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DEPARTMENT OF LAND AND NATURAL RESOURCES
COMMISSION ON WATER RESOURCE MANAGEMENT
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DRAFT STAFF SUBMITTAL

for the meeting of the
COMMISSION ON WATER RESOURCE MANAGEMENT

December 17, 2019 (Tentative)
Honolulu, Hawai‘i

Proposed Amendment and Update
to the Water Resource Protection Plan of the Hawai‘i Water Plan
to Combine the Waimea (80301) and ‘Anaeho‘omalu (80701) Aquifer System Areas (ASA)
Into the Waimea-‘Anaeho‘omalu System/Sector Area (80302)

SUMMARY OF REQUEST

Authorize staff to initiate a public hearing for an aquifer boundary change to combine the ‘Anaeho’omalu (80701) and Waimea (80301) Aquifer System Areas (ASA), by removing the boundary that divides them, and combine them into a single Aquifer System Area to be called the Waimea-‘Anaeho’omalu System Area (80302) (Exhibit 1, Proposed Boundary Change). The resulting Waimea-‘Anaeho‘omalu System Area will also cause the combining of the existing W. Mauna Kea and N. W. Mauna Loa Aquifer Sector Areas into the W. Mauna Kea-N. W. Mauna Loa Aquifer Sector Area (803).

BACKGROUND

Ground water sustainable yields (SY) and hydrologic units called Aquifer System Areas (ASA) are established by the Commission through the Water Resource Protection Plan (WRPP) of the Hawai‘i Water Plan as established by the State Water Code, HRS 174C. The WRPP was last updated in 2008 and the 2019 WRPP update will be coming before the Commission for approval in July 2019.

In 2011 the Waimea ASA came under consideration for a sustainable yield (SY) reduction from 24 million gallons per day (mgd) to 16 mgd, based upon the new recharge estimate made by the U.S. Geological Survey (USGS) in Scientific Investigations Report 2011-5078 (Engott 2011). This was part of the overall effort to update to the 2008 Water Resource Protection Plan (WRPP) of the Hawai‘i Water Plan originally targeted for 2013.

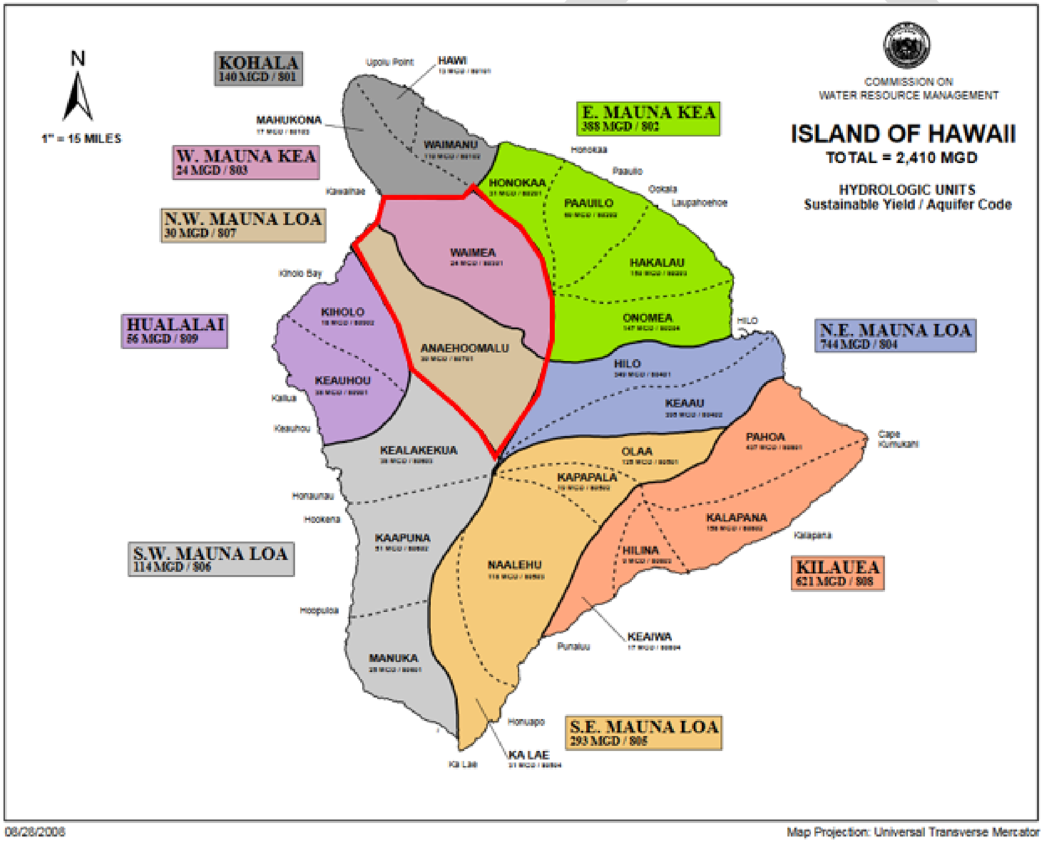
On December 17, 2013, staff met its water professional group composed of Private Sector Professionals, Commission on Water Resource Management (CWRM), Hawai‘i Department of Water Supply (HDWS), National Park Service (NPS), University of Hawai‘i Mānoa, and United States Geological Survey (USGS) to solicit comments on the overall proposed SY updates based on Engott’s 2011 recharge updates. Meeting notes were taken and compiled by Townscape, Inc. (Exhibit 2). It was evident back then there was much concern about the proposed lowering of sustainable yields and aquifer system area boundaries between ‘Anaeho‘omalu to Hāwī.

In 2015, Tom Nance Water Resource Engineering (TNWRE) and HDWS, with experience in the Waimea ASA further responded to the proposed SY reduction with additional written concerns (Exhibit 3 - letters from TNWRE and HDWS) that a reduction of the Waimea ASA SY did not reflect observed conditions from pumping and monitor wells.

In 2019, staff completed the public hearings on the draft of the 2019 Water Resource Protection Plan Additional comments on the proposed SY reduction to the Waimea ASA were received (Exhibit 4).

DISCUSSION

The current Waimea and ‘Anaeho‘omalu ASAs are shown in Figure 1, and the relevant comparative data is tabulated below:



	Area		Millions of gallons per day (mgd)			
ASA	miles^2	meters^2	2008 SY	2019 Recharge Range	2019 SY Range	Proposed 2019 SY
Waimea	299.97	776,907,632	24	36.62-54.0	16-24	16
‘Anaeho‘omalu	319.2	826,734,124	30	69.0-176.0	30-77	30

Figure 1. Current Waimea and ‘Anaeho‘omalu ASA Boundaries

After discussions on the WRPP update commencing in 2013, three main issues on the sustainable yield for the Waimea ASA have been raised and investigated: 1) an apparent discrepancy between recharge as a percentage of hydrologic inputs for Waimea ASA and Kohala Aquifer Sector Area and the rest of the island; 2) the aquifer area boundaries of the Waimea ASA; and 3) ground water monitoring behavior.

Waimea Recharge Issue

As raised by Nance (Exhibit 3), the Waimea ASA recharge percentage compared to overall hydrologic inputs in Engott (USGS 2011) seemed unreasonably low compared with neighboring ASAs.

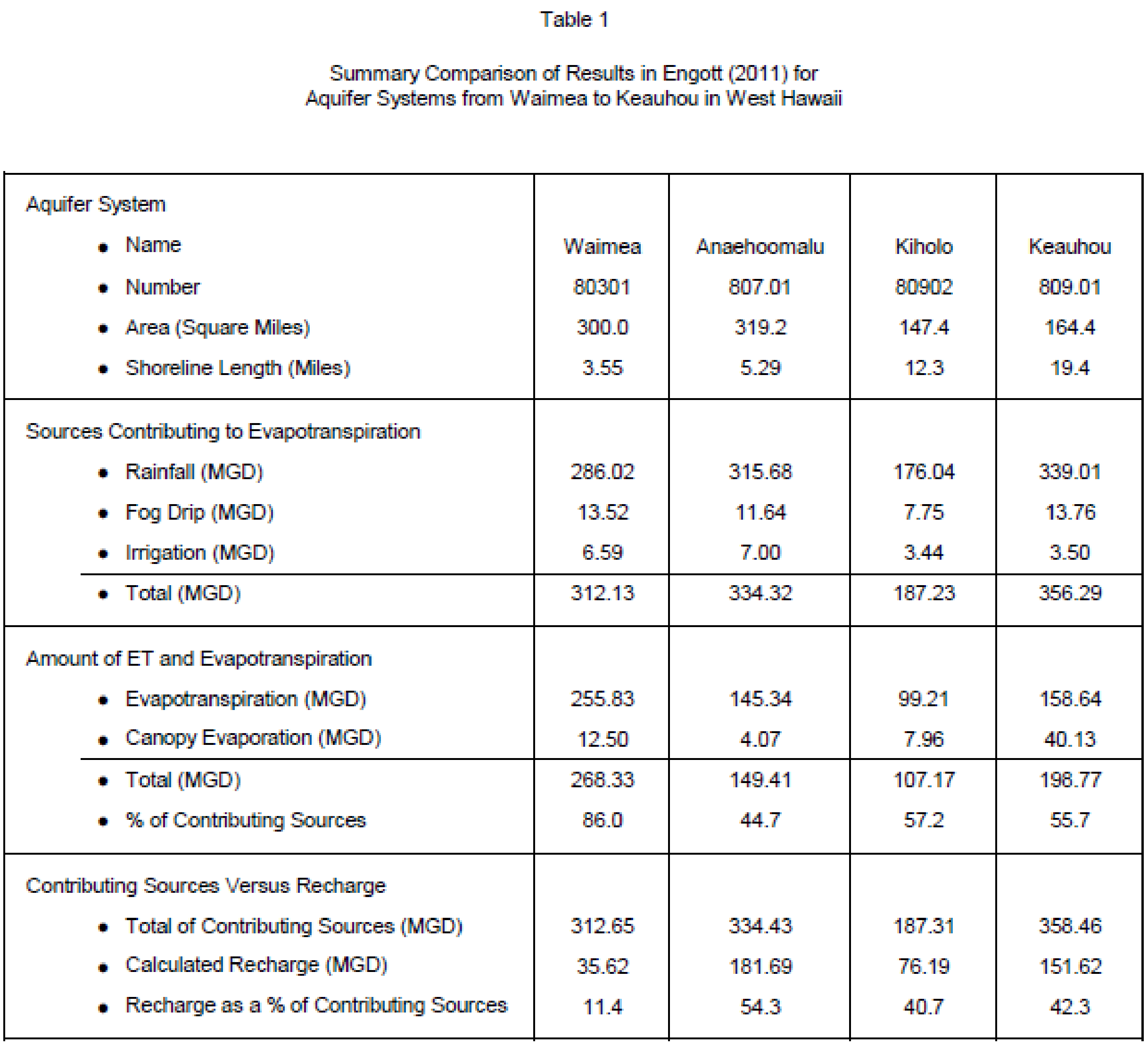


Table 1

Summary Comparison of Results in Engott (2011) for
Aquifer Systems from Waimea to Keauhou in West Hawaii

Aquifer System				
• Name	Waimea	Anaehoomalu	Kiholo	Keauhou
• Number	80301	807.01	80902	809.01
• Area (Square Miles)	300.0	319.2	147.4	164.4
• Shoreline Length (Miles)	3.55	5.29	12.3	19.4
Sources Contributing to Evapotranspiration				
• Rainfall (MGD)	286.02	315.68	176.04	339.01
• Fog Drip (MGD)	13.52	11.64	7.75	13.76
• Irrigation (MGD)	6.59	7.00	3.44	3.50
• Total (MGD)	312.13	334.32	187.23	356.29
Amount of ET and Evapotranspiration				
• Evapotranspiration (MGD)	255.83	145.34	99.21	158.64
• Canopy Evaporation (MGD)	12.50	4.07	7.96	40.13
• Total (MGD)	268.33	149.41	107.17	198.77
• % of Contributing Sources	86.0	44.7	57.2	55.7
Contributing Sources Versus Recharge				
• Total of Contributing Sources (MGD)	312.65	334.43	187.31	358.46
• Calculated Recharge (MGD)	35.62	181.69	76.19	151.62
• Recharge as a % of Contributing Sources	11.4	54.3	40.7	42.3

Table 1 from TNWRE 11/27/2015 letter (Exhibit 3)

Staff reviewed this relationship for the rest of the Big Island and found this very low ratio to be isolated to other aquifer system areas within the Kohala Sector Area. The ASAs of Māhukona (11.0%), Hāwī (13.3%), and Waimea (11.6%)) are much lower compared to the rest of the island’s 21 other aquifer system areas. Figure 2 below is a map showing the recharge percentage compared to overall hydrologic inputs from Engott (USGS 2011).

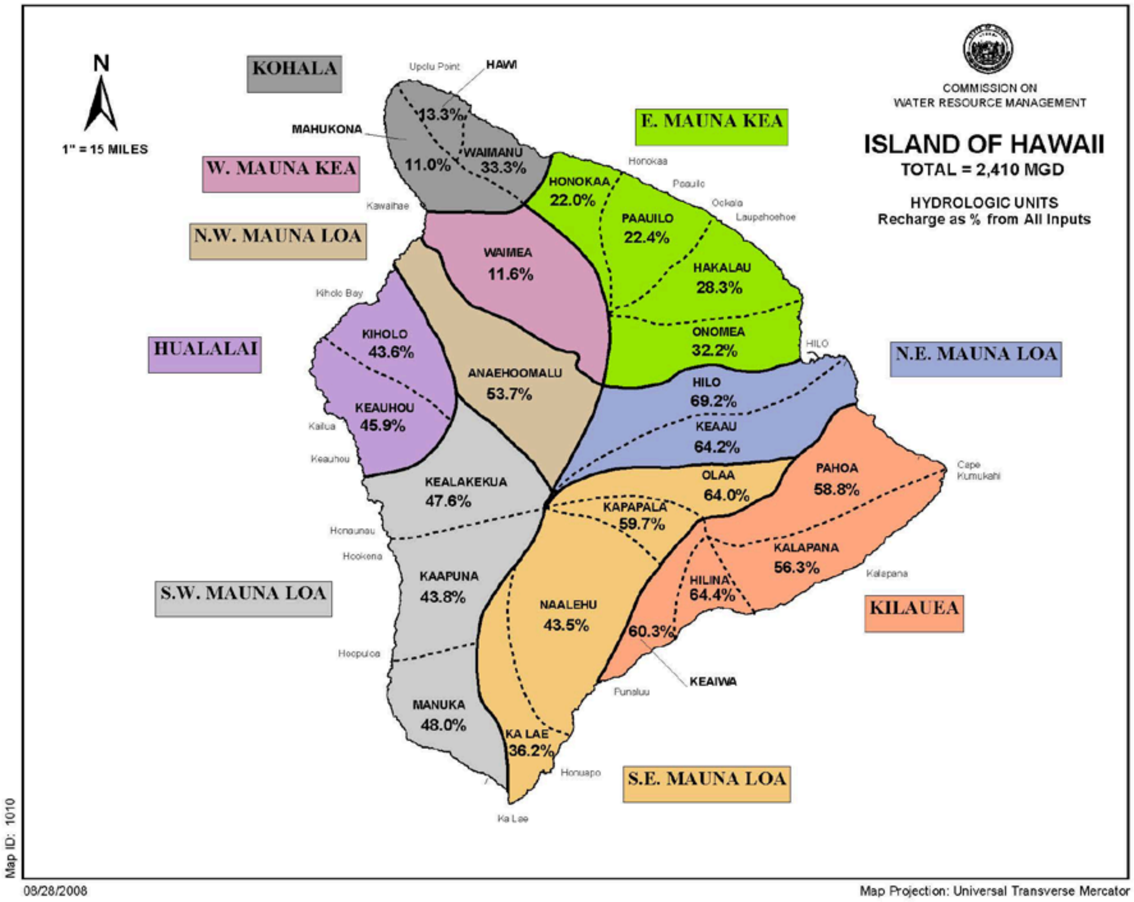


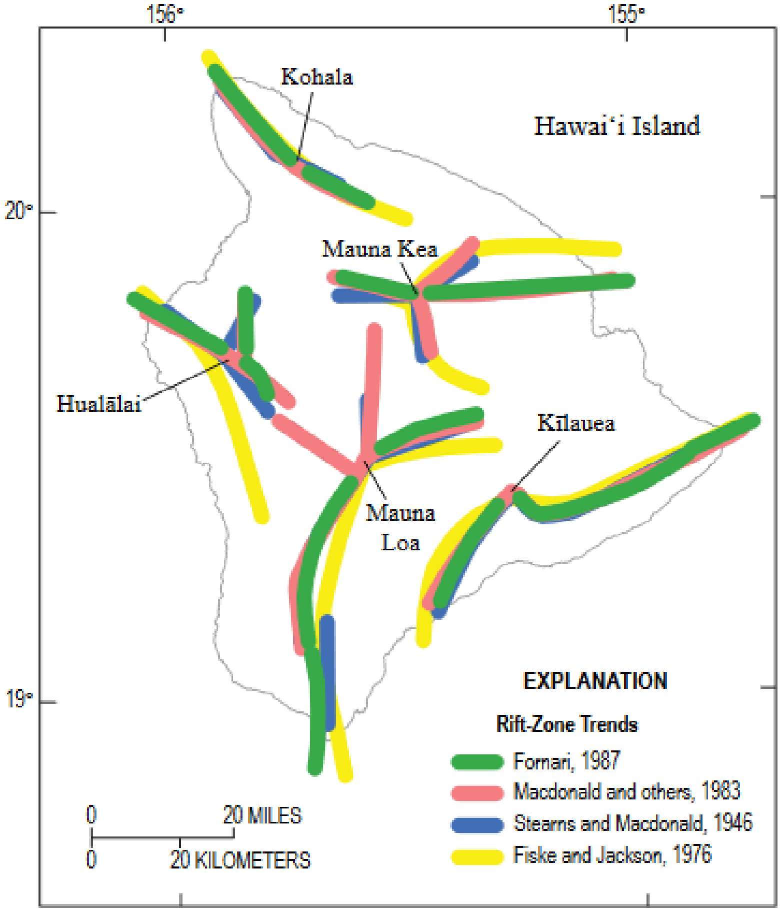
Figure 2. Recharge as % of All Inputs Map based on USGS Engott 2011 Climate II scenario

In discussions with Engott, he explained recharge values are most likely low due to the thicker soil coverage differences and clarified that losing stream effects across ASAs were also not included. TNWRE calculated that the surface and subsurface recharge from “offsite” could amount to as much as 10 to 20 mgd being discounted from calculations for recharge in the Waimea ASA alone (Exhibit 3). For these reasons, the Waimea ASA recharge estimate appears to be underestimated in Engott (USGS 2011).

