Update Regarding the Development of a First-Generation Keauhou Aquifer System Area Groundwater Adaptive Management Plan, Keauhou Aquifer System Area, Island of Hawaiʻi

The Keauhou Aquifer System Area Groundwater Adaptive Management Plan (Keauhou AMP) effort continues to advance from concept to implementation. With facilitation support from Peter Adler of GUILD Consulting, Inc., Commission staff convened three Expert Groups throughout the summer and early fall.

With assistance from Commission staff and GUILD, each expert group completed a report summarizing their discussions and recommendations.

The expert group reports are available on the Commission's website at https://dlnr.hawaii.gov/cwrm/planning/keauhou-amp/ and are provided as **Attachments 1-3**. The following section highlights key findings and takeaways from each report; however, readers are encouraged to review the full documents for a complete understanding of each group's analyses and perspectives.

Participants

Hydrology Group

- Donald Thomas, Geochemist, Director of the Center for the Study of Active Volcanoes, University of Hawaiʻi at Mānoa
- Heidi L. Kane, Hydrologist, Pacific Islands Water Science Center, United States Geological Survey
- Brytne Okuhata, Hydrologist, Pacific Islands Water Science Center, United States Geological Survey
- Scot K. Izuka (AMP Advisor), United States Geological Survey (ret.)
- Ryan Imata, Hydrologic Program Manager, Ground Water Branch, CWRM

Indicator Species/Ecology Group

- Celia Smith - The Wilder Chair and Professor of Botany, School of Life Sciences, University of Hawaiʻi at Mānoa
- Diamond Tachera; Project Scientist I, Mesoscale & Microscale Meteorology Laboratory, Co-Principal Investigator, NSF CoPe Rising Voices, Changing Coasts, NSF National Center for Atmospheric Research (NCAR)
- Henrietta Dulai, Professor, Department of Earth Sciences, School of Ocean Earth Science and Technology, University of Hawaiʻi at Mānoa
- Ryan Okano, Aquatic Biologist, DLNR, Division of Aquatic Resources
- Troy Sakihara, Aquatic Biologist, DLNR, Division of Aquatic Resources

- Veronica Gibson, Postdoctoral wetland researcher, He‘eia National Estuarine Research Reserve
- Katie Roth - Hydrologic Planning Program Manager, Planning Branch, CWRM

Contaminants and Pollutants Group

- Jennifer Doi, Environmental Health Specialist, Hawai‘i Department of Health (DOH), Clean Water Branch
- Christopher Shuler, Hydrologist, University of Hawai‘i at Mānoa, Water Resources Research Center
- Robert Whittier, Geologist, DOH, Safe Drinking Water Branch
- Neal Fujii, Statewide Drought & Water Conservation Coordinator, Planning Branch, CWRM

Also participating and contributing to many of the discussions were:

- Hannah Springer (CWRM Commissioner), participating in her personal capacity as a knowledgeable Kona resident and practitioner
- Leah Bremer (AMP Advisor), Institute for Sustainability and Resilience, UHERO, and Water Resources Research Center, University of Hawai‘i at Mānoa
- Charles Young (AMP Advisor), Hawai‘i Island po‘o, DLNR ‘Aha Moku

Key Findings by Expert Group

Hydrology Group

The group confirmed that Keauhou’s groundwater system consists of at least three interacting freshwater bodies—a thin coastal basal lens, a deeper confined groundwater body, and a high-level inland groundwater body—whose connections remain poorly understood.

Recommended hydrologic indicators include:

- Water levels and salinity in GDEs
- Biota counts
- Well pumpage, rainfall changes, salinity profiles, and tides
- Stable isotopes of hydrogen and oxygen at multiple points in the water column

Recommended data collection methods:

- A deep monitor well in the deep-confined body
- Piezometers in the basal lens and deep-confined body

- Periodic synoptic water-level surveys

Recommended conditions for future well permits:

- Collection of water-level data under non-pumping conditions, including during well construction before drilling commences each day

An alternative approach to management of the Keauhou Aquifer System Area was recommended over the single-aquifer sustainable yield management approach currently used. Alternatives considered were the assignment of individualized sustainable yields for each of the three water bodies and management of withdrawals from each based on salinity thresholds or some combination of other indicators associated with each water body’s contributions to GDE.

Other investments that would aid in further study of the boundaries, interconnections, health, and discharge of the aquifers were recommended.

Contaminants and Pollutants Group

The group focused on nutrients, including applied nutrients, pathogens, herbicides and pesticides, wastewater indicator compounds, and petroleum-related contamination indicators.

Recommended indicators include:

- Nutrients: nitrate, nitrite, ammonium, total dissolved nitrogen, phosphate, and total phosphorus
- Limu and ʻōpaeʻula as indicators of stable nitrogen isotopes ($\delta^{15}N$)
- Agricultural herbicides and pesticides: neonicotinoids and glyphosate
- Wastewater pathogens: *E. coli / Enterococcus spp.* and *Clostridium perfringens*
- Wastewater indicator compounds: sucralose, acesulfame K, caffeine, sulfamethoxazole, and carbamazepine
- Petroleum-related contamination indicators: total petroleum hydrocarbons in the diesel (TPH-d) and lubricating oil range (TPH-o)

Recommended data collection locations:

- Known locations of wastewater impact: Honokōhau Harbor and along Kailua-Kona. These sites also have known impacts from TPH.
- Large resorts, luxury homes, and golf course developments, including Hualalai/Kukio and Kohanaiki
- Keauhou Bay, noted for both resorts and coastal and submarine springs
- Sewer line along Aliʻi Drive

- Kahaluʻu Bay, seaward of an injection well that is identified as impacting nutrients on the north side of the bay

Indicator Species and Ecology Group

The ecology group identified biological indicators that reflect both ecological and cultural health. The group also emphasized that:

- A suite of indicators covering a range of hydrological parameters would be most effective, and limiting indicators to 3 native and 3 non-native seemed arbitrary
- Selecting biocultural indicators – locally and culturally relevant metrics that combine social, cultural, and ecological information to assess the health and resilience of a community and its environment, is critical.
- To be more effective, indicator species must be place-based and informed by cultural practitioners and resource managers of the place.

Recommended native indicators (among others):

- Limu such as limu pālahalaha (*Ulva lactuca*)
- Herbivorous grazers that prefer brackish water habitats, particularly ʻamaʻama (*Mugil cephalus*) and āholehole (*Kuhlia xenura* and *Kuhlia sandvicensis*)
- ʻŌpaeʻula (*Halocaridina rubra*) – resilient species with a broad salinity tolerance, but whose presence may reveal subsurface water connections and flow paths
- Damselflies (*Megalagrion spp.*)
- Terrestrial "water-seeker" plants like hau and ʻulu

Proposed non-native indicators:

- Guppies (*Gambusia affinis* and *Poecilia reticulata*) and mosquito fish
- New invasive algae such as *Hypnea musciformis*

Other recommended indicators:

- Mollusks, especially hapawai (*Neritina vespertina*) and pīpīwai (*Neritina spp.*, especially *Neritina granosa*)
- Microbial communities and color of ponds
- Opelu

Recommended data collection methods:

- eDNA and DNA metabarcoding at whole sentinel sites, to encompass full diversity of species found within the site

Recommended data collection locations:

- Queen Liliʻuokalani Trust's Keahuolū lands, Kaloko-Honokōhau NHP, and Kahaluʻu Bay, due to their inclusion of diverse GDE habitats, active fisheries, existing community monitoring efforts, and potential representation of a variety of landowners
- Honokōhau Harbor and Kailua Bay as vectors of significant SGD

For further consideration and research:

- How much does tapping into high-level fresh water impact shallower GDEs?
- Should the definition of a GDE be expanded to include mesophotic algae, corals, and black corals, as well as pelagic fisheries?

Next Steps and Incorporation of Place-Based Knowledge

Commission staff will identify areas of overlap and integration between the three reports as well as existing sources like the meeting record of the 2018 Adaptive Management Symposium on Groundwater Dependent Ecosystems at Kaloko-Honokōhau National Historical Park (KHNHP) to establish a unified framework for the first-generation AMP.

Planning is underway to convene the three expert groups and Native Hawaiian practitioners and ʻāina stewards from the Keauhou region for a joint meeting, tentatively in November 2025.

The session will:

- Review the scientific summaries and recommendations;
- Gather cultural perspectives on hydrology, ecology, and water quality; and
- Identify a concise list of scientific and biocultural indicators to guide baseline monitoring and inform future withdrawal requests.

Decision Points and Project Direction

Currently, $200,000 in annual operating funds have been appropriated specifically for operational costs related to a Keauhou monitoring pilot program for FY26 and FY27, and $4,000,000 in capital improvement (CIP) funds have been appropriated for deep monitor wells in the Keauhou aquifer. The contract between GUILD and the Commission for facilitation and other support concludes November 30, 2025. Continued staff capacity is critical to sustain the AMP through 2026.

$200,000 (Operating Funds)

Staff propose using these funds primarily to continue work on the AMP and develop an initial monitoring plan. The preferred approach is to recruit a dedicated project lead who can guide the preparation and implementation of the plan. If recruitment efforts are not successful, the alternate approach would be to contract for completion of the plan, with existing Commission staff providing oversight and direction to the consultant.

Ongoing costs associated with data collection, analysis, and other operations will be supported from the remaining balance of this appropriation. In the longer term, staff anticipate that operational needs for sustaining the plan will be met through cost-sharing or other funding from well owners and operators within the Keauhou Aquifer System, additional appropriations from the Legislature, or other means.

$4,000,000 (CIP Funds)

Staff will determine how best to use these funds to advance our current understanding of the Keauhou Aquifer System, based in part on the recommendations of the expert groups.

ATTACHMENT 1

HYDROLOGY GROUP SUMMARY

9.16.25

I. Background

Fresh water in the Keauhou Aquifer System Area (KASA) exists in at least three groundwater bodies: a basal lens near the coast, a deeper confined groundwater body beneath the basal lens, and a high-level groundwater body farther inland. The connection among these groundwater bodies is not well understood. Nearshore and offshore groundwater-dependent ecosystems (GDEs) such as anchialine pools, fishponds, estuaries, and reefs, depend on natural discharge of fresh groundwater from the KASA.
These GDEs are important sites for biodiversity and Native Hawaiian traditional and customary (T&C) practices which include, among others, food collection, water gathering, and bathing. The Commission on Water Resource Management (CWRM) is obligated to balance the withdrawal and use of groundwater with the protection of these T&C practices under the public trust doctrine.

