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

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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.

References

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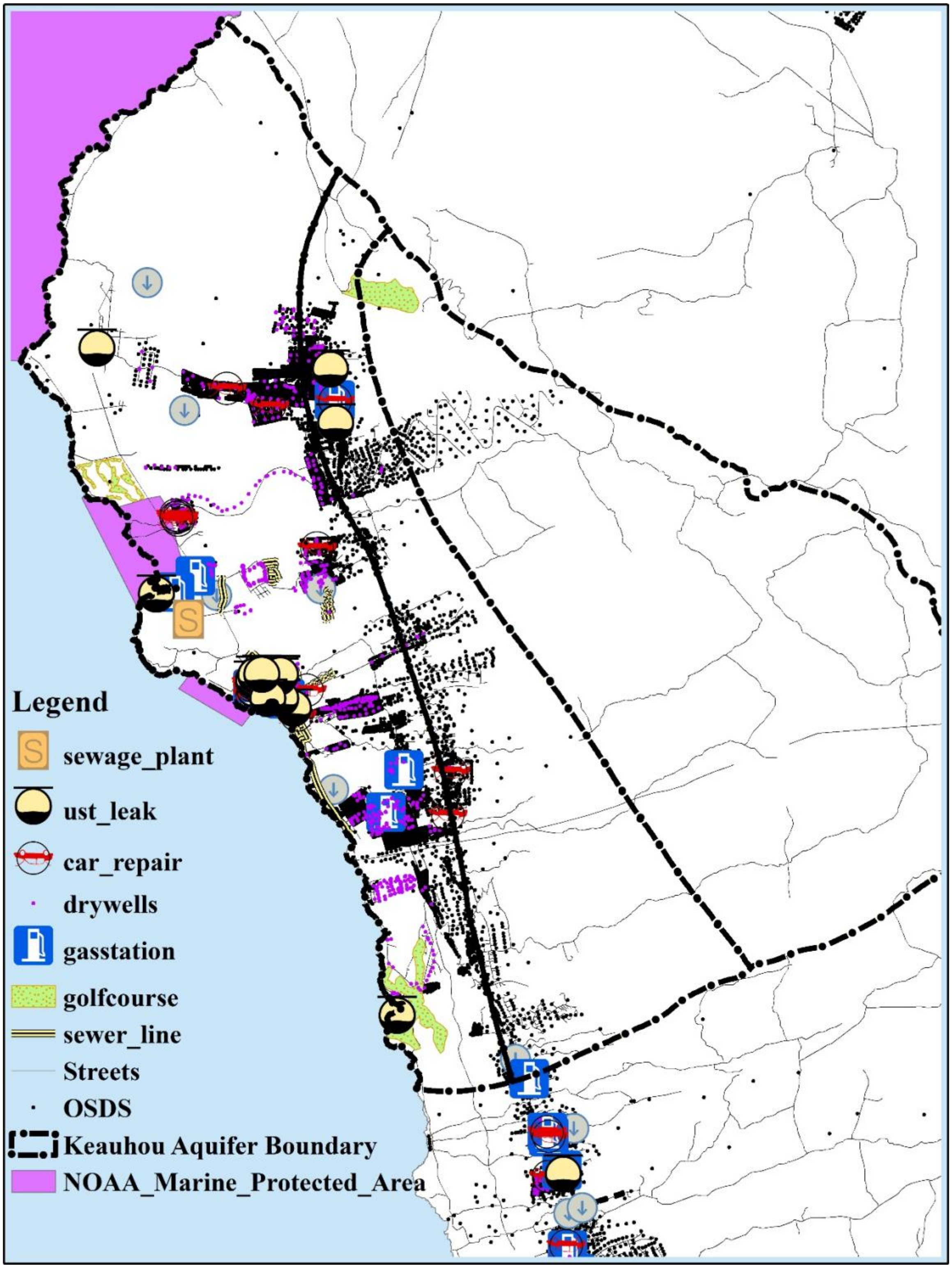

Figure 1. The location of the primary sources of potential contamination to groundwater.