Waimea-‘Anaeho‘omalu Aquifer System Area Boundaries

As currently delineated, the lateral boundaries of these two ASAs are surface contacts rather than geologic rift or valley fills that normally govern other aquifer sector boundaries. The Waimea ASA lateral boundaries are the surface contacts between the Kohala and Mauna Kea lavas on the north side, the ridge on the northwest flank of Mauna Kea on the northeast side, and the surface contact between Mauna Kea and Mauna Loa lavas on the south side. Likewise, the lateral boundaries of the Anaeho’omalu ASA are the surface contacts of the Mauna Kea and Mauna Loa lavas on the north side, the Humu‘ula Saddle between Mauna Kea and Mauna Loa on the east side, and the surface contact between Hualālai and Mauna Loa lavas on the south side. In the case of the ‘Anaeho‘omalu ASA northern boundary we know that this contact reflects the northern most extent of Mauna Loa's encroachment onto older Mauna Kea lavas and that water infiltrating into the Mauna Kea slope above the Saddle Road area flows directly beneath that surface contact and below the Mauna Loa surface lavas. Therefore, the water within the ‘Anaeho‘omalu ASA is derived from recharge infiltration entering both the southern flank of Mauna Kea as well as the northern flank of Mauna Loa.

From geologic information gathered to date in the area, and in the opinion of the water providers and professionals familiar with Hawaii Island geology, the buried physical aquifer boundaries associated with changes in the characteristics of the geologic formations governing groundwater flow and changes in the hydraulic conductivity of the rocks that affect or impede the transport of water are not clear in the area. Clearly there are no valley fills in the area, and a rift zone (where dense intrusive rocks are present), which are the predominant effective barriers to groundwater flow, has not been identified near the current Waimea/’Anaeho’omalu boundary. There has been speculation regarding Mauna Kea's rift zones for several decades. Figure 2, below, is an interpreted rift zones map (USGS SIR 2015-5164, Figure 45), that suggested western-trending rift zones from the summit of Mauna Kea. However, these interpretations were from studies conducted from 1946 through 1987.



North American Datum 1983, Universal Transverse Mercator projection, zone 4N.

Figure 45. Interpretations of rift-zone trends on Hawai‘i Island.

Figure 3. USGS Rift Zone Map (from 1946 to 1987 Studies)

A more recent analysis indicates that an east and a west rift zone that had previously been proposed (with sufficient density to serve as an effective barrier to groundwater flow), has not been geophysically confirmed, (GSA, Morgan, 2010). A current map of Hawaii Island rift zones (highlighted in yellow) from the 2010 Morgan study is shown in Figure 4 below.

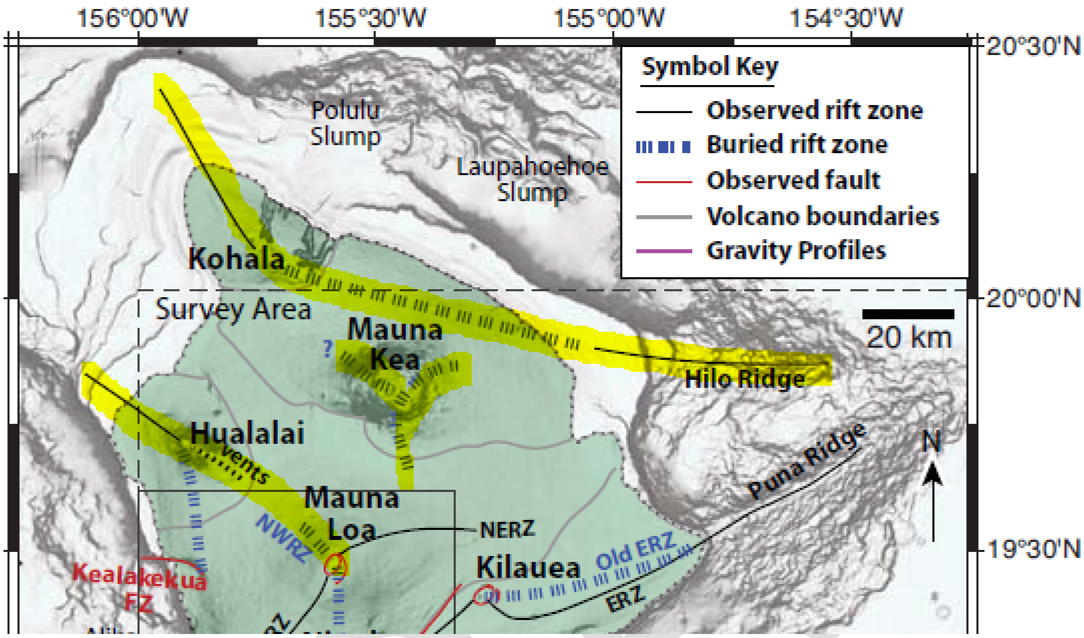


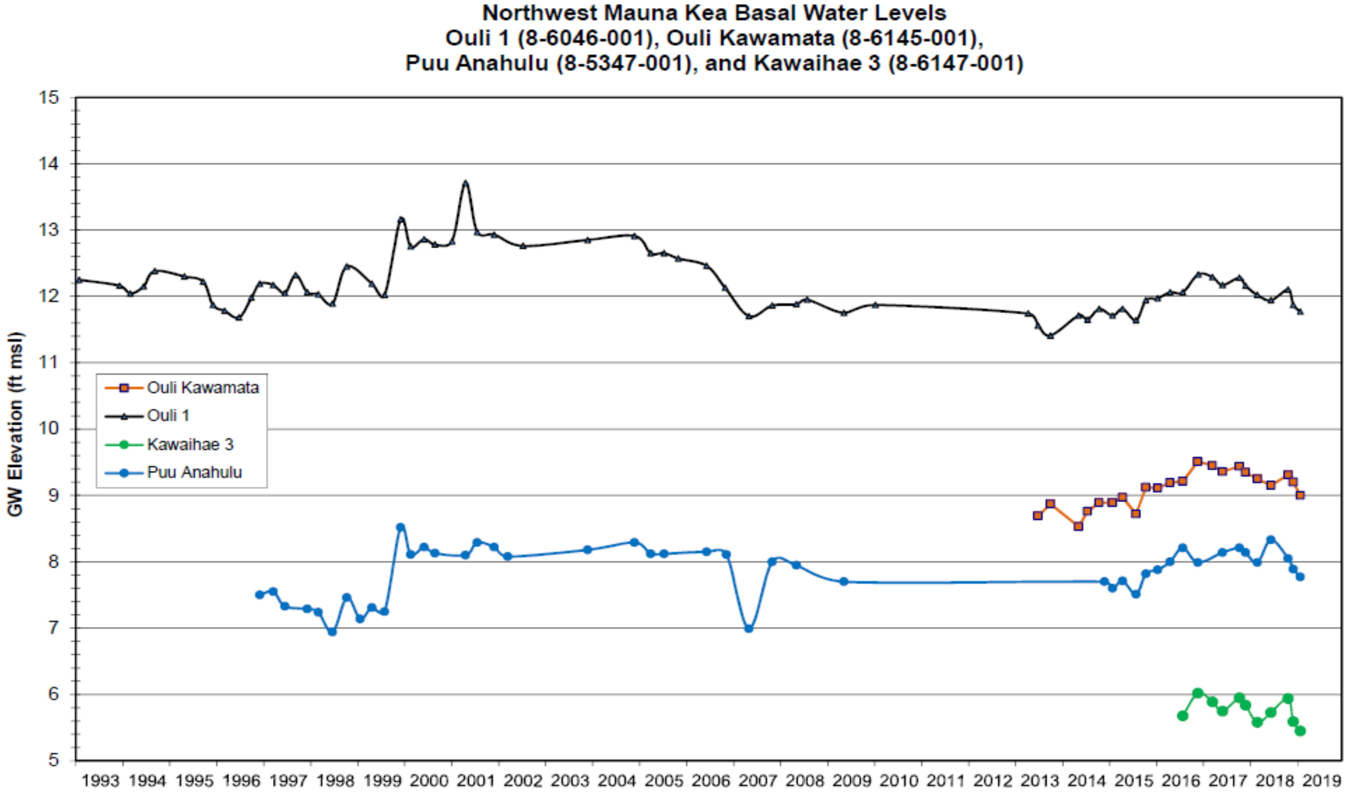
Figure 4. Section from 2010 Morgan Rift Zone Map

The presence of the rift zones identified by the Morgan report would further support the Waimea-‘Anaeho‘omalu hydrologic unit concept, bounded by rift zones to the southwest and north.

Recent drilling projects in the area have provided additional geologic evidence that the Mauna Kea and Mauna Loa lavas interfinger within the ground water basin comprised of the Waimea and ‘Anaeho’omalu aquifer systems (D. Thomas, 2019 Exhibit 5). Results also indicate that the ground waters flowing from Mauna Kea and Mauna Loa mix in this basin; and are not separate ground water bodies.

Waimea/‘Anaeho‘omalu Ground Water Monitoring

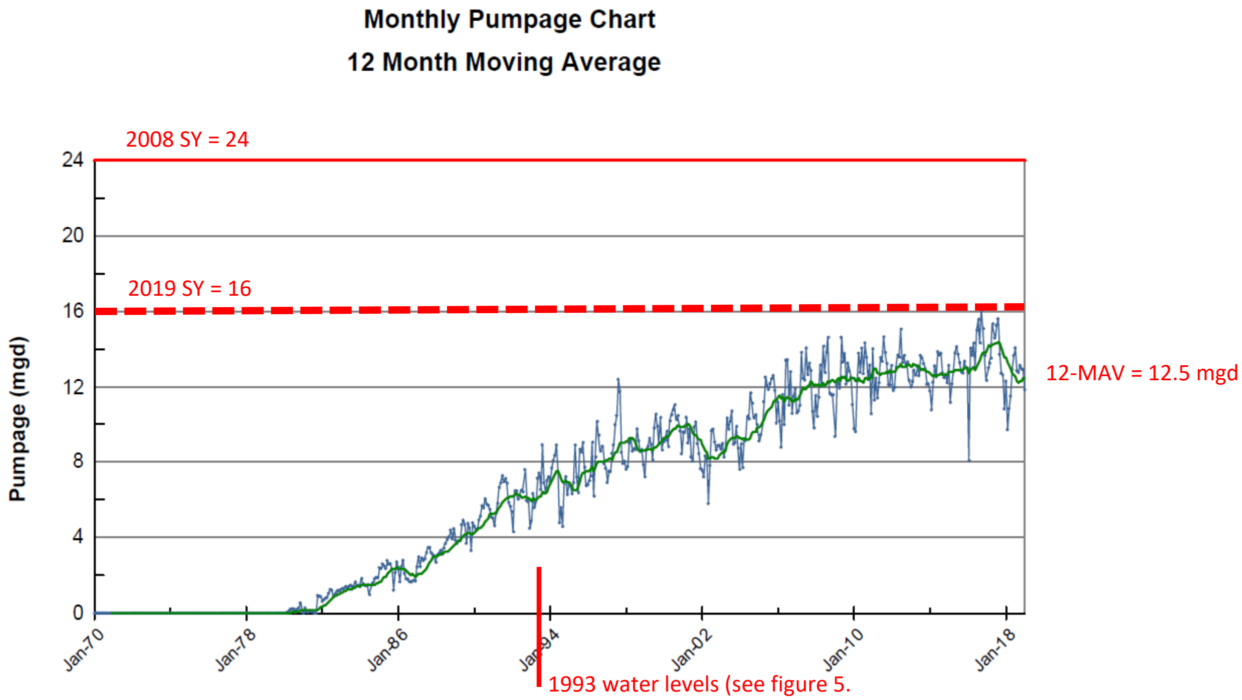
There is a limited amount of observed well ground water data in these ASAs, but enough to suggest that the Waimea Aquifer Area is not near sustainable yield as suggested by the proposed 2019 WRPP update. There are no deep monitor wells in the area; however, the Commission staff and private consultants have been monitoring the existing well pumpage, water levels and chlorides. In addition to the Keauhou Aquifer System Area, staff had established a water-level monitoring network in the area beginning in 1993, or 26 years ago. Basal ground water levels have been measured quarterly in 4 selected wells in the Waimea and ‘Anaeho‘omalu ASAs and are updated on the Commission’s website (see https://dlnr.hawaii.gov/cwrm/groundwater/monitoring/). Figure 5 below is a compilation of the data provided on the website for the area and shows stable water levels between 1993 to the present.

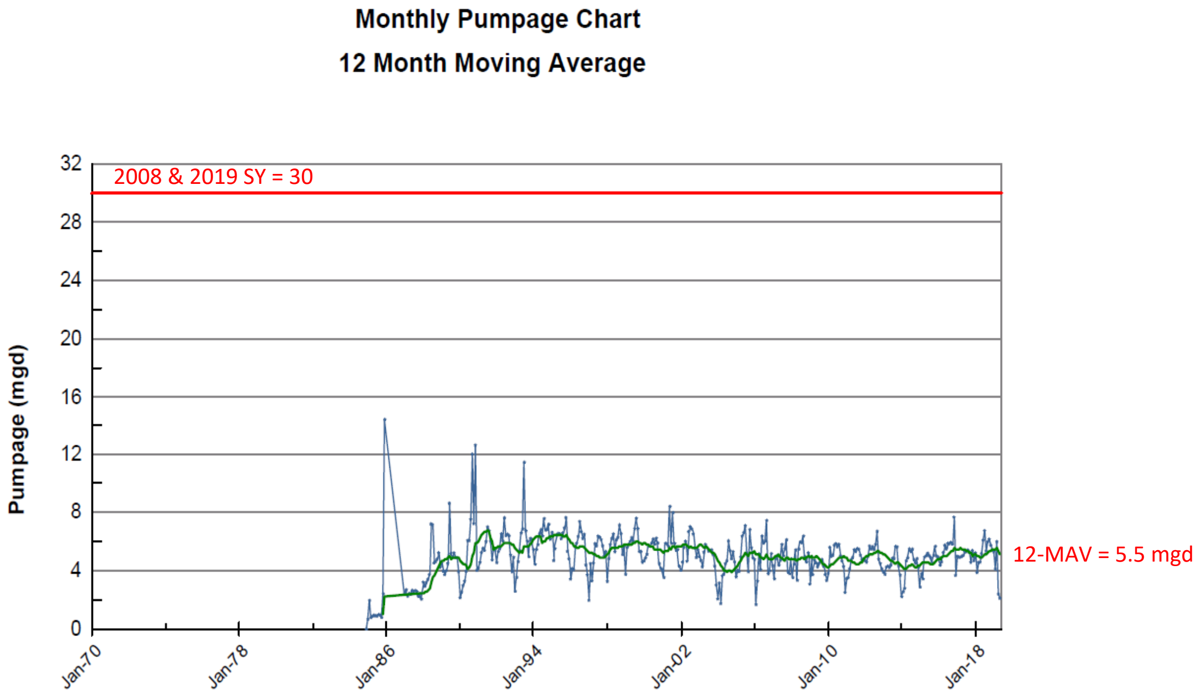


Updated 4/24/2019

Figure 5. Monitoring network basal water-levels within the Waimea-ʻAnaehoʻomalu ASAs

As can be seen, water level data from these monitor wells away from the local influences of pumpage show steady water-levels despite increased reported pumpage since 1993, which is shown in Figures 6 & 7. These data and observations show that the aquifers' reaction to the stresses of pumpage since 1993 has been unchanged and suggests that it may not be near sustainable yield.





Figures 6 & 7. Waimea and ‘Anaeho‘omalu ASA Pumpage

Figures 6 & 7 show the pumpage for the Waimea and ‘Anaeho‘omalu ASAs. Waimea is the main ASA of concern. Combining both ASAs would form a new ASA with a total 12-month moving average (12-MAV) of 17.5 mgd and a 2019 sustainable yield 46 mgd. All wells within the two ASAs are shown in Figure 8.

Staff has been reviewing reported water-levels and chlorides data from production wells in the Waimea and ‘Anaeho‘omalu ASAs. Reporting has been varied depending on owner, but in general chlorides have been better reported than water-levels. In the Waimea ASA, basal chlorides show steady and good quality chlorides that improve moving from north to south and makai to mauka through the various well fields of Hapuna, Lalamilo, Parker Ranch, and Waikoloa. High-level wells of Waiki‘i Ranch show very low chloride content as well.

