STATE OF HAWAII
DEPARTMENT OF LAND AND NATURAL RESOURCES
**COMMISSION ON WATER RESOURCE MANAGEMENT**
P.O. BOX 621
HONOLULU, HAWAII 96809

STAFF SUBMITTAL

for the meeting of the
COMMISSION ON WATER RESOURCE MANAGEMENT

March 28, 2012
Honolulu, Oahu

Request to Authorize the Chairperson to
Enter into an Agreement with U.S. Geological Survey to Evaluate the Degree of Connection
Between the High-Level and Coastal Ground Water Systems in the Kona Area, Hawaii

SUMMARY OF REQUEST:

The Commission on Water Resource Management (Commission) proposes to authorize the Chairperson to enter into an agreement with the U.S. Geological Survey (USGS) to evaluate the connection between the high-level and coastal ground water systems in the Kona area on the Island of Hawaii.

BACKGROUND:

The State Water Code requires the Commission to carry out research and investigations into "all aspects of water use and water quality." Haw. Rev. Stat. §174C-5(1). This is especially important in areas experiencing development pressures where management decisions depend on an adequate understanding of complex hydrologic systems. The Commission's determination of sustainable yield is reliant upon having the best available information relating to our ground water resources.

When development first began in West Hawaii, the majority of the exploratory drinking wells were drilled near the coast to utilize the basal aquifer system. However, many of these early wells were abandoned due to low water levels and high chloride concentrations. Despite this, growth continued and new wells were drilled farther from the coast at higher elevations to provide more reliable drinking water sources.

D1

Around 1990, public and private entities began exploratory drilling for potable water sources at elevations greater than 1,600 feet on the flanks of Hualalai and Mauna Loa. This resulted in the discovery of high-level ground water at elevations ranging from approximately 25 feet to 460 feet above mean sea level. Exhibit 1 shows the hypothesized boundary between the high-level and coastal water systems based on measured water levels. High-level aquifers are also associated with volcanic dikes occurring in rift zones. This is not the case in West Hawaii as the high-level ground water does not correspond with mapped rift zones of Mauna Loa or Hualalai. Instead, high-level ground water in the Kona area appears to occur due to a low-permeability subsurface geologic feature of uncertain origin.

The hydrology of the area is complex and not well understood. Recently, fresh water was discovered flowing at depth *beneath* salt water. There is a need to further study the geohydrologic system to refine our understanding of how water moves from the high-level to coastal aquifers. USGS has developed a numerical model and is cooperating with the National Park Service (NPS) to update the model. The results of this study will aid in the model update.

The Kona area is designated a growth area in Hawaii County's land use plans and policies. Concerns have been expressed regarding the accuracy of the current sustainable yield estimate of the Keauhou Aquifer System Area and the cumulative impact of pumpage needed to sustain the growth. In particular, the NPS has expressed concern that upgradient withdrawals will negatively impact the cultural and ecological resources at the Kaloko-Honokohau National Historical Park. In addition, NPS is concerned that degradation of water quality, associated with the increased urbanization of the area, will detrimentally impact Park resources.

To address these issues the USGS has been collaborating with the NPS to establish base-line ground water monitoring data. As noted above, the USGS is also working to refine a previously developed model to assess the impacts to the coastal ground water system at the Park from surrounding pumping wells. The Commission has responded to these concerns by expanding its ground water monitoring network in West Hawaii to include more high-level monitoring wells. However, additional information is needed to evaluate the connection between the high-level and coastal grounds water systems.

To fill this important data gap, the USGS is proposing a 2.5 year study that will evaluate the extent of this connection. The study will use geochemical methods to test hypothesized conceptual models of the hydrologic system. The findings will help to reduce the uncertainty associated with potential impacts from upslope development on coastal ground water quality and quantity, and refine our current understanding of the hydrologic flow system.

SCOPE OF SERVICES:

The USGS proposes to undertake a 2.5 year study to evaluate the degree of connection between the high-level and coastal ground water systems in the Kona area of the Island of Hawaii. The study area boundary coincides with the boundary of the Keauhou Aquifer System Area (Exhibit 2). The study will consist of two major phases with a proposed completion date of September 30, 2014.

First, a sampling plan will be developed to collect ground and surface water from production wells, monitoring wells, anchialine pools, and fishponds. The samples will then be sent to the USGS National Water Quality Lab and the Reston Stable Isotope Laboratory for characterization and analysis. The water collected will be analyzed for major ions, silica, selected metals, salinity, and selected naturally occurring stable isotopes.

