Adaptive Management Symposium on Groundwater Dependent Ecosystems at Kaloko-Honokōhau National Historical Park (KHNHP)

Meeting Record and Summary

Peter S. Adler, PhD. and Katie Ranney
The Accord3.0 Network

Kona, Hawaii
November 8-9, 2018

Uē ka lani, ola ka honua
When the heavens cry, the land lives

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Executive Summary

This document is a summary of discussions held at the "Adaptive Management Symposium on Groundwater Dependent Ecosystems at Kaloko-Honokōhau National Historical Park (KHNHP)" on November 8 and 9, 2018 at the Gateway Center in Kona, Hawaii. The symposium brought together 44 cultural experts and scientists who could provide:

- The best information we have from Native Hawaiian practitioners who live in the area and currently access KHNHP for traditional and customary practices or possess knowledge of historic uses and conditions of the area.

- The best inventory we have of the historic and current biota of KHNHP's anchialine pools, fishponds, and other in-shore flora and fauna, including their adaptive saltwater tolerances.

- The best data we have on water-level changes, salinity fluctuations, and long-term trends, including mean or median oscillations of salinity, basal and high-level Submarine Groundwater Discharge (SGD) outflows, seasonal tides, and other factors.

The meetings were convened and funded by CWRM, organized by Peter S. Adler, PhD and Katie Ranney of The *ACCORD3.0* Network, and conducted in cooperation with Kaloko-Honokōhau National Historical Park (KHNHP) and in partnership with the ʻAha Moku Advisory Committee from the five *ahupuaʻa* on which the park is located, and the University of Hawaii's National Science Foundation-funded ʻIke Wai water research program.

The long-term goal is to inform ways in which water decisions can best contribute to an adaptive management effort for groundwater dependent ecosystems in Hawaiʻi.

Acknowledgments and Appreciation

Much gratitude to all 44 cultural practitioners, scientists, and technical experts who participated in the symposium, especially those who helped prepare materials and kick-start specific discussions. Our thanks also to the ʻAha Moku Advisory Committee and Leimana DeMate who helped organize their participation, the leaders from Kaloko-Honokōhau National Historical Park (KHNHP) who led the site visit and advised on the agenda, to Candee Ellsworth who graciously made NELHA's Gateway Center available for meetings, and to Jeffrey Pearson, Roy Hardy, and Lenore Ohye who initiated, funded, and advised on the symposium's purposes, objectives, planning, and implementation. A very special thanks to Francine Roby who took copious notes for the meeting.

Picture 1: The group comes together midway through the site visit at ʻAimakapā

Introduction and Background

This report summarizes presentations and discussions from the "Adaptive Management Symposium on Groundwater Dependent Ecosystems at Kaloko-Honokōhau National Historical Park (KHNHP)" held on November 8 and 9, 2018 at the Gateway Center in Kona, Hawaii.

The authors have sought to provide as accurate a summary as possible of the proceedings for future use by the Commission, the Park, the ʻAha Moku Advisory Committee, UH's ʻIke Wai water research program, and others interested in the development of new knowledge.[1] Understanding that science and culture are in constant motion, the symposium offers a glimpse of what is known and understood today and what further research might prove significant.

Background

In February 2017, the Commission on Water Resource Management (CWRM) directed its staff to further investigate the science of coastal freshwater discharge and its water impacts for consideration in setting or adjusting future sustainable yields. This directive was part of the Commission's action on a designation petition filed by the National Park Service to provide greater regulatory protections for its Groundwater Dependent Ecosystems (GDEs) and the traditional and customary practices dependent upon them as they occur in the Kaloko-Honokōhau National Historical Park (KHNHP).[2]

The invitational symposium followed up on that directive and sought to examine the best available traditional and contemporary knowledge associated with GDEs in the Park's boundaries.

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The symposium brought together 44 cultural, technical, and scientific experts to share information and opine on what we know and still need to know about GDE-related topics (See **Annex-1, "Project Description"** and **Annex-2, "Participants"**). Building on the work of the symposium, the subsequent goal is to develop an improved analytic framework based on robust monitoring indicators. Such a framework, when it is evolved,

[1] All mistakes, errors, or omissions in the report are solely the fault of the authors and not CWRM, KHNHP, the AMAC, or symposium participants. We ask for forgiveness if we have mischaracterized any discussions.

[2] Additional background on the petition and the Commission's actions are at http://dlnr.hawaii.gov/cwrm/groundwater/activities/keauhou/.

can lead to quantitative and qualitative measures needed for adaptive management and inform the ways that water decisions may best contribute.

An online literature review and collection of resource materials were gathered, including power points and submissions from participants, and can be found at http://accord3.com/pg1028.cfm. These will be relocated to the CWRM website https://dlnr.hawaii.gov/cwrm/groundwater/activities/keauhou/ after January 15, 2019.

Groundwater Dependent Ecosystems

KHNHP and other areas in the Keauhou region and on other islands are rich in freshwater dependent habitats, which include anchialine pools, ponds, and near shore waters. GDEs are complex environments. All GDEs are living biological networks that are reliant on groundwater. In many places, GDEs include springs, sinkholes, caves, karst systems, and deep-rooted plant communities. In some cases, rivers, wetlands, and lakes nourish groundwater-dependent ecosystems.

At KHNHP, GDEs are largely comprised of brackish anchialine pools, natural and culturally historic fishponds, and coastal freshwater seeps, which are important for a variety of animals and plants. Understanding GDEs in general, and at specific locales in Hawaiʻi, requires strong biological, hydrological, and cultural information.

The Symposium's Meta-Questions

This symposium sought to inform the following long-term questions:

- What rates of groundwater discharge are sufficient to sustain the public trust resources that enable traditional and customary practices and the essential habitat of endangered species?

- In addition to fresh groundwater, what are the other critical determinants of healthy and enduring GDEs in the Park?

- What are the most relevant parameters and indicators that can be tracked and monitored to evaluate the effectiveness of CWRM's water management policies at Keauhou?

The symposium sought to work on these questions, but not to create a hasty consensus. To that end, it assembled individuals who could provide:

- The best information we have from Native Hawaiian practitioners who live in the area and currently access KHNHP for traditional and customary practices or possess knowledge of historic uses and conditions of the area.

- The best inventory we have of the historic and current biota of KHNHP's anchialine pools, fishponds, and other in-shore flora and fauna, including their adaptive saltwater tolerances.

- The best data we have on water-level changes, salinity fluctuations, and long-term trends, including mean or median oscillations of salinity, basal and high-level Submarine Groundwater Discharge (SGD) outflows, seasonal tides, and other factors.

Additionally, acknowledging practical limitations of any monitoring system, the symposium would try to generate ideas about specific indicators that can be used as "dashboard" proxies and most easily monitored for purposes of long-term adaptive management.

Symposium Plan and Agenda

The symposium began with a tour of some of the Park's features led by KHNHP staff, and then adjourned to the meeting venue at Gateway Center[3] for a day and a half of presentations and discussions. It also included time for informal interactions. The process and style of the symposium were unique and essential to productive conversation, which was made clear at the beginning. These elements included the explicit goals of (a) taking stock of what we know and can say with reasonable confidence about the hydrological, biological, and cultural status at the KHNHP and (b) thinking through possible additional research that might advance our understandings and insights. The full agenda can be found at **Annex-3, "Agenda**".

In addition, the symposium was not a time and place to reargue the designation request of 2013 – 2017; admonish CWRM or National Park staff for perceived faults and failures; or make policy recommendations on the future sustainable yield of the Keauhou aquifer.

Peter Adler, symposium coordinator and moderator, acknowledged at the start this was necessarily a constrained effort with insufficient time to fully explore the topics at hand. He noted that everyone who had been invited was an expert and that the panelists would serve only as "discussion starters" to initiate the process of capturing the best state of our current knowledge. Participants were encouraged to refer to the bios at the website to familiarize themselves with the panelists.

[3] Friends of Natural Energy Laboratory of Hawaii Authority (NELHA)'s Gateway Visitor Center

Site Visit

Courtesy of the National Park Service, more than half of the symposium participants visited parts of KHNHP to see some of its key features first hand prior to the start of the meeting. The tour began at the park's south entrance near the harbor.

After an opening *pule* by local cultural practitioner Mahēalani Pai, and welcoming remarks from Superintendent Bill Thompson and CWRM Deputy Director Jeffrey Pearson, Superintendent Thompson and Environmental Specialist Jeff Zimpfer led the tour to provide background on some of the anchialine pools, fishponds, and shoreline.

Picture 2: (left to right) Cynthia Nazara, Mabel Pai, Annie Kauka'a, and Suzanne Case during the morning site visit.

Their comments and explanations were augmented by additional historic, cultural, and technical information from Mahēalani Pai and other members of the 'Aha Moku Advisory Committee (AMAC) who had family ties to the park. Additional information and photos are at **Annex-4 to 6, "Site Visit"**.

Panel 1: Traditional and Customary Knowledge about the Park's GDEs

The opening symposium panel provided participants deeper insights into the ecological, social, and cultural landscape as seen by Native Hawaiians with generational ties to the land and water encompassed by KHNHP. Participating were AMAC members Annie Kauka'a, Mabel Pai, Cynthia Nazara, Nicole Lui, Mahēalani Pai, and Reggie Lee. Gregory Chun served as moderator.

Greg Chun introduced the 'Ohana and emphasized the importance of the perspective of traditional knowledge coming from *mālama 'āina* and "place, people, and process," and how critical it is to bring traditional knowledge to the table to inform research and problem solving. He noted that all six 'Ohana members had lived on the lands under discussion and brought not just memories, but valuable ecological insights handed down from centuries of residency. He also suggested studying and incorporating land use commission award information from the *mahele* as it can help with scientific studies.

Reggie Lee said he was brought up on a hill in the *kula* or central area, and came from a long line of farmers. Historically, there were a lot of trails and if you came from Kona, you would know every trail. His mom rode a donkey down to the shoreline area with which they were intimately familiar.

His grandfather used to bring down their food and use the *loko i'a and loko wai*, lagoons and ponds, to keep their food refrigerated. They would put it in a burlap bag and place it on a shelf in certain little caves. They would also dry the fish there on the *pāhoehoe,* smooth lava rock, since there were no flies back then. His grandfather also created a *loko 'au 'au* for Reggie's mother's privacy and use as she was one of the few females there and they saved it as a cultural site. They would always pay respects to the *kupuna* that were buried there when they gathered salt from the flats. They observed the colder water in the *pāhoehoe* cracks but couldn't measure flow volumes back then.

Cynthia Nazara reflected on the morning site visit and remembered going to the exact location where the park's bathrooms are now and which were where her great grandparents and her mom lived. Her great grandparents were the caretakers of Kaloko and the pond itself. Her mother was a very avid writer who would write everything down. Thanks to her, Cynthia still has all of her written records and stories of how it was then.

She said that, like the other houses there, her family would wash their rice at the back of the house where there was a freshwater pond, and then recycle the water for other purposes. The people there drank brackish water, which they were used to. On the way down to the shoreline, they would pick ripe mangoes and put them underground by springs in plastic bags to chill them. Different ponds had different qualities and different uses. Some even grew watercress and had *hihiwai*. Cynthia recalled how her grandparents always talked about the water and how important it is to life. “We learned to take care of the water,” she said. You have to live *mālama ʻāina*. It has to come from your *naʻau* not just your mind and learning through books or school.

Mabel Pai recalled that growing up in Honokōhau her family didn't have a car, donkey or canoe, so they walked everywhere. When they went to the shoreline, she would get a long stick that would fit over her shoulder to carry two 5-gallon buckets, one in the front and one in the back, for food and clothing. There was no harbor at that time. They walked on the *aʻa*, jagged lava rock, and halfway down would stop to collect *pānini*, prickly pear cactus, and other plants, like ʻ*oloa*, which was a Hawaiian medicine.

Near the shore, brackish and fresh water was plentiful. They would take a bath in one pool, use another section to wash clothes, and another section to cool food. They had lots of water. The ocean and its food were free. They caught *ʻōpelu* and would move earth and sand on to the lava to plant squash, banana, watermelon, lauhala, crown flower, and watercress. It was their “Costless” and “First Hawaiian Bank” savings account, but everyone had to work hard to gather and maintain it. Everything was eaten or if not then you would “suck air” or “suck wind” and starve.

Picture 3: Greg Chun (standing on the left) moderates the discussion on traditional and customary practices while Nicole Lui talks about her experiences.

Although it was difficult and consistent work to maintain their environment, nobody thought it was a hard life, and people were happy with what they had. Her son Mahēalani, would come home from work every day and rake the beach that was loaded with broken glass, bottles, and beer cans. He would rake up debris by the drum-full and haul it away to keep it clean and safe.

Mabel also noted there were no tall trees like those seen today. There was a little pond there with a lot of *ʻōpae ʻula*. When the tide was down you couldn’t see the tiny shrimp, but when the tide came up, they all would swim up into the pond. Today, she lamented, when you go down there, there is no pond and the place is a mess.

Annie Kauka‘a, Mabel’s mom and Mahēalani’s grandmother, is 94. She echoed many of the comments from the others, and said everything was hands-on and handmade. Fishing was her dad’s business; weaving *lauhala* was her mom’s. She remembered them distinctly telling her and siblings to *mālama* the ‘*āina*, to care for the land and water, by *mālama* with your head, heart, and hands to then *mālama* the *‘āina*. We eat to live and live to serve, which is what all at the symposium are doing. She then spoke about some of the specific plants and animals they used, but always with the reminder that the land and all its creatures were connected and infused with spirit. They had water catchment.

Nicole Lui followed Annie and said she was seeing the end of old ways. She was raised on tank water. She shared similar memories of going *holoholo* along the coastline with her uncles. The young ones had to carry the fish bag. The Hawaiian language was still spoken, but she also remembered the *kupuna* telling the kids to leave the room and not to learn the Hawaiian language. They encouraged the children to learn the *haole* language, so they could be just as good as them. In her time, the old ways were disappearing but she hung onto their teachings.

Her auntie made it a point to talk to her about the spiritual and physical worlds and her tutu Solomon Kainamakule taught her three specific family values: to *maka‘ala,* be vigilant and watchful in everything; to *akahele*, ponder and reflect on what you’re thinking and what you’re doing and if it’s correct, do it, if not, don’t do it; and finally, *makawalu* that in some translations is a battle formation, but also means to keep your eye on the sacred number eight and to keep your spiritual and physical sides in balance.

You need to connect with deity or something higher than yourself so you can get answers and understand the Hawaiian community feelings and thinking. It is very important to know the land basis of what you are studying – the *ahupua‘a* and the resources within that area, and the most important is *wai*. Meet with the people of the area and present your reports so they can point out if there are mistakes. Her tutu taught her *aloha* is a compound word of *alo* (front/face/presence) and *hā* (breath of life). So you remember are sharing your *hā* with others when you say *aloha.*

Mahēalani Pai showed historic photos retrieved from the Mission Houses archives, which can be found at **Annex-5, “Historic Photos”**. He said that when he looks at the pictures, it takes him back in time and he can better know the lifestyle in old Honokōhau at ‘*Ai‘opio*. He said the pictures exemplify the purpose and work that he and the other families are striving to achieve: to educate, to share knowledge. At the same time, he and others are asking: “what does it now mean to be Hawaiian?”

After doing genealogy research, he came upon his family’s history called *“Ke ka‘a‘aina maloho*”, compiled by cultural anthropologist Marion Kelly. Kelly talked about the families of Honokōhau and Kaloko. Mahēalani reminded everyone that the landmark Public Access Hawaii case (“PASH”), which led to important Supreme Court rulings, actually started in Honokōhau. It concerned the use of *‘ōpae ‘ula* to catch *ōpelu* as that was where his family harvested them when the tide was exceptionally low. He actually wanted to start the field visit in

Honokōhau-iki rather than Kealakehi to travel to ʻAimakapā through Honokōhau-nui because that's where to *ʻōpae ʻula* ponds were located.

However, those ponds are now overgrown with vegetation and *huna*, hidden. He explained that the pond was, and still is, not for everybody. It's a sacred space connected to transformation and ritual. There are protocols for visiting that pond and it is not for everybody. Like the other presentation on the dragonfly it is about transformation and *ʻolohe*, to obey and carry out ritual. Not everybody belongs there or should go there so as to keep it clean and to respect the place. When they go to the ponds they *hoʻoʻemaʻe* (clean) themselves so they don't *kāpulu* (pollute) the ponds. They put stones in the pond to walk on so they don't *haukaʻe* or disturb the habitat. Over time mud accretes in the ponds and must be cleaned. It's about "keeping the house in order" and the ponds are gift, which keep their families alive.

He continued by talking about catching and using crab, *ʻōpae ʻula*, and certain grasses in the ponds to provide *palu* (bait/chum) to catch bigger fish in the ocean. The grasses keep the *palu* cool.

He was concerned about activities within the harbor that pollute the water so they do not eat and gather food from there. There are ʻōpae ponds and saltpans located near the harbor they used to take care of but are now overgrown. He wanted the whole group to follow along the shoreline to ʻAimakapā to point out *wai hou* (spring) that helped to grow *limu* like *limu ʻeleʻele* and show the alignment with the *hōlua* slide for surfing and at the base of the slide is a water source. He concluded with a summary of his and other families from that area, concern for the future *moʻo* generations to be able to continue the practices, and expressed their willingness to help improve the condition of the park's natural resources, with research, and with the implementation of comprehensive adaptive management.

In the discussion that followed, Mahēalani and others marked some of the important places within and outside of the park they had spoken of on a map (**Annex-6, "Some Important Places on the Map**") and then answered questions. Those places are identified on the full video of their presentation, which is entitled "Traditional & Customary Knowledge about KHNHP Groundwater Dependent Ecosystems" and is available at https://vimeo.com/300026659.

Panel 2: Knowledge from Recent and Current Studies Related to the Park's GDEs or Analogous Areas in Other Geographies

Part A *How has groundwater coastal discharge at KHNHP changed historically and currently as pumping has increased? How might it change in the future if additional pumping does or doesn't occur?*

Delwyn Oki suggested that the difference in water levels at two wells over time might be an indicator of groundwater discharge decrease, but the decreases could be related to other factors. One possibility is that ocean levels over the same time period have gone up. He reminded participants that correlations are not causations, and he indicated that although semidiurnal variations in groundwater levels related to ocean tides are greater in wells closer to the ocean relative to farther inland, long-term changes in groundwater levels related to sea-level rise likely will be similar in wells close to the ocean and farther inland.

Another possible factor could be that pumping has increased over time and noted back to 1960, pumpage had been 0 to 15MGD but seemed to have stabilized between 2009-2017. A third and possibly more important factor could be rainfall decline. Delwyn's slides are at **Annex-7, "Groundwater Discharge in the Keauhou Area".**

Henrietta Dulai described how coastal submarine groundwater discharges towards the ocean and are then impacted by tides and sea levels. She described tides as "gatekeepers" and sea levels dictate how much groundwater discharges into ponds and eventually out to the ocean. In the ponds and pools, measurements of water give an indication of a tidal signature that can be quantified over a tidal cycle. Basal lands breathe with tides and with longer seasonal changes.

If we want to know where water is coming from, we should look at water chemistry. She deduced that about 30% of the current SGD is coming from the high-level aquifer, half of it from much higher. Not all water is discharged along the shoreline. In fact, shoreline discharge comprises a fraction of the amount that studies suggest is being recharged. Some water is going deeper (see **Annex-8, "The Intersection of Marine and Terrestrial Hydrological Processes"**).

Craig Glenn described a 10-year-old flyover study to map groundwater and noted fluctuations with currents. He suggested that where Henrietta was comparing the whole coastline of west Hawaii, his work focused on a more localized plume of discharge, which correlated with nutrient concentrations. He used a color ramp for groundwater values, which used silica and nitrous phosphate as a relative index of nutrients and indicators of potential origins. His studies showed drinking water wells and coastal and more elevated wells as well as mixes and potential dilutions with seawater.