In an effort to update the current understanding of Keauhou's hydrology, CWRM convened three initial meetings with hydrology experts Brytne Okuhata, Don Thomas, and Heidi Kāne. These meetings were led by CWRM staff Ryan Imata, facilitated by their consultant Peter Adler, with additional input from the Adaptive Management Plan (AMP) advisor Scot Izuka. Each meeting lasted about two hours and included other CWRM staff and AMP advisers who listened, observed, and participated in group discussions at the end of each meeting.

II. Initial Goals

The meetings were meant to be a comfortable consensus-seeking exchange of ideas with five aspirations:

- Identify and agree upon a general conceptual (prevailing) model for groundwater flow in the KASA and articulate underlying assumptions, including hypotheses of how groundwater moves through the aquifers;

- Identify possible specific AMP baseline-monitoring indicators to test these hypotheses;

- Articulate the current assumptions behind each recommended indicator;

- Design a preliminary monitoring program to accompany the AMP baseline-monitoring indicators, including what to monitor for, frequency of monitoring, and monitoring sites; and

- Prioritize a short list of specific additional future research projects and questions that will inform subsequent updates to the AMP.

III. Take-Aways from the Expert Discussions

A. **Keauhou is Enigmatic**. Though some of the hydrogeology in the KASA is known, some of its fundamental characteristics remain unknown. The water bodies within the KASA do not fit the single freshwater lens conceptual model that is the basis for most aquifers in Hawai`i and on which the Robust Analytical Model (RAM) is based. RAM is a simple model used to calculate sustainable yield in basal aquifers. Given the complexity of the KASA's hydrogeology and CWRM's need to assess the impacts of groundwater withdrawal for all current and prospective users of water from the Keauhou aquifers, there is a need to establish a new framework for managing all the groundwater aquifers in the KASA.

B. **Interconnectivity is not well understood.** The conceptual model for Keauhou groundwater currently includes: (a) a thin freshwater basal lens that extends from the shoreline into the flank of Hualālai by a yet undefined distance; (b) one or more deeper fresh groundwater bodies beneath confining geologic structures (and possibly underlain by deeper confining structures) that extend from the submerged flank of Hualālai into its interior, also by an undefined distance; and (c) a high-level groundwater body farther inland with a water table that is substantially higher than that in the coastal basal lens.

Based on constructed wells and water-level information, the high-level groundwater body extends to the north at least as far as the Kalaoa Well; farther north, water levels drop off sharply to those typical of a basal lens. Existing hydrogen- and oxygen-isotopic data indicate possible interconnectivity among the three groundwater bodies, but the locations and magnitudes of the connection(s), and how pumping from one body may affect flow in the others, are not fully understood.

The high-level and deep-confined water bodies have similar hydrogen- and oxygen-isotopic compositions – that are quite distinct from the compositions of the basal groundwater – and suggest a possibly close connection between the former two bodies. The isotopic compositions of the high-level and deep-confined water bodies indicate that they are likely recharged from the upper elevations of Hualālai, Mauna

Loa, and Mauna Kea, far outside the geographical region typically attributed to recharging the KASA. The isotopic composition of the basal lens waters is more similar to what would be expected for direct rainfall infiltration, but the isotopic and chloride data indicate some contribution from one or both of the other two water bodies.

C. **Future Rainfall and Recharge**. Projection of recharge rates to these aquifers into the future carry inherent uncertainty, but current studies indicate the possibility of statistically significant declines in rainfall into the future. Future recharge to the KASA may be reduced by rainfall decline. One estimate, for the mid-century (2041-2071) is that recharge may be reduced to 62 million gallons per day (MGD), representing a 38% decline from the current estimate for recharge. It should be noted that these estimates are predicated on the (possibly incorrect) assumption that recharge to the system area is confined to the geographic region defined by the KASA.

D. **GDE Indicators to Monitor**. Critical hydrologic indicators for benchmarking and monitoring at sentinel sites can, and should, build off existing data sources (e.g., currently approved production and monitoring wells, and data collected by the Natural Energy Laboratory of Hawaiʻi Authority, National Park Service's Kaloko-Honokōhau National Historical Park, and Queen Liliʻuokalani Trust).

   Salinity monitoring is important for anchialine pools, as some coastal species that reside in these pools require specific brackish conditions, but not much is known about the salinity thresholds under which different species thrive. There are natural fluctuations of water and salinity levels attributed to tides and seasonal changes. Monitoring water levels and salinities in these GDEs, as well as biota counts, in conjunction with the collection of well pumpage, rainfall changes, salinity profiles, and tides can help assess the impacts of changes in fresh water influx related to both groundwater use by humans and climate change.

   Another valuable parameter to monitor is the hydrogen and oxygen isotopic compositions at multiple points in the water column to: (1) gain insights into the relative contributions of the different source water bodies supplying the GDE and nearshore groundwater on which the GDE depend; and (2) enable CWRM to monitor changes in the relative contributions from the three water bodies as a result of changes in groundwater withdrawal as well as long-term climate impacts. Analyzing stable isotopes will help to determine (1) where [at what altitude] the recharge occurs and (2) if and how water from different recharge areas may have mixed to shed light on possible interconnectivity of the various fresh groundwater bodies.

CWRM does not currently collect groundwater hydrogen and oxygen isotopic data from their deep monitor wells. Rather, salinity profiles and water levels are collected on a quarterly basis. Additionally, there are wells where water levels are measured in the high-level and the basal water bodies. In conjunction with salinity profiles, these help to assess the health of the aquifer bodies.

E. Placement of Future Monitoring Wells

The Hawai`i State legislature has appropriated four million dollars for a pilot study for Keauhou. This funding was estimated based on two new undefined monitoring wells. Discussion among the group of how to best utilize these funds yielded a few possible projects.

One suggestion was to drill a new well into the deep-confined fresh groundwater body and determine whether a bottom confining layer is present that would limit its volume or discharge rate. If a bottom confining layer did not exist, and there was a transition zone in the sub-basal deeper confined water body, the Ghyben-Herzberg principal would apply and therefore the transition zone for this confined aquifer could be monitored in the same way that CWRM monitors a typical basal lens. While this would be valuable information, it could also be very expensive. One, possibly more cost-effective, suggestion was to deepen an existing monitoring well, although doing so has challenges of its own that need to be further explored.

Water-level data under non-pumping conditions are seldom, if ever, collected or reported from production wells. Requiring these measurements as a condition for future permits would document the impacts of pumping on local water levels (heads) and might tie directly into the AMP's goal of informing pumping permit decisions and helping expand indicators into possible conditions for permits.

Piezometers—a specific type of monitoring well with a relatively short, specified “open” interval—could provide valuable insight to the hydraulics of the different fresh groundwater bodies in the KASA and how interconnected they may be. For example, one piezometer could be installed to monitor the basal lens and another installed to monitor the deep confined body. Data from these piezometers could help determine whether new pumping from the high-level groundwater body causes changes in the basal lens, the confined body, or both, and to what degree. The alternative—a single monitoring well that is open to both groundwater bodies—will only provide a less-informative average of the hydraulics.

Another common monitoring approach is to conduct periodic synoptic water-level surveys. These surveys consist of nearly simultaneous water-level measurements in multiple wells over a specified area. If done periodically, successive surveys can be compared to assess changes in the shape of the water table in response to pumping, climate change, or other related processes.

F. Different Aquifer Management Strategies

It is recognized that the single-aquifer sustainable yield management approach (a) does not account for the multiple fresh groundwater bodies in the KASA; (b) does not account for the impacts to GDEs; and (c) is probably not realistic given the geographic regions that potentially recharge the multiple fresh groundwater bodies. Given these shortcomings, an alternative approach to management of the KASA is needed.

Among the alternatives considered were the assignment of individualized sustainable yields to each of the three water bodies, and management of withdrawals from each based on managing salinity thresholds, or by some combination of managing other indicators that are associated with contributions by each water body to the GDE. In the immediate term, valuable information can be gained by increasing the data recovered from future wells into any of these aquifers. In particular, requiring careful measurement of water levels before drilling resumes each day would allow the identification of perched or confined water bodies during drilling. With a properly designed AMP, the management approach can be modified as more is learned about the KASA from future monitoring and research.

G. **Future Studies**.

To further study the boundaries, interconnections, health, and discharge of the aquifers, the following investments could yield insights:

- Additional submarine groundwater discharge (SGD) surveys can be done to understand both the location of the discharge of groundwater, as well as possible changes over time.

- Monitor the head and the salinity profile in the basal lens and in the deeper confined fresh groundwater body (if it does not have a bottom confining unit).

- Analyze historical Keauhou pumpage records, rainfall data, and anchialine-pool data to observe any possible correlations and trends.

- Undertake surface-based geophysical surveys (e.g. aeromagnetics or seismic reflection) to potentially identify large-scale features that may be causing the enigmatic high-level groundwater body

- Conduct core drilling along upper highway to establish the geology of the high-level groundwater body.

- Conduct studies using natural or artificial tracers to analyze the movement and interconnectivity among the fresh groundwater bodies.

ATTACHMENT 2

Proposed Monitoring Framework for Contamination and Pollution in the Keauhou Aquifer System

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Chris Shuler, Hydrologist, UH Water Resources Research Center; and
Robert Whittier, Geologist, Department of Health

October 8, 2025

Background and Key Issues

Groundwater in the Keauhou Aquifer System Area (KASA) discharges into anchialine pools, fishponds, springs, and nearshore waters that are essential for both ecosystem health, Native Hawaiian cultural practices, and community well-being. Three major land-based pressures on this system are:

- **Wastewater (WW):** Leaching from cesspools, septic tanks, sewer lines, and treatment facilities (specifically treated effluent release to known discharge locations) introduces nutrients and pathogens into groundwater. In addition, treated municipal effluent release (injection and percolation into the aquifer) has been shown to increase nutrient and CEC loads in coastal waters. Hunt (USGS), Bennett (consultant) and found caffeine, sucralose, carbamazepine etc. in the water in Honokohau harbor and along Kailua Kona.

- **Agriculture (Ag) and Golf Courses (GC):** Fertilizers, herbicides, and pesticides used in Kona's coffee belt diversified agriculture, and residential landscaping contribute additional nutrient and chemical inputs. Resort golf courses are located very near the shoreline increasing the potential for fertilizer and pesticide/herbicide contamination into anchialine pools.

