APPENDIX G

Monitoring of Water Resources

Water Resource Protection Plan 2019 Update

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A vital component of water resource protection is the implementation of an effective program to monitor resource conditions. In 2001, the USGS published Circular 1217, entitled *Ground-Water-Level Monitoring and the Importance of Long-Term Water-Level Data*[1], intending to highlight the importance of ground water-level measurements, and to foster a more comprehensive and systematic approach to the long-term collection of water-level data. The report calls attention to the need for a nationwide program to obtain more systematic and comprehensive records of water levels in observation wells, as a joint effort among the United States Geological Survey (USGS) and state and local agencies:

> *"…[W]ater-level monitoring in the United States is fragmented and largely subject to the vagaries of existing local projects. A stable, base network of water-level monitoring wells exists only in some locations. Moreover, agency planning and coordination vary greatly throughout the United States with regard to construction and operation of water-level observation networks and the sharing of collected data."*
>
> *…More recently, the National Research Council (2000) reiterated, "An unmet need is a national effort to track water levels over time in order to monitor water-level declines."*
>
> *…It is hoped that this report [Circular 1217] will provide a catalyst toward the establishment of a more rigorous and systematic nationwide approach to ground-water-level monitoring – clearly an elusive goal thus far. The time is right for progress toward this goal. Improved access to water data over the Internet offers the opportunity for significant improvements in the coordination of water-level monitoring and the sharing of information by different agencies, as well as the potential means for evaluation of water-level monitoring networks throughout the United States."*

The need for improved monitoring programs and agency coordination described in Circular 1217 is true for Hawai'i's ground water monitoring activities, but the need is even more apparent for Hawai'i's surface water and climate monitoring programs, which are fairly new and in need of sensible expansion. The overall goal of establishing a "rigorous and systematic" approach to resource monitoring across the State should be carefully addressed by program planning, implementation of prioritized actions, plan update and revision, and interagency & private/public cooperation. This appendix of the Water Resources Protection Plan (WRPP) describes Hawai'i's existing ground water, surface water, and climate monitoring and

[1] Taylor, Charles J. and William M. Alley. 2001. *Ground-Water-Level Monitoring and the Importance of Long-Term Water-Level Data: U.S. Geological Survey Circular 1217.* Internet, available online at: http://pubs.usgs.gov/circ/circ1217/html/pdf.html.

assessment programs, as well as recommendations for follow-up action, program expansion, and agency coordination.

Under the State Water Code, the Commission on Water Resource Management (CWRM) is primarily responsible for assessing the quantity issues of ground and surface water resources, while the Department of Health (DOH) has primacy over ground and surface water quality issues. Please refer to **Appendix M** for more information about DOH programs and plans.

G.1 Overview

CWRM, in cooperation with federal agencies, State DOH, and county agencies, is responsible for monitoring ground water resources, surface water resources, and climate conditions throughout the state of Hawaiʻi. Monitoring activities include the collection of:

- Vertical-profile conductivity and temperature data (indicates the extent of saltwater intrusion and the behavior of the freshwater and transition zone over time) from state, Honolulu Board of Water Supply (BWS), USGS, and private deep monitor wells;
- Instantaneous and continuous long-term water-level data from water-level monitoring wells;
- Continuous and long-term stream discharge data and surface water quality data;
- Rainfall data from the National Weather Service (NWS), the USGS, the State, and privately-operated rain gages;
- Ground water pumping, chloride (or conductivity), water-level, and temperature data from all production wells statewide; and
- Surface water diversion data from streams

As water usage increases, it is necessary that at least minimal hydrologic data be collected and made available for decision-making, regarding availability and use of the resource. Climate change, including sea level fluctuations, will directly affect aquifers adjacent to the coastlines, and inland aquifers will be affected by changes in recharge from precipitation, necessitating careful monitoring to maintain an accurate assessment of aquifer health. Water withdrawals must be continuously inventoried, and the impacts of these withdrawals must be monitored to protect and prevent any degradation of ground and surface water sources.

In an effort to respond to the increasing pressure on Hawaiʻi's water resources, CWRM and the USGS have begun a joint effort to evaluate water-resource monitoring needs in Hawaiʻi. The current network of groundwater, streamflow, and rainfall monitoring stations will be examined to determine how data collections sites can be best utilized and expanded to protect and manage Hawaiʻi's water resources. The results of this effort will be published in a USGS Scientific

Investigations Report and will include a 20-year implementation plan with preliminary cost estimates.

Continuous and consistent water data collection is critical to CWRM's ability to protect water resources. CWRM collects, analyzes, and verifies hydrologic data; this is then correlated, or analyzed to provide an understanding of water within a particular area. Ground water data are used to observe empirical trends and calibrate computer models that will refine sustainable yield estimates, and surface water data are used in the development of instream flow standards. Data is also obtained through required, regular reports by well owners. At the time of this publication, a new online water use reporting database has been implemented (Water Resource Information Management System [WRIMS]), and will be able to provide reports on water use and other time-series data by aquifer system area, island, user, type of use (e.g., domestic, municipal, and agricultural), and other source information and documentation.

Although it is recognized that groundwater and surface water resources are interconnected, CWRM splits the data collection and management duties between two separate programs. Groundwater monitoring is the responsibility of the Ground Water Regulation Branch, and surface water monitoring is the responsibility of the Stream Protection and Management Branch. The following sections are organized to reflect this separation of duties within CWRM.

G.1.1 Water Resource Monitoring Goal and Objectives

The following goals, policies, and objectives have been determined by CWRM to guide and focus water resource monitoring programs and the use of resultant monitoring data:

Goal: Develop the best available information on water resources, including current and future water use monitoring and data collection, surface water and ground water quality (e.g., chlorides) and availability, stream flow, stream biota, and watershed health to make wise decisions about reasonable and beneficial use and protection of the resource.

- Compile water-use and resource data collected by CWRM, other government agencies, community organizations, and other private entities into a comprehensive database.
- Enhance surface and ground water use data collection throughout the State, such that stream diversion and well operators and users participate in recording and reporting stream diversion withdrawals, well pumpage, well water chloride (or conductivity) concentrations, non-pumping water-levels, and temperatures.
- Identify priority areas for new ground and surface water monitoring. Submit funding requests, as needed, for monitoring programs (e.g., deep monitor wells, water-level observation wells, spring flow measurements, rain gage data, fog drip analysis, stream gaging, stream surveys, etc.).
- Pursue cooperative agreements and partnerships with other governmental agencies and private stakeholders to work with the USGS in the collection of hydrologic data.

- o Participate in watershed partnerships to better understand and facilitate the collection of data to support watershed management.
- o Assess the impacts of climate change on the components of the hydrologic cycle.
- o Maintain awareness of latest technologies and methodologies of hydrologic computer/numerical models.
- o Promote and support the continuation of long-term hydrologic and climate data collection stations as well as the establishment of new stations and the reinstatement of important discontinued stations.
- o Update:
  - Hydrologic Geographic Information System (GIS) data for the State;
  - Ground water recharge information;
  - Benchmark ground water well network for water level elevations; and
  - Deep monitor well network.

G.2 Monitoring of Ground Water Resources

Management of ground water resources cannot be responsibly accomplished without long-term monitoring information. Long-term data allows water scientists and managers to identify emerging trends and problems in Hawaiʻi's ground water aquifers. For example, the effects of natural climatic variations and induced stresses upon aquifer systems could be better identified. Since ground water provides much of the municipal and drinking water supply statewide, and demand for high-quality ground water continues to increase, long-term monitoring data is needed to determine the response of island aquifers to climatic variability and change, changing land use, and increasing withdrawals. Such data is useful in defining trends, providing a basis for comparison, measuring the impacts of water development, detecting ground water threats, and determining the best management and corrective measures.

The practical applications of data from monitoring activities are numerous and varied, but generally include actions toward:

- Managing ground water withdrawals for purposes such as protecting sustainable yields and existing wells;
- Providing insight into regional hydrology including emerging regional conceptual ground water model differences; and
- Providing data to construct and test analytical and numerical ground water models to assess ground water occurrence and recharge.

The following comprise the main elements that contribute to ground water monitoring activities in Hawaiʻi, and these elements are further described in the sections below:

- Deep monitor wells;
- Water-level observation wells;
- Spring discharge measurements and conductivity measurements;
- Pumpage, chloride (or conductivity), water-level, and temperature data from well owners; and
- Rainfall data.

Deep Monitor Wells: Deep monitor wells (DMWs) penetrate through the freshwater zone and transition zone and terminate in the saltwater zone. In some cases, on the island of Hawaiʻi, DMWs have encountered deep confined freshwater aquifers below saltwater. Deep monitor wells allow for the study of the entire basal aquifer water column. The wells are used to track changes in the thickness of the freshwater lens over time; thereby providing data on the aquifer's response to groundwater withdrawals and longer-term precipitation changes. In addition, deep monitor wells serve as water-level observation wells and can be used to sample the water chemistry at depth (refer to the cross section depicted on **Figure G-1 Schematic Diagram of a Deep Monitor Well**). The location of DMWs in the State of Hawaiʻi are shown on **Figure G-2 Deep Monitor Wells (DMWs) in the State of Hawaiʻi**. **Table G-1 Summary of CWRM Deep** Monitor Wells provides a list of the CWRM DMWs.

Figure G-1 Schematic Diagram of a Deep Monitor Well

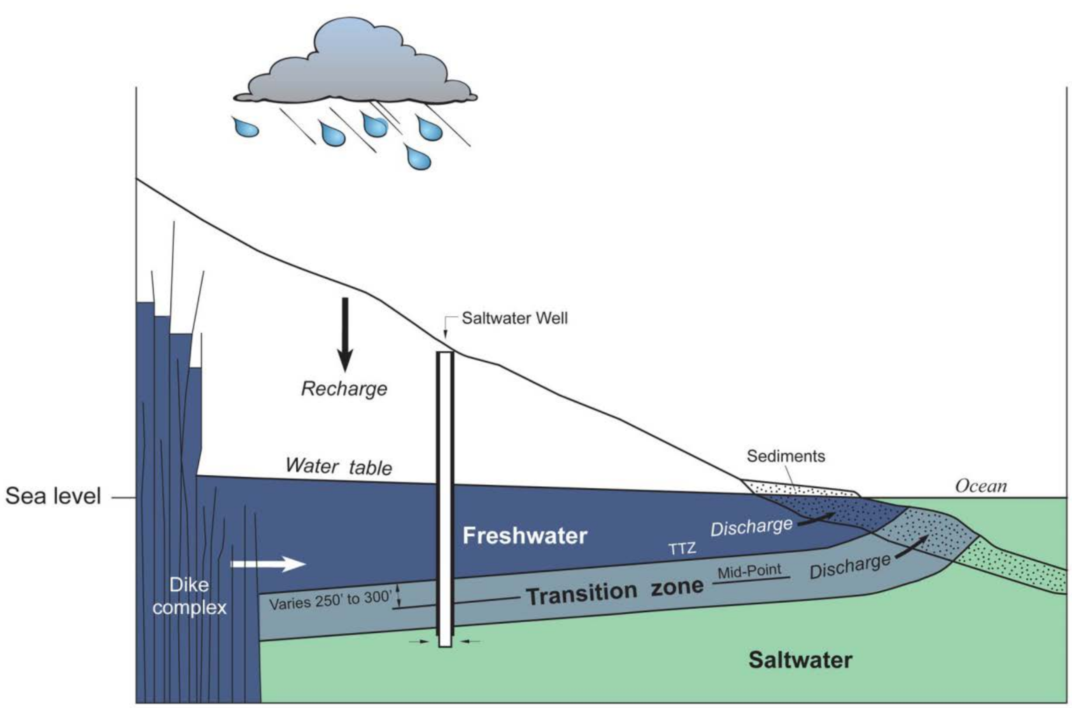
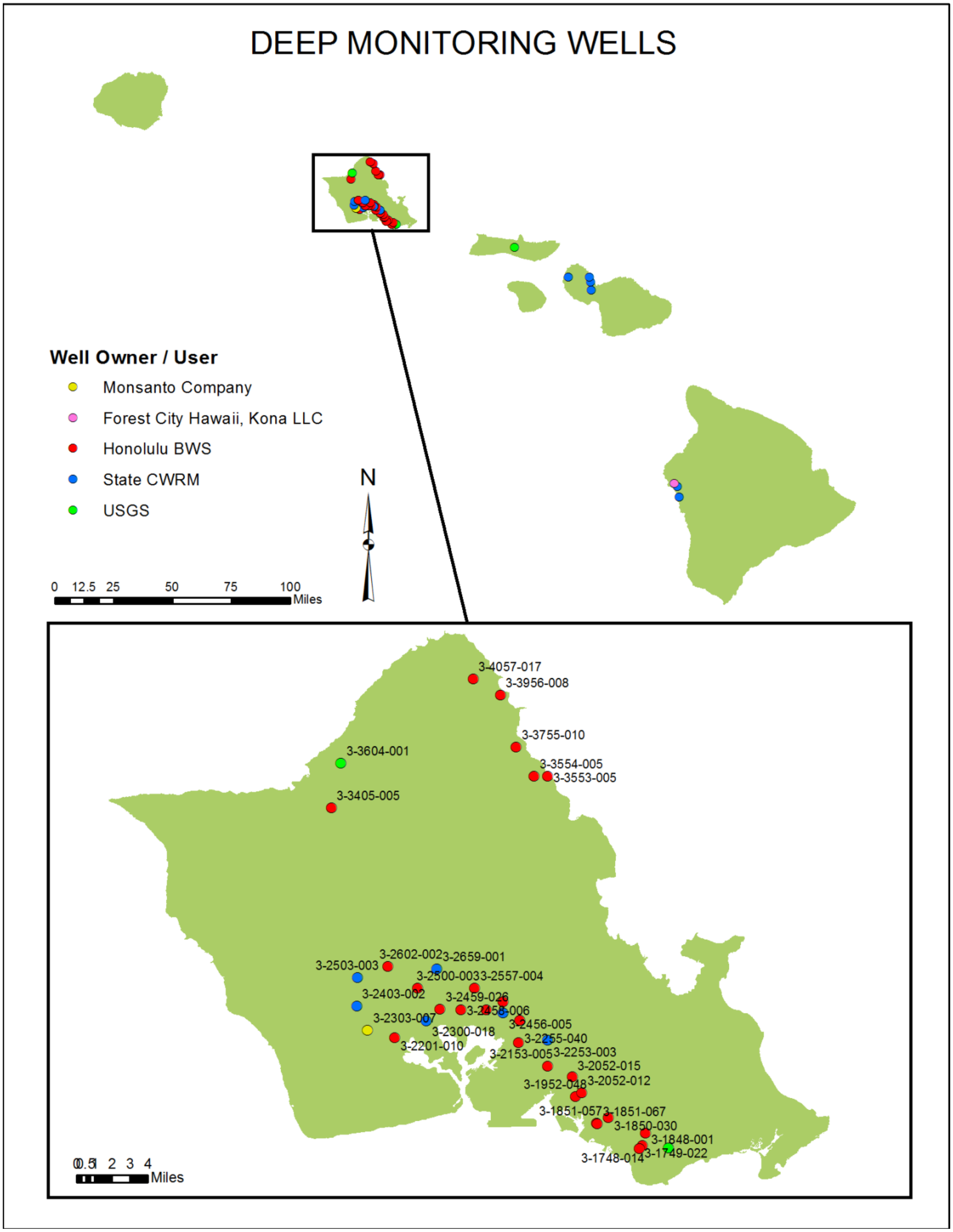


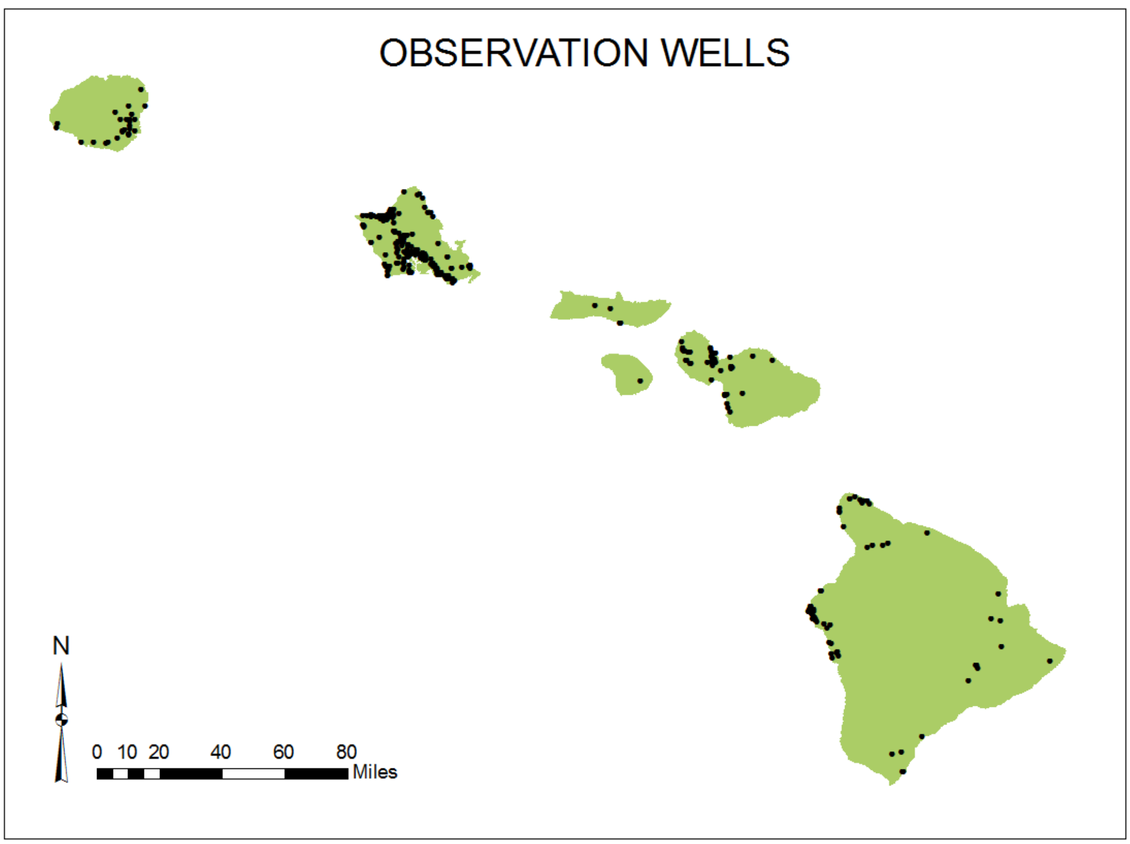
Figure G-2 Deep Monitor Wells (DMWs) in the State of Hawai‘i



Recent studies (Rotzoll USGS, 2010) have shown that natural or anthropogenic vertical borehole flows within a DMW can influence the measured transition zone elevations, and as a result, Conductivity, Temperature, and Depth (CTD) profiles may not accurately reflect the transition zone elevations within the aquifer. CWRM will evaluate the influence of vertical borehole flow on a well by well basis and develop recommendations for future DMW design and installation details (and consider existing DMW retrofits) to mitigate the influence of vertical flow within the DMWs.

Water-Level Observation Wells: Water level data can be obtained from any well that penetrates the desired aquifer. Water level is the height of water in a well relative to mean sea level. Such data provides information on aquifer response to rainfall patterns and ground water withdrawals. Water level data can be analyzed in combination with spring discharge, pumpage, and chloride (or conductivity) data to study aquifer response to climatic events and induced stresses. A summary list of observation well in the State of Hawaiʻi (including water level and DMWs) is provided in **Table G-5 Statewide Summary of Registered Observation Wells Not Included in the CWRM, CWRM-USGS, or Honolulu BWS Monitoring** Programs. The locations of water level observation wells in the State of Hawaiʻi are shown on **Figure G-3 Water-Level Observation Wells in the State of Hawaiʻi**.

Figure G-3 Water-Level Observation Wells in the State of Hawaiʻi



Spring Discharge and Conductivity Measurements: Spring flow can represent the visible discharge from a basal freshwater lens or from dike-impounded ground water. Information on the rate of spring discharge and chloride concentrations (or conductivity) can be correlated to water-level data and chloride (or conductivity) trends at observation wells in the vicinity of the spring. The relationship between the amount of ground water withdrawals (pumpage) and spring discharge can provide estimates on the amount of ground water flux through an aquifer. The USGS is the primary collector and disseminator of this information.

Pumpage, Chloride, Water-Level, and Temperature Data from well owners: There are over 4,000 wells statewide that are required to report monthly to CWRM. Reported water use and chloride (or conductivity) data over the long-term provides information on the rate of ground water withdrawals and the resulting water quality, water-levels, and temperature responses within aquifer system areas. Water use and chloride (or conductivity) information can be compared with monitor water-level data, deep monitor well data, irrigation practices, and land use and demographic changes to gain insight into the sustainability of ground water resources. Pumpage is also compared against current supply and uses. For more information on this refer to **Appendix H, Existing and Future Demands**.

Pumping Test Data: Data collected during pump tests as required by the HWCPIS (2004) can provide information to help identify and interpret flow relationships between ground water bodies and can also be indicative of geothermal activity. For example, water levels can help determine if the pumpage will impact streams or other existing wells. A rise in chlorides can indicate upconing and pump capacity limitations. Additionally, if ground water temperature remains constant throughout a pumping test, it is most likely that all water derived from the borehole or test well is from the same source. Conversely, if water temperature changes, it could be that observed variations are due to the introduction of water from another related source. As for indicating geothermal activity, a rise in water temperature accompanied by an increase in chloride concentration, typically suggests that the water is associated with regions of geothermal activity.

Rainfall Data: Rainfall data represents the “input” to ground water systems and provides basic information to complete the water balance equation. Ground water recharge models rely on rainfall and land use information to determine how much rainfall percolates into the subsurface aquifer systems. Rainfall data should be complemented by fog drip and evapotranspiration data to allow computation of more accurate recharge information. Rainfall and precipitation monitoring are discussed further in **Section G.4 Rainfall Monitoring Activities**.

G.2.1 Data Management

WRIMS, is a computer program that maintains a record of water resource withdrawals for the State of Hawaiʻi. WRIMS provides the basis for informed decisions that:

- Protect and sustain viable sources of ground and surface water in the state;
- Promote efficient and environmentally-compatible withdrawals of water resources;
- Provide best available information to resolve water disputes involving ground and surface water resources.

One of the primary functions of WRIMS is to allow CWRM water users to report their water-use via a web-based interface. Data is stored on secure, updated, backed-up daily servers in a highly-secure data center. WRIMS users will never have to download, install or update software and will only input data required by CWRM. The WRIMS water-use reporting function is accessible anywhere with a valid user name and password at:

- Department of Land and Natural Resources (DLNR), Commission on Water Resource Management (CWRM) website at http://dlnr.hawaii.gov/cwrm/;
- Go directly to the WRIMS website at http://dlnr.hawaii.gov/cwrm/info/waterusereport/.

Along with facilitating online water-use reporting, WRIMS is a statewide water resource information management system that is used by CWRM. A common data standard and domain helps to oversee and track permit activities, compliance responses, and water quantity tracking. WRIMS features tools to routinely upload data to fulfill regulatory directives/compliance and regulations, allow for graphing and mapping of data, schedule and track when deliverables/ reports are due from responsible parties, and evaluate sites for risk and allocate staff resources. WRIMS key features include:

- Water resource asset management (wells, diversions, aquifers, hydrologic units, etc.)
- Contact management system
- Complaints management
- Violations management
- Water use electronic reporting
- Electronic document management
- Permit application processing
- Data analysis and reporting

G.2.2 CWRM Ground Water Monitoring Programs in Hawaiʻi

CWRM is responsible for collecting basic hydrologic data and conducting water availability and sustainable yield analyses statewide. The purpose of the monitoring network is to meet the goals, policies, and objectives outlined in **Section G.1.1** by improving our understanding of (1) the movement and behavior of ground water within and between aquifer system areas; (2) the interactions between basal, dike impounded, and other ground water sources; (3) the interactions between ground water and surface water bodies; (4) the response of individual aquifers and ground water systems to changes in land use and climate; and (5) the impacts of ground water withdrawals on aquifers and ground water systems.

CWRM's monitoring activities support the protection, conservation, planning, and utilization of water resources for social, economic, and environmental needs, as mandated by the State Water Code. The information presented below describes CWRM's monitoring activities, as well as monitoring programs undertaken in cooperation with the USGS and the Honolulu BWS. On Oʻahu, CWRM, USGS, and Honolulu BWS have robust monitoring networks; however, monitoring networks in other counties are not as expansive and area data in most cases, is lacking.

G.2.2.1 CWRM Deep Monitor Well Program

Hawaiʻi's unique volcanic geology provides for large aquifers that are able to support the State's population by supplying domestic and municipal potable ground water, as well as water for agriculture and other purposes. These aquifers are naturally replenished by precipitation and, in some areas, by irrigation return flow. Because fresh ground water is less dense than seawater, it floats on top of the saline water, forming what is known as a Ghyben-Herzberg lens, referred to in Hawaiʻi as a "basal" aquifer (see **Appendix F** for a discussion of the Ghyben-Herzberg relationship). According to the Ghyben-Herzberg relationship, for every foot of freshwater above sea level, there is 40 feet of freshwater below sea level. Between the freshwater and saltwater boundaries of the lens is a zone of mixing, known as the "transition zone."

In Hawaiʻi, the chloride-ion concentration (milligrams per liter, or mg/L) is used to determine the freshness or saltiness of ground water. It is also listed as a contaminant in the EPA Secondary Drinking Water Regulations. The Hawaiʻi Revised Statutes do not define "potable water," but the law does provide for the establishment of maximum contaminant levels for various chemicals, as well as other parameters for drinking water quality. While CWRM defers to DOH on most water quality related matters, CWRM management principles utilize operational water quality definitions based on chloride concentration as follows:

- **Fresh Water:** Chloride concentrations from 0 to 250 milligrams per liter (mg/L)
- **Brackish Water:** Chloride concentrations from 251 to 16,999 mg/L
- **Seawater:** Chloride concentrations of 17,000 mg/L and higher

Chloride in small concentrations is not harmful to humans, but in concentrations above 250 mg/L, or two percent that of seawater, it imparts a salty taste in water that is objectionable to many people. By definition, the transition zone is the vertical zone with water quality that varies from 250 mg/L chloride to 19,000 mg/L chloride (approximately seawater). The midpoint of the transition zone (MPTZ) is defined as the area in the vertical profile where the water contains 9,500 mg/L chloride. Because the amount of water that can be developed from a freshwater lens for potable use is constrained by the salinity of the water, the altitude of the top of the transition zone (where chloride concentration is two percent that of seawater) and the thickness of the transition zone are important. The transition zone is in constant flux, responding to changes caused by variations in pumping and ground water recharge.

A deep monitor well penetrates the entire water column from freshwater into saltwater (see **Figure G-1 Schematic Diagram** of a Deep Monitor Well). Well data is used to track the changes in and movement of the transition zone over time. This can be accomplished either by direct sampling at discrete elevations (below mean sea level) or by lowering an instrument known as a CTD logger, which measures changes in the electrical conductance, temperature, and depth of the water, to the bottom of the well. The saltier the water, the greater the conductivity. A sample graph of CTD data, indicating the changes in water salinity and temperature with depth, is shown in **Figure G-4**.

Going inland, water levels increase and the elevation of the MPTZ below mean sea level decreases. Ideally there should be enough deep monitor wells to provide data that adequately defines the vertical cross-section of the transition zone from the mountains to the sea. The deep monitor wells should be roughly located on a mauka to makai orientation. Often, three properly spaced deep monitor wells within each aquifer system area are adequate for this purpose.

Table G-1 lists the deep monitor wells included in the CWRM program. CWRM owns and operates deep monitor wells on Oʻahu, Maui, and Hawaiʻi. Two deep monitor wells are located in the Keauhou Aquifer System Area (ASA) on the island of Hawaiʻi, where there are concerns of development in West Hawaiʻi negatively impacting regional water resources. Four deep monitor wells are located on Maui: two in the ʻĪao ASA, which is an essential municipal water source for the Maui Department of Water Supply and is showing signs of over-pumpage, one located in the adjacent Waiheʻe ASA to provide data to augment information collected from the ʻĪao ASA wells, and one located in the Honokōwai ASA near Lahaina in west Maui. Six deep monitor wells are located in the Pearl Harbor Aquifer Sector Area, which is the most important ground water supply on Oʻahu.

Figure G-4 Sample Graph of CTD Data from a Deep Monitor Well

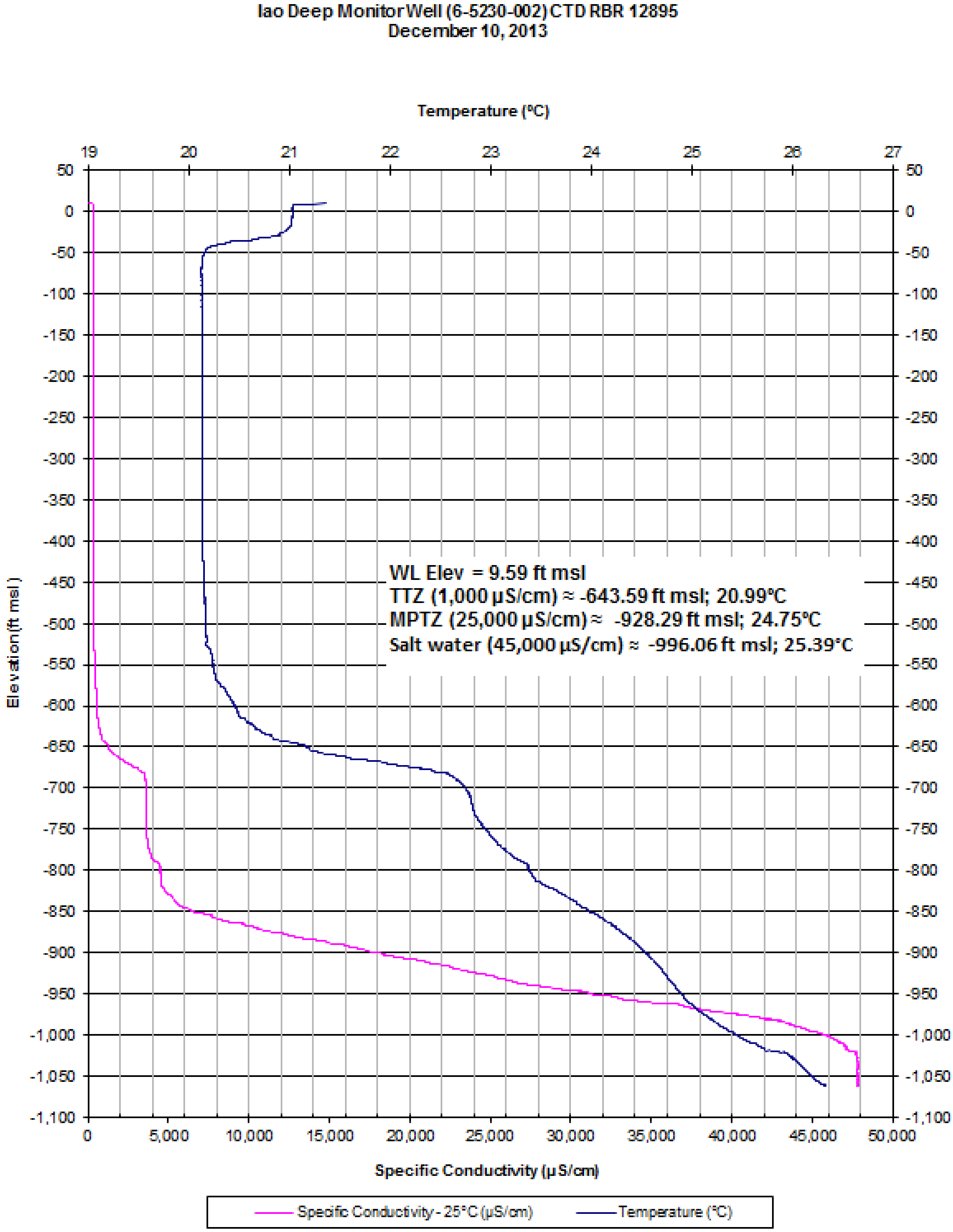


Table G-1 Summary of CWRM Deep Monitor Wells

Island	Aquifer System Area Code	Aquifer System Area Name	Well Number	Well Name
Hawaiʻi	80901	Keauhou	8-3457-004	Kahaluʻu Deep Monitor
Hawaiʻi	80901	Keauhou	8-3858-001	Keōpū Deep Monitor
Maui	60102	ʻĪao	6-5230-002	ʻĪao Deep Monitor
Maui	60102	ʻĪao	6-5430-005	Waiehu Deep Monitor
Maui	60103	Waiheʻe	6-5631-009	Waiheʻe Deep monitor
Maui	60203	Honokōwai	6-5739-003	Lahaina (Māhinahina) Deep Monitor
Oʻahu	30201	Waimalu	3-2253-003	Hālawa Deep Monitor
Oʻahu	30201	Waimalu	3-2456-005	Waimalu Deep Monitor
Oʻahu	30203	Waipahu-Waiawa	3-2300-108	Waipahu Deep Monitor
Oʻahu	30203	Waipahu-Waiawa	3-2659-001	Waipiʻo Mauka Deep Monitor
Oʻahu	30204	ʻEwa-Kunia	3-2403-002	Kunia Middle Deep Monitor
Oʻahu	30204	ʻEwa-Kunia	3-2503-003	Kunia Mauka Deep Monitor

(CWRM DMW Locations shown on **Figure G-2**)

G.2.2.2 Analysis of Selected Aquifer System Areas

As noted above, CWRM has constructed deep monitor wells and established monitoring networks in aquifers facing development pressures and those that are major sources of drinking water supply. **Table G-5** provides a summary of all registered observation wells in Hawaiʻi. Currently there are 357 observation wells, including 45 DMWs, in the state. Wells that are currently classified as unused (896 wells) could potentially provide additional data points for water levels, chlorides, and temperature.

