets is due in part to recruiting partnerships that were developed during Years 1 and 2 and strengthened during Year 3 with Native Hawaiian-serving programs, particularly Kapiʻolani Community College's Native Hawaiian Advancement Office and UH Native Hawaiian Student Services. We anticipate student diversity will remain high in future cohorts of undergraduate scholars.

The 16 Oʻahu-based Scholars were hired at 3 levels: 8 Trainees, 6 Interns and 2 Fellows. The 8 trainees participated in a group research project through a newly developed course at KCC. In Fall 2018, Dulai and Engels team-taught SCI295 at KCC for 8 students (Trainee-level Scholars). The classes consisted of lectures and discussions on water resources and their cultural relevance and current issues, as well as hands on field and laboratory training in hydrology and water quality testing. The students presented on their research projects in December 2018 at the KCC Student Undergraduate Research Fair (SURF).

The 6 Interns and 2 Fellows each have individualized, closely mentored research projects. The Fellows are seniors who served as research interns in prior years. As Fellows, they serve as peer mentors and role models for the Interns and Trainees. Both fellows will be graduating in May 2019 and have applied to graduate school. The 8 interns and fellows delivered poster presentations on their research results at an ʻIke Wai symposium held on the Mānoa campus in May 2018. Mitigation Plan: None needed, on track for Year 3.

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

Results: Eight PD workshops were offered in Spring & Fall 2018. All workshops are run in partnership with Native Hawaiian Student Service and incorporate a culture/science focus. Workshop topics include traditional Hawaiian land divisions, water-related place names within ahupuaʻa, translating Hawaiian language newspaper articles with a focus on fresh water, water use and management in traditional Hawaiian culture, the role of water-related laws in today's state agencies, and forecasting future directions for water use in Hawaiʻi. The final professional development workshop of Spring 2018 was a student symposium (mentioned under Activity 3.1.1 above).

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

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

Activity 3.2.1: Oʻahu Summer Bridge for rising sophomores. (Bruno, Pelayo)

Results: In May 2018 we developed and delivered a field-based summer bridge program between Kapiʻolani Community College (KCC) and UH Mānoa based on ʻIke Wai research covering four main content areas: (1) Hawaiian culture and community; (2) Geology; (3) Hydrology; and (4) College/ Careers. The teaching team (recruited and trained in Spring 2018) included ʻIke Wai graduate students and faculty in geoscience, data science, engineering and Hawaiian language. Our partners at KCC's Native Hawaiian Advancement Office recruited 20 students, with diverse majors ranging from Hawaiian studies to various STEM disciplines, and 5 peer mentors who served as teaching assistants. The peer mentors were all program alumni and many were ʻIke Wai Scholars. The summer bridge program is part of pathway through which we recruit KCC students into undergraduate ʻIke Wai Scholars program and SOEST majors. May 2018 summer bridge students became Fall 2018 (and Spring 2019) Trainees (SCI 295 students), and will be recruited as May 2019 summer bridge mentors.

Our KCC partners are currently recruiting students and peer mentors for the Year 3 program.

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

Activity 3.2.2: Hilo Summer Bridge for rising freshmen and sophomores. (Bruno, Eason)

Results: In Summer 2018, Pelayo updated the curriculum for Hilo Summer Bridge program. For 5 weeks in June - July 2018, ten high school and UH Hilo students participated in the intensive bridge experience, which they earned credit-bearing Mathematics and Computer Science courses: PreCalculus or Calculus 1 and a Fundamentals of Data Science in R course. 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 Data Science Fundamentals in R course was taught by Drs. Mike Peterson and Keith Edwards from the UH Hilo Computer Science department.

New in Summer 2018 was in the inclusion of the Hilo Bridge Research program, which headed by Mandel and Weyenberg. Ten UHH students participated in a 5-week research experience that exposed students to topics in Machine Learning. Weyenberg's project including using neural network techniques to automate detections in songbird recordings of an endangered species endemic to Hawaiʻi island. Mandels' project focused on obtaining data and utilizing machine learning techniques to optimize educational games.