Additionally, though data is limited and not definitive, recent isotopic sample analyses further indicate that the ground waters flowing from Mauna Kea and Moana Loa mix in this basin; and are not separate ground water bodies. Figure 8 (Courtesy R. Whittier) illustrates the similarity of isotopic content in ground water samples collected from within the Waimea/‘Anaeho‘omalu ASAs. More isotopic sample analyses would be helpful to confirm this observation and staff is working with other scientists and Ike Wai to obtain more isotopic information.

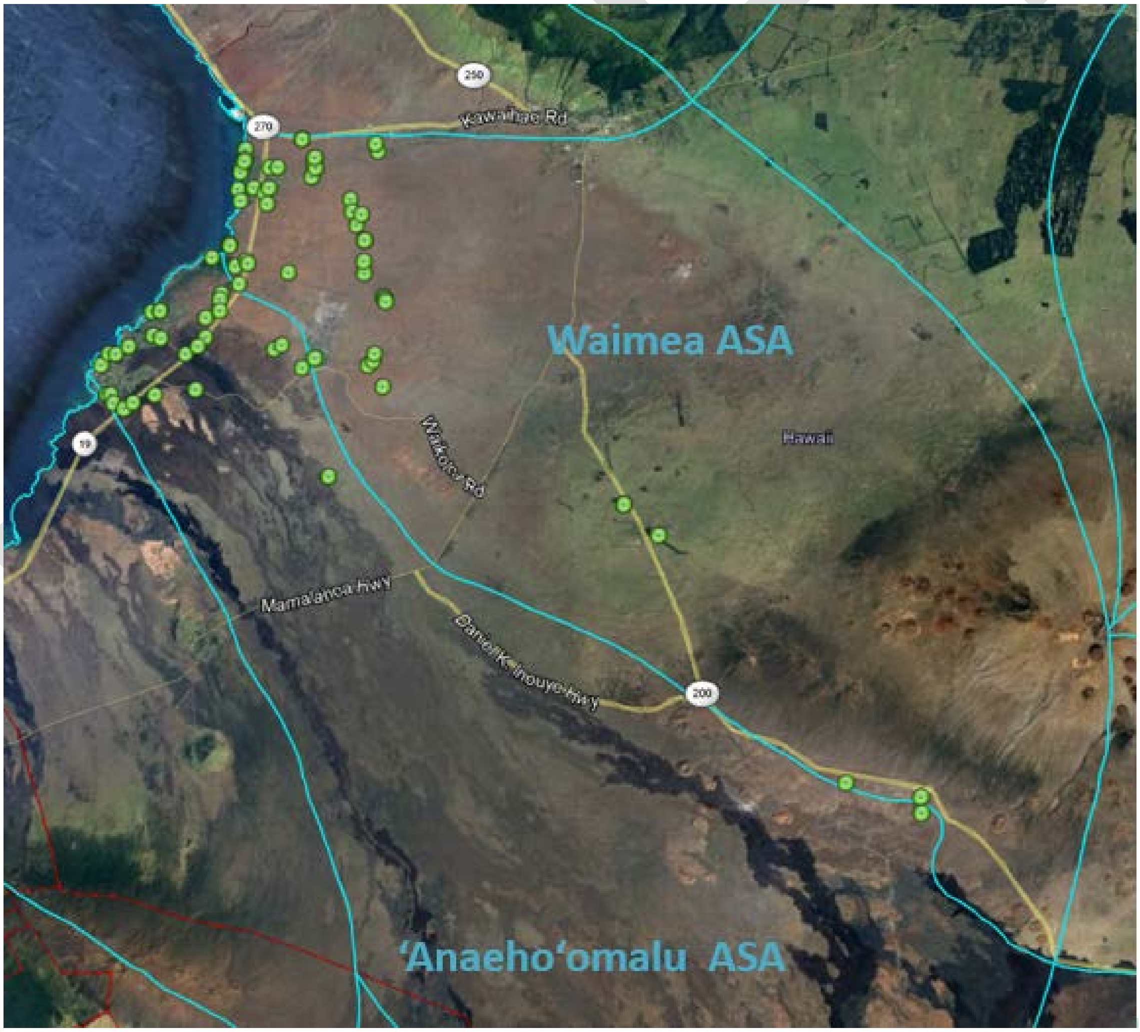


Figure 8. Well Locations within Waimea and ‘Anaeho‘omalu ASAs

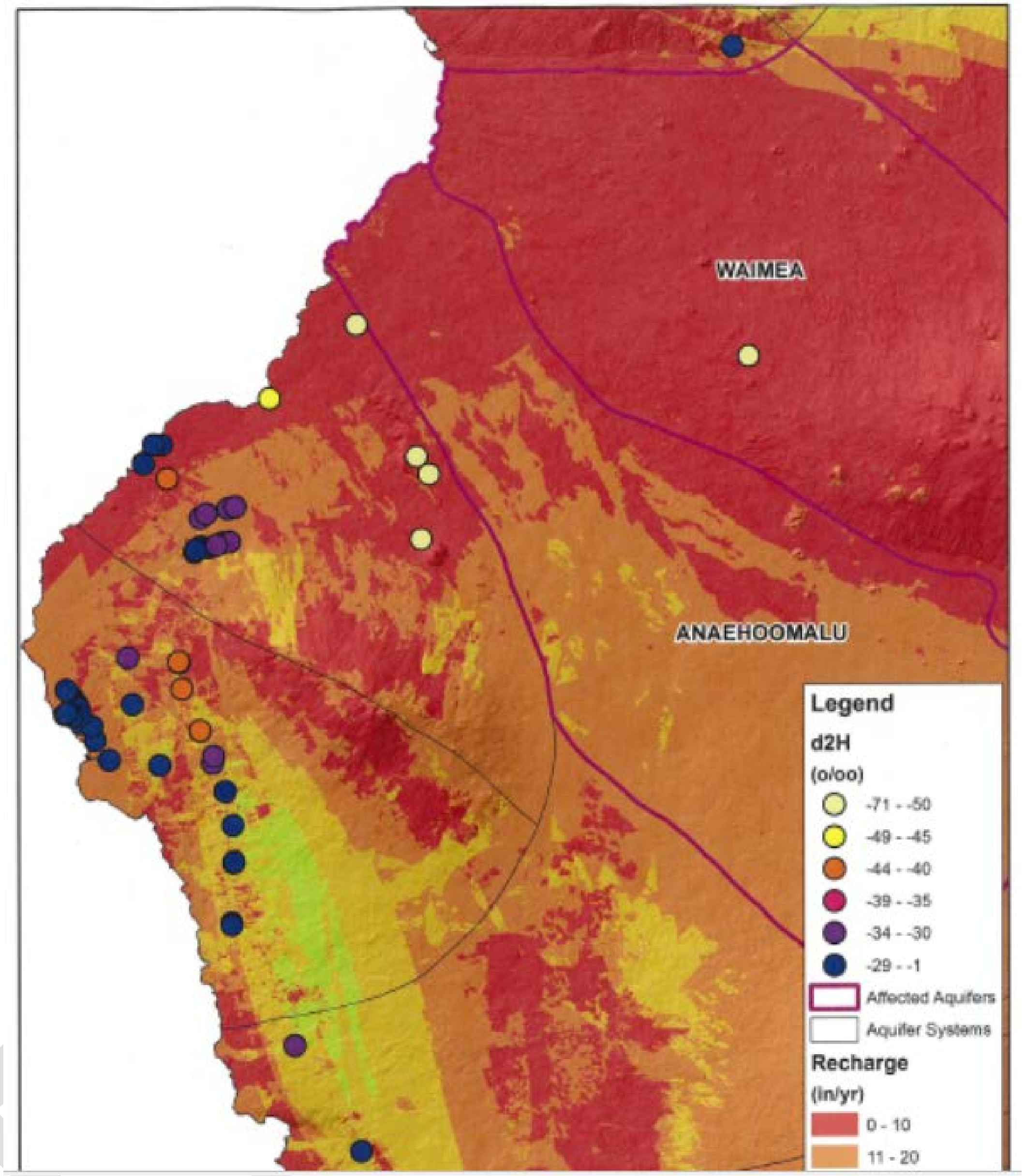


Figure 9. Results of Ground Water Isotope Sampling Analyses (Whittier, 2019)

Some professional group comments were made to adjust the Waimea ASA boundaries to account for recharge/underflow from the adjacent Māhukona ASA and other changes in the Waimea and ‘Anaeho‘omalu ASAs in addition to the missing imported surface water flows from Māhukona ASA (see Exhibit 3). These boundary changes have merit; however, from a ground water resource management perspective, the simplest and most expeditious approach to addressing the concerns of the proposed decrease in SY in the Waimea ASA is to combine the ‘Anaeho‘omalu and Waimea ASAs, and manage the described ground water basin as one ASA. Alternatively, keeping the ASA boundaries intact but including the importation of surface water and a re-review of the considerations towards the high evapotranspiration for the Kohala area could be done, but this would take some time to reassess with the U.S. Geological Survey.

PROPOSED BOUNDARY MODIFICATION

Based on the overall information from monitoring, recent drilling projects & studies, and comments from the professional group and public from the Water Resource Protection Plan public hearings, staff is proposing to combine the current Waimea and ‘Anaeho‘omalu ASAs into the Waimea-‘Anaeho‘omalu Aquifer System (80302) of the West Mauna Kea/Northwest Mauna Loa Aquifer Sector Area (803), Exhibit 1. Note that this figure incorporates the proposed 2019 sustainable yield SY figures of 16 mgd (reduced from 24 mgd) for Waimea, and 30 mgd (unchanged minimum) for ‘Anaeho‘omalu, yielding 46 mgd for the new Waimea-‘Anaeho‘omalu ASA. This is a reasonable management approach that does not require recalculation of system areas and the resulting corresponding changes in recharge.

Given the geologic setting, a contiguous ground water basin comprised of interfingered lavas from Mauna Loa and Mauna Kea, containing co-mingled ground water from both mountains, the concept of combining the two hydrologic units into one is logical, is supported by the available data, addresses the concerns of the public and water professionals, and can be accomplished with simple arithmetic without additional modifications to areal and recharge calculations as shown in Table 2.

Table 2 – Waimea-‘Anaeho‘omalu Aquifer System Area (ASA) Area & Sustainable Yield Values

	Area		Millions of gallons per day (mgd)			
ASA	miles^2	meters^2	2008 SY	2019 Recharge Range	2019 SY Range	Proposed 2019 SY
Waimea	299.97	776,907,632	24	36.62-54.0	16-24	16
‘Anaeho‘omalu	319.2	826,734,124	30	69.0-176.0	30-77	30
Waimea-‘Anaeho‘omalu	**619.17**	**1,603,641,756**	**-**	**105.62-230.0**	**46-101**	**46**

Moreover, this proposed change is not precedent setting; in March 1993 to address similar concerns, on O‘ahu, the ‘Ewa and Kunia ASAs were combined into the Ewa-Kunia ASA, and the Waipahu and Waiawa ASAs were similarly combined into the Waipahu-Waiawa ASA.

This approach has been recirculated to the water professionals group for further comment and the public hearing will provide additional opportunity to comment on this management approach.

LEGAL AUTHORITY

Legal authority to modify the Hawai‘i Water Plan is established in the Hawai‘i Water Code under HRS 174C Part III, Sections 31 & 21.

Additionally, under its general powers and duties, the Commission has the authority to plan and coordinate programs for the conservation of water and to contract with private persons to assist with these programs. Under section §174C-5 (4), HRS, the Commission “*[m]ay contract and cooperate with the various agencies of the federal government and with state and local administrative and governmental agencies or private persons*”. Section §174C-5 (13), HRS, further provides that the Commission “*[s]hall plan and coordinate programs for the development, conservation, protection, control, and regulation of water resources based upon the best available information, and in cooperation with federal agencies, other state agencies, county or other local governmental organizations and other public and private agencies created for the utilization and conservation of water*”.

The Code defines a "Hydrologic Unit" as: *"a surface drainage area or a ground water basin or a combination of the two."*. This would indicate that there is a great amount of flexibility afforded to the Commission in setting boundaries by which to manage. Surface drainage boundaries are rarely equivalent to ground water basin barriers yet the State Water Code clearly allows the Commission to combine them if there is some advantage to be gained above and beyond actual physical boundaries. In most cases, the sector boundaries are the best *"estimate"* of the actual geophysical boundaries of an aquifer. However, the Code clearly allows the Commission to manage using boundaries other than actual physical boundaries if there is some advantage to be gained. Therefore, the Commission can define boundaries which are most advantageous and helpful towards fulfilling its management objectives.

SCHEDULE

Updates to the Water Resource Protection Plan (WRPP) require 90-day notice prior to the public hearing on any update. Therefore, a public notice on June 28, 2019 will allow for a September 26, 2019 public hearing in Waimea with an October 28, 2019 deadline for written comments. This would allow for Commission action at its scheduled November 19, 2019 meeting.

ENVIRONMENTAL REVIEW CHAPTER 343, HAWAII REVISED STATUTES

This planning study is exempt from the application of HRS Chapter 343 pursuant to HRS §343-5(b) and Hawaii Administrative Rule §11-200-5(d). This is for a planning-level study and will not involve testing or other actions that may have a significant impact on the environment.

RECOMMENDATION

Staff recommends that the Commission:

1. Amend the 2019 Water Resources Protection Plan of the Hawai‘i Water Plan by modifying the Waimea (80301) and ‘Anaeho‘omalu (80701) Aquifer System Areas (ASA) boundaries by removing their shared boundary as specified in this submittal. The name of this new hydrologic unit would be the Waimea-‘Anaeho‘omalu Aquifer System Area (80302) of the West Mauna Kea/Northwest Mauna Loa Aquifer Sector Area (803).

Ola i ka wai,

M. KALEO MANUEL
Deputy Director

Figures:
1. Current Hydrologic Units, Hawaii Island
2. Recharge as % of All Inputs Map based on USGS Engott 2011
3. USGS Rift Zone Map (from 1946 to 1987 Studies)
4. Section from 2010 Morgan Rift Zone Map
5. Monitoring network basal water-levels within the Waimea-‘Anaeho’omalu ASAs
6. Waimea ASA pumpage
7. ‘Anaeho’omalu ASA pumpage
8. Well Locations within Waimea and ‘Anaeho‘omalu ASAs
9. Results of Ground Water Isotope Sampling Analyses (Whittier, 2019)

Exhibits:

1. Proposed Hydrologic Units, Hawaii Island
2. Townscape, Inc. notes from 12/17/2013 CWRM/Water Professionals meeting
3. TNWRE letters (11/27/2015 and 7/6/2016)
   HDWS letters (11/27/2015 and 3/28/2019)
4. WRPP Public Hearing comments
5. Don Thomas, PhD Memo May 13, 2019
6. Rift zone abandonment and reconfiguration in Hawaii: Mauna Loa’s Ninole rift zone

APPROVED FOR SUBMITTAL:

SUZANNE D. CASE
Chairperson

REFERENCES

Morgan, J.K., J. Park, and C. A. Zelt, 2010, Rift zone abandonment and reconfiguration in Hawaii: Mauna Loa’s Ninole rift zone, Geology, v. 38, no. 5, pp. 471-474.

Pierce, Herbert A. and Thomas, Donald M., 2009. Magnetotelluric and audiomagnetotelluric groundwater survey along the Humu'ula portion of Saddle Road near and around the Pohakuloa Training Area, Hawaii. USGS Open-File Report 2009-1135.

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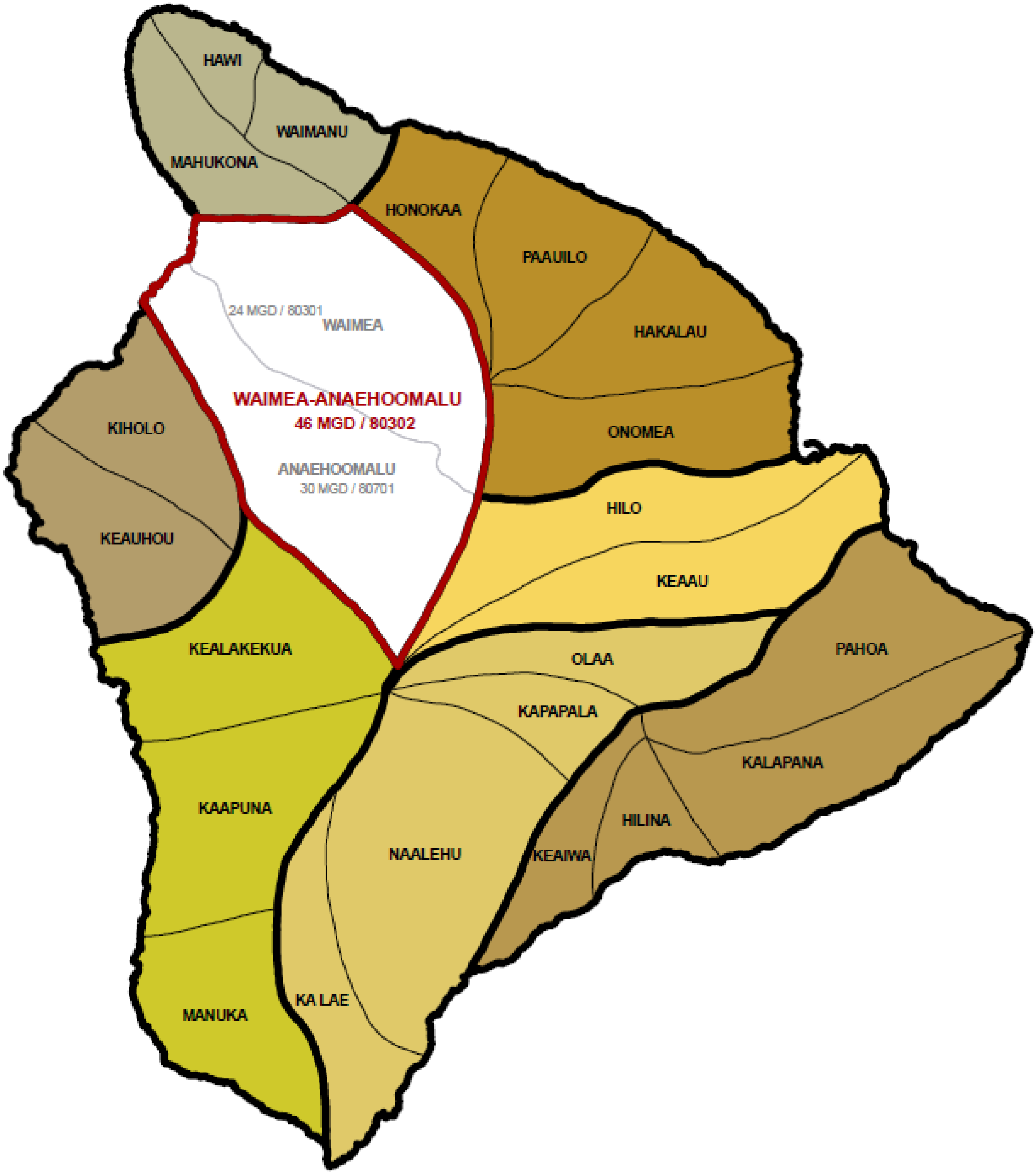
Thomas, D.M. and Haskins, E., 2015, New Insights into the Influence of Structural Controls Affecting Groundwater Flow and Storage Within an Ocean Island Volcano, Mauna Kea, Hawaii, Abstract H31D-1446 presented at 2015 Fall Meeting, AGU, San Francisco, Calif., 14-18 Dec.