In 2014, CWRM conducted an analysis of current and historic hydrologic data in the following eight selected aquifers to examine aquifer trends, to assess aquifer health and viability, and to develop management recommendations based on the findings. The eight aquifer system areas selected for analyses are: ʻĪao and Waiheʻe aquifer systems on Maui; Waimalu, Waipahu-Waiawa, and ʻEwa-Kunia aquifer system areas on Oʻahu; and the Kealakekua, Keauhou, and Kīholo aquifer system areas on Hawaiʻi.

In each of the above areas historical ground water data from CWRM, USGS, BWS, and a variety of historical sources were compiled to identify hydrologic trends. The identified trends were then analyzed to determine contributing factors so that management and/or monitoring recommendations could be made. This provides CWRM with a critique of the current management and monitoring actions being implemented in these important aquifer systems.

The findings of this report are summarized in the sections below. For the most part, the estimated sustainable yields for each aquifer system appear to be appropriate.

G.2.2.3 Kona Ground Water Monitoring Program

Since 1991, CWRM has collected ground water elevation measurements in public and private wells and test holes throughout the North and South Kona and South Kohala Districts of the County of Hawaiʻi. In September 2003, CWRM published the findings and conclusions of area monitoring activities in a report titled "A Study of the Ground-Water Conditions in North and South Kona and South Kohala Districts, Island of Hawaiʻi, 1991-2002."[2] The background information summarized in CWRM's 2003 and 2014 reports, and the findings of the Kona ground water monitoring activities to date, are presented below.

During the 1980s and through the early 1990s, and continuing into the current millennium, Kailua-Kona has experienced tremendous growth. Associated with the activities of the early 1990s was the high demand on water supplies and competition among large landowners and developers for new sources. As wells were drilled, new and interesting geological and hydrological information began to emerge that spurred additional wells at higher elevations, and at greater cost.

CWRM initiated a series of meetings in the North Kona and South Kohala Districts among the major landowners, developers, engineers, and hydrologic consultants, in order to come to agreement as to the proper development of ground water resources. This effort was in response to competition for well-site locations and CWRM concerns regarding planning, well placement, and well interference. Two ad-hoc groups were formed: 1) The Hualālai Users Group focused on problems near Kailua-Kona and the North Kona District, and 2) the Lālāmilo Users Group that focused on problems related to the South Kohala District. These meetings provided an avenue for collaboration and to forestall designation of the West Hawaiʻi region as a ground water management area due to concerns that the rates, times, spatial patterns, or depths of and existing potential withdrawals of ground water are endangering the stability or optimum development of the ground water body. As these meetings took place, it became clear that good baseline ground water data was sparse and that major decisions were not made using a "complete data-set," but rather by incomplete knowledge of the resource. It was for this reason that CWRM started its ground water monitoring program in West Hawaiʻi.

From 1959 to 1978, average daily pumpage for the aquifer system increased from less than 1 to about 3.5 MGD. With the Kahaluʻu Shaft coming online in mid-1979, average pumpage increased to between 5 and 6 MGD. Prior to the development of the high-level wells, increasing water use demands were met by increasing pumpage from the Kahaluʻu wells and shaft, so by the mid-1980's to mid-1990's, average pumpage was averaging about 8 MGD. When the high-

[2] Bauer, G. R. A Study of Ground-Water Conditions in North and South Kona and South Kohala Districts, Island of Hawaii, 1991-2002. State of Hawaii Department of Land and Natural resources Commission on Water Resource Management. 2003. PR-2003-01

level wells were installed, the withdrawal rate increased. As noted by Oki, the mean monthly pumpage in 1997 was 11.1 MGD, and 9.8 MGD of that amount was pumped by the Hawaiʻi Department of Water Supply (DWS)[3]. Average withdrawal of ground water at the end of 2012 was 12.8 MGD and 1.1 MGD of that was reported private pumpage.

In summary, total pumpage from the Keauhou aquifer is small when compared to the estimated sustainable yield and total average daily recharge into the system. Nevertheless, individual basal wells are affected by pumpage because the static water levels in these wells are 5 feet above MSL or less, and the chloride concentration in the water is sensitive to pumpage. The high-level wells are not affected in this way.

Currently, CWRM monitors 15 wells (2 DMWs and 13 water level wells) in West Hawaiʻi. Major findings and conclusions listed below are based upon the individual water-level measurements in high-level wells, and water level measurements in the basal wells from 1991 through January 2014:

- The data strongly suggests a slow decline of water levels in some of the high-level wells, and an apparent relationship to water-level decline and climatic conditions as recorded in the Lanihau and Huʻehuʻe Ranch rain gages. Prior to pump installation, future wells drilled into this resource should be used as observation wells to verify the trends documented in the CWRM report.

- The data suggests that the high-level wells tap interconnected, though bounded, aquifers whose rate of water level decline is inversely proportional to its volume. Future well drilling for high-level potable sources must include accurate, well-designed aquifer tests that will aid in the determination of geologic boundaries to provide information on the geometry of the aquifer.

- The data suggests that there may be more than one geological mechanism that created the high-level aquifer and perched water above the high-level aquifer area may be significant.

- The data suggests that there is a water-level pattern observed in the high-level wells with Keōpū being the “drain” for the ground water flow system. The ground water flux south of Keōpū is to the north, and north of Keōpū, the ground water flow is to the south.

- Two deep monitoring well drilling projects, Keōpū DMW (8-3858-001), and Kamakana (8-3959-001), intercepted deep fresh water zones beneath the saltwater zone. Horizontal extent and capacity of this deep freshwater zone is unknown but may be a potential additional freshwater source for the Kona area.

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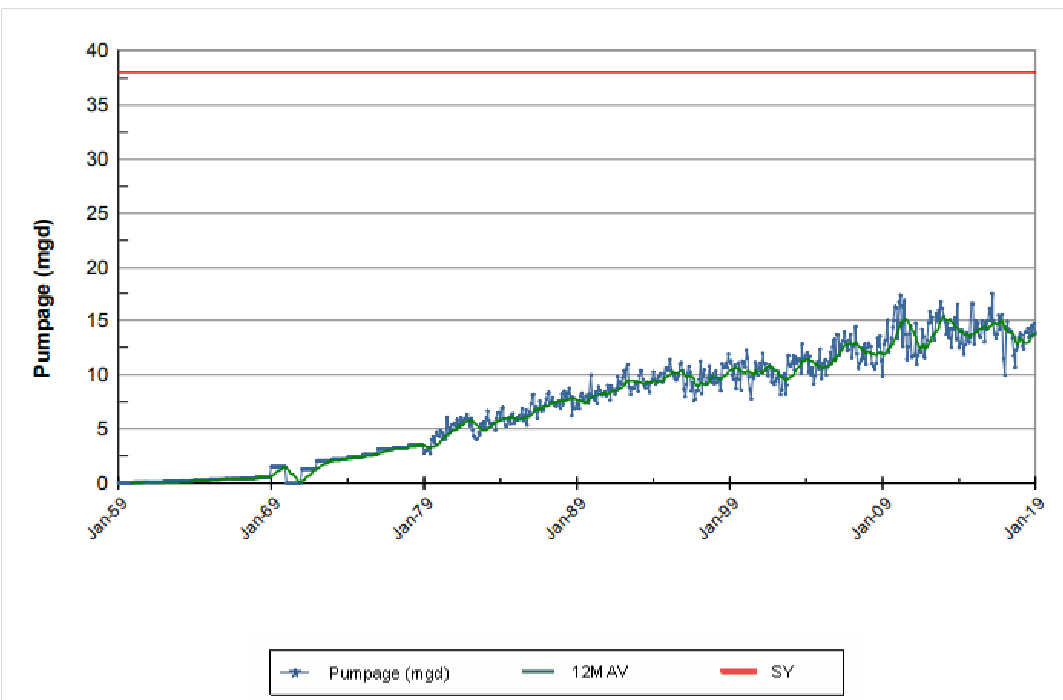
[3] Oki, D. S., 1999, Geohydrology and numerical simulation of the ground-water flow system of Kona, Island of Hawaii: Water Resources Investigations Report 99-4073, prepared in cooperation with CWRM and NPS, 70 p.

- Some high-level wells do exhibit declining water levels over time. Long-term, continuous water-level monitoring should continue in these wells. Real-time correlation between water levels in the wells with climatic conditions measured at Lanihau Rain Gage will provide better insight into the behavior of the potable high-level aquifers.
- The data suggests the influence of climate over long-term trends in the basal aquifers.
- The strong correlation between well pairs will aid in predicting a water level, if only one of the wells can be measured.
- The data suggests that the variability of the ground water flow direction in a shallow basal lens system, as can be seen at the West Hawaiʻi Landfill, is translatable to other areas.
- The low ground water gradients suggest a highly permeable basal coastal aquifer where basaltic lavas comprise the aquifer, and this finding is supported by tidal analysis. The composition of the lava flows determines its permeability, and in turn, the ground water gradient.
- This data will become the calibration target for future numerical and analytical ground water models and will aid in the site selection for new wells.

CWRM review of reported water levels, temperatures and chlorides from production wells in the Keauhou ASA indicate that the data needs to be more comprehensively accurate and complete.

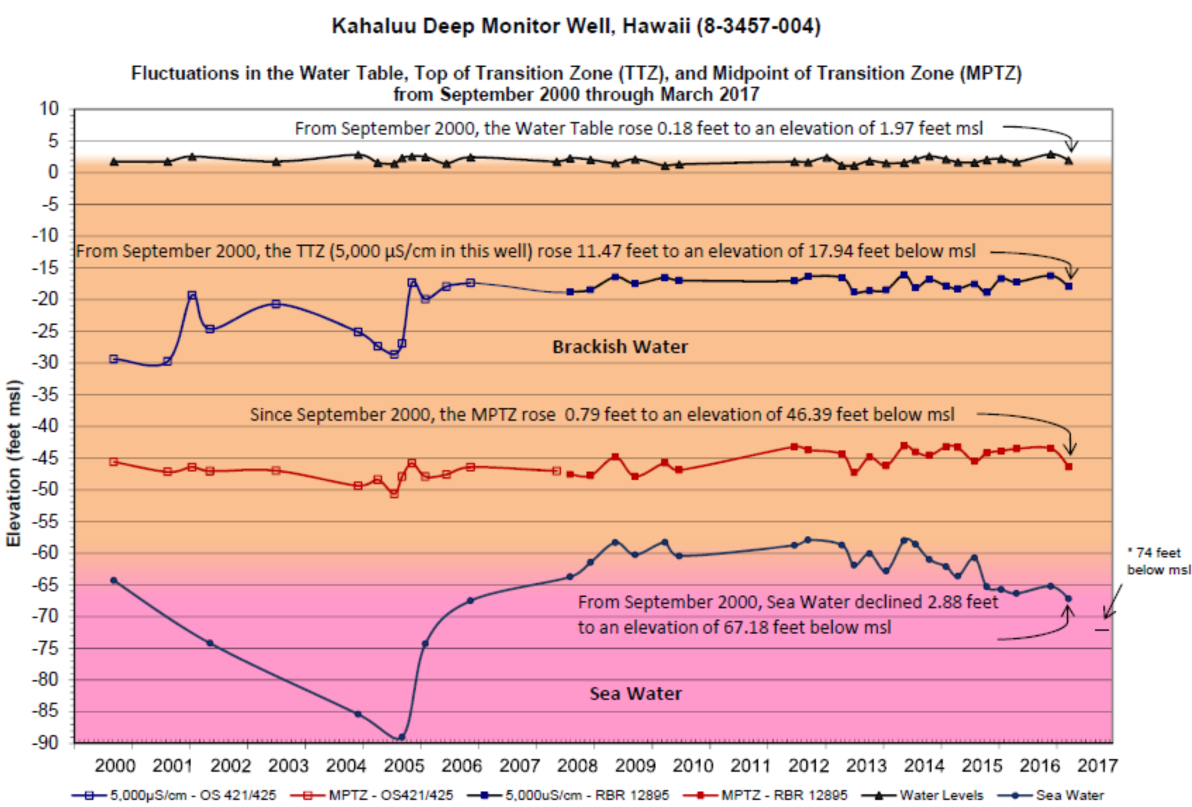
Figure G-5 Average Pumpage for Wells Within the Keauhou Aquifer System



Currently two deep monitoring wells in the Kona area are being monitored quarterly for conductivity and temperature. Presented below in **Figure G-6**, the fluctuations of the water table, top and midpoint of the transition zones, and the sea water interface at the Kahaluʻu Deep Monitoring Well are shown from September 2000 through January 2014.

The top of the transition zone (TTZ) is rising more quickly than both the MPTZ and sea water levels, indicating a thickening of the brackish water lens or localized upconing. This is likely due to the Hawaiʻi DWS supply wells skimming fresh water from the top of the thin basal lens directly upslope of this well. Given the 2.09 foot of head above MSL, the midpoint of the transition zone at equilibrium should be 83 feet thick using the Ghyben-Herzberg equation. The MPTZ was measured at 44 feet below MSL, or about half the equilibrium thickness of fresh water. This is due to the proximity of the monitoring well to a major pumping source for the Hawaiʻi DWS, which produces approximately 5 MGD from a thin basal freshwater lens. This also emphasizes the importance of placing monitor wells a significant distance from large pumping sources. **Figure G-7** below shows the relationship between pumpage and chlorides at the Kahaluʻu Shaft production well.

Figure G-6 Fluctuations in the Water Table, Transition Zones, and Sea Water in the Kahaluʻu Deep Monitoring Well

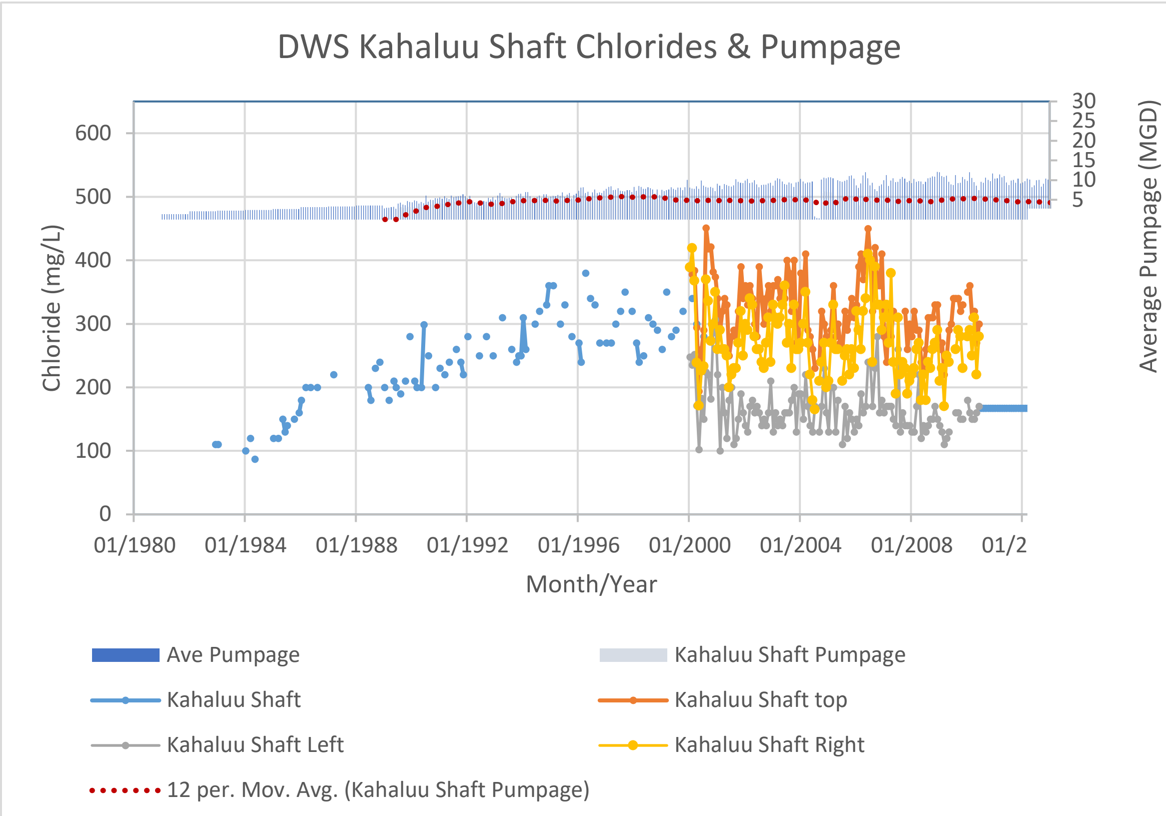


Notes: (1) Minimum conductivity in this well is greater than 1,000 µS/cm Therefore, TTZ = 5,000µS/cm; MPTZ = 25,000 µS/cm; (2) Fresh Water < 220 mg/L Cl¯, Brackish Water 220 mg/L CL¯ to 16,999 mg/L Cl¯, Sea Water >= 17,000 mg/L Cl¯; (3) OS 421/425 = Ocean Sensors CTD (absolute conductivity); (4) RBR 12895 = RBR Global CTD (Specific Conductivity); (5) msl = mean sea level.

* Since the year 2000, the MPTZ rose 0.79 feet to an elevation of 46.39 feet below msl, where it is above a calculated Ghyben-Herzberg equilibrium elevation of 74 feet beow msl, relative to the Water Table measured at 1.97 feet above msl.

last updated 4/13/2017

Figure G-7 Pumpage and Chlorides at the DWS Kahalu‘u Shaft Production Well

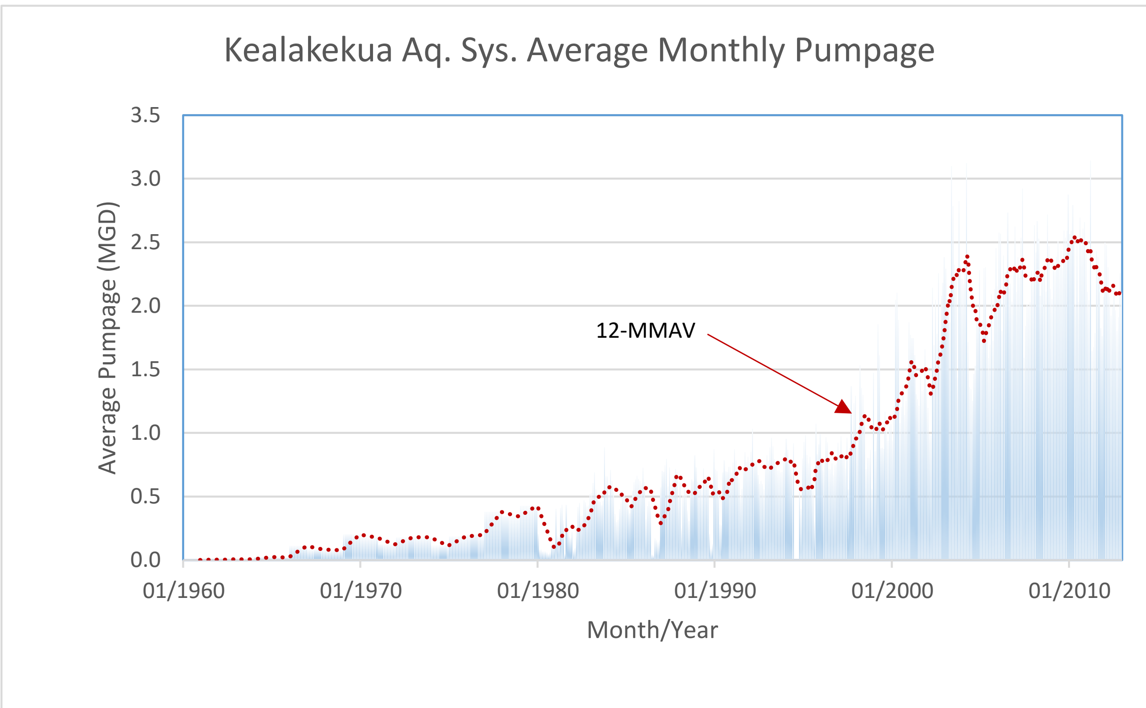


Kealakekua Aquifer System:
From 1960 to about the year 2000, average daily pumpage for the aquifer system remained below 2 MGD. Since 2000, the average daily pumpage has increased to between 2.5 and 3 MGD. Total pumpage is small when compared to the estimated sustainable yield and total average daily recharge into the system (see **Figure G-8**).

Individual wells with low basal heads are chloride-sensitive to pumping. The two high-level wells are not affected by pumping.

Long-term water levels for basal wells do not exist in the ground water database. Instantaneous water level measurements taken at the USGS high-level observation well since 1991 shows a steady decline in water level that is attributed to climate.

Figure G-8 Average Pumpage for Wells Within the Kealakekua Aquifer System

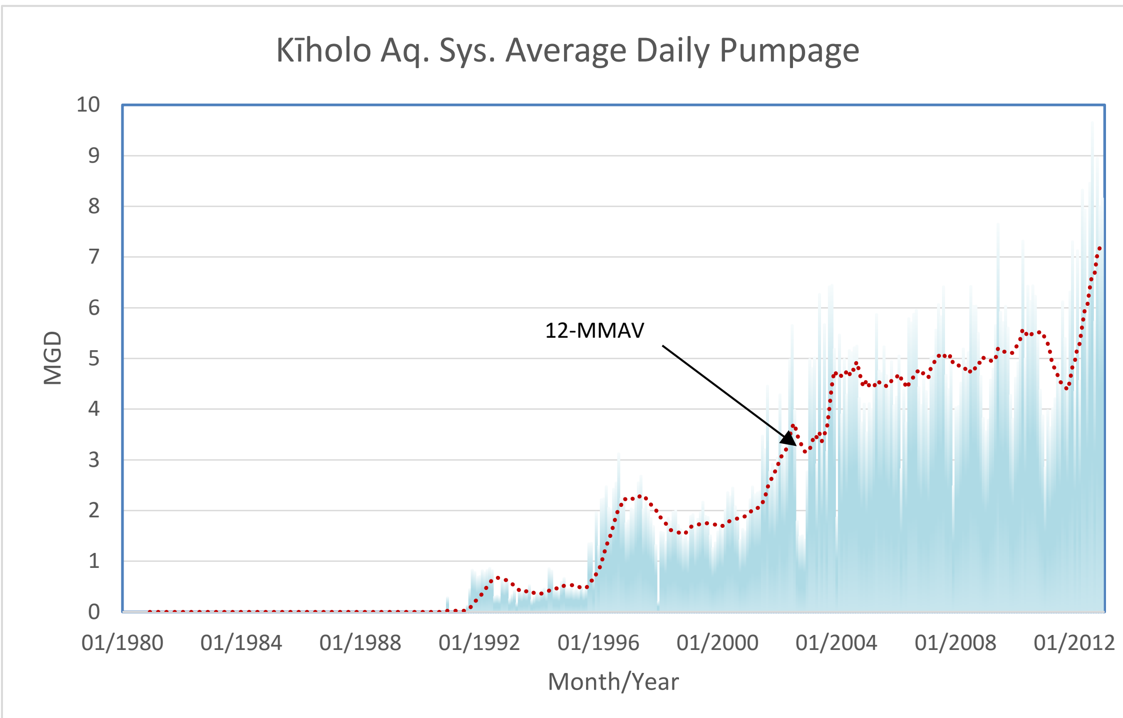


Kīholo Aquifer System:
Pumpage averages about 8 MGD in the aquifer system. This is less than 50 percent of the estimated sustainable yield. Irrigation and potable wells each produce about half of the total average pumpage.

The salinity in the basal potable and irrigation wells is marginal. Irrigation wells have lower water levels and are sensitive to pumping. The wells that have elevated water levels are much fresher.

Water levels in the basal sources seem to be loosely correlated to climatic conditions but are more related to ocean tidal signals transmitted through very permeable lava flows. The only elevated water level well with data, HR-5, responds to head changes differently due to a thick trachyte lava flow(s) overlying the aquifer.

Figure G-9 Average Daily Pumpage in the Kīholo Aquifer System Since 1991



Recommendations for the Kona Area include:

- Expand the network of basal and high-level monitoring wells.
- Coordinate with other ground water researchers to determine a prospective location, and design, core, and install a new DMW in the boundary zone between basal and high-level aquifers to better understand the hydrologic conditions of the boundary.
- Explore the origin, transport, and fate of perched water bodies and their relationship with the high level and basal aquifers.
- Long-term, continuous water-level monitoring should continue in high level wells, combined with correlating water levels in the wells with climatic conditions measured at Lanihau Rain Gage to provide better insight into the behavior of the potable high-level aquifers.
- Use information derived through USGS refinement of their numerical ground water model to better understand the relationship and connectivity between perched, basal, and high-level ground water.
- Conduct a geodetic survey and synoptic water level survey to determine current water levels.
- Continue to work with well owners and reporters to improve the quality and timeliness of their data reporting.

G.2.2.4 Maui Ground Water Monitoring Program

Three aquifer system areas on Maui are currently monitored quarterly by four deep monitoring wells: two wells in the ʻĪao ASA, one in the Waiheʻe ASA, and one in the Honokōwai ASA.

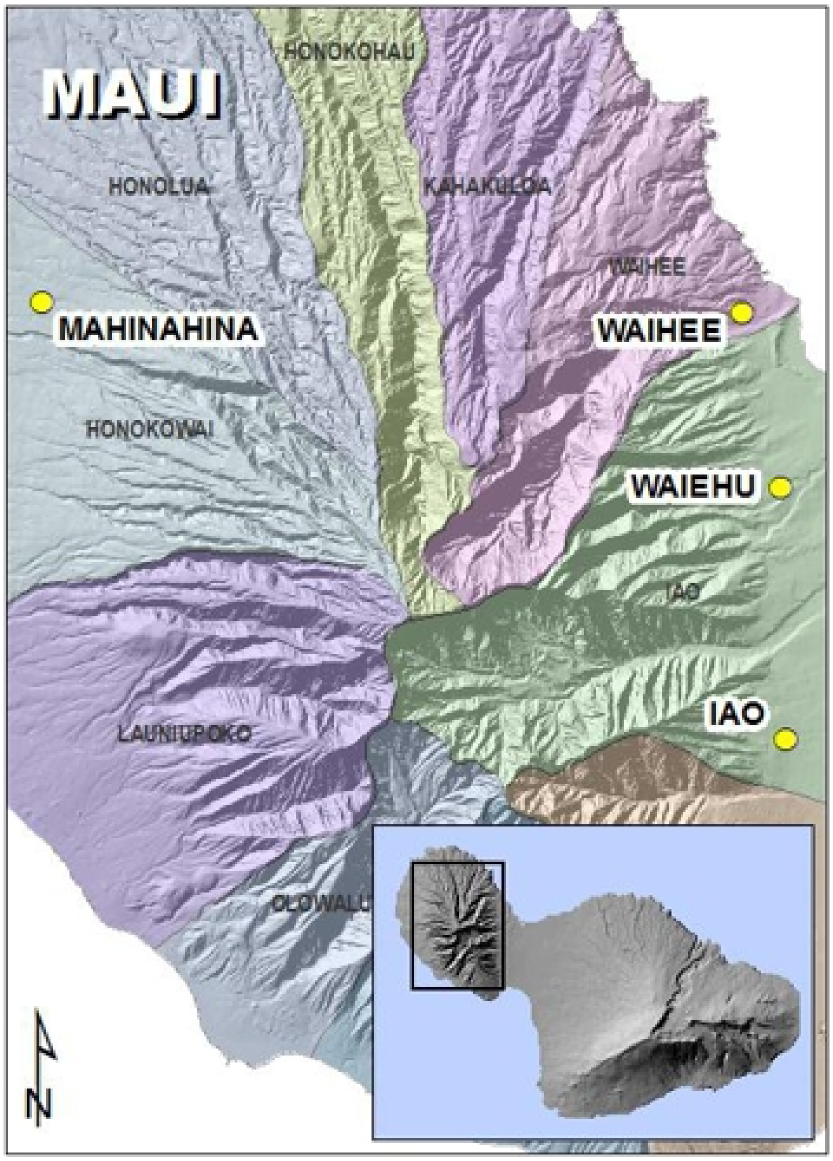
Measuring water levels in the ʻĪao ASA began before ground water development. The first test hole was drilled in 1940 and produced the first measured basal water level of 31.98 feet, MSL. Since 1940, 14 other test wells were drilled. Water levels have declined over time as a result of heavy pumping of DWS sources. However, after 1997 water levels started to rise as a direct result of lower pumping.

CWRM drilled two deep monitor wells in the ʻĪao Aquifer System. Waiehu Deep Monitor Well was constructed in 1982, and the ʻĪao Deep Monitor Well was completed in 2006. The USGS and CWRM continue to measure water levels in the test holes as well as instantaneous measurements in the deep monitor wells, respectively.

Currently, CWRM monitors 4 DMWs in West Maui, with locations shown on **Figure G-10.**

ʻĪao Aquifer System Area: The average pumpage has been reduced since designation of ʻĪao Aquifer System Area as a Water Management Area in 2003. The current 12-month moving average is about 15 MGD and appropriate for the basal portion of the aquifer. The high-level aquifer withdrawal rate (2.5 MGD) is small compared to the basal wells. Spreading the pumpage out to new sources drilled south of ʻĪao Stream will help alleviate the concentrated pumping north of ʻĪao Stream. The result may increase water levels and reduce chlorides in some wells.

Figure G-10 CWRM Monitored DMWs in West Maui

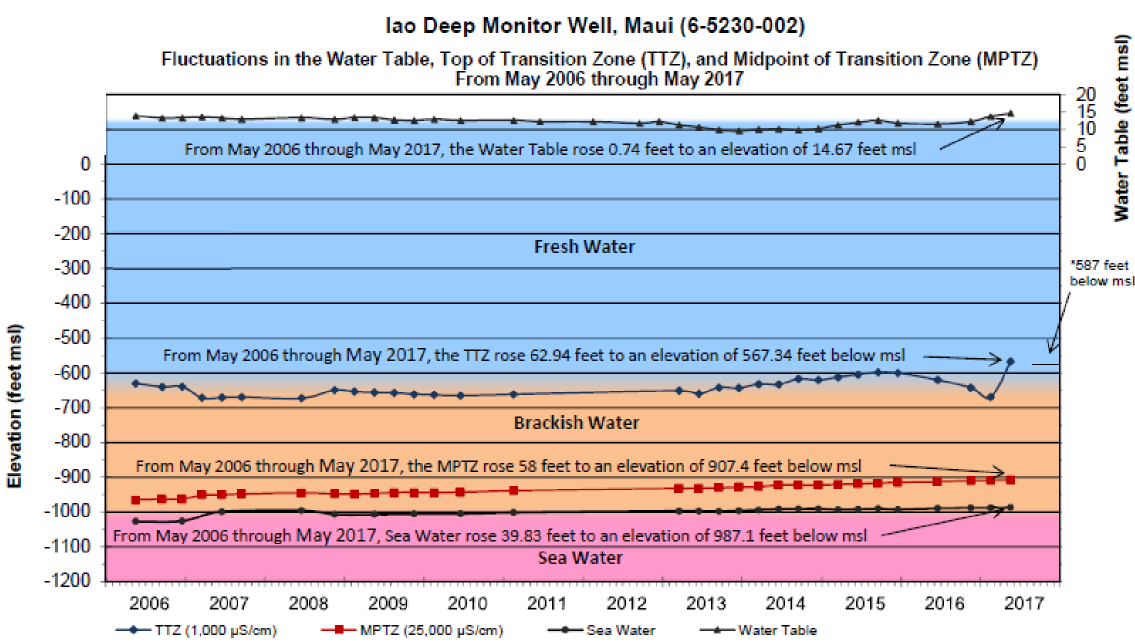


Chlorides in all DWS pumping wells north of ʻĪao Stream have risen over time, except for Kepaniwai which pumps dike-impounded ground water. New wells south of ʻĪao Stream will help reduce chlorides in existing sources.