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 postdocs. (Bruno, Eason)

Results: Training sessions were held each term for all incoming ʻIke Wai graduate students and postdocs on how to create an effective IDP. All graduate students and postdocs are required to complete an IDP within 60 days of hire. As of Dec 2018, we have 100% compliance: all 14 active graduate students and postdocs have completed IDPs, for a running total of 19 graduate students and postdocs with IDPs over the course of the project. A key outcome of this self-assessment of job-related skills/experience and career goals is enhanced awareness of the additional skills and experience needed to obtain their professional goals.

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

Activity 3.3.2: Mentoring Cascade. (Bruno, Eason)

Results: All ʻIke Wai graduate students and postdocs participated in the mentoring cascade as mentees. All 14 active (plus 5 previous) graduates students and postdocs have selected PD mentors from a list of ʻIke Wai faculty and staff members outside their research group/field. Mentoring workshops are held once a term (March and November 2018) to train new mentors in effective ways to provide feedback and support to their mentees as they develop their IDPs. These workshops also serve as a safe space to discuss mentoring challenges and successes.

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, Postdocs, Faculty and Staff.

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

Results: We have revised the cohorted training to include fewer external facilitators (e.g., COACh), and instead are focusing on in-house professional development workshops. Remaining workshops from external facilitators include: two pedagogy workshops conducted by External Consultant Dr. Sarah Sherman of the Carl Wieman Science Education Institute in February 2018, including Metacognition (aimed primarily at Faculty) and Teaching & Learning fundamentals (for graduate students and postdocs). 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 oral communication skills. Moving forward, a series of workshops focused on data management and data visualization skills are being developed in coordination with the Hawaiʻi Data Science Institute for Spring 2019 and Years 4-5.

Risks and Mitigation Plan: None needed, on track for Year 3. Through external funding (Bruno's IUSE Geopaths grant), Dr. Sherman will be funded in Spring 2019 to deliver two pedagogy workshops (one for faculty and one for ʻIke Wai graduate students and postdocs).

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

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

Results: Dr. John Burns joined the UHH faculty as a tenure-track assistant professor in the Marine Science department August, 2018. Dr. Burns has successfully created one Data Science Course, Mare 375 - "Applied Informatics". Dr. Burns is mentoring undergraduate and graduate students in Marine Science and Data Science optics, frequently utilizing 3D models of Hawaiʻi corals and computer vision techniques to automate measurements and data collection.

The fourth and final recruitment for an "Assistant Professor of Data Science in Business/Economics" is underway, review of applications were completed Dec. 2018. This new his new hire will be an expert in Predictive Analytics and contribute two new Data Science courses to the overall curricular efforts and will be housed in the College of Business and Economics (CoBE). The successful candidate will join the faculty in August 2019.

Risks and Mitigation Plan: None needed, on track for Year 4

Activity 3.5.2: Develop a Data Science Pathway. (Pelayo)

Results: The UHH Data Science Education Advisory Board includes Burns, Weyenberg, Mandel, Pelayo and existing faculty members Drs. Edwards and Peterson (Computer Science). The Advisory Board began developing 300- and 400-level courses in Data Science, which were approved late in 2018. The newly developed courses are: CS 370 - "Data Management", CS 373 - "Data Security and Privacy", Math 371 - "Multivariable Modeling with R", and Mare 375 - "Applied Informatics". The Advisory Board has also been working with administration and several departments to develop the Authorization to Plan (ATP), the primary step in developing the Data Science B.S. degree. This is expected to be submitted in early 2019.

Risks and Mitigation Plan: None needed, on track for Year 4.

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

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

Results: The ʻIke Wai Community Engagement Packet created in February 2018, contains a primer on the project, maps of study sites and Hawaiian translations and other geo-coded information. This is a must-read resource to ʻIke Wai students and faculty. We are now working to develop new (as well as compile existing) resources to support faculty as they integrate place and community into their pedagogy (see 3.7.1 below). One partnership has been developed with the Hawaiʻi Department of Health, and one undergraduate who interned during Summer 2018 is now on a pathway to getting a full-time permanent job. Hawaiʻi will host the 2019 meeting of the Society for the Advancement of Chicanos and Native Americans in Science (SACNAS). This meeting will be a superb venue to showcase ʻIke Wai to private industry and government agencies. Three ʻIke Wai Members (Bruno, Tachera, Watson) are on the SACNAS conference planning committee.