The second phase of the study will utilize the findings of the data collection to identify and evaluate the presence or lack of a geochemical connection between the high-level and coastal ground water systems. The data collected will also provide information into the altitude and seasonality of ground water recharge to the two systems, as well as the extent of mixing that occurs in the coastal water system. A detailed outline of the analysis and interpretation is attached in the USGS proposal (Exhibit 3).

The results of this study will be published in a USGS Scientific Investigations Report.

The total cost of this agreement is $135,000. The Commission's share will be $95,000. The USGS will provide $40,000. The amount specified in the agreement will be applied towards the total study cost of $306,000. The remainder of the funds required for the entire study will be provided by the NPS through the USGS-NPS Water-Quality Partnership Program under a separate agreement.

FUNDING:

Staff requests the Commission approve $95,000 for the joint funding agreement with the USGS. Funding will be from the Commissions general fund, special fund, or a combination of both, subject to available funding. .

ENVIRONMENTAL REVIEW (CHAPTER 343, HRS)

HRS Chapter 343 does not apply because this is a planning study. Administrative Rule 11-200-5(d) provides:

"*For agency actions, chapter 343, HRS, exempts from applicability any feasibility or planning study for possible future programs which the agency has not approved, adopted, or funded. Nevertheless, if an agency is studying the feasibility of a proposal, it shall consider environmental factors and available alternatives and disclose these in any future assessment or subsequent statement. If, however, the planning and feasibility studies involve testing or other actions which may have significant impact on the environment, then an environmental assessment shall be prepared.*"

The proposed study is a planning study, which does not involve testing or other actions that will impact the environment. Therefore, HRS Chapter 343 is not applicable to this agency action.

RECOMMENDATION

Staff recommends that the Commission:

1. Authorize the Chairperson to enter into an agreement between the Commission and the U.S. Geological Survey to evaluate the connection between the high-level and coastal ground water systems in the Kona area on the Island of Hawaii, and to approve funding not to exceed $95,000 to complete the study.

2. Authorize the Chairperson to amend or modify the joint funding agreement provided that such amendment or modification does not include any additional funding.

The terms of this agreement will be subject to the approval of the Chairperson and the Department's Deputy Attorney General.

Respectfully submitted,

WILLIAM M. TAM
Deputy Director

Exhibits: (1) Map of the Study Area
(2) Island of Hawaii Ground Water Hydrologic Unit Map
(3) USGS Proposal

APPROVED FOR SUBMITTAL:

WILLIAM J. AILA, JR.
Chairperson

EXHIBIT 1

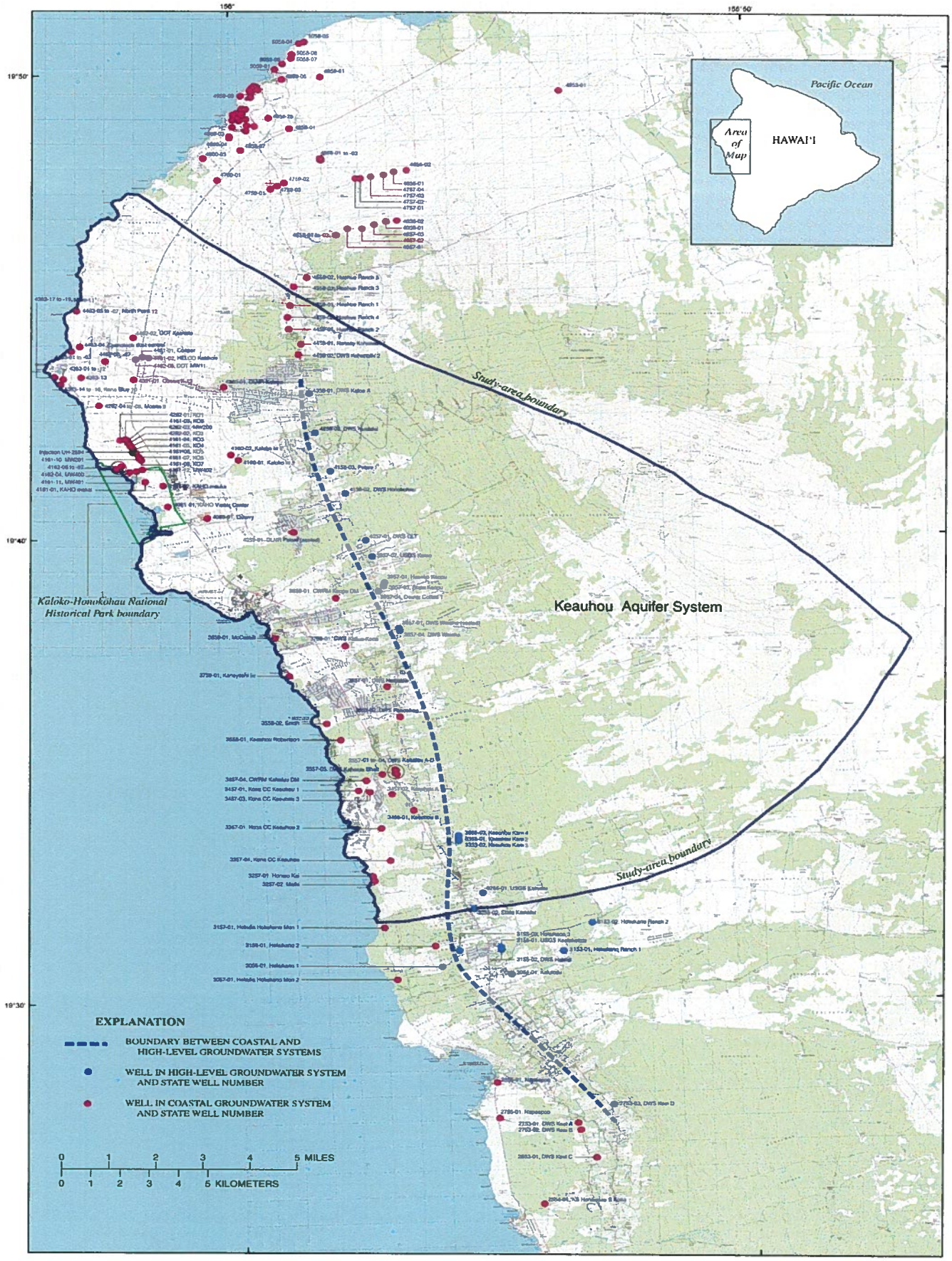
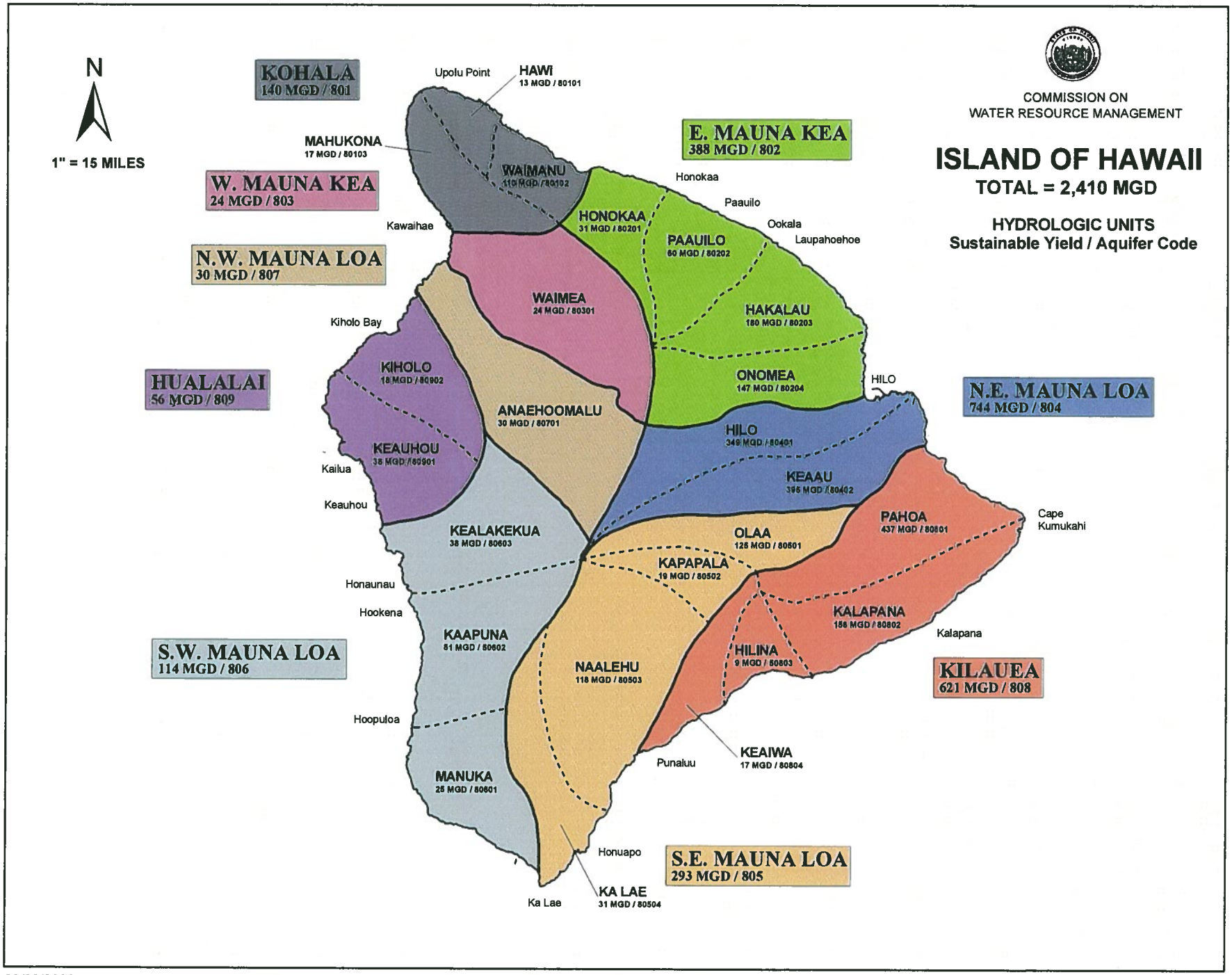