- **Petroleum Pollution (TPH):** leaching from underground storage tanks, car repair facilities, and road runoff introduces petroleum related contaminants into the groundwater that then migrates to the nearshore environment.

The **primary contamination impacts in this area come from applied nutrients** (nitrogen and phosphorus), which can promote algal blooms, coral reef decline, and ecosystem imbalance. **Pathogens** are also a concern for public health and recreation but are considered secondary to nutrient stress. Pesticides and Herbicides from

Agricultural activity are potential contaminants but currently their impacts remain unknown. Impacts from pesticides, herbicides and, personal care products and pharmaceuticals are currently undocumented, and additional studies are needed to better understand the role of these and other contaminants of emerging concern in Hawai'i's coastal and terrestrial ecosystems.

Other potential sources of contamination to the coastal environment include petroleum related contamination from leaky underground storage tanks, gas station and car repair operations, street runoff into dry wells. Industrial-anthropogenic impacts through spilled TPH or other contaminants (metals, etc) are likely present in groundwater in some (potentially negligible) quantity, however few/no studies have ever detected or sought to detect their impacts in this area and the impact of human-industrial activities also remains unknown. The small industrial footprint in the Keauhou area makes investigation of these impacts a lower priority objective.

It should be noted that while saltwater intrusion derived excess Cl^- could be interpreted as a pollution source, this document will not cover this effect as this issue is primarily a hydrological consequence of over-extraction and thus is more appropriately covered by the hydrogeology working group

Recommended Monitoring Indicators

1. Nutrient Indicators

- **Parameters:** Nitrate (NO_3^-), nitrite (NO_2^-), ammonium (NH_4^+), total dissolved nitrogen (TDN), phosphate (PO_4^{3-}), and total dissolved phosphorus (TDP).

- **Rationale:** Nutrients are the clearest signal of both WW and Ag contamination. Elevated levels directly enhance algal overgrowth and degrade reef systems.

- **Use:** Establish baseline. Salinity unmixed and dissolved nutrient levels in water samples at coastal discharge points (anchialine pools, seeps, nearshore sites) will be important because salinities of these water samples will be varying greatly. We recommend salinity unmixing and comparing these at background (upgradient) groundwater salinity to account for variability due to tidal/seasonal/etc. variations.

2. Stable Isotopes of Nitrogen ($\delta^{15}N$)

- **Targets:** While analysis of $\delta\,^{15}N$ of the dissolved NO_3^- in water samples is possible and has been widely used, this test is costly, difficult to run and relies on finding waters with a relatively high amount of NO_3^- (at least 1 μM). Additionally, water masses quickly move, dilute, mix and display extreme variability based on changing environmental conditions. Therefore bio-indicators of organisms that integrate the $\delta^{15}N$ signal of the N they are utilizing for their growth presents a more practical long-term monitoring sampling strategy.

  - **ʻōpaeʻula - Shrimp (*Halocaridina rubra*)** – long-lived anchialine pool grazer that integrates N inputs over ~20 days.
    Limu (macroalgae) – effective bioindicator of sewage-derived nitrogen on reefs. this analysis also provides C:N ratios that are another useful parameter (algae stocking up on N under N enriched conditions) and provides C:N ratios that are another useful parameter (algae stocking up on N under N enriched conditions)

- **Rationale:** $\delta^{15}N$ values can help to distinguish sewage-derived nitrogen from agriculturally derived nitrogen, and sometimes from naturally derived N in groundwater sources. Using bio-indicators provides an integrated measure less sensitive to short-term variability than water samples. Stable isotopes of nitrogen can inform as to the source of elevated nitrate. Wastewater is enriched in the heavy Nitrogen-15 isotope relative to that of fertilizer. Analysis for Nitrogen-15 enrichment can be done using water samples or tissue of coastal algae. The algae tissue analysis has the advantage that it continually uptakes nitrogen from the submarine groundwater discharge providing a time integrated nitrogen isotope sample.

- **Use:** Pair isotope analyses with nutrient data to confirm sewage vs. fertilizer signals.

2A . Agriculture-Specific Contaminants (Selected herbicides and pesticides)

- **Neonicotinoids (e.g., imidacloprid, clothianidin, thiamethoxam)**
  - Highly soluble, persistent, and documented to leach into groundwater.
  - However, sample analysis may be prohibitively expensive. Realistic labor and analysis costs need to be considered in any monitoring plan

- **Glyphosate**. This is a common herbicide in coffee production, golf courses, and homeowner yards and has the potential to infiltrate permeable basalt soils. While not the only herbicide/pesticide used, its use is so common as to indicate the potential for other pesticide and herbicides without incurring the large costs associated with a broad-spectrum analysis suite. Dulai analyzed glyphosate in springs along South Kohala and found that a lot of glyphosate comes from resort landscaping and private/household use.

- **Rationale:** These inputs are specific to Kona's agricultural and private and resort landscaping footprint and help separate agricultural sources from wastewater.

2B. Wastewater-Specific Pathogen Indicators

- **E. coli / Enterococcus spp.**
  - Standard fecal indicator bacteria (FIB) for public health, though Enterococcus can have natural soil sources in Hawaiʻi.

- **Clostridium perfringens**
  - If tests for these are not too costly, these would be reliable secondary indicators in Hawaiʻi since spores persist and strongly signal sewage inputs.

- **Rationale:** Provide direct evidence of fecal contamination and human health risk in nearshore and anchialine waters.

2C. Wastewater Indicator Compounds

Wastewater contains a broad variety of pharmaceutical, personal care product, and other organic compounds including those that adversely impact the sexual morphology of marine organisms (endocrine disrupters). Analyzing for all potential wastewater organic compounds would be prohibitively expensive given labor and analysis costs but the potential presence of these compounds can be screened for looking for the most commonly detected wastewater indictor compounds. These include:

- **Sucralose** – an artificial sweetener that occurs in highest concentration in wastewater relative to other artificial sweeteners. However, Sucralose tends to be less persistent in transport through unconsolidated media.
- **Acesulfame K** – an artificial sweetener that while present in lower concentrations than Sucralose is detected more frequently in groundwater that has passed through unconsolidated media. The Acesulfame K concentration is significantly reduced during wastewater treatment so the combined analysis of Sucralose and Acesulfame K can help discriminate between wastewater contamination from raw sources versus the use of recycled water for irrigation.

    - **Caffeine** – is a stimulant in many drinks such as coffee and tea and survives the wastewater treatment process. However, coffee is a major agricultural crop in the area so caffeine may also be an agricultural contaminant.
    - **Sulfamethoxazole** – is an antibiotic used for bacterial infections and has a high rate of detection in wastewater contaminated waters.
    - **Carbamazepine** – is an anticonvulsant and neuropathic pain medication that has a high rate of detection in wastewater contaminated groundwater.

3. **Petroleum Related Contamination Indicators**

- While there are a very large number of petroleum related compounds that can be leached from the various sources, the Red Hill environmental investigation shows that a composite analysis of petroleum compounds is the best screening indicator for this contamination source.
    - Total Petroleum Hydrocarbons in the Diesel range (TPH-d) and Total Petroleum Hydrocarbons in the lubricating oil range (TPH-o)

Implementation Considerations

- **Adaptive, phased approach:**
  Sampling priorities should depend on **preliminary results at each location**. There are results for most of the coastline, (Hunt, USGS reports). Okuhata incorporated observations into a model to derive source specific N etc. so there is a lot of information to work with. The process of selecting specific sites has been started. Wastewater impact is clear in Honokohau Harbor and along Kailua Kona. If nutrients or isotopes suggest sewage influence, then expand pathogen wastewater indicator compound monitoring. If sites are dominated by agricultural land use, prioritize fertilizer nutrients then pesticide/herbicide testing. Large resorts/luxury home/golf course developments including Hualalai/Kukio and Kohanaiki should be noted. Keauhou bay, noted for its resorts, has many coastal and submarine springs that should be prioritized for sampling points.

- If TPH is detected, analysis could be expanded to include metals associated with petroleum contamination. Known impacted sites such as Honokohau Harbor and along Kailua Kona, should also be prioritized.

- While On-Site Sewage Disposal Systems and wastewater injection are the most frequently considered sources of sewage, other infrastructure needs to be considered. Specifically the sewer pipe along Alii drive should be looked at. When a portion of sewer line at the Kailua bay section was replaced, the pipe was completely open and corroded undoubted leaking sewage to the environment. The remainder of sewer line along alii drive to Keauhou has not been replaced and is a potential sewage source to the environment. Occasional algae/cyano bacteria blooms also occur along the Kailua bay section suggesting release of sewage to the groundwater that eventually discharges into the coastal waters. We suggest sewage monitoring there as well as seaward of an injection well in Kahaluu bay that local stewards say impacts nutrients on the north side of the bay. Kohala center and Cindi Punihaole have this data/site location.

- **Location specificity:**
  More site-level information (land use, hydrology, groundwater flow paths) is needed before a detailed sampling plan can be finalized. Different areas of Keauhou may require different indicator emphasis.

- **Integration with existing work:**
  This framework complements prior studies in Kona (Prouty et al. 2017; Wada et al. 2021; Marrack & Beavers 2023, Hunt et al., Okuhata et al., Johnson et al) and can feed into the broader Adaptive Management Plan baseline monitoring.

Sampling Locations

Three considerations when selecting sampling locations are the location of the contaminating sources, location of acceptable sampling points such as wells, and locations with a history of sampling. Figure 1 shows the locations of primary contaminating activities, while Figure 2 shows the locations potential sampling sites. Figure 3 from Johnson (2008) shows how airborne (or drone) thermal imaging can be used to identify zones where cooler groundwater discharges into the warmer coastal seawater. Table 1 that follows summarizes suggested sampling locations while Figure 4 shows the annotated locations of these sampling locations.

We would suggest monitoring at the GDEs (anchialine pools, fishponds, seeps, estuaries) to get a baseline and initial understanding of the current health of these waterbodies, as these are the area of concerns.

Existing Sampling Programs

The Keauhou Adaptive Management Plan should take advantage of existing sampling programs. Below is a list of the primary programs, but other sampling programs that may provide valuable information also exist.