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

Activity 3.7.1: Educational Research. (Bruno, Eason)

Results: We are on track for submission of 2 manuscripts to peer-reviewed journals on (1) active pedagogical techniques (based on the Classroom Observation Protocol for Undergraduate STEM (COPUS)) and (2) Place- and Community-based teaching. Both manuscripts focus on undergraduate instruction at UH Manoa. (1) We collected and analyzed data relating to 64 COPUS observations and (2) We conducted a baseline survey of students and faculty in Fall 2018 and have analyzed the data, which resulted in a comprehensive understanding of students and faculty needs.

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

IV. Solicitation-Specific Project Elements

A. Workforce Development: Workforce development efforts during the reporting period have focused on research and professional development training for undergraduates (Objectives 3.1-3.2), graduate students and postdocs (Objectives 3.3-3.4) and faculty/staff (Objectives 3.4-3.5). The goals, objectives and activities associated with these workforce development programs are detailed immediately above in Section III. A key part of faculty-level workforce development is establishing and filling new tenure-track positions at UH Mānoa and UH Hilo to build capacity in water science and data science, respectively. This brings new expertise into the UH system, enabling the creation of new undergraduate and graduate training programs and ultimately resulting in the development of a diverse, local workforce equipped to tackle pressing challenges such as ensuring Hawaiʻi's future water security. To date, 6 of 7 tenure-track faculty positions have been filled. The remaining position is in data science and is on track to be filled in project Year 4, in accordance with the strategic plan (See Faculty Hiring Update on p. 10).

B. Diversity: Broadening participation is integral to the ʻIke 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 Hawaiians and Pacific Islanders (NHPI). We are making excellent progress toward these targets, as our undergraduate Scholars cohort includes 47% women and 72% URM (including 31% NHPI). We have established a recruiting partnership with several programs to reach out to Native Hawaiian undergraduates to join our summer bridge and undergraduate Scholars programs, including the Kapiʻolani Community College Native Hawaiian Advancement Office and UH Native Hawaiian 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/postdoc cohort comprises 57% female and 48% URM. These hires were broadly advertised through local and national minority-serving organizations, including UH Native Hawaiian Student Services, Institute of Broadening Participation, Society for Advancement of Chicanos and Native Americans in Science (SACNAS), the American Indian Science and Engineering Society (AISES) and the NSF Science and Technology education and diversity listserv.

Our commitment to diversity is reflected in our core values and the demographic makeup of the leadership team, which is 54% female and 54% URM. We are actively mentoring and supporting women faculty, in addition, we support the dissemination and advancement of Native Hawaiian cultural insights and traditional/historical knowledge both within and beyond the ʻIke Wai project. For example, IHLRT has offered olelo Hawaiʻi (Hawaiian language) workshops to a diverse group of faculty, staff, students and administrators during Year 2.

Role in Project	Total Participants	% Female	% URM
Faculty participants	29	45%	38%
Technical support staff	11	27%	18%
Non-technical staff	3	100%	67%
Post docs	5	40%	20%
Graduate students	16	63%	56%
Undergraduate students	36	47%	72%
RII Leadership Team	13	54%	54%
Overall Total	102	54%	57%