Different types of regional aquifers have distinct slopes and can show wastewater effluent that is discharged upslope. He believed isotope studies would tell us there are very high elevation waters flowing to shore. Taking into consideration contributions from rain versus wells forces us to use higher elevation correlations, some coming from Mauna Loa and Maunakea and taking different pathways. (see **Annex-9, "Groundwater Aerial Survey")**

Part B How do tidal and seasonal oscillations of GDE water levels and salinity affect the biota of the anchialine pools and fishponds?

Dan Polhemus asked, "Who are the critters that actually live in these habitats?" There are not that many insects in anchialine pools. Most of the fauna are fishes and decapod crustaceans. There are native damselflies and dragonflies; many of them are yellow, bluish, red and orange. Twenty-seven types are endemic. Some species are widespread, but most of them are found on the Big Island. Other species have disappeared on Kauai or are reduced to small populations. One species is left on Oahu, 4 or 5 populations are left on Maui, a few clusters on Molokai, and one on Lanai.

DLNR is attempting captive damselfly propagation. Will Haines has managed to procure a fantastic number of immature damselflies in submerged aquatic vegetation. He plans to cultivate the immatures and return them to their natural habitat. Lorrie Tango did her Master's thesis on habitat tolerance, observing reactions to temperature and salinity. Breeding was documented at 20-28°C, whereas hatching occurred between 20-24°C at salinity levels of 20ppt. No hatching took place in high salinity environments, especially at high temperatures. Immatures can't tolerate salinity, and eggs can't even handle as much salinity as immatures.

The salinity of pools is changing. When it nears 20 ppt, the damselflies die off, because they can't complete their life cycle, which is especially dangerous for endangered species. If they do make it to the immature stage, they are then more susceptible to predation by fishes present in anchialine pools (See **Annex-10, "Native Damselflies"**).

Kiana Frank focused on microbiota. She encouraged participants to think holistically about the natural system. Microbes sit at the base of the food web, and are especially important for cycling nutrients, such as carbon, sulfur, iron, and nitrates. Microbes tend to be overlooked when considering ecological systems. The *kupuna* understood the effects of the microbes, though they may not have known why, and used that knowledge as a basis for the management of *loko* and *wai ʻōpae*. They managed the mixing of different sources of water for the right balance of microbes to support the rest of the food chain.

Picture 4: Kiana Frank presents on the interrelated ecosystem of microbiota in KHNHP

She thought of GDEs as a large “buffet” table from which different crowds eat depending on the microbiome. Today, researchers employ genetic techniques to understand diversity, such as in the study of photosynthesizers. However, Frank said more genetic studies are needed. She described Stephanie Hoffman’s study comparing microbial communities in different anchialine pools. Each site has a distinctive microbial community that is driven by different physical and chemical variables. The parameters of these may rely on temperature, salinity, pH factors, tidal oscillations, and seasonal cycles. Spring and lunar tides probably influence the bottom of the food chain, which then impacts all have the way up food chain. (See **Annex-11, “Food Web and Microbes”**).

Richard Brock wanted to serve as a devil’s advocate. Some fishponds lack direct connection to the ocean. Fishponds, which have a surface connection to the ocean, are especially important to local culture. All native fish species require the ocean to complete their life cycles. The biota in these ponds are usually widespread, and can be commonly found in other habitats.

Anchialine ponds, on the other hand, are tidally influenced on the Kona coast that lack surface connections and are only indirectly connected to the ocean. Species in these more restricted habitats are largely confined to the upper portions of the pools. They include epigeal species, like mollusks, crustaceans, and fish, as well as more unusual species that are only found in anchialine pools, including eight types of shrimp and one type of crab. All but two of these anchialine-specific species are rare. If nonnative fish are introduced into one of ponds and they become established, they are very difficult to eradicate.

Common *ʻōpae ʻula*, predatory shrimp, occur in ponds with a range of salinity. If alien fish are absent, we can confidently state that an aquatic organism or wetland plant species, in or around the brackish water body can survive most changes in water level and/or salinity, if they are within tolerance levels for each species. Data suggests epigeal species may have more impact than the observed increase in salinity in the pools. The more serious issue may be invasives.

Veronica Gibson focused on macroalgae and talked about the influences that marine species face with tidal and seasonal changes. She set the stage by noting that Kona is one of the only places where wet and dry seasons are switched. Though that can change as a consequence of El Niño-type weather events. Winter days are characteristically shorter and cooler with strong North swells. The plants and animals in near shore ecosystems experience strong wave actions, but less wind and rain. During the wet season, in summer, there are longer and wetter days and South swells.

Plant and animal matter builds up in the summer, and reduces in the winter. Native species seem well adapted to these conditions. During spring and summer, we see blooms of macroalgae in calmer seas. Many species of fish spawn during this season as well. However, there are also strong tidal influences. Some plants or animals are solely adapted to oceanic conditions, whereas other communities move with the cycles and to different bodies of water. Fish can come and go. Diatom blooms can happen easily and cyanic bacteria can increase or decrease. Gibson suggested ecosystem-wide studies that establish a current baseline as well as needed system-wide assessments (see **Annex-12, "Seasonal and Tidal Effects"**).

Questions, Answers, and Discussion

Moderator Peter Adler asked the panelists and other participants where they might invest new dollars to further improve our understandings of the KHNHP GDE and opened the floor for both questions and discussion. The following is a summary of comments from the group.

- We need more concrete evidence that the restoration of fishponds would positively impact the fishery, including the full microbial layer.

- We still don't know enough about the underground system of water flow. SGD is a really important part, but we need do additional drilling for monitoring wells and carefully watching the salinity levels of the pools. We also need a better baseline and more data on substrate, how ponds connect, and how El Niño trends fit in.

- The biota can handle a range of tolerances based on tidal cycles, which tend to be short, but when there is chronic long-term change, we are likely to see bigger changes in the biota. For example, increased temperature of the water over a longer time led to the 2015 bleaching event. When big chronic shifts happen, can organisms complete their full reproductive cycles? Damselflies cannot. We need more information on tolerances of various species in anchialine pools. Just because they can experience a tidal range doesn't mean they can handle a longer change.

- *Limu* thrive in different salinity ranges. Within a local area, there are certain target species of fish like the ʻ*amaʻama*, which prefer specific chain-forming diatoms that are sensitive to salinity conditions. So, understanding what the salinity range of the *limu* that target fish species want to eat, and what's going to support their growth is important. Money is needed to understand the diets of these fish that are being raised for aquaculture as well as their preferential habitats.

- We want to know more about water levels, transition zones, salinity, and their trends. More monitoring wells and better correlations between data from different monitor wells would be important.

- We are losing the anchialine resource to nonnative fish. It's over 90% gone. Invasive, nonnative fish have taken over and can complete their life cycles in ponds. Once they take hold, they are nearly impossible to eliminate. The most effective method to get rid of invasive, nonnative fish is sterile male programs for mosquito fish and tilapia.

- Anchialine pools are integral to understanding GDEs. Yet, anchialine pools, as we know them, are going to be a piece of history in the not-too-distant future. In 1972, about 12% of the ponds on the Kona coast had alien fish. In 1985, it was 45%. By the late 90's, it was nearing 80%. We're at over 90% right now.

- If there is money to help preserve anchialine ponds, you need to also focus on protecting the generational knowledge of the people who are here.

- Craig's slide showing groundwater going off shore elicits several questions: Is that changing the near shore circulation? If there were no groundwater flowing out, would there be a different circulation pattern? That groundwater is pushing water and materials farther offshore, where the currents are stronger. How does that affect larval transport from our reef system?

- What that slide shows is happening at the surface, but what you don't see happening below is a "conveyor belt circulation", where sea water is possibly coming in and impacting circulation on that reef.

- A lot of it is the residence time within the area, and then we've got this buoyancy difference and density difference which acts as the bigger inhibitor between the bottom and the surface. If you break it down, you've got more mixing.

- There's a really useful review paper that showed more viruses reaching the coral that way and the mixing in the absence of strong surf. The plumes actually create their own mix.

- We have a lot of information about submarine groundwater discharge at the shoreline and traditionally we have treated aquifers in a 2-dimensional way, where we've drawn them on the map. But in reality, the geology is 3-dimensional and the aquifers likewise are 3-dimensional. One of our biggest gaps in terms of information is what submarine groundwater discharge is occurring outside of what we can see and easily sample. We know, on the Hilo side, there is deep submarine groundwater discharge 300 meters below sea level. And we have good reason to suspect that something similar is going on here. We need to include investigations of that deep-water discharge.

- There is a recent study but results aren't in yet. Important to remember when people think of currents, they think horizontal, and there are vertical gyres too, which are important to submarine discharge.

- It's very important for us to understand what the metric of success is in a groundwater dependent ecosystem. When we talk about GDEs, there are more layers to be successful than salinity and nutrient values. Each person may have a different definition of success. It should really be driven by the ʻOhana of that place and what it means for the survival and preservation of these practices for their *moʻo*, their ʻohana, and their grandkids. We're not thinking about restoring these groundwater dependent ecosystems for tomorrow; we're thinking about maintaining them for the next 800 years.

Picture 5: Participants would discuss and network during breaks between panels.

Panel 3: Natural and Non-Natural Fluctuations in the Park’s GDEs

Part A What is the known range of water and salinity levels in the tidal pools and ponds and how are they measured?

Paula Cutillo discussed KHNHP’s current monitoring regime. Groundwater levels and salinity are measured every 10 minutes at 4 sites in the Park. This data is very valuable for understanding the groundwater system and for identifying long-term trends. However, the monitoring sites in the Park are relatively shallow. If similar data was collected from deeper wells outside of the Park, it could improve our understanding of the groundwater system. The park’s continuous data gathering is done with loggers installed at specific depths in 3 wells, and one in a brackish pond. The 3 wells are shown on maps as KAHO 3, 2, 1.

These loggers measure water pressure, conductance, and temperature and then store the data. USGS downloads the data and recalibrates the loggers quarterly. Then they review the data for quality control, and calculate groundwater elevation and specific conductance from those measurements. Finally, USGS posts the approved data on its “Endless Data Portal” and NPS consolidates and posts all the new data on its Aquarius data port. The data is available to the public and downloadable.

Water levels fluctuate at the same frequency of ocean tides, but there is a time lag between high tides. The magnitude of these fluctuations decreases as you move away from the coast. So in the park, the largest fluctuation is seen at KAHO 3, the northernmost well. Water levels there fluctuated between 0.3 and 3 feet from 2007 to the present. Fluctuations due to ocean tides can be mitigated in analysis by calculating average daily values of the well, and using the averages to identify longer trends. The data set from KAHO 2, the most inland well, serves as a good example.

According to salinity data collected by the park, all the water passing through monitoring wells on parklands is less than 50% of the salinity of seawater. The freshest water at the monitoring sites is KAHO 2, the most inland well with the smallest fluctuations due to the tides. Salinity fluctuates at the same frequency as the ocean tides, but peak salinity does not occur at the same time as high tides or peak water levels. There are time lags and advances. Salinity also varies with depth. If there was continuous monitoring at deeper wells outside of the park, there could be a better understanding of what’s going on deeper in the aquifer system.

Another way to compare data is to calculate the coefficient of variations, a measure of how data varies relative to the mean. When the data sets for the wells were analyzed in this manner, the coefficient varies from 2% to 5%. The largest coefficient is from KAHO 2 that had the freshest water and smallest variation, which is not very intuitive. When the data from KAHO 2 and KAHO 3 was examined, which are the two wells with the longest records, they found salinity was actually decreasing for a while, but is currently increasing at both sites. These variations are difficult to fully explain with current data; continuous monitoring in the park paired with data from deep wells outside of the park would be critical components to an adaptive management plan (**Annex-13, "Fluctuations in Groundwater"**).

Keith Olson said it was hard to really know the actual range of salinity in west Hawaiʻi, because everyone keeps his or her own data sets. According to data from NELHA about the 3 pond complexes on their property, one of which is stratified with different salinities, the range is 6.4 and 16.3 ppt. This range seems to be in agreement with numbers from Dr. Brock and Dr. Dulai. Between 1993 and 2000, salinometer grab samples determined out to 4th decimal proved difficult and expensive. In 2007, a different method was put in place that is still in use today. The bigger question is where salinity is measured and how those values are determined. Surface? Deep down? NELHA decided to measure at random depths for a global view.

Picture 6: Scene from ʻAimakapā pond, which is now a bird sanctuary with restricted public access

The change in pond salinity could be from sea level rise over thousands of years. The global average sea level rise is 3.1mm per year. Data pulled from a Kawaehae sea level gauge since 1993 shows 6.9 mm per year. But Olson said that it might not be attributable only to sea level rise. The island is sinking. Clear data depends on the meter remaining stable, and it appears to be sinking. To complicate matters, between stratified and unstratified and only 25 years of data, no one can be sure what should be considered standard or normal. Things change over time. 30 years of data might represent one data point!

Olson proposed a way to gather critical pieces of research that appealed to an engineer's wish for real-time data. If someone could design cheap sensors to distribute everywhere, it would create a global communication system that can report into a centralized database. The database would collate the data and display it on a dashboard. Resource managers could compare their ponds to other ponds in the area, and it would lead to standardization of data. Lastly, a single agency would receive and manage the data to further centralize it. **(Annex-14, "Range of Salinity")**

Dave Barnes stated he is a "field guy". His company, Waimea Water Service, designed and built the irrigation system at Kohanaiki. A mentor of his, Steve Bowles, always said the company's first client is the resource. However, it's difficult to balance the needs of a developer with the mitigation of detrimental environmental effects. One way to address that is with a monitoring plan. Some of his equipment uses water level sounders at 8 monitoring wells: 3 near the coast, 3 along the border of KHNHP, one deep monitor, and 2 monitoring wells in line with 8 production wells situated far from park. Each one pumps water and influences the others and surrounding areas.

The sounder is heavily influenced by tides. Monitoring wells can range from 0.5 foot to 2.5 feet, but the range decreases as the wells are found further *mauka*. Barnes' company also tests for chlorides with titration kits and has done so for the last 10 years. There is a lot of noise in the data since the chlorides are influenced by tides. Other influences include a reverse osmosis plant in 2008 and a few freshening incidents.

There was an initial rise in chlorides when the reverse osmosis plant was first installed, but over 10 years it has settled down. The freshening incidents were a result of irrigation in specific locations, such as bananas trees and community gardens that needed fresh water. Barnes' monitoring detected the added fresh water from irrigation. When they moved a garden, salinity levels increased. His monitoring wells detect changes, which can be mitigated with a change of irrigation strategies.

More comprehensive data comes from Barnes' deepest monitoring well, Coral-. The data logger descends to about 115 feet below sea level. The freshest water floats on top and occasional rain events show this. There is a sharp transition at 8.5 feet below mean sea level to 20 feet. Conductivity sharply increases. He then offered his company's 10 years of data to those present for comparison and analysis. Barnes proposed a whole network of deeper monitor wells, *mauka* to *makai,* set at different depths and with continuous monitoring to get a broader picture of the region. If he had extra money, he would support Henrietta Dulai's and Don Thomas' work on SGD and deep aquifers. **(Annex-15, "Kohanaiki Monitoring")**

Questions, Answers, and Discussion

- Paula's last slide is consistent with broader climate trends; a cool to warm phase we just went through. There was a peak El Niño 2014-2015 effect. Mark Merrifield says it was a stable trend until 1997, then there was a hockey stick inflection point.

- Brian Glazier from UH Mānoa has pond water level detectors throughout the state, part of a grid. It's a big database and available on mobile devices in real time. He wants to democratize science with usable information.

- Can we get continuous data with nutrient information to take out tidal variations and get a more robust understanding?

- We have some. Continuous data is more useful for that.

- Is continuous monitoring telling us something different from intermittent monitoring? Is there a great divergence?

- No, not trend wise. Salinity measurements are different and there shouldn't be a difference. Different methods bring different results. We do what we can with what budget we have. Standardizing a method would be good. Then we could compare 2 types.

Part B What do we currently know about the types and amounts of contaminants and pollutants in the pools, ponds, and near shore habitats, and their effects on biota?

Ryan Okano noted he is a *limu* guy, so his answers are "*limu*-centric". A lot of things affect *limu:* sunshine, herbivorous fish, people harvesting. Though here in Hawaii, people try to plant as well, and not only take. Some *limu* need the groundwater to grow and flourish, and in some places, the groundwater is tainted and polluted. All of the cesspools and septic tanks contribute to the contamination. There are more nutrients going into the water. How do the nutrients in the groundwater affect the *limu*?

Okano presented two broad opposing scenarios and how the intrusion of groundwater with nutrients has an effect on the near shore *limu*. In one place with a lot of desirable *limu*, extra nutrients going into water might be good! The *limu* can grow and people can harvest plenty of food. Also, if that near shore water contains a lot of herbivorous fish, they're going to be feeding on this *limu* too. It's production. Everyone has more *limu* and fish to eat. Good for the culture, good for the people of Hawaiʻi.

On the other hand, if the receiving water has alien algae and not too much herbivorous fish, the nutrients that enter the water could create a proliferation of undesirable *limu* without any fish to eat it. Then the invasive nonnative *limu* are going to expand and kill the coral. Depending on community needs and the type of *limu*, an influx of nutrients can be perceived in different ways. Climate change, more precipitation, and sea level rise may also affect the interaction between groundwater and near shore biology. But one of the main questions is how does the increase or decrease in submarine groundwater discharge influence the nutrient concentrations and loads that enter our near shore environment? It may be as simple as less groundwater, less nutrients, no one really knows. **(Annex-16, "Impacts on Limu")**

Bob Whittier works for the Department of Health, Safe Drinking Water Branch, and his program manages source water protection. He is not directly involved in coastal resources or in research science. The EPA mandates the Safe Drinking Water Branch to look at contamination risks to public drinking water. To do that, they develop groundwater models and determine the flow field of groundwater to a drinking water well and then look at the activities within that flow field that may contaminate the groundwater. He referred to it as the zone of contribution.

To determine contamination potential, they examine the zone of contribution, inventory potential contaminating activities, and then do a contamination risk assessment. In the KHNHP zone, it seems wastewater disposal has the greatest contamination potential. Explaining the map he presented, Whittier said it would take groundwater 2 to10 years to arrive at the park, depending on its origin.

Whittier said they concentrate on 3 zones in west Hawaiʻi. If the groundwater travels for a 2-year period, they assume that biological and chemical contaminants could potentially affect the drinking water or the ecosystem in the park. If the period of travel of groundwater is extended to 10 years, then they primarily look at chemical contaminants. Some are more persistent, like nitrates. Once a nitrate absorbs into oxygen-rich groundwater, it tends to be fairly stable and can travel a far distance to wherever the receptor is located.

West Hawaiʻi has a lot of onsite sewage disposal systems, primarily from septic systems and cesspools. There are also golf courses and an industrial park upslope from the park. On the edge, there is a sewer plant, sewage treatment plant, and a point of disposal for effluent from that plant. In the more developed areas, there are light industrial service stations, dry cleaners, and injection wells.


Picture 7: Kaloko Fishpond

Although there are a large number of onsite disposal systems throughout west Hawaiʻi, within the specific capture zone of KHNHP, it appears that there isn't an overabundance. In the 2-year travel zone, there are approximately 75 septic systems and 45 cesspools. In the 10-year travel zone, there are another 21 septic systems and 67 cesspools. In the upland area, there are about 53 septic systems and 82 cesspools. In total, there is an approximate total daily nitrogen load of 26 kilograms.

If we look at wastewater disposal that falls outside of the model capture zone, you are putting in a significant amount of water, about 1.5 million gallons per day, which adds about 3.8 milligrams per liter of nitrogen concentration. So, we have a nitrogen load of about 20 kg per day, compared to about 26 here, so even though we're putting in a lot more effluent, the nitrogen load is less but it's concentrated within a very small area. So, is this having an impact?

Craig Glenn has done some work on the isotopic composition of algae collected along the coast as part of the coral reef initiative through the University of Hawaii. In more heavily developed areas, we interpret the isotopic composition as having increased wastewater impact. The Honokōhau small boat harbor seems to be receiving a large amount of wastewater influence from the municipal disposal.