- Drinking water compliance sampling – Samples are routinely collected from about 19 wells to verify compliance with the Safe Drinking Water Act. This program monitors for a broad range of organic, inorganic, and biological contaminants. These data can be requested from the Hawaii Dept. of Health Safe Drinking Branch. https://health.hawaii.gov/sdwb/compliance-section/

- The Hawaii Dept. of Health, Clean Water Branch monitors selected sites for nutrients and wastewater indicator bacteria. https://health.hawaii.gov/cwb/
- The Natural Energy Laboratory, Kohanaiki Resort, and Kaloko-Honokohou have active monitoring programs
- Commission on Water Resources Management and Hawaii Dept. of Water Supply – routinely monitor the thickness of the freshwater lens in Deep Monitoring Wells

Figure 5 shows locations where monitoring is currently being done. The organization responsible for the monitoring is shown for selected locations usually showing the bounds of points monitored by each organization.

Table 1. Suggested sampling locations including PCAs evaluated, analytes recommended and the monitoring logic.

Monitoring Location	PCAs Evaluated	Media & Analytes	Monitoring Logic/Remarks
Honokohau Deepwell A (8-4158-002)	Background	Groundwater NO2/NO3, N15 enrichment, Selected wastewater trackers, selected herbicides and pesticides, TPH.	Characterize high level water with little anthropogenic influence. All analytes except for N15 enrichment and Selected Wastewater Trackers are included in the Drinking Water compliance monitoring. Also baseline data from Hunt, 2014
Huehue Ranch 1 (8-4559-001	Background and upcountry golf course	Groundwater NO2/NO3, N15 enrichment, Selected wastewater trackers, selected herbicides/pesticides, TPH	Characterize high level water with little anthropogenic influence and potential influence from a golf course and small residential development. All analytes except for N15 enrichment and Selected Wastewater Trackers are included in the Drinking Water compliance monitoring.
Kahaluu Shaft (8-3557-005)	Residential development and OSDS	Groundwater NO2/NO3, metals, N15 enrichment, Selected wastewater trackers, selected herbicides/pesticides, TPH	Characterize water with impacted by residential development and wastewater disposal. All analytes except for N15 enrichment and Selected Wastewater Trackers are included in the Drinking Water compliance monitoring.

Monitoring Location	PCAs Evaluated	Media & Analytes	Monitoring Logic/Remarks
Keauhou Well (8-3457-001), Keauhou 2 (8-3357-001), or Kahaluu Deep Monitor (8-3457-004)	Golf course, and residential and resort development	Groundwater. Nutrient suite (i.e., NO2/3, NH4, Total N, TKN, PO4, Total phosphorus, selected herbicides and pesticides, N15 enrichment	Need to check suitability for sampling. Keauhou Well (8-3457-001) is an irrigation well and Keauhou 2 (8-3357-001) is an unused well that might be suitable for environmental sampling. Kahaluu Deep Monitor (8-3457-004) has a long open interval and is used to monitor the thickness of the freshwater lens. Selective depth sampling could be done to get a vertical profile of the freshwater lens water quality.
KK (8-3658-052)	Residential and commercial development, gas station,	Groundwater NO2/NO3, N15 enrichment, Selected wastewater trackers, TPH	Characterize water with impacted by residential development and wastewater disposal. This is an irrigation well and it needs to be verified that a sampling point is available.
Kailua Bay, coastal discharge of groundwater	Urban and residential development, service stations, underground storage tanks	Submarine groundwater discharge. Selected wastewater trackers, Drinking water organic contaminants, TPH. Algae total nitrogen, and Nitrogen-15 enrichment	No groundwater monitoring point available so will need to sample groundwater that discharges into the bay. Will need to do a specific conductivity and/or thermal survey along the shoreline to identify areas of fresher water discharge. See Hunt and Rosa (2009) for guidance on such a survey. Also, a critical location of algae-N sampling

Monitoring Location	PCAs Evaluated	Media & Analytes	Monitoring Logic/Remarks
Network of observations wells for the Kohanaiki Resort, Nat'l Energy Lab, Keahole Airport, Koloko-Honokohau National Park.	Residential and resort development, golf course, light industrial development, wastewater disposal	Groundwater Nutrient suite (i.e., NO2/3, NH4, Total N, TKN, PO4, Total phosphorus, selected herbicides and pesticides, N15 enrichment, Selected Wastewater Trackers, TPH.	Many wells collect nutrient and contaminant data and report to DOH. Work with well owners and select a limited number of wells to request additional monitoring. Should include wells from each activity since the PCAs will be different (e.g. airport versus resort)
A network of small capacity irrigation wells in the NW corner of the Keauhou Aquifer.	Some potential golf course influence low density residential and commercial	Groundwater Nutrient suite (i.e., NO2/3, NH4, Total N, TKN, PO4, Total phosphorus, selected herbicides and pesticides, N15 enrichment, Selected Wastewater Trackers	Work with well owners and select a limited number of wells to request monitoring access
Coastal submarine groundwater discharge	Wastewater disposal and fertilizer leachate	Algae Total tissue nitrogen percent Tissue Nitrogen 15 enrichment	Sites that were sampled during the 2021 Nearshore Sewage Pollution Study, Honokohou Small Boat Harbor, and Kailua Bay zone of fresher water discharge

Summary

The literature identifies **nutrients as the primary contamination driver** in the Keauhou Aquifer system, with **pathogens, pesticides, and herbicides as secondary but important indicators**. A tiered wastewater tracker monitoring framework such as Johnson at USGS suggests is recommended: A basic in-situ water quality characterization should be included in this sampling using a multiparameter probe
- salinity, temperature, turbidity, dissolved oxygen, pH

1. **Nutrients (N, P)** – core indicator of contamination stress.

2. **$\delta^{15}N$ in shrimp and limu** – source attribution (sewage vs. fertilizer).
    a. Following with **Neonicotinoids & glyphosate** – agriculture-specific contaminants. AND/OR
    b. **E. coli / Enterococcus & C. perfringens** – wastewater-specific pathogen indicators.

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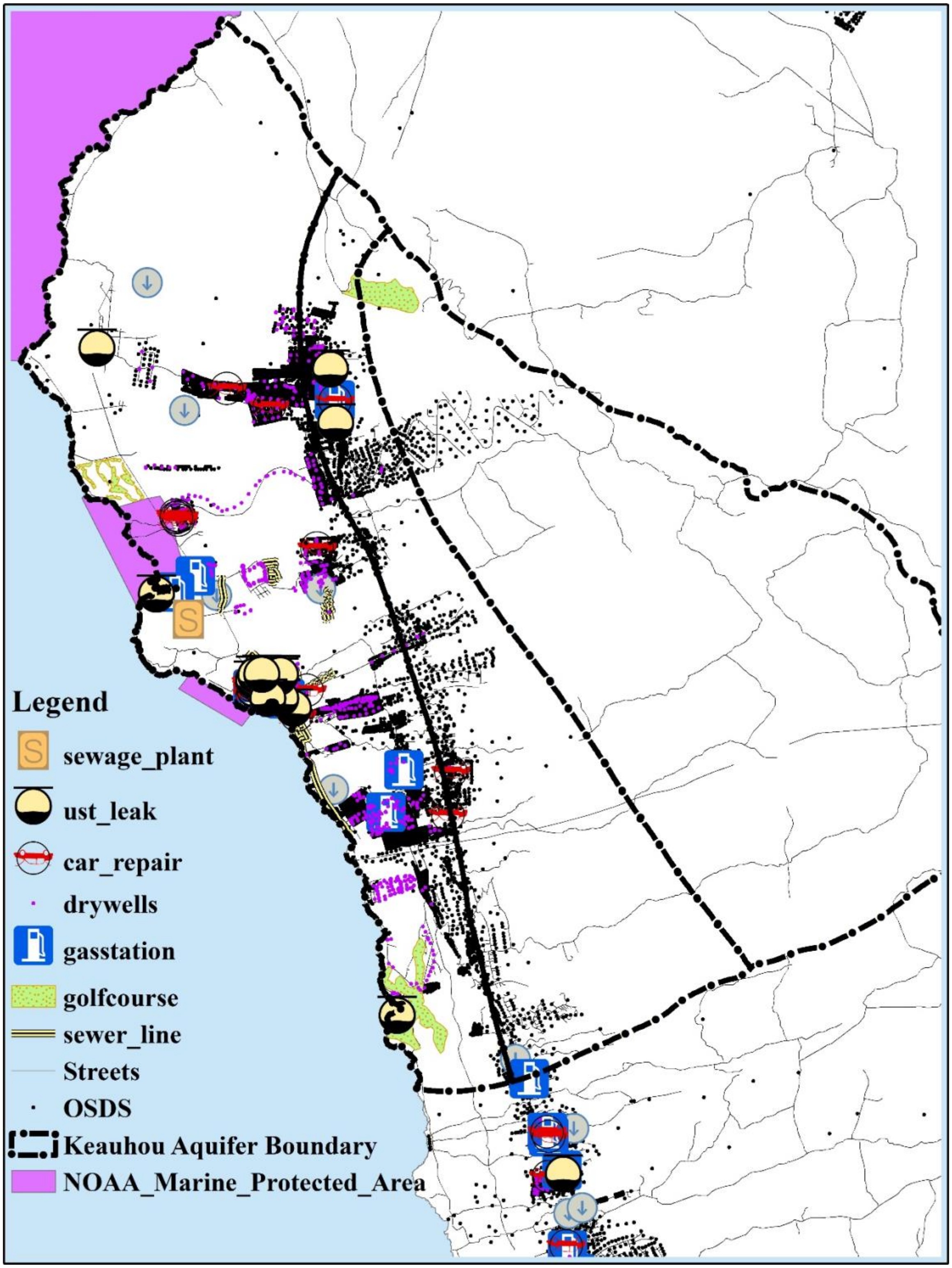

Figure 1. The location of the primary sources of potential contamination to groundwater.