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

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

- **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.
- **Hawai'i Community Foundation** – There are opportunities to develop an ongoing strategic partnership with HCF, one proposal is for collecting existing water legacy data in the State not included in agency data and the second is to develop a methodology for determining ROI on watershed conservation. These are unanticipated opportunities arising post-award.
- **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.
- **Hawai''i 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.
- **Kohnana'iki Resort (KR)** - Land/well owner; study site access and data sharing.
- **Queen Lili''uokalani 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.
- **Department of Hawaiian Homelands community of Kailapa, and the Richardson School of Law (University of Hawaiʻi):** collaboration initiated to assess water resources as part of the Māhukona aquifer system.
- **Puʻu Waʻawaʻa Ranch (PWR)** - Land/well owner; study site access and data sharing.
- **HI-SEAS** - Land owner; study site access and data sharing.
- **Mauna Loa Observatory (MLO)** - Land owner; study site access and data sharing.
- **Office of Mauna Kea Management (OMKM)** - Land owner; study site access and data sharing.
- **Department of Fish and Wildlife (DOFAW)** - Land owner; study site access and data sharing.
- **The Nature Conservancy** - Land owner; study site access and data sharing.
- **Hualālai Resort** - Land owner; study site access and data sharing.
- **Huehue Ranch** - Land/well owner; study site access and data sharing.
- **Napuʻu Water Inc. (NW)** - Land/well owner; study site access and data sharing.
- **Hawaiʻi Water Service (HWS)** - Land/well owner; study site access and data sharing.
- **West Hawaiʻi Landfill (WHL)** - Land/well owner; study site access and data sharing.
- **Makani Golf Club (MGC)** - Land/well owner; study site access and data sharing.
- **Hui Aloha Kiholo** - Study site access and data sharing
- **Kaʻūpūlehu Marine Advisory Council** - Study site access and data sharing
- **Kaʻonohi Farms** - Land owner, study site access and data sharing
- **Sumida Farms** - Land owner, study site access and data sharing

D. Collaborations: During the reporting period ʻIke Wai researchers were involved in 12 collaborations across ten institutions and 21 collaborators. In Year 3 we continued our collaborations with:

- **USGS Pacific Island Water Science Center:** Groundwater Modeling & USGS Pearl Harbor Groundwater Management
- **Texas Advanced Computing Center (TACC):** Ike Wai Gateway Software Development
- **University of British Columbia (SEI):** Pedagogy Training
- **COACh:** Career Building Workshops
- **Department of Water Supply (Hawaiʻi Island):** Return on Investment on Watershed Conservation

During Year 3 ʻIke Wai researchers initiated the following collaborations:

- **East West Center-Pacific RISA:** Land-use scenario research
- **Science Gateways Community Institute:** SGCI Usability
- **Bishop Museum/ UH Manoa:** Understanding environmental stressors and deep reefs to support management of Papahanaumokuakea
- **Scripps Institution of Oceanography (UCSD, SIO):** CSEM Survey*

The following Collaborations were completed during Year 3:

- **Texas Advanced Computing Center (TACC):** AGAVE Platform Development
- **Science Gateways Community Institute:** Science Gateways Bootcamp*

*Started and finished in Year 3

E. Sustainability

Continued funding beyond the five-year duration of this award is essential for expanding the scope of our water resources research and our continued engagement with the community. During the award period, a record number of 41 proposals were submitted by ‘Ike Wai faculty.

Awards totaling $14,484,880 were received by ‘Ike Wai faculty during the reporting period. The vast majority of those awards ($10,699,500) were to 3 highly experienced senior faculty (Jacobs, Lerner, Leigh). We are proud to report that three ‘Ike Wai faculty hires successfully competed for a total of $1,510,151 during the reporting period:

- Nicole Lautze: 2 awards, $843,784
- John Burns: 2 awards, $541,417
- Leah Bremer, 2 awards, $124,950

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 three. As reported in Section B: Diversity (p.47) we are striving for an participation profile for undergraduates of 75% women and 50% underrepresented minorities (URM), including 25% Native Hawaiians and Pacific Islanders (NHPI) and Graduate and Post-doctoral participants of 50% women and 25% URM. We are making excellent progress toward these targets, as our current undergraduate Scholars cohort includes 47% women and 72% URM (including 31% NHPI) and our graduate/postdoc cohort comprises 57% female and 48% URM. Demographic data sorted by participating campus (Table 3) shows consistent success in the engagement of women and URMs at all campuses however we will focus on recruiting more women undergraduates at UH Hilo. The low personnel count at the UH System level with no new hires planned will make it difficult to improve diversity figures at that unit.