156°
155°50'
19°50'
19°40'
19°30'
Pacific Ocean
Area of Map
HAWAI'I
Study-area boundary
Keauhou Aquifer System
Kaloko-Honokohau National Historical Park boundary
EXPLANATION
BOUNDARY BETWEEN COASTAL AND HIGH-LEVEL GROUNDWATER SYSTEMS
WELL IN HIGH-LEVEL GROUNDWATER SYSTEM AND STATE WELL NUMBER
WELL IN COASTAL GROUNDWATER SYSTEM AND STATE WELL NUMBER
0 1 2 3 4 5 MILES
0 1 2 3 4 5 KILOMETERS

EXHIBIT 2




Map ID: 1010

08/28/2008

Map Projection: Universal Transverse Mercator

EXHIBIT 3

# Use of Stable Isotopes and Other Natural Tracers to Evaluate the Degree of Connection between High-Level and Coastal Groundwater Systems in the Kona Area, Island of Hawai'i

**U.S. Geological Survey**
**Pacific Islands Water Science Center**
**Proposal, March 2012**

## SUMMARY

Since 1970, west Hawai'i has experienced a population increase of about 83 percent and the fastest economic growth on Hawai'i Island, although the effects of development on groundwater resources remain uncertain. At issue among stakeholders is whether urban development over, or withdrawals of freshwater from, the high-level groundwater system will adversely affect the coastal groundwater system, which itself is developed for municipal, agricultural, and industrial uses and which sustains aquatic resources. High-level groundwater (water levels of tens to hundreds of feet above sea level) exists adjacent to and inland from the coastal groundwater system (water levels of a few feet above sea level), and is created by a low-permeability subsurface geologic feature that separates the high-level and coastal groundwater systems.

The purpose of this study is to evaluate whether water-quality or water-quantity changes in the inland high-level groundwater system can alter the quality of the coastal groundwater system. The study design will enable testing and evaluation of the degree of connection between the inland and coastal groundwater systems. This evaluation is critical for determining potential water-quality impacts associated with nearby developments. The objective of the proposed 2.5-year study is to evaluate whether high-level groundwater discharges into the coastal groundwater system, and whether there are characteristic chemical or isotopic signatures that aid in making this discrimination.

This cooperative study will provide data and analyses to help reduce uncertainty associated with potential impacts from upslope development on coastal groundwater quality. This study will provide critical data needed to evaluate the degree of connectivity between high-level and coastal groundwater systems, with implications for potential threats to coastal groundwater quality. This study also will provide data needed to inform

management actions related to proposed water and land-use developments. Data collected during this study will be made publicly available in the USGS National Water Information System (NWIS) database. Results from this study will be published in the USGS Scientific Investigations Report series and made available on the internet. The cost of this 2.5-year study is estimated to total $306,000.

## PROBLEM

The Kona area of western Hawai'i (fig. 1) is rapidly being developed, although the effects of development on groundwater resources remain uncertain. Since 1970, western Hawai'i has experienced a population increase of about 83 percent and the fastest economic growth on Hawai'i Island. A recent newspaper article (Honolulu Star Advertiser, October 17, 2010, p. D1 and D8) described the Kona as "ground zero" for urban growth in western Hawai'i. At issue among stakeholders is whether urban development over, or withdrawals of freshwater from, the high-level groundwater system will adversely affect the coastal groundwater system, which itself is developed for municipal, agricultural, and industrial uses and which sustains aquatic resources. High-level groundwater (water levels of tens to hundreds of feet above sea level) exists adjacent to and inland from the coastal groundwater system (water levels of a few feet above sea level), and is created by a low-permeability subsurface geologic feature of uncertain origin that separates the high-level and coastal groundwater systems. Previous studies and interpretations have assumed that the high-level and coastal groundwater systems are hydrologically connected. Recently, however, some stakeholders have claimed that the high-level groundwater system is hydrologically disconnected from the