Thomas, D.M., Lienert, B.R., 2015, Three-dimensional Magnetotelluric Modeling of the Pohukuloa Training Area, Hawaii Island, Abstract GP13A-1281, presented at 2015 Fall Meeting, AGU, San Francisco, Calif., 14-18 Dec.

USGS, 2011 (Engott). Scientific Investigations Report 2011-5078, A Water-Budget Model and Assessment of Groundwater Recharge for the Island of Hawaii

USGS, 2018. Scientific Investigations Report 2015-5164. Volcanic Aquifers of Hawai’i – Hydrogeology, Water Budgets, and Conceptual Models



Note: The SY of 46 mgd for the new Waimea-'Anaeho'omalu ASA reflects the proposed 16 mgd for the Waimea ASA, and 30 mgd for the 'Anaeho'omalu ASA.

EXHIBIT 1. Proposed Boundary Change

TOWNSCAPE, INC.
ENVIRONMENTAL AND COMMUNITY PLANNING

900 Fort Street Mall, Suite 1160, Honolulu, HI 96813
Telephone (808) 536-6999 Facsimile (808) 524-4998 email address: mail@townscapeinc.com

WATER RESOURCES PROTECTION PLAN (WRPP) UPDATE
MEMORANDUM NO. 18

Date: December 17, 2013
To: Project Files
From: Townscape, Inc.
RE: Water Professionals Group Meeting

Meeting Participants:

Private Sector Professionals
- David Barnes, Waimea Water Services (WWS)
- Stephen Bowles, Waimea Water Services (WWS)
- Dan Lum, Water Resource Associates
- Tom Nance Water Resource Engineering
- Glenn Bauer (retired)

Commission on Water Resource Management (CWRM)
- Roy Hardy, Ground Water Regulation Branch
- Patrick Casey, Ground Water Regulation Branch
- Paul Eyre, Ground Water Regulation Branch
- Lenore Ohye, Planning Branch
- Jeremy Kimura, Planning Branch
- Neal Fujii, Planning Branch

County of Hawai'i Department of Water Supply
- Larry Beck (*phone*)

National Park Service (NPS)
- Paula Cutillo

UH Manoa
- Clark Liu, Civil & Environmental Engineering, Water Resources Research Center
- Tom Giambelluca, Geography
- Craig Glenn, Geology & Geophysics
- Joseph Fackrell, Geology & Geophysics
- Aly El-Kadi, Geology & Geophysics, Water Resources Research Center
- Donald Thomas, Hawaii Institute of Geophysics & Planetology

EXHIBIT 2. Water Professionals meeting notes 12-17-2013 WRPP Update

Meeting Participants (continued)

U.S. Geological Survey (USGS)
- Stephen Anthony
- Delwyn Oki
- John Engott (*phone*)

Jeremy opened the meeting and reviewed its purpose: to present proposed revisions to the sustainable yield (SY) for Hawai'i Island and to discuss concerns with the revisions and the methodology that was used to develop them. After a brief background on the Hawaii Water Plan and Water Resource Protection Plan (WRRP) Update process, Roy provided background on SY, the model used to develop the revised SYs, basic caveats associated with the numbers, and proposed SYs for Hawai'i island (see attached slideshow)

Water Budget Model and Assessment of Groundwater Recharge for the Island of Hawai'i (2011). John Engott then presented the results of the USGS study (*31:16 in audio file*)

- Report available on-line at: http://pubs.usgs.gov/sir/2011/5078/
- In forested areas, two reservoirs were used: forest canopy and soil. In unforested areas, only one reservoir was used: soil.
- The model calculated the water budget for each sub-area and aggregated the results. Hawaii Island had over 467,000 subareas.
- The estimated recharge distribution was based on:
  - Land cover (2008)
  - Mean rainfall from 1986 Rainfall Atlas of Hawaii (1916-1983 rainfall)
  - Mean Pan Evaporation 1985 study
- Differences in recharge between 2008 WRPP numbers and the new estimates: some were lower, some higher, and some over 100% higher. The new model:
  - Used a daily time step vs. an annual time step (2008 WRPP)
  - Included fog interception
  - Subtracted runoff from baseflow
  - Used a more rigorous approach to calculate evapotranspiration (ET)
- 2011 water budget report
  - Is a transient recharge model
  - Identified four aquifer systems in Kona: Kiholo, Keahou, Kealakekua, Kaapuna
  - Ran the model in 5-year increments
  - Used estimated rainfall from the time period: 1984-2008
  - The 1984-2008 rainfall estimates are presented in terms of the percent of the 1916- 1983 rainfall mean presented in the 1986 Rainfall Atlas of Hawai'i.
  - Shows that using more current rainfall could make a substantial difference in recharge estimates, particularly in the Kona area.

- New datasets being incorporated into the water budget studies:
  - 2011 Rainfall Atlas (1978-2007 rainfall data)
  - Updated historical rainfall – monthly rainfall (1920 – 2007, to be extended to 2010)
  - New ET datasets being finalized by T. Giambelluca (UH)
  - Updated methods for calculating runoff
  - New climate data
  - Estimating runoff in ungaged basins
  - Updated how canopy interception is calculated
- Ongoing recharge projects:
  - Kauai 1978-2007 recharge estimate (uses 2011 Rainfall Atlas) : long-term average for a given area
  - 2010-2011 recharge estimates; Cooperator: USGS Ground Water Resources Program; expected in 2015
  - Oahu 1870: predevelopment condition
  - Oahu long term average 2010-2011
  - Oahu future scenario: incorporates climate change estimates
  - Oahu 1900-2010 transient study in 10 –year periods; Cooperators: CWRM, BWS, USGS GWRP; expect incremental reports from mid-2014 to early 2015
  - Maui 1978-2007 recharge estimates
  - Maui 2001-2010 drought scenario; Cooperators: GWRP, CWRM, Maui DWS; expected 2014-2015
  - Molokai 1940 – 2010 transient study in ten year period; Cooperators: USGS, Office of Hawaiian Affairs, Department of Hawaiian Home Lands, Maui Department of Water Supply; expected late 2014
- Would like to update Hawaii Island with new datasets but currently no funding

PROPOSED 2014 WRPP HAWAI'I ISLAND SY (*44:40 in audio file*)

- Generally affected upper range of SY; did not affect lower range of SY as much
- Yellow: lower ranges affected (*slide 19 of presentation*)
- Red: upper ranges affected (*slide 19 of presentation*)

DISCUSSION

- Hawi SY is too low
  - The original pumping numbers from sugar plantation days are a good starting point in determining more realistic numbers.
  - Water is being imported from Honokane and probably accounts for 50% of SY.
- Waimea and 'Anaeho'omalu aquifers – best available data is not being used
  - The table shows over 176 mgd recharge in 'Anaeho'omalu, but only about 20 percent of that in Waimea.

- We are currently pumping 14 mgd out of Waimea (nearing the lower end of the SY range) and only 4.3 mgd out of 'Anaeho'omalu, but sampling of shoreline discharge shows that there is at least an order of magnitude greater flow coming out of Waimea than 'Anaeho'omalu.
- The aquifer boundaries here do not make sense.
- The implication of recharge study is that there is more water in 'Anaeho'omalu, but on the ground observations contradict that. All wells drilled in 'Anaeho'omalu have been less productive and higher salinity than on the Waimea side of boundary.
- Northern side (Waimea) wells are tapping water from the Kohala Mountains. There are wells close to the boundary on both sides of Wai'ula'ula Gulch at the 700' elevation that are drinking-water fresh.
- **Starting with the recharge numbers is misleading. We need to start by redrawing the aquifer boundaries.**
  - The north boundary is far more important than the south.
  - This would shortchange the Mahukona aquifer, but a portion of the Kohala Mountains in the Mahukona aquifer above Waimea Town is a source of recharge to the Waimea aquifer.
- **Would not use the subsurface boundary as the aquifer boundary, but would move the aquifer boundary to the north to include the top of the Kohala Mountains.**
- Recharge for 'Anaeho'omalu would suggest that there is an average of 20 mgd coming out at the shoreline, but it's not coming out.
- There may be subsurface paths where groundwater is moving, which would explain the lack of coastal discharge from 'Anaeho'omalu, but there is actually a small fraction of that coming out. The water was never there.
- This area will become a hot spot in the future because it is slated for development.
- **Suggest new deep monitor wells in the Waimea/'Anaeho'omalu Aquifer System Area (ASYA)**
- Pu'uanahulu State well (drilled but not cased) on the south boundary of 'Anaeho'omalu area. The open-hole pump test at the 1500-1600-foot well elevation yielded <100 Cl and eight-foot water level.

- **SY should be ranges, rather than a single number, but how should we determine the minimum and maximum?**

1:10:06 in the audio file – break for move

EXHIBIT 2. Water Professionals meeting notes 12-17-2013 WRPP Update

- Basal vs. High Level Aquifers (*1:18:55 in audiofile*)
  - Hawai'i Island is expected to develop both basal and high level water.
  - The RAM model only works for basal aquifers, so how do we determine SY for high- level aquifers?
    - For high level water, we make a conservative estimate. Is the 0.44 draft/recharge (D/I) ratio in the table (*slide 19 of the presentation*) a conservative estimate?
    - The 0.44 D/I ratio is from J. Mink's suggestion for basal aquifers, but it's the best we have for high level water.
  - Hilo borehole hit water at 10,000 feet below msl
  - Schofield SY was left at the status quo; no additional pumping is allowed. Not sure how much water is going to Pearl Harbor vs. North Aquifer Sector Area (ASA)
  - "Water budgeting" is problematic in that it suggests that we know all of the other parameters and are trying to figure out one "left-over" number, but in reality, there are two or three parameters subject to uncertainty.
  - For water budgeting, a daily time step may not make sense because the other data is averaged.
  - There are other methods to estimate recharge beyond the water budget method.
  - Numerical modeling is not ready to replace RAM or RAM2 models for estimating SY, but it is still valuable for other roles, such as delineating boundaries, testing conceptual models, etc.
  - **Recommendations for more study:**
    - Delineate boundaries between basal and high-level aquifers
    - How to evaluate high level SY; D/I estimation
    - How to utilize the RAM2 model in basal aquifer evaluation, which requires monitor well data (RAM does not require monitoring data)
    - In the long-term, we need to investigate other methods beyond hydrological budgeting and investigate the underlying physics more: recharge vs. how much infiltration actually takes place under different scenarios.
    - More research on water budget estimation
- Water budget models are useful in that they provide recharge data to be used in determining SY estimates, which is what the State needs.
- Suggest using SY as a starting point. Come up with a reasonable SY with an "easy" methodology that people can understand and agree on. Assuming there is a reasonable SY, what is the process for determining when things are ok or not ok, so we know when/where to enforce management? How do you know where there's a problem? Is there an alternative method other than SY to manage water resources?
  - **We need to simplify water resource management – use direct observation as a tool.**
  - **Monitor measurable elements: rainfall and water levels + pumpage + salinity + streamflow**

  - **Need to monitor in the high level area**
  - **Need to monitor on a regular basis to be able to see changes**
  - If we use SY as a starting point, how often and under what circumstances should we be revisiting SY? When data show evidence of some change in factors affecting SY.
- Professional vs. casual/citizen observer. CWRM is using technology to allow for each user to report use. Is it sufficient to have "non-professional" monitoring at a monthly interval?
  - Take advantage of data we can get, but have some quality assurance/quality control (QA/QC) for monitoring – how good is the data collected?
  - **Provide periodic training to those providing the data to check calibration methods and ensure that the data being used to make decisions (water levels, pumpage, etc.) is good data.**
  - CWRM is planning to hire a consultant to help get users on board with reporting and to verify that the older wells have a meter. New wells after 1997 are supposed to have meters, based on construction standards.
  - **It might it be better to get a good representation of wells across a given area, rather than try to get 100% compliance in reporting? Water professionals could agree to a set of key monitorwells.**
  - Kiholo USGS well had good data in real time, but it was discontinued due to vandalism.
  - Honolulu BWS collected island-wide water level data which was readily available, but CWRM doesn't have this kind of data set.
  - Due to limited resources and personnel, CWRM began its groundwater data collection program in "hot spot" areas. Complicating factors: collecting data on neighbor islands and on private property, large sampling areas. Resources will limit the amount of data that an organization is able to collect.
  - **Develop better collaboration between private and public partners to maintain a useful monitoring network.**
- CWRM will build off of existing data and analysis – e.g., Kona area.
  - Kona high-level wells are responsive to rainfall, so we should **concentrate on the high level aquifers** (e.g., Keopu). Look at where water is coming out from high- level to the basal. If water is coming out, identify where it is coming out.
  - Need to both get additional data and analyze existing data to find out what is happening in the high-level Keauhou-Kona area
  - Some high level well trends are inconclusive – there are large changes, +/-10 feet
  - **Need to re-establish the "Bauer-era" monitor well network**
- **In areas where the SY range is changing, CWRM should look at monitoring data and identify how to correlate monitoring efforts with management, then bring that up for discussion.**

  - Water budgets and recharge estimates can be a starting point to revising SY, but there should be multiple lines of evidence for getting at SY, e.g., operational data. How do we incorporate operational data in the setting of SY?
  - How are we going to address high level data if RAM does not provide that? Especially now that we've found high level water in the Keahou area, there is uncertainty as to how we are going to manage that resource.
- Results of the isotope study may help to ascertain the elevation that water is recharging and the path of ground water, but there are uncertainties.
  - Preliminary results suggest that recharge may be coming from high elevation rainfall and that water may not be going where most people think it is going.
  - Isotope analysis is complicated by mixing with seawater.
- Role of geologic data (i.e., deep borehole, gravity survey, data) in explaining ground water occurrence, aquifer boundaries, water movement and barriers (inferred dike systems, etc.) (*2:01:45 in audio file*)
  - Modeled gravity data and inferred substantial diking
  - Geologic structure is a major player in where groundwater is moving, but we do not understand the geologic structure.
  - Future expansion of magnetotelluric groundwater (MT) surveys could indicate where fresh water is and where the transition is between fresh and saltwater. There may be sharp boundaries in the ground water system. Study areas include Waimea region and the Hualalai transect.
  - Land access and permission are challenges to MT research projects.
  - Data expected hopefully by 2015.
- To model high elevation water, we need to know aquifer thickness.
  - Beyond a certain depth we assume that water will be stagnant.
  - Based on what we see at the Saddle borehole, porosity is maintained for about one kilometer. Beyond that, things "pancake."
  - At 5,000 feet, we can see the flow boundaries but they are "pancaked." Do not see the same loose formations we see at 2,000 feet.
  - Saddle borehole cores can help to determine porosity and find barriers. This type of analysis was not included in the current study, but the cores are available to others for analysis.
- Purpose of the borehole was to determine the elevation ground water is at and what is its water quality because the Army is interested in it as a potential water supply.
  - The first 2,900 feet of the hole is unstable and experienced a lot of caving. The team needed to install casing to 2,918 feet to stabilize the hole. Will be perforating the casing and doing a pump test in spring 2014.