Water levels have dropped significantly since 1940. After designation of ʻĪao as a water management area, pumping stabilized, although water levels at the ʻĪao DMW have continued to decline. Measured heads south of ʻĪao Stream are higher because pumpage is lower. Wet and dry periods also have an effect on heads as related to pumpage as an increase or reduction in recharge.

Chlorides in some wells are still problematic due to their depths. Backfilling may provide some relief from upconing. The large capacity pumps in other wells could be reduced as more water development occurs south of ʻĪao Stream to replace Shaft 33. Spreading out the pumpage will also help to reduce chlorides in some wells north of ʻĪao Stream and should cause water levels to rise at test holes that are near large pumping centers.

Figure G-11 Fluctuations in the Water Table, Transition Zones, and Sea Water in the ʻĪao Deep Monitoring Well



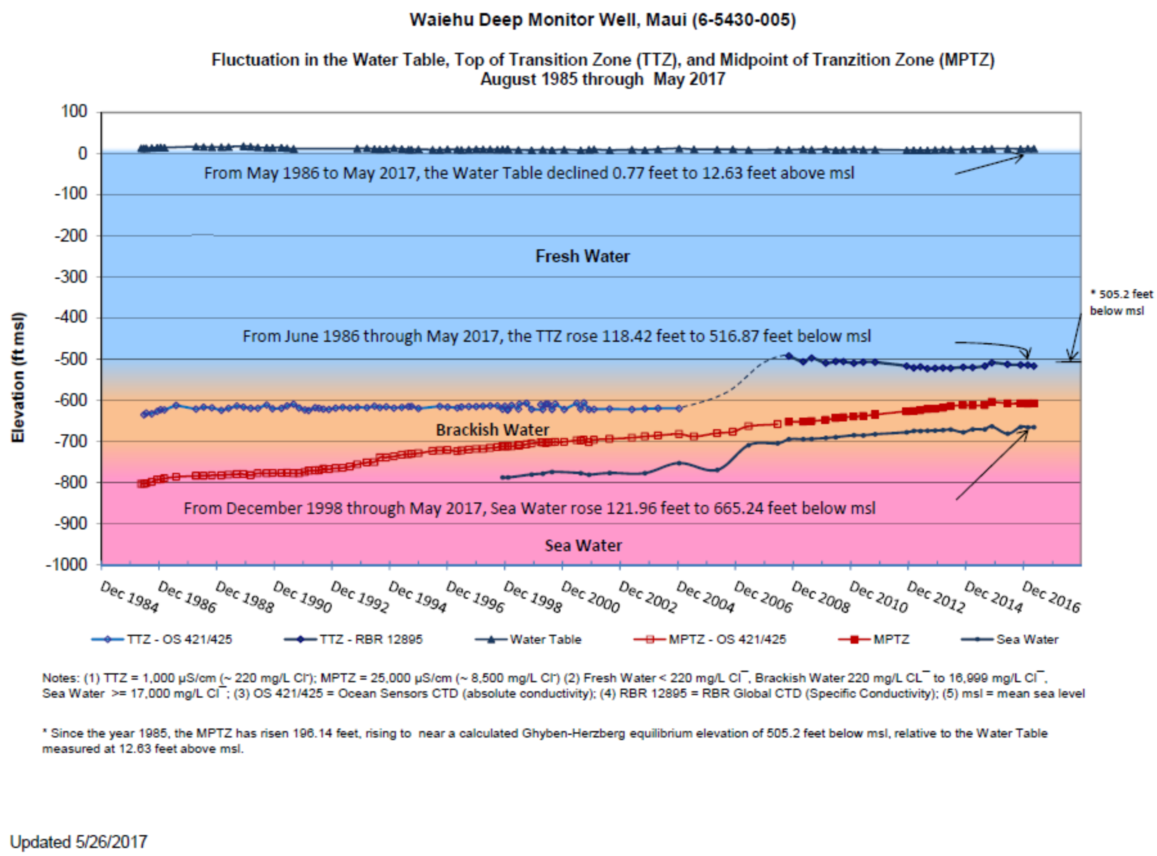
Notes: : (1) TTZ = 1,000 µS/cm (~ 220 mg/L Cl⁻); MPTZ = 25,000 µS/cm (~ 8,500 mg/L Cl⁻) (2) Fresh Water < 220 mg/L Cl⁻, Brackish Water 220 mg/L CL⁻ to 16,999 mg/L Cl⁻, Sea Water >= 17,000 mg/L Cl⁻; (3) OS 421/425 = Ocean Sensors CTD (absolute conductivity); (4) RBR 12895 = RBR Global CTD (Specific Conductivity); (5) msl = mean sea level.

* Since the year 2006, the MPTZ rose 58 feet, to near a calculated Ghyben-Herzberg equilibrium elevation of approximately 587 feet below msl, relative to the Water Table measured at 14.67 feet above msl.

last updated 5/26/2017

The water levels in the ʻĪao DMW have risen approximately 0.7 feet in the 11 years that it has been monitored. The TTZ has not changed substantially over that period, however, both MPTZ and sea water are rising towards a calculated Ghyben-Herzberg equilibrium elevation of 587 feet below MSL. Although the fresh water zone is currently much thicker than would be measured in an equilibrium condition, the declining head and rising MPTZ foreshadows a reduction in fresh water storage within the ʻĪao aquifer.

Figure G-12 Fluctuations in the Water Table, Transition Zones, and Sea Water in the Waiehu Deep Monitoring Well



Since monitoring began in 1985 in the Waiehu DMW, the position of the MPTZ has risen over time, while the TTZ has risen only slightly, and has been stable since 2008. From 1985 to 1999, the interpolated elevation of the MPTZ went from -803 ft., MSL to -713 ft., MSL or a rise of 90 feet. The TTZ during that same period went from -635 ft., MSL to -613 ft., MSL. The MPTZ seems to be rising linearly, but the position of TTZ changed dramatically in 2008.Chloride sampling by the USGS confirmed the sudden 90-foot rise of the TTZ. It is possible that borehole flow in the Waiehu Deep Monitor Well may be distorting actual chlorides at any given depth.[4]

[4] Meyer, W. and T. K. Presley, 2001, The response of the Iao Aquifer to ground-water development, rainfall, and land-use practices between 1940 and 1998, Island of Maui, Hawaii: USGS Water Resources Investigations Report 00-4223, 60 p.

Waiheʻe Aquifer System Area: The first wells drilled this aquifer system were in 1981. The average ground water withdrawal at present is about 4 MGD, half of the estimated sustainable yield of 8 MGD, with most of the pumpage concentrated at the south end of the aquifer system. Pumpage needs to be spread out.

The salinity in the Waiheʻe Aquifer System Area is low, though at the Kānoa well field, chloride content is sensitive to pumping. The North Waiheʻe wells are stable.

Water level measurements by the USGS have been done in a number of Waiheʻe Aquifer System Area wells since 1988. However, the USGS working with the National Geodetic Survey (NGS) found discrepancies between the assumed benchmarks and measuring points for a number of wells. In some instances, the differences in the benchmark elevation caused the measured water levels to be lowered by as much as 1.66 ft. at the Kānoa Test Hole. In summary, water levels in the Waiheʻe Aquifer System are stabilizing, though remain low (see **Figure G-13**). Prior to 1997, climate, and perhaps pumping in ʻĪao, had an effect on the decline. The rise of 0.5 feet in the Waiheʻe Deep Monitor Well is an indication of stability (see Figure G-13 for water levels and pumpage, and

Figure G-14 for corresponding chloride concentrations).

Figure G-13 Water Levels and Pumpage in the Waiheʻe Aquifer System

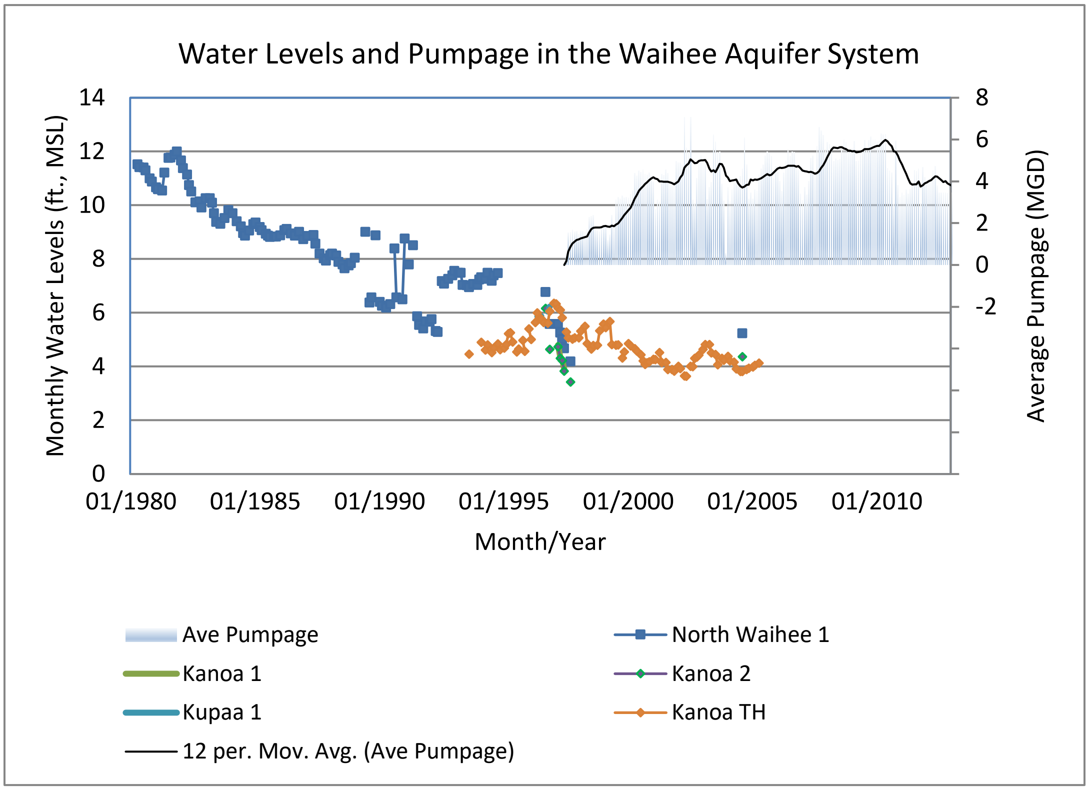


Figure G-14 Showing Relationship Between Pumpage and Chlorides in DWS Waiheʻe Wells

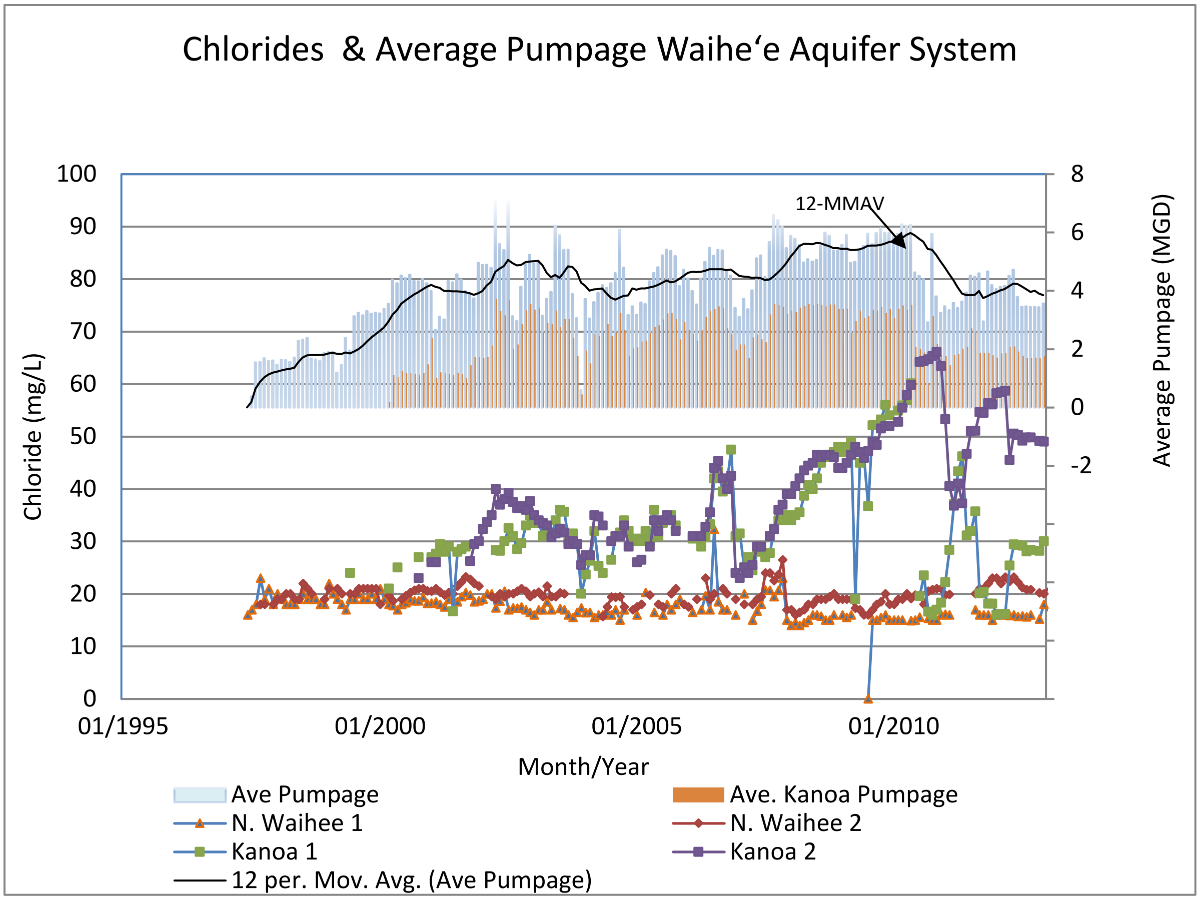
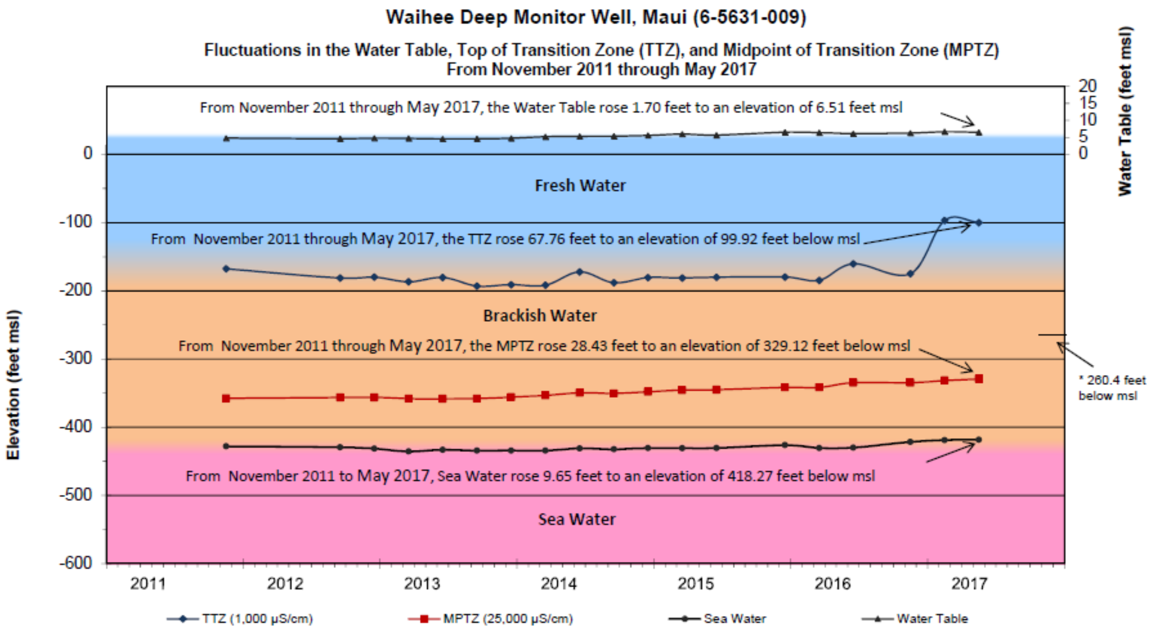


Figure G-15 Fluctuations in the Water Table, Transition Zones, and Sea Water in the Waiheʻe Deep Monitoring Well



Notes: : (1) TTZ = 1,000 µS/cm (~ 220 mg/L Cl⁻); MPTZ = 25,000 µS/cm (~ 8,500 mg/L Cl⁻) (2) Fresh Water < 220 mg/L Cl¯, Brackish Water 220 mg/L CL¯ to 16,999 mg/L Cl¯, Sea Water >= 17,000 mg/L Cl¯; (3) msl = mean sea level.

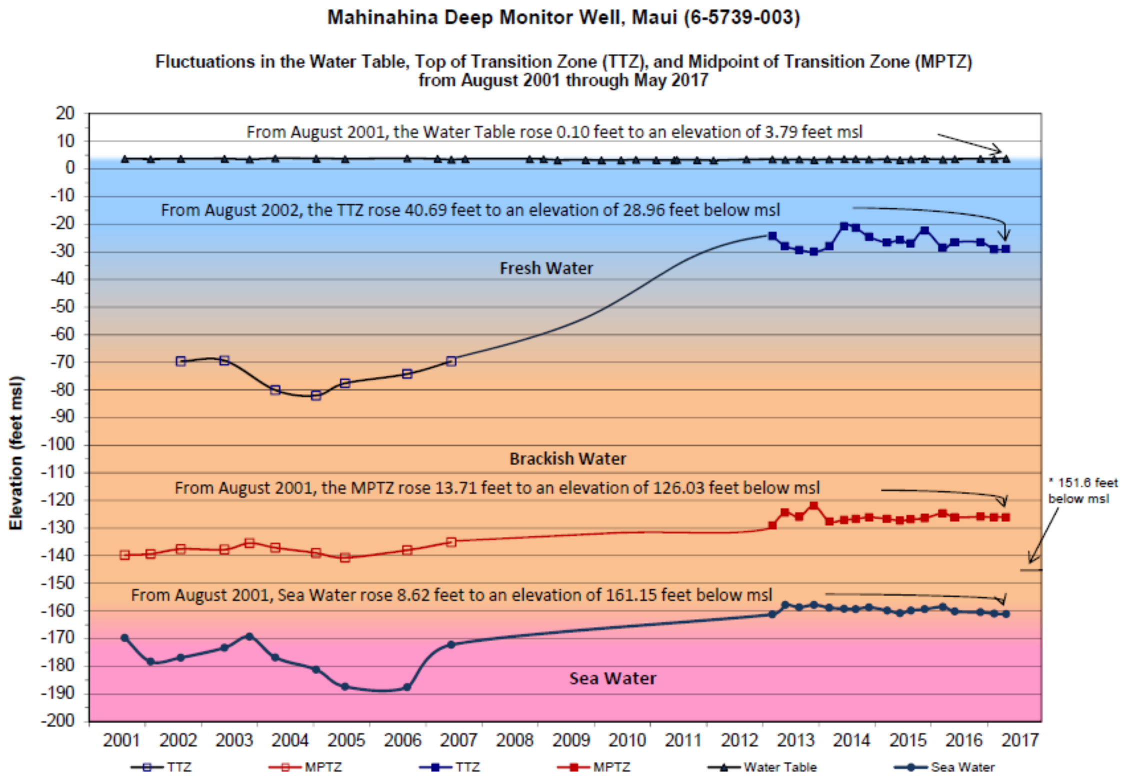
* Since the year 2011, the MPTZ rose 28.43 feet toward a calculated Ghyben-Herzberg equilibrium elevation of approximately 260 feet below msl, relative to the Water Table measured at 6.51 feet above msl.

last updated 5/26/2017

Honokōwai Aquifer System Area: Monitoring of the transition zone in this aquifer system began in 2001 with the installation on the Māhinahina Deep Monitoring Well, located at an elevation of 665 feet above MSL, upslope of the Kāʻanapali Airport.

The CTD profiles conducted since August 2001 indicate a thinning of the fresh water zone: the TTZ has risen nearly 50 feet, the MPTZ has risen 13 feet, and sea water rose 11 feet. The change in land use away from sugar cane, combined with the rise in construction and water demand in the Kāʻanapali and Honokōwai areas near the beach have imposed additional demands on the thin basal lens from wells installed upslope from the Māhinahina well, resulting in the upward trend of the top of the transition zone (TTZ), denoted the dramatic thinning of the fresh water lens in recent years.

Figure G-16 Fluctuations in the water table, transition zones, and sea water in the Māhinahina Deep Monitoring Well



Notes: : (1) TTZ = 1,000 µS/cm (~ 220 mg/L Cl⁻); MPTZ = 25,000 µS/cm (~ 8,500 mg/L Cl⁻) (2) Fresh Water < 220 mg/L Cl⁻, Brackish Water 220 mg/L CL⁻ to 16,999 mg/L Cl⁻, Sea Water >= 17,000 mg/L Cl⁻; (3) OS 421/425 = Ocean Sensors CTD (absolute conductivity); (4) RBR 12895 = RBR Global CTD (Specific Conductivity); (5) msl = mean sea level. Conditions inside the well prevented successful CTD deployment from 2006 through 2012, CTD profiling of this well was resumed 3-13-2013.

* Since the year 2001, the MPTZ rose 13.71 feet, to an elevation of 126.03 feet below mean sea level, where it is above the calculated Ghyben-Herzberg equilibrium elevation of 151.6 feet below msl, relative to the Water Table, measured at 3.79 feet above msl.

last updated 5/26/2017

Recommendations for Maui include:

- CWRM staff will deploy a vertical flow meter in the Waiehu DMW to detect measurable vertical borehole flow.
- Continue to monitor position of the TTZ and MPTZ and water levels quarterly
- Work with Maui DWS and USGS to determine validity of West Maui numerical model.

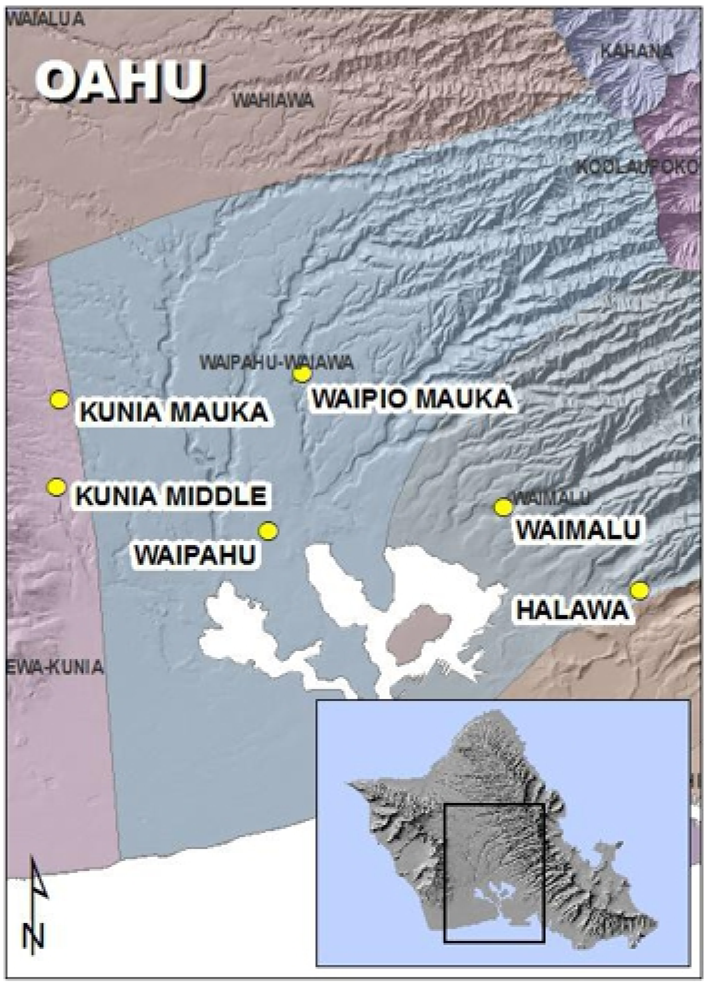
G.2.2.5 Pearl Harbor Ground Water Monitoring Program

The Pearl Harbor Aquifer Sector Area is comprised of the Waimalu, Waipahu-Waiawa, and ‘Ewa- Kunia Aquifer Systems. CWRM owns and monitors six deep monitoring wells in this Sector, two in the Waimalu Aquifer System and two in the ‘Ewa-Kunia Aquifer System.

Currently, CWRM monitors 6 DMWs in the Pearl Harbor ASA, with location shown on

Figure G-17.

Figure G-17 CWRM monitored DMWs in the Pearl Harbor ASA



Waimalu Aquifer System Area: Large scale ground water development in the Waimalu ASA began in 1899 with the development of Honolulu Plantation's Pump 2. Sugar cultivation created large withdrawal rates, but return irrigation water from furrow irrigation offset some the pumpage.

Although the average pumpage in the Waimalu ASA is near the estimated sustainable yield of 45 MGD, the average water use has declined slightly since the 1980's. This is in due to better management of the BWS integrated water system, increased monitoring of the resource though deep monitor wells, and by carefully monitoring chlorides in pumping wells that require action such as lowering pumpage, and/or "resting" of individual wells. Average total pumpage in the Waimalu ASA has been reduced 6.597 MGD since 1990.

Chlorides have risen over time for the larger BWS sources, even though the average pumpage has been slowly reduced. The small pumping stations remain relatively stable during the same period of time.

Water levels have declined in the Waimalu ASA since measurements were systematically collected starting in 1910. Return irrigation water kept the water levels higher than would be expected had no irrigation recharge input occurred. The war years saw a steep decline in area heads, but they recovered in the 1950's, only to decline again after the demise of sugar in this area. Since the late 1960's, water levels have remained relatively stable. Periods of dry or wet weather causes head variations of up to 6± feet.

There are six deep monitor wells in the Waimalu ASA (CWRM owns two of the six). From deep monitor well data, thicker zones of mixing are in the eastern part of Waimalu ASA where greater pumpage occurs. The Waimalu DMW shows a thickening of the fresh water zone, indicating stability within this area of the aquifer, with the TTZ and MPTZ declining towards a calculated Ghyben-Herzberg elevation of 753 feet below MSL, based upon a water level of 18.8 feet above MSL.

The January 2014 public disclosures of fuel releases from the Navy's Red Hill Fuel Facility (RHFF) prompted the Hawaiʻi State Legislature to direct the HDOH to form and head a task force with members from the BWS, DOH, CWRM, U. S. Navy, Hawaiʻi State Legislature, and the neighboring community representatives. The task force has met to address the issues facing the stakeholders and the community regarding the impacts to the drinking water aquifer beneath the RHFF. To date, the task force has assembled a draft report to the Legislature with recommendations to document the Navy's efforts to update the 70-year old facility, and to ensure Navy, BWS, and DOH participation in increased ground water and soil vapor monitoring, leak detection, and mitigation of releases to the environment.

Waipahu-Waiawa Aquifer System Area: The average daily pumpage for sugar cultivation between 1890 and 1960 was 92.1 MGD. Up until the early 1980's, sugar was irrigated using the furrow method. With the loss of agricultural lands tied with the increasing urbanization of the Pearl Harbor area, pumpage from BWS sources increased as new stations were added. During the decade from 1970 to 1979, the average pumpage was 155.4 MGD. Designation of the aquifer system in 1979 reduced pumpage. The demise of sugar cultivation in 1994, greatly reduced pumpage in the aquifer system. The average withdrawal rate from 1990 to 1999 was 69.2 MGD, from 2000 to end of 2012 the average pumpage dropped even further to 51.7 MGD.

High pumping rates and deep wells owned by the sugar companies contributed to the salting up of the Waipahu-Waiawa ASA below an elevation of 700 ft., MSL. Action by the state in adopting sustainable yields for state-wide aquifer systems, controlling the amount of pumpage, and limiting the depths of new wells allowed for the freshening of the potable sources since the mid-1990's.

Water levels in the Waipahu-Waiawa ASA are a function of pumpage, which is in turn influenced by climatic conditions. Since designation, water levels have continued to rise. There are eight deep monitor wells in Waipahu-Waiawa ASA (CWRM owns one of the eight). Deep monitor wells also show that the structure of the basal lens in Waipahu-Waiawa has been relatively stable over the last 20 years.

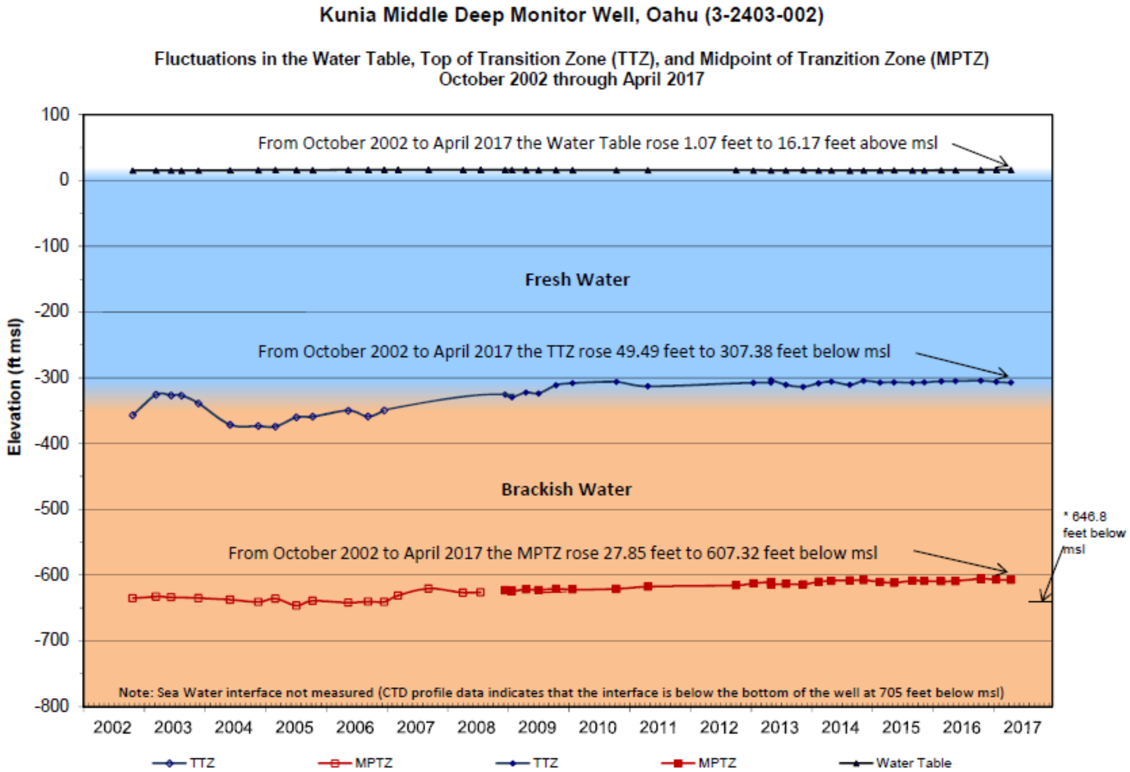
'Ewa-Kunia Aquifer System Area: For almost 90 years agricultural water use was high. In the 1970's and 80's agriculture combined with increasing urbanization led to a greater use of potable water provided by BWS and the Navy. Action by the state through the designation process to regulate pumpage, forced a decline in the average withdrawal rate. Pumpage is now 4 MGD less than sustainable yield.

Designation and the demise of sugar cultivation freshened up the 'Ewa-Kunia basal lens. Some BWS sources as well as the Navy Shaft have chloride concentrations that are sensitive to pumpage.

Water levels are several feet lower in the 'Ewa-Kunia ASA than in the Waipahu-Waiawa ASA. After designation and the cessation of sugar cultivation, water levels in observation wells stabilized. CWRM has two deep monitor wells in the aquifer system. The basal lens shows only a small rise in the MPTZ in both wells, otherwise the lens is stable.

The BWS and CWRM monitoring wells and data shows a stabilizing of water levels (refer to **Figure G-18** and **Figure G-19**). This indicates the current sustainable yield is greater than current pumping rates.