coastal groundwater system. This claim implies that: (1) any contaminants introduced to the high-level groundwater may not affect coastal water resources, (2) contaminants introduced to the coastal groundwater system will not be diluted by influx of high-level groundwater, (3) flushing of contaminants introduced to the coastal groundwater system will be slower than in areas where high-level groundwater does discharge directly into the coastal system, and (4) any increased withdrawal of high-level groundwater will not affect the salinity of water flowing through the coastal groundwater system. Clearly, understanding the extent of the connection between the high-level groundwater and coastal groundwater systems is critical in evaluating potential current and future effects of development on water quality in the coastal groundwater system.

The Kona coast contains a variety of ecologically and culturally significant water resources, including hundreds of anchialine pools (small brackish coastal pools that lack a surface connection to the ocean but that are hydrologically connected to groundwater and the ocean through a permeable aquifer [Brock and Kam, 1997]), ancient Hawaiian fishponds, (Kikuchi and Belshe, 1971; Kikuchi, 1976), wetlands (Morin, 1994), and marine waters that support coral reefs, fishes, invertebrates, and mammals (Gibbs and others, 2007). The

anchialine pools may have been an important source of drinking water for pre-industrial Native Hawaiians (Cordy and others, 1991), particularly during dry periods, and the fishponds were used for aquaculture. The anchialine pools, fishponds, wetlands, and marine waters also provide habitat for ten threatened, endangered, and candidate threatened or endangered species. These habitats are sustained by, and in some cases entirely dependent on, high-quality groundwater. The Kona coast contains at least a third (and likely more than half) of the estimated 700 anchialine pools in Hawai'i (Mitchell and others, 2005; Maciolek and Brock, 1974) and these pools support rare endemic species (some of which have not yet been described) and candidate species. The wetlands and fishponds are important breeding and foraging habitat for the endangered Hawaiian coot (*Fulica americana alai*) and the Hawaiian stilt (*Himantopus mexicanus knudseni*) (Morin, 1994).

The coastal groundwater system in the Kona area is composed of brackish water overlying saltwater in a highly permeable volcanic-rock aquifer (Oki and others, 1999). Water levels in the coastal groundwater system are affected strongly by ocean tides and ocean level. The brackish water is formed by seaward-flowing fresh groundwater mixing with underlying saltwater from the ocean. Brackish water flowing through the coastal

groundwater system ultimately discharges to the coastal fishponds and anchialine pools or to the ocean. The main source of fresh groundwater is inland areas, although the inland extent of the recharge area has recently come into question by some who claim that coastal resources will not be affected by contaminants associated with urban development or by withdrawals of high-level groundwater. Recent baseline water-quality sampling by USGS in and near Kaloko-Honokōhau National Historical Park (KAHO) indicates little (if any) wastewater signature in KAHO groundwater (C.D. Hunt, oral commun., 2010), but the study (in preparation) did not address the hydrologic connection between the high-level and coastal groundwater systems. Additional information related to the extent of connection between the high-level and coastal groundwater systems is critically needed to assist State land and water managers in making informed decisions.

## OBJECTIVES

The objective of this 2.5-year study is to evaluate whether high-level groundwater discharges into the coastal groundwater system, and whether there are characteristic chemical or isotopic signatures that aid in making this discrimination. A critical information need addressed by this proposal is to evaluate whether the high-level and coastal groundwater systems

are hydrologically connected or disconnected, which will determine the risk associated with development over, and groundwater withdrawal from, the inland high-level groundwater system. This information need will be addressed by sampling existing wells and anchialine pools and analyzing water samples for stable isotopes and other natural tracers, including silica. Information from this study will assist stakeholders in objectively evaluating the potential effects of proposed developments in order to protect the coastal water resources.