Currently, it doesn't seem like much of a problem. In 2014, USGS looked at trace contaminants. A well further *makai* contained some trace wastewater contaminants and elevated nitrates. The nitrates are almost double the background level measured in the upland well. Whittier asserted that wastewater should be the main concern of current potential contamination sources to the park. **(Annex-17, "GDE Contamination")**

Questions, Answers, and Discussion

- If funds should magically appear, one of the participants would direct them to defining that relationship between groundwater and biology, the clearer the better.

- Algae data from Megan Taylor hasn't been released yet, but the percentage of nitrogen in algae tissue is something that we're starting to be concerned about.

- DLNR has a data set for commercial fisheries and all commercial fishermen have to turn in their reports of what they caught and where they caught it. The Honolulu sewer outfall in the old days was in 38 feet of water to the west of Sand Island. In that data set is a classification of the amount of *limu* taken off a reef flat directly west of Sand Island. That little reef flat was producing hundreds of thousands of pounds of *ogo* annually; huge amounts of *ogo*. In the 38 feet of water that was raw sewage, *ogo* was over-producing at an incredible rate. They stopped dumping sewage in 1977-78, and in a year *ogo* decreased to about 60-80 pounds coming off that reef. The data is mind-boggling.

- Some of the old timers who used to work, and still work in that place, tell me that they used to fish there and the fish were fat and abundant.

- With the water that's coming in and the pumping that's happening, should we be focused on what's happening inside those lines?

- For salinity, you have to focus on the volume. If you have a concentration of nitrate in the groundwater, this is actually the mass of nitrate that's going to be delivered, that is the concern, not necessarily the concentration.

- Will pumping well outside of that area influence discharge in the park? They're not the same, like capture areas for contaminants.

- The groundwater flow system in this area is not well understood. What is the relationship between the high-level water and the shallow basal water, or do we have deep offshore discharge? As far as we know we have not answered those questions.

- You need enough pumping to change the flow field going *mauka-makai*. It wouldn't be just one or two wells. It would be a whole group taking from this aquifer, and the north part of KAHO versus the south part. And does the groundwater flow parallel to it or directly over it?

- What is the difference between wastewater and raw sewerage?

- Raw sewage is just a subset of wastewater.

- Where the raw sewerage was, that was where the *limu* were?

- Yes. There were a lot fish in the shallow reef. I grew up in Pepeekeo. The pigpens were down by the rivers and they shot waste down into the river. And the end of the river was a good fishing ground. Puna fisherman said, you know what is the biggest toilet? The ocean! Some of us believe if we make doodoo in the ocean and the fish eat the doodoo, they become bigger and fatter. I'm not saying poo in the water is good for the environment! I'm just telling you what it is, stories I've heard about what happens.

- We have another paper from Heather Spalding that came out recently on Ewa Beach in Oahu. Everyone used to go there to collect *limu*, and it started to disappear, people were saying something must be wrong with the water, maybe we're polluting it. But she actually connected it to the sugar cane that was fertilizing those *limu*-picking grounds. And everyone was using it culturally for years, but it wasn't really a natural thing. When sugar cane production stopped, the *limu* stopped growing. It wasn't that we were polluting but we just stopped fertilizing those *limu* grounds by stopping sugar cane.

Part C What do we currently know about the types and numbers of invasive non-native species in the pools, ponds, and near shore habitats and their effects on biota?

Sallie Beavers said the coastal wetlands habitat has a myriad of threats. Today, the National Park Services believes the primary threat is the reduction of groundwater discharge to those systems from pumping. The threats from invasive species described by U.S. Fish and Wildlife Service, Pacific Joint Venture, are secondary. Even if the waters were clear of tilapia and invasive algae, this symposium would still be here to talk about groundwater. The status of invasive species in these systems in 2015 showed that of the park's 191 pools, 18.8% were infected with tilapia.

With USGS's multi-pronged approach, extra work is being done on mollusks to ensure successful eradication. Kaloko has a plant that resembles an upside-down octopus which people think is *limu*, but is an alien algae. KHNHP monitors native starfish, but still contend with outbreaks. Invasive fish are a low priority compared to other management activities, such as *kiawe* removal. Vegetation clearing is hampered by the difficulties of removal, but the park is now using helicopters to clear away more. **(Annex-18, "Invasive Species - A")** Troy Sakihara (via video conference) noted the contrast of fish invading and believed 2% of fish in his samples are invasive. **(Annex-19, "Invasive Species - B")**

Questions, Answers, and Discussion

- The Division of Aquatic Resources does not have information on the percentage of anchialine ponds that are invaded by species statewide.

- Is there a connection between groundwater and invasive species?

- It's the quality of groundwater, not just volume. Being able to monitor contaminants and getting a better idea of what the animals in pools are living on is important. Fish can be bio-indicators of contaminants, which is a useful tool to see how the pools are affected by contaminants. We don't know if there's a direct impact or not.

Part D What projections can be made as to how impending climate changes and sea level rise may affect the salinity and water levels in the pools, ponds, and offshore habitats?

Brad Romine drew from his work with the State DLNR Office of Conservation & Coastal Land from the last 6 years and with the Climate Adaptation Commission report for an online mapping tool. Links are at the symposium website, but more detailed studies are currently being done. Tide gauges and satellite images show acceleration of sea level rise leading to a doubling by mid-century. The Hilo sea level rise rate is roughly the same as global records.

State sea level projections looked at Intergovernmental Panel on Climate Change (IPCC) projections, which suggested a 3-meter rise by the end of the century. How much this affects the research and work of the participants depends on what time frame is useful for them. Decades? End of the century? Chip Fletcher's work shows sea level rise as a smooth curve punctuated by more frequent high sea level events (such as King Tides) in the next decade or two. Peaks will not only be more frequent but they will also have noticeable effects in the ponds. **(Annex-20, "Sea Level Rise")**

Chad Wiggins noted that no matter what, increases in sea level are guaranteed, not theoretical. Groundwater floats on top of salt water. If ocean water patterns accelerate, we will see an increasing curve of groundwater. What that means isn't fully clear. Healthy anchialine ecosystems have shells, sea grasses, and fishes. If any one piece goes away, everything else is affected.

By the way, one of the best ways to feed *ōpelu* is pumpkin or chopped up *ōpelu*. In a sustainable open ocean and the cage-less systems used by Hawaiians, many fish see their food rather than smell it like sharks.

Meanwhile, online tools show what to expect from sea level rise up to 2080. There will be influences on native and invasive species. The tools show the current status of anchialine pools with low, medium, high scales. Some culturally sensitive areas are not included in these maps. The goal in the creation of these online tools was to form collaboration between GIS, USGS and NPS, so the information will be ready to update and populate the maps, and engage citizens in the effects of sea level rise. **(Annex-21, “Coastal Resilience”)**

Questions, Answers, and Discussion

- In a survey of state and county water agencies, everyone wanted visualization tools.

- Temperature increases and ocean acidification will have impacts. Globally, we have seen 2° F changes over the last century. The IPCC interim report is very alarming. More rapid warming is coming which creates public health concerns, more heat emergencies for people, and warmer ponds. The chemistry within the ponds will change. *Mauka* to *makai* planning for south Kohala shows increased rain, rising ocean temperature, coral reef impacts, and shoreline erosion. Less rainfall will also impact groundwater: more droughts, changing pH factors, and additional carbon dioxide. It’s difficult to get a handle on the chemical composition of waters due to diurnal fluctuations. Tropical storms seem to be forming closer to islands, not shearing apart like they used to. Extreme events can also drive storm surge inland. Sea level rise will equal more anchialine pools.

- The current flows of groundwater discharge will change through rainfall reduction and sea level rise. Reducing flows will also exacerbate the effects of sea level rise. Some species can adapt and fly away. Others can’t move.

- There will be more pools in places some animals and plants can move to and wetlands where you don’t have them now.

- Corals can’t move. Invasive algae are actually the best at moving to new areas. Tilapia also have a wide range. Invasives can out-compete the endemics in a new area.

- Vegetation is being removed but it also requires public education and watching to keep people from introducing fish.

- In our lifetime, there have been many changes. Coral was dredged to create Ala Moana. There weren’t just surface impacts. Underground channels and sandstone caves were filled in with rising ocean levels. The shoreline at Kakaʻako Park was once a prime *limu* area. Pipes are now in place to release methane gas from rotting garbage so the gas doesn’t explode.

- It occurs to me that taking care of ponds now will help with future ponds.

- I hope bright people here override selfish people, so we help the next generation

Panel 4: Tracking and Monitoring Measures for the Park's GDEs

Leah Bremer said her work has focused on trying to link social, ecological, economic, and cultural indicators. The first step is to formulate a theory of change: where are we going and a process to get there. Then it's selecting indicators. Often people think indicators are only quantitative, but there are also important qualitative indicators to be developed that can relate to cultural outcomes: narratives, stories, etc. Picking indicators that relate specifically to what people care about is key.

David Raikow presented a series of slides showing what KHNHP currently monitors and displaying some of the trends **(Annex 22 - "Indicators")**

Peter Fahmy said he serves as a policy analyst for the National Park Service's Water Resources Division and has been involved in adaptive management plans, monitoring, mitigation plans, and associated water resources development. The Division has a technical manual on adaptive management, the most recent version from 2009. It describes adaptive management as a systemic approach for improving resource management and learning from management outcomes.

For NPS, adaptive management is comprised of 5 structural elements, which include stakeholder involvement, management objectives, potential management actions, and others. These elements need to comply with legislation for the Park, the Endangered Species Act, the Public Trust Doctrine, and the statutes that CWRM has with regard to water resources. They also include performance metrics, which are the same as indicators. Adaptive management was developed to deal with scientific uncertainty. You have to start somewhere.

Symposium participants then revisited a question raised the day before: what is our definition of success? Potentially these definitions might be convergences that tie together the Hawaiian cultural resources needed to sustain their practices, the impacts of groundwater and biological productivity, and some notion of what "enduring" abundance in the GDE looks like.

Small Group Brainstorm of Indicators

Participants then broke up into four subgroups to brainstorm a short list of the top three "dashboard" indicators that might be used to help steer an adaptive management approach for GDEs. Each group rotated its initial ideas to other groups so everyone had a chance to review all ideas. The results were as follows:

Water

Top Indicators for Dashboard

- Rainfall
- Water level in all wells
- Salinity in wells (vertical profile) in GDE
- Pumping reports

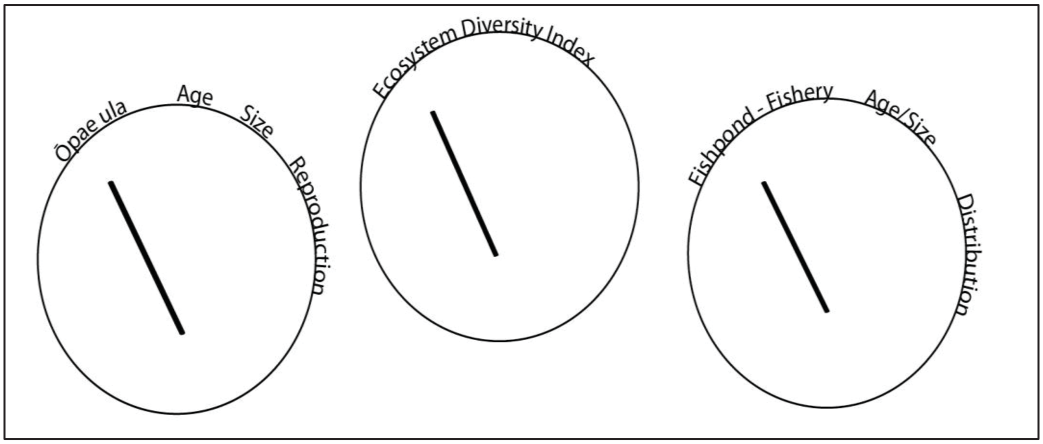
Ideas and Notes Behind the Dashboard Dials

- Water level – *mauka*
- Thickness of the freshwater lens (center line - transition zone)
- Measurements of water isotopes
- Fishpond culture status
- Status of ponds cleanliness
- Status of development above the park
- Pond harvest ability
- Measures of sea level
- Density of unwanted/invasive species
- Change in water flux/volume flowing through the GDE
- Spatial extent of indicator plants and algae animals (easily spotted sentinel species)
- SGD (measure radon + salinity + temperature)
- Monitor indicators outside of the park
- Distribution of monitoring wells (spatially and vertically)
- Subsurface geophysical structure mapping for resistivity

Native Species

Top Indicators for a Dashboard

- Ecosystem diversity index of the suite of possible habitats associated with native species (Brock, 1974; microbes; pollen core; kamaʻāina testimony)
- ʻŌpae ʻula age/size distribution, evidence of mature individuals & recruits throughout life history – "abundance"
- Age-Size distribution of fishpond fish to inform sustainable harvest



Picture 8: The "Native Species" small group made an illustration of the "dashboard" indicators they would focus on.

Ideas and Notes Behind the Dashboard Dials

- Status Indicators: *ʻōpae ʻula*: abundance, fecundity, age class, sustained harvest (catch rate), day/night surveys
- Habitat modifying invasive species (e.g. fish in anchialine pools)
- Abundance & biomass of key functional guilds (fish) transects/cast net/acoustics
- Habitat: algae per unit area
- Plants: where they occur, survive, community
- Fecundity: # of adult fish, spawning size, seasons
- Species diversity based on community dynamics - some pools have algal crust, rupia, *hihiwai*, damselfly, *ʻōpae*
- Community access to place
- Generational & locational knowledge of the place
- Continuous stream of knowledge between community, agencies, scientists
- Waterbird usage - competition with fish harvest?
- Good balance among all species
- Eventual harvest from the fishpond
- ESA-listed species presence/absence, abundance (shrimp, damselflies)
- Sentinel species with cultural relevance, i.e., easily identifiable by the community
- Inter-generational cultural maintenance, e.g., young people eating traditional foods
- Art, photography
- Abundant resources for cultural crafts: *makaloa*-weaving
- Need to cut back previously scarce plants

- *ʻōpae*, *awa*, *limu*, damselflies, mullet
- Qualitative: does CWRM pumping allocations support efforts to maintain habitat that can sustain harvest?
- Coots, stilts, culturally important species
- Threatened and endangered species

Contaminants and Pollutants

Top Indicators for a Dashboard

- Groundwater: add contaminants to existing well monitoring using a broad-spectrum approach
- Ponds: Fish tissue due to biomagnification (goes to edibility, public understanding)
- Surface scum: Easily identifiable indicator of sunscreen or other contaminants and can be easily taught

Ideas and Notes Behind the Dashboard Dials

- Sunscreen
- Pharmaceuticals/endocrine disruptors
- Herbicides
- Insecticides
- Petroleum
- Metals
- Nutrients
- Monitoring wells
- Nitrogen source in algae
- Potability
- *ʻŌpae ʻula* - presence/spatial extent
- Fish are edible
- People are actually eating fish
- Healthy fish (indicator of success)
- # of people visiting/using park
- # of young people
- Adding contaminants to I + M water quality sampling
- Monitoring - If you stop higher discharge (pumping) or with sea level rise, there could be increased nutrients
- You need to measure both nutrients + algae

- Things you would measure nutrients, salinity, silicate, temperature
- Mapping all activities upslope and in ocean that contribute contaminants
- Flux, residence time, uptake rates
- Uses for wastewater + pharmaceutical indicator compounds (lab schedule)
- Establish monitoring stations based on actions
- Nutrient concentrations and isotopic composition O18, N15, C13 (not Boron)
- Semi-permeable lipid membranes + invasive fish tissue sampling for contaminants; test fish removed from pools
- Petroleum (total hydrocarbons), pH, wastewater (nitrate concentration, ∂15N, Caffeine
- Ciguatera (not just in freshwater systems) - testing underway
- Heavy metals

Invasive Species

Top Indicators for a Dashboard

- Presence or absence of invasive fish in how many ponds
- Plants percent
- # of invasive species that have the greatest negative impact on the ecosystem. This will allow us to choose which to monitor

Ideas and Notes Behind the Dashboard Dials

- How much groundwater does kiawe uptake?
- How does groundwater flow/gradient change with invasive species eradication?
- Most important for anchialine pools & fishponds - poeciliids + tilapia
- New wells needed to monitor
- Predators (cats, mongoose)
- Monitoring for potential new invasives, eradicate immediately
- Depth of sediment/organic content
- Closely monitor new pools created by sea-level rise to prevent invasions
- # of fish species
- Focus monitoring on invasives-free pools to catch invasions early, and prevent spread
- Extent of kiawe, to prevent bogus arguments about water uptake
- There is no direct connection to groundwater pumping. CWRM is regulating the pumping only. Regulation of invasives is not CWRM's role and can be eliminated from adoption of management plan

After final expressions of appreciation, last comments, an enclosing pule, and encouragement to do a simple evaluation, the meeting came to a close.

Picture 9: As the sun set outside NELHA's Pacific Gateway Visitor Center, the symposium came to a close.

Annexes

Note: *Some of the following annexes comprised of slides have accompanying 1-page written discussions available at (http://accord3.com/pg1029.cfm)*

1. Project Description
2. Participants
3. Agenda
4. Site Visit
5. Historic Photos
6. Some Important Places on the Map
7. Groundwater Discharge in the Keauhou Aquifer
8. The Intersection of Marine and Terrestrial Hydrological Processes
9. Native Damselflies
10. Groundwater Aerial Study
11. Food Web and Microbes
12. Seasonal and Tidal Effects
13. Fluctuations in Groundwater
14. Ranges of Salinity
15. Kohanaiki Monitoring
16. Impacts on Limu
17. GDE Contaminants
18. Invasive Species - a
19. Invasive Species – b
20. Sea Level Rise
21. Coastal Resilience
22. Indicators

Annex-1

Project Description

Adaptive Management Symposium on Groundwater Dependent Ecosystems at Kaloko-Honokōhau National Historical Park (KHNHP)

An Invitational Symposium

Sponsored By

The State of Hawaiʻi
Commission on Water Resource Management

Kona Hawaiʻi
November 8-9, 2018

In Partnership With

University of Hawaiʻi
ʻIke Wai – Securing Hawaii's Water Future

And

ʻOhana Members from the Ahupua'a Lands
On which the Park is situated

And in Cooperation With
Kaloko-Honokōhau National Historical Park

I. Background

In February 2017, the Commission on Water Resource Management (CWRM) directed its staff to further investigate the science of coastal freshwater discharge impacts for consideration in setting or adjusting sustainable yields. This directive was part of the Commission's action on a designation petition filed by the National Park Service to provide greater regulatory protections for Groundwater Dependent

Ecosystems (GDEs), and the traditional and customary practices dependent upon them as they occur in the Kaloko-Honokōhau National Historical Park (KHNHP).[1]

This symposium follows up on that directive and will advise CWRM by examining the best available traditional and contemporary knowledge associated with GDEs in the Park's boundaries, including the shoreline and boundary that extends into the ocean. The ultimate goal is to gather state-of-the-moment knowledge and help move the topic of protecting/conserving/managing GDE from dialogue to informed long-term action.

To accomplish this, we seek to develop an analytic framework and/or indicators that can be used by CWRM and others to monitor GDE health as short- and long-term conditions fluctuate for either natural or anthropomorphic reasons. The framework we hope to develop needs to include ecosystem functions under varying conditions as well as current and future traditional and customary (T&C) practices.

Ultimately, these discussions and any resulting framework can help lead to the best quantitative monitoring and benchmarking of the fresh water needed for adaptive management and help inform future CWRM practices and decisions.

II. Groundwater Dependent Ecosystems

KHNHP and other areas in the Keauhou region are rich in freshwater dependent habitats, which include anchialine pools, ponds, and the Park's near shore waters. All GDEs are living biological networks that are reliant on groundwater. In many places, GDEs include springs, seeps, sinkholes, caves, karst systems, and deep-rooted plant communities. In some cases, rivers, wetlands, and lakes are also groundwater-dependent ecosystems.