Institution or RII Track-1 Totals	Category	Total individuals in category	Male	Female	% Female	URM	% URM	Native Hawaiian	% Native Hawaiian
	Faculty participants	2	1	1	50%	0	0%	0	0%
	Technical support staff	5	3	2	40%	0	0%	0	0%
	Non-technical support staff	1	0	1	100%	1	100%	0	0%
UH System	Post docs								
	Graduate students								
	Undergraduate students								
	RII Leadership Team	2	1	1	50%	0	0%	0	0%
	Faculty participants	22	10	12	55%	9	41%	2	9%
	Technical support staff	5	4	1	20%	0	0%	0	0%
	Non-technical support staff	1	0	1	100%	1	100%	1	100%
UH Manoa	Post docs	5	3	2	40%	1	20%	0	0%
	Graduate students	16	6	10	63%	7	44%	4	25%
	Undergraduate students	14	6	8	57%	13	93%	8	57%
	RII Leadership Team	8	3	5	63%	5	63%	2	25%
	Faculty participants	5	5	0	0%	1	20%	0	0%
	Technical support staff	1	1	0	0%	1	100%	0	0%
	Non-technical support staff	1	0	1	100%	0	0%	0	0%
UH Hilo	Post docs								
	Graduate students								
	Undergraduate students	22	13	9	41%	9	41%	3	14%
	RII Leadership Team	1	1	0	0%	1	100%	0	0%
	Faculty participants	29	16	13	45%	10	34%	2	7%
	Technical support staff	11	8	3	27%	1	9%	0	0%
	Non-technical support staff	3	0	3	100%	2	67%	1	33%
RII total	Post docs	5	3	2	40%	1	20%	0	0%
	Graduate students	16	6	10	63%	7	44%	4	25%
	Undergraduate students	36	19	17	47%	22	61%	11	31%
	RII Leadership Team	13	6	7	54%	6	46%	2	15%
Program Total	All Participants	113	58	55	49%	49	43%	20	18%
External Advisory Board (EAB)		7	4	3	43%	0	0%	0	0%

Table 3: ʻIke Wai demographic data by participating campus.

VI. Expenditures and Unobligated Funds

The ʻIke Wai has been awarded $12M in the first three years of the project's cooperative agreement. As of December 31, 2018, total funds expended are $9,223,257. There are current outstanding purchase orders of $443,522 and encumbrances of $1,685,962 (salary, fringe, contracts, indirect costs). Together, these committed expenses of $11,352,742 represent 94.6% of all available funds. This is a significant increase from the 78.3% of available funds reported in the Year 2 annual report.

We currently have remaining funds of $647,470 or 14.8% of our Year 3 allocation of $4,367,000. Budget projections (not including encumbered funds reported above) include significant expenditures for the March sampling expedition to Kona, ongoing geochemical and genetic sample analyses, geophysics travel and training, and the purchase of a refurbished gravimeter (Lautze Research Initiation funds). Our budget projections forecast remaining funds of $476,418 (10.9% of Year 3 funds) on May 31, 2019.

VII. Special Conditions

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

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

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

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

Actions: Dr. Cliff Voss has served on our External Advisory Board since Year 1. In addition to attending our EAB meeting he has spent an additional week in one on one meetings with our young investigators.

VIII. Response to External Evaluation Recommendations

Recommendation 1. *Continue to Develop/Refine Internal Project Communication:*

Build improved processes to support better communication among/across project teams and members:

- Add dependencies with hard deadlines that cross project focus areas to project timelines and;
- Review existing and explore further means for sharing communication internally, such as a project newsletter and regular update letters from the director and administrator.
- Continue to refine and fine tune the ER Core database, consider what information is most desired, and provide support for participants to enter and update data on an ongoing basis.

Response: Maria Dumanlang has been hired as Communications Director and is starting in January 2019. Her duties include expanding the newsletter, developing new content for the website and improving internal communications. The ER-Core database has been updated to the new Drupal-8 version. The reporting interface is vastly improved and work is underway to improve data quality.

Recommendation 2. *Develop a Tactical Plan for Community Engagement*

Develop a detailed tactical plan for communicating and engaging with stakeholders, agencies,

and other communities. A comprehensive plan should:

- Reflect the variety of audiences and communication/engagement goals;
- Have clear messaging with a timeline detailing outreach activities and identifying specific groups/ individuals, and;

- Include training for all ʻIke Wai participants on relevant local history as well as the cultural and environmental perspectives and concerns of Native Hawaiians.