## APPROACH

The purpose of this study is to evaluate whether water-quality or water-quantity changes in the high-level groundwater system can alter the quality of the coastal groundwater system and surface-water features. The proposed study differs from previous studies in that it directly addresses the extent of the hydrologic connection between the high-level and coastal groundwater systems. The study design will enable testing and evaluation of which hypothesized conceptual model of the hydrologic connection is most valid. To accomplish the objectives of this study, the USGS proposes to undertake a 2.5-year study with the following 2-phased approach:

1. *Groundwater and Surface Water Sample Collection and Analyses* - This study will collect water samples from existing wells and

anchialine pools within the Keauhou Aquifer System during both dry and wet seasons. Because the coastal groundwater system is strongly affected by ocean tides, water samples will be collected at both low and high tide during the initial dry-season sampling event to characterize constituent variability and the relation between salinity and constituent concentrations. If a strong relation exists between constituent concentrations and ocean tide, then wet-season samples at a particular site will be collected during similar tidal conditions to allow for meaningful comparisons. Samples will be collected from (1) 5-10 production wells in the upgradient high-level groundwater system; (2) 5-10 monitoring or production wells in the coastal groundwater system; (3) 5-10 anchialine pools, and (4) the fishponds and ocean. Samples will be collected twice, once during the wet season and once during the dry season, from each site during similar tidal conditions (if warranted). Samples from production wells in the upgradient high-level groundwater system will be collected only if pumps have been in continuous operation during the 30-minute period prior to sampling. Samples from monitoring wells in the coastal groundwater system will be collected with bailers or a portable submersible pump following USGS protocols. Grab samples from anchialine pools will be collected by dipping bottles into the water column. Water

quality parameters (pH, specific conductance, dissolved oxygen, temperature) will be measured at the time of sampling. Water samples will be analyzed for major ions, silica, selected metals, and salinity at the United States Geological Survey (USGS) National Water Quality Lab (NWQL). Concurrently, a second set of water samples will be sent to the USGS Reston Stable Isotope Laboratory for $^{2}H/^{1}H$ and $^{18}O/^{16}O$ stable isotope analysis. In addition to the groundwater and surface water samples, rain samples will be collected to establish a local meteoric line for water isotopes and to quantify isotopic differences associated with different rain-producing mechanisms. To understand the potential for sample bias, an equipment blank and field blank will be analyzed for analytical schedule 2054 (major ions, trace metals). To investigate sample variability, two replicates will be collected during each sampling round.

2. *Data Analyses and Interpretation* - Concentrations of constituents and ratios of stable isotopes for the high-level and coastal systems will be compared in order to: (1) identify a geochemical connection or lack of a connection between the two systems, (2) identify the altitude and seasonality of groundwater recharge to the two systems, and (3) identify the extent of groundwater-ocean water mixing in the coastal system. Stable isotopes of oxygen ($\delta^{18}O$) and hydrogen ($\delta^{2}H$) in

precipitation become progressively depleted with altitude (see for example Scholl and others, 2007) and, thus, recharge at higher altitudes also will be depleted. The isotopic composition of coastal groundwater relative to high-level groundwater will provide insight into the extent of hydrologic connection between the two systems. Because silica in groundwater in the study area is mainly derived from weathering of basalt, silica concentrations are expected to progressively increase in a downgradient, coastal direction, after accounting for mixing with seawater, if the high-level and coastal groundwater systems are connected. Other constituents, including major ions, metals, and salinity, will provide insights into mixing among the different sources of water contributing to coastal groundwater. Water quality parameters and water chemistry results will be entered into geochemical modeling software AquaChem, which utilizes PHREEQC, to determine saturation indices and create Stiff and Piper diagrams. The diagrams will indicate the degree of similarity or dissimilarity between the coastal and high-level groundwater systems. Ternary mixing analyses will be used to parse out the relative contributions of constituents from ocean, inland, and local sources. Previous mixing-line analyses (for example, Tom Nance Water Resource Engineering, 2000; Johnson and others, 2007) have indicated that nutrient

concentrations (nitrogen and phosphorus) may not be entirely explainable by simple mixing of seaward-flowing groundwater with seawater.

## PRODUCTS

The anticipated products of this study are a report in the USGS Scientific Investigations Report series. The report will be made available on the website of the USGS Pacific Islands Water Science Center. The probable report title, report outlet, and milestone dates are listed in table 1.

**Table 1.** Milestone dates for planned report

| Probable title | Report outlet | First draft | Review | Approval | Publication |
|---|---|---|---|---|---|
| Use of Stable Isotopes and other Natural Tracers to Evaluate the Degree of Connection Between High-Level and Coastal Groundwater Systems in the Kona Area, Island of Hawai'i | USGS SIR | 02/2014 | 03/2014 | 06/2014 | 09/2014 |

## BUDGET

A total of about $306,000 is needed for this 2.5-year study. The total cost will be shared among the State of Hawaii Commission on Water Resource Management, National Park Service, and U.S. Geological Survey. A cost breakdown is provided in table 2. Labor includes salary and indirect costs for leave,

facilities, and overhead assessments. Science support includes indirect costs for project management, technical services, and report processing fees.