Understanding GDEs and building a framework for monitoring and managing them requires biological, hydrological, and cultural knowledge as well as a grasp of how CWRM might utilize such a framework in its oversight practices.

III. The Critical Questions

With the participation and best advice from all invited experts, this symposium will try to help address the following questions:

[1] Additional background on the petition and the Commission's actions are at http://dlnr.hawaii.gov/cwrm/groundwater/activities/keauhou/.

1. **What rates of groundwater discharge are sufficient to sustain the public trust resources that enable traditional and customary practices and the essential habitat of endangered species?**

2. **In addition to fresh groundwater, what are the other critical determinants of healthy and enduring GDEs in the Park?**

3. **What are the most relevant parameters and indicators that can be tracked and monitored to evaluate the effectiveness of CWRM's water management policies at Keauhou?**

Developing possible answers to these questions likely requires the creation of a GDE framework that could include some or all of the following:

1. The best information we have from Native Hawaiian practitioners who historically or currently access KHNHP and the T&C rights Native Hawaiians currently exercise.

2. The best inventory we have of the historic and current biota of KHNHP's anchialine pools, fishponds, and other in-shore flora and fauna, including their adaptive salt-water tolerances. Such an inventory could include

    - Birds (stilts, coots, and others)
    - Shrimp (ʻōpaeʻula and others)
    - Insects (orangeblack Hawaiian damselflies and others)
    - Corals
    - Algae (limu and others)
    - Fish (ʻamaʻama (mullet), ʻawa (milkfish) and others)
    - Invertebrates
    - Other

3. The best data we have on water-level changes, salinity fluctuations, and long-term trends including mean or median oscillations of the following and how they are monitored:

    - Salinity profiles
    - Basal and high level Submarine Groundwater Discharge (SGD) out flows
    - Seasonal tides

- Long-term water-level changes (SLR)
- Water temperatures
- Natural nutrient flows
- Anthropogenic contaminants
- Other

4. Knowing we can't measure everything all the time, are there specific indicators that might be used as proxies and most easily monitored for purposes of long-term adaptive management?

These and other questions may be taken up during the two-day symposium to help begin to create an analytic framework and tracking measures.

IV. Symposium Plan

1. Invitational

The symposium will be held on Thursday and Friday, November 8 and 9, 2018 at a site and venue close to the Kona airport and KHNHP. It is an invitational gathering of experts who hold traditional and contemporary scientific information and not a public meeting.

The symposium itself will start with a field visit to the park followed by a series of brief synthesis presentations and discussions aimed at summarizing what we currently know about Keahou's GDEs with a reasonable degree of confidence, and concluding with a collective effort at articulating future tracking indicators.

A written post-symposium report will be available to everyone and videos will be made of the panel and made available to anyone.

2. Invited Contributors

Because of budget, space, and logistical constraints, not more than 40 participants will be involved in this symposium including local ʻohana experts from the Ahupua'a lands on which KHNHP is situated; scientists and technical experts from different disciplines; and a few staff from CWRM, UH-ʻIke Wai, and KHNHP. Exact number of invitations is yet to be determined and will be based on budget.

3. Materials. An online literature review and collection of resource materials, including power points from all discussions and presentations, will be available electronically ahead of time, during the symposium, and available publically after the symposium. A post-symposium report will be posted at CWRM and other websites. We anticipate making available videos of the panels.

4. Corresponding Public Event

A public discussion called "The Waters of Keauhou" will be held late afternoon of November 9th from 4:00p to 6:00pm. This event will be an Informational briefing and update on research and knowledge-building and will be sponsored by the University of Hawaiʻi's ʻIke Wai program which is engaged in long-term water research in the Keauhou area. ʻIke Wai is a 5-year research program funded by the National Science Foundation. In addition to ʻIke Wai's work, a summary of the two day symposium will be provided.

Annex-2

Participants

(**Note**: More detailed bios for participants can be found at http://www.accord3.com/docs/GDEsymposium/Participant-bios.pdf.)

	LAST NAME	FIRST NAME	AFFILIATION
1	Aloua	Ruth	KHNHP
2	Brasher	Anne	USGS (ret)
3	Barnes	Dave	Consultant
4	Beavers	Sallie	KHNHP
5	Bremer	Leah	Ike Wai
6	Brock	Richard	UH
7	Case	Suzanne	DLNR/CWRM
8	Chun	Greg	Ike Wai
9	Colbert	Steven	UHH
10	Cutillo	Paula	KHNHP
11	DaMate	Leimana	AMAC
12	Dulai	Henrietta	Ike Wai
13	Fahmy	Peter	KHNHP
14	Frank	Kiana	Ike Wai
15	Gibson	Veronica	Ike Wai
16	Glenn	Craig	UH
17	Hardy	Roy	CWRM
18	Ikeda	Mike	QLT
19	Kanuha	Jerome	AMAC
20	Kauka'a	Annie	AMAC
21	Lane-Kamahele	Melia	KHNHP
22	Lee	Reggie	AMAC
23	Lui	Nicole	AMAC
24	Nazara	Cynthia	AMAC
25	Okano	Ryan	DAR
26	Oki	Delwyn	USGS
27	Olson	Keith	NELHA
28	Pai	Mahealani	AMAC
29	Pai	Mabel	AMAC
30	Pearson	Jeff	CWRM
31	Polhemus	Dan	FWS

32	Purdy	Mana	QLT
33	Raikow	David	KHNHP
34	Romine	Brad	UH
35	Sakihara	Troy	DAR
36	Sedar	Dena	State Parks
37	Scheuer	Jonathan	KHNHP
38	Tagawa	Annette	DAR
39	Thomas	Don	UHH
40	Thompson	Bill	KHNHP
41	Tribble	Gordon	USGS
42	Whittier	Bob	DOH
43	Wiggins	Chad	TNC
44	Zimpfer	Jeff	KHNHP

	Staff		
	Adler	Peter	Facilitation & Planning
	Ranney	Katie	Facilitation & Logistics
	Dennison	Dan	DLNR - Videographer
	Roby	Francine	Note Taker

Annex-3
Agenda

Day 1 - November 8, 2018

8:30a **Gather at KHNHP** *(See logistics memo for directions to the south side of the park near K-H Harbor)*

- Welcomes
  - Jeffrey Pearson - Deputy Director, CWRM
  - William Thompson, Superintendent, KHNHP
  - Opening Pule - Mahealani Pai

9:15 **Site Visit to Selected Pools, Ponds, and Shore Features**

A walking tour Led by Park Superintendent William Thompson and NPS Environmental Protection Specialist Jeff Zimpfer

11:30 **Depart for Gateway Center at NELHA**

12:00p **Lunch** *(at Gateway Center)*

1:00 **Introductions, Discussion Plan, Procedures & Protocols**

- Startup – Jeff Pearson
  - Opening Pule

- Objectives, Key Questions, Website, Protocols, Logistics, Meals, Transport, Notes, Filming - Peter Adler

1:15 **Panel-1: Traditional and Customary Knowledge about the Park's GDEs**

Historic and generational knowledge from the park's ahupua'a families. A relaxed conversation with seven representatives of families from Kealakekua, Honokohau and Kohanaiki on what we know from past practices about the uses, care, and stewardship of the ponds, pools, and shoreline

- Introduction – Greg Chun, Moderator
- Pule
- Conversation

- Annie Kauka'a
- Mabel Pai
- Cynthia Nazara
- Nicole Lui
- Mahealani Pai
- Reggie Lee
- Jerome Kanuha

• Questions, Answers, Discussion

3:00 Break

3:15 Panel-2: Knowledge from Recent and Current Studies Related to the Park's GDEs or Analogous Areas in Other Geographies

- Introduction - Roy Hardy, Moderator
- **(2.A)** How has groundwater coastal discharge at KHNHP changed historically and more recently as pumping has increased? How might it change in the future if additional pumping does or doesn't occur? Discussion Starters:
  - Delwyn Oki
  - Henrietta Dulai
  - Craig Glenn

- **(2.B)** How do tidal and seasonal oscillations of GDE water levels and salinity affect the biota of the anchialine pools and fishponds? Discussion Starters:
  - Dan Polhemus
  - Kiana Frank
  - Richard Brock

- **(2.C)** How do those same tidal and seasonal cycles affect the biota of the immediate offshore habitats? Discussion Starter:
  - Veronica Gibson

4:45 Closing and Pau Hana

- Closing Pule

5:00 Refreshments

6:00 **Dinner** *(On your own)*

Day 2 - November 9, 2018

8:00a **Coffee, Tea, Pastries, Fruit**

8:30 **Welcome and Startup**

- Opening Pule
- Recap of Day 1 and Day's Agenda
    - Peter Adler

8:45 **Panel-3: Natural and Non-Natural Fluctuations in the Park's GDEs**

- Introduction - Peter Adler, Moderator
- **(3.A)** What is the known range of water and salinity levels in the tidal pools and ponds and how are they measured? Discussion Starters:
    - Paula Cutillo
    - Keith Olson
    - David Barnes

- **(3:B)** What do we currently know about the types and amounts of contaminants and pollutants in the pools, ponds, and near-shore habitats and their effects on biota? Discussion Starters:
    - Ryan Okano
    - Bob Whittier

- **(3.C)** What do we currently know about the types and numbers of invasive non-native species in the pools, ponds, and near-shore habitats and their effects on biota?
    - Sallie Beavers
    - Troy Sakihara

- **(3.D)** What projections can be made as to how impending climate changes and sea level rise may affect the salinity and water levels in the pools, ponds, and offshore habitats?
    - Brad Romine
    - Chad Wiggins

10:00 **Break**

10:15 **Development of Possible Tracking and Monitoring Measures for GDEs - Breakout and Rotations** (Peter Adler and Katie Ranney)

- What specific short list of indicators might be monitored and tracked over the next 5-years to best inform CWRM's policies in the ahupua'a in which the park is located and (b) how might those best be monitored?
    - Group-1: Water
    - Group-2: Endemic Species
    - Group-3: Invasive Species
    - Group-4: Contaminants and Pollutants

12:00p **Lunch**

1:00 **Reports from Indicators Work Groups**

- Group-1: Water
- Group-2: Endemic Species
- Group-3: Invasive Species
- Group-4: Contaminants and Pollutants

1:30 **TBD**

2:45 **Closing**

- Next Steps
- Appreciations
- Closing Pule

3:00 **Pau Hana**

3:30 **Public Event** (At Gateway Center)

Public Event

ʻIKE Wai: Ensuring Hawaiʻi's Water Resources

A Community Informational Update on Research Underway in West Hawaiʻi Including a Brief Summary of Key Themes from the Symposium