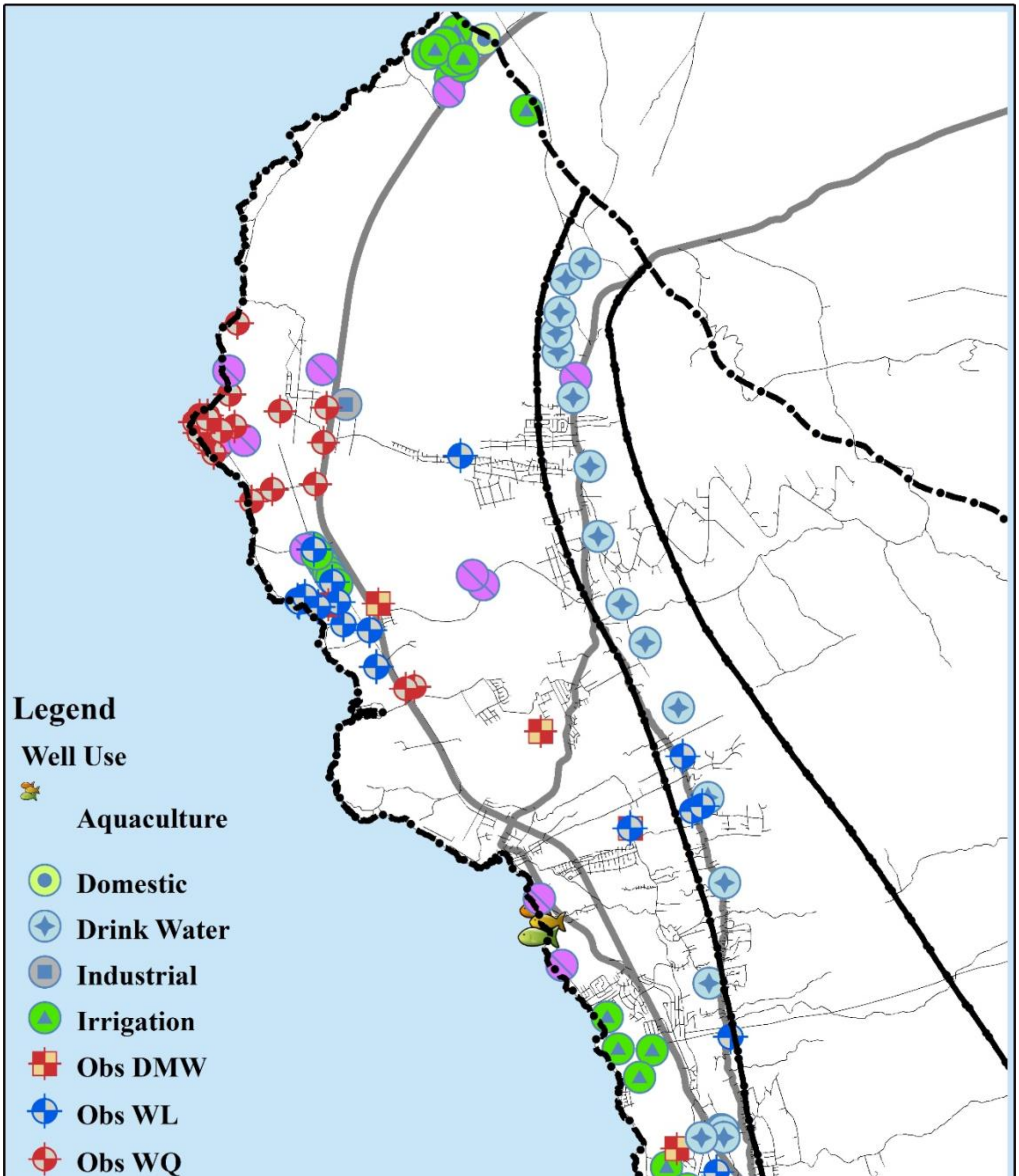

Figure 2. Locations of potential groundwater sampling sites

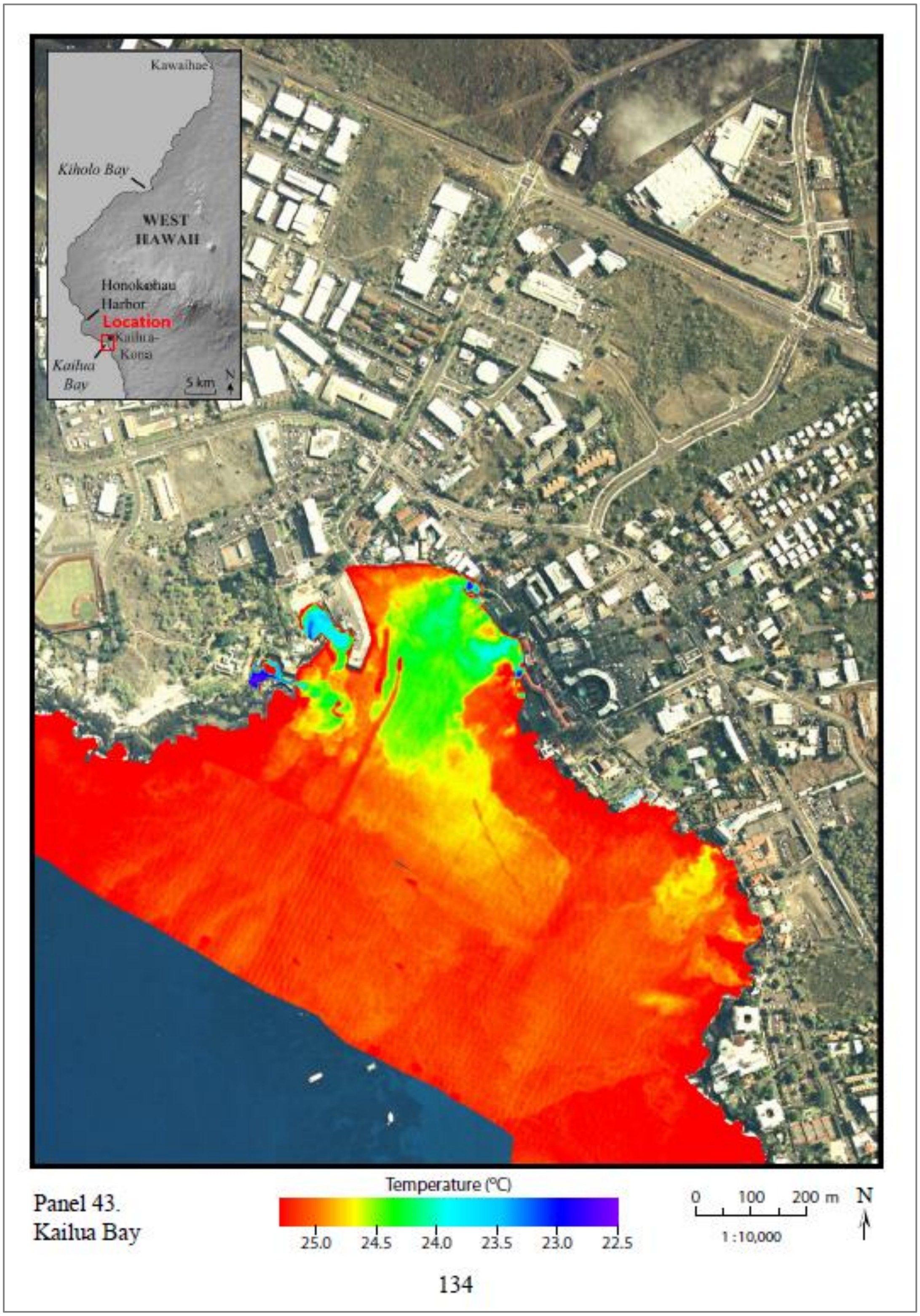

Figure 3. Airborne thermal image of Kailua Bay showing the cooler groundwater (green shading) discharging into the warmer ocean water (red shading). The groundwater discharge zone is a potential sampling site.