Response: We continue to implement the activities outlined in our strategic plan Objective 2.4: Community Engagement. The research teams continue to synchronize community outreach events around quarterly sampling trips to Hawaiʻi Island resulting in over 10 meetings with key community partners where strong relationships are built around discussions of research results and their meaning, scientifically and culturally, to the community. We partnered with the Committee for Water Resources Management (CWRM) to host the Adaptive Management Symposium on Groundwater Dependent Ecosystems at the Gateway Center at the Natural Energy Laboratory of Hawaiʻi (NELHA). The opening discussion, organized by the local Ahu Moku Advisory Committee (AMAC) composed of family members from the area with specific generational knowledge, focused on traditional and customary knowledge from the park's ecosystems. Panels discussed the current state of knowledge of Hawaiʻi aquifers and worked to identify what additional research might improve our water resource knowledge.

ʻIke Wai has hired a Communications Director, Maria Dumanlang, who is starting in January 2019. She will dramatically impact our ability to improve both internal and external communications.

Recommendation 3. *Regularly and explicitly revisit Core Project Values*

Given continued influx of new students, as well as new faculty and other hires who were not a part of planning processes, revisit the ʻIke Wai values regularly with the team in order to further build and strengthen shared understanding of and commitment to project processes and goals.

Response: We acknowledge the complexity of achieving the goals of this project as a truly integrated and high functioning team and we welcome the recommendation that we revisit our core values. The team has adopted four core values that will guide behavior and serve as a foundation for team efforts. We will work with the core value of Pono (what is right) to bring science and data to support decisions and communities in fairness, not advocating for one side or the other. By reviewing our core values at all-hands meetings at the beginning of each semester we expect improvements in team focus and cohesion with the adoption of these values.

Recommendation 4. *Foster and support further grant proposal development*

Given the importance of obtaining grant funding, both for individuals' career success and for the overall project, consider stronger and more focused professional development in this area for all ʻIke Wai participant groups. Perhaps explore the possibilities of engaging The Implementation Group in this endeavor.

Response: Each year a representative from The Implementation Group (TIG) visits all participating campuses in the UH System. In February 2018 Hawaiʻi EPSCoR hosted two proposal workshops. The first focused on training for graduate students, post-docs, and faculty on the main points of responding to solicitations and crafting a competitive proposal. This workshop was attended by 108 people and an additional 22 joined the workshop from 7 UH campuses across the state (62% Female, 25% URM).

In Year 3 a workshop focused on NSF CAREER proposals was added to further support grant proposal development for young and early career faculty. This workshop attracted 45 participants. (40 faculty, 5 staff, 35% Female, 18% URM)).

IX. Tabular/Graphic Representation of Progress to Date

		Year 1	Year 2	Year 3	Year 4	Year 5
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					
Activity		🔴	🟢	🟢		
Activity		🟡	🟢	🟡		
Activity		🟢	🟢	🟢		
Activity		🟢	🟢	🟢		
Activity		⚪	⚪	🟢		
Objective 1.2	Map groundwater flow paths and improve estimates of connectivity and flux in the Pearl Harbor and Hualalai aquifer systems using integrated isotope, biogeochemical, and submarine groundwater discharge data by the end year 5					
Activity		🟡	🟢	🟢		
Activity		🟡	🟢	🟢		
Activity		🟡	🟢	🟢		
Activity		🟢	🟡	🟢		
Objective 1.3	Produce datasets on physical and chemical parameters of groundwater by establishing novel sensor-based monitoring network in wells within targeted regions of the Pearl Harbor and Hualalai aquifer systems by the end of Year 3.					
Activity		🟢	🟢	🟢		
Activity		🟢	🟢	🟡		