Sponsored by the University of Hawaiʻi

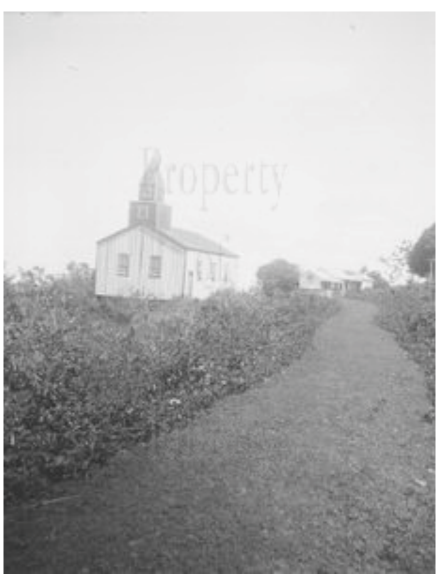
5:30 **Pau Hana**

Annex-4
Site Visit

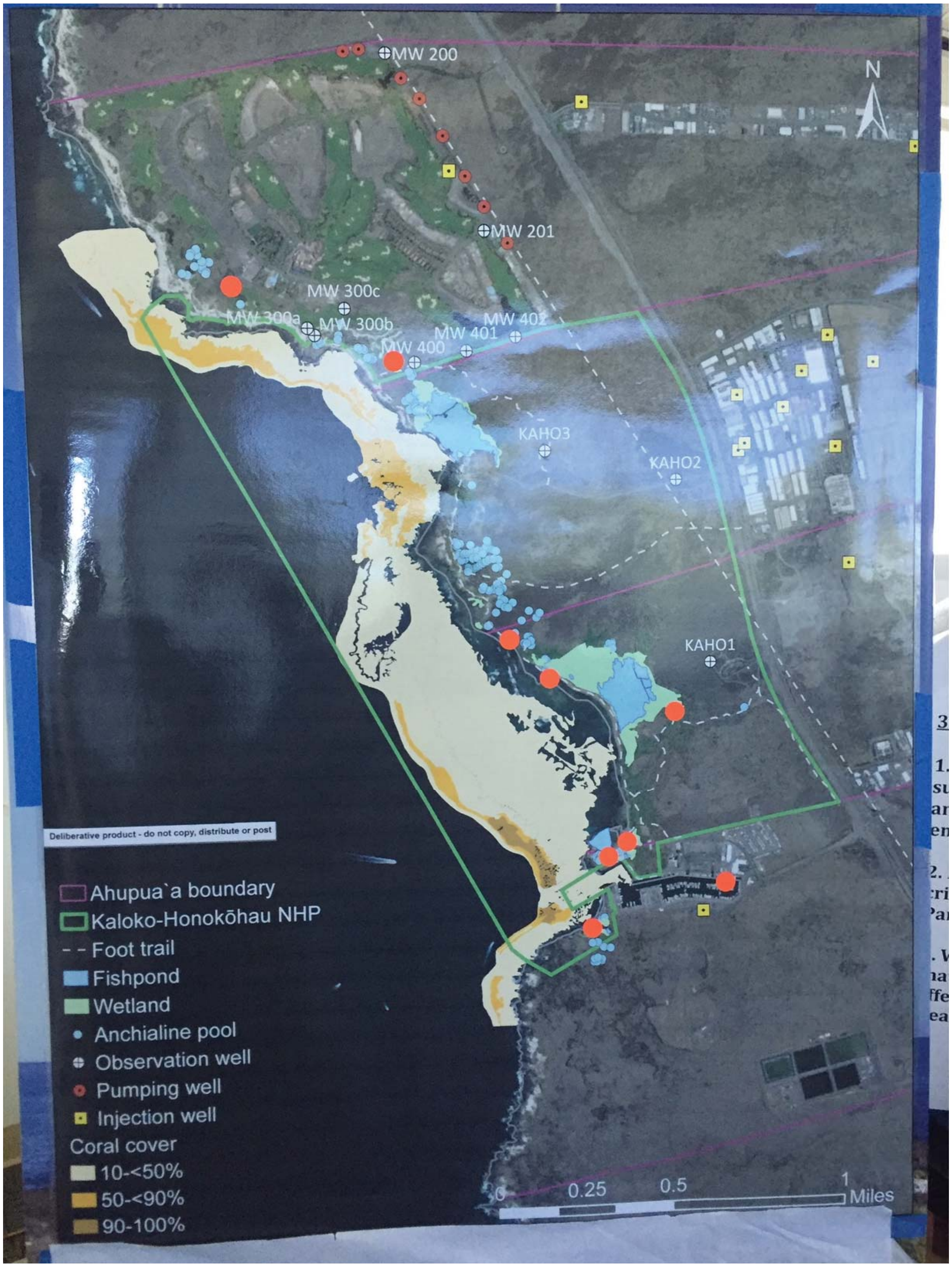
Annex-5
Historic Photos



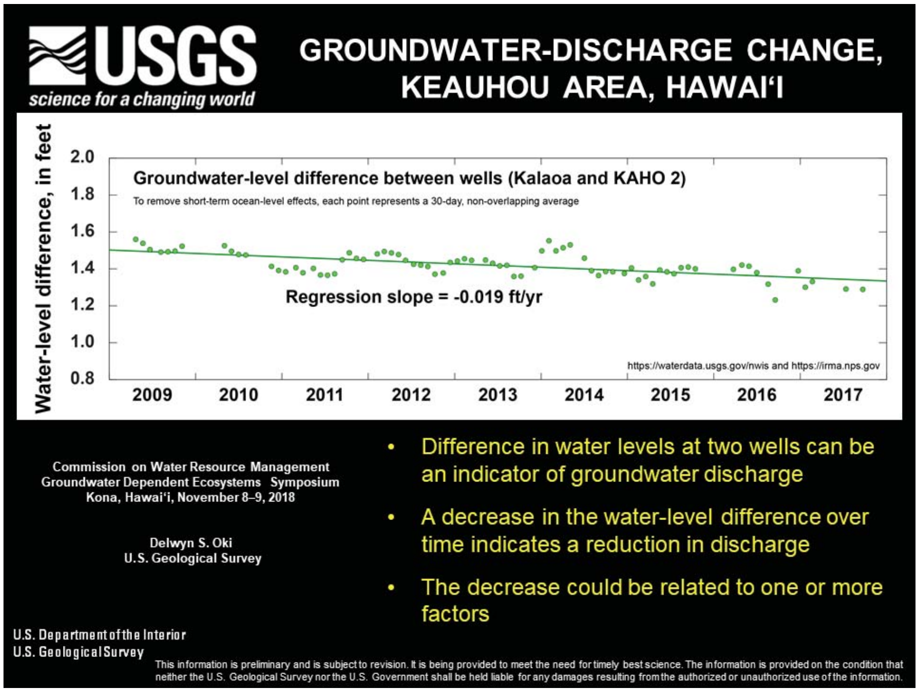


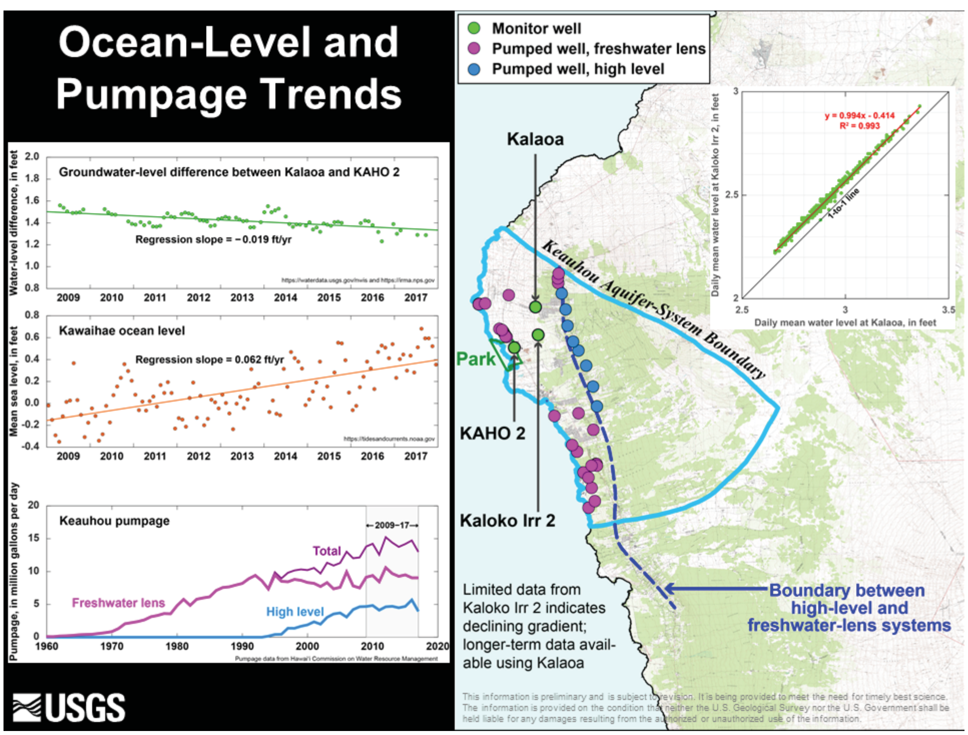


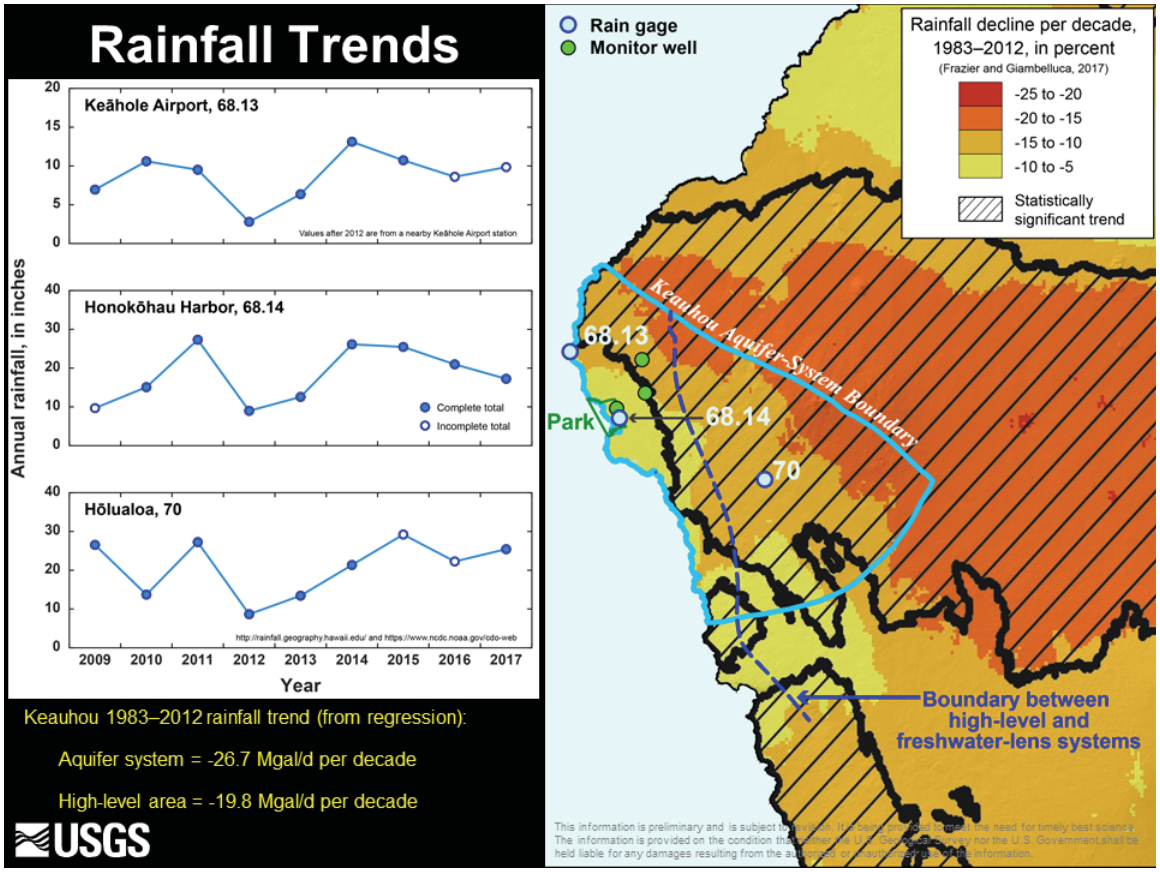

Annex-6
Some Important Places on the Map



Annex 7
Groundwater Discharge in the Keauhou Aquifer







Rainfall Trends
Keāhole Airport, 68.13
Values after 2012 are from a nearby Keāhole Airport station
Honokōhau Harbor, 68.14
Complete total
Incomplete total
Hōlualoa, 70
http://rainfall.geography.hawaii.edu/ and https://www.ncdc.noaa.gov/cdo-web
Annual rainfall, in inches
20
15
10
5
0
40
30
20
10
0
2009
2010
2011
2012
2013
2014
2015
2016
2017
Year
Keauhou 1983–2012 rainfall trend (from regression):
Aquifer system = -26.7 Mgal/d per decade
High-level area = -19.8 Mgal/d per decade
USGS
Rain gage
Monitor well
Rainfall decline per decade, 1983–2012, in percent
(Frazier and Giambelluca, 2017)
-25 to -20
-20 to -15
-15 to -10
-10 to -5
Statistically significant trend
Keauhou Aquifer-System Boundary
68.13
68.14
70
Park
Boundary between high-level and freshwater-lens systems

Annex-8
The Intersection of Marine and Terrestrial Hydrological Processes

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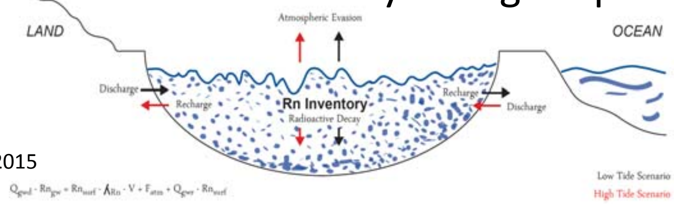
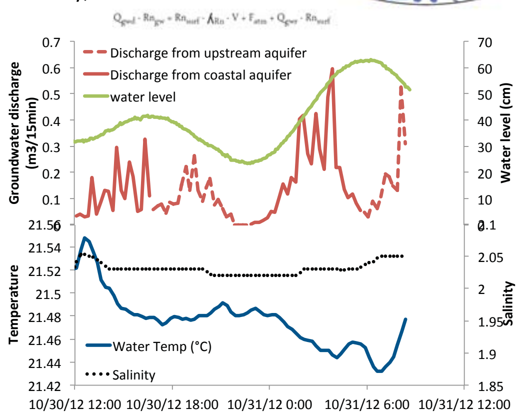
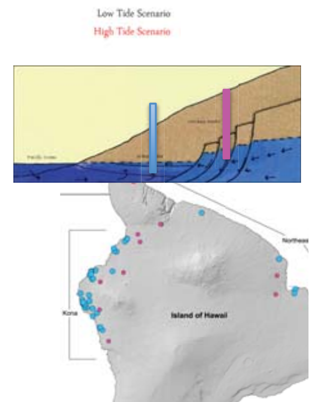
Coastal ponds lay at the intersection of marine and terrestrial hydrological processes



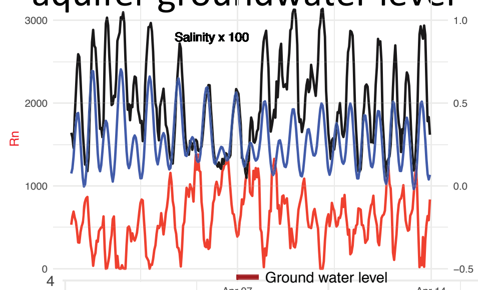
Dudley, 2015

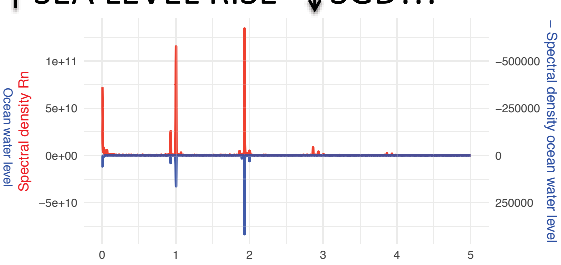


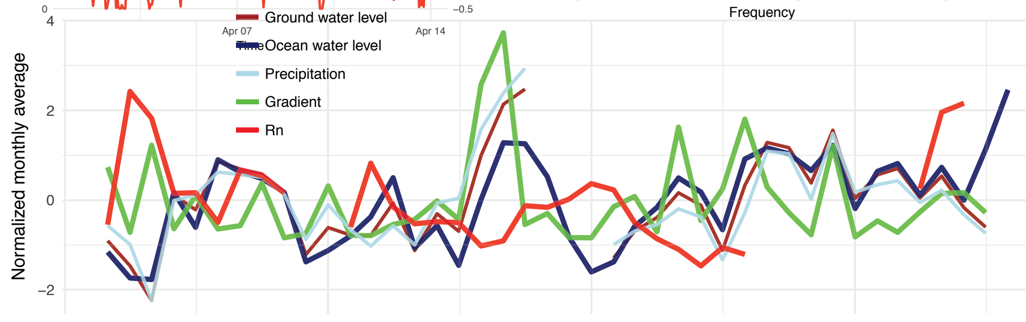


Rotzoll, 2013

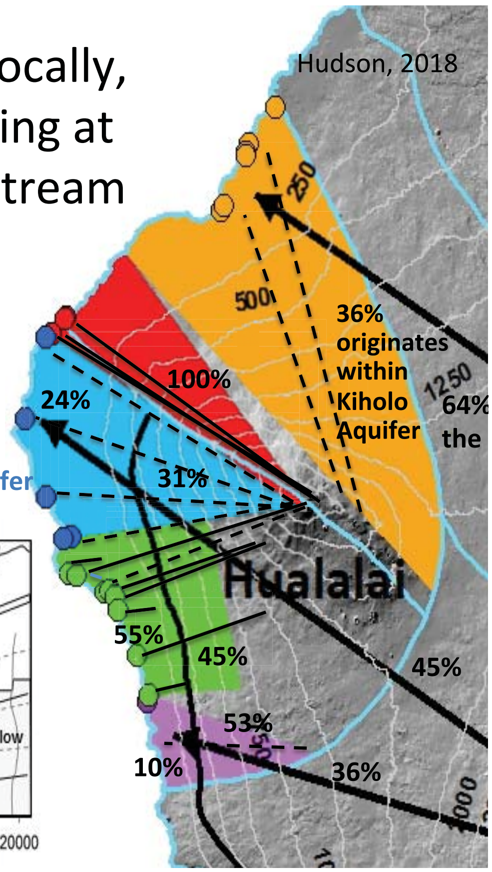
Monitoring over longer time period shows that submarine groundwater discharge (SGD) is affected by sea level because sea level affects both, ocean water level and aquifer groundwater level ↑ SEA LEVEL RISE= ↓ SGD!!!



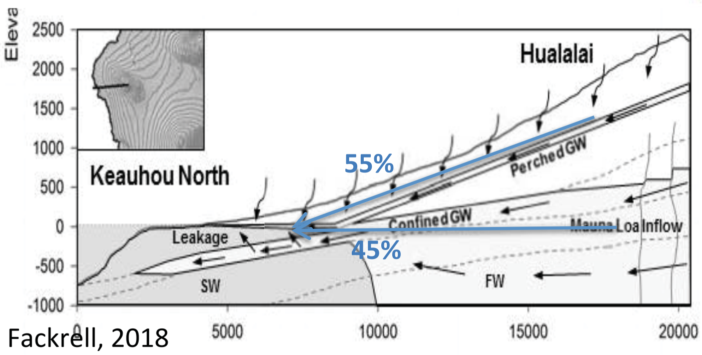




SGD is sourced only partially locally, at least half of water discharging at the coast comes from the upstream aquifer



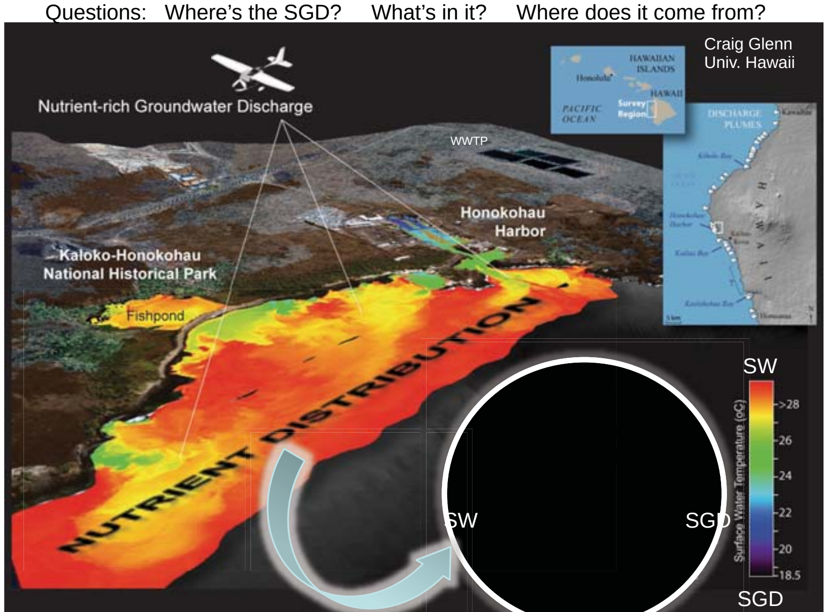
SGD=24% basal+31% high-level+45% upstream aquifer



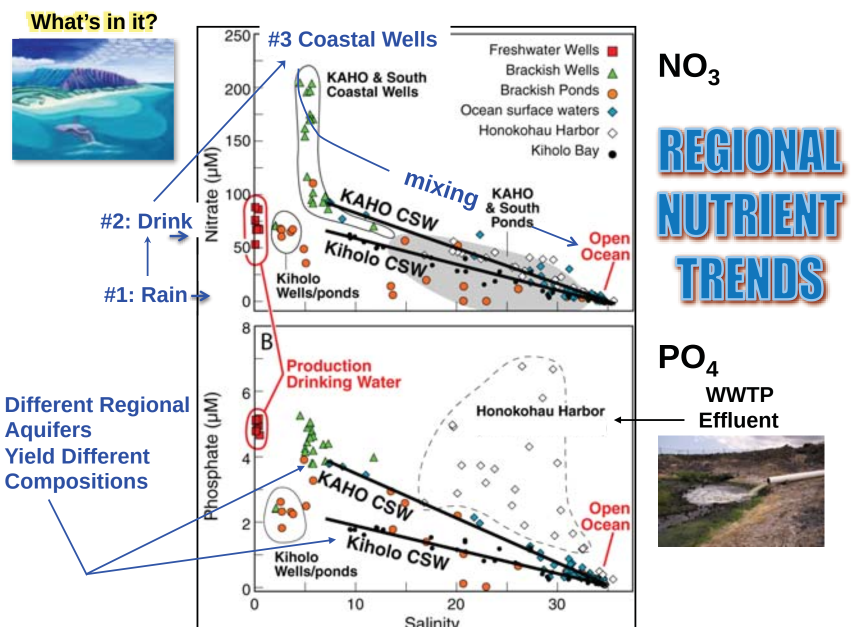
Fackrell, 2018

Annex-9
Groundwater Aerial Study

Questions: Where's the SGD? What's in it? Where does it come from?



Johnson et al., 2008

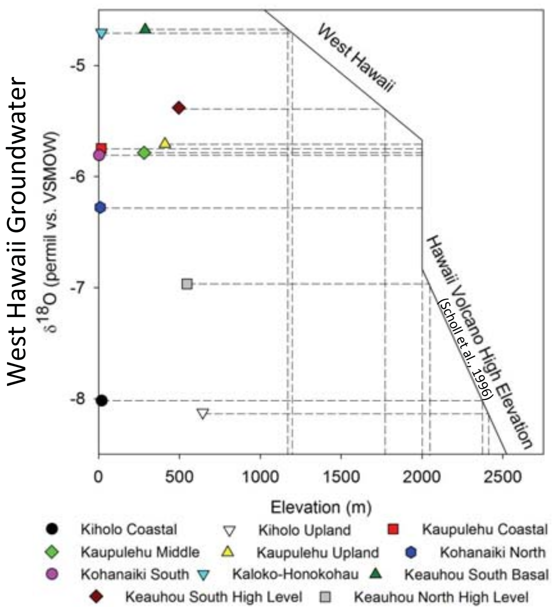


Johnson et al., 2008

Where does it come from?

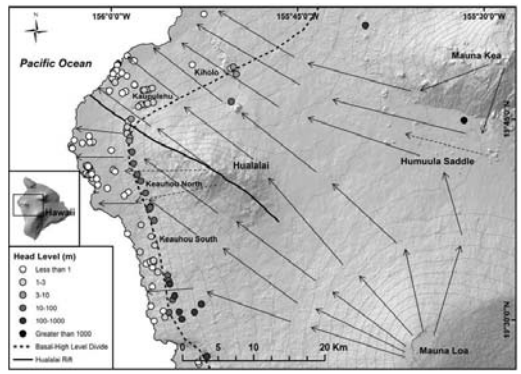
ISOTOPES OF WATER

Flowpaths is more complicated than once thought



Average groundwater recharge elevations extrapolated using precipitation collector δ18O-elevation relationships from West and from high elevation Kilauea volcano.

Very low groundwater $\delta^{18}O$ values suggests significant fractions of coastal groundwater derived from very high elevations (>2000 m), far inland.



Generalized summary of West Hawai‘i groundwater flow paths based on calculated flow paths and conceptual models.

From Fackrell et al., submitted 2018
- Also see Tillman et al., 2014 -

Annex-10
Native Damselflies

All native Hawaiian damselflies are in the endemic genus *Megalagion*
27 currently recognized taxa – most are strictly freshwater breeders
One species, *M. xanthomelas*, can tolerate mixohaline waters
This species is currently listed as Threatened under the ESA

Megalagrion xanthomelas

Megalagrion xanthomelas Biology

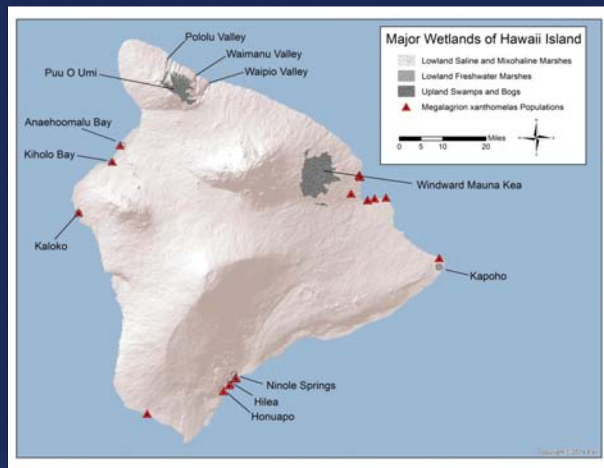
Immatures are fully aquatic, then hatch out into flying adults
Have recently been reared in captivity

Go through 8-10 instars
Development time to adult stage is
114 days at 22° C in fresh water
Data from Will Haines, Hawaii DLNR

Documented breeding water temperature range of 20-28° C
Eggs will hatch at salinities up to 20 ppt at 24-28° C
No hatching at 20 ppt if water temperature falls to 20° C
Immatures cannot tolerate salinities over 15 ppt
Data from Lori Tango, UH Hilo and Robert Peck, USGS

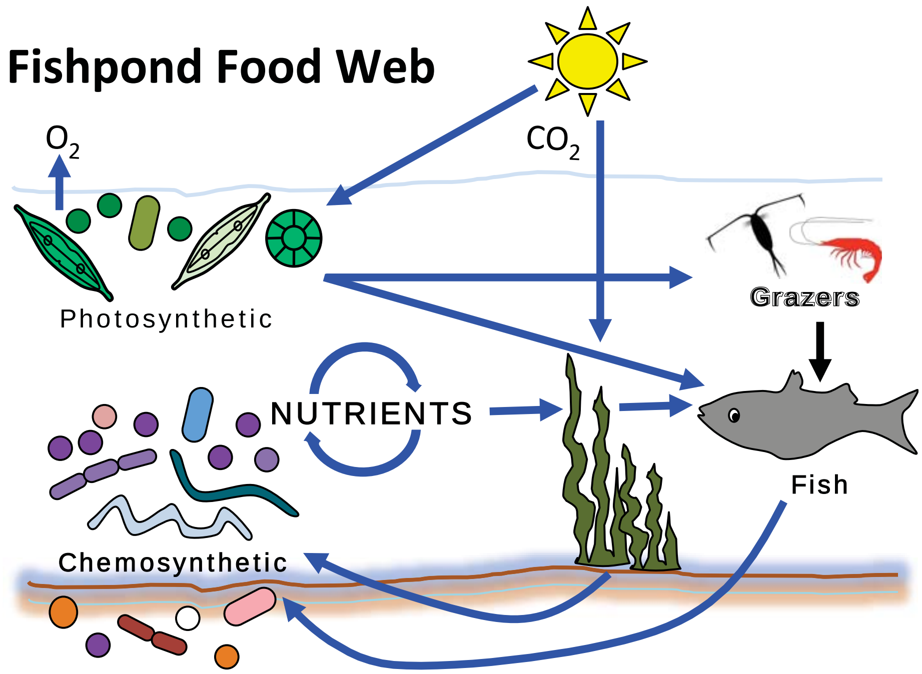
Immature stages are susceptible to predation by introduced fishes
Apparently extirpated on Kauai, only one population remaining on Oahu
A few scattered populations remain on Lanai, Molokai and Maui