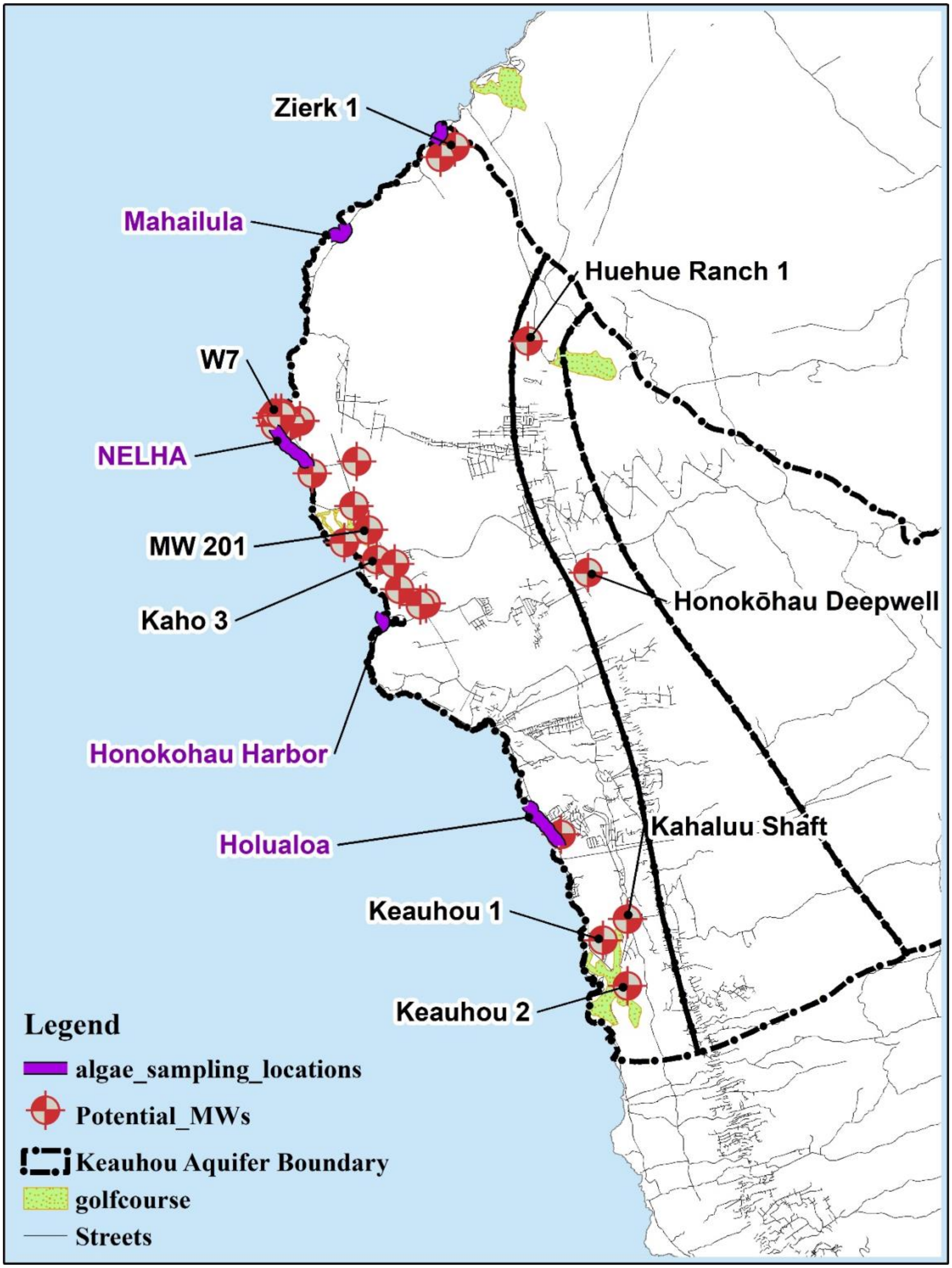

Figure 4. Potential sampling sites. Where there is a group of wells, labels are only shown for two wells.