  - The hole diameter is about 4-1/2-inched (casing) to the 2,918 foot depth, then HQ coring size from there to 5,786-foot depth. The only water that could be sampled is 1,100-feet below the surface of what appears to be the stable water table.
  - At about 3,000' to 4,000 feet below the surface, the rocks lose permeability.
  - The Waiki'i pump well went to 3,700 feet.
- At what depth is an aquifer non-water bearing or impermeable?
  - Hilo borehole saw different results from the Saddle borehole.
  - Hilo borehole drilled to 3,600 feet and found fractures that are much more open.
  - Started at about 25 feet above msl, drilled through 2,760 feet of lava before hitting submarine haloclastites, but even those were open.
  - Saw a flat temperature gradient until 4,500 feet, then saw conducted gradient. Core got mineralized and compacted. This seemed to happen sooner in Saddle borehole.
  - The Saddle borehole hit the first perched water at 500 feet depth to about 540 feet, hit another perched aquifer at 700 feet to 1200 feet, then hit a sequence of unsaturated zones. All standing water in the borehole was lost at around 1,500 feet, then the final water table was hit at 1,800 feet and the borehole never lost water after that. The bottom of the hole is at 600 feet above msl.
  - Large scale perching formations will affect water flow.
- Traditional and Customary (T&C) Practices (*2:16:00 in audio file*)
  - Is how we currently define sustainable yield enough? We currently allow for 56% of recharge to flow into the ocean?
  - Do we need a monitoring for outflow? Is that an end-use?
- Climate Change Impacts
  - There is a current study on climate change impacts (sea level rise) on O'ahu aquifers
  - Climate change (sea level rise) will affect anchialine ponds
    - Rising sea level will make the ponds more saline
    - It will occur faster on Big Island since it is sinking
    - Impacts depend on how sea level rise interacts with nearshore topography
  - Change in storage boundaries due to rising sea level
  - Changes in rainfall will also affect recharge. Has there been an analysis in rainfall patterns in Kona area (there are still a number of active gages)?
- Volcanic Eruption Impacts
  - Rainfall decrease of about 30% in Kona due to vog (data shows this in downwind rain gages).
  - Rainfall is corrosive due to atmospheric sulphur from volcanic emissions (acid rain)
  - Possible increased sulphur in rainfall, and thus in the groundwater?
  - Really high concentrations of pollutants in the rift zone area – Ka'upulehu wells are enriched in every dissolved constituent. The water becomes semi carbonated and fouls up the R-O filters at Four Seasons resort.

  - Is the decline in rainfall in Kona exacerbated by volcanic activity (vog)? There is a correlation between decreased rainfall and vog, but there are no known studies that show causation. There are papers on polluted cities (where there are more particulates in the air) getthing reduced rainfall Water does not rain out of the atmosphere, but there tends to be more fog. There may be more fog interception in the upland Kona area.
- Is Kona high-level water moving into the basal aquifer – spillover vs. throughflow. The actual mechanism will affect management.

  Are the water bodies separate? How should we be treating this? Isotope studies are crucial so we can determine this.
  - Is basal water really just high level water just coming down? This is how we have been treating it. If not, how do we treat it?
  - If high level water is spilled over from the high level aquifer, then drawdown will have a more drastic effect than if we have throughflow, which would be driven by hydrostatic head. Drawdown of a few percent would affect throughflow by a few percent.
  - **Monitoring is essential. It will inform our understanding of how the systems work and we can then adjust our management.**
- Do we need something in Kona similar as the Pearl Harbor Monitoring Working Group that agreed on a monitoring network and triggers were proposed for management actions?
  - If we do not have a proactive approach, we will permit a lot of wells and development will occur, and we would have to pullback.
  - O'ahu was developed and had to cut back, but we should be able to plan for it better now.
  - What is the best management philosophy?
- **We need to have better monitoring. We need to identify the most critical data points, and get data in a timely manner.**
- How do we factor T&C into the SY? How much is sufficient? Is leaving a certain percentage of the water in the ground enough?
  - **Begin with SY as a starting point. Do not modify SY, but take that and other things into consideration when evaluating T&C impacts: well location, drilling, site specific studies on ecosystems, and other factors which may impact T&C practices.**
  - T&C is very site specific but SY is over a broad area.
  - Ascertain T&C practices through the permitting process (Ka Pa'akai analysis).

Next Steps

- There are areas where SY numbers are in question: CWRM staff should take a look at those and re-send the table out to the group.
- D. Thomas to send Flinders, et.al., paper to CWRM.
- Bowles and Nance to propose boundary changes on aquifer map.
- Isotope study analysis may help to identify aquifer boundaries, but data will not come out until after the WRPP.
    - New sampling point: Pace's Ranch well (hit water 1,000 feet above msl) – for isotope study.
- University group to identify relevant academic research in the area.
- Group should suggest new research projects in the area to improve knowledge inthe area.
- Locations for new deep monitor wells, particularly in Kona
- Potential to meet again, if needed.

EXHIBIT 2. Water Professionals meeting notes 12-17-2013 WRPP Update

DEPARTMENT OF WATER SUPPLY • COUNTY OF HAWAI‘I
345 KEKŪANAŌ‘A STREET, SUITE 20 • HILO, HAWAI‘I 96720
TELEPHONE (808) 961-8050 • FAX (808) 961-8657

March 28, 2019

Commission on Water Resource Management
Attention: Lenore N. Ohye and Roy Hardy, P.E.
Kalanimoku Building
1151 Punchbowl Street, Room 227
Honolulu, HI 96813

Dear Sirs:

Subject: Water Resource Protection Plan Update - Sustainable Yield Numbers and Aquifer Boundaries; Hawai‘i Island

The Department of Water Supply (DWS) respectfully requests, that until the aquifer boundary changes under consideration are resolved, and ready to be adopted, the Commission on Water Resource Management (CWRM) refrain from adopting the proposed changes to the aquifer sustainable yield numbers found in the *draft* update [Public Review Draft October 2018] to the Water Resource Protection Plan (WRPP).

DWS recognizes that boundary changes could have a significant impact on the application of the sustainable yield (SY) numbers. DWS believes that adopting new SY numbers without incorporating potential boundary changes at the same time could result in an unnecessarily misleading outlook on resource capacity and that it would be better to include all the pertinent information available to provide the most accurate determinations for sustainable yield. Doing so will help ensure the public's trust and support for the WRPP Update. Once the boundary changes have been appropriately addressed and those boundary changes can then be reflected in the determination of sustainable yield, then both the boundary changes and new sustainable yield numbers should be adopted.

Following are some additional comments and questions regarding some of the specific information found in the draft WRPP Update document.

SY Table – 201810 – The bottom of this page refers to Appendix F, however, if this table may sometimes be viewed as a stand-alone document, then the SY Table, itself, should include the footnotes that are found in Appendix F.

Appendix E – Memorandum No. 18: What is being done to consider the water professionals group's input on the Waimea and Anaehoomalu Aquifers in Memorandum No. 18, drafted December 17, 2013 by Townscape, Inc.?

Appendix F – Table F-10: Although the reference to Note 29 follows the SY (2019) estimates for the Waimea, Anaehoomalu and Mahukona Aquifer Systems, there should be a clear indication within the

EXHIBIT 3. – HDWS (5/28/19)

table that these numbers are under special consideration and are preliminary in order to avoid potential misconceptions.

Appendix F – Table F-11: Same as above. In addition to the comments in the column following, it should be made clear that this number is "preliminary until further confirmation."

Appendix H – Table H-10: This table does not indicate in any way, the intention of the 16 MGD being preliminary until further confirmation, nor does it indicate any potential aquifer boundary changes. This should be made clear as this is definitely a source of information that could be misleading.

Appendix H, Section 6.3.6 – County of Hawaiʻi WUDP 2010: This section addresses the WUDP as is and does not take into account the 2019 SY numbers. There should be some reference to the 2019 SY numbers and the potential aquifer boundary changes. It should also make it clear that the 2019 SY for the Waimea Aquifer in particular, is only preliminary until further confirmation and that the aquifer boundary changes are being considered based on the input of the water professionals' memorandum in Appendix E.

Appendix J, Section J.6.3.1: Reference to the County of Hawaiʻi, Waimea Reservoir. Please note that this is not intended to mean DWS' Waikoloa Reservoirs.

Should there be any questions or concerns, please contact Mr. Larry Beck of our Water Resources and Planning Branch at 961-8070, extension 260.

Sincerely yours,

Keith K. Okamoto, P.E.
Manager-Chief Engineer

LEB:dfg

copy – Fukunaga and Associates
Ms. Bethany Morrison, Planning Department

EXHIBIT 3. – HDWS (5/28/19)

TNWRE
Tom Nance Water
Resource Engineering

No. of pages: 12
Email: Robert.F.Chenet@hawaii.gov
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todd@tnwre.com

Original ☐ will ☑ will not
be mailed to you.

November 27, 2015
15-239 | 15-63

MEMORANDUM

To: Bob Chenet and Roy Hardy – Commission on Water Resource Management

From: Tom Nance

Subject: Comments on the Proposed Reduction of the Sustainable Yield of the Waimea Aquifer System (Code 80301) from 24 to 16 MGD

Introduction

This memo and its attachments provide comments on the proposal to reduce the sustainable yield of the Waimea Aquifer System from 24 to 16 MGD solely on the basis of a recharge estimate in USGS Scientific Investigations Report 2011-5078 (Engott 2011). I have been working on well development, monitoring well performance, and have been involved in other aspects of groundwater movement and its shoreline discharge in the Waimea Aquifer and elsewhere in West Hawaii continuously since the early 1970s. I believe my 40 plus years of experience puts me in a unique position to comment on the merits of the proposed reduction.

In my view, the proposed reduction is not warranted and would unnecessarily lead to the aquifer's near term designation as a groundwater management area. To demonstrate that, I will focus on the following three areas: recharge into the aquifer from beyond its currently delineated boundaries that is not included in Engott (2011); the unrealistic evapotranspiration amount in the Waimea Aquifer calculated in Engott (2011); and the field reality of conditions in the Waimea Aquifer itself and in comparison to other aquifers in West Hawaii. It is important that this unwarranted reduction not be enacted. Since January 2010, pumpage in the Waimea Aquifer has averaged about 13 MGD (Figure 1). Planned increases in groundwater use, particularly in Waikoloa (served by the Hawaii Water Service Company System), at the Mauna Kea Resort (potable and non-potable uses), and in DWS' Lalamilo System would trigger designation proceedings in the near future without any field evidence that such designation would be warranted.

EXHIBIT 3. – TNWRE (03/27/17)

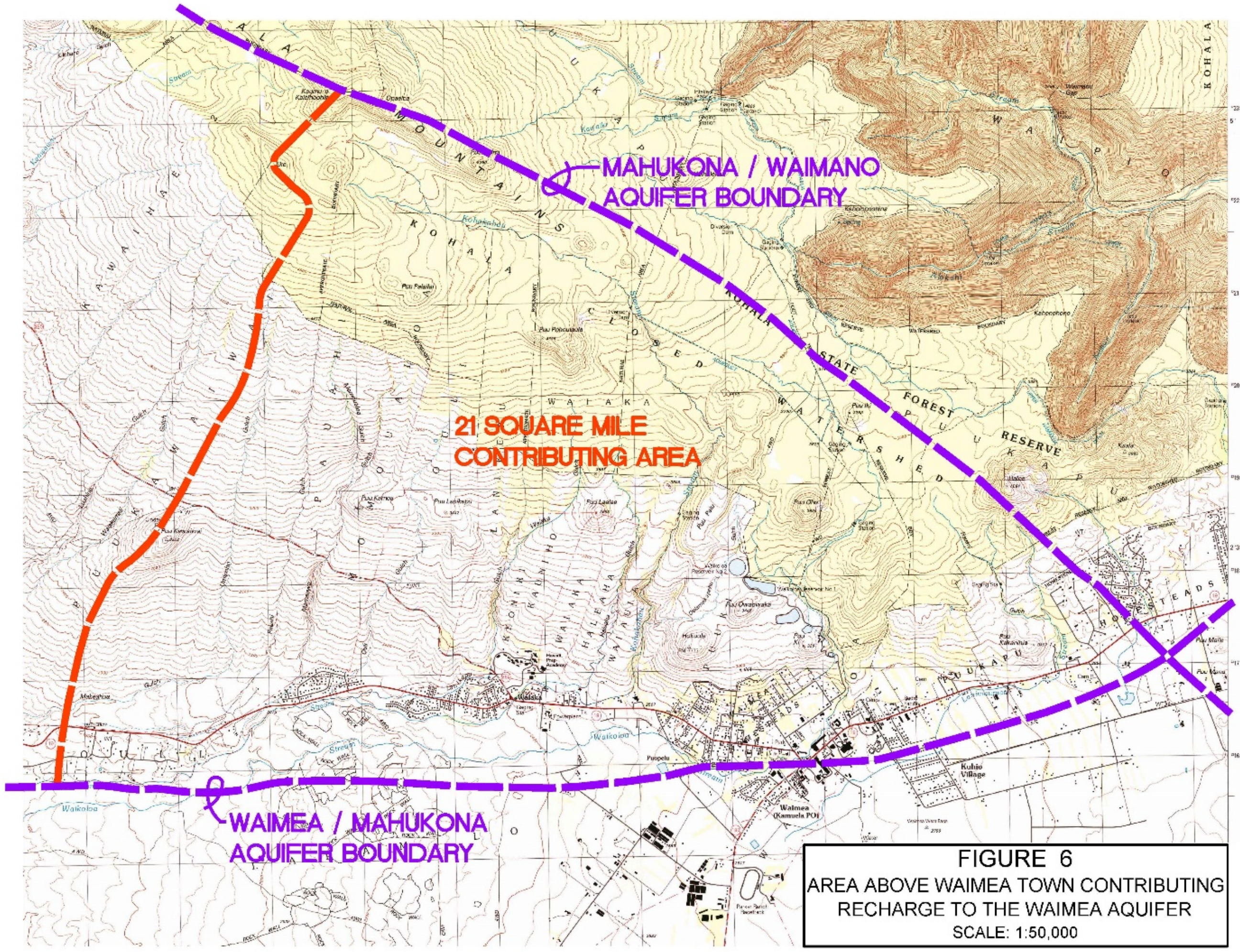


FIGURE 6
AREA ABOVE WAIMEA TOWN CONTRIBUTING
RECHARGE TO THE WAIMEA AQUIFER
SCALE: 1:50,000

EXHIBIT 3. – TNWRE (03/27/17)

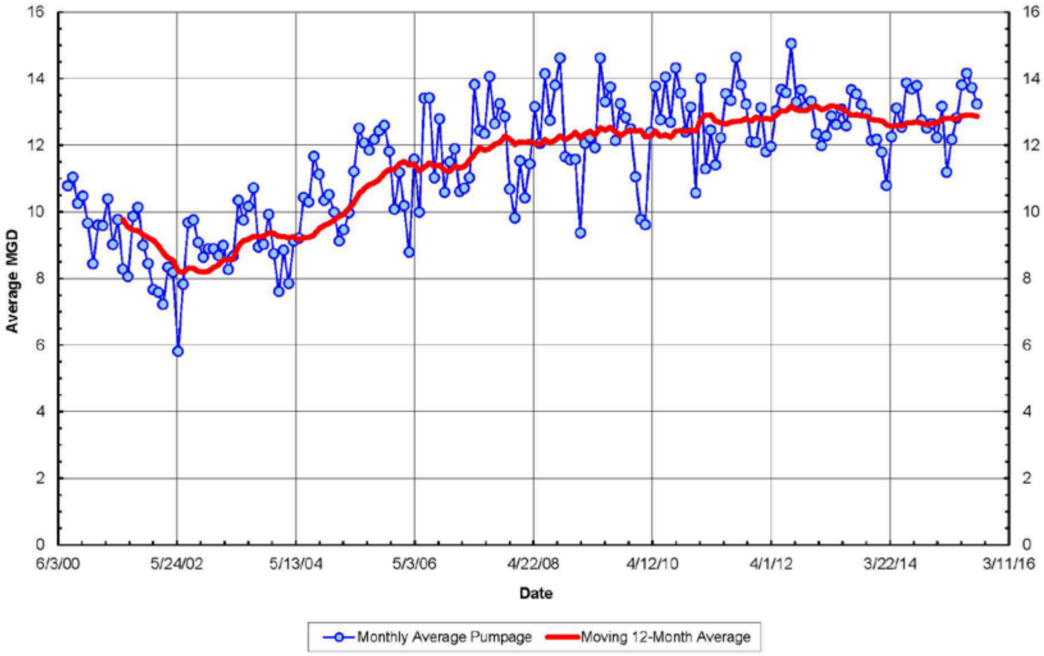
Table 1

Summary Comparison of Results in Engott (2011) for
Aquifer Systems from Waimea to Keauhou in West Hawaii

Aquifer System				
• Name	Waimea	Anaehoomalu	Kiholo	Keauhou
• Number	80301	807.01	80902	809.01
• Area (Square Miles)	300.0	319.2	147.4	164.4
• Shoreline Length (Miles)	3.55	5.29	12.3	19.4
Sources Contributing to Evapotranspiration				
• Rainfall (MGD)	286.02	315.68	176.04	339.01
• Fog Drip (MGD)	13.52	11.64	7.75	13.76
• Irrigation (MGD)	6.59	7.00	3.44	3.50
• Total (MGD)	312.13	334.32	187.23	356.29
Amount of ET and Evapotranspiration				
• Evapotranspiration (MGD)	255.83	145.34	99.21	158.64
• Canopy Evaporation (MGD)	12.50	4.07	7.96	40.13
• Total (MGD)	268.33	149.41	107.17	198.77
• % of Contributing Sources	86.0	44.7	57.2	55.7
Contributing Sources Versus Recharge				
• Total of Contributing Sources (MGD)	312.65	334.43	187.31	358.46
• Calculated Recharge (MGD)	35.62	181.69	76.19	151.62
• Recharge as a % of Contributing Sources	11.4	54.3	40.7	42.3

EXHIBIT 3. – TNWRE (03/27/17)

Figure 1. Monthly Pumpage of the Waimea Aquifer (Data from the CWRM)