**Table 2.** Project budget.

| Category | Total |
|---|---|
| Labor | 189,000 |
| Travel | 28,000 |
| Equipment and supplies | 15,000 |
| Analytical Services | 43,000 |
| Science Support | 31,000 |
| Total | $ 306,000 |

EXHIBIT 3

## WORK PLAN

The major tasks and associated periods of activity for this 2.5-year study are summarized in table 3. The anticipated study period is May 1, 2012 to September 30, 2014.

**Table 3**. Major work tasks and timelines.

| Task | May 2012 | Jun. 2012 | Jul. 2012 | Aug. 2012 | Sep. 2012 | Oct. 2012 | Nov. 2012 | Dec. 2012 | Jan. 2013 | Feb. 2013 | Mar. 2013 | Apr. 2013 | May 2013 | Jun. 2013 | Jul. 2013 | Aug. 2013 | Sep. 2013 | Oct. 2013 | Nov. 2013 | Dec. 2013 | Jan. 2014 | Feb. 2014 | Mar. 2014 | Apr. 2014 | May 2014 | Jun. 2014 | Jul. 2014 | Aug. 2014 | Sep. 2014 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site selection | x | x | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Data collection | | | x | x | x | x | x | x | x | x | x | | | | | | | | | | | | | | | | | |
| Data analysis and interpretation | | | | | | | | | | | x | x | x | x | x | x | x | x | x | | | | | | | | | |
| Report Preparation | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Writing | | | | | | | | | | | | | | | | | x | x | x | x | x | | | | | | | |
| Review and approval | | | | | | | | | | | | | | | | | | | | | | x | x | x | x | | | |
| Publication | | | | | | | | | | | | | | | | | | | | | | | | | | x | x | x |

## REFERENCES CITED


Brock, R. E., and Kam, A. K. H., 1997, Biological and water quality characteristics of anchialine resources in Kaloko-Honokohau National Historical Park, with recommendations for their management: Cooperative National Park Resources Study Unit, Technical Report no. 112, Department of Botany, University of Hawai'i, Honolulu, Hawai'i, 115 p.

Cordy, R., Tainter, J., Renger, R., and Hitchcock, R., 1991, An ahupuaÿa study: the 1971 archaeological work at Kaloko ahupuaÿa, North Kona, Hawaii—archaeology at Kaloko Honokōhau National Historical Park: Western Archeological and Conservation Center, Publications in Anthropology no. 58, 633 p.

Gibbs, A.E., Cochran, S.A., Logan, J.B, and Grossman, E.E., 2007, Benthic habitats and offshore geological resources of Kaloko-Honokōhau National Historical Park, Hawai'i: U.S. Geological Survey Scientific Investigations Report 2006- 5256, 62 p.

Johnson, A.G., Glenn, C.R., Burnett, W.C., Peterson, R.N., and Lucey, P.G., 2008, Aerial infrared imaging reveals large

nutrient-rich groundwater inputs to the ocean: Geophysical Research Letters, v. 35, L15606, doi:10.1029/2008GL034574.

Kikuchi, W.K., 1976, Prehistoric Hawaiian fishponds: Science, v. 193, no. 4250, p. 295-299.

Kikuchi, W.K., and Belshe, J.C., 1971, Examination and evaluation of fishponds on the leeward coast of the Island of Hawaii: unpublished report prepared for the Hawaii County Planning Commission, Hilo, Hawaii, 18 p. + appendixes.

Maciolek, J.A., and Brock, R.E., 1974, Aquatic survey of the Kona coast ponds, Hawaii Island: Sea Grant Advisory Report UNIHI-SEAGRANT-AR-74-04, 73 p.

Mitchell, C., Ogura, C., Meadows, D.W., Kane, A., Strommer, L., Fretz, S., Leonard, D., and McClung, A., 2005, Hawaii's Comprehensive Wildlife Conservation Strategy. Department of Land and Natural Resources, Honolulu, Hawai'i, 722 p. www.state.hi.us/dlnr/dofaw/cwcs/