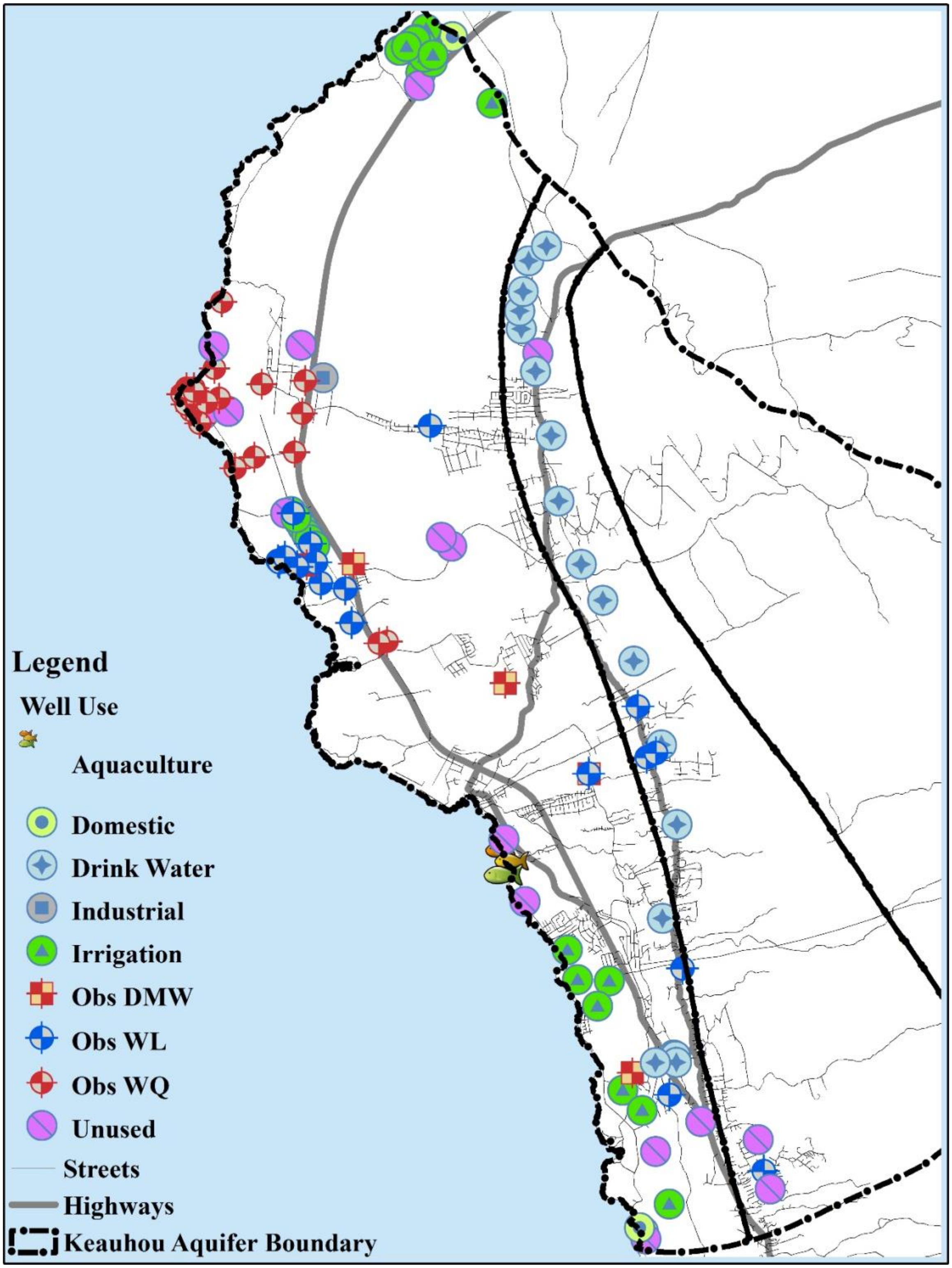

Figure 2. Locations of potential groundwater sampling sites

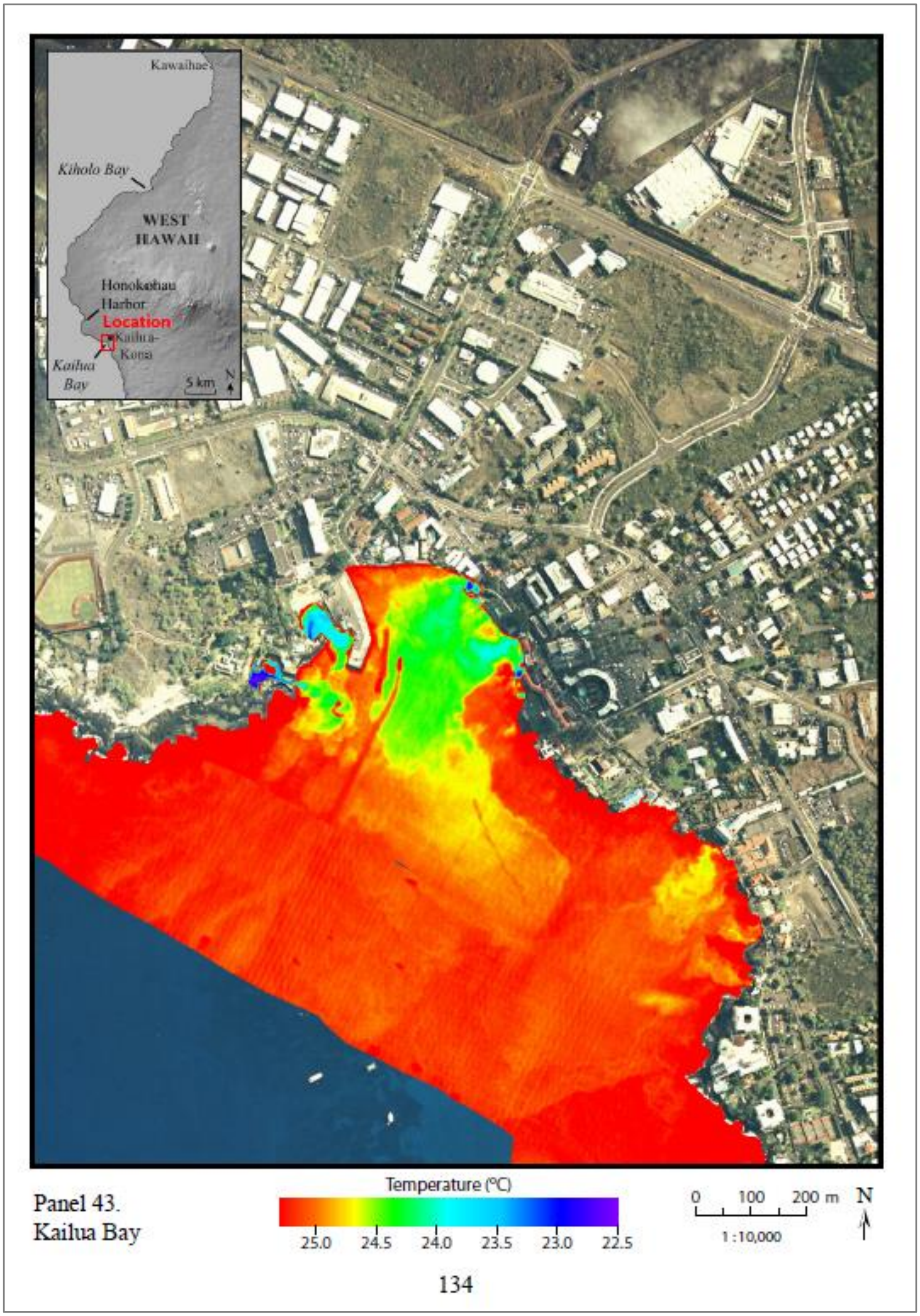

Figure 3. Airborne thermal image of Kailua Bay showing the cooler groundwater (green shading) discharging into the warmer ocean water (red shading). The groundwater discharge zone is a potential sampling site.

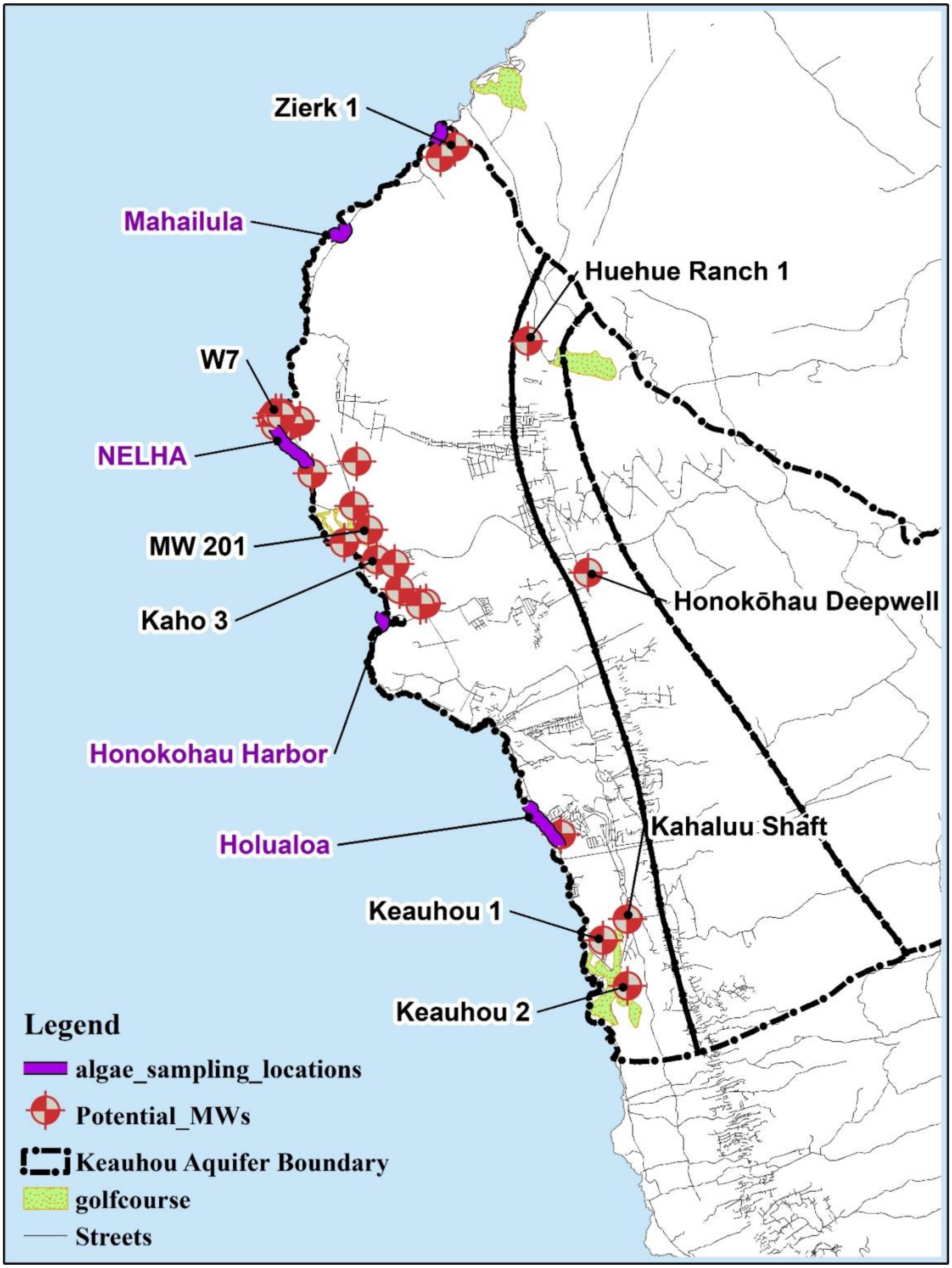

Figure 4. Potential sampling sites. Where there is a group of wells, labels are only shown for two wells.