Figure G-18 Fluctuations in water level and transition zones in the Kunia Middle DMW

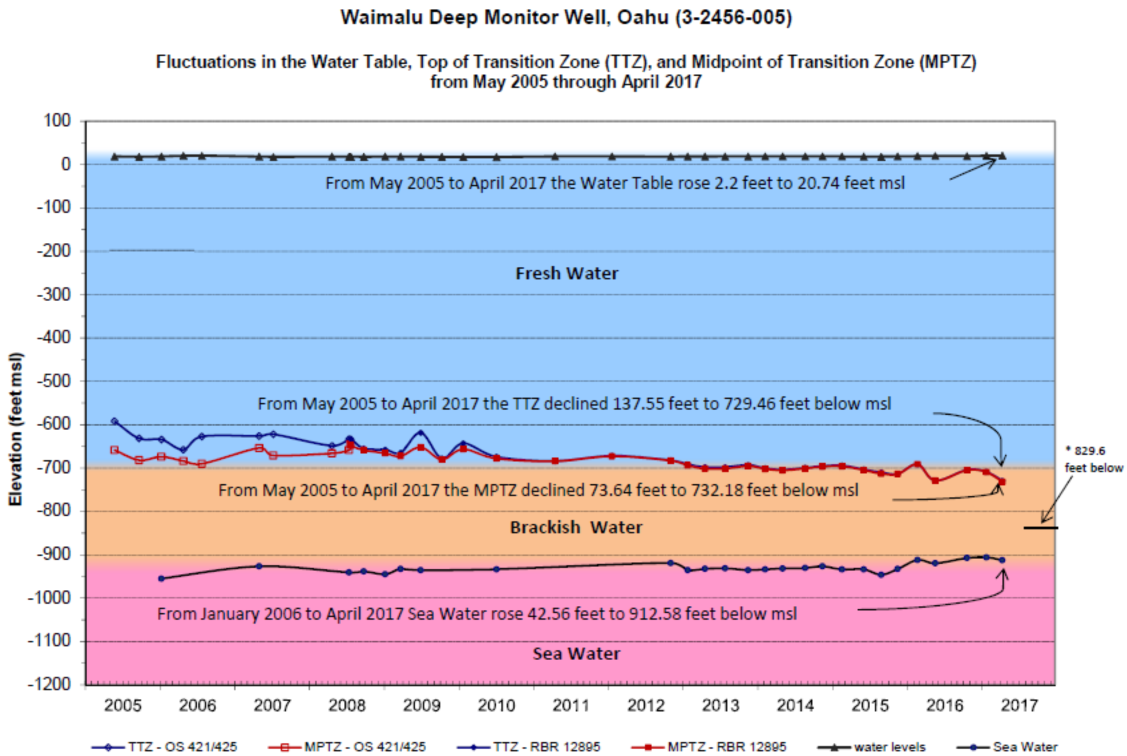


Notes: (1) TTZ = 1,000 µS/cm (~ 220 mg/L Cl⁻); MPTZ = 25,000 µS/cm (~ 8,500 mg/L Cl⁻) (2) Fresh Water < 220 mg/L Cl¯, Brackish Water 220 mg/L CL¯ to 16,999 mg/L Cl¯, Sea Water >= 17,000 mg/L Cl¯; (3) OS 421/425 = Ocean Sensors CTD (absolute conductivity); (4) RBR 12895 = RBR Global CTD (Specific Conductivity); (5) msl = mean sea level.

* Since the year 2002, the MPTZ has risen 27.85 feet to an elevation of 607.32 feet msl, where it is higher than the calculated Ghyben-Herzberg elevation of 646.8 feet below msl, relative to the Water Table measured at 16.17 feet above msl

last updated 4/27/2017

Figure G-19 Fluctuations in water level and transition zones in the Waimalu DMW



Notes: : (1) TTZ = 1,000 µS/cm (~ 220 mg/L Cl⁻); MPTZ = 25,000 µS/cm (~ 8,500 mg/L Cl⁻) (2) Fresh Water < 220 mg/L Cl¯, Brackish Water 220 mg/L CL¯ to 16,999 mg/L Cl¯, Sea Water >= 17,000 mg/L Cl¯; (3) OS 421/425 = Ocean Sensors CTD (absolute conductivity); (4) RBR 12895 = RBR Global CTD (Specific Conductivity); (5) msl = mean sea level.

* Since the year 2005, the MPTZ has declined 73.64 feet toward a calculated Ghyben-Herzberg equilibrium elevation of approximately 829.6 feet below msl, relative to the Water Table measured at 20.74 feet above msl.

last updated 4/27/2017

Recommendations for Pearl Harbor

- Continued monitoring of the DMWs for changes in the transition zones
- Continued participation in the RHFF Task Force
- Move the Waimalu/Moanalua ASA boundary to the northwest, so that the Moanalua ASA encompasses the South Hālawa Valley, and the new Moanalua/Waimalu boundary lies along the H-3 alignment in the North Hālawa Valley. Deeper sediments in the North Hālawa Valley provide a more natural geologic boundary than do the shallower sediments noted in the South Hālawa Valley, where heads are similar to those measured in the Moanalua aquifer.

G.2.2.6 CWRM-USGS Cooperative Ground Water Monitoring Program

CWRM-USGS cooperative monitoring program includes ground water, surface water, and rainfall monitoring activities on the Islands of Kauaʻi, Oʻahu, Molokaʻi, Maui, and Hawaiʻi. The objectives of the ground water data collection program in Hawaiʻi are to collect, analyze, and publish data on ground water levels and quality (chloride concentration) data from a network of springs, observation wells, pumping wells, and deep monitoring wells to allow assessment of regional ground water resources and to identify trends in response to natural climatic variations and induced stresses. Data is used by federal, State, local officials, and private parties to: assess the ground water resources, predict future conditions, detect and define saltwater intrusion problems, and manage water resources. Data is particularly useful in determining long-term trends in water levels, sustainable yields, climatic effects on water levels, and in the development of flow- and salt-transport models that allow prediction of future conditions and detection and definition of contaminant and water-supply problems.

Data from the cooperative monitoring program is published annually and is available online from the USGS at http://waterdata.usgs.gov/nwis.

The cooperative agreement between the USGS and the State officially began in 1909 when the USGS entered into an agreement with the Territory of Hawaiʻi to install and monitor gages on 12 streams. Ground water data collection was initiated in 1972 to gather baseline data throughout the state. The program began with 170 wells, where new knowledge of ground water conditions was needed. Currently, a regionally representative network of wells is maintained on the islands of Kauaʻi, Oʻahu, Molokaʻi, Maui, and Hawaiʻi to allow measurement of water levels and collection of water quality samples in most aquifers within the state. The ground water well networks are designed to meet the needs of the cooperators. New wells are added to the network as old wells are sealed or as other needs arrive.

Significant changes in the ground water monitoring network have occurred since 1995, when a total of 187 wells were included in the program. Program reductions induced by budgetary constraints reduced the number of wells to 160 for fiscal year 1996. By 2000, budget constraints caused monitoring activities to be discontinued at three more wells, bringing the total program well sites to 157. Fiscal Year (FY) 2001 saw another dramatic decrease, with the total number of program wells falling to 120. From 2002 to 2003, another 39 wells were cut, along with 10 more wells in 2004. Another well was discontinued in 2005 to bring the total well sites to 70. The budget for subsequent Fiscal Years resulted in decreased numbers of monitor wells. For FY 2014, the contract included 14 water-level monitor wells. Over a period of only 15 years, 173 of the 187 monitoring well sites that were active in 1999 have been discontinued; that translates to a 95% reduction in the number of monitoring locations statewide. Currently, the Survey Branch is expanding the network of CWRM monitored wells on Oʻahu, Maui, and Hawaiʻi to fill in the data gaps that have resulted from the discontinuation of the formerly USGS-monitored wells.

While the number of gages funded by CWRM has decreased over time, other agencies have taken on the responsibility as it is more directly related to their programs (e.g. crest stage gages) and redundancies in funding have been eliminated. In addition, the current network includes gages that the USGS has identified as a priority for long-term climate change monitoring and regulatory support. Organizations that participate (FY 14) as cooperators with the USGS are listed in **Table G-2** by government jurisdiction:

Table G-2 USGS Cooperative Monitoring Program Fiscal Year 2014 Cooperators

Agency/Entity	Abbreviation
Federal:	
U.S. Army Corps of Engineers	COE
U.S. Army Garrison Hawaiʻi Directorate of Public Works	Army
USGS National Streamflow Information Program	NSIP
National Weather Service	NWS
State of Hawaiʻi:	
Department of Land and Natural Resources, Commission on Water Resource Management	CWRM
Department of Land and Natural Resources, Engineering Division	DNLR-Eng. Div.
Department of Land and Natural Resources, Land Division	DLNR-Land Div.
Department of Land and Natural Resources, Division of Forestry and Wildlife	DLNR-DOFAW
Department of Transportation	DOT
Department of Health	DOH
Office of Hawaiian Affairs	OHA
Civil Defense Department	SCD
County of Kauaʻi:	
Department of Water	KDOW
City and County of Honolulu:	
Board of Water Supply	HBWS
Department of Planning and Permitting	DPP
County of Maui:	
Department of Water Supply	MDOW
County of Hawaiʻi:	
Department of Water Supply	DWS
Department of Public Works	DPW
Other	
Dole Food Company Hawaiʻi	Dole-Hawaiʻi

A full list of the stations operated by the USGS in the Hawaiʻi and more information about their mission can be found at https://hi.water.usgs.gov/.

G.2.3 Other Ground Water Monitoring Programs

G.2.3.1 Honolulu BWS Ground Water Monitoring Program

The Honolulu BWS has developed an extensive ground water monitoring program. The program includes 29 deep monitor wells and 11 water level monitor wells on Oʻahu. The Honolulu BWS utilizes data from these wells to operate and manage the integrated municipal water system serving the City and County of Honolulu. Kauaʻi County, Maui County, and Hawaiʻi County currently utilize data from wells included in the USGS Cooperative Monitoring Program.

Table G-3 BWS Deep Monitor Wells

Aquifer system	Well Number	Well Name
Waiʻalae-West	3-1747-004	Waiʻalae SH Deep Monitor
Pālolo	3-1748-014	Kaimukī Sta Deep Monitor
Pālolo	3-1749-022	Kaimukī HS Deep Monitor
Pālolo	3-1848-001	Waʻahila Deep Monitor
Nuʻuanu	3-1850-030	Punchbowl Deep Mon
Nuʻuanu	3-1851-057	Beretania Deep Monitor
Kalihi	3-1952-048	Kalihi Sta Deep Monitor
Kalihi	3-2052-012	Jonathan Springs
Moanalua	3-2052-015	Kalihi Sh Deep Monitor
Moanalua	3-2153-005	Moanalua Deep Monitor
Waipahu-Waiawa	3-2201-010	Kunia T41 Deep Monitor
Waimalu	3-2255-040	Hālawa-BWS Deep Monitor
Waipahu-Waiawa	3-2300-018	Waipahu Deep Monitor
Waimalu	3-2355-015	Kaamilo Deep Monitor
Waimalu	3-2456-004	Newtown Deep Monitor
Waimalu	3-2457-004	Punanani DMW
Waipahu-Waiawa	3-2458-006	Manana Deep Monitor
Waipahu-Waiawa	3-2459-026	Waiawa Deep Monitor
Waipahu-Waiawa	3-2500-003	Waiola Deep Monitor
Waipahu-Waiawa	3-2557-004	Waimano Deep Monitor
Waipahu-Waiawa	3-2602-002	Poliwai Deep Monitor
Waialua	3-3405-005	Helemano Deep Monitor
Koʻolauloa	3-3553-005	Punaluʻu Deep Monitor
Koʻolauloa	3-3554-005	Kaluanui 2 Monitor
Kawailoa	3-3604-001	Kawailoa Deep Monitor
Koʻolauloa	3-3755-010	Hauula Deep Monitor
Koʻolauloa	3-3956-008	Lāʻie Deep Monitor
Koʻolauloa	3-4057-017	Kahuku Deep Monitor
Waipahu-Waiawa	3-2659-001	Waipiʻo Mauka

[shaded] Reported in 2017

Table G-3 lists the deep monitor wells included in the Honolulu BWS monitoring program. **Table G-4** lists the water level monitoring wells included in the Honolulu BWS Monitoring program. The BWS uses data from the deep monitor wells to identify changes in the freshwater lens, while data from the water level monitor wells are used to ensure operational safety and prevent water shortages.

Table G-4 BWS Water Level Well Network

Aquifer System	Well Number	Well Name
Pālolo	3-1748-011	Kaimukī Deep 1
Pālolo	3-1748-012	Keanu
Pālolo	3-1749-014	Kaimukī High School
Nuʻuanu	3-1849-011	Wilder Ave
Nuʻuanu	3-1849-012	Wilder Ave
Nuʻuanu	3-1851-002	Thomas Square
ʻEwa-Kunia	3-2006-012	Kahe Point
Nuʻuanu	3-2047-003	Mānoa
Nuʻuanu	3-2047-004	Mānoa
Kalihi	3-2052-010	Kapālama
Moanalua	3-2153-009	Moanalua-Manaiki
Moanalua	3-2253-002	Moanalua DH 43
Waimalu	3-2255-033	Hālawa Obs. T45
Nānākuli	3-2307-001	Nānākuli
Koʻolaupoko	3-2348-001	Kuou TH
Koʻolaupoko	3-2348-004	Kuou TH
Waimalu	3-2355-008	Kalauao
Waimalu	3-2356-053	ʻAiea T-75
Waimalu	3-2356-057	Waimalu
Waipahu-Waiawa	3-2358-020	Pearl City Obs T-27
Waimalu	3-2455-001	Upper Waimalu T52
Koʻolaupoko	3-2751-004	Waiheʻe Obs
Waiʻanae	3-2809-002	Waiʻanae Valley
Waialua	3-3406-004	Waialua

(Shaded) Currently provides Monthly levels

G.2.3.2 Public and Private Observation Wells

There are several federal, State, and county agencies that own and operate observation wells. Many private landowners and corporations also have wells permitted for observation purposes. These publicly and privately-owned wells are not included in the CWRM, USGS, or Honolulu BWS monitoring programs. **Table G-5** lists all observation wells registered with CWRM that are not part of the CWRM, USGS, or Honolulu BWS monitoring programs (the table does not include temporary monitor wells, such as the Kona area water level wells that are developed into production wells).

In 2014, CWRM affirmed its requirement for reporting of monthly water levels and salinity for all observation wells. CWRM also requires owners of unused wells to report monthly data on a case-by-case basis, as determined by staff[5]. Any water quality data from observation wells should be submitted to the DOH.

Table G-5 Statewide Summary of Registered Observation Wells Not Included in the CWRM, CWRM-USGS, or Honolulu BWS Monitoring Programs

Island	Aquifer system	Well number	Well name	Well owner
Kauaʻi	Hanamāʻulu	2-0023-001	Pukaki Res Monitor	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
Kauaʻi	Kekaha	2-0044-014	Kaunalewa Ks8	Kekaha Sugar Company, Ltd
Kauaʻi	Hanamāʻulu	2-0121-001	South Wailua	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
Kauaʻi	Wailua	2-0123-001	Maalo Road Mon	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
Kauaʻi	Wailua	2-0124-001	Ne Kilohana	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
Kauaʻi	Wailua	2-0126-001	NW Kilohana Mon	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
Kauaʻi	Wailua	2-0222-001	ʻAʻahoaka Mon	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
Kauaʻi	Wailua	2-0327-001	Waikoko Mon	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
Kauaʻi	Anahola	2-0518-002	Mahelona Hospital	State Dept. of Health, DOH

[5] January 22, 2014 CWRM Staff Submittal

Table G-5: Statewide Summary of Registered Observation Wells Not Included in the CWRM, CWRM-USGS, or Honolulu BWS Monitoring Programs (continued)

Island	Aquifer system	Well number	Well name	Well owner
Kauaʻi	Anahola	2-0523-002	Wailua Hmstds 3	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
Kauaʻi	Anahola	2-1019-001	Aliomanu	LPC Corporation
Kauaʻi	Kōloa	2-5424-001	HDF-2	Hawaiʻi Dairy Farm LLC
Kauaʻi	Kōloa	2-5425-016	HDF-1	Hawaiʻi Dairy Farm LLC
Kauaʻi	Kōloa	2-5425-017	HDF-3	Hawaiʻi Dairy Farm LLC
Kauaʻi	Kōloa	2-5425-018	HDF-4	Hawaiʻi Dairy Farm LLC
Kauaʻi	Kōloa	2-5430-001	Lawai TH 3	McBryde Sugar Company, LLC
Kauaʻi	Kōloa	2-5529-002	Kalawai TH 5	McBryde Sugar Company, LLC
Kauaʻi	Kōloa	2-5534-006	Upper ʻEleʻele Mon	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
Kauaʻi	Makaweli	2-5537-001	8-inch Mill Test	Olokele Sugar Co. Ltd.
Kauaʻi	Hanamāʻulu	2-5626-001	Puakukui Springs	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
Kauaʻi	Hanamāʻulu	2-5723-001	MW-1	Department of Public Works Kauaʻi, KDPW, Engineering Division
Kauaʻi	Hanamāʻulu	2-5723-002	MW-2	Department of Public Works Kauaʻi, KDPW, Engineering Division
Kauaʻi	Hanamāʻulu	2-5723-003	MW-3	Department of Public Works Kauaʻi, KDPW, Engineering Division
Kauaʻi	Hanamāʻulu	2-5821-002	Kauaʻi Inn Tank	Department of Water Kauaʻi, KDW
Kauaʻi	Hanamāʻulu	2-5823-003	Garlinghouse Tunnel Observation Well	Department of Water Kauaʻi, KDW
Kauaʻi	Hanamāʻulu	2-5824-007	Puhi Obs 3	Neil Tagawa (Grove Farm Company, Inc.)
Kauaʻi	Hanamāʻulu	2-5825-002	Haʻikū Mauka Obs	Neil Tagawa (Grove Farm Company, Inc.)
Kauaʻi	Hanamāʻulu	2-5825-003	Haʻikū Mauka Obs	Neil Tagawa (Grove Farm Company, Inc.)
Kauaʻi	Hanamāʻulu	2-5923-008	Hanamāʻulu TZ	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
Kauaʻi	Kekaha	2-5944-002	MW-II-7	State of Hawaiʻi

Table G-5: Statewide Summary of Registered Observation Wells Not Included in the CWRM, CWRM-USGS, or Honolulu BWS Monitoring Programs (continued)

Island	Aquifer system	Well number	Well name	Well owner
Oʻahu	Waiʻalae-West	3-1646-002	Waiʻalae Golf	Kamehameha Schools
Oʻahu	Waiʻalae-West	3-1647-001	Kahala	D. Cromwell
Oʻahu	Waiʻalae-West	3-1747-004	Waiʻalae SH Deep Monitor	Honolulu Board of Water Supply, BWS
Oʻahu	Pālolo	3-1748-001	Kanewai Park Obs	Kamehameha Schools
Oʻahu	Pālolo	3-1748-011	Kaimukī Deep 1	Honolulu Board of Water Supply, BWS
Oʻahu	Pālolo	3-1748-012	Keanu	Honolulu Board of Water Supply, BWS
Oʻahu	Pālolo	3-1748-014	Kaimukī Sta Deep Monitor	Honolulu Board of Water Supply, BWS
Oʻahu	Pālolo	3-1749-007	Kapahulu	City & County of Honolulu, C&CH
Oʻahu	Pālolo	3-1749-014	Kaimukī High School	Honolulu Board of Water Supply, BWS
Oʻahu	Pālolo	3-1749-022	Kaimukī HS Deep Monitor	Honolulu Board of Water Supply, BWS
Oʻahu	Waipahu-Waiawa	3-1800-001	ʻEwa Beach B	National Weather Service
Oʻahu	Malakole	3-1806-007	Conoco Ref Obs 2	Dill-Conoco
Oʻahu	Malakole	3-1806-008	Conoco Ref Obs 1	Dill-Conoco
Oʻahu	Pālolo	3-1848-001	Waahila Deep Monitor	Honolulu Board of Water Supply, BWS
Oʻahu	Nuʻuanu	3-1849-011	Wilder Ave	Honolulu Board of Water Supply, BWS
Oʻahu	Nuʻuanu	3-1849-012	Wilder Ave	Honolulu Board of Water Supply, BWS
Oʻahu	Nuʻuanu	3-1850-030	Punchbowl Deep Mon	Honolulu Board of Water Supply, BWS
Oʻahu	Nuʻuanu	3-1851-002	Thomas Square	Honolulu Board of Water Supply, BWS
Oʻahu	Nuʻuanu	3-1851-019	Halekauwila St	Harbor Square
Oʻahu	Nuʻuanu	3-1851-022	Ala Moana Blvd	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
Oʻahu	Nuʻuanu	3-1851-057	Beretania Deep Monitor	Honolulu Board of Water Supply, BWS
Oʻahu	Puʻuloa	3-1900-012	ʻEwa Beach	Pacific Islands Water Science Center, USGS, U.S. Geological Survey

Table G-5: Statewide Summary of Registered Observation Wells Not Included in the CWRM, CWRM-USGS, or Honolulu BWS Monitoring Programs (continued)

Island	Aquifer system	Well number	Well name	Well owner
O‘ahu	Pu‘uloa	3-1900-014	‘Ewa Beach C	National Weather Service
O‘ahu	Pu‘uloa	3-1900-015	‘Ewa Beach D	National Weather Service
O‘ahu	Pu‘uloa	3-1902-005	Coral Creek 5	Coral Creek Golf, Inc.
O‘ahu	Malakole	3-1906-008	Barbers Pt. MW-1	State of Hawai‘i DOT, Harbors Division
O‘ahu	Malakole	3-1906-010	Barbers Pt. MW-3	State of Hawai‘i DOT, Harbors Division
O‘ahu	Kalihi	3-1952-004	Kapālama	Kapuna Apartments, LLC
O‘ahu	Kalihi	3-1952-046	HCC O-6	Honolulu Community College
O‘ahu	Kalihi	3-1952-048	Kalihi Sta Deep Monitor	Honolulu Board of Water Supply, BWS
O‘ahu	Waipahu-Waiawa	3-1959-005	Ft Weaver Rd	Department of the Navy, Navy Region Hawai‘i
O‘ahu	Waipahu-Waiawa	3-1959-006	Ft Weaver Rd	Department of the Navy, Navy Region Hawai‘i
O‘ahu	Waipahu-Waiawa	3-1959-007	‘Ewa Beach A	National Weather Service
O‘ahu	Pu‘uloa	3-2001-016	Coral Creek 3	Coral Creek Golf, Inc.
O‘ahu	‘Ewa-Kunia	3-2006-012	Kahe Point	Honolulu Board of Water Supply, BWS
O‘ahu	‘Ewa-Kunia	3-2006-016	Makaīwa Mon TH-1	James Campbell Company LLC
O‘ahu	Malakole	3-2006-018	Barbers Pt. MW-4	State of Hawai‘i DOT, Harbors Division
O‘ahu	‘Ewa-Kunia	3-2007-002	Makaīwa Mon TH-2	Makaīwa Hills, LLC
O‘ahu	Makaīwa	3-2007-003	Makaīwa Mon TH-3	Makaīwa Hills, LLC
O‘ahu	Waimānalo	3-2042-005	Waimānalo STP 1	Honolulu Sewers
O‘ahu	Waimānalo	3-2042-006	Waimānalo STP 2	Honolulu Sewers
O‘ahu	Waimānalo	3-2042-007	Waimānalo STP 3	Honolulu Sewers
O‘ahu	Waimānalo	3-2042-008	Waimānalo STP 4	Honolulu Sewers
O‘ahu	Waimānalo	3-2042-009	Waimānalo STP 5	Honolulu Sewers
O‘ahu	Waimānalo	3-2042-010	Waimānalo STP 6	Honolulu Sewers
O‘ahu	Waimānalo	3-2042-011	Waimānalo STP 7	Honolulu Sewers
O‘ahu	Waimānalo	3-2042-012	Waimānalo Stp 8	Honolulu Sewers
O‘ahu	Waimānalo	3-2042-013	Waimānalo	Pacific Concrete & Rock Co.
O‘ahu	Waimānalo	3-2044-001	Olomana Golf	State of Hawai‘i

Table G-5: Statewide Summary of Registered Observation Wells Not Included in the CWRM, CWRM-USGS, or Honolulu BWS Monitoring Programs (continued)

Island	Aquifer system	Well number	Well name	Well owner
O‘ahu	Nu‘uanu	3-2047-003	Mānoa	Honolulu Board of Water Supply, BWS
O‘ahu	Nu‘uanu	3-2047-004	Mānoa	Honolulu Board of Water Supply, BWS
O‘ahu	Kalihi	3-2052-010	Kapālama	Honolulu Board of Water Supply, BWS
O‘ahu	Kalihi	3-2052-012	Jonathan Springs	Honolulu Board of Water Supply, BWS
O‘ahu	Moanalua	3-2052-015	Kalihi Sh Deep Monitor	Honolulu Board of Water Supply, BWS
O‘ahu	Moanalua	3-2053-010	Fort Shafter Monitor	Directorate of Public Works, Environmental Division, DPW, U.S. Army Garrison
O‘ahu	Waipahu-Waiawa	3-2101-003	Honouliuli	State of Hawai‘i, Department of Transportation, Highways Division, DOT
O‘ahu	Waipahu-Waiawa	3-2101-009	Honouliuli F	‘Ewa Plantation
O‘ahu	‘Ewa-Kunia	3-2103-001	Pu‘u Makakilo	Naval Facilities Engineering Command Hawai‘i, Environmental, NAVFAC Hawaii
O‘ahu	‘Ewa-Kunia	3-2103-002	Pu‘u Makakilo	Naval Facilities Engineering Command Hawai‘i, Environmental, NAVFAC Hawaii
O‘ahu	‘Ewa-Kunia	3-2103-004	Barbers Pt. Mon	Naval Facilities Engineering Command Hwai‘i,, Environmental, NAVFAC Hawaii
O‘ahu	‘Ewa-Kunia	3-2103-005	Barbers Pt Shallow M	Naval Facilities Engineering Command Hawai‘i, Environmental, NAVFAC Hawaii
O‘ahu	Moanalua	3-2153-005	Moanalua Deep Monitor	Honolulu Board of Water Supply, BWS
O‘ahu	Moanalua	3-2153-009	Moanalua-Manaiki	Honolulu Board of Water Supply, BWS
O‘ahu	Moanalua	3-2153-013	TAMC MW-2	Directorate of Public Works, Environmental Division, DPW, U.S. Army Garrison
O‘ahu	Waipahu-Waiawa	3-2201-010	Kunia T41 Deep Monitor	Honolulu Board of Water Supply, BWS
O‘ahu	Moanalua	3-2253-002	Moanalua DH 43	Honolulu Board of Water Supply, BWS

Table G-5: Statewide Summary of Registered Observation Wells Not Included in the CWRM, CWRM-USGS, or Honolulu BWS Monitoring Programs (continued)

Island	Aquifer system	Well number	Well name	Well owner
Oʻahu	Waimalu	3-2253-003	Hālawa Deep Monitor	Commission on Water Resource Management, CWRM
Oʻahu	Waimalu	3-2253-004	RHMW06	Naval Facilities Engineering Command Hawaiʻi, NAVFAC Hawaiʻi
Oʻahu	Waimalu	3-2253-005	RHMW07	Naval Facilities Engineering Command Hawaiʻi, NAVFAC Hawaiʻi
Oʻahu	Moanalua	3-2253-007	RHMW08	Naval Facilities Engineering Command Hawaiʻi, NAVFAC Hawaiʻi
Oʻahu	Moanalua	3-2253-008	RHMW09	Naval Facilities Engineering Command Hawaiʻi, NAVFAC Hawaiʻi
Oʻahu	Waimalu	3-2255-021	Hālawa	State of Hawaiʻi
Oʻahu	Waimalu	3-2255-022	Hālawa	State of Hawaiʻi
Oʻahu	Waimalu	3-2255-026	Hālawa	State of Hawaiʻi
Oʻahu	Waimalu	3-2255-027	Hālawa	State of Hawaiʻi
Oʻahu	Waimalu	3-2255-033	Hālawa Obs. T45	Honolulu Board of Water Supply, BWS
Oʻahu	Waimalu	3-2255-040	Hālawa -BWS Deep Monitor	Honolulu Board of Water Supply, BWS
Oʻahu	Waimalu	3-2256-010	FW 1	State of Hawaiʻi
Oʻahu	Waimalu	3-2256-012	FW 3	State of Hawaiʻi
Oʻahu	Waipahu-Waiawa	3-2300-010	Waipahu P6	Kamehameha Schools
Oʻahu	Waipahu-Waiawa	3-2300-018	Waipahu Deep Monitor	Honolulu Board of Water Supply, BWS
Oʻahu	ʻEwa-Kunia	3-2303-007	Honouliuli Deep Monitor	Monsanto Company - Oʻahu
Oʻahu	Nānākuli	3-2307-001	Nānākuli	Honolulu Board of Water Supply, BWS
Oʻahu	Koʻolaupoko	3-2348-001	Kuou TH	Honolulu Board of Water Supply, BWS
Oʻahu	Koʻolaupoko	3-2348-004	Kuou TH	Honolulu Board of Water Supply, BWS
Oʻahu	Waimalu	3-2355-001	ʻAiea	Steven Ohata
Oʻahu	Waimalu	3-2355-008	Kalauao	Honolulu Board of Water Supply, BWS
Oʻahu	Waimalu	3-2355-015	Kaamilo Deep Monitor	Honolulu Board of Water Supply, BWS

Table G-5: Statewide Summary of Registered Observation Wells Not Included in the CWRM, CWRM-USGS, or Honolulu BWS Monitoring Programs (continued)

Island	Aquifer system	Well number	Well name	Well owner
O‘ahu	Waimalu	3-2356-053	‘Aiea T-75	Honolulu Board of Water Supply, BWS
O‘ahu	Waimalu	3-2356-057	Waimalu	Honolulu Board of Water Supply, BWS
O‘ahu	Waipahu-Waiawa	3-2358-020	Pearl City Obs T-27	Honolulu Board of Water Supply, BWS
O‘ahu	Waipahu-Waiawa	3-2400-007	Waikele Obs. D	Pacific Islands Water Science Center, USGS
O‘ahu	Waipahu-Waiawa	3-2401-002	Royal Kunia A-1	Royal O‘ahu Resorts, Inc.
O‘ahu	Waipahu-Waiawa	3-2401-003	Royal Kunia A-2	Royal O‘ahu Resorts, Inc.
O‘ahu	‘Ewa-Kunia	3-2403-002	Kunia Middle Deep Monitor	Commission on Water Resource Management, CWRM
O‘ahu	Waimalu	3-2455-001	Upper Waimalu T52	Honolulu Board of Water Supply, BWS
O‘ahu	Waimalu	3-2456-004	Newtown Deep Monitor	Honolulu Board of Water Supply, BWS
O‘ahu	Waimalu	3-2456-005	Waimalu Deep Monitor	Commission on Water Resource Management, CWRM
O‘ahu	Waimalu	3-2457-004	Punanani DMW	Honolulu Board of Water Supply, BWS
O‘ahu	Waipahu-Waiawa	3-2459-015	Waipahu	II Estate
O‘ahu	Waipahu-Waiawa	3-2459-026	Waiawa Deep Monitor	Honolulu Board of Water Supply, BWS
O‘ahu	Waipahu-Waiawa	3-2500-003	Waiola Deep Monitor	Honolulu Board of Water Supply, BWS
O‘ahu	‘Ewa-Kunia	3-2503-003	Kunia Mauka 2 Deep Monitor	Commission on Water Resource Management, CWRM
O‘ahu	‘Ewa-Kunia	3-2503-004	BMW 5	Edward Littleton (Del Monte Fresh Produce (Hawai‘i), Inc)
O‘ahu	Waipahu-Waiawa	3-2557-004	Waimano Deep Monitor	Honolulu Board of Water Supply, BWS
O‘ahu	Waipahu-Waiawa	3-2558-008	Waiawa	Naval Facilities Engineering Command Hawai‘i, Environmental, NAVFAC Hawai‘i
O‘ahu	Waipahu-Waiawa	3-2600-005	Kipapa Mon MW-8	United States Air Force
O‘ahu	Waipahu-Waiawa	3-2600-006	Kipapa ST01MW05	United States Air Force

Table G-5: Statewide Summary of Registered Observation Wells Not Included in the CWRM, CWRM-USGS, or Honolulu BWS Monitoring Programs (continued)

Island	Aquifer system	Well number	Well name	Well owner
O‘ahu	Waipahu-Waiawa	3-2600-007	Kipapa ST01MW06	United States Air Force
O‘ahu	Waipahu-Waiawa	3-2600-008	Kipapa ST01MW07	United States Air Force
O‘ahu	Waipahu-Waiawa	3-2600-009	Kipapa ST01MW10	United States Air Force
O‘ahu	Waipahu-Waiawa	3-2602-002	Poliwai Deep Monitor	Honolulu Board of Water Supply, BWS
O‘ahu	Waipahu-Waiawa	3-2659-001	Waipio Mauka Deep Monitor	Commission on Water Resource Management, CWRM
O‘ahu	Waipahu-Waiawa	3-2702-001	Waikakalaua MW-6	United States Air Force
O‘ahu	Waipahu-Waiawa	3-2702-002	Waikakalaua MW-7	United States Air Force
O‘ahu	Waipahu-Waiawa	3-2702-006	Waikaka ST12MW03	United States Air Force
O‘ahu	Waipahu-Waiawa	3-2702-007	Waikaka ST12MW04	United States Air Force
O‘ahu	Waipahu-Waiawa	3-2702-008	Waikaka ST12MW05	United States Air Force
O‘ahu	Waipahu-Waiawa	3-2702-009	Waikaka ST12MW08	United States Air Force
O‘ahu	Waipahu-Waiawa	3-2702-010	Waikaka ST12MW09	United States Air Force
O‘ahu	Waipahu-Waiawa	3-2702-011	RW001	United States Air Force
O‘ahu	Waipahu-Waiawa	3-2703-003	BMW 2	Edward Littleton (Del Monte Fresh Produce (Hawai‘i), Inc)
O‘ahu	Waipahu-Waiawa	3-2703-004	BMW 4	Edward Littleton (Del Monte Fresh Produce (Hawai‘i), Inc)
O‘ahu	‘Ewa-Kunia	3-2703-005	BMW 6	Edward Littleton (Del Monte Fresh Produce (Hawai‘i), Inc)
O‘ahu	‘Ewa-Kunia	3-2704-001	BMW 3	Edward Littleton (Del Monte Fresh Produce (Hawai‘i), Inc)
O‘ahu	Ko‘olaupoko	3-2751-004	Waihee Obs	Honolulu Board of Water Supply, BWS
O‘ahu	Wahiawā	3-2801-002	Schofield MW2-4	Directorate of Public Works, Environmental Division, DPW, U.S. Army Garrison
O‘ahu	Waipahu-Waiawa	3-2802-001	Schofield MW2-6	Directorate of Public Works, Environmental Division, DPW, U.S. Army Garrison