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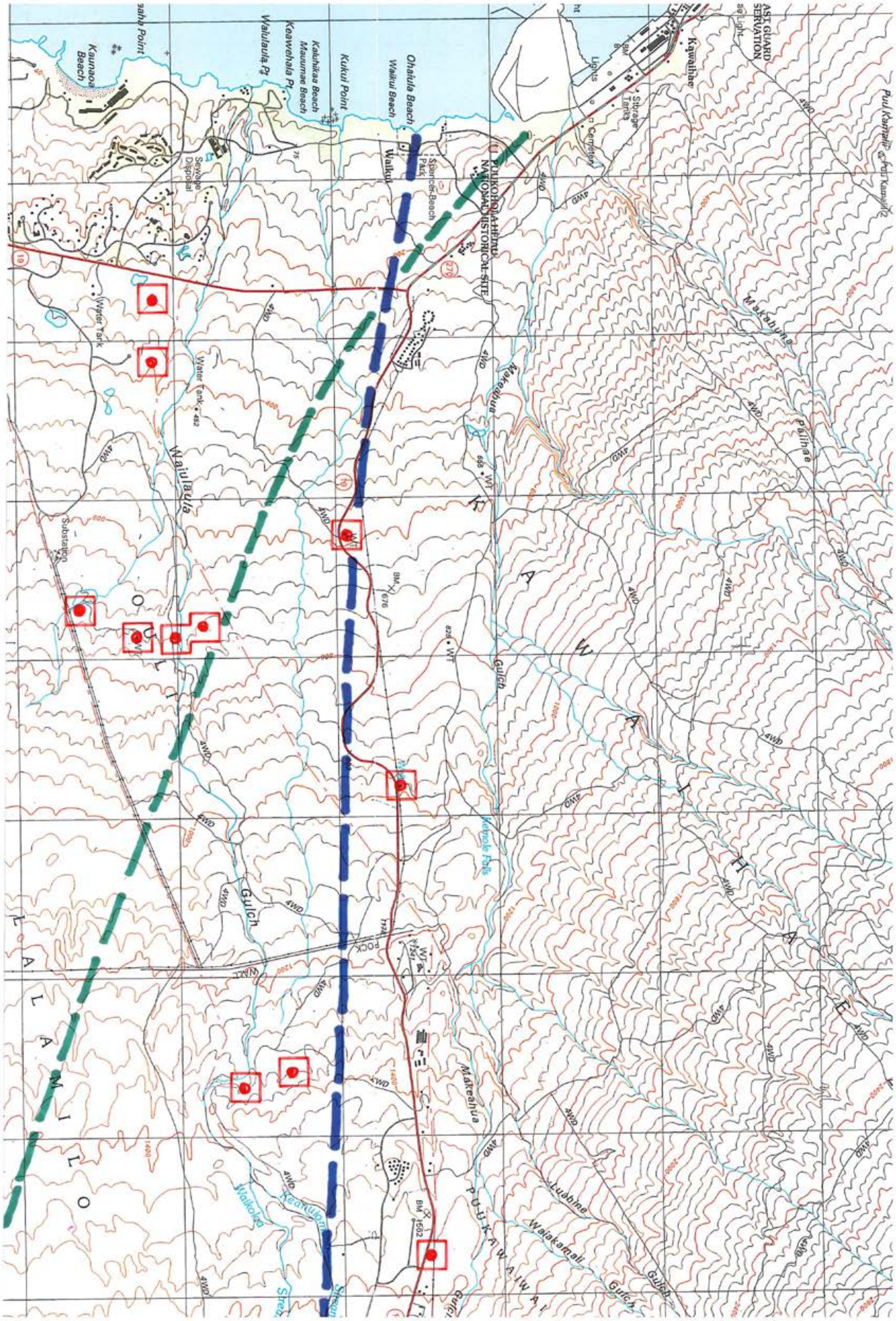

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Figure 3. Adjusted Flowrate at USGS Gage 7580 on Waikoloa Stream

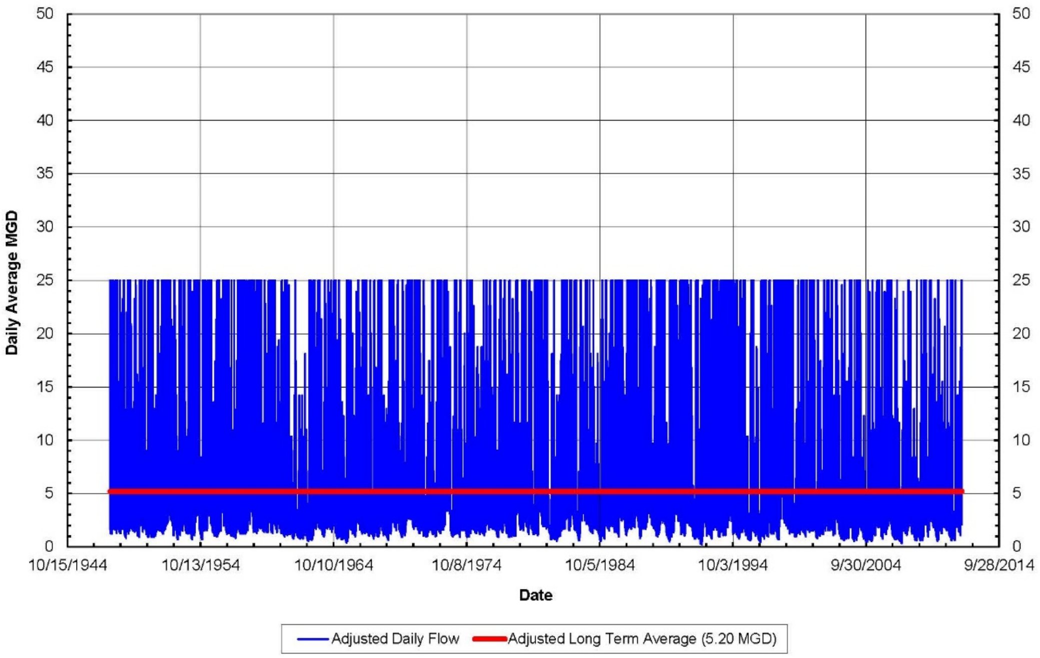


EXHIBIT 3. – TNWRE (03/27/17)

Figure 4. Adjusted Flowrate at USGS Gage 7565 on Keanuiomano Stream

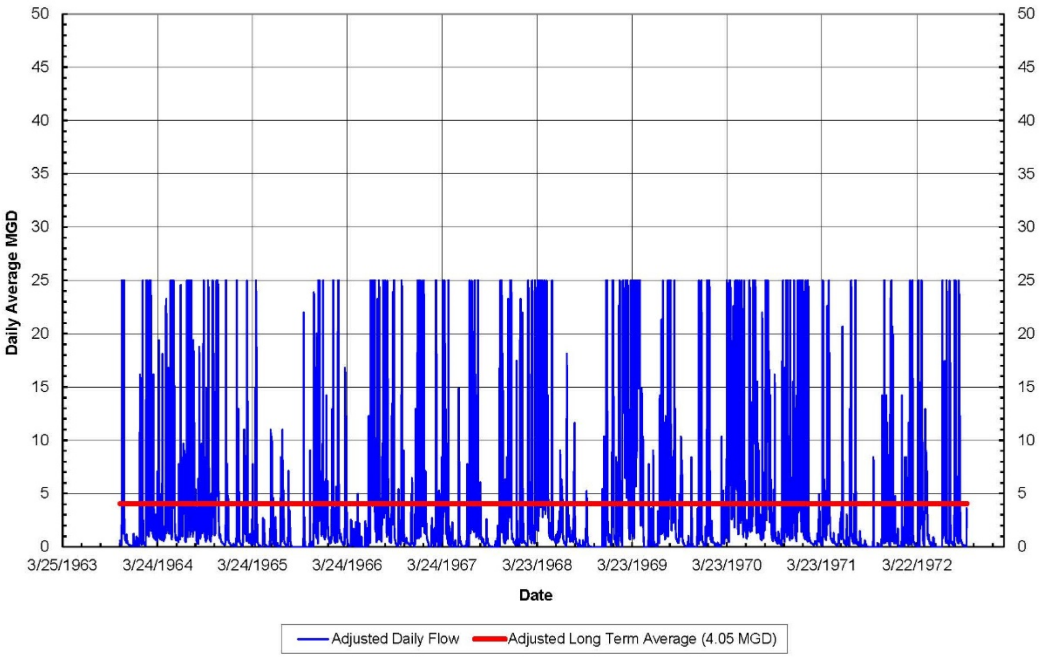
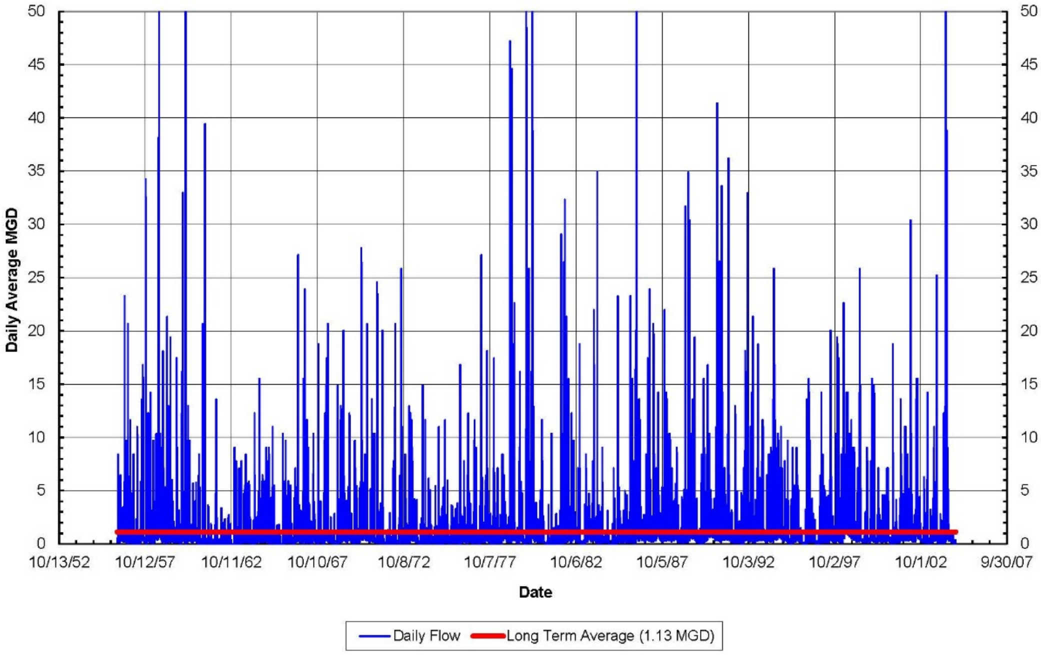


EXHIBIT 3. – TNWRE (03/27/17)

Figure 5. Flowrate at USGS Gage 7590 on Hauani Stream



Lateral Boundaries of the Waimea Aquifer and the Recharge from Beyond these Boundaries into the Waimea Aquifer

As currently delineated, the lateral boundaries of the Waimea Aquifer are the surface contacts of Kohala and Mauna Kea lavas on the north side and the Mauna Kea and Mauna Loa lavas on the south side. The reality is that neither of these surface contacts functions as a hydrologic boundary. From the perspective of the Waimea Aquifer's sustainable yield, the most egregious of these boundary delineations is on the north side. Without question, substantial recharge as surface runoff and as subsurface flow moves from the Kohala Mountain into the Waimea Aquifer. This very substantial contribution to the Waimea Aquifer's recharge, which is not included in Engott 2011, is described below:

- A projection of the Kohala Mountain lavas to sea level (Figure 2) is a way of illustrating a long known fact that a number of wells in the Waimea Aquifer actually draw water from the Kohala Mountain lavas. Further, a contact surface between the Kohala and Mauna Kea lavas that might impede the flow of groundwater between the two lava formations has never been encountered in the drilling of any of these wells.
- A substantial amount of surface runoff which originates on the slopes of the Kohala Mountain flows out onto the Waimea Aquifer, most of which never reaches the ocean and becomes groundwater recharge. The incredibly low salinity in the Hapuna 3 and 4 wells (State Nos. 6047-04 and -05) is attributable to this occurrence. An approximation of this contribution can be made with USGS gaging station data. By eliminating flowrates above 25 MGD as being lost to shoreline discharge(Figures 3, 4, and 5), the recharge to the Waimea Aquifer via surface water originating on the Kohala Mountain is on the order of 10 MGD (tally below which assumes a cancelling of flow diverted from Waikoloa Stream by DWS with runoff in ungagged streams and from below the USGS gages on gaged streams):

Approximation of Surface Runoff from the
Kohala Mountain Into the Waimea Aquifer

Stream	Average MGD
Waikoloa	4
Keanuiomano	4
Hauani	1
Other	0.5
Total	10+

EXHIBIT 3. – TNWRE (03/27/17)

- If the subsurface inflow from the Kohala Mountain into the Waimea Aquifer is conservatively limited to the 21 square mile area above Waimea Town shown on Figure 6, its contribution to the Waimea Aquifer's recharges is on the order of 10 MGD (approximated as 20% of its 47 inches per year of rainfall and 3 to 5 MGD of fog drip).

In short, by not including the indisputable subsurface and surface water sources of recharge from the Kohala Mountain into the Waimea Aquifer, the recharge amount in Engott (2011) has not included about 20 MGD of "offsite" recharge.

Unrealistic Evapotranspiration Calculation for the Waimea Aquifer in Engott (2011)

The information in attached Table 1 has been extracted from Table 7 of Engott (2011) to highlight the anomalous numbers calculated for the Waimea Aquifer. The tally in Table 1 compares the aquifer systems along West Hawaii from Waimea to Keauhou. Two calculated amounts for the Waimea Aquifer jump out as being unrealistic. First, evapotranspiration and canopy evaporation are calculated to be 86 percent of its potential sources (rainfall, fog drip, and irrigation). This is far higher than for the other three aquifer systems and is not realistic.

Second, groundwater recharge as a percentage of its contributing sources (rainfall, fog drip, irrigation, and direct recharge) is just 11.4 percent for the Waimea Aquifer. For the other three aquifer systems, the recharge percentages vary from 40.7 (Kiholo) to 54.3 (Anaehoomalu), an almost absurd contrast of numbers.

Field Reality versus a Desk Top Exercise

As indicated previously, my professional work in the Waimea Aquifer and elsewhere in West Hawaii spans 40 plus years. During this time, I have been responsible for the construction and pump testing of most of the currently active wells in the Waimea and adjacent Anaehoomalu aquifer systems. I have and continue to monitor the pumped salinity of the wells. In addition to work on the wells, I have made about forty assessments of groundwater conditions as required for proposed projects in various stages of land use entitlement processes. These assessments have included extensive and repeated sampling of groundwater discharge along the shoreline, done exclusively at low tide in the early morning when groundwater discharges are easiest to locate. The totality of this work translates to an extensive knowledge of field conditions in West Hawaii. From the perspective of this field experience, I have the following additional reactions to some of the calculations in Engott (2011):

- The computed recharge in Engott (2011) less ongoing pumpage should presumably reflect the balance of groundwater flow discharging along the shoreline. For the Waimea Aquifer, this would amount to 6.37 MGD per coastal mile (35.62 MGD recharge less 13 MGD pumpage over 3.55 coastal miles). For Anaehoomalu, it would be 33.4 MGD per coastal mile (181.69 MGD recharge less 5 MGD current pumpage over 5.29 coastal miles). The contrast is completely unrealistic. The Waimea shoreline discharge rate is too low and the Anaehoomalu shoreline rate is absurdly higher than reality.
- The Kiholo Aquifer (147.4 square miles) is less than half the size of the Waimea Aquifer (300.0 square miles), yet its computed recharge is more than double (76.19 versus 35.62 MGD). As someone how has been responsible for developing most of the active pumping wells in the Kiholo Aquifer and has continued to track their pumped water salinity, I can state unequivocally that the flowrate through the Waimea Aquifer is far greater than it is through the Kiholo Aquifer. The Engott (2011) calculations simply do not come close to reflecting field reality.
- Present pumpage of 13 MGD in the Waimea Aquifer amounts to about 80 percent of its proposed reduced sustainable yield. If the proposed sustainable yield is actually accurate, some indication of increasing salinity trends in the nearshore brackish irrigation wells or in the more inland freshwater wells is likely to have occurred. No such trend is evident in any of the actively pumped wells.

Summary Recommendations

1. To reflect reality, the CWRM must consider the indisputable contribution to the Waimea Aquifer's recharge from the Kohala Mountain either as a revision to the aquifer's lateral boundaries (both north and south) or simply as an adjustment to the mathematical accounting.
2. To accept the Engott (2011) calculations for the Waimea Aquifer as the sole basis for reducing its sustainable yield is to endorse its unrealistic results which are contrary to existing field conditions. Engott (2011) may have been peer reviewed within the USGS, but it was not by individuals such as myself who, through years of experience, can immediately identify its unrealistic results. The shoreline discharge rate from the Anaehoomalu Aquifer being more than five times the discharge rate from the adjacent Waimea Aquifer does not reflect reality. Recharge in the Kiholo Aquifer being more than double the recharge in the Waimea Aquifer is not at all realistic.
3. There is no distress due to overdraft anywhere in the Waimea Aquifer. The anticipated growth in groundwater use will be slow and can and will be carefully monitored. Given actual conditions in the aquifer, there is absolutely no reason to reduce its sustainable yield at this time.

Attachments

ec: Greg Fukumitsu and Todd Yonamine – TNWRE, Inc.

EXHIBIT 3. – TNWRE (03/27/17)

TNWRE
Tom Nance Water
Resource Engineering

No. of pages: 2
Email: Roy.Hardy@hawaii.gov
Robert.F.Chenet@hawaii.gov
Patrick.N.Casey@hawaii.gov
sgreen@hawaiiwaterservice.com
greg@tnwre.com
todd@tnwre.com

Original ☐ will ☑ will not
be mailed to you.