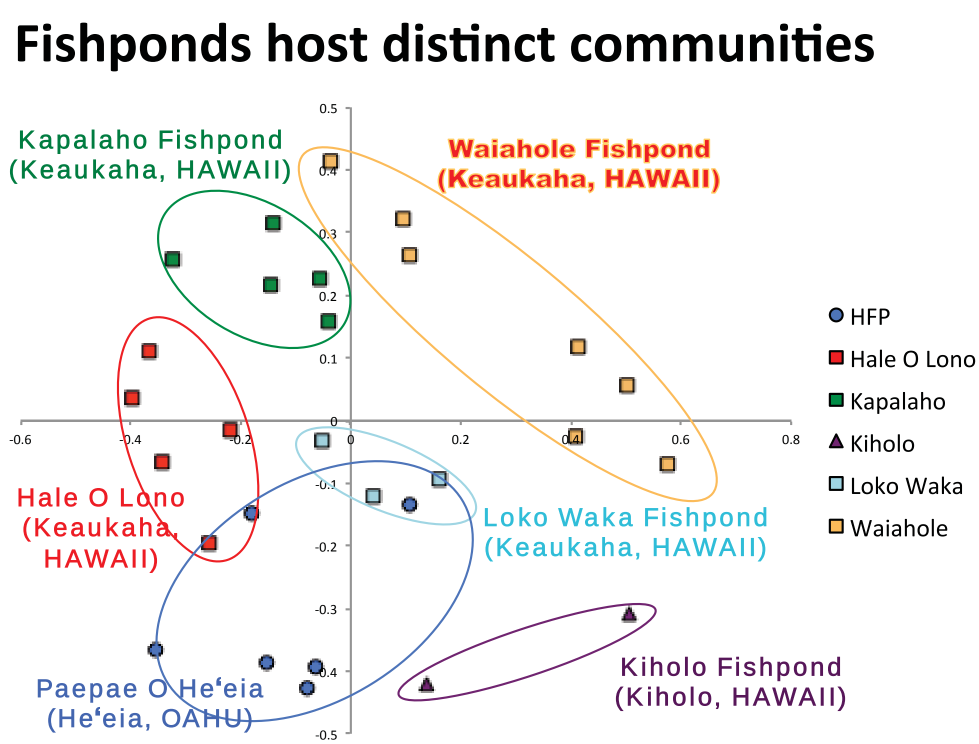
Populations of *Megalagrion xanthomelas*
are scattered in coastal wetlands around Big Island



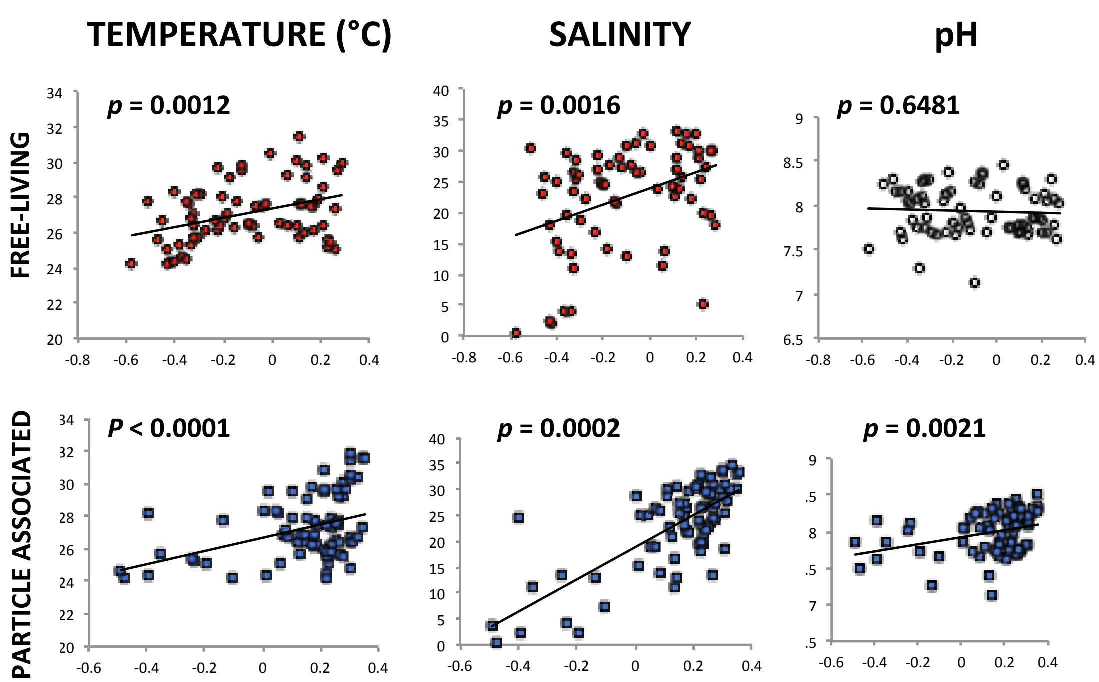
Kapoho populations were recently lost due to East Rift Zone eruption of Kilauea

Annex-11
Food Web and Microbes





Communities correlated to physical variables

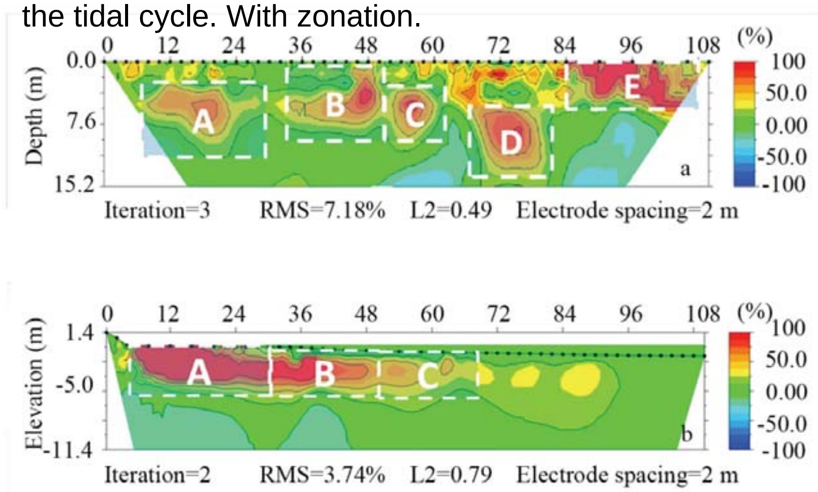


Annex-12
Seasonal and Tidal Effects

Ho'oilo-Kona Dry Season- October through April	**Ka'u-Kona Wet Season- April through October**
• Winter (short cool days) • Large north and west swells, wave action, wave set up, mixing • Little wind, little rain • Fewer species spawning in this season.	• Summer (long hot days) • Long period south swells, little wave action on north facing shores • Winds: Kona, Hurricanes, Tradewinds • High frequency of late afternoon or early evening showers • Blooms, reproduction of macroalgae • Many species of fish spawning • Late in the season fish stocks are high
Strong mixing by winter swells, less exposure to SGD with wave set up and mixing, cleaning out of accumulated biomass and detritus.	**Calm seas,** more exposure to SGD (salinity, pH, nutrients, mixing) under calm conditions, build up of biomass in macroalgae and fish stocks.

Effects of the tidal cycle

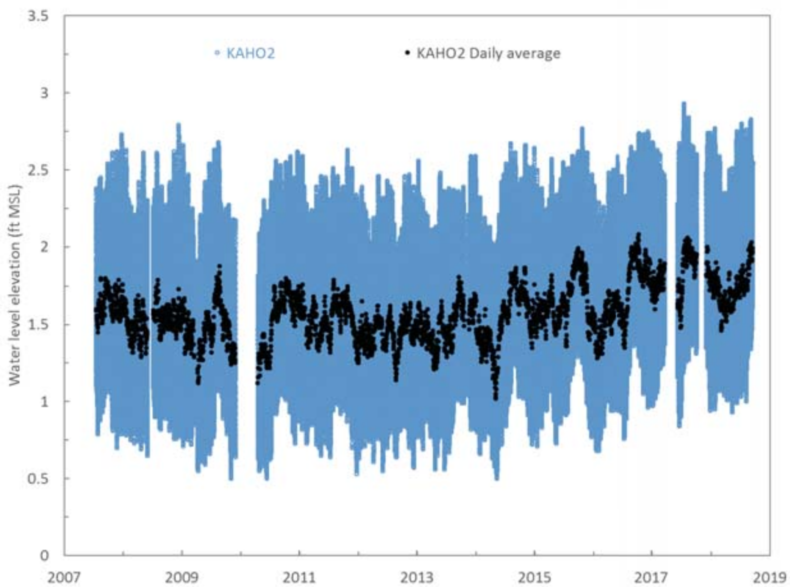
Pulsing changes in salinity, nutrients, temperature and pH with the tidal cycle. With zonation.



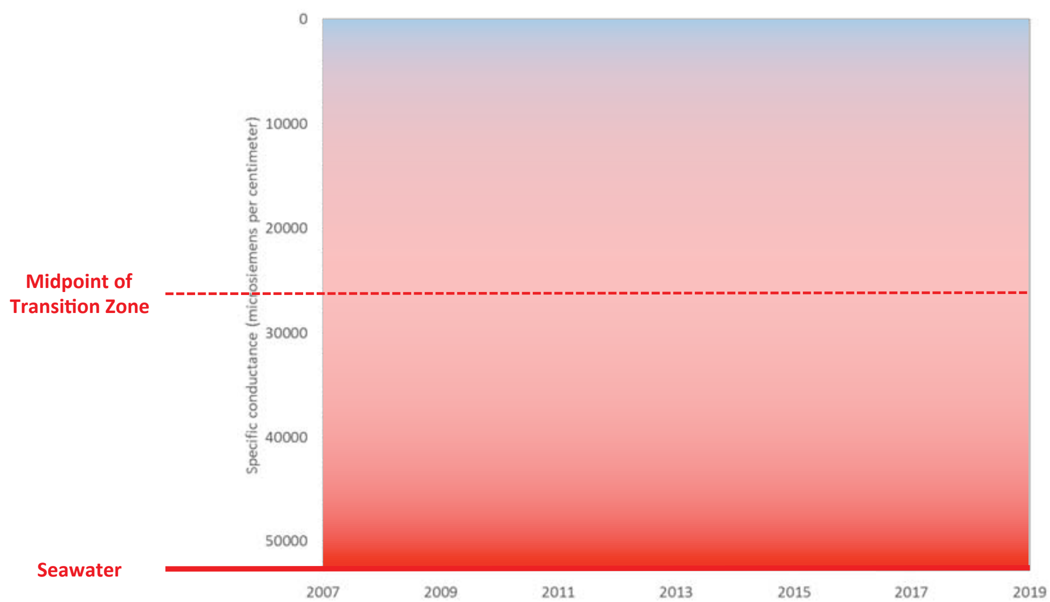
Percent difference change in resistivity between high at low tide at Kiholo Bay and Wailupe Beach. (Dimova *et all* 2012).

Organism(s)	**Effects of SGD**
Phytoplankton and Bacteria-	• Diatom blooms with DIP, DIN, and silicate. • Cascading effects of diatom blooms • Cyanobacteria can increase with diatom cascade, but can also decrease with diatom competition, increase with salinity. • Fecal indicator bacteria and viruses from anthropogenic waste sources.
Macroalgae and Marine Plants-	• Blooms are common where DIN pollution is high • Reduced biodiversity with DIN pollution • High macroalgae biomass possible at SGD seeps • Decreased biomass in some species with Increased competition and epiphytes
Animals-	• Reduction in coral cover and species diversity, reduced calcification, disease from bacteria • Increased fibropapillomatosis virus tumors in *Chelonia mydas* with algal blooms • Meiofauna and fish can increase or decrease with SGD
Ecosystems-	• Dynamic, productive and structured • Zones of SGD tolerance

Annex-13
Fluctuations in Groundwater

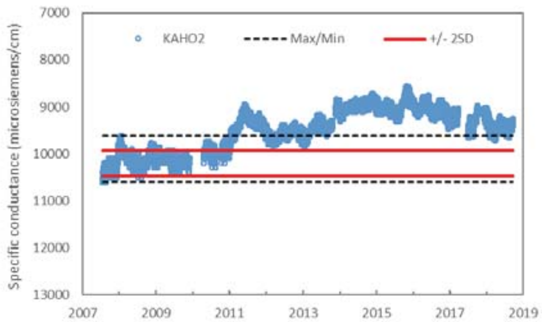


https://waterdata.usgs.gov/nwis https://irma.nps.gov/aqwebportal/



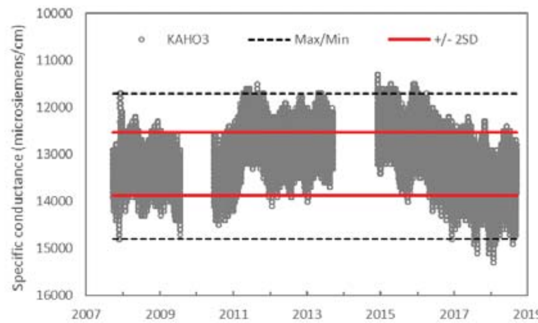
https://waterdata.usgs.gov/nwis https://irma.nps.gov/aqwebportal/

KAHO2



Baseline period = 7/23/2007 to 12/31/2008

KAHO3

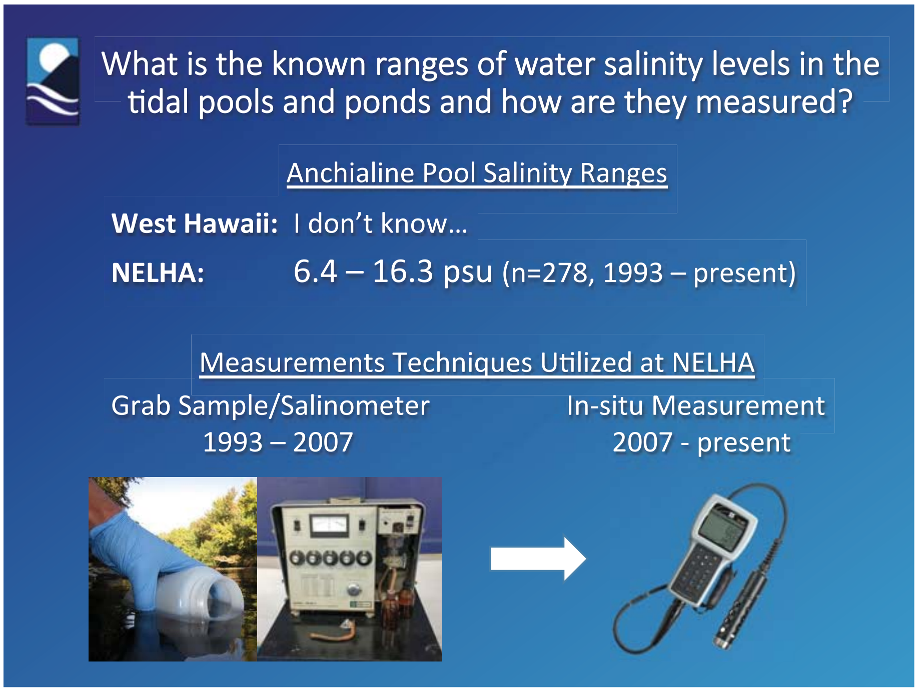


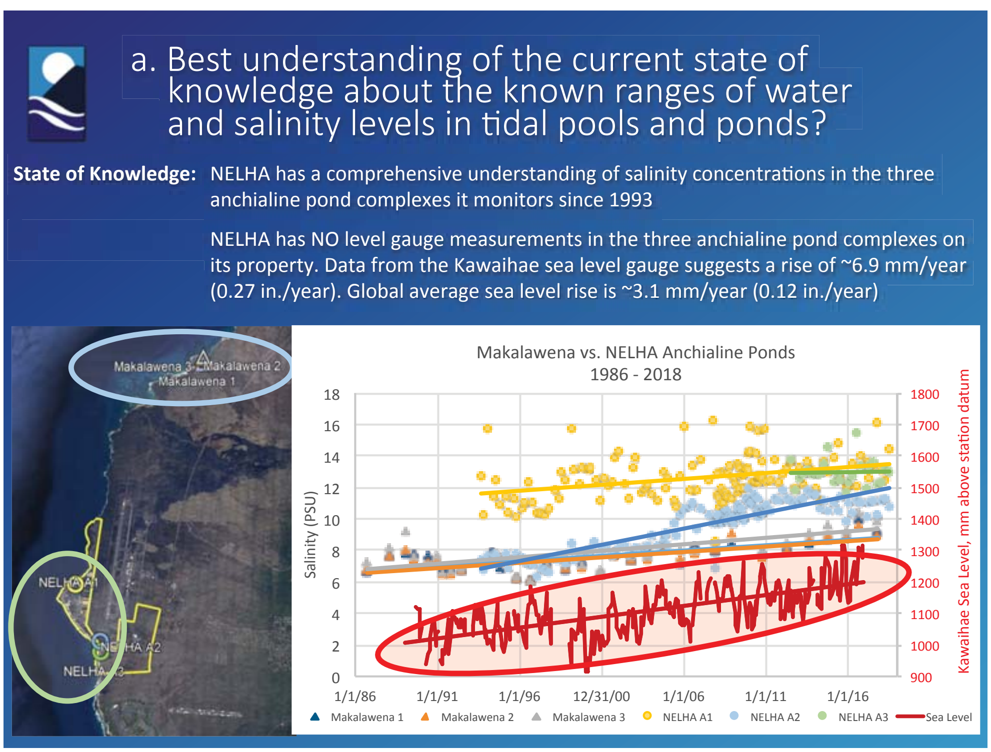
Baseline period = 9/25/2007 to 12/31/2008