Table G-5: Statewide Summary of Registered Observation Wells Not Included in the CWRM, CWRM-USGS, or Honolulu BWS Monitoring Programs (continued)

Island	Aquifer system	Well number	Well name	Well owner
Oʻahu	Waiʻanae	3-2809-002	Waiʻanae Valley	Honolulu Board of Water Supply, BWS
Oʻahu	Wahiawā	3-2900-002	Schofield MW2-1	Directorate of Public Works, Environmental Division, DPW, U.S. Army Garrison
Oʻahu	Wahiawā	3-2901-001	Schofield Batt	Directorate of Public Works, Environmental Division, DPW, U.S. Army Garrison
Oʻahu	Wahiawā	3-2901-013	Schofield MW1-1	Directorate of Public Works, Environmental Division, DPW, U.S. Army Garrison
Oʻahu	Wahiawā	3-2902-003	Schofield MW2-3	Directorate of Public Works, Environmental Division, DPW, U.S. Army Garrison
Oʻahu	Wahiawā	3-2903-001	Schofield MW2-2	Directorate of Public Works, Environmental Division, DPW, U.S. Army Garrison
Oʻahu	Wahiawā	3-2959-001	Schofield MW2-5	Directorate of Public Works, Environmental Division, DPW, U.S. Army Garrison
Oʻahu	Wahiawā	3-3004-001	Schofield MW4-1	Directorate of Public Works, Environmental Division, DPW, U.S. Army Garrison
Oʻahu	Wahiawā	3-3004-002	Schofield MW4-2	Directorate of Public Works, Environmental Division, DPW, U.S. Army Garrison
Oʻahu	Wahiawā	3-3004-003	Schofield MW4-3	Directorate of Public Works, Environmental Division, DPW, U.S. Army Garrison
Oʻahu	Wahiawā	3-3004-004	Schofield MW4-4	Directorate of Public Works, Environmental Division, DPW, U.S. Army Garrison
Oʻahu	Wahiawā	3-3004-005	Schofield MW4-2A	Directorate of Public Works, Environmental Division, DPW, U.S. Army Garrison
Oʻahu	Keaʻau	3-3113-002	ERDC-MW-1	Directorate of Public Works, Environmental Division, DPW, U.S. Army Garrison
Oʻahu	Keaʻau	3-3113-003	ERDC-MW-4A	Directorate of Public Works, Environmental Division, DPW, U.S. Army Garrison

Table G-5: Statewide Summary of Registered Observation Wells Not Included in the CWRM, CWRM-USGS, or Honolulu BWS Monitoring Programs (continued)

Island	Aquifer system	Well number	Well name	Well owner
Oʻahu	Keaʻau	3-3113-004	ERDC-MW-4B	Directorate of Public Works, Environmental Division, DPW, U.S. Army Garrison
Oʻahu	Keaʻau	3-3113-005	ERDC-MW-4C	Directorate of Public Works, Environmental Division, DPW, U.S. Army Garrison
Oʻahu	Keaʻau	3-3113-006	ERDC-MW-5	Directorate of Public Works, Environmental Division, DPW, U.S. Army Garrison
Oʻahu	Waialua	3-3204-001	Kaheaka Obs.	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
Oʻahu	Keaʻau	3-3213-008	ERDC-MW-2	Directorate of Public Works, Environmental Division, DPW, U.S. Army Garrison
Oʻahu	Keaʻau	3-3213-009	ERDC-MW-3A	Directorate of Public Works, Environmental Division, DPW, U.S. Army Garrison
Oʻahu	Keaʻau	3-3213-010	ERDC-MW-3B	Directorate of Public Works, Environmental Division, DPW, U.S. Army Garrison
Oʻahu	Keaʻau	3-3213-011	ERDC-MW-3C	Directorate of Public Works, Environmental Division, DPW, U.S. Army Garrison
Oʻahu	Mokulēʻia	3-3307-017	T-116	G Tree Ranch, LLC
Oʻahu	Mokulēʻia	3-3307-018	T-117	G Tree Ranch, LLC
Oʻahu	Waialua	3-3307-020	Thompson Corner 1	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
Oʻahu	Waialua	3-3307-021	Thompson Corner 2	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
Oʻahu	Mokulēʻia	3-3310-003	Mokulēʻia 3	Mokulēʻia Land Co.
Oʻahu	Waialua	3-3404-002	Waialua	Dole Food Company, Inc. Hawaiʻi
Oʻahu	Waialua	3-3405-005	Helemano Deep Monitor	Honolulu Board of Water Supply, BWS
Oʻahu	Waialua	3-3406-004	Waialua	Dole Food Company, Inc. Hawaiʻi

Table G-5: Statewide Summary of Registered Observation Wells Not Included in the CWRM, CWRM-USGS, or Honolulu BWS Monitoring Programs (continued)

Island	Aquifer system	Well number	Well name	Well owner
O‘ahu	Waialua	3-3406-012	Twin Bridge Deep	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
O‘ahu	Waialua	3-3406-013	Kamooloa Obs.	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
O‘ahu	Waialua	3-3406-014	Helemano Cap 1	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
O‘ahu	Waialua	3-3406-015	Helemano Cap 2	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
O‘ahu	Waialua	3-3407-029	Waialua	Dole Food Company, Inc. Hawai‘i
O‘ahu	Waialua	3-3407-037	Kiikii Cap Mon 2	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
O‘ahu	Mokulē‘ia	3-3409-016	Mokulē‘ia	Mokulē‘ia Associates
O‘ahu	Mokulē‘ia	3-3410-008	Mokulē‘ia	Dole Food Company, Inc. Hawai‘i
O‘ahu	Kahana	3-3453-012	Makalii 2	Ko‘olau Agricultural Co., Ltd.
O‘ahu	Kawailoa	3-3503-001	N Upper Anahulu	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
O‘ahu	Kawailoa	3-3505-025	N Lower Anahulu	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
O‘ahu	Waialua	3-3505-026	Opaeula Obs	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
O‘ahu	Ko‘olauloa	3-3553-005	Punalu‘u Deep Monitor	Honolulu Board of Water Supply, BWS
O‘ahu	Ko‘olauloa	3-3554-005	Kaluanui 2 Monitor	Honolulu Board of Water Supply, BWS
O‘ahu	Kawailoa	3-3604-001	Kawailoa Deep Monitor	Honolulu Board of Water Supply, BWS
O‘ahu	Kawailoa	3-3605-024	Kawailoa Pump 4	Waialua Sugar Company, Inc.
O‘ahu	Kawailoa	3-3605-025	Kawailoa Pump 4	Waialua Sugar Company, Inc.

Table G-5: Statewide Summary of Registered Observation Wells Not Included in the CWRM, CWRM-USGS, or Honolulu BWS Monitoring Programs (continued)

Island	Aquifer system	Well number	Well name	Well owner
O‘ahu	Ko‘olauloa	3-3755-010	Hauula Deep Monitor	Honolulu Board of Water Supply, BWS
O‘ahu	Ko‘olauloa	3-3956-008	Lā‘ie Deep Monitor	Honolulu Board of Water Supply, BWS
O‘ahu	Ko‘olauloa	3-4057-005	Kahuku	B. Tsukamoto
O‘ahu	Ko‘olauloa	3-4057-017	Kahuku Deep Monitor	Honolulu Board of Water Supply, BWS
O‘ahu	Kawailoa	3-4101-003	Waiale‘e	State of Hawai‘i
Moloka‘i	Kawela	4-0457-003	Kawela 2	Kawela Plantation Homeowners' Association
Moloka‘i	Kawela	4-0458-002	Kawela 3	Kawela Plantation Homeowners' Association
Moloka‘i	Kualapu‘u	4-0800-001	Kualapu‘u Deep Monitor	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
Lāna‘i	Leeward	5-4954-001	Lāna‘i 3	Lāna‘i Holdings, Inc.
Maui	Kama‘ole	6-3925-001	Makena 68	State of Hawai‘i, DLNR Land Division O‘ahu, DLNR-LD
Maui	Kama‘ole	6-4026-005	Wailea 6	Wailea Golf LLC
Maui	Kama‘ole	6-4126-001	Wailea 1	Wailea Golf LLC
Maui	Kama‘ole	6-4327-008	Kalama Beach A1	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
Maui	Kama‘ole	6-4327-009	Kalama Beach A2	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
Maui	Kama‘ole	6-4327-010	Kalama Beach A3	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
Maui	Kama‘ole	6-4422-001	Waiohuli	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
Maui	Kama‘ole	6-4426-001	Kihei Inject TH	County of Maui Department of Environmental Management, Solid Waste Division

Table G-5: Statewide Summary of Registered Observation Wells Not Included in the CWRM, CWRM-USGS, or Honolulu BWS Monitoring Programs (continued)

Island	Aquifer system	Well number	Well name	Well owner
Maui	Kamaʻole	6-4427-006	Kihei Fire B1	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
Maui	Kamaʻole	6-4427-007	Kihei Fire B2	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
Maui	Kamaʻole	6-4427-008	Kihei Fire B3	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
Maui	Waikapu	6-4831-001	Māʻalaea 272	State of Hawaii, DLNR Land Division Oʻahu, DLNR-LD
Maui	Pāʻia	6-5125-001	Wailuku MW-1	County of Maui Department of Environmental Management, Solid Waste Division
Maui	Pāʻia	6-5125-002	Wailuku MW-2	County of Maui Department of Environmental Management, Solid Waste Division
Maui	Pāʻia	6-5125-003	Wailuku MW-3	County of Maui Department of Environmental Management, Solid Waste Division
Maui	Pāʻia	6-5125-004	Wailuku MW-4	County of Maui Department of Environmental Management, Solid Waste Division
Maui	Pāʻia	6-5125-005	Wailuku MW-5	County of Maui Department of Environmental Management, Solid Waste Division
Maui	Pāʻia	6-5125-006	Wailuku MW-6	County of Maui Department of Environmental Management, Solid Waste Division
Maui	ʻĪao	6-5230-002	ʻĪao Deep Monitor	Commission on Water Resource Management, CWRM
Maui	Launiupoko	6-5237-001	Kauaula TH 1	State of Hawaiʻi, DLNR Land Division Oʻahu, DLNR-LD
Maui	Launiupoko	6-5237-002	Kauaula TH 2	State of Hawaiʻi, DLNR Land Division Oʻahu, DLNR-LD
Maui	Honopou	6-5313-001	EMI Kailua Mon	East Maui Irrigation Co., Ltd.
Maui	ʻĪao	6-5329-018	Waiale Obs	Astoria International Inc.
Maui	ʻĪao	6-5330-003	Field 63	Wailuku Sugar

Table G-5: Statewide Summary of Registered Observation Wells Not Included in the CWRM, CWRM-USGS, or Honolulu BWS Monitoring Programs (continued)

Island	Aquifer system	Well number	Well name	Well owner
Maui	ʻĪao	6-5330-004	Wailuku Mill TH	Wailuku Sugar
Maui	ʻĪao	6-5330-006	Mokuhau TH 1	Igarta, Bernard Trust
Maui	ʻĪao	6-5330-007	Mokuhau TH 2	Bernard Paet (Paet, Bernard Revoc TR/ETAL)
Maui	ʻĪao	6-5330-008	Mokuhau TH 3	Timothy Bachand
Maui	ʻĪao	6-5331-001	ʻĪao Valley TH	Wailuku Sugar
Maui	ʻĪao	6-5332-004	Kepaniwai TH	State of Hawaiʻi, DLNR Land Division Oʻahu, DLNR-LD
Maui	Launiupoko	6-5338-001	Kanaha TH 1	State of Hawaiʻi, DLNR Land Division Oʻahu, DLNR-LD
Maui	Launiupoko	6-5338-002	Kanaha TH 2	State of Hawaiʻi, DLNR Land Division Oʻahu, DLNR-LD
Maui	Haʻikū	6-5418-001	EMWDP Monitor	Maui Department of Water Supply, MDWS
Maui	Kahului	6-5425-002	Sprecklesville	Hawaiian Commercial & Sugar Co. (HC&S)
Maui	ʻĪao	6-5430-003	Waiehu TH-E	Wailuku Sugar
Maui	ʻĪao	6-5430-004	Waiehu TH-D	State of Hawaiʻi, DLNR Land Division Oʻahu, DLNR-LD
Maui	ʻĪao	6-5430-005	Waiehu Deep Monitor	Commission on Water Resource Management, CWRM
Maui	ʻĪao	6-5431-001	Waiehu TH-B	Wailuku Sugar
Maui	ʻĪao	6-5530-001	Waiehu Tunnel	Wailuku Sugar
Maui	ʻĪao	6-5631-001	Waiheʻe TH A1	Wailuku Sugar
Maui	Waiheʻe	6-5631-009	Waiheʻe DMW	Commission on Water Resource Management, CWRM
Maui	Honokōwai	6-5637-001	Honokōwai TH 1	AMFAC
Maui	Honokōwai	6-5637-002	Honokōwai TH 2	AMFAC
Maui	Honokōwai	6-5637-003	Honokōwai TH 3	AMFAC
Maui	Honokōwai	6-5637-004	Honokōwai	AMFAC

Table G-5: Statewide Summary of Registered Observation Wells Not Included in the CWRM, CWRM-USGS, or Honolulu BWS Monitoring Programs (continued)

Island	Aquifer system	Well number	Well name	Well owner
Maui	Honokōwai	6-5638-001	Honokōwai TH 6	AMFAC
Maui	Honokōwai	6-5638-002	Honokōwai TH 7	AMFAC
Maui	Honokōwai	6-5639-001	Honokōwai TH 5	AMFAC
Maui	Honokōwai	6-5639-002	Honokōwai TH 8	AMFAC
Maui	Waiheʻe	6-5731-005	Kanoa TH	Waiheʻe Sweetwater Farm LLC
Maui	Honokowai	6-5739-003	Mahinahina Deep Monitor	Commission on Water Resource Management, CWRM
Maui	Honolua	6-5840-001	ʻAlaeloa	State of Hawaiʻi, DLNR Land Division Oʻahu, DLNR-LD
Hawaiʻi	Kalae	8-0339-001	South Point Tank	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
Hawaiʻi	Nāʻālehu	8-0437-001	Waiohinu Exploratory	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
Hawaiʻi	Manuka	8-0445-001	HOVE Obs	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
Hawaiʻi	Nāʻālehu	8-0831-001	Ninole Gulch TH-1	Hawaiiana Invest. Co., Inc
Hawaiʻi	Hilina	8-2317-001	Hawaiʻi Volcano National Park	U.S. National Park Service, Hawaiʻi Volcanoes, NPS
Hawaiʻi	ʻŌlaʻa	8-2714-001	Volcano TH-4	State of Hawaiʻi, DLNR Land Division Oʻahu, DLNR-LD
Hawaiʻi	ʻŌlaʻa	8-2714-002	Volcano TH5	State of Hawaiʻi, DLNR Land Division Oʻahu, DLNR-LD
Hawaiʻi	ʻŌlaʻa	8-2715-002	Volcano TH 3	State of Hawaiʻi, DLNR Land Division Oʻahu, DLNR-LD
Hawaiʻi	ʻŌlaʻa	8-2815-001	Volcano TH-1	State of Hawaiʻi, DLNR Land Division Oʻahu, DLNR-LD
Hawaiʻi	Kalapana	8-2883-007	Puna Geo MW2	Puna Geothermal Venture
Hawaiʻi	Kealakekua	8-3057-001	Hokukano Mon 2	Bob Stuit (Hokulia)
Hawaiʻi	Kealakekua	8-3155-001	Kealakekua Obs.	Pacific Islands Water Science Center, USGS, U.S. Geological Survey

Table G-5: Statewide Summary of Registered Observation Wells Not Included in the CWRM, CWRM-USGS, or Honolulu BWS Monitoring Programs (continued)

Island	Aquifer system	Well number	Well name	Well owner
Hawai‘i	Kealakekua	8-3157-001	Hokukano Mon 1	Bob Stuit (Hokulia)
Hawai‘i	‘Ōla‘a	8-3207-004	‘Ōla‘a -Mt. View	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
Hawai‘i	Keauhou	8-3255-001	Kainaliu Obs	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
Hawai‘i	Keauhou	8-3255-002	Kainaliu Test	Kona Research and Extension Center, CTAHR
Hawai‘i	Keauhou	8-3457-002	Keauhou A	Kamehameha Schools
Hawai‘i	Keauhou	8-3457-004	Kahaluu Deep Monitor	Commission on Water Resource Management, CWRM
Hawai‘i	Keauhou	8-3858-001	Keopu Basal Monitor	Commission on Water Resource Management, CWRM
Hawai‘i	Keauhou	8-3957-002	Komo Monitor	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
Hawai‘i	Keauhou	8-3959-001	Kamakana	Forest City Hawai‘i Kona, LLC
Hawai‘i	Hilo	8-4007-001	Waiakea Monitor	Okahara and Assoc., Inc.
Hawai‘i	Hilo	8-4010-001	Kaumana	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
Hawai‘i	Keauhou	8-4060-002	Kaiser 1	Maryl Group, Inc.
Hawai‘i	Keauhou	8-4060-003	Kaiser 2	Maryl Group, Inc.
Hawai‘i	Keauhou	8-4061-001	Kaho 1	U.S. National Park Service, Kaloko-Honokohau Historical Park, NPS
Hawai‘i	Keauhou	8-4161-001	Kaho 3	U.S. National Park Service, Kaloko-Honokohau Historical Park, NPS
Hawai‘i	Keauhou	8-4161-002	Kaho 2	U.S. National Park Service, Kaloko-Honokohau Historical Park, NPS
Hawai‘i	Keauhou	8-4161-010	MW 201	Kohanaiki Shores, LLC

Table G-5: Statewide Summary of Registered Observation Wells Not Included in the CWRM, CWRM-USGS, or Honolulu BWS Monitoring Programs (continued)

Island	Aquifer system	Well number	Well name	Well owner
Hawaiʻi	Keauhou	8-4161-011	MW 401	Kohanaiki Shores, LLC
Hawaiʻi	Keauhou	8-4161-012	MW 402	Kohanaiki Shores, LLC
Hawaiʻi	Keauhou	8-4162-004	MW 400	Kohanaiki Shores, LLC
Hawaiʻi	Keauhou	8-4162-005	MW 300a	Kohanaiki Shores, LLC
Hawaiʻi	Keauhou	8-4162-006	MW 300b	Kohanaiki Shores, LLC
Hawaiʻi	Keauhou	8-4162-007	MW 300c	Kohanaiki Shores, LLC
Hawaiʻi	Hilo	8-4203-016	HSDP 2 Deep	University of Hawaiʻi Hilo, UHH
Hawaiʻi	Keauhou	8-4262-003	MW 200	Kohanaiki Shores, LLC
Hawaiʻi	Keauhou	8-4262-004	Moana 9	Natural Energy Laboratory of Hawaiʻi Authority, NELHA
Hawaiʻi	Keauhou	8-4262-005	Moana 9A	Natural Energy Laboratory of Hawaiʻi Authority, NELHA
Hawaiʻi	Keauhou	8-4262-006	Moana 9B	Natural Energy Laboratory of Hawaiʻi Authority, NELHA
Hawaiʻi	Keauhou	8-4262-007	W1	Natural Energy Laboratory of Hawaiʻi Authority, NELHA
Hawaiʻi	Keauhou	8-4262-008	W-2	Natural Energy Laboratory of Hawaiʻi Authority, NELHA
Hawaiʻi	Keauhou	8-4262-009	W2A	Natural Energy Laboratory of Hawaiʻi Authority, NELHA
Hawaiʻi	Keauhou	8-4262-010	W2B	Natural Energy Laboratory of Hawaiʻi Authority, NELHA
Hawaiʻi	Keauhou	8-4361-001	Queen K 13	Natural Energy Laboratory of Hawaiʻi Authority, NELHA
Hawaiʻi	Keauhou	8-4363-014	Kona Blue 10	Natural Energy Laboratory of Hawaiʻi Authority, NELHA
Hawaiʻi	Keauhou	8-4363-015	Kona Blue 10A	Natural Energy Laboratory of Hawaiʻi Authority, NELHA
Hawaiʻi	Keauhou	8-4363-016	Kona Blue 10B	Natural Energy Laboratory of Hawaiʻi Authority, NELHA
Hawaiʻi	Keauhou	8-4363-017	Mera 11	Natural Energy Laboratory of Hawaiʻi Authority, NELHA
Hawaiʻi	Keauhou	8-4363-018	Mera 11A	Natural Energy Laboratory of Hawaiʻi Authority, NELHA

Table G-5: Statewide Summary of Registered Observation Wells Not Included in the CWRM, CWRM-USGS, or Honolulu BWS Monitoring Programs (continued)

Island	Aquifer system	Well number	Well name	Well owner
Hawaiʻi	Keauhou	8-4363-019	Mera 11B	Natural Energy Laboratory of Hawaiʻi Authority, NELHA
Hawaiʻi	Keauhou	8-4363-021	W3	Natural Energy Laboratory of Hawaiʻi Authority, NELHA
Hawaiʻi	Keauhou	8-4363-022	W3A	Natural Energy Laboratory of Hawaiʻi Authority, NELHA
Hawaiʻi	Keauhou	8-4363-023	W3B	Natural Energy Laboratory of Hawaiʻi Authority, NELHA
Hawaiʻi	Keauhou	8-4363-024	W4	Natural Energy Laboratory of Hawaiʻi Authority, NELHA
Hawaiʻi	Keauhou	8-4363-025	W4A	Natural Energy Laboratory of Hawaiʻi Authority, NELHA
Hawaiʻi	Keauhou	8-4363-026	W5	Natural Energy Laboratory of Hawaiʻi Authority, NELHA
Hawaiʻi	Keauhou	8-4363-027	W5A	Natural Energy Laboratory of Hawaiʻi Authority, NELHA
Hawaiʻi	Keauhou	8-4363-028	W5B	Natural Energy Laboratory of Hawaiʻi Authority, NELHA
Hawaiʻi	Keauhou	8-4363-029	W6	Natural Energy Laboratory of Hawaiʻi Authority, NELHA
Hawaiʻi	Keauhou	8-4363-030	W6A	Natural Energy Laboratory of Hawaiʻi Authority, NELHA
Hawaiʻi	Keauhou	8-4363-031	W6B	Natural Energy Laboratory of Hawaiʻi Authority, NELHA
Hawaiʻi	Keauhou	8-4363-032	W7	Natural Energy Laboratory of Hawaiʻi Authority, NELHA
Hawaiʻi	Keauhou	8-4363-033	W7A	Natural Energy Laboratory of Hawaiʻi Authority, NELHA
Hawaiʻi	Keauhou	8-4363-034	W7B	Natural Energy Laboratory of Hawaiʻi Authority, NELHA
Hawaiʻi	Keauhou	8-4363-035	W8	Natural Energy Laboratory of Hawaiʻi Authority, NELHA
Hawaiʻi	Keauhou	8-4363-036	W8A	Natural Energy Laboratory of Hawaiʻi Authority, NELHA
Hawaiʻi	Keauhou	8-4363-037	W8B	Natural Energy Laboratory of Hawaiʻi Authority, NELHA
Hawaiʻi	Hilo	8-4403-003	HSDP 1 Pilot	University of Hawaiʻi Mānoa, UHM
Hawaiʻi	Keauhou	8-4462-005	Keahole MW-11	State of Hawaiʻi, Department of Transportation, Airports Division, DOT

Table G-5: Statewide Summary of Registered Observation Wells Not Included in the CWRM, CWRM-USGS, or Honolulu BWS Monitoring Programs (continued)

Island	Aquifer system	Well number	Well name	Well owner
Hawai‘i	Keauhou	8-4462-006	Keahole MW-13A	State of Hawai‘i, Department of Transportation, Airports Division, DOT
Hawai‘i	Keauhou	8-4462-007	Keahole MW-13B	State of Hawai‘i Department of Transportation, Airports Division, DOT
Hawai‘i	Keauhou	8-4463-001	Keahole MW-14A	State of Hawai‘i, Department of Transportation, Airports Division, DOT
Hawai‘i	Keauhou	8-4463-002	Keahole MW-14B	State of Hawai‘i, Department of Transportation, Airports Division, DOT
Hawai‘i	Keauhou	8-4463-003	Keahole MW-14C	State of Hawai‘i, Department of Transportation, Airports Division, DOT
Hawai‘i	Keauhou	8-4463-005	North Point 12	Natural Energy Laboratory of Hawai‘i Authority, NELHA
Hawai‘i	Keauhou	8-4463-006	North Point 12A	Natural Energy Laboratory of Hawai‘i Authority, NELHA
Hawai‘i	Keauhou	8-4463-007	North Point 12B	Natural Energy Laboratory of Hawai‘i Authority, NELHA
Hawai‘i	Waimea	8-4532-002	PTA Test Well 1	U.S. Army Garrison, Hawaii, Directorate of Public Works, DPW Army
Hawai‘i	Onomea	8-4708-002	Kaieie Mauka	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
Hawai‘i	Kiholo	8-4959-010	Kukio Obs C	Kukio Community Association
Hawai‘i	Kiholo	8-4959-011	Kukio Obs E	Kukio Community Association
Hawai‘i	Kiholo	8-4959-012	Kukio Obs F	Kukio Community Association
Hawai‘i	Kiholo	8-4960-001	Kukio Obs D	Kukio Community Association
Hawai‘i	Kiholo	8-4960-003	Kukio Obs B	Huehue Ranch Associates, L.P.
Hawai‘i	Kiholo	8-4960-004	Kukio Obs A	Huehue Ranch Associates, L.P.
Hawai‘i	Mahukona	8-6141-001	Waiaka Tank	Pacific Islands Water Science Center, USGS, U.S. Geological Survey

Table G-5: Statewide Summary of Registered Observation Wells Not Included in the CWRM, CWRM-USGS, or Honolulu BWS Monitoring Programs (continued)

Island	Aquifer system	Well number	Well name	Well owner
Hawaiʻi	Mahukona	8-6144-001	Kanehoa	Pacific Islands Water Science Center, USGS, U.S. Geological Survey
Hawaiʻi	Waimea	8-6146-001	Ouli 2	Hale Wailani Partners LP
Hawaiʻi	Mahukona	8-6240-001	Waimea Obs.	Pacific Islands Water Science Center, U.S. Geological Survey
Hawaiʻi	Honokaa	8-6428-001	Honokaa (Hospital) Deepwell [NIU]	Department of Water Supply Hawaiʻi - Hilo, HDWS
Hawaiʻi	Mahukona	8-6652-001	Puanui 1	Kamehameha Schools
Hawaiʻi	Mahukona	8-7053-001	Mahukona MW 3	Wendell Brooks Jr.
Hawaiʻi	Mahukona	8-7154-002	Mahukona MW 2	Wendell Brooks Jr.
Hawaiʻi	Mahukona	8-7254-001	Mahukona MW 1	Wendell Brooks Jr.
Hawaiʻi	Hāwī	8-7345-003	Makapala Obs A	Pacific Islands Water Science Center, U.S. Geological Survey
Hawaiʻi	Hāwī	8-7347-003	Halaula Makai E	Pacific Islands Water Science Center, U.S. Geological Survey
Hawaiʻi	Hāwī	8-7347-004	Halaula Mauka B	Pacific Islands Water Science Center, U.S. Geological Survey
Hawaiʻi	Hāwī	8-7347-005	Halaula B	Pacific Islands Water Science Center, U.S. Geological Survey
Hawaiʻi	Hāwī	8-7445-001	Hapuu Bay D	Pacific Islands Water Science Center, U.S. Geological Survey
Hawaiʻi	Hāwī	8-7448-006	Kohala Obs F	Pacific Islands Water Science Center, U.S. Geological Survey
Hawaiʻi	Hāwī	8-7449-003	Hāwī Obs H	Pacific Islands Water Science Center, U.S. Geological Survey
Hawaiʻi	Hāwī	8-7451-001	Upolu Obs J-A	Pacific Islands Water Science Center, U.S. Geological Survey
Hawaiʻi	Hāwī	8-7451-002	Upolu Obs J-B	Pacific Islands Water Science Center, U.S. Geological Survey
Hawaiʻi	Hāwī	8-7549-003	Hāwī Makai I	Pacific Islands Water Science Center, U.S. Geological Survey
Hawaiʻi	Kalae	8-8836-001	Kaalualu TH 1	Kawaihae Ranch
Hawaiʻi	Kalae	8-8837-001	Kaalualu TH 2	Kawaihae Ranch

G.2.4 CWRM Management of Ground Water Data

CWRM utilizes four tools to manage information on ground water: a well index database, verifications of ground water well sources, a digital library of published Hawaiʻi related hydrologic reports, and water use reports submitted by individual well owners or operators. These tools are described below.

G.2.4.1 CWRM Well Index Database

CWRM maintains a well index database to track specific information pertaining to the construction and installation of production wells in Hawaiʻi and assists CWRM staff in protecting ground water resources from excessive withdrawals. The database contains information on well location, ownership, operation, well construction, pump type and capacity, and contractor information. The well index also contains aquifer properties and geologic information from well-drilling logs and pump-test reports.

G.2.4.2 Ground Water Well Verification

In 1988, CWRM initiated a program for well registration and declaration of existing water uses and began requiring well owners and operators to report water use to CWRM (see **Section H.3** for more information on water use reporting requirements). To date, CWRM has completed field verifications of all registered wells located in ground water management areas on Oʻahu, Molokaʻi, and Maui. In non-water management areas, CWRM has not completed field verification of many wells drilled prior to 1988.

Verification of wells since 1988 has been accomplished via 1) field investigations through the registration program for Oʻahu, Molokaʻi, and parts of Hawaiʻi, Maui, and Kauaʻi; 2) field investigations in existing ground water management areas related to the statutory 20-year review (§174C-56) in 2008, and 3) well & pump completion report correspondence and photo documentation provided by the drilling contractors as part of their permit requirements. Well construction and pump installation permits require the contractor to file completion reports as a condition of the permits and pump maintenance restorations. On occasion, staff will make a field visit to an existing or new well, but for the most part, day to day well verification is based on information provided by the drilling contractor.

CWRM can indirectly verify information on a well by examining ground water use reports submitted by the owner or operator. Water-use reports must identify the volume of ground water withdrawn over specific intervals, the water level in the well referenced to mean sea level, and the temperature of well water. Until the Hawaiʻi Well Construction and Pump Installation Standards were adopted by CWRM in 1997, CWRM did not consistently require pumpage metering and elevation benchmark references on all new wells. CWRM has not revised water use reporting policies to require the installation of meters and benchmarks at wells located outside water management areas that were drilled before 1988. Such requirements would better enable CWRM to indirectly verify reported well data.

G.2.4.3 Digital Library

CWRM staff maintains a digital library of all known hydrologic reports related to establishing ground water quantity in Hawaiʻi. Documents are searchable and provide a valuable research tool when analyzing permits, plans, organization, establishing the sustainability, etc., of ground water resources.

G.2.4.4 CWRM Water Use Reports

Ground water withdrawal data is obtained through reports submitted to CWRM by well operators/owners. Report submittals are inconsistent, with some users diligently reporting on a monthly basis, and others filing no reports until enforcement actions are taken against them. A monthly ground water use reporting form is available for use by well operators/owners on the CWRM website. The form asks for the following information:

- Well identification information;
- Start date and end date of reporting period;
- Quantity pumped (gallons);
- Method of quantity measurement;
- Chloride concentration (milligrams per liter) (or conductivity [µSeimens]);
- Water temperature; and
- Non-pumping water level (elevation in feet above mean sea level).

To improve data collection from well operators/owners, CWRM has developed a database for tracking water use reports and has enhanced the database to include an automated system for issuing notices of reporting delinquencies to permittees. An important feature is a web-based reporting program that enables water users to more efficiently report water usage to CWRM.