July 6, 2016
16-122 | 15-63

MEMORANDUM

To: Roy Hardy, Bob Chenet, and Patrick Casey – Commission on Water Resource Management

From: Tom Nance

Subject: Suggested Revisions of the Boundaries of the Waimea Aquifer System

As a follow up to my November 27, 2015 memo commenting on the proposed reduction of the sustainable yield of the Waimea Aquifer, this memo has an accompanying figure with recommended revisions to the boundaries of the Waimea Aquifer. The most significant revision is on the north side to add that portion of the Kohala Mountain which augments recharge to the Waimea Aquifer in two ways: as surface runoff onto the South Kohala plain which sinks into the ground rather than traveling all the way to shoreline discharge; and as subsurface underflow. The additional area is more than 20 square miles (essentially identical to Figure 6 attached to my November 27th memo) and adds on the order of 20 MGD of recharge to the Waimea Aquifer.

The suggested revision to the south boundary of the Waimea Aquifer is quite modest and limited to the nearshore area. The revision aligns the boundary to be parallel to the direction of groundwater flow toward shoreline discharge. Although the inland portion of the southern boundary may also ultimately need to be revised, I don't believe sufficient information exists to confidently suggest changes at this time.

Attachment

ec: Steve Green – Hawaii Water Service Company
Greg Fukumitsu and Todd Yonamine – TNWRE, Inc.

560 N. Nimitz Hwy. - Suite 213 • Honolulu, Hawaii 96817 • Phone: (808) 537-1141 • Fax: (808) 538-7757 • Email: tom@tnwre.com

EXHIBIT 3. – TNWRE (07/06/16)

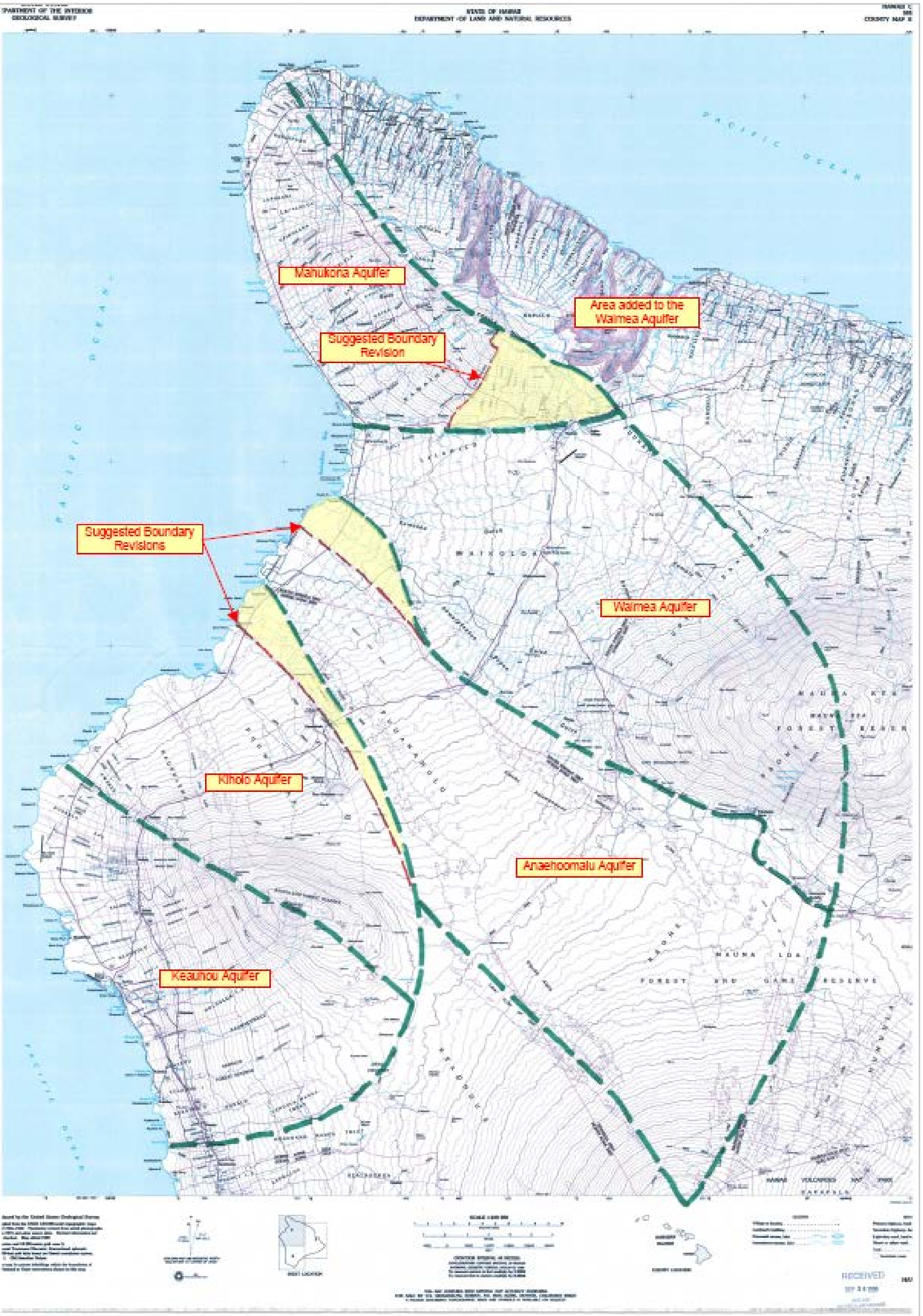


EXHIBIT 3. – TNWRE (07/06/16)

DEPARTMENT OF WATER SUPPLY • COUNTY OF HAWAI'I
345 KEKŪANAŌ'A STREET, SUITE 20 • HILO, HAWAI'I 96720
TELEPHONE (808) 961-8050 • FAX (808) 961-8657

November 27, 2015

Mr. Robert F. Chenet
State of Hawai'i
Department of Land and Natural Resources
Commission on Water Resource Management
1151 Punchbowl Street, Room 227
Honolulu, HI 96813

Dear Mr. Chenet:

Subject: Proposed Changes to Sustainable Yields
2016 Update to the Water Resource Protection Plan

We have received your email regarding the request for comments from the Water Professionals Group with respect to proposed changes in the 2016 Update to the Water Resource Protection Plan (WRPP). We strongly support CWRM's careful consideration of their comments and data before seriously contemplating any changes to Sustainable Yield numbers in the 2016 Update to the Water Resource Protection Plan (WRPP).

While the Department of Water Supply (DWS) does not have any hydrologists on staff, we rely on consultants with the appropriate expertise, including critical field experience in Hawai'i, such as Tom Nance Water Resource Engineering (TNWRE). We have received a copy of the TNWRE letter dated November 27, 2015, regarding the proposed change in the Sustainable Yield (SY) for the Waimea Aquifer. Upon review of this letter and the facts presented in the TNWRE letter, we request that the SY for the Waimea Aquifer remain at 24 mgd until additional studies or information become available and are analyzed for this aquifer. The proposed SY (16 mgd) is significantly lower than the existing SY (24 mgd), and a premature reduction could cause unnecessary concerns. The TNWRE letter points out discrepancies in the USGS sir2011-5078 study (Engott) and asserts that obvious subsurface and surface flow transferring from one aquifer to another is not considered at all in the study and that the SY numbers need to reflect this approximate 20 mgd of recharge, or the aquifer boundaries should be adjusted accordingly. It is extremely important to realistically evaluate the limitations of model parameters and the input data and to fully understand what critical factors may not be taken into account by any particular methodology. Thus, the DWS asks that the TNWRE information be strongly considered as Mr. Tom Nance had had been intimately involved with the development of most of the wells within the Waimea Aquifer. In addition, his data collection and evaluation of groundwater sources in this aquifer has spanned over 40 years, and continues currently.

EXHIBIT 3. – TNWRE (11/27/15)

We believe that we both share the same concerns to protect our resources as it is as much our responsibility as it is yours and that is why we are asking you to consider not only the best available, but more importantly, the most complete and reliable information prior to deciding on any changes to the proposed SY numbers.

Should you have any questions, please feel free to contact Mr. Kurt Inaba of our staff at 961-8070, extension 238.

Sincerely yours,

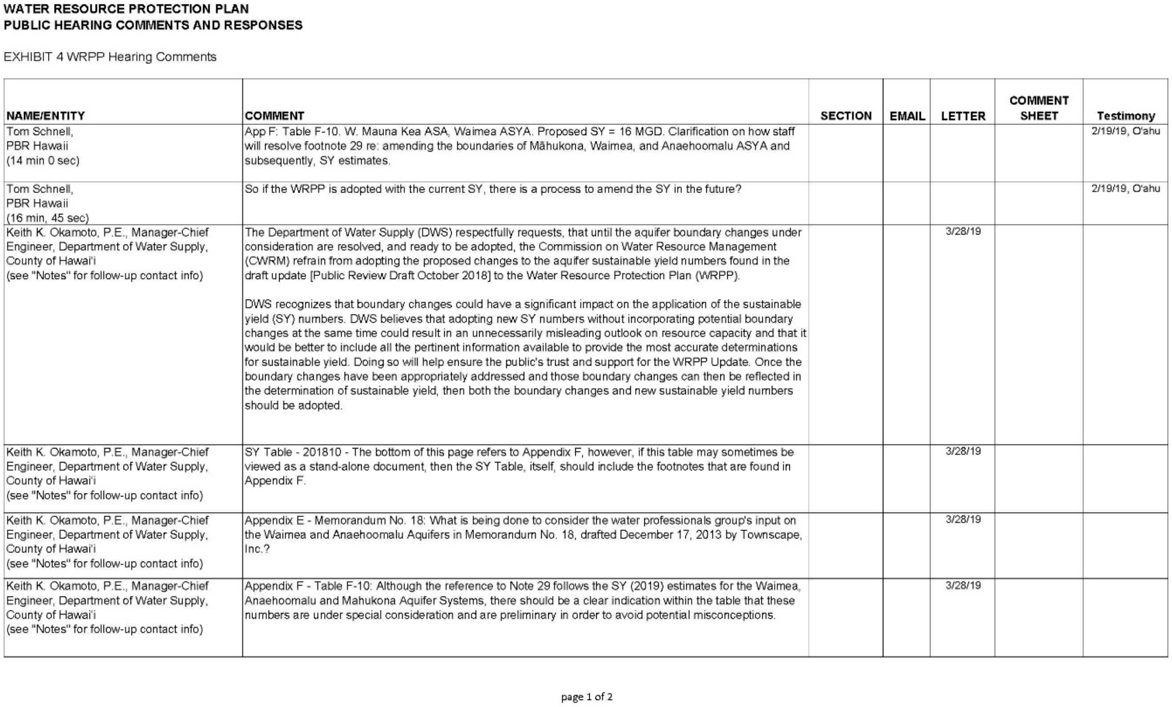
for Keith K. Okamoto, P.E.
Manager-Chief Engineer

KYI:dmj

Enc.

copy – (w/enc.) Mr. Roy Hardy, Commission of Water Resource Management

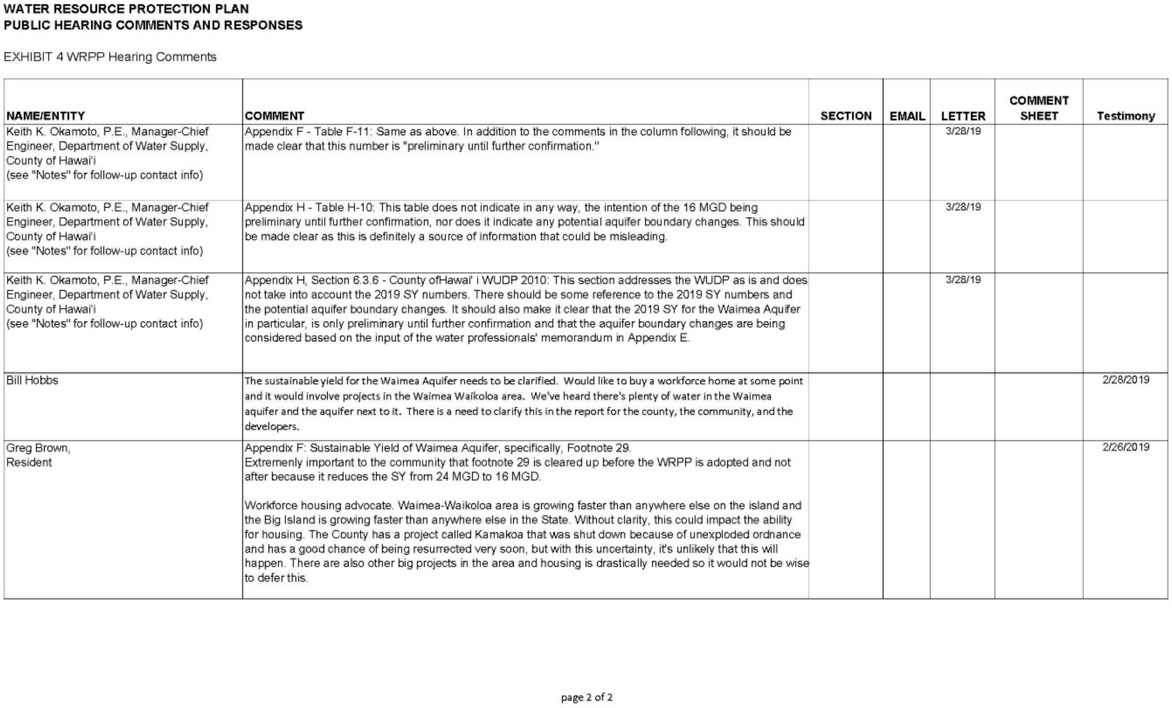
EXHIBIT 3. – TNWRE (11/27/15)



WATER RESOURCE PROTECTION PLAN
PUBLIC HEARING COMMENTS AND RESPONSES

EXHIBIT 4 WRPP Hearing Comments

NAME/ENTITY	COMMENT	SECTION	EMAIL	LETTER	COMMENT SHEET	Testimony
Tom Schnell, PBR Hawaii (14 min 0 sec)	App F: Table F-10. W. Mauna Kea ASA, Waimea ASYA. Proposed SY = 16 MGD. Clarification on how staff will resolve footnote 29 re: amending the boundaries of Māhukona, Waimea, and Anaehoomalu ASYA and subsequently, SY estimates.					2/19/19, O'ahu
Tom Schnell, PBR Hawaii (16 min, 45 sec)	So if the WRPP is adopted with the current SY, there is a process to amend the SY in the future?					2/19/19, O'ahu
Keith K. Okamoto, P.E., Manager-Chief Engineer, Department of Water Supply, County of Hawai'i (see "Notes" for follow-up contact info)	The Department of Water Supply (DWS) respectfully requests, that until the aquifer boundary changes under consideration are resolved, and ready to be adopted, the Commission on Water Resource Management (CWRM) refrain from adopting the proposed changes to the aquifer sustainable yield numbers found in the draft update [Public Review Draft October 2018] to the Water Resource Protection Plan (WRPP). DWS recognizes that boundary changes could have a significant impact on the application of the sustainable yield (SY) numbers. DWS believes that adopting new SY numbers without incorporating potential boundary changes at the same time could result in an unnecessarily misleading outlook on resource capacity and that it would be better to include all the pertinent information available to provide the most accurate determinations for sustainable yield. Doing so will help ensure the public's trust and support for the WRPP Update. Once the boundary changes have been appropriately addressed and those boundary changes can then be reflected in the determination of sustainable yield, then both the boundary changes and new sustainable yield numbers should be adopted.			3/28/19		
Keith K. Okamoto, P.E., Manager-Chief Engineer, Department of Water Supply, County of Hawai'i (see "Notes" for follow-up contact info)	SY Table - 201810 - The bottom of this page refers to Appendix F, however, if this table may sometimes be viewed as a stand-alone document, then the SY Table, itself, should include the footnotes that are found in Appendix F.			3/28/19		
Keith K. Okamoto, P.E., Manager-Chief Engineer, Department of Water Supply, County of Hawai'i (see "Notes" for follow-up contact info)	Appendix E - Memorandum No. 18: What is being done to consider the water professionals group's input on the Waimea and Anaehoomalu Aquifers in Memorandum No. 18, drafted December 17, 2013 by Townscape, Inc.?			3/28/19		
Keith K. Okamoto, P.E., Manager-Chief Engineer, Department of Water Supply, County of Hawai'i (see "Notes" for follow-up contact info)	Appendix F - Table F-10: Although the reference to Note 29 follows the SY (2019) estimates for the Waimea, Anaehoomalu and Mahukona Aquifer Systems, there should be a clear indication within the table that these numbers are under special consideration and are preliminary in order to avoid potential misconceptions.			3/28/19		