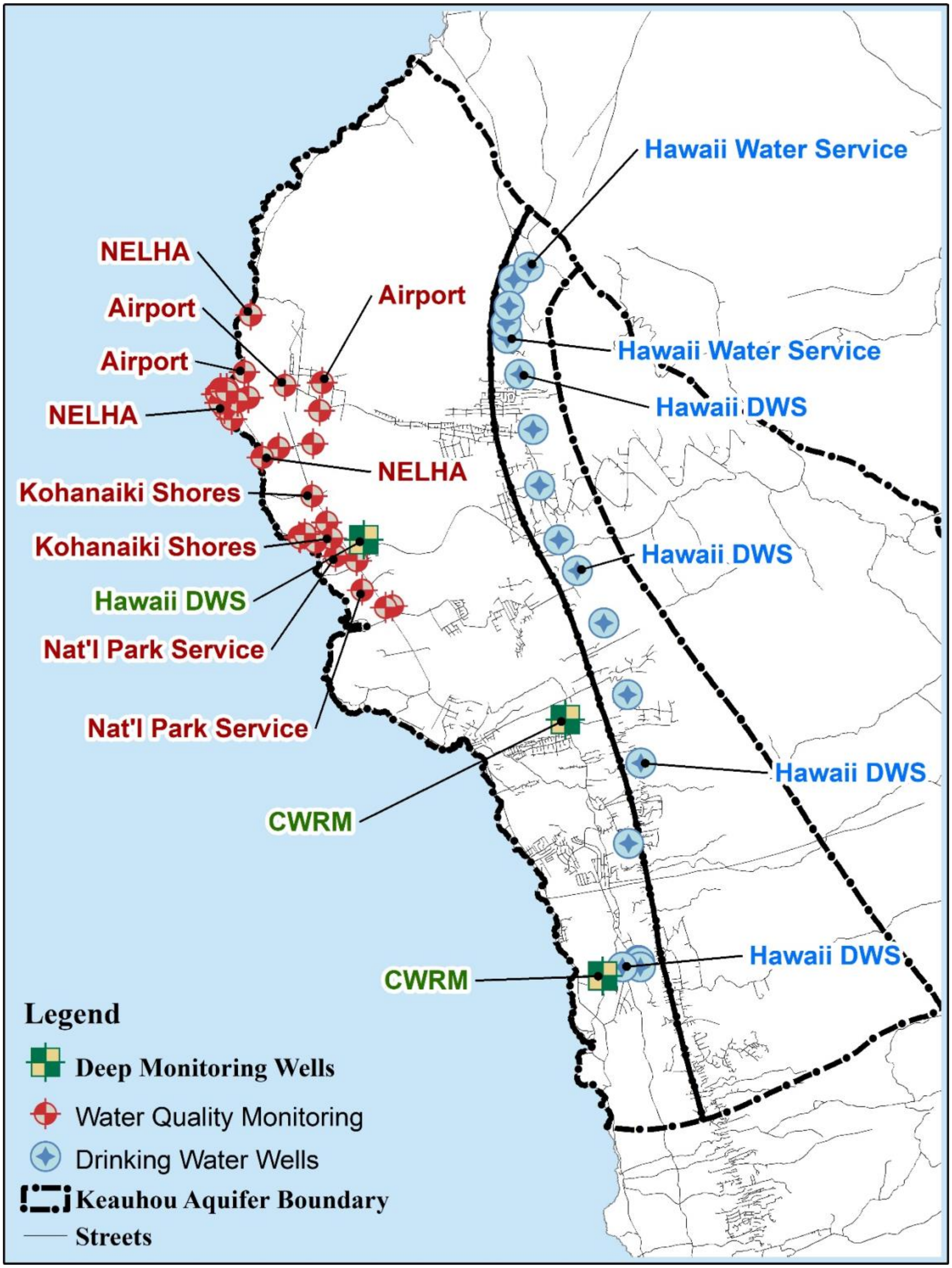

Figure 5. Sites where monitoring is currently occurring. The Organization responsible for the monitoring listed for selected site.

ATTACHMENT 3

INDICATOR SPECIES / ECOLOGY GROUP SUMMARY

I. Background [1]

At many sites along the coast of the Keauhou Aquifer System Area (KASA), groundwater feeds springs, anchialine pools, fishponds, offshore seeps, near shore estuaries, and reef life from tidal benches to great distances off-shore. These groundwater dependent ecosystems (GDEs) are important sites for biodiversity and Native Hawaiian biocultural practices which include, among others, food and resource collection, aquaculture production, water gathering, food preservation, medicine production, traditional ceremonies and bathing (Gibson et. al 2022). The Commission on Water Resource Management (CWRM) is obligated to protect these as part of its responsibilities under the public trust doctrine.

In preparation of a first generation Keauhou Aquifer System Groundwater Adaptive Management Plan (AMP) that will eventually inform permit and groundwater pumpage decisions, CWRM convened three different groups of experts. The Indicator Species / Ecology expert group focused on GDEs, specifically the organisms that rely on fresh water and how those species may be impacted by groundwater withdrawals in the KASA. Three initial meetings with biological and ecological experts were held in August and September of 2025. The meetings were convened by CWRM Planning Branch manager Katie Roth and facilitated by consultant Peter Adler. Invited experts included:

- Celia Smith - The Wilder Chair and Professor of Botany, School of Life Sciences, University of Hawaiʻi at Mānoa
- Diamond Tachera - Project Scientist I, Mesoscale & Microscale Meteorology Laboratory, NSF National Center for Atmospheric Research (NCAR)
- Henrietta Dulai – Professor, Department of Earth Sciences, School of Ocean Earth Science and Technology, University of Hawaiʻi at Mānoa
- Ryan Okano - Aquatic Biologist, DLNR, Division of Aquatic Resources
- Troy Sakihara - Aquatic Biologist, DLNR, Division of Aquatic Resources
- Veronica Gibson – Postdoctoral wetland researcher, Heʻeia National

[1] A few citations are included in this summary but a more extended list of references is at Section-2 of https://dlnr.hawaii.gov/cwrm/files/2025/07/AMP-Literature-Gathering-07_07_25.pdf.

Estuarine Research Reserve, Hawaiʻi Institute of Marine Biology, University of Hawaiʻi at Mānoa

Also participating in most of the discussions were Water Commissioner, Hannah Springer (who noted that her participation was more as a practitioner and person of that place rather than as a commissioner), AMP Advisor Charles Young, Hawaiʻi Island ʻAhā Moku, AMP Advisor Leah Bremer, County Department of Water Supply Manager-Chief Engineer Keith Okamoto, and other CWRM and DWS staff members including Ryan Quitoriano and Shari Uyeno. Each meeting lasted approximately two hours.

II. Initial Goals

The meetings sought to foster a comfortable consensus-seeking exchange of ideas with five aspirations:

(a) Identify not more than three possible specific Adaptive Management Plan (AMP) baseline monitoring indicators regarding <u>native species</u> found in the GDEs;

(b) Identify not more than three possible specific <u>non-native, invasive, or disruptive species</u> found in the GDEs;

(c) Articulate the current assumptions behind each recommended indicator;

(d) Design a preliminary monitoring program to accompany the AMP baseline monitoring indicators, including what to monitor for, frequency of monitoring, and monitoring (sentinel) sites; and

(e) Prioritize a short list of specific additional future research questions that will improve a second-generation AMP.

III. Take Aways from Expert Discussions

A. **The Delicate Balance: Groundwater's Role in Ecosystem Resilience**. Despite natural fluctuations from tides, seasons, sea level, and rainfall, there is a delicate balance over widespread coastal regions, that allows native species to thrive. However, persistently reduced groundwater quantity or quality can tip the balance in favor of invasive and non-native aquatic and terrestrial species (including plants, algae, parasites, diseases, and animals across a range of ecosystems). Some Hawaiian limu, for example, are adapted to thrive under low-salinity, high-nutrient conditions created by Submarine Groundwater Discharge, or “SGD” (Dulai et. al., 2021). If groundwater pumping reduces the volume of freshwater discharge, coastal salinity and temperature can rise, nutrient levels can drop, and habitat parameters can shift away from the groundwater affected conditions in which native species thrive. Reduced freshwater discharge may also impact other water quality parameters, including pH, dissolved oxygen, and turbidity. The habitat essentially is no longer a native habitat and becomes favorable for invasive species, several of which are poised to outcompete and overgrow native species. This creates a "perfect storm" scenario where reduced fresh water flow and excessive increases in nutrient influx above ambient levels can lead to blooms of invasive algae~~.~~

Native species will decline or cease to grow if their habitat needs are not met, even without the proliferation of invasive species. Thus, the occurrence and growth rates of some limu such as limu pālahalaha (*Ulva lactuca*) emerge as good indicators of groundwater health. Limu pālahalaha has long been established as a biocultural indicator by cultural practitioners and resource managers of the Kona region (Gibson et al. 2022), and the positive impacts of protecting SGD on limu pālahalaha habitat are well studied (Okuhata et al. 2023, Richards-Donà et al. 2023).

B. **The Role of Herbivores**. Some invasive algae such as *Acanthophora spicifera* are present in Kona but seem to be controlled outside of fishponds by healthy populations of diverse, native grazing fish. The continued survival of these fishes, such as manini, pualu, palani, ʻamaʻama and āholehole, which prefer brackish water habitats particularly as juveniles, make them good potential indicators of groundwater health. Particularly, ʻama’ama (*Mugil cephalus*) and aholehole (*Kuhlia xenura* and *Kuhlia sandvicensis*) are well studied and have narrow salinity tolerance ranges for juvenile phases and will be unable to reproduce without the lowered salinities produced by SGD inputs (see Gibson et. al. appendix, 2022).