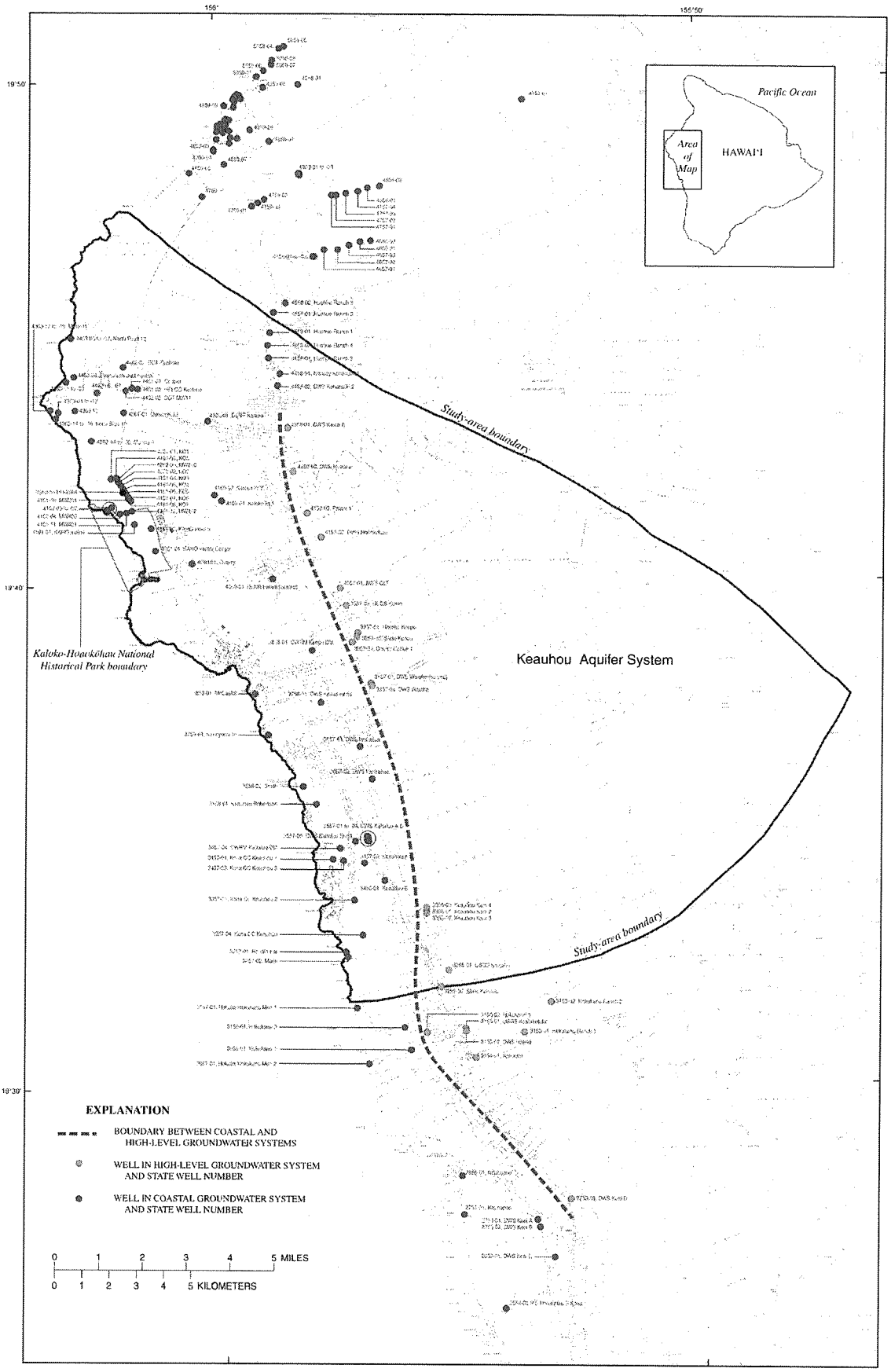
Morin. M.P., 1994, Hawaiian fishponds and endangered waterbirds on the Kona coast: Transactions of the Western Section of the Wildlife Society, v. 30, p. 66-71.

Oki, D.S., Tribble, G.W., Souza, W.R., and Bolke, E.L., 1999, Groundwater resources in Kaloko Honokohau National Historical Park, Island of Hawaii, and numerical simulation of the effects of groundwater withdrawals: U.S. Geological Survey Water-Resources Investigations Report 99-4070, 49 p.

Scholl, M.A., Giambelluca, T.W., Gingerich, S.B., Nullet, M.A., and Loope, L.L., 2007, Cloud water in windward and leeward mountain forests: the stable isotope signature of orographic cloud water: Water Research Research, v. 43, W12411, doi:10.1029/2007WR006011.

Tom Nance Water Resource Engineering, 2000, Potential impact on water resources of phases III and IV of the Kaloko Industrial Park in North Kona, Hawaii: in Wilson Okamoto and Associates, Inc., Final Environmental Impact Statement, Kaloko Industrial Park Phases III and IV, Kaloko, North Kona, Hawaii, Appendix A, 38 p.

EXHIBIT 3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0 1 2 3 4 5 KILOMETERS

EXHIBIT 3

**Figure 1.** Map of study area showing the location of wells and boundary between high-level and coastal groundwater systems in the Kona area, Island of Hawai'i.