G.2.5 Gaps in Ground Water Monitoring Activities

G.2.5.1 Statewide Ground Water Monitoring Plan

There is a need for a statewide plan to coordinate and implement monitoring activities, and to direct the expansion of monitoring networks. There is also the associated need to increase funding for data collection networks.

G.2.5.2 Deep-Monitor Wells

There are 45 deep-monitor wells in the state (see **Figure G-2** and **Table G-5**). All but seven of them are on Oʻahu. Although Oʻahu has the most deep-monitor wells, there is still a need for more wells in inland locations. Also, development is proceeding rapidly on Kauaʻi, Maui and Hawaiʻi, and basal aquifers are often developed to supply these developments. Deep-monitor wells should be drilled on the neighbor islands to provide baseline data and to provide data on the influence of pumpage and climate change on ground water.

Aquifer-wide monitoring is severely limited throughout most of the state. Useful data on the behavior and status of ground water resources is lacking. This data gap may be especially dangerous in aquifers that are critical municipal sources. The coverage of water level and deep monitor wells should be increased. The State, in cooperation with the USGS, counties, and private entities should plan for idealized well placement in each aquifer sector area and create maps showing the ideal well locations, existing wells, funded wells, and planned wells.

Considerations for locating future deep monitor wells include:

- Providing the necessary *mauka*-to-*makai* spatial coverage within each aquifer system area;
- Enhancing hydrologic knowledge of the ground water system;
- Locating wells in areas that are not directly influenced by pumping centers and replacing those that are;
- Where feasible, identifying and converting former production and/or existing water-level observation wells into deep monitor wells; and
- Minimizing site requirements to obtain well easements, rights-of-entry, and property ownership.

Primary locations for deep monitor wells are areas where:

- The aquifer is a major potable resource and/or is being heavily pumped; and
- There is uncertainty about the sustainable yield and/or the conceptual hydrogeologic model and concern about the relationship between pumpage and saltwater intrusion.

Secondary locations for deep monitor wells should be chosen in light of the following considerations:

- Collecting baseline data from an aquifer system area before it is developed to capacity (e.g., Kailua-Kona and Lahaina);
- Planning an additional well in an aquifer to provide greater understanding of the ground water hydrology (e.g., Pearl Harbor); and
- Minimizing cost by converting unused wells to deep monitor wells.

G.2.5.3 Water-Level Observation Wells

The statewide water-level observation well network is inadequate. In most areas of the state, the present water-level observation network lacks wells that continuously measure water levels from interior sites within aquifer system areas. There are also not enough wells in the high-level aquifers, which are important in measuring the effects of pumpage on streamflow. Also, high-level aquifers are often relatively small and need to be monitored for resource depletion. Interior water-level observation wells are important in defining the inland extent of basal aquifers.

Additionally, wells used to measure water levels are not tied into the same datum. It is essential to have well measuring points tied to the same datum; otherwise, the measured water levels may not be comparable.

Elevations in Hawaiʻi are related using geodetic control points. The geodetic control in Hawaiʻi was last updated by the National Geodetic Survey in the 1970s. Construction and land development over the last 30 years has resulted in the destruction or disturbance of many of the control benchmarks. In addition, land subsidence, changes in sea level, and other natural causes have also altered these controls. The Hawaiʻi Department of Transportation is leading an effort to modernize elevations in Hawaiʻi by obtaining funding and assistance from the National Geodetic Survey. Once a new geodetic control is in place it will be possible to link elevations at the current and future monitor well networks. Recent work reestablishing benchmarks in Central Maui and in the Pearl Harbor Aquifer Sector Area, Oʻahu by the National Geodetic Survey (NGS), using global positioning satellite (GPS) technology, has shown benchmark elevations can be rapidly and accurately reestablished (vertical accuracy with the NGS survey is about 2 cm). With these benchmarks established it is possible to then perform synoptic water levels that help establish and compare water levels throughout an aquifer at a single moment in time.

G.2.5.4 Spring Discharge and Chemistry Measurements

Although spring discharge and chemistry data are collected in some areas (e.g., the Pearl Harbor Aquifer Sector Area), there has been minimal progress toward using the data in a meaningful way. Little has been done to correlate spring chemistry and flow quantities with land use changes over time, and the following opportunities should be explored:

- Because basal spring discharge essentially occurs at the coast, the challenge is to use coastal and submarine springs to monitor changes within the basal lens and impacts to nearshore environments. Springs can provide information on the impacts of past land use activities and other changes to recharge.

- Continued sampling and discharge measurements are imperative, but other chemical constituents or measurable parameters (e.g., completing an annual mineral analysis of selected spring sampling points) should be measured to present a more complete understanding of the dynamics of ground water flow.

- The effect of spring data on the calibration of numerical ground water models should be further studied, as such data may provide additional insight.

- Databases on spring information are kept by multiple agencies; however, these databases are generally not integrated. Although jurisdictional issues must be addressed, the integration and sharing of data would be useful in understanding flow dynamics and would allow for better application of shared resources and information.

G.2.5.5 Pumpage, Water-Level, Temperature, and Chloride (or Conductivity) Information

Currently, all reported well pumpage data is entered into CWRM's water use reporting database. It is CWRM's priority to update and maintain ground water pumpage information. Pumpage data is updated on a regular basis, however, other functions of the database are still undergoing beta testing.

Due to staff constraints, CWRM has prioritized pumpage data collection to focus on designated water management areas and large users in non-designated areas. Once CWRM achieves a greater level of compliance with the reporting of pumpage data, CWRM intends to improve compliance with chloride (or conductivity) data reporting, followed by water-level reporting.

The following issues and concerns are associated with pumpage, water-level, and chloride (conductivity) data collection:

- Immediate correlation between pumpage, chloride (or conductivity), and water levels cannot be achieved. Time lags exist between pumping activities and aquifer response. Changes in water levels and chlorides (or conductivity) may not manifest immediately and lag periods may be several months long. In addition, water levels in coastal monitoring wells may be overwhelmingly governed by ocean level and tidal signals and may completely mask changes due to recharge or withdrawal.

- It is difficult to correlate water uses with the associated changes in chloride concentrations (or conductivity) and water levels; the effects of additional variables such as subsurface geology are also difficult to correlate.

- It is difficult to execute analyses of small-user data versus large-user data.

- Presently, pumpage, water-level, and chloride (or conductivity) data is not shared between agencies through integrated databases. As is the case with spring discharge information, agency jurisdictional issues must be addressed before the integration and sharing of data can occur.

CWRM anticipates that the issues listed above can be addressed by the agency when the water use reporting database is fully operational and updated with current water use reports. It is a priority to obtain more ground water pumpage, chloride (or conductivity), and water level information. Without this data, comprehensive, accurate and timely hydrologic analysis cannot be executed; CWRM will be unable to asses all stresses placed on ground water and the resulting individual well reaction to such stresses. Water use reporting (large and small users) in a generally uniform and timely fashion is a major goal of the water use database, as is the capability of having online reporting. This will greatly speed up correlations between pumpage, chloride concentrations (or conductivity), and water levels. CWRM enforcement of water use reporting requirements is essential to improving the quality and timeliness of the CWRM database, which will in turn provide a quicker and more accurate picture of aquifer health.

G.2.6 Recommendations for Monitoring Ground Water Resources

Recommendations for the improvement and expansion of ground water monitoring activities in the State of Hawai‘i are listed below and are categorized by activity type.

G.2.6.1 General Recommendations

The recommendations listed below apply to statewide activities for maintaining current programs and planning for future monitoring activities.

- **Maintain/increase USGS co-op funding:** The number of wells monitored by the USGS in the UGSG-CWRM cooperative agreement has declined by 95 percent since 1995. Water-level monitoring on the neighbor islands is not adequate and must be expanded. Federal and State funding for the cooperative program should be increased. The increased funding would reflect inflationary costs as well as expanding the data collection network to monitor new centers of water development.

- **Conduct Regular Analysis of Aquifer Health**: As the Survey Branch collects water use and aquifer data through its monitoring programs, regular analysis should occur to identify potential threats to aquifer sustainability. Water data is critical to support current management policies regarding the sustainability of ground water resources.

- **Planning a Statewide Ground Water Monitoring Network:** It is recommended that a statewide plan be developed to implement monitoring activities and to direct the expansion of monitoring networks, especially for deep monitoring wells. This plan should also project funding requirements for data collection activities and improvements to the monitoring networks.

- **Develop Comprehensive Monitoring Plans for Aquifer System Areas of Concern:** It is recommended that comprehensive monitoring plans be developed for aquifer system areas under threat or there is uncertainty about the hydrogeologic conditions.

Deep Monitor Wells

The items below summarize the recommendations for the Deep Monitor Well Program. Included in this listing are planned near-term improvements, as well as other projects that require the approval and appropriation of funds.

- **Drill new deep monitor and water level monitor wells:** Deep monitor wells should be drilled in most of the basal aquifers in Hawai‘i. Also, dedicated water-level monitor wells should be located or drilled in all of the aquifers in Hawai‘i.

- **Better Spatial Coverage:** Ideally, deep monitor wells within an aquifer should be located to provide coverage from an inland or mauka site, a middle site near withdrawal areas, and a makai site to monitor changes in the distal portion of the basal lens. Locating wells in this fashion provides a cross-section of the basal aquifer.

- **Review Monitoring Well Network:** The monitoring well network should be reviewed to: 1) identify wells located in large pumping batteries, that are directly influenced by pumpage, and should be considered for replacement; and 2) identify former production and/or existing water-level observation wells where it may be feasible to convert existing wells to deep monitoring wells.

- **New Data Collection:** Existing wells or new wells should be outfitted with nested piezometers or multiple piezometers to observe vertical flow in the aquifer system areas where such information is important. In addition, conductivity data loggers could be lowered to depths identified in the conductivity profile logs that suggest vertical flow and left to monitor changes in conductivity over time. Where available, calibrated dispersion coefficients from deep monitor well data should be included in new 3-D solute transport ground water flow models.

- **Graphical Mapping of Data**: Conduct geospatial mapping of top of TZ, MPTZ, and water-level elevations. These maps would show actual water levels and expected water levels from the deep monitor well data.

- **Borehole Flow Analysis**: Recent data collected by the USGS and CWRM has shown that borehole flow does occur under certain natural and induced (anthropogenic) conditions in deep monitor wells[1] (Rotzoll USGS, 2010). As a result, CTD profiles may not accurately reflect the transition zone elevations within the aquifer. CWRM will evaluate the influence of vertical borehole flow on a well by well basis and develop recommendations for future DMW design and installation details (and consider existing DMW retrofits) to mitigate the influence of vertical flow within the DMWs.

Water-Level Observation Wells

The items below summarize the recommendations for water-level observation wells. Included in this listing are planned near-term improvements, as well as other projects that require the approval and appropriation of funds.

- **Upgrade Data Collection System:** 1) All new CWRM deep monitor wells will be fitted with transducers or other devices that will collect water-level data on a continuous basis. 2) Add transducers (or other devices) to provide continuous water-level data collection at existing BWS and USGS deep monitor wells in the network throughout the Pearl Harbor Aquifer Sector Area. 3) Eliminate redundant data collection from some monitoring sites.

- **Drill New Water-Level Observation Wells**: The primary considerations for drilling new observation wells is to better delineate the basal aquifer boundaries, and to locate geological boundaries and/or structures that would affect ground water flow. In general, even with the addition of water-level measuring devices in the existing deep monitor and water-level observation wells, coverage is lacking toward the interior of aquifer sector areas. New water-level observation wells or test holes should be drilled or developed in interior areas following a mauka-to-makai orientation.

- **Resurvey All Measuring Points for Water-level Observation Wells, Including Deep Monitor Wells:** In addition to new water-level monitoring, a priority goal is to resurvey all measuring points (benchmarks) related to water-level data. This action would include all new wells and existing wells. Because many of the observation wells were drilled over a timespan of several years, it is uncertain whether the elevation of measuring points located on the wells (from which the water-level elevations are derived) are referenced to the same datum. Therefore, synoptic water-level maps may not provide an accurate representation of water-level gradients. Geodetic-control benchmarks in the State of Hawaiʻi should be resurveyed to ensure consistent and accurate water level measurements.

- **Conduct More Synoptic Water-level Surveys:** In a cooperative effort, the USGS, Honolulu BWS, and CWRM completed two synoptic water-level surveys of the Pearl Harbor Aquifer Sector Area (August 17, 2011 and April 26, 2012). The most recent synoptic survey of the ʻĪao and Waiheʻe Aquifer System Areas was on September 15, 2015. Water-level measuring tapes owned by the three agencies were calibrated against a USGS reference steel tape. Correction factors to the individual tapes were applied to each measurement. All measurements within the Pearl Harbor Aquifer Sector Area were completed within a four-hour period on each day.

Synoptic water level surveys should be conducted at least twice a year in all important areas. All water-level tapes should be calibrated against the USGS reference steel tape at least once every two years and correction factors updated. With the height modernization of measuring point benchmarks, the synoptic water levels will provide an accurate "snapshot" into the direction of ground water movement.

- **Reinstate Water Level Measurement in Discontinued Observation Wells:** CWRM should evaluate the list of 173 discontinued observation wells and prioritize important wells that should be monitored. Once this is done, arrangements should be made with well owner to begin quarterly measurement of water levels in selected wells. CWRM should also coordinate with USGS on monitor well details, e.g., benchmarks, reference points, site access, etc.

- **Monitor Water Levels in High-Level Wells:** There is insufficient coverage in the high-level aquifers, and water level monitoring is crucial in order to assess the effects of pumpage from these systems. High-level aquifers are often relatively small and need to be monitored for resource depletion.

Spring Discharge and Chemistry Measurements

The items below summarize the recommendations regarding spring discharge and chemistry data collection, information management, and data analyses. Included in this listing are planned near-term improvements, as well as other projects that require the approval and appropriation of funds.

- **Integration of Databases:** Secure commitments from agencies who collect spring data, to further the use and integration of the spring discharge and chemistry databases, and to explore options for data application/studies to help understand flow dynamics of basal lenses.

- **Additional Analyses**: Analyze spring data for parameters, such as nitrate, and compare with data analyses performed in well water. This may provide insight on the velocity of ground water flux over time.

- **Additional Monitoring:** Use data loggers to monitor temperature and conductance at spring orifices, logging daily changes. Temperature and conductance data may provide greater insight into the movement of the lens.

Pumpage, Water-Level, and Chloride Data Management

The items below summarize the recommendations for well pumpage, water-level, and chloride (or conductivity) data management and dissemination. Included in this listing are planned near-term improvements, as well as other projects that require the approval and appropriation of funds.

- **Updating and Maintaining CWRM's Water Use Reporting Database**: In the effort to become more efficient at managing all its water resource information, CWRM's Water Resource Management Information System (WRIMS) was launched in July 2012. This system enables Water Use Reporters to file their Water Use Reports on-line and monitor their historical use from each source via the internet. The updating and maintenance of the WRIMS database is paramount for timely analysis and reporting of pumpage, water-level, and chloride (or conductivity) data statewide. CWRM is currently focused on obtaining pumpage reports from all users in designated water management areas and from large users in non-designated areas. Subsequently, CWRM will pursue statewide reporting of pumpage, water-level, and chloride (or conductivity) data from all water use reporters.

- **Integration of Databases and Public Access**: Honolulu BWS historical pumpage and chloride data should be integrated with CWRM and USGS information in an appropriately managed database. Assuming that security and sensitivity of the data can be preserved, there should be limited public access via the Internet. Based on the success of this effort, the database should be expanded to include information from other county water departments.

- **Design and Implement Quality Assurance / Quality Control Protocols:** Data voluntarily submitted to CWRM may have quality and accuracy issues – particularly well pumping reports. Site visits with well operators to verify measurement equipment and methods and to provide training and outreach would improve confidence in data submitted to CWRM.

G.3 Surface Water Monitoring

Similar to ground water resources, long-term monitoring information is critical to developing appropriate management scenarios for surface water resources. There is a long history of surface water monitoring in Hawaiʻi; however, much of the historic record is focused on large, agricultural irrigation systems that were active throughout the state for much of the 20th Century. Surface water management has grown in complexity, due largely to recent closures of sugar and pineapple plantations and the potential for restoration of stream ecosystems. These changes are further complicated by the demands of a burgeoning population that requires high-quality ground water for drinking purposes, as well increasing amounts of surface water for irrigation needs (e.g., diversified agriculture, golf courses, landscaping, etc.) and for the perpetuation of cultural gathering rights.

Monitoring various stream characteristics, along with appropriate climate and physical data, can provide valuable information on stream health and integrity. Important considerations for surface water monitoring are described below.

Streamflow: Streamflow is the primary surface water characteristic measured during surface water monitoring activities. Most often, streamflow is measured at continuous-record gaging stations, which are permanent structures constructed on the bank of a stream. These stations typically remain in operation for a number of years, provided that funding is available. The stations provide annual flow values and allow for long-term trend analysis. The USGS maintains numerous stations throughout Hawaiʻi. These stations collect data with sufficient frequency to identify daily mean values and daily variations in flow. Streamflow may also be measured at specific sites intermittently or as necessary for a specific study. The USGS refers to these sites as partial-record stations. While flow is often not measured with sufficient frequency to provide daily statistics, these measurements may aid in trend analysis and provide a snapshot of flow at a specific period in time.

Rainfall: Rainfall data represents the “input” to surface water systems and provides basic information to complete the water balance equation. Surface water runoff models rely on rainfall, landcover, soil, geology, and land use information to determine how much rainfall percolates into subsurface layers, and how much water runs off the land as surface water. Ideally, rainfall data should be complemented with fog drip and evapotranspiration data to provide for more accurate modeling conditions. Rainfall and precipitation monitoring are discussed further in **Section G.4**.

Diversions: There are approximately 1,380 registered and permitted stream diversions statewide. A considerable number of these diversions have been verified in the field, but much of the information is outdated as landowners change and systems deteriorate. In 2007, CWRM initiated a statewide field investigations project to verify registered stream diversions. CWRM recognized early that available funding would not be sufficient, so a prioritized list was developed that first looked at areas with issues pending before the Commission followed by regions that contained large irrigation systems. The resulting study covered much of Maui and Kauaʻi, but not Oʻahu and Hawaiʻi. Portions of Koʻolaupoko on the island of Oʻahu were also verified with the assistance of the Honolulu Board of Water Supply. CWRM continues to refine its Water Resource Information Management System and update diversion information as field investigations are conducted statewide.

One of the difficulties in assessing surface water diversions is the wide range of methods that are employed to divert stream water. Diversion structures may consist of various materials and installations, including PVC pipes, hoses, concrete intakes, or hand-built rock walls. Water can be moved from the stream channel into the diversion by pump or by gravity flow. It is difficult to quantify the amount of diverted stream flow statewide, as most diversions are not equipped with gages, and access to diversion sites may be restricted or require special arrangements. Often, particularly for irrigation systems associated with former plantation lands, intake structures are located high in the mauka sections of the watershed and are only accessible by four-wheel drive or on foot. The quantification of diverted flow, whether estimated or measured directly, is a key component in streamflow analysis, allowing investigators to estimate natural streamflow and identify diversion impacts to instream uses. Continuous, long-term measurement of diverted streamflow is ideal.

A long-term monitoring program must be supported by an initial verification of each registered and permitted diversion structure and the amount of flow diverted at each site. This is a critical first step towards comprehensive management of surface water and is being executed by CWRM. Long-term monitoring programs and improved regulation of stream diversion structures will be facilitated by field verification activities.

Irrigation Systems: Throughout Hawai‘i, large irrigation systems are responsible for the majority of the annual volume of diverted surface water flow. While this water was traditionally used for irrigation of sugarcane and pineapple, the closure of these industries has made both land and irrigation water available for diversified agriculture, stream restoration, and other applications. Due to the complex nature of large irrigation systems, it is difficult for irrigation managers to measure flow diverted at all surface water intakes. Instead, water flow through irrigation systems is usually measured at a handful of key locations along the system alignment. As a result of the September 1992 Commission action exempting surface water users from reporting requirements until standard methods are approved (see **Appendix H, Section H.3 CWRM Water Use Reporting Requirements**), few irrigation system managers provided CWRM with water use reports. In January 2014, the Commission repealed this policy as CWRM staff sought to develop greater surface water use reporting. CWRM's Stream Protection and Management (SPAM) Branch has compiled an inventory of stream diversion measurement methods, developed a water user reporting database, implemented a web-based water use reporting function, and continues to seek out and work with new surface water use reporters. Workshops for large and small irrigation system operators were conducted to provide education and onsite training for measuring and reporting diverted surface water as part of CWRM's water conservation plan implementation. These water use reports are the primary information source for CWRM's monitoring and regulating of stream diversions and surface water use by irrigation systems.

End Uses: End use primarily refers to the diversion of water from large irrigation systems. Reporting water use amounts for end uses is not required by CWRM, except in designated surface water management areas. However, via the registration of stream diversion works process (circa 1989), CWRM received a large number of applications by end users reporting their water use. In addition, CWRM may often request end use amounts when addressing surface water issues for a specific area. End use information is critical to determine system efficiency and reasonable and beneficial water use.

Biology: Stream biology is an important factor in determining CWRM's regulatory authority for a stream channel and in the setting of instream flow standards. CWRM relies heavily on biological information provided by the DLNR Division of Aquatic Resources (DAR), along with data collected by other agencies such as USGS and DOH. The point-quadrat study method preferred by DAR is a combined survey of macrofauna and microhabitat, often performed randomly along the length of a stream segment. Biological surveys generally provide information on species composition (native v. exotic), distribution, flow type, substrate, and basic water quality parameters.

Water Quality: Water quality monitoring falls under the jurisdiction of the DOH. However, the State Water Code provides that CWRM consider surface water quality in determining instream flow standards, in the issuance of stream channel alteration permits, and in permitting stream diversion works. Stream channel alterations, such as channel hardening, ford crossings, culverts, and diversion structures, may have a direct impact upon water quality. Conversely, CWRM must weigh the impact of existing alterations and diversions in its determination of appropriate instream flow standards. Relationships between water quality, aquatic species habitat, biodiversity, and land use may be taken into consideration when determining water availability for instream and offstream uses.

G.3.1 Existing CWRM Surface Water Monitoring Programs in Hawaiʻi

The Hawaiʻi Administrative Rules, Chapter 13-169-20 (2), recognizes that, "a systematic program of baseline research is…a vital part of the effort to describe and evaluate stream systems, to identify instream uses, and to provide for the protection and enhancement of such stream systems and uses." CWRM's SPAM Branch is currently developing an independent, long-term monitoring program, and continues to work closely with the USGS to operate and maintain a statewide network of surface water gaging stations (see **Figure G-21** to **Figure G-25**[6]). The data collected through the CWRM-USGS cooperative monitoring program serves as the backbone of CWRM's SPAM Program. The long-term record provided by the gaging station network supports a wide range of statewide studies (e.g., flood analysis, water quality, ground/surface water interaction, biology, etc.).

G.3.1.1 CWRM-USGS Cooperative Monitoring Program

Similar to the cooperative groundwater monitoring program described in the previous sections, CWRM and the USGS work together to collect surface water data throughout the State. Of the 376 perennial streams in Hawaiʻi, over 140 have been gaged since the inception of the cooperative agreement. Stream gage data is collected and analyzed as part of the overall hydrologic data-collection network. CWRM staff continuously reviews and evaluates the data-collection network for duplication of effort, usefulness of information, and for monitoring deficiencies in a particular geographic area. USGS data collection and analysis methods are described below.

Data Collection

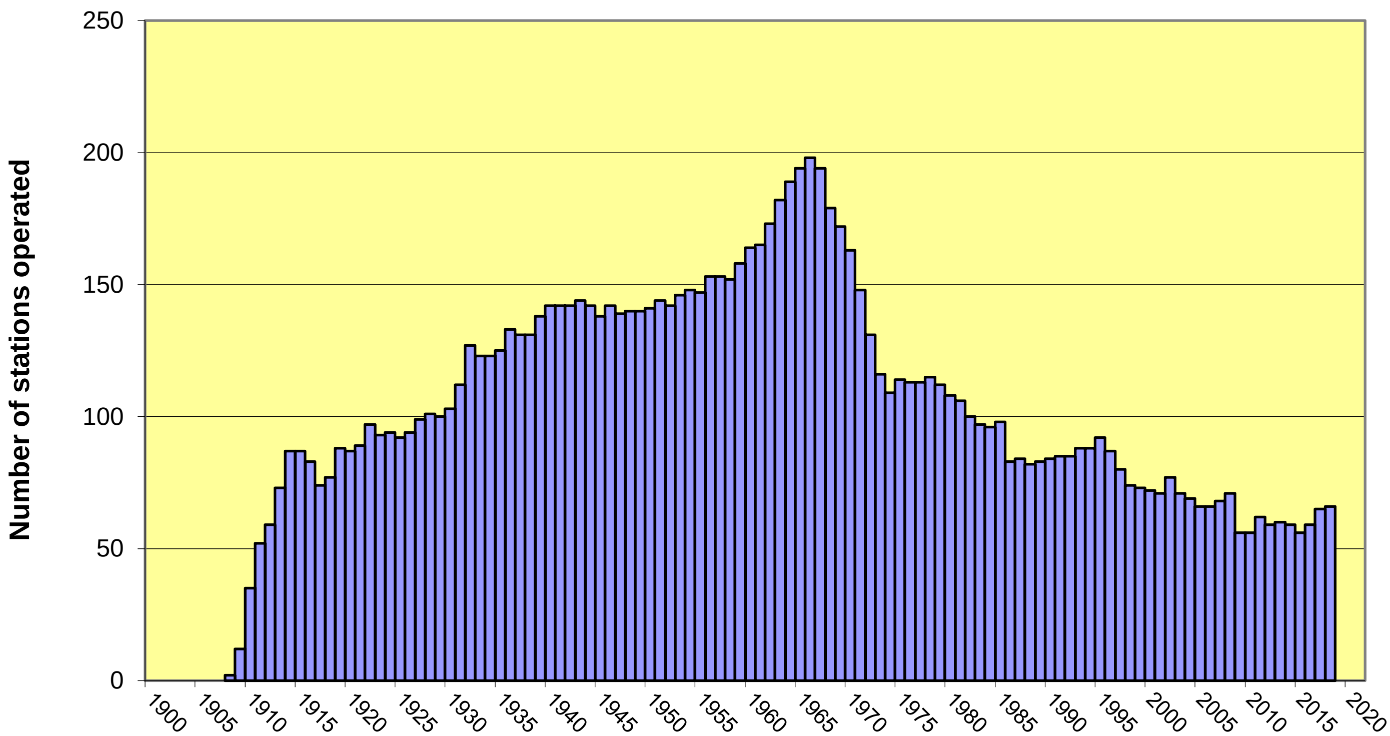
Continuous-Record Gaging Stations: The Hawaiʻi surface water data collection program operated by the USGS officially began in 1909, with the establishment of 12 continuous-record gaging stations. The program quickly expanded so by 1914, there were 87 continuous-record gages in operation, however most gages were installed to evaluate potential sources of irrigation water for agriculture. The program continued to grow and peaked in 1966 with a total of 197 continuous-record gages. Over the years, gages were discontinued for a variety of reasons. The primary reasons have been either economic and/or because a gage has fulfilled its data collection requirements. **Figure G-20** shows the number of continuous-record gaging stations in operation from 1909 to 2008. The CWRM funded surface water data-collection stations in operation for Fiscal Year 2017 are listed in **Table G-6**.

[6] Fontaine, R.A., 2006, Water Resources Data, Hawaii and other Pacific Islands, Water Year 2005, Volume 1. Hawaii, U.S. Geological Survey Water-Data Report HI-05-1, 344p.

Continuous-record gaging stations are gages that record some type of data, generally water-surface elevation, on a continuous basis. This data can be used to compute streamflow for any instantaneous period or for selected periods of time (e.g., day, month, year). These stations collect long-term baseline data, in order to provide a series of consistent streamflow observations. Streamflow data is used to identify trends in streamflow over time, analyze the statistical structure of hydrologic time series, and to evaluate flow regime trends in response to various local, regional, or global changes.

Some continuous-record gaging stations have been designated as long-term trend stations. These stations provide data used analyzing the statistical structure of hydrologic time series and can be used as a baseline for evaluating the flow regimes of other streams or for climate change monitoring purposes. For a gage to be considered a long-term trend station, it must be on a stream in a drainage basin that has undergone no significant human alterations and is expected to remain that way into the future.[7]

Figure G-20 History of USGS continuous-recording stream gage operation



[7] Fontaine, R.A., 1996, *Evaluation of the surface-water quantity, surface-water quality, and rainfall data-collection programs in Hawaii, 1994*: U.S. Geological Survey Water-Resources Investigations Report 95-4212, 125 p.