This is likely also true for other juvenile fish species for which the salinity requirements have not yet been measured. Again, native species tend to be resilient under the ranges of water quality and quantity of groundwater found in a wide spectrum of native coastal habitats. If the quantity of freshwater discharged in groundwater dependent regions is reduced, populations are likely to change away from the presence of native species. If we increase nutrient concentrations even moderately, coupled with a decline in native grazers, invasive algae may overgrow these once-native habitats.

C. **Potential Indicators.** Beyond limu pālahalaha (see Section A above) other species warrant consideration as indicator species. Because of their cultural importance and complex behaviors, including their use of subsurface water conduits to move between ponds, ʻōpaeʻula (*Halocardinia rubra*) may be an especially significant indicator to track. It may reveal not just the presence of brackish groundwater but also the subsurface water connections and flow paths.

The hesitation in using ʻōpaeʻula is that they have a broad salinity tolerance and are resilient to natural changes, making them more of a reactive rather than proactive indicator. Dragonflies and damselflies may also be important indicators because they require much lower salinity than the aforementioned coastal fish species (~ 10 parts per thousand (ppt)), making them relatively more sensitive to changes in anchialine pool chemistry. Damselflies are also an endemic, endangered species. Dragonflies and damselflies are also found within the anchialine pool habitat, rather than the coastal habitat in which the aforementioned fish species are found. The hau tree (*Hibiscus tiliaceus*) was proposed as a terrestrial plant that acts as a "water seeker." Changes in the health or location of hau could signal a shift in the freshwater-saltwater interface.

Guppies (*Gambusia affinis* and *Poecilia reticulata*) and mosquito fish were proposed as good indicators of changing water conditions in anchialine pools because they are less tolerant of high salinity than other invasives such as mollies or tilapia. Their absence can indicate a reduction in groundwater, leading to higher salinities. In reference to invasive algae, experts advocated for monitoring for the arrival of any new threats (e.g., *Hypnea musciformis*) and tracking the abundance of established species. Reductions in SGD have been shown to expand habitat and invasion potential for the invasive algae *Hypnea musciformis* (Okuhata et al 2023, Richards-Donà et al. 2023). Further work is needed to demonstrate how reduced SGD may expand habitat for other invasive species and reduce native species habitat within this region.

A complete list of all possible indicators is attached (see Appendix 1 and 2) but the following top three in each category seem to have potential for a first-generation AMP. However, we also think more diverse subcategories may ultimately be needed because of the varieties of coastal features and creatures. This would allow limu pāhalaha to be a major primary indicator for coastal regions that would quickly 'report' changes in large coastal regions such as tidal benches versus anchialine pools.

Native species	Invasive / non-native species

Limu pālahalaha *(Ulva lactuca)* **ʻŌpae ʻula** *(Halocardinia rubra)* **Damselflies** *(Megalagrion)*	**Guppies** *(Gambusia affinis* and *Poecilia reticulata)* **Macro or micro algae** *(e.g., Hypnea musciformis)* **Non-native damselflies**

Other taxa to be considered include mollusks, especially hapawai (*Neritina vespertina*) and pīpīwai (*Neritina spp.,* especially *Neritina granosa*) and, most importantly, microbial communities which may be the fastest and best indicators of change before more cascading impacts are seen. Practitioners and resource managers know what "color" ponds should be, and this could be a powerful first alert.[2] Opelu were also mentioned as an important biocultural species and food source for the region (Gibson et al. 2022), that should be considered for monitoring.

D. Sentinel Sites.

Three specific sites were mentioned as possible sentinel sites: Queen Liliʻuokalani Trust (QLT) at Keahuolū, Kaloko Honōkohau National Historic Park, and Kahaluʻu Bay. These initial sites were suggested based on their inclusion of diverse GDE habitats, active fisheries, existing community monitoring efforts, and may represent a variety of landowners. Other possible sentinel sites include the Honokōhau Harbor and Keauhou Harbor due to their role as vectors of significant SGD.

It should be noted that many of the experts thought studying whole sentinel sites and using eDNA and DNA metabarcoding methods which account for the diversity of species found within the site might be better than only focusing on individual species. Their reasoning was that an ecosystem-level approach would better capture the complex interactions between species and be more effective at detecting unpredictable new invasives or parameters wherein natives act invasively.

Experts emphasized that a suite of indicators covering a range of hydrological parameters (i.e., temperature, salinity, nutrients) would be most effective and that limiting indicators to 3 native and 3 invasive / non-native seemed arbitrary. The

[2] See research by Dr. Kiana Frank

importance of selecting biocultural indicators—locally and culturally relevant metrics that combine social, cultural, and ecological information to assess the health and resilience of a community and its environment—was also stressed. It was noted that, to be more effective, indicator species need to be place-based and informed by cultural practitioners and resource managers of the place.

Experts recommended the inclusion of "control" sites, where localized impacts within the KASA would not be expected. This is critical in separating outside drivers from drivers directly related to parameters within the KASA. The scientific control provides a reliable basis for comparison that is essential to distinguish between localized impacts (like groundwater pumping) and broader, coastline-wide changes (such as sea-level rise), thereby minimizing misinterpretation of data trends.

D. **Further Research and the Challenge of Linking Hydrology and Biology.** The experts acknowledge the immense difficulty in drawing a direct, causal line from specific pumping wells to a specific biological outcome, in part because of the lag time between groundwater pumping and depletion in submarine groundwater discharge (SGD). For example, isotopic analysis of water emerging as SGD in the Kīholo and Keauhou aquifer systems shows that it originated as rain at an elevation higher than the summit of Hualālai. To account for these isotopic compositions, water might be coming from Mauna Loa or Mauna Kea through complex and interconnected subsurface features, traveling for thousands of years underground before emerging at the coast. This complex hydrogeology makes it difficult to predict the response time to changes in groundwater pumping.

In addition, the KASA consists of three distinct aquifer bodies (the high level, the basal, and the deep confined). More research is needed to better understand how these 3 aquifer bodies are connected and how groundwater withdrawals from one could impact another and subsequently impact fresh water discharge at the coast. Additionally, experts mentioned new confirmation of a massive, deep offshore freshwater reservoir containing an estimated 4 cubic kilometers of fresh water, known to local practitioners for generations. This system is actively discharging nutrient-rich fresh water up to 2 kilometers offshore, supporting a previously unconfirmed by modern scientific methods deep-water, offshore GDE. While likely separated from the shallow GDEs by confining layers, the deep system is under immense hydrostatic pressure, and any connection would likely involve deep water flowing upward to feed the upper basal aquifer fresh water lens.

Tapping into high-level fresh water that feeds this deep system cannot be ruled out as having a potential impact on the shallower GDEs that are the focus of this effort.

This finding also raises the question of whether the definition of a GDE should be expanded to include our diverse mesophotic communities of algae, corals, and black corals as well as pelagic fisheries. This is an important point due to the biocultural value of these ecosystems along the Kona coast, which support important commercial and sport fishing, diving, and marine tourism industries. Finally, another challenge is that fluctuations in salinity and temperature could be the result of changes in sea level and saltwater intrusion into the basal aquifer rather than changes in fresh water inputs from the aquifers as demonstrated in Kīholo Bay.

Appendix 1: Proposed Indicators for Native and Endemic Flora and Fauna

<u>Limu (e.g. pālahalaha, ʻakiʻaki)</u>

Amplified by several experts, limu and other marine plants are valuable indicators due to their critical role as the foundation of all marine / coastal ecosystems as primary producers and their accessibility to sampling. Often attaching to a site and spreading in place, these plants allow for consistent monitoring across specific sites. They generally exhibit a much faster response to environmental changes compared to corals, making them effective early warning indicators. Changes in occurrence of native limu (e.g., limu pālahalaha, ʻeleʻele, ʻakiʻaki, and paheʻe) may indicate changes in SGD. Limu pālahalaha, in particular, thrives in the low-salinity, high-nutrient conditions characteristic of healthy groundwater influence. A decline in its population may suggest a disruption in SGD flow, while an increase could indicate elevated nutrient levels. Other native limu genera like *Cladophora, Dictyosphaeria*, *Rhyzoclonium*, and cyanobacteria are also useful indicators of increased nutrient concentrations. For instance, Limu manauea requires specific salinities (27% minimum 35%), and its disappearance from previously observed locations can signify a reduction in spring flow.

Challenges/Considerations: Preliminary research indicates that the relationship between limu and SGD can be complicated by exceptionally high nutrient levels, particularly from concentrated sources of wastewater, which might allow invasive species like *Hypnea* to outcompete native limu even in low-salinity environments. Further research is necessary to fully understand these complex interactions, especially concerning the distinction between natural and anthropogenic nutrient sources. Studies, such as that by Okuhata et al. (2023), demonstrate that pālahalaha can either expand with wastewater presence or shrink with decreasing SGD and/or increased salinity. Modeling techniques, such as "hindcasting" its pristine distribution, could establish a baseline for monitoring.

Limu ʻakiʻaki can be an important indicator especially in basaltic areas, offering a different sensitivity and vulnerability profile compared to other limu species. It would require significant research as its salinity tolerance is unknown, however redundancy in selecting indicators could be a useful strategy. More work is needed to identify specific salinity thresholds for diverse limu species along the Kona coast. See Gibson et al. 2022, appendix 1 for a more complete list of GDE associated limu species.

<u>ʻŌpaeʻula (*Halocardinia rubra*)</u>

Culturally, historically vital and a key biological indicator. Also proposed as a hydrological tool: genetic population testing between ponds could reveal subsurface water connections and flow paths. The presence of this species in anchialine pools typically indicate a relatively healthy ecosystem, and the absence or minimal presence of invasive fish and invertebrates.

Challenges/Considerations: Its tolerance to a broad range in salinity, water temperature and other natural variations in habitat conditions may make it a less sensitive, "reactive" indicator.

Damselflies (*Megalagrion*)

Damselflies, particularly the *Megalagrion* species, are considered highly sensitive, or "finicky sentinel species." Their immature larvae are intolerant of salinities exceeding 15 PSU, and their eggs have a very narrow temperature and salinity range for successful hatching. As an endangered species, their presence and health are critical indicators of pristine groundwater-dependent habitats.