https://waterdata.usgs.gov/nwis

https://irma.nps.gov/aqwebportal/

Annex-14
Ranges of Salinity



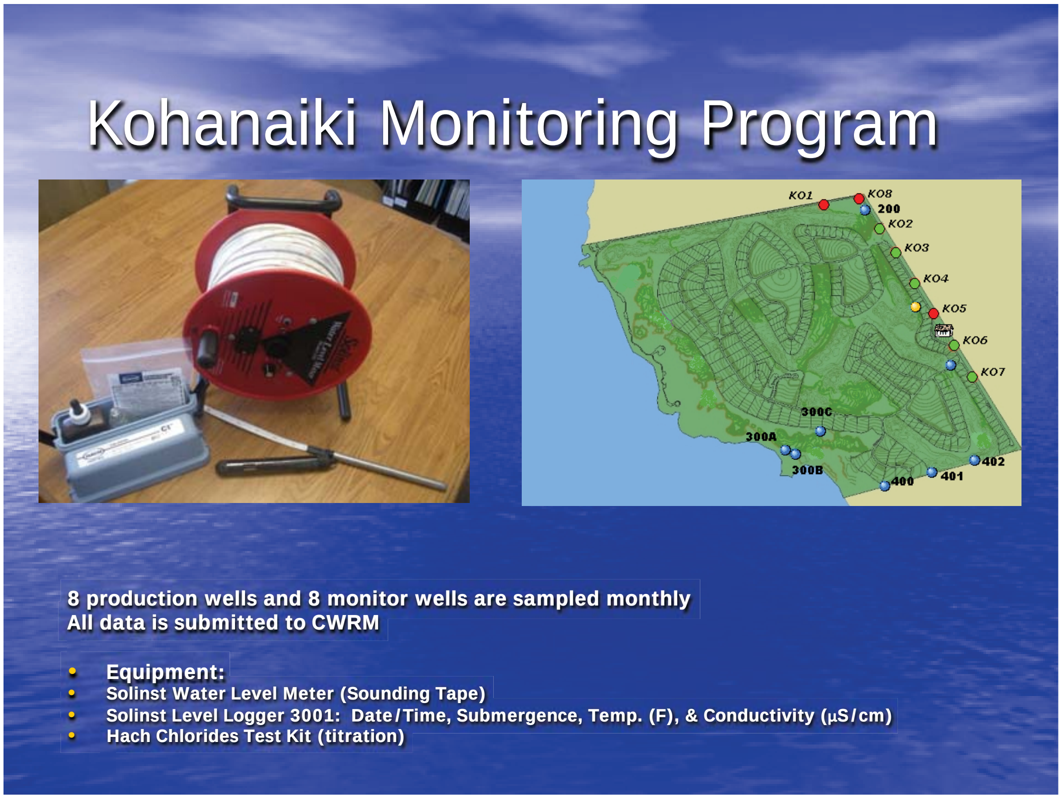


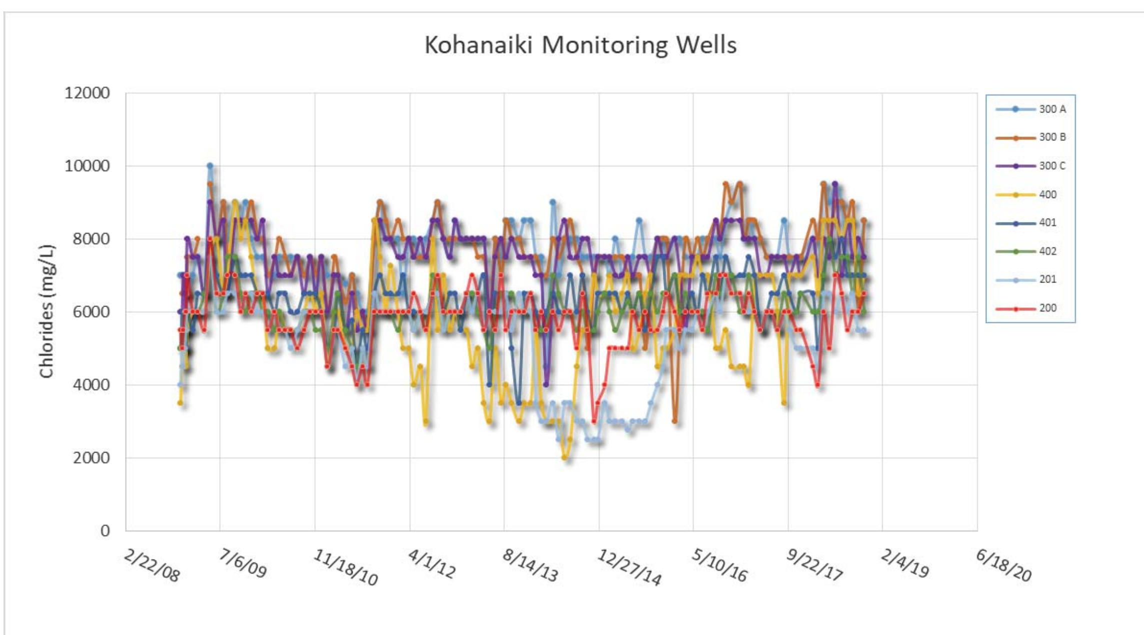
b. What are the critical pieces of additional research that might help improve knowledge if money, time and energy were invested

Multiple level and salinity sensors deployed in anchialine ponds in West Hawaii that communicate to a centralized database with access to a dashboard plotting real time conditions and archiving raw data. The data generated can be analyzed to determine conditions outside of the normal environmental variations. These abnormal conditions can trigger alerts to resource mangers so mitigative actions can be implement, if necessary.

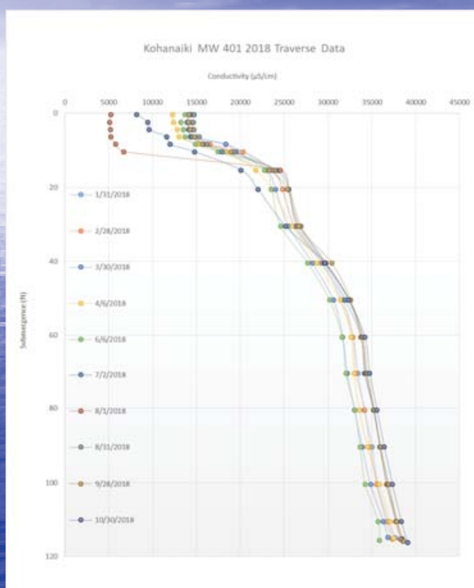
Sensors | Communications | Database | Control Charts and Alerts

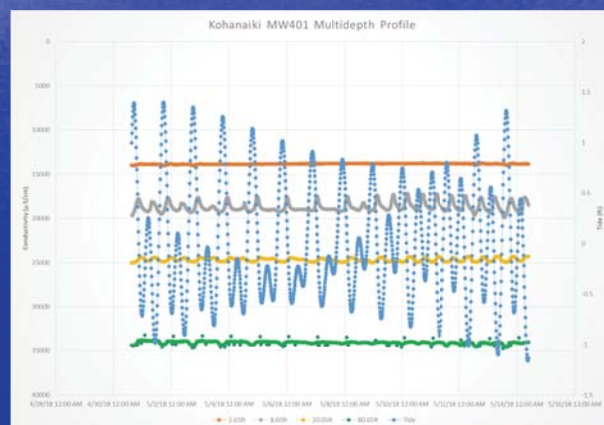
Annex-15
Kohaniki Monitoring



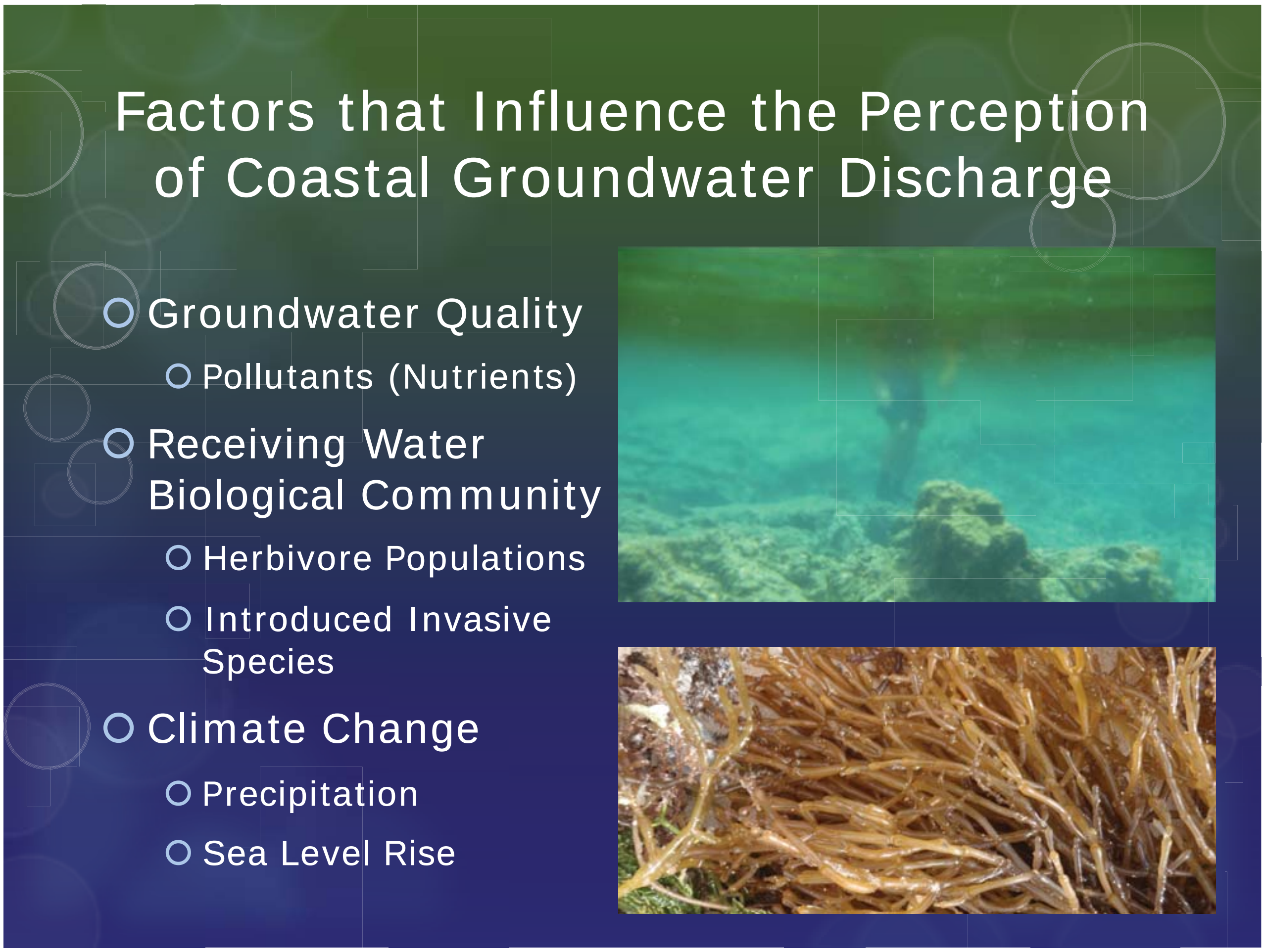


MW-401 2018 Profile Data





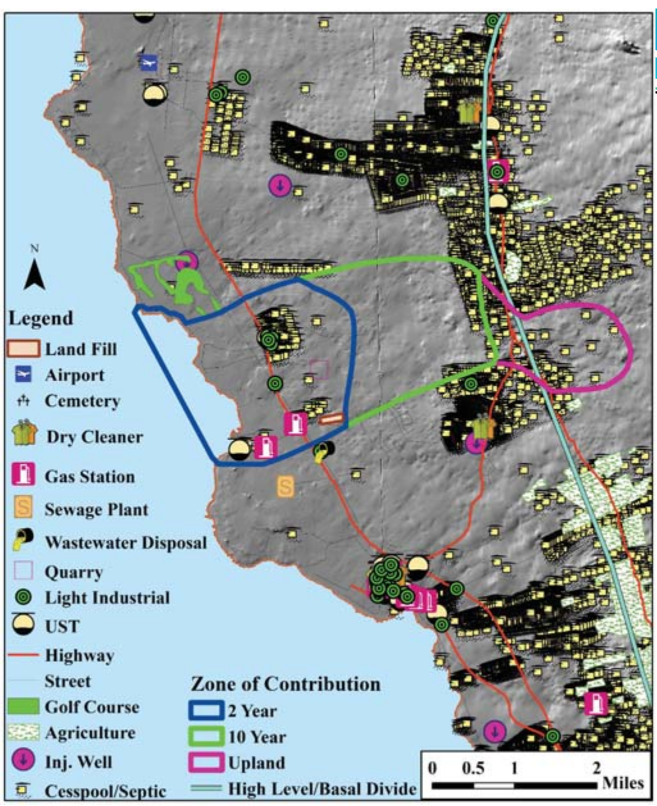
Annex-16
Impacts on Limu



Annex-17
GDE Contaminants

Source Water Assessment

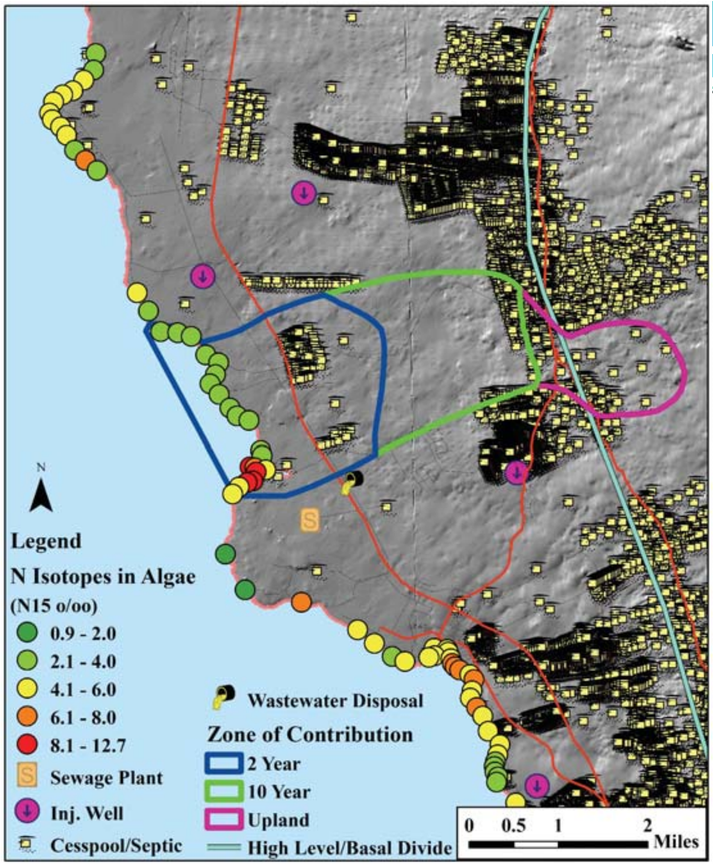
- Coastal groundwater discharge is the primary contaminant transport vehicle
- Zone of Contribution (ZOC)
  - That land area under which groundwater travels to coastal discharge areas
  - Activities within the ZOC may contribute contamination to the Kaloko-Honokōhau National Historical Park (KHNHP)
- Delineate the ZOC using a groundwater model
- Inventory the potential contamination sources within the ZOC
- Wastewater disposal has the greatest contamination potential
  - Nitrogen isotope data indicate wastewater impact to the KHNHP is not severe compared to other coastal areas of West Hawaii



Potential Sources of Contamination

- Primary Potential Contaminants
  - Wastewater disposal
  - Light industrial
- USGS sampling
  - Found only trace levels of contaminants
- Data Sources:
  - Hunt, 2014, Baseline water-quality at Kaloko-Honokōhau National Historical Park, USGS Scientific Investigations Report 2014-5158, 52 p
  - Hawaii Dept. of Health, Safe Drinking Water Branch Contaminant Data Base

3



Potential wastewater Contamination

- Wastewater Sources
  - Septic/Cesspool disposal
  - Municipal Disposal
- Nitrogen Isotopic Composition of Algae
  - Hawaii Coral Reef Initiative, 2013, Survey of the Nitrogen Isotopic Composition of West Hawaii Coastal Algae
  - Potential wastewater contribution when $\delta^{15}N > 4\ ^{o}/_{oo}$
- Septic/Cesspools within the ZOC
  - 2 yr. – 75 septic, 45 cesspools
  - 10 yr. – 21 septic, 67 cesspools
  - Upland – 53 septic, 82 cesspools
  - Total nitrogen load
    - 26 kg(N)/d
- Wastewater Disposal
  - ~1.5 mgd
  - 3.8 mg/L (N)
    - Hunt, 2008
  - N Load – 20 kg(N)/d
  - Likely discharge to the small boat harbor?

4

Annex-18
Invasive Species - A

Table 1. Direct threats to coastal wetland habitats.

Threat	Rank
Groundwater pumping	Very High
Climate change: increased storm surge, flood frequency and intensity	Very High
Climate change: sea level rise	High
Stream channelization	High
Climate change: changing rainfall patterns	High
Freshwater diversion	High
Tree and shrub encroachment (non-wetland plants)	High
Urban development	High
Introduction of invasive plants	High
Flood protection levees and dikes	Medium
Climate change: projected increases in air temperature	Medium
Non-point source pollution: storm water run-off	Medium
Sewage overflow/other human waste	Medium
Non-point source pollution: nutrients	Medium
Overgrazing and riparian use by domestic livestock	Medium
Introduction of non-native fish	Medium
Feral ungulates	Medium
Non-native birds	Low

From: Pacific Birds Joint Habitat Venture 2017: Threat Rankings for Coastal Wetland Habitat

Invasive Fish in West Hawaiʻi

Study	% of pools with invasive fish	# of pools surveyed	Poecillids	Tilapia*
Maciolek & Brock 1974	11%	n=264		
Marrack et al. 2015	25%	n=398	23.9% (n=95)	3.5% (n=14)
NPS unpub. (KHNHP) 2018	18.8%	n=191	18.8% (n=36)	1.6% (n=3)

*Tilapia introduced to ʻAimakapā 2008 (MacKenzie and Bruland 2012)

USGS-NPS Research Fish Eradication Methods

- **Assess efficacy to eradicate tilapia and Poeciliids & determine effects on native species (Nico et al. 2015)**
  - **Rotenone**
  - **Auhuhu –*Tephrosia purpurea***
  - **Carbon Dioxide**
- **eDNA – confirm presence/absence**

EXPERIENCE YOUR AMERICA™

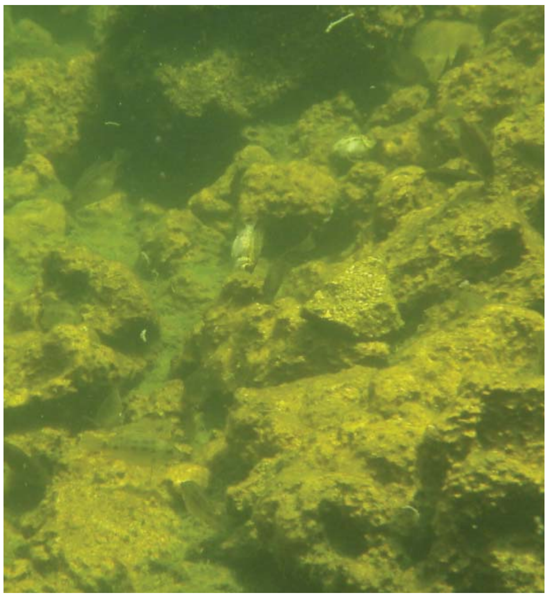
- Kaloko Fishpond
  - Upside Down Jellyfish
    Cassiopeia andromeda
  - Alien Alga –
    Acanthophora spicifera
    (Weijerman et al. 2008)

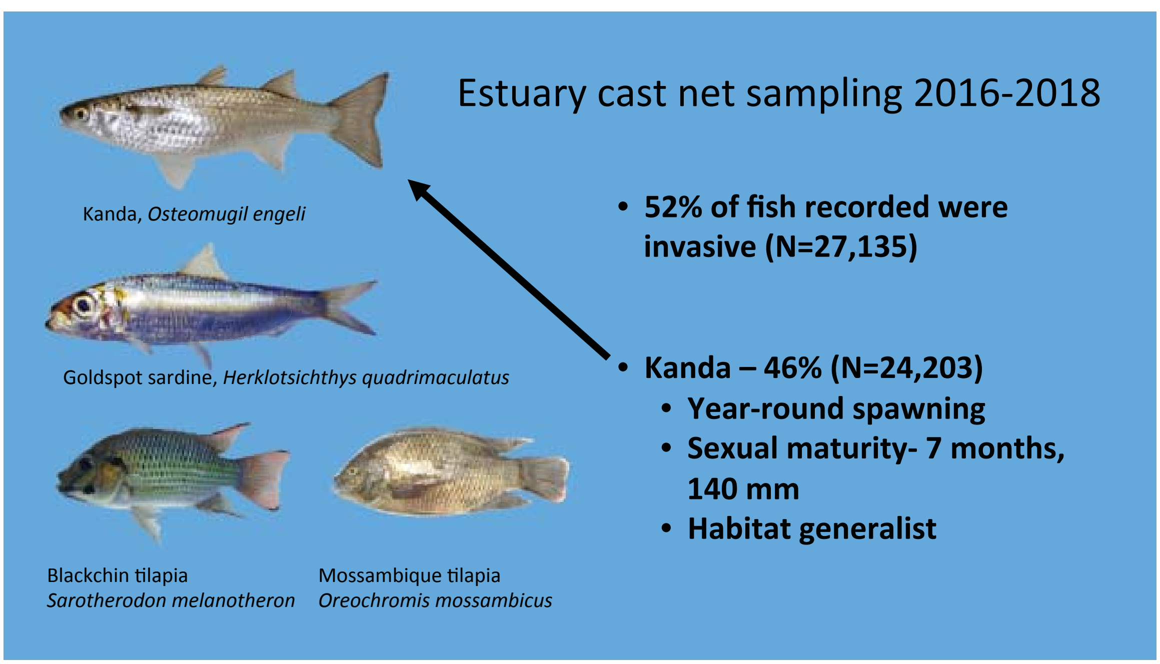
- Marine waters
  - Crown of Thorns Starfish (native can be invasive)
    Acanthaster planci
    -Regular monitoring (Brown et al. 2011, Marrack et al. 2014, Weijerman et al. 2014)
  - Invasive Snapper, Grouper