Table G-6 CWRM Funded USGS Surface Water Data-Collection Stations in Operation for Water Year 2017

USGS Station No.	Island	USGS Station Name	Station Type	Frequency
16031000	Kauai	Waimea River at Waimea	SW RT-Cont	Continuous - RT
16049000	Kauai	Hanapepe Riv blw Manuahi Str near	SW RT-Cont	Continuous - RT
16060000	Kauai	SF Wailua River near Lihue	SW RT-Cont	Continuous - RT
16068000	Kauai	EB of NF Wailua River near Lihue	SW RT-Cont	Continuous - RT
16071500	Kauai	Left Branch Opaekaa Str near Kapaa	SW RT-Cont	Continuous - RT
16097500	Kauai	Halaulani Str at alt 400 ft near Kilauea	SW RT-Cont	Continuous - RT
16103000	Kauai	Hanalei River near Hanalei	SW RT-Cont	Continuous - RT
16208000	Oahu	SF Kaukonahua at E. Pump nr	SW RT-Cont	Continuous - RT
16227500	Oahu	Moanalua Stream near Kaneohe	SW RT-Cont	Continuous - RT
16229000	Oahu	Kalihi Str near Honolulu	SW RT-Cont	Continuous - RT
16240500	Oahu	Waiakeakua Str at Honolulu	SW RT-Cont	Continuous - RT
16294900	Oahu	Waikane Str at alt. 75 ft at Waikane	SW RT-Cont	Continuous - RT
16345000	Oahu	Opaeula Str near Wahiawa	SW RT-Cont	Continuous - RT
16294100	Oahu	Waiahole Stream above Kamehameha	SW RT-Cont	Continuous - RT
16296500	Oahu	Kahana Str at alt 30 ft near Kahana	SW RT-Cont	Continuous - RT
16301050	Oahu	Punaluu Str above Diversion near	SW RT-Cont	Continuous - RT
16508000	Maui	Hanawi Stream near Nahiku	SW RT-Cont	Continuous - RT
16604500	Maui	Iao Stream at Kepaniwai Park near	SW RT-Cont	Continuous - RT
16614000	Maui	Waihee Rv above Waihee Dtch Intake	SW RT-Cont	Continuous - RT
16620000	Maui	Honokohau Stream near Honokohau	SW RT-Cont	Continuous - RT
16518000	Maui	West Wailuaiki Stream near Keanae**	SW RT-Cont	Continuous - RT
16587000	Maui	Honopou Stream near Huelo	SW RT-Cont	Continuous - RT
16704000	Hawaii	Wailuku River at Piihonua	SW RT-Cont	Continuous - RT
16720000	Hawaii	Kawainui Stream near Kamuela	SW RT-Cont	Continuous - RT
16770500	Hawaii	Paauau Gulch at Pahala	SW RT-Cont	Continuous - RT
16717000	Hawaii	Honolii Stream near Papaikou	SW RT-Cont	Continuous - RT
16725000	Hawaii	Alakahi Stream near Kamuela	SW RT-Cont	Continuous - RT

Figure G-21 Locations of Streamflow gaging stations on Kaua‘i (Water Year 2017)

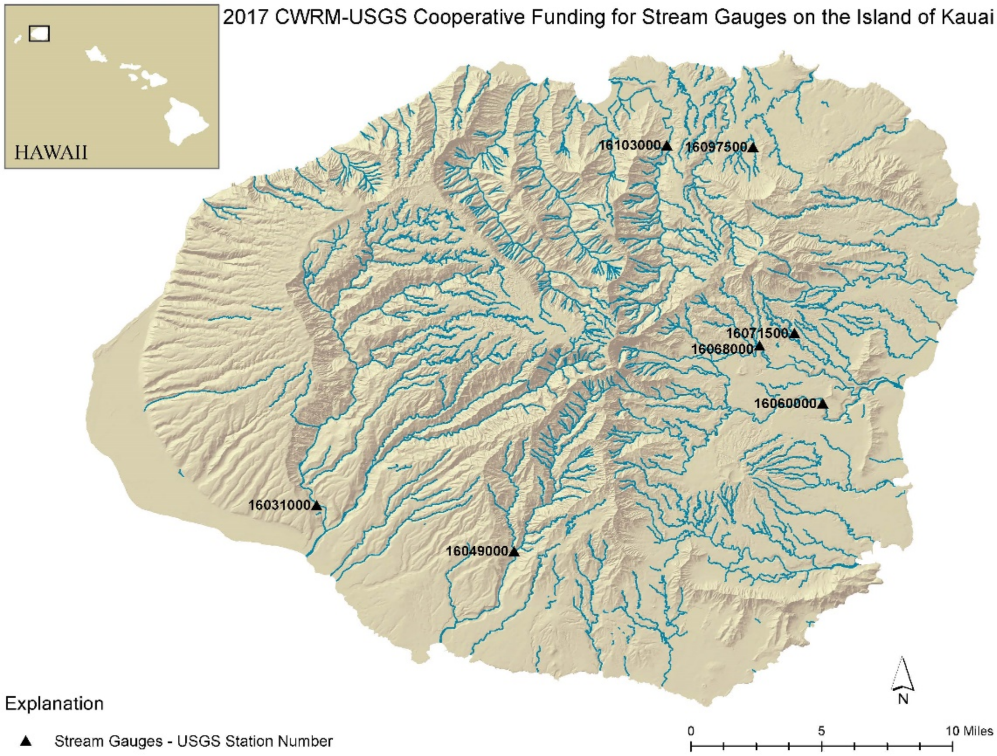


Figure G-22 Locations of Streamflow gaging stations on O‘ahu (Water Year 2017)

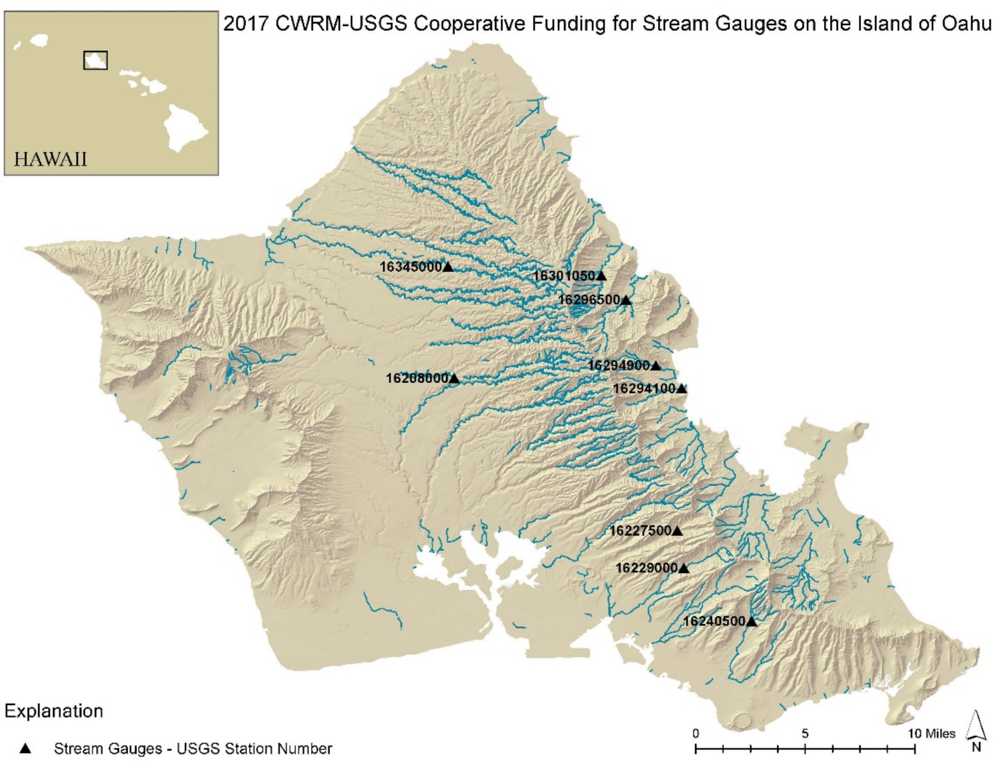
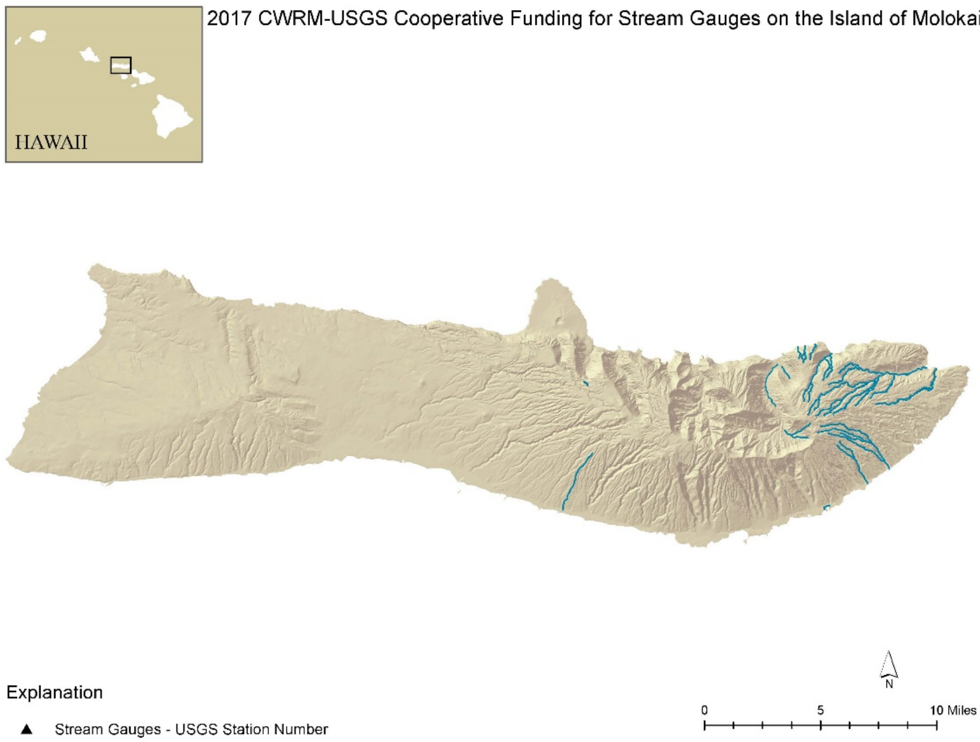


Figure G-23 Locations of Streamflow gaging stations on Moloka'i (Water Year 2017*)



*No CWRM Funded USGS streamflow gaging stations on Moloka'i for Water Year 2017

Figure G-24 Locations of Streamflow gaging stations on Maui (Water Year 2017)

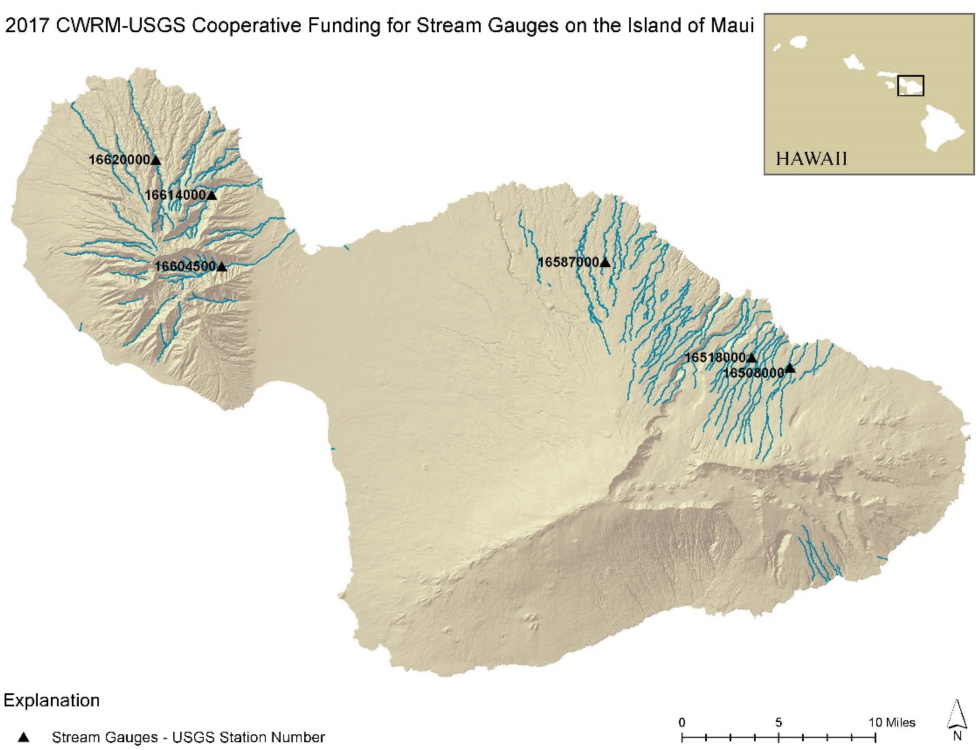
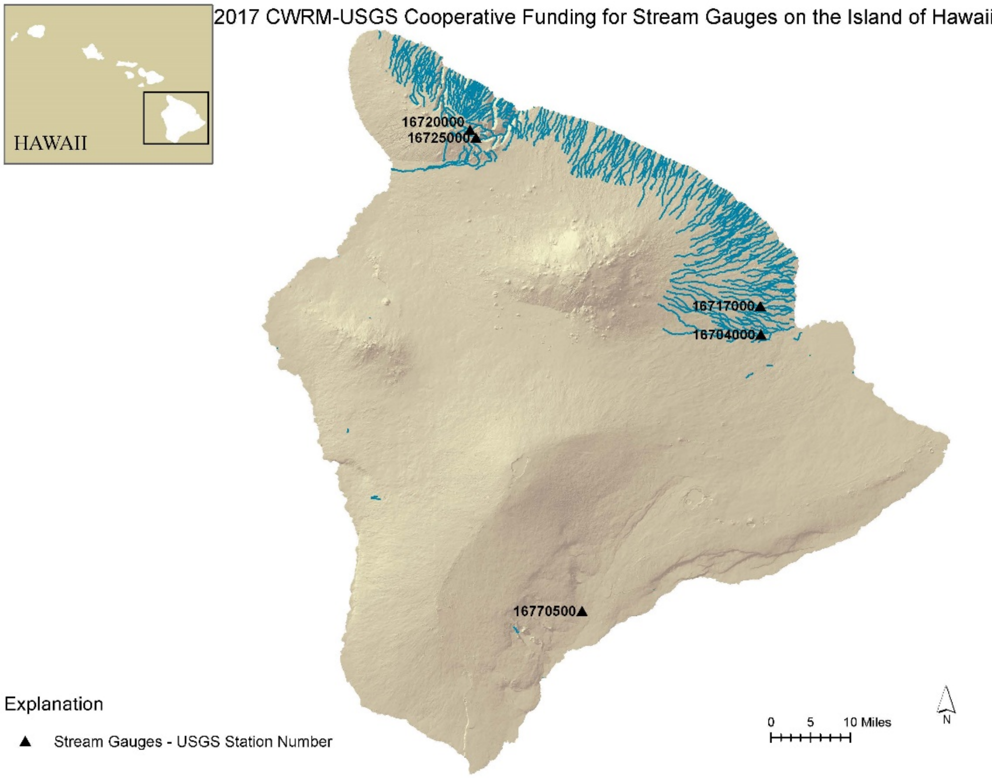


Figure G-25 Locations of Streamflow gaging stations on Hawai‘i (Water Year 2017)



Crest-Stage Gaging Stations: Crest-stage gages provide only the peak surface water elevation that occurred between servicing visits to the gages. Peak elevation data is often used to compute discharges for selected flood peaks, and only the maximum flood peak for each water year is typically published.

Data from crest-stage gaging stations can be incorporated into a regional flood frequency analysis, by determining the magnitude and frequency of peak flow data for a period of at least ten years. This is especially important in areas where continuous-record gaging stations do not exist, as crest-stage gages are an efficient and cost-effective means of collecting flood stage data.

Low-Flow Partial Record Stations: For streams that lack an extensive or comprehensive long-term gaging station record, alternative methods that are both timely and cost-effective may be required. Low-flow partial records stations have been demonstrated to be a viable alternative in Hawai‘i for use in estimating base flow at sites without long-term gaging stations.[8]

[8] Fontaine, R.A., Wong, M.F., and Matsuoka, Iwao, 1992, *Estimation of median streamflows at perennial stream sites in Hawaii*: U.S. Geological Survey Water-Resources Investigations Report 92-4099, 37 p.

Low-flow, partial records stations require a minimum of ten discharge measurements during periods of base flow. Measurements should be made over a variety of baseflow conditions and during independent recessions, following periods of direct runoff. The discharge measurements are then correlated with the concurrent daily discharges recorded at an index station (a nearby gaging station with long-term data available) to accurately estimate streamflow statistics.[9]

Seepage Runs: With the complex nature of ground and surface water interactions, it is often necessary to conduct seepage runs to identify gaining stream reaches (where base flow increases due to ground water discharge) and losing stream reaches (where base flow decreases due to outflow through the streambed into the underlying ground water body). Seepage runs are particularly important when conducting hydrologic investigations on streams that have been altered by diversions and return-flow practices. Seepage runs can accurately identify stream flow losses and gains throughout the system.

A seepage run is an intensive data collection effort, in which discharge measurements are made at several locations along a stream reach. Measurements are made during periods of base flow when flow rates at any given location in the stream are relatively constant. The time between the first and last measurement in the seepage runs are minimized to reduce the effects of temporal variability.

Data Analysis

Similar to the data collection efforts identified above, CWRM depends on the data analysis efforts of the USGS. These analyses are based on the data compiled from USGS' extensive network and historical records of surface water gaging stations. Data analysis is important in characterizing past and present streamflow conditions, identifying short-term and long-term trends, and understanding the interaction of ground and surface water. In turn, this information is applied to a wide range issues, such as stream biology, water quality, flooding, agriculture, and ultimately water resource management and planning. The basic analyses identified below are essential to understanding the general nature and occurrence of surface water. More detailed analyses are conducted by USGS on a project-specific basis.

Streamflow Hydrograph: A streamflow hydrograph is a graphical representation illustrating changes in flow or water-level elevation over time. This is the simplest analysis of data obtained from continuous-record gaging stations. At a glance, the hydrograph is useful in identifying periods of high- and low-flows and making general observations of streamflow characteristics.

[9] Fontaine, R.A., 2003, *Availability and distribution of base flow in lower Honokohau Stream, Island of Maui, Hawaii*: U.S. Geological Survey Water-Resources Investigations Report 03-4060, 37 p.

Summary Statistics: Under the cooperative agreement between the USGS, CWRM, and various other agencies, the USGS previously produced an annual hydrologic data report for Hawai'i, documenting the information gathered from its surface and ground water data collection network. The data was analyzed and published in summary tables that are useful in understanding basic streamflow characteristics. Such data is also valuable for infrastructure design and water resources planning and management. A description of the summary statistics and the most recent data (by water year) is available for download from the USGS website (http://hi.water.usgs.gov). Current and historical water data is now provided by USGS' National Water Information System Web Interface (NWISWeb). NWISWeb is the online tool to search, display, and download a gaging station's entire record and general station information.

Flow Duration Curves: Flow duration curves provide a simple and useful way of representing streamflow data by illustrating the flow characteristics of a stream throughout the range of discharge.[10] By definition, a flow duration curve is a cumulative frequency curve that shows the percentage of time that specified discharges are equaled or exceeded. For example, one of the most frequently used points on a flow duration curve is the 50th percentile, or median discharge. This is the discharge that is equaled or exceeded 50 percent of the time.

Generally, a smooth flow duration curve indicates that there are no flow manipulations of significance affecting the discharge recorded. A curve with a steep slope denotes a highly variable stream that receives flow volumes largely from direct runoff, whereas a curve with a flat slope that levels out at the higher percentiles is indicative of a significant, sustained source of base flow.

Hydrograph Separation: Identifying a stream's base flow component is important for water resource planning and management, as base flow indicates the long-term flow volume that can be sustained by the stream. Streamflow data recorded from a gaging station is frequently divided into two basic components, base flow and direct runoff. Base flow is that part of stream flow, derived from ground water, while direct runoff is the remainder of stream flow, derived from surface and subsurface flow occurring in response to excess rainfall.[11]

The USGS commonly uses an automated hydrograph separation method.[12] This computerized base flow separation program, or Base Flow Index (BFI), is a FORTRAN program based on a set of procedures developed by the Institute of Hydrology (United Kingdom). The method requires the input of two variables, *N* (number of days) and *f* (turning-point test factor). The separation method divides the daily streamflow data into non-overlapping periods, each *N*-days

[10] Searcy, J.K., 1959, *Flow-duration curves: U.S. Geological Survey Water-Supply Paper 1542-A*, 33p.

[11] Fontaine, R.A., 2003.

[12] Wahl, K.L., and Wahl, T.L., 1995, *Determining the flow of Comal Springs at New Braunfels, Texas: Proceedings of Texas Water '95, A Component Conference of the First International Conference on Water Resources Engineering, American Society of Civil Engineers, August 16-17, 1995*, San Antonio, Tex., 77-86.

long, and determines the minimum flow in each period. If the minimum flow within a period is less than *f* times the minimums of the adjacent periods, then the central period minimum is made a pivot (or turning point) on the base-flow hydrograph. Conceptually, the variable *N* represents the number of days following a storm before direct runoff generally ceases.[13]

G.3.2 Other Surface Water Monitoring Programs

G.3.2.1 USGS Cooperative Agreements with Other Entities

The cooperative agreement between USGS and CWRM is one component of a larger gaging network that is cost-shared by several cooperators, including county water departments, State and federal agencies, DLNR divisions, and private landowners (for a complete list, see **Table G-2 USGS Cooperative Monitoring Program Fiscal Year 2014 Cooperators**). The aggregate of data collected through these various agreements is available online via the USGS' NWISWeb. The online tool includes the entire range of data collected through the USGS's extensive network: discharge at surface water gaging stations, crest-stage partial record stations, low-flow partial record stations, water surface elevation for ground water wells, rainfall records, and water quality for both surface and ground water stations. All USGS hydrologic data is available online at https://waterdata.usgs.gov/nwis.

G.3.2.2 Division of Aquatic Resources Aquatic Survey Database

As noted earlier in **Section G.3**, CWRM works closely with the DLNR Division of Aquatic Resources in collecting and managing biological data related to streams. This data is necessary to evaluate applications for Stream Channel Alteration Permits (SCAP) and Stream Diversion Works Permits (SDWP), and anticipated impacts to instream uses. Biological data is also a key consideration in the establishment of measurable instream flow standards.

DAR utilizes a fairly comprehensive aquatic survey database to store and maintain information on a wide range of biological data. The database was originally intended to update the information from the 1990 Hawaiʻi Stream Assessment, and to store data obtained through DAR's point-quadrat survey method. In the course of database development, DAR discovered and incorporated into the database historic records from the early Hawaiʻi Division of Fish and Game. The database is constantly being updated as new sources of information, including various independent biological studies, are encountered and reviewed. Most recently, new data has been added pertaining to macroinvertebrates (e.g., damselflies). By evaluating the information in the DAR database, CWRM will be able to identify biological resources associated with each stream, as well as to identify those streams which have little or no data.

[13] Fontaine, R.A., 2003.

G.3.2.3 DOH Water Quality Data

The Department of Health is the agency responsible for the collection of water quality data statewide. Specifically, the DOH's Clean Water Branch, Monitoring Section oversees the collection, assessment, and reporting of numerous water quality parameters in three high priority categories as follows:

- Possible presence of water-borne human pathogens;
- Long-term physical and chemical characteristics of coastal waters; and
- Watershed assessments, including the integrity of natural aquatic environments.[14]

DOH plays an integral role in the review process for all of CWRM's surface water related permits, as DOH's water quality data and assessments are vital to instream use considerations.

Under the federal Clean Water Act, DOH is required to prepare and submit lists biennially of waterbodies not expected to meet State water quality standards. This list is referred to as the 303(d) List of Impaired Waters (303(d) List), which was most recently prepared and approved in 2004. The DOH Environmental Planning Office has developed a methodology for preparation of the 303(d) List. Part of this methodology involves the review of various sources of water quality data including:

- DOH Clean Water Branch data;
- USGS North American Water Quality Assessment Program data;
- AECOS, Inc. stream survey data (surveys conducted using the National Resource Conservation Service Visual Assessment Protocol); and
- Biological Assessments and various other studies and reports.[15]

The 303(d) List for Hawai‘i serves to contribute to the assessment of instream flow standards.

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[14] Department of Business, Economic Development and Tourism's Office of Planning–Coastal Zone Management and Department of Health's Clean Water Branch Polluted Runoff Control Program, 2000, *Hawaii's Implementation Plan for Polluted Runoff Control*.

[15] Koch, Linda, Harrigan-Lum, June, and Henderson, Katina, 2004, *Final 2004 List of Impaired Waters in Hawaii*, *Prepared Under Clean Water Act §303 (d):* Hawaii State Department of Health, Environmental Planning Office.

G.3.3 CWRM Management of Surface Water Data

CWRM has a comprehensive database to manage surface water use and stream permitting information statewide. Similar to CWRM's Ground Water Regulation program, the SPAM program requires an information management system to track and maintain data for water use reports, stream channel alterations, and stream diversion works. Labeled the Surface Water Information Management System, this database has been integrated into CWRM's Water Resource Information Management System (WRIMS) and will ultimately facilitate the setting of instream flow standards by helping CWRM to track and manage water use data, location and type of alterations to stream channels, and water use for various offstream purposes. This information will allow CWRM to assess impacts upon instream uses and to develop appropriate management scenarios at the watershed level.

G.3.3.1 Surface Water Information Management System

The Surface Water Information Management (SWIM) System addresses CWRM's need for a single, comprehensive database to store and manage all stream-related CWRM activities. This includes requests for determination, permits, petitions, complaints and disputes, and emergency authorizations. CWRM staff continues to input data into the SWIM System and improve the database design.

The SWIM System was primarily developed as a means of storing and managing data. The database will contribute to improved surface water use reporting statewide as the SPAM Branch increases staffing. The SWIM System also provides CWRM with another tool to improve CWRM operations and the agency's ability to manage surface water resources. For example, the database enables CWRM to generate reports identifying pending activities and follow-up actions. Geographic location data from the SWIM System allows staff to perform geospatial analyses of stream diversions and CWRM regulatory actions.

The SWIM System's ultimate utility is as a tool for developing measurable instream flow standards. Issues related to permitted stream channel alterations and diversions, determinations, and complaints provide information regarding on-the-ground activities occurring within watersheds. CWRM plans to expand the SWIM System to include information on stream channel alterations (e.g., channelizations, bridges, culverts, etc.) constructed prior to the establishment of CWRM; and reference materials (e.g., bibliographical information on published reports and studies) for various watersheds. The compilation of these resources into a single system will further CWRM's efforts to establish instream flow standards throughout Hawaiʻi.

G.3.3.2 Stream Diversion Verification

In 1988, CWRM began registering declarations of water use (see **Appendix H Existing and Future Demands**). At the time, staffing and funding constraints largely prevented CWRM from completing field verifications for the majority of stream diversions statewide. Policy developments placed an emphasis on ground water protection, while the statewide decline of plantations raised questions about the continued diversion of water to plantation irrigation systems. As a result, there is a deficit of surface water use data and increasing concerns regarding watershed health, stream and riparian ecosystems, and surface water resource protection.

In 2007, CWRM attempted to undertake a statewide verification of stream diversions, but due to a lack of funding was only able to complete verifications for a considerable number of areas on Maui and Kauaʻi. Subsequent assistance from the Honolulu Board of Water Supply also provided verifications for a number of diversions in the Koʻolaupoko region, Oʻahu. The data collected from these efforts will contribute to the assessment of instream uses and the establishment of instream flow standards statewide. Updated diversion information is also critical to the development of appropriate surface water monitoring programs and will identify water users that should be included in a surface water use reporting program. CWRM is continually working to verify and update diversion information and increase water use reporting.

G.3.4 Gaps in Surface Water Monitoring Activities

Surface Water Monitoring: Since the inception of the CWRM-USGS cooperative monitoring program, the USGS cost of operating a continuous-record stream gaging station has steadily increased, while CWRM funding available for monitoring has declined. The resulting gaps in the statewide monitoring network could potentially affect the integrity of hydrologic studies and investigations, as well as increase risk to public safety. Public safety is impacted where the monitoring network maintained by USGS serves the additional purpose of alerting the public of potential flood hazards. This is true particularly in large watersheds where real-time gaging stations provide government agencies and the public with up-to-date streamflow data via the Internet. Also, public agencies rely heavily on surface water discharge data for streams serving municipal water systems and for consideration in the design of highway culverts, bridges, flood structures, and other infrastructure. Maintenance of the current surface water monitoring network will require greater funding commitments in light of rising costs, along with the need for additional partner agencies that rely on the network to share in overall operating expenses.

Water Use Data: Surface water use data for the State of Hawaiʻi is inadequate. For certain areas, water use studies have been conducted either by the USGS or other government agencies. However, comprehensive watershed-wide studies are important to understanding processes within the entire drainage area, and most studies only assess a small portion of the watershed. Therefore, the extent and intensity of surface water use remains unknown in many areas of the state. Increased surface water use data is critical to the protection and management of surface water resources.

G.3.5 Recommendations for Monitoring Surface Water Resources

In light of the gaps in surface water-monitoring activities summarized in **Section G.3.4**, CWRM has identified the following recommendations for the improvement and expansion of surface water monitoring activities in the State of Hawaiʻi:

- **Increase surface water use reporting:** The SPAM Branch has completed the development and integration of its surface water use reporting system into CWRM's Water Resource Information Management System, but some enhancements still remain to be implemented. This includes necessary improvements to querying, reporting, and graphing functions. These improvements are underway as the SPAM Branch is actively reaching out to water users to begin reporting.

- **Adopt guidelines for surface water monitoring**: CWRM currently faces difficulties in regulating the amount of water diverted via registered and permitted stream diversion works. This problem stems from the lack of guidelines for surface water monitoring and the wide range of methods for diverting water. Additionally, technical knowledge among water users varies considerably. Public understanding of water use regulations must be encouraged, especially among water users and diversion works operators. Users should be educated on the correct application of water use metering and gaging methods that are appropriate for each end use. A small user, who may divert water for landscaping and small water features, has very different water metering needs compared to that of a large irrigation system operator diverting millions of gallons daily over large expanses of agricultural land. These issues offer considerable challenges, and CWRM must continue its work to develop a standardized set of methods for measuring diverted flow and water use, in accordance with CWRM's policy directive. CWRM's first effort towards this objective was to compile an inventory of surface water measurement methods in 2008. The result was a handbook of methods designed to educate and inform water users with little to no knowledge of measuring surface water flow. In 2014, CWRM conducted workshops for large and small irrigation system operators to provide education and training on measuring diverted water flow. Despite these efforts, challenges remain in developing the surface water use reporting program further. CWRM will continue to reach out to all surface water users to determine which measurement methods would best suit them and how water use reporting could be made more convenient.

- **Estimates of Streamflow Characteristics:** The lack of information on the availability of water during low-flow conditions has been particularly difficult for the development of instream flow standards. Currently, there are equations to estimate median flow in streams across the state and similar equations for high-flows have been developed to assist in flood frequency planning. In 2013, CWRM entered into a cooperative agreement with USGS for the first of two phases to apply regionalization techniques to estimate low-flow duration discharges (between the 50 and 95 flow-duration percentiles) for streams that have limited streamflow data. The study will focus on the islands of Kauaʻi, Oʻahu, Molokaʻi, Maui, and Hawaiʻi. Phase 1 consisted of extensive data entry, fieldwork, and analysis, and was completed in August 2016 with results provided in USGS' Scientific Investigations Report 2016-5103. Phase 2 was initiated in January 2017 and will involve the integration of regionalized low-flow equations into the USGS' StreamStats web-based geographic information system. Phase 2 is expected to be completed in September 2021. Upon implementation, StreamStats will allow users to interactively calculate low-flow statistics for selected streams and watersheds.

- **Maintain/increase funding for the CWRM-USGS cooperative monitoring program:** The number of continuous surface water gages maintained by the USGS has declined roughly 30 percent since 2000. Continuous monitoring in various areas throughout the state is currently inadequate to appropriately measure and monitor surface water resources and must be expanded. Both federal and state funding for the cooperative program should be increased concomitantly. Funding increases should reflect inflationary costs, as well as the need to expand the data collection network in areas where competition for surface water resources is greatest.

- **Instream flow standard monitoring**: As part of setting measurable instream flow standards statewide, CWRM must continue to plan for and develop a streamflow monitoring program. This program should include appropriate staff training, establishing protocols, assessing the existing USGS stream-gaging network, and developing a schedule to measure streams at regular time intervals on a regional scale. Monitoring efforts have been implemented for streams in Na Wai ʻEhā (Central), East Maui, and West Kauaʻi, but challenges remain including staffing turnover, changing stream conditions, maintenance of gages, and the development of technical systems to store and process collected stream data.

- **Increase collaboration to achieve goals**: The involvement of public agencies, private entities, and community organizations in watershed partnerships, alliances, and other collaborative efforts is critical in identifying water uses and assessing watershed conditions. Such partnerships foster relationships and build trust within the communities ultimately impacted by surface water management decisions. Partnerships also contribute to sound planning and can help in obtaining funding for local implementation of stream-related studies and programs.

- **Outreach and Education on Stream Diversion Measurement Methods:** In order to improve stream diversion water measurement and reporting compliance, it is important to communicate with stream diverters on what is required and expected for their water use reporting. Training workshops in the community would help to disseminate this information and assist stream diverters in meeting their water use reporting obligation.

- **Design and Implement Quality Assurance / Quality Control Protocols:** Data voluntarily submitted to CWRM may have quality and accuracy issues – particularly surface water diversion reports. Site visits with stream diversion operators to verify measurement equipment and methods and to provide training and outreach would improve confidence in data submitted to CWRM.

G.4 Rainfall Monitoring Activities

G.4.1 Overview

Rainfall data collection is fundamental to monitoring hydrologic conditions and water resources in Hawaiʻi. Rainfall is the ultimate natural source of freshwater for streams, springs, and underground aquifers. Studies have shown fog drip may be a significant contribution,[16] and melting snow (to a much lesser degree) may also contribute to ground water recharge and baseflow in some areas.

Long-term rainfall data is also important in analyzing the effects of long-term climate changes, as well as decadal and shorter-term atmospheric fluctuations, such as the Pacific Decadal Oscillation, El Niño, and La Niña events, on Hawaiian water resources. This data is also important when analyzing the effects of extreme weather events, such as floods and droughts, on water resources.

Rain gages are grouped into two categories: non-recording and recording rain gages. Non-recording instruments are manually read rain gages, which are typically sampled daily. Recording instruments are typically tipping-bucket rain gages, which can be programmed to sample at different intervals, usually 15 minutes or one hour. Some recording rain gages are telemetered to provide real-time data.

G.4.2 Rainfall Data Collection Networks

Rainfall data has been collected in Hawaiʻi since the mid-1800s. Sugar and pineapple plantations and ranches established and operated the majority of rain gages across the state. There have been over 2,000 rain gages operating at some time or another since rainfall data collection began in Hawaiʻi. In many instances, however, data quality is uncertain, due to the lack of data quality control and standardized collection methods.

Hawaiʻi had one of the densest rainfall monitoring networks in the world, due in part to the large gradient in average rainfall over very short distances and the varied microclimates across the state. There are several principal rainfall data collection networks in Hawaiʻi operated by the NWS, USGS, University of Hawaiʻi, and private entities. **Figure G-26** to **Figure G-30** show the locations of all the historic and active raingages as of 2013.

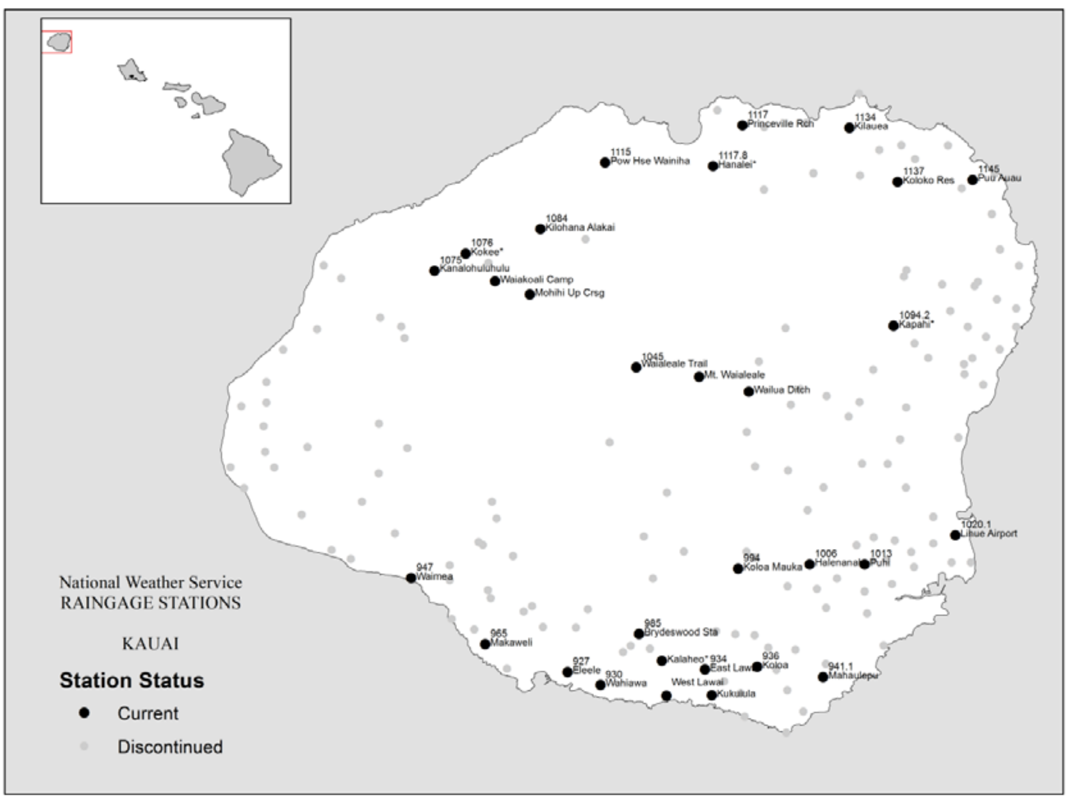
[16] Hardy, R. (1996). *A Numerical Ground-Water Model for the Island of Lanai, Hawaii*. Commission on Water Resource Management Report No. CWRM-1.