		Year 1	Year 2	Year 3	Year 4	Year 5
GOAL 2: Develop a new data and modeling platform for Hawaii						
Objective 2.1	IKE Platform: Implement a fully featured data management, analysis, and visualization application based on the AGAVE software framework.					
Activity		🟢	🟢	⚪		
Activity		🟢	🟢	🟢		
Activity		🟢	🟢	🟢		
Activity		🟢	🟢	🟢		
Activity		🟢	🟢	🟢		
Objective 2.2	Data Store Population: Aggregate, annotate and store legacy, existing and new scientific data.					
Activity		🟢	🟢	🟢		
Activity		🟡	🟢	🟢		
Activity		🟡	🟡	🟢		
Activity		🟡	🟢	🟢		
Activity		🟡	🟡	🟢		
Activity		🟡	🟡	🟢		
Activity		🟡	🟢	🟢		
Activity		🔴	🟢	🟢		
Objective 2.3	Use economic modeling to forecast water availability, and qualify economic impacts of aquifer utilization.					
Activity		🟡	🟢	🟢		
Activity		🟡	🟡	🟢		
Activity		🟡	🟢	🟢		
Objective 2.4	Community Engagement					
Activity		🟢	🟡	🟡		
Activity		🟡	🔴	⚪		
Activity		🟢	🟢	🟢		
Activity		🔴	🔴	🟡		
Activity		🟢	🟡	🟢		
Activity		🟢	🟢	🟢		
Activity		🟢	🟡	🟢		

		Year 1	Year 2	Year 3	Year 4	Year 5
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						
Objective 3.1	ʻIke Wai Scholars Program: Undergraduate research and professional development.					
Activity		🟢	🟢	🟢		
Activity		🟢	🟢	🟢		
Objective 3.2	Summer Bridge Programs: Attract early undergraduates to ʻIke Wai-related STEM fields by developing & implementing summer bridge programs.					
Activity		🟢	🟢	🟢		
Activity		🟢	🟢	🟢		
Objective 3.3	Individual Professional Development: Create and implement individualized professional development plans for graduate students and postdocs, and Mentoring Cascade.					
Activity		🟢	🟢	🟢		
Activity		🟢	🟢	🟢		
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		🟢	🟢	🟢		
Objective 3.5	Data Science: Establish two academic programs at UH Hilo in Data Science, a certificate and a BA in data analytics.					
Activity		🟢	🟢	🟢		
Activity		🟢	🟢	🟢		
Objective 3.6	Business and Community: Connect ʻIke Wai to business and community.					
Activity		⚪	🟡	🟢		
Objective 3.7	Education Research.					
Activity 3.7.1		⚪	⚪	🟢		

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

Appendix A: Abbreviations and Hawaiian Language Terms

A-bay	Anaehoʻomalu Bay
AGU	American Geophysical Union
AMT	Audio-Magnetotellurics
BWS	Board of Water Supply (Honolulu)
CI	Cyberinfrastructure
CKAN	Comprehensive Knowledge Archive Network
COACH	Council of Academic Chemists
COE	College of Engineering
CSEM	Controlled-source Electromagnetic
CSS	College of Social Sciences
CWRM	Commission on Water Resource Management
CWSEI	Carl Wieman Science Education Initiative
DLNR	Department of Land and Natural Resources
DOFAW	Department of Fish and Wildlife
DROP	Down-well Remote Operating Platform
EAB	External Advisory Board
EPA	Environmental Protection Agency
FWAC	Fresh Water Advisory Council
G&G	Geology and Geophysics
GDE	Groundwater-Dependent Ecosystems
GW	Groundwater
HCF	Hawaiʻl 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 Hawaiian Language Research and Translation
IKE	Integrated Knowledge Environment
ITS	Information Technology Services
KBA	Keauhou Basal Aquifer
KCC	Kapiʻolani Community College
KS	Kamehameha Schools
KR	Kohnana'iki Resort
LT	Leadership Team

MGF	Moanalua Gardens Foundation
MT	Magnetotellurics
NELHA	Natural Energy Laboratory of Hawai'i Authority
NPV	Net Present Value
OMKM	Office of Mauna Kea Management
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
SGCI	Science Gateways Community Institute
SEI	Sceince Education Initiative (University of British Columbia)
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
URM	Underrepresented Minorities
WFD	Workforce Development
WHR	West Hawai‘i Regional
WMP	Water Master Plan
WR	Waiki'i Ranch
WRAC	Water Resources Advisory Council
WRRC	UH-Water Resources Research Center

Hawaiian Language Terms

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