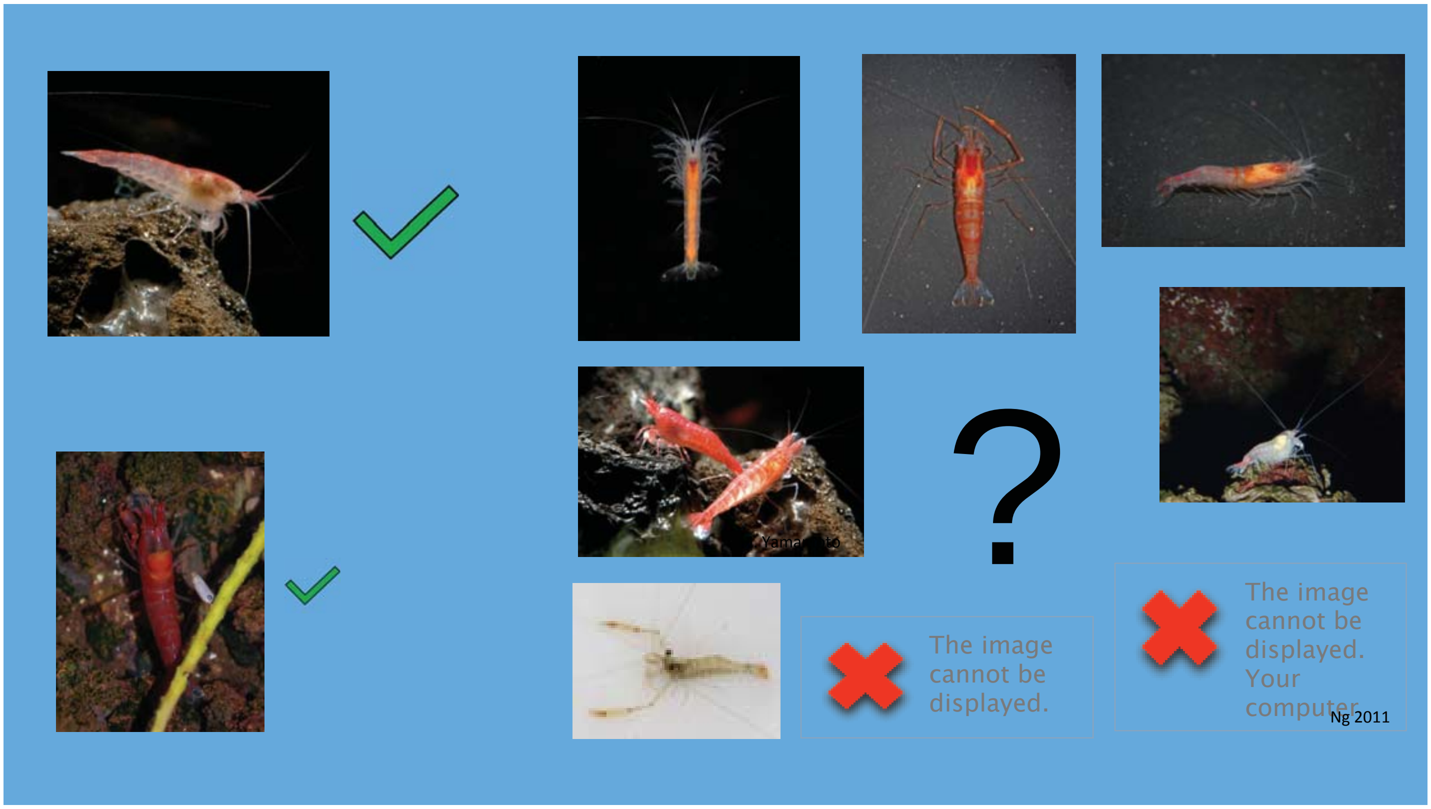
Kiawe Forest Removal

Mālama ‘Aimakapā Fishpond
B. maritima & *Paspallum* removal

Annex-19
Invasive Species - B






Yamamoto
?
The image cannot be displayed.
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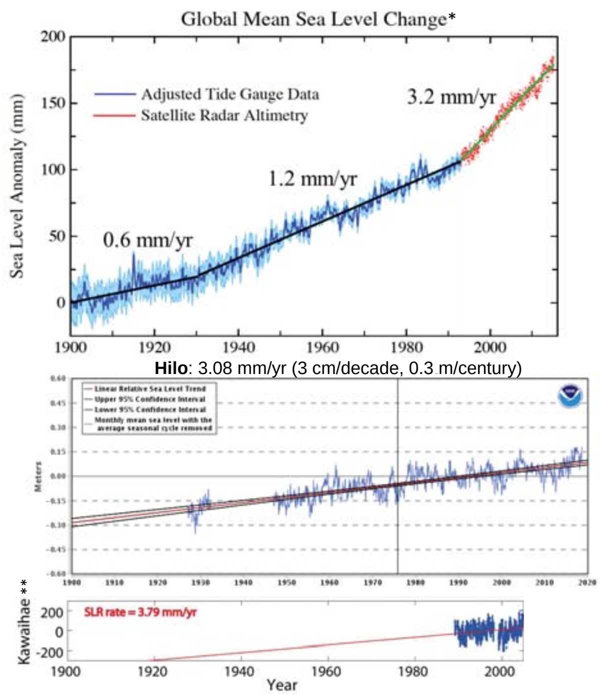
Ng 2011

Annex-20
Sea Level Rise



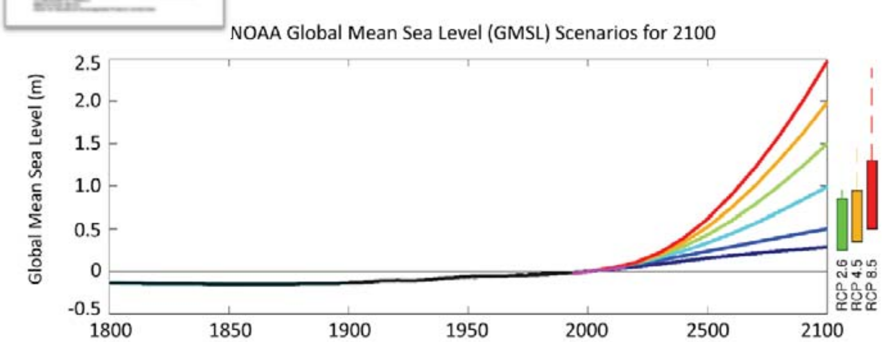
*Is the detection of accelerated sea level rise imminent? J. T. Fasullo, R. S. Nerem & B. Hamlington Scientific Reports 6, Article number: 31245 (2016) doi:10.1038/srep31245; Hansen et al., 2015; Church and White, 2011; Nerem et al., 2010; Hay et al., 2015; Yi et al., 2015. **Vitousek, et al. 2009. Pu'ukoholā Heiau National Historic Site and Kaloko- Honokōhau Historical Park, Big Island of Hawai'I Coastal Hazard Analysis Report. For the NPA Geologic Resources Division.

NOAA (2017) Global Mean SLR Scenarios

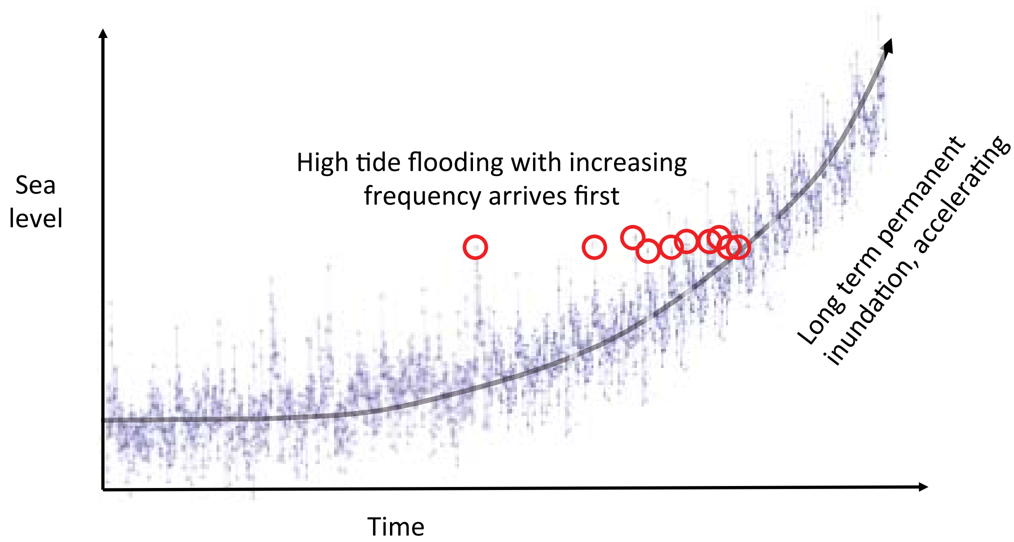
2030: 0.13 to 0.24 m, Intermediate = 0.16 m

2050: 0.24 to 0.63 m, Intermediate = 0.34 m

2100: 0.50 to 2.5 m, Intermediate = 1.0 m

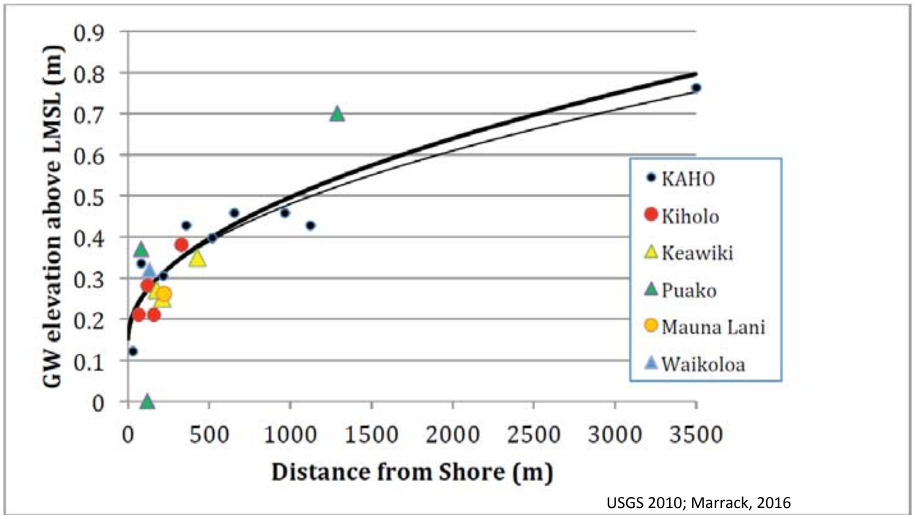


Sea level rises in 2 styles



(Chip Fletcher, UH SOEST)

Annex-21
Coastal Resilience




maps.coastalresilience.org/hawaii

Annex-22
Indicators

Pacific Island Network
Inventory and Monitoring Division

National Park Service
Department of the Interior

Water quality monitoring in Pacific parks:

- Ala Kahakai National Historic Trail
- American Memorial Park
- Haleakalā National Park
- Hawaiʻi Volcanoes National Park
- Kalaupapa National Historical Park
- Kaloko-Honokōhau National Historical Park
- National Park of American Samoa
- Puʻuhonau o Hōnaunau National Historical Park
- Puʻukoholā Heiau National Historic Site
- War in the Pacific National Historical Park

- Total Dissolved Phosphorus (TDP)
- Total Dissolved Nitrogen (TDN)
- Nitrate + Nitrite
- pH
- Oxygen
- Turbidity
- Chlorophyll
- Temperature
- Salinity by specific conductance

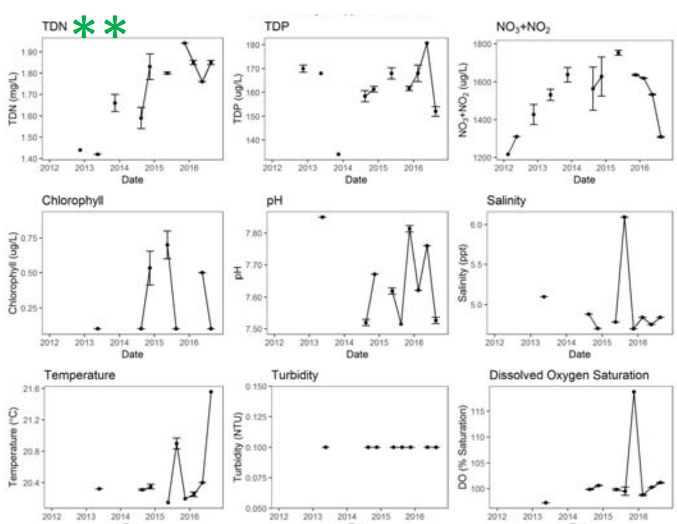
- Certified data, not reported, marine report written.
- Rough analysis using Linear Mixed-Effects Model.

Contact: David Raikow
808-985-6325
david_raikow@nps.gov
Groundwater Dependent Ecosystems Symposium Nov 2018

Pacific Island Network
Inventory and Monitoring Division

National Park Service
Department of the Interior

Upper
Kaloko
Well

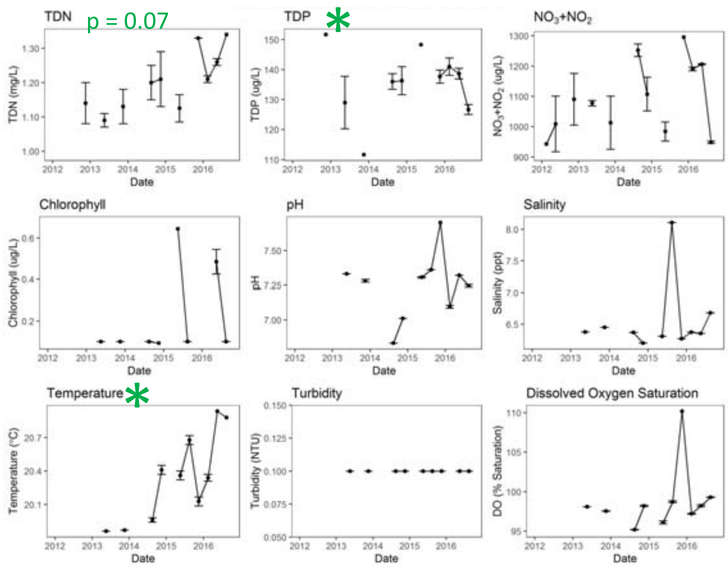


* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$
**** $p < 0.0001$

Pacific Island Network
Inventory and Monitoring Division

National Park Service
Department of the Interior

Lower
Kaloko
Well

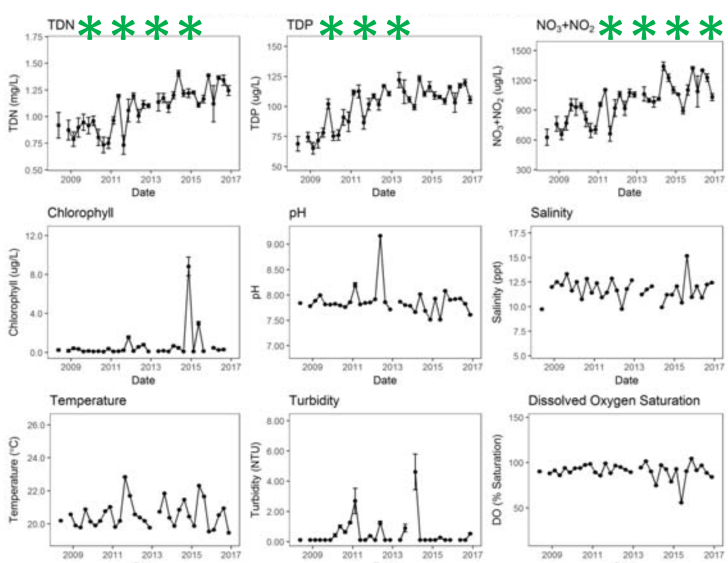


* p < 0.05
** p < 0.01
*** p < 0.001
**** p < 0.0001

Pacific Island Network
Inventory and Monitoring Division

National Park Service
Department of the Interior

Central
Anchialine
Pools

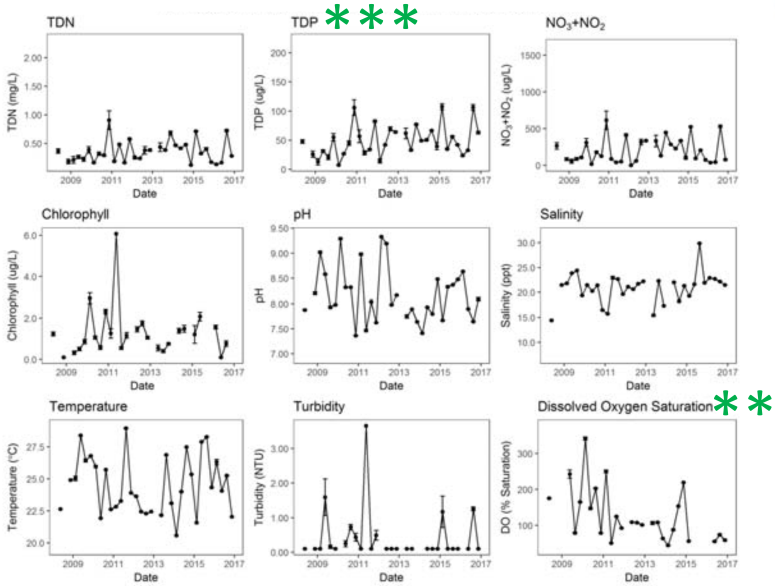


* p < 0.05
** p < 0.01
*** p < 0.001
**** p < 0.0001

Pacific Island Network
Inventory and Monitoring Division

National Park Service
Department of the Interior

South
Anchialine
Pools
(north of harbor)

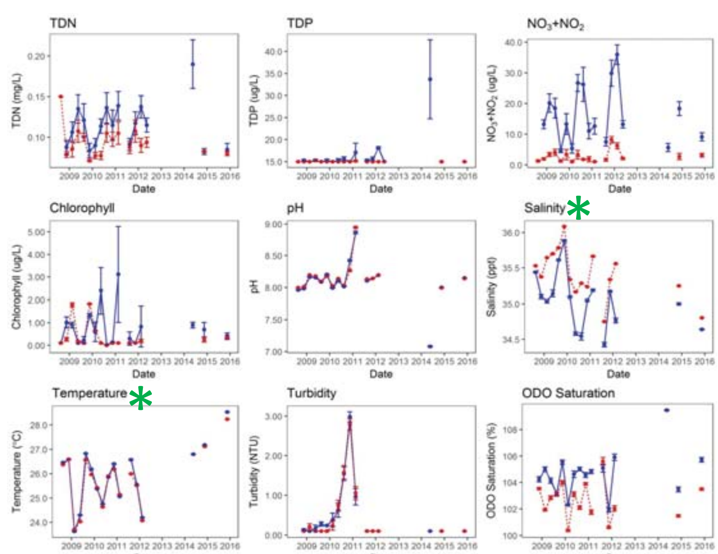


* p < 0.05
** p < 0.01
*** p < 0.001
**** p < 0.0001

Pacific Island Network
Inventory and Monitoring Division

National Park Service
Department of the Interior

Marine
Surface
Bottom



* p < 0.05
** p < 0.01
*** p < 0.001
**** p < 0.0001