G.4.3 Rainfall Data Availability

Over the years there have been numerous data summaries published on rainfall in Hawai'i, and many of these are available in the public or University of Hawai'i libraries' reference section. Monthly summaries of data collected through the NWS cooperative observer program are published and available in hard copy or electronically from the National Climatic Data Center (NCDC). Individual NWS station data is also available electronically and on hard copy through NCDC for a fee. Data is available in daily, monthly, and annual formats. In some cases, 15-minute and one-hour data is available. This data is also available from the Western Regional Climate Center for a fee. Some USGS rainfall data is made available on their website and annual summaries are published in their Annual Water Data report. Specialized data requests can be accommodated for a fee.

To develop the 2011 *Rainfall Atlas of Hawai'i* the University of Hawai'i compiled several datasets from DLNR, the Office of the State Climatologist, the USGS, the NCDC, and data from other smaller raingage networks, thereby creating the most comprehensive raingage database to date.[17] The data however is only available as monthly totals.

Figure G-26 Raingage Stations on Kaua'i



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[17] Giambelluca TW, Chen Q, Frazier AG, Price JP, Chen Y-L, Chu P-S, Eischeid J., and Delparte, D. 2011. The *Rainfall Atlas of Hawai'i*. Available online at: http://rainfall.geography.hawaii.edu.

Figure G-27 Raingage Stations on O‘ahu

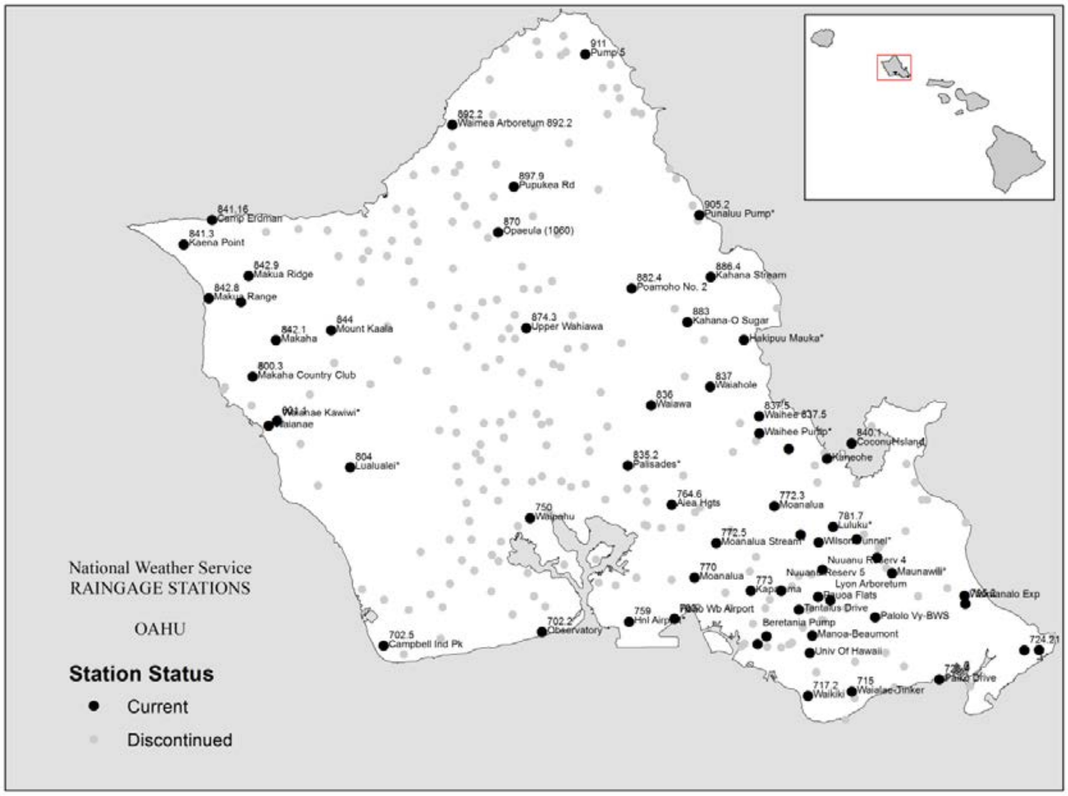


Figure G-28 Raingage Stations on Moloka‘i and Lāna‘i

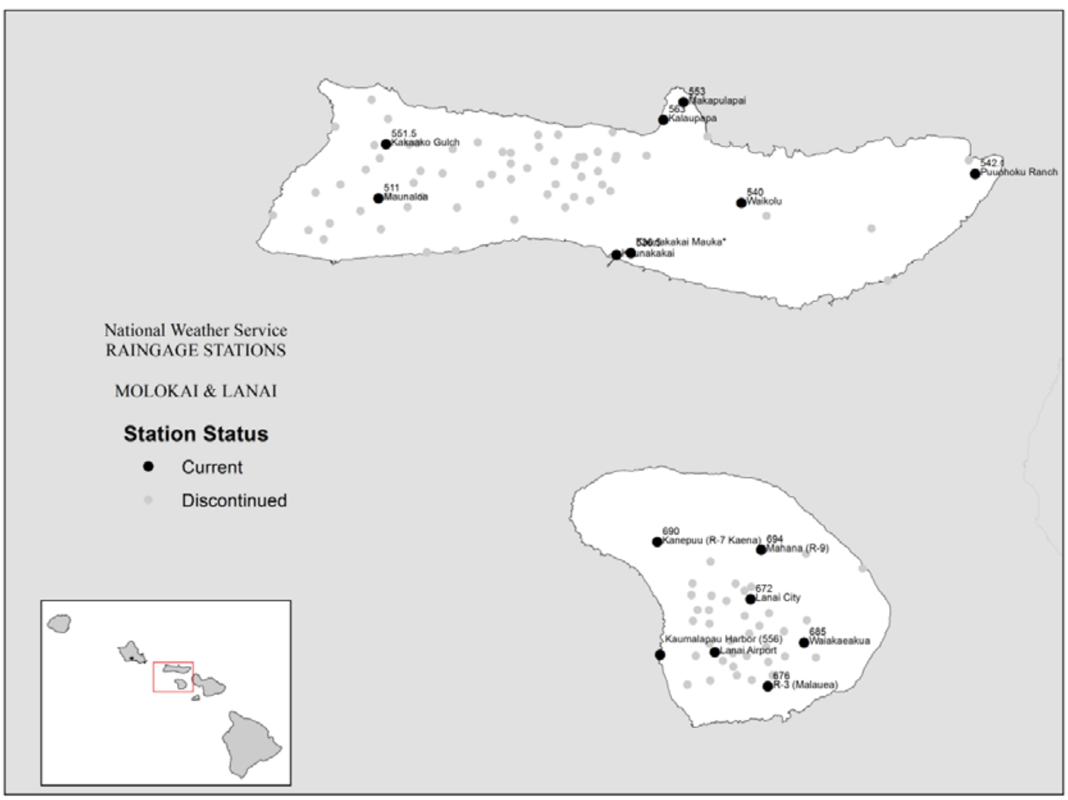


Figure G-29 Raingage Stations on Maui and Kahoolawe

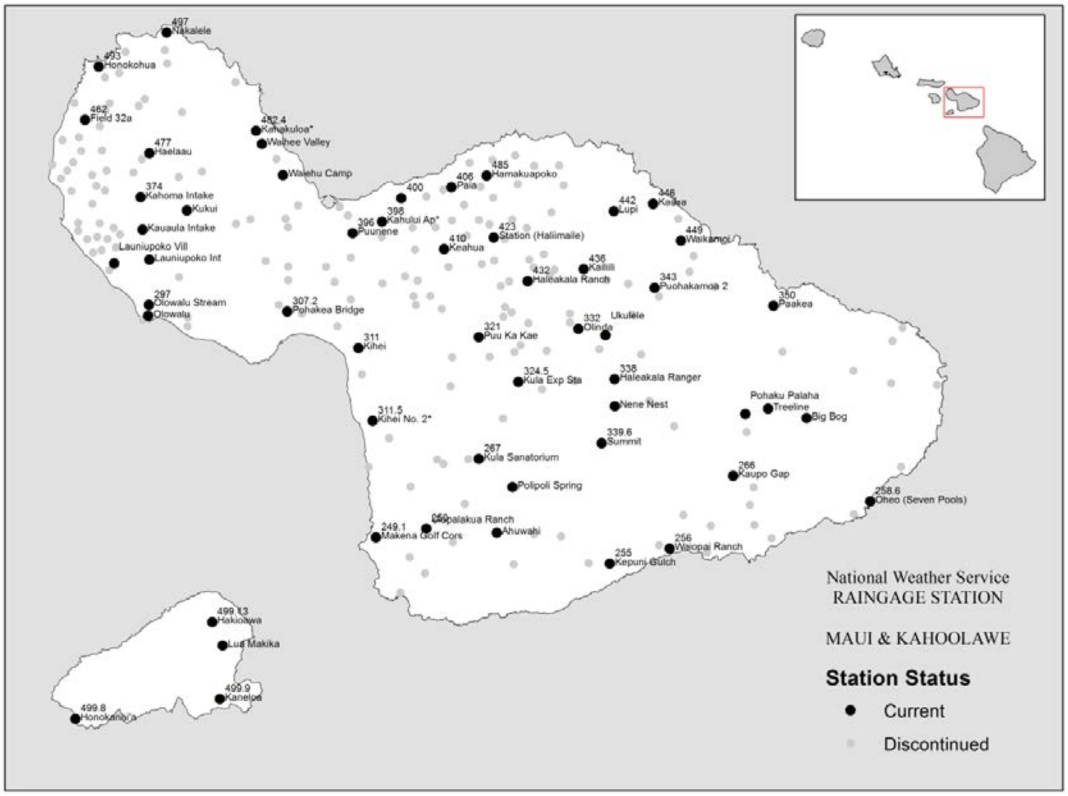
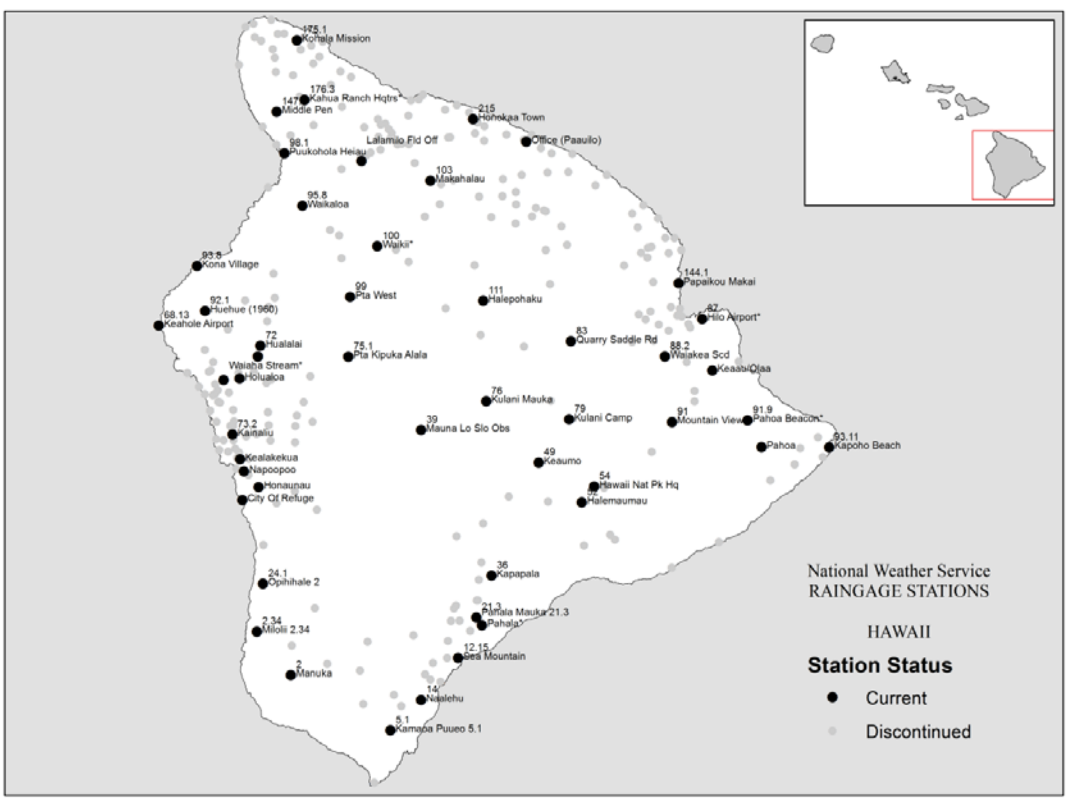


Figure G-30 Raingage Stations on Hawai‘i



G.4.4 Rainfall Data Analysis

There have been several analyses done of mean and median rainfall for monthly and annual data for Hawaiʻi. The most recent report, *Rainfall Atlas of Hawaii* (2011), has resulted in maps of the spatial patterns of rainfall for each of the islands. Developed by the University of Hawaiʻi and available online, the maps provided in the *Rainfall Atlas of Hawaii* serve as the standard isohyet maps for use in hydrologic studies and represent the best estimates of the mean rainfall for the 30-yr base period 1978-2007.[18] CWRM supports the consistent use of these maps to ensure consistent assumptions in data analyses. It should be noted, however, that there are other data sources available that may not be controlled to the data standards of the NWS. The results of studies that use such data are difficult to compare with the results of investigations that use standardized data.

G.4.5 Gaps in Rainfall Data

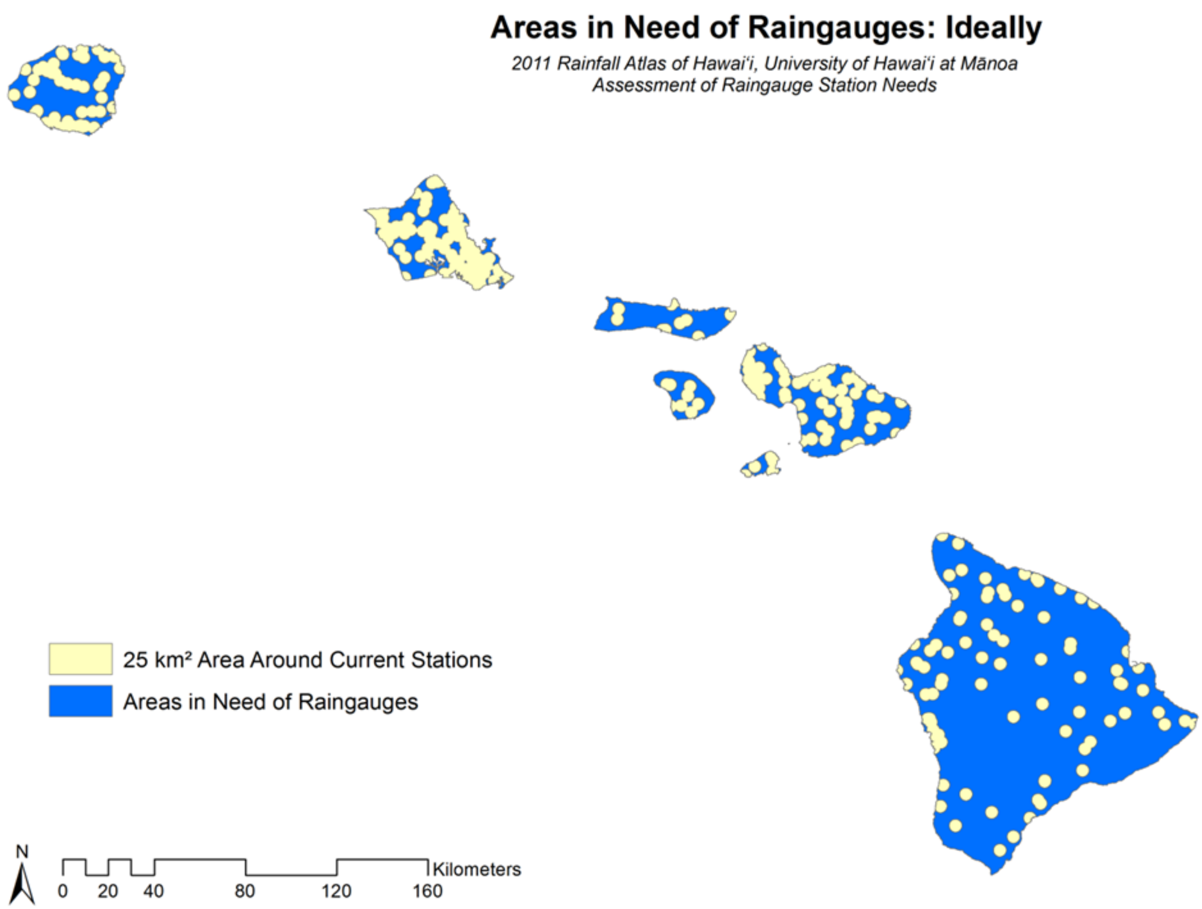
Due to the closing of sugar and pineapple plantations across the state beginning around 1990, there has been a drastic decrease in rain gage sites in the former plantation areas. This has resulted in the discontinuation of monitoring activities at many rainfall stations with long periods (50-100 years) of record. On Kauaʻi, Oʻahu, Maui, and Molokaʻi, there is a lack of rain gages located in high rainfall areas (areas receiving more than 80 inches of rain annually), which often correspond to forest reserve, watershed, and ground water recharge areas. There is also insufficient rain gage coverage in many agricultural areas across the state.

The lack of coverage is further exacerbated by Hawai'i's topography. Rainfall patterns can be very diverse over small distances, thereby requiring a dense network of rain gage sites to improve the accuracy of rainfall estimations. The World Meteorological Organization (WMO) recommends that small islands should have a minimum gage density of 1 gage per 25 km^2. Through the development of the current *Rainfall Atlas of Hawai'i*, the University of Hawai'i determined that an ideal raingage network would contain 667 gages to adequately provide the spatial coverage needed to account for Hawaiʻi's complex terrain (**Figure G-31**).[18] This would require adding 327 stations to 340 currently in operation. However, due to the financial and logistical challenges associated with establishing such a large number of stations, researchers at the University of Hawai'i prioritized locations based on the following criteria:

1) Areas where people live and work (residential and agricultural lands);
2) High rainfall areas (areas that receive at least 3000mm annually, as these are important ecological recharge areas);
3) High rainfall gradient areas (500mm/km rate of change or greater, areas where the rainfall changes drastically over a short area – it is important to have high station density for accuracy); and
4) Areas within the typical trade wind inversion (TWI) band (between 1800 and 2600 m in elevation – these are areas that are extremely sensitive to climate change).

[19]Frazier A., Special Report: Assessment of Raingauge Network Needs for Hawai'i

Figure G-31 Areas in Need of Raingauges



CWRM has also been considering the use of radar data to estimate rainfall in areas with no raingages. The NWS uses high resolution doppler weather radar stations called NEXRAD to detect rainfall and thunderstorms. NEXRAD can detect atmospheric movement and precipitation. NEXRAD is used to estimate rainfall intensities and issue flood warnings and special weather statements. In areas without rain gage coverage, NEXRAD can estimate rainfall accumulations. However, there are limitations to this approach and the data must be vetted prior to its use. The University of Hawaiʻi extensively reviewed the NEXRAD data prior to incorporating it into the *Rainfall Atlas of Hawaiʻi*.

G.4.6 Gaps in Rainfall Analysis

The 2011 *Rainfall Atlas of Hawai'i* was the first time a manual analysis of rainfall values was not used. In other words, past analysis of rainfall required manually creating lines of equal value (isohyets) based on data from a well distributed network of rainfall stations. As the number of reliable rainfall stations has decreased greatly over the years another approach was required to develop a good estimate of rainfall values for the entire state. The *Rainfall Atlas of Hawai'i* used an innovated approach of supplementing raingage data with other predictors such as rainfall maps from NEXRAD data, global climate models, and vegetation maps. Despite this thorough approach, uncertainties do exist, and more research is needed to understand the discrepancies between the rainfall maps and data recorded at rainfall stations.

The assessment by the researchers at the University of Hawai'i was an important first step to address the gaps in climate data collection in Hawai'i. There will be a further refinement and analysis of data needs in the aforementioned USGS report on hydrologic data monitoring needs in Hawai'i. This project is expected to conclude sometime in 2018.

G.4.7 Recommendations for Rainfall Monitoring

As discussed in the previous sections, the loss of rainfall stations due to the closure of sugar and pineapple plantations have reduced rain gage coverage and ended many stations with long periods of record. The historic rainfall record should be properly maintained and easy access to this data should be provided. Reports of rainfall analysis of all types need to be updated, and the effects of climate change on Hawaiian rainfall should be studied. The following recommendations hope to address these concerns:

- Increase rainfall data collection, especially in the watershed, agricultural, and high-precipitation areas.
- Explore partnerships and identify potential funding sources to increase the coverage of rain gages in high priority areas.
- Incorporate the recommendations of the *Special Report: Assessment of Raingauge Network Needs in Hawai'i* and continue or reestablish long-term rainfall stations.
- Better coordinate rainfall data sharing between major data collection networks and improve delivery of data for public consumption (including the acquisition and review of historic plantation data kept by the Hawai'i Agricultural Research Center).
- Continue to investigate the effects of climate change on precipitation in Hawai'i through collaborative studies with partners such as the University of Hawai'i and the USGS.
- Study newer technologies and tools for rainfall estimation in Hawai'i.

G.5 Cloud Water Interception and Fog Drip Monitoring Activities

G.5.1 Overview

Cloud water interception or fog drip is the direct interception of water, from clouds or fog, by vegetation. Some of this water makes its way into the ground. Fog drip is likely an important contribution to the hydrologic budget in Hawaiʻi's forested areas frequently enveloped in clouds. This is especially true when there is little or no precipitation occurring. Although this subject has been studied to some degree in Hawaiʻi and other locations around the world, there are still uncertainties as to what contributions cloud interception and fog drip make to the hydrologic cycle, and specifically to ground water recharge.

G.5.2 Measuring Fog Drip

The interception of cloud water, or fog drip, can be measured by fog collectors, which use screens, strings, or some other surface to capture cloud or fog droplets, which is then collected by receptacles or tipping bucket gages. Another method of measuring fog beneath vegetative canopies is by using throughfall collectors, which capture fog drip and precipitation using gutter-like troughs situated beneath the forest canopy. A rain gage is usually positioned nearby to account for the precipitation's contribution.

G.5.3 Existing Programs

There is no systematic, long-term cloud water/fog drip collection network in Hawaiʻi. There have been several fog drip studies conducted on Lānaʻi, Maui, and Hawaiʻi, which yielded site-specific fog collection data of various periods of record. These sites have typically been in the cloud covered mountainous regions of these islands, ranging from approximately the 1,500-foot to 10,000-foot elevation.

G.5.4 Analyses and Reports

There are few analyses and reports done on the subject of cloud water interception / fog drip in Hawaiʻi. The University of Hawaiʻi Water Resource Research Center published two technical reports, *Methodical Approaches in Hawaiian Fog Research,*[19] and *A Climatology of Mountain Fog on Mauna Loa Hawaii Island.*[20] Other researchers have conducted studies and investigations[21] on this subject. It should be noted that due to the lack of data on cloud water interception, there is uncertainty of the contribution of cloud water to the overall water budget of our forested watersheds.

G.5.5 Gaps

Since there is no fog drip data collection network, almost all of the islands' mountainous regions within the cloud belt have no data. Most of these areas have no vehicular access, and the difficult and often steep terrain prevents easy access for installation and maintenance of the fog drip data collection instruments.

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[19] McKnight, J. H. and Juvik, J. O., 1975, Methodological approaches in Hawaiian fog research, Technical Report No. 85, Project Completion Report for fog precipitation along topo-climatic gradients on the Island of Hawaii, OWRT Project No. A-041-HI, Grant Agreement No. 14-31-0001-4011, Project Period: July 1, 1972 to June 30, 1975.

[20] Juvik, J. O. and Ekern, P. C., 1978, A climatology of mountain fog on Mauna Loa, Hawaii Island, Technical Report No. 118, Project Completion Report for fog precipitation along topo-climatic gradients on the Island of Hawaii, OWRT Project No. A-041-HI, Grant Agreement No. 14-34-0001-5011, Project Period: 1 July 1974 to 31 December 1975.

[21] Juvik, J. O, and Nullet, D., 1994, A climate transect through tropical montane rain forest in Hawaii: Journal of Applied Meteorology, v. 33, No.11, p. 1304.

Juvik, J. O, and Nullet, D., 1995, Comments on "A Proposed Standard Fog Collector for Use in High Elevation Regions": Journal of Applied Meteorology, v. 34, No.9, p. 2108-2110.

Scholl, M., T. W. Giambelluca, S. B. Gingerich, M. A. Nullett, and L. L. Loope (2007), Cloud water in windward and leeward mountain forests: The stable isotope signature of orographic cloud water, Water Resour. Res., doi:10.1029/2007WR006011, in press. http://www.agu.org/journals/pip/wr/2007WR006011-pip.pdf" (accepted 31 August 2007).

Scholl, M.A., Gingerich, S.B., and Tribble, G.W., 2002, The influence of microclimates and fog on stable isotope signatures used in interpretation of regional hydrology: East Maui, Hawaii: Journal of Hydrology, v. 264, p. 170-184.

Giambelluca, T.W., DeLay, J.K., Nullet, M.A., Scholl, M.A., and Gingerich, S.B. Interpreting canopy water balance and fog screen observations: Separating cloud water from wind-blown rainfall at two contrasting forest sites in Bruijnzeel, L.A., Juvik, J., Scatena, F.N., Hamilton, L.S., and Bubb, P., Mountains in the Mist: Science for Conserving and Managing Tropical Montane Cloud Forests, Honolulu, HI, University of Hawaii Press.

G.5.6 Recommendations for Cloud Water Interception and Fog Drip Monitoring

As mentioned above, there is no long-term or widespread data collection network that gathers cloud water interception information in Hawai‘i. The amount of research and study on this subject is sparse compared to those of other hydrologic elements, especially rainfall. The following recommendations aim to increase the knowledge of cloud water interception and its contribution to watershed hydrology and water balance:

- Increase cloud water interception data collection in important watersheds;
- Explore partnerships and identify potential funding sources to increase the collection of cloud water interception data;
- Increase research into cloud water interception and its contribution to the hydrologic budget and aquifer sustainable yield;
- Develop methods to estimate cloud water interception over large areas; and
- Assess impacts of climate change on cloud water interception.

G.6 Evaporation Data

G.6.1 Overview

The most common way of determining evaporation is direct measurement from an instrument called an evaporation pan. Factors that influence evaporation include temperature, humidity, wind speed, and solar radiation. Other instruments, such as evaporimeters, can measure evaporation indirectly. Other empirical and psuedo-physical models can be used to estimate evaporation, based on other observed weather elements.

Evaporation data was used extensively in Hawai‘i to assist in crop irrigation and to assess the amount of water used by crops. Evaporation is also an important tool in determining an area’s hydrologic budget, since evaporation can be used to estimate evapotranspiration, which is an important component of the hydrologic budget. Evapotranspiration (ET) equals the water evaporated from the soil and other surfaces combined with the transpiration from plants in a vegetated area. It can be directly measured, computed from meteorological data, or estimated from pan evaporation data. In Hawai‘i, pan evaporation data is relied upon heavily when estimating ET, since there are few direct measurements of ET and the meteorological data to compute evapotranspiration is sparse.

G.6.2 Data Collection

In Hawaiʻi, pan evaporation data collection began in the late 19th century, with the majority of stations beginning in the mid-1950s. The proliferation of pan evaporation stations was directly influenced by the expanse of sugar and pineapple cultivation, and the vast majority of this network was comprised of sugar and pineapple plantation stations. Some of these stations were co-located with the NWS cooperative observer program rainfall stations. However, since the closure of these plantations, most of these pan evaporation stations have been discontinued. Many of these stations were located in the areas where sugar was grown, which were usually lower elevation areas with relatively low rainfall, although there are some data from higher elevations in wetter areas.

The University of Hawaiʻi currently operates two eddy covariance measurement stations on the Island of Hawaiʻi that allow researchers to directly measure energy balance changes.[22] As these stations are positioned directly above the forest canopy very accurate measurements of evaporation can be made.

G.6.3 Existing Programs

As described above, the network of pan evaporation stations has almost disappeared due to the plantation closures. The NWS currently maintains two evaporation stations, one in Lihue, Kauaʻi, and the other in ʻEwa, Oʻahu. Former plantation areas on Maui and Kauaʻi may still be collecting pan evaporation data; however, this data is not published or reported to the State Climate Office. The University of Hawaiʻi operates two stations on the Island of Hawaiʻi that allows them to directly measure or compute evapotranspiration. Historic data can be found in the reports mentioned below. Evaporation data from the Lihue and ʻEwa stations are available from the National Climatic Data Center.

G.6.4 Analyses and Reports

The Department of Land and Natural Resources published three pan evaporation reports. *Pan Evaporation Data, State of Hawaii* (1961) and *Pan Evaporation in Hawaii 1894-1970* (1973) described the pan evaporation data collection network in Hawaiʻi, presented data from these stations, and discussed data analysis. *Pan Evaporation: State of Hawaii 1894-1983* (1985) is a similar report with in-depth technical discussion of pan evaporation methods and analysis, as well as maps of annual evaporation isopleths for Kauaʻi, Oʻahu, Maui, and Hawaiʻi.

In 2014 the University of Hawaiʻi produced the first comprehensive estimation of the amount, spatial patterns, and temporal variability of ET. The data will allow resource managers to analyze the hydrological and ecological changes that occur due to changes in the landscape.

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[22] Giambelluca, T.W., et al., Evapotranspiration and energy balance of native wet montane cloud forest in Hawaiʻi. Agric. Forest Meteorol. (2008), doi:10.1016/j.agrformet.2008.08.004

G.6.5 Gaps

ET data is critical when computing water budgets and sustainable yields in Hawai‘i. The anticipated work by the University of Hawai‘i will allow researchers to determine where further study is needed to refine the data and to understand the impacts of climate change. There is a lack of direct evapotranspiration measurements in the forested watershed areas. Currently only two stations exist in the entire state. There is also a lack of meteorological data for computing evapotranspiration. Raw pan evaporation data is not readily available, and there is uncertainty in estimating evapotranspiration data using pan evaporation data.

A critical element in estimating ET is solar radiation. There are few solar radiation stations across the state of Hawai‘i, with the majority on Maui as part of the University of Hawai‘i’s HaleNet. The lack of solar radiation makes it difficult to readily ground truth solar radiation estimates, which are crucial to estimating ET. Efforts should be taken to continue the HaleNet climate station network and to establish long-term comprehensive (including solar radiation sensors) climate monitoring stations in critical areas across the state.

G.6.6 Recommendations for Evaporation Monitoring

Although fairly long periods of evaporation data exist for a number of pan evaporation stations, much of this data is for low elevation and low rainfall areas, and the data is not readily available to the general public. There is little measured and computed evapotranspiration data in the State, although the work by the University of Hawai’i will greatly improve the state of existing datasets. The following recommendations address these main concerns with evaporation and evapotranspiration data:

- Identify sources of evaporation and evapotranspiration data and improve access to this data;
- Investigate establishing island-wide or regional evapotranspiration reference networks comprised of measurement stations in areas needing real-time data to schedule irrigation, such as agricultural districts and urban areas with extensive landscaping;
- Establish evapotranspiration measurement stations in areas where aquifer sustainable yields need to be reassessed or improved;
- Increase and improve evapotranspiration estimates in areas where aquifer sustainable yields need to be reassessed or improved; and
- Conduct additional research on evapotranspiration in areas where aquifer sustainable yields need to be reassessed or improved.