Terrestrial, Emergent and Aquatic Plants (e.g., hau, ʻulu)

Practitioners have observed that native plants such as hau exhibit changes in health or distribution, including dying off, when springs shift spatially or dry up. The presence of these “water seeking” plants indicates the presence of water, making areas suitable for the creation or restoration of anchialine ponds. These species are selected as potential indicators for the migration of the freshwater-saltwater interface. Changes in the health or location of these trees could signal shifts in groundwater due to factors like sea-level rise or increased pumping. Additionally, hau possesses numerous utilitarian uses, further emphasizing its biocultural significance.

The die-off of ʻulu trees in other Pacific regions due to saltwater intrusion highlights their potential as indicators of environmental change, especially given their importance as a food staple and their low salinity tolerance. Such die-offs can signal a loss of submarine spring flow. Another water-seeking species is the niu or coconut tree. .. For example, the historic niu grove at Mahaiʻula north, which is spring-fed. Other emergent and aquatic plants associated with springs and anchialine pools, including Makaloa, *Pritchardia*, ʻaeʻae, ʻōhelo kai, *Ruppia*, and ʻakaʻakai, are also sensitive to salinity changes.

eDNA

Environmental DNA (eDNA) is a modern tool capable of detecting a wide range of organisms, including microbes, plants, and fish, from a single water sample. This method allows for the early detection of species changes within an ecosystem or the detection of species that may be difficult to observe through other means. When combined with other techniques including conventional sampling and surveying methods, eDNA can provide a more comprehensive and accurate assessment of species present in a habitat. CWRM already incorporates eDNA into some of their monitoring partnerships. It is proposed as an enhancement tool to capture the presence of all species in a given area, offering a broad snapshot of biodiversity and ecosystem health. NOAA has results from an eDNA and benthic surveys from 80 reefs along the Kona coast conducted in 2022, which could serve as a good baseline for comparison

Loss of ʻamaʻama (*Mugil cephalus*) and āholehole (*Kuhlia xenura, Kuhlia*

***sandvicensis*)**

ʻAmaʻama (striped mullet) and āholehole are key biocultural species whose reproduction and specific life history phases are intrinsically linked to particular salinity conditions in nearshore environments. A decline in the recruitment of pua ʻama and āholehole in areas previously known for submarine groundwater discharge (SGD) seeps could indicate a loss of lower salinity conditions. For ʻamaʻama, eggs require 30-32‰, larvae 26-28‰, and juveniles less than 15‰. Conversely, in Heʻeia, the expansion of āholehole habitat has been observed with the restoration of spring flow. Other species, such as moi, weke, awa and awaʻawa, ʻōpae huna and ʻōpae ʻoehaʻa, while not extensively studied for salinity tolerance, are known to be associated with springs and could also serve as indicators.   (Note: combined with above)

Decline in recruitment of amphidromous/diadromous species (e.g., 'o'opu, pua'ama, āhole hole)

A variety of native fishes and crustaceans in Hawaiʻi have an amphidromous life cycle where eggs hatch in fresh or brackish water, larvae drift out to sea to develop, then return to fresh and brackish inshore habitats as small juveniles. These animals key in on signals of freshwater to find these brackish habitats. For regions without perennial streams, SGD is the primary source providing the freshwater signal. Because of this, a reduction in SGD may result in a reduction in recruitment of native amphidromous species in these areas. Challenges/considerations: many other factors can influence recruitment of amphidromous species.

Hapawai, Pī pīwai

This indicator combines the monitoring of snails, specifically hapawai and pīpīwai, whose salinity tolerance is lower than that of ʻamaʻama. For these species, including fish and snails, there is a strong potential for them to serve as subtidal indicators of salinity when take together as a subrtidal community assemblage. Hapawai, in particular, is valued for both food and adornment, highlighting its biocultural significance.

Coral

Increasing coral bleaching events may be linked to rising and lasting elevated temperatures resulting from declining submarine groundwater discharge (SGD). Resource managers at Kīholo perceive this connection. The mitigation in temperature, influenced by SGD, plays a crucial role in coral health.

Birds

The loss of shorebird nesting habitats due to a decrease in fresh drinking water is a significant concern. The Kaloko-Honokōhau National Historical Park (KHNHP) possesses data on bird distribution correlated with available salinities. Species such as Aeʻo, nēnē, Koloa maoli, ʻuaʻu, ‘auku‘u, koloa mōhā, ‘akeke, and lesser caup are among those whose populations are affected by changes in freshwater availability.

Meiofauna

Meiofauna are small invertebrate animals typically less than 1 mm in size that are common in aquatic environments including anchialine pools. Their high abundance, diversity, short lifespans and sensitivity to environmental changes can serve as a good early indicator of changes to habitat conditions. **Challenges/considerations:** a unique knowledge base, skill sets and experience is required for studying meiofauna, which may be more limited than other disciplines and fields of study.

Community Composition/Benthic Microbial Community

Alterations in the benthic microbial community within anchialine pools or nearshore intertidal habitats can be the "fastest and best indicator of change" before more significant cascading impacts become apparent. Changes in these communities are often visible as shifts in water color or clarity, allowing practitioners to observe and respond to early signs of environmental stress. Challenges/considerations: expertise in microbiology and microbial ecology with specific technical skillsets and knowledge is required.

Tissue N and Stable Isotopes

Analysis of tissue nitrogen (N; usually on macroalgal tissue) and stable isotopes can be a valuable tool for detecting pollution in coastal environments. These analyses help in identifying and quantifying nutrient loads, including total nitrogen, total phosphorus, nitrate, silicate, and phosphate, providing insights into the sources and impacts of nutrient enrichment on groundwater-dependent ecosystems.

Appendix 2: Proposed Indicators Invasive and Non-native Flora and Fauna

Fish (e.g., guppies, mosquitofish)

The absence of certain invasive fish species, such as guppies and mosquitofish, in anchialine ponds can be a strong indicator of salinity levels being too high for their tolerance. These species are considered better indicators than mollies or tilapia, which possess a much wider range of salinity tolerances, making them less sensitive to subtle changes in groundwater-dependent ecosystems. The presence or absence of guppies and other salinity-limited invasive species in anchialine pools can therefore provide valuable insights into the hydrological conditions

Limu and macroalgae

Monitoring for the arrival and occurrence of invasive macroalgae like *Hypnea musciformis* is important especially since it is not yet believed to be present on Hawaiʻi Island. Its detection would signal significant environmental reductions in SGD in the Kona region. *Acanthophora spicifera,* an already established invasive red alga, can serve as an inexpensive proxy for local herbivory pressure due to its high palatability to reef fish. Any rapid expansion of bloom-forming macroalgae, including *Cladophora, Ulva, Dictyosphaeria,* and *Caulerpa*, could indicate increased nutrient levels or shifts in salinity that disadvantage native competitors. Similarly, the rapid expansion of *A. spicifera, Cladophora, Ulva, Cyanobacteria (microalgae), Caulerpa*, or other limu, or the occurrence of *G. salicornia*, could signal reductions in herbivory as well as increased nutrients / salinity changes that enhance invasive over native competitors. The presence or absence of invasive salinity-tolerant macroalgae, and whether their occurrence is permanent or episodic, provide important data.

Challenges/Considerations: The utility of *Acanthophora* as an indicator is complicated by its strong confounding with herbivory, making it difficult to isolate the signal of water quality changes. Effective monitoring would necessitate concurrent monitoring of herbivores in the same area. Furthermore, it is challenging to predict which invasive macroalgae species will arrive next. Therefore, a comprehensive approach that monitors for all invasive macroalgae, and even native limu (like Pālahalaha) that can exhibit invasive behavior during nutrient-fueled blooms, is often advocated

Tissue analysis of Limu via δ15N and %N: Tissue analysis for percentage nitrogen (%N) and δ^{15}N (delta-^{15} nitrogen) is proposed to be included as a standard component of monitoring protocols for the detection of wastewater as well as agricultural fertilizers.. This method offers a direct way to monitor the primary driver of many invasive algal blooms. By analyzing the tissue of algae, a nitrogen content of 1 - 4% or more serves as a clear, low-cost (approximately $20 per sample) indicator of nutrient pollution (wastewater and ag fertilizes), which is a significant factor in fueling the growth of some invasive species.

Systemic Literature Review: A systematic literature review and/or meta-analysis is an effective method of identifying habitat parameters, especially for globally distributed and aquacultured species. This involves systematically reviewing existing global scientific literature on known invasive and native species, such as *Hypnea musciformis*, to understand their preferred growth parameters (e.g., salinity, nutrients, light). This process helps in building "habitat parameters" that can inform monitoring strategies and predict where these species are most likely to thrive.

eDNA

Amplified by several experts, eDNA (Environmental DNA) is proposed as a modern tool for early detection. While it requires an initial investment to create species-specific primers (to distinguish invasives from similar native species), it becomes a cost-effective and easy way to monitor for the presence of an invasive species just by sampling the water. Early detection facilitated by eDNA allows for rapid response and removal efforts, complementing ongoing monitoring. This approach would be particularly useful for detecting *Hypnea musciformis* if saltier, more nutrient-rich conditions develop in coastal regions.

Challenges/Considerations: The development of species-specific primers for detecting individual species through eDNA work requires significant time and initial financial investment. However, once developed, these tools are powerful for ongoing monitoring.

Bacteria

An increase in bacterial presence, such as fecal indicator bacteria, could signal a decline in groundwater quality or quantity, potentially leading to increased coral disease where SGD is impacted. Any rapid increase in disease among any species within groundwater-dependent ecosystems would be a cause for concern, indicating broader environmental stress.

Terrestrial Plants (e.g. Mangroves, Kiawe)

Invasive terrestrial plants can also serve as indicators. Mangroves, for instance, often indicate the presence of springs and can, in some areas, clog spring outflows. While not prevalent in Kona, they represent a type of terrestrial invasive plant that can significantly alter hydrological systems. Other examples include Tropical Almond (also known as false kamani or Indian almond, *Terminalia catappa*), an invasive tree that frequently grows near water sources, whose leaf litter can negatively impact the water body's health. Pluchea is another invasive shrub with similar implications. Kiawe stands, as deep-rooted phreatophytes, directly access groundwater, making their biological condition a monitorable indicator of groundwater availability and quality.

Non-native Damselflies / Dragonflies

It is assumed that non-native damselflies and dragonflies would exhibit similar salinity tolerances to their native counterparts, making their presence or absence a potential indicator of changes in salinity within GDEs.

Invasive Grasses

Seashore Paspalum, an invasive grass, can escape from managed areas like golf courses and have detrimental effects on natural environments. Other invasive grass species that could be a good indicator of salinity changes.