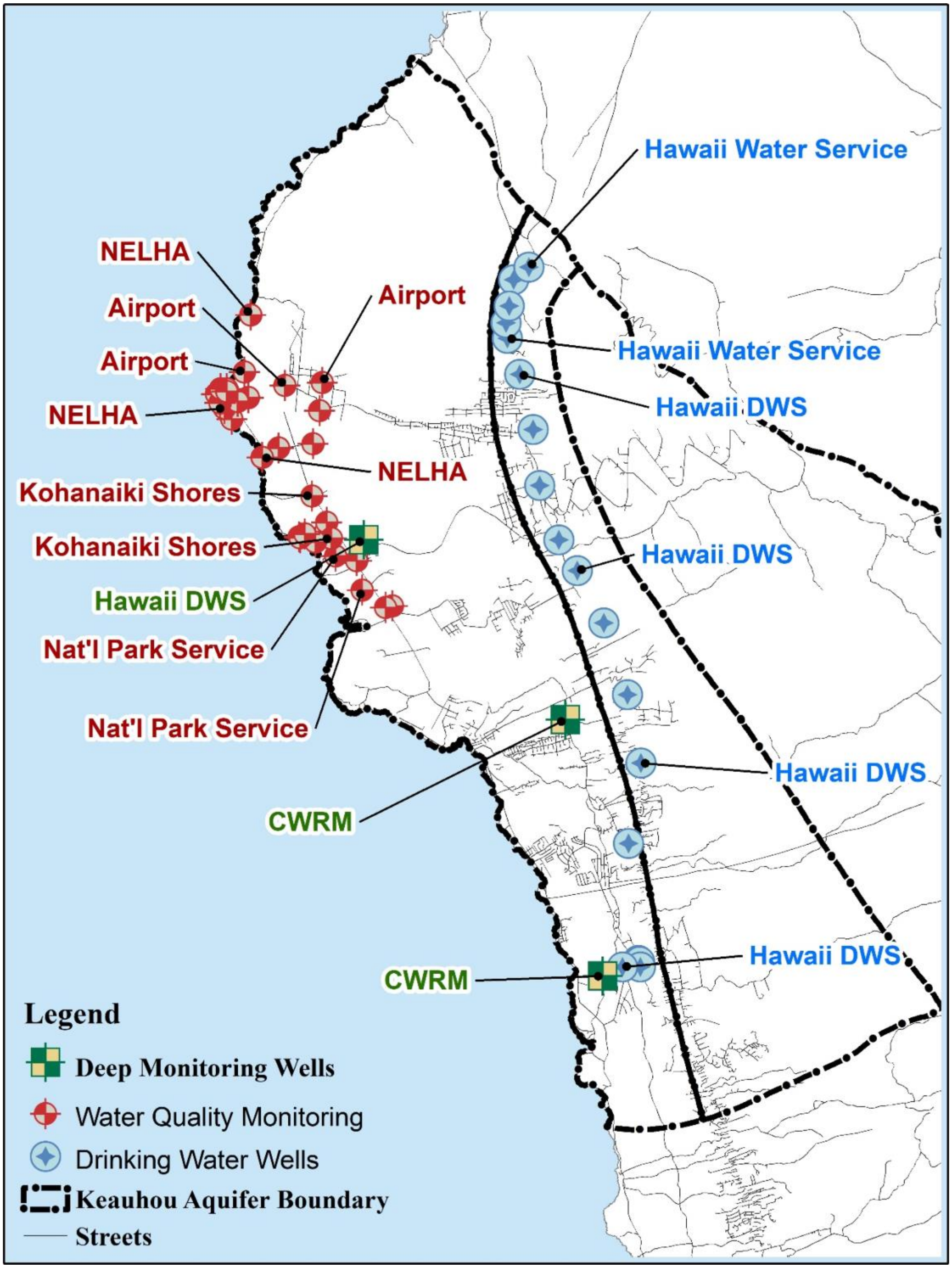

Figure 5. Sites where monitoring is currently occurring. The Organization responsible for the monitoring listed for selected site.