WATER RESOURCE PROTECTION PLAN
PUBLIC HEARING COMMENTS AND RESPONSES

EXHIBIT 4 WRPP Hearing Comments

NAME/ENTITY	COMMENT	SECTION	EMAIL	LETTER	COMMENT SHEET	Testimony
Keith K. Okamoto, P.E., Manager-Chief Engineer, Department of Water Supply, County of Hawai'i (see "Notes" for follow-up contact info)	Appendix F - Table F-11: Same as above. In addition to the comments in the column following, it should be made clear that this number is "preliminary until further confirmation."			3/28/19		
Keith K. Okamoto, P.E., Manager-Chief Engineer, Department of Water Supply, County of Hawai'i (see "Notes" for follow-up contact info)	Appendix H - Table H-10: This table does not indicate in any way, the intention of the 16 MGD being preliminary until further confirmation, nor does it indicate any potential aquifer boundary changes. This should be made clear as this is definitely a source of information that could be misleading.			3/28/19		
Keith K. Okamoto, P.E., Manager-Chief Engineer, Department of Water Supply, County of Hawai'i (see "Notes" for follow-up contact info)	Appendix H, Section 6.3.6 - County ofHawai' i WUDP 2010: This section addresses the WUDP as is and does not take into account the 2019 SY numbers. There should be some reference to the 2019 SY numbers and the potential aquifer boundary changes. It should also make it clear that the 2019 SY for the Waimea Aquifer in particular, is only preliminary until further confirmation and that the aquifer boundary changes are being considered based on the input of the water professionals' memorandum in Appendix E.			3/28/19		
Bill Hobbs	The sustainable yield for the Waimea Aquifer needs to be clarified. Would like to buy a workforce home at some point and it would involve projects in the Waimea Waikoloa area. We've heard there's plenty of water in the Waimea aquifer and the aquifer next to it. There is a need to clarify this in the report for the county, the community, and the developers.					2/28/2019
Greg Brown, Resident	Appendix F: Sustainable Yield of Waimea Aquifer, specifically, Footnote 29. Extremenly important to the community that footnote 29 is cleared up before the WRPP is adopted and not after because it reduces the SY from 24 MGD to 16 MGD. Workforce housing advocate. Waimea-Waikoloa area is growing faster than anywhere else on the island and the Big Island is growing faster than anywhere else in the State. Without clarity, this could impact the ability for housing. The County has a project called Kamakoa that was shut down because of unexploded ordnance and has a good chance of being resurrected very soon, but with this uncertainty, it's unlikely that this will happen. There are also other big projects in the area and housing is drastically needed so it would not be wise to defer this.					2/26/2019

EXHIBIT 4. WRPP Public Hearing Comments

Rift zone abandonment and reconfiguration in Hawaii: Mauna Loa's Ninole rift zone

Julia K. Morgan, Jaewoo Park*, and Colin A. Zelt
Department of Earth Science, Rice University, 6100 Main Street, Houston, Texas 77005, USA

ABSTRACT

A new onshore-offshore three-dimensional seismic velocity model for the Island of Hawaii reveals a massive buried rift zone within Mauna Loa's southeast flank, introduced here as the Ninole rift zone. This feature extends more than 60 km south of Mauna Loa's summit, spans a depth range of ~2–14 km below sea level, and is the probable source of the 100–200 ka Ninole volcanics in several prominent erosional hills. The ancient rift zone may stabilize Mauna Loa's southeast flank, focusing recent volcanic activity and deformation onto the unbuttressed west flank. The upper portion of the Ninole rift zone appears to have migrated westward over time, possibly triggered by landsliding, causing its eventual abandonment in preference to Mauna Loa's present-day southwest rift zone. Subsequently, the lower southwest rift zone broke away, tracking rift intrusions along the trace of the Kahuku detachment fault. Similar rift zone migration is thought to be under way at Kilauea volcano, and may one day lead to the abandonment of the east rift zone. Such rift zone reconfiguration is a reflection of changing stress conditions within growing volcanoes; it is probably much more common than previously assumed, and may enable the growth of large volcanic edifices such as Mauna Loa.

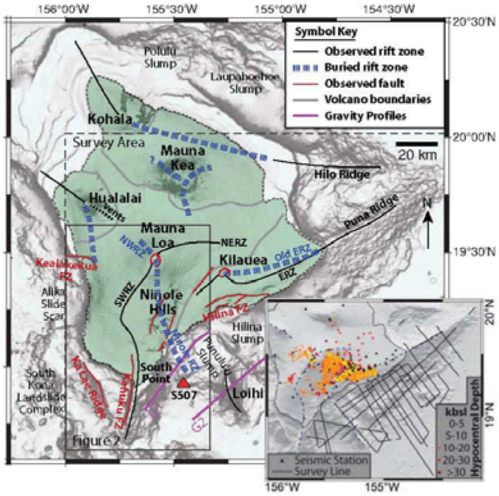


Figure 1. Present-day morphology of Island of Hawaii, showing active volcanic rift zones (solid black lines), buried rift zones (wide dashed blue lines) inferred from gravity and seismic velocity models (Hill and Zucca, 1987; Kauahikaua et al., 2000; Park et al., 2009), major fault scarps (red lines), and tracks of gravity profiles (purple lines) shown in Figure 4. Location of Shinkai Dive S507 is indicated by red triangle. Solid box shows area of Figure 2; dashed box is model domain (Park et al., 2009). SWRZ—Mauna Loa's southwest rift zone; NWRZ—Mauna Loa's northwest rift zone; ERZ—Kilauea's east rift zone. Bathymetry is from Eakins et al. (2003). Inset: Survey geometry showing locations of on-land seismic stations operated by U.S. Geological Survey Hawaii Volcanoes Observatory (black triangles) and 1998 R/V *Ewing* seismic survey lines, and earthquakes used in this study.

INTRODUCTION

Large oceanic volcanoes commonly develop elongate rift zones that disperse viscous magmas to the distal reaches of the edifice. The origins of such rift zones vary with location, but accompanying dike intrusions are thought to occur during extension perpendicular to the rift zones (Fiske and Jackson, 1972; Rubin and Pollard, 1987). Extension can be induced by gravitational loading and sagging of an elastic medium (e.g., Fiske and Jackson, 1972), spreading of the rift flanks on weak layers or detachments (Dieterich, 1988; Borgia, 1994), or slope failure (Walter et al., 2005). Topographic buttressing or resistance to basal sliding, however, can alter the axial stress regime, trapping intrusions at depth or blocking their lateral propagation (Dieterich, 1988). Thus, as volcanoes grow and interact, the controlling stress fields will change, potentially altering the orientations and activities of rift zones (e.g., Fiske and Jackson, 1972). The reconfiguration of volcanic rift zones has been documented along the boundaries of shallow slope failures (Walter and Schminke, 2002; Walter et al., 2005), and in response to volcano superposition and flank buttressing (Carracedo et al., 1999; Day et al., 1999). This phenomenon may be common, and can produce complex internal structures that influence the evolution of a volcano and its neighbors. However, little direct evidence for such rift zone reconfiguration exists, primarily due to poor preservation or recognition of earlier volcanic configurations.

One setting in which major rift zone reconfiguration has been interpreted is Mauna Loa volcano, Hawaii (Fig. 1). With a lateral extent of more than 120 km, and a vertical height of 16–18 km above the downbowed ocean floor, Mauna Loa is the oldest and largest of three active volcanoes that overlie the vigorous Hawaiian hotspot. Two active rift zones dominate the edifice today: the northeast rift zone trends toward Kilauea volcano and the southwest rift zone bends sharply to the south ~30 km from the summit, entering the ocean at South Point (Fig. 1). However, asymmetric gravity anomalies along the upper southwest rift zone (Lipman, 1980), further constrained by three-dimensional (3-D) gravity modeling (Kauahikaua et al., 2000), hint of buried intrusive rocks east of the active rift zone. Lipman (1980) interpreted an older rift zone left behind as the southwest rift zone migrated westward, possibly precipitated by catastrophic landsliding of Mauna Loa's west flank (Lipman et al., 1990).

Further evidence for past rift zone geometries comes from submersible surveys along the submarine Kahuku fault zone and Ka Lae ridge to the south (Fig. 1), where thick exposures of intrusive dikes are found (Garcia et al., 1995; Garcia and Davis, 2001). Either the southwest rift zone was unusually wide, or the Ka Lae exposures were emplaced by landsliding (Garcia and Davis, 2001). Until recently, few data existed to probe these hypotheses further, although each has significant implications for the evolution of large basaltic edifices in Hawaii and elsewhere.

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*Current Address: GX Technology Corporation, Building III, Suite 900, 2105 CityWest Boulevard, Houston, Texas 77042.

Geology, May 2010; v. 38; no. 5; p. 471–474; doi: 10.1130/G30626.1; 5 figures.

EXHIBIT 5. - Rift zone abandonment and reconfiguration in Hawaii: Mauna Loa's Ninole rift zone

MAUNA LOA VELOCITY STRUCTURE

We carried out a joint seismic tomographic inversion for the 3-D P-wave velocity structure of the southeastern part of the Island of Hawaii and adjacent offshore areas, using an offshore airgun shot–onshore receiver geometry, as well as earthquake sources beneath the subaerial edifice (Fig. 1, inset). The methodology and a more complete description of our preferred velocity model were presented by Park et al. (2009). The data were inverted for 3-D P-wave velocity structure using the regularized first-arrival-time seismic tomography method of Zelt and Barton (1998), modified to simultaneously relocate the hypocentral parameters, i.e., location and origin time (Ramachandran et al., 2005). The final velocity model is parameterized on a 1 km grid spacing. Based on checkerboard tests, we estimated the lateral resolution to be better than 10 km down to ~20 km depth beneath Mauna Loa's southeastern flank (Park et al., 2009).

Based on this preferred velocity model, the occurrence of high velocities of 6.5–7.5 km/s beneath the summits and major rift zones of the island's volcanoes was demonstrated by Park et al. (2009), consistent with intrusive complexes composed of dense intrusive dikes, gabbros, and olivine cumulates (Hill and Zucca, 1987; Okubo et al., 1997). In addition, several buried rift zones extending away from the major volcano summits (Fig. 1) were identified by Park et al. (2009), showing that Hawaiian volcanoes looked very different in the past. We take this effort one step further, exploring one such feature within Mauna Loa's southern reaches, previously recognized by Okubo et al. (1997), to understand the evolution of this massive edifice and implications for the future.

Figure 2 shows three depth slices through our velocity model at 3, 5, and 7 km below sea level (kbsl). Seismic velocities as high as 7.0–7.5 km/s occur in all three sections. At 3 kbsl (Fig. 2A), the high-velocity zone trends southwest of Mauna Loa's summit. At 5 kbsl (Fig. 2B), high velocities occur in an elongate zone that extends ~40 km due south of the summit. A marked step down in velocities also occurs just seaward of the bend in the southwest rift zone (arrow in Fig. 2B). By 7 kbsl (Fig. 2C), the high-velocity region has broadened, and a second one is revealed within the lower southwest rift zone. A prong of lower, but still anomalous velocities (5.5–6.2 km/s) continues another 20 km onto the submarine flank (Fig. 2C). A vertical section along the length of the anomaly (Fig. 3A) shows that the anomalous body extends to ~14 kbsl, where it merges with high velocities in the upper mantle. The highest velocities occur between 4 and 8 kbsl, and are sharply truncated at their southern end. A transverse profile (Fig. 3B) reveals the high velocity feature to be ~10–15 km wide, with a sharp velocity boundary on its northeastern side and smaller velocity step adjacent to the southwest rift zone (arrow in Fig. 3B).

The great length and thickness of the velocity anomaly in Mauna Loa's southeastern flank, along with its elongate geometry and unusually high seismic velocities, indicate that this feature is a buried rift zone, which does not correlate with any recent volcanic activity (Park et al., 2009). Based on its location beneath the prominent Ninole Hills (Fig. 1), we introduce this feature here as the Ninole rift zone.

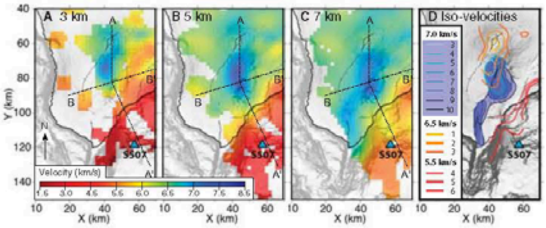

Figure 2. Depth slices through three-dimensional velocity model in vicinity of Mauna Loa volcano overlain by morphology; plotted region shown in Figure 1. Unsampled regions of velocity model are white. Dotted lines show locations of vertical cross sections shown in Figure 3. A: Velocity slice for 3 km below sea level (kbsl). B: Velocity slice for 5 kbsl. C: Velocity slices for 7 kbsl. D: Isovelocity contours for 5.5, 6.5, and 7.0 km/s between 1 and 10 kbsl.

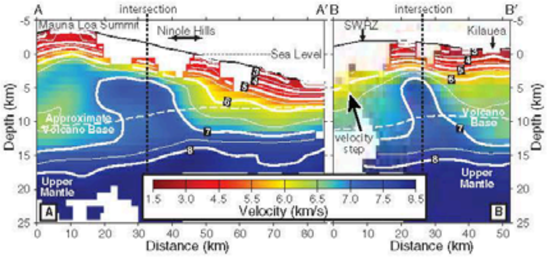

Figure 3. Vertical cross sections along line segments shown in Figure 2. Unsampled regions of slices are white. A: Profile A-A′ parallels long axis of interpreted rift zone within Mauna Loa's south flank. B: Profile B-B′ crosses Mauna Loa's buried rift zone. Dashed lines indicate base of volcanic edifice. Velocity contours in km/s. SWRZ—Mauna Loa's southwest rift zone.

To better constrain the 3-D geometry of the enormous Ninole rift zone, we plot velocity contours for several depth slices (Fig. 2D). Contours for 6.5 km/s from 1 to 3 kbsl show that the velocity anomaly aligns with the present-day southwest rift zone at shallow depths. The most prominent high-velocity anomaly is resolved by 7.0 km/s contours (Fig. 2D). At 3 kbsl, the 7.0 km/s contour outlines a small region trending south-southwest of the summit, just east of the present-day upper southwest rift zone. By 5 kbsl and deeper, the 7.0 km/s contour defines a broad north-south–trending body, which terminates along a high-angle velocity boundary beneath the Ninole Hills. The continuation of the high velocity feature into the submarine flank is indicated by seaward deflection of the 5.5 km/s contours (Fig. 2D).

A smaller region of high velocity is along the lower southwest rift zone between 8 and 10 kbsl (Fig. 2D). In contrast, there is a distinct lack of high velocities beneath the central southwest rift zone. It is significant that the large south-trending anomaly attributed to the Ninole rift zone is distinct from the high-velocity regions beneath the southwest rift zone throughout most of the edifice (Fig. 2D), and appears to be unrelated to the present-day active rift zones.

NINOLE RIFT ZONE

The recognition of a voluminous south-trending rift zone in Mauna Loa's southeast flank confirms and refines the interpretations for intrusive rocks to the east of the southwest rift zone based on gravity anomalies (Lipman, 1980; Kauahikaua et al., 2000), and also helps to explain several puzzles in Hawaiian geology. The origin of the highly eroded Ninole Hills on Mauna Loa's southeastern flank has been a subject of continuing debate. Their prominence and noncomformable east-dipping layers suggested that the hills were remnants of an older volcano underlying Mauna Loa (Stearns and Clark, 1930; Wright, 1971). Subsequent geochemical analyses, however, support a Mauna Loa origin for the Ninole volcanics, albeit quite old, 100–200 ka (Lipman et al., 1990). Lipman et al. (1990) suggested that the hills represented blocks entrained within the large Punulu'u landslide responsible for stepped lobate terraces on the submarine flank (Fig. 1).

We now believe that the high Ninole Hills are remnants of surface flows erupted from the ancient Ninole rift zone buried beneath them, and although breached by normal faults, are nearly in situ. The north-south trend of the Ninole rift zone is consistent with several north-south dikes

EXHIBIT 5. - Rift zone abandonment and reconfiguration in Hawaii: Mauna Loa's Ninole rift zone

that dissect the ancient hills (Lipman, 1980; Lipman et al., 1990). The east-dipping layering within the Ninole Hills can be explained by draping flows along the eastern flank of the rift zone. At the scale of our model, the steep frontal scarps of the Ninole Hills (Fig. 1) coincide with the sharp velocity boundary at the south edge of the high velocity anomaly (Fig. 3A), suggesting that past landsliding disrupted the downslope portions of the hills.

The offshore flank may preserve evidence for such landsliding (Lipman et al., 1990), but the geology and morphology are also consistent with a submarine rift zone (e.g., Smith, 1996), which we argue extends from Mauna Loa's summit. Two additional pieces of evidence support this interpretation: (1) a Bouguer gravity anomaly above the interpreted rift zone (G1, Fig. 4), comparable in magnitude to that over Loihi seamount (G2, Fig. 4), which is also underlain by a high-velocity body at a similar depth to the Ninole rift zone (Park et al., 2007); and (2) geochemical evidence for submarine erupted Mauna Loa pillow flows and massive basalt units (Lipman et al., 2002, Table A5), recovered during JAMSTEC (Japan Marine Science and Technology Center) Shinkai Dive S507 (Fig. 1). Relatively high sulfur contents of 400–600 ppm in these rocks indicate that these flows erupted from a submarine vent (Moore and Fabbi, 1971), likely along the Ninole rift zone. Future studies of this submarine flank could investigate these findings further.

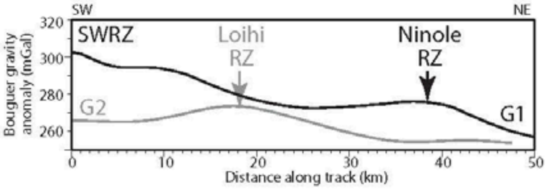

Figure 4. Bouguer gravity anomalies for tracks denoted in Figure 1; data sources and processing explained in Park (2008). Black line crosses interpreted Ninole rift zone (RZ), showing elevated anomaly relative to regional slope. Bouguer anomaly increases to southwest, where track approaches shallow intrusives in Mauna Loa's younger southwest rift zone (SWRZ). Gray line traverses Loihi seamount, and shows similar Bouguer anomaly associated with high-velocity body at similar depth to Ninole anomaly (Park et al., 2007).

RIFT ZONE RECONFIGURATION IN HAWAII

Our data offer general support for past rift zone migration and rotation on Mauna Loa (e.g., Lipman et al., 1990), but we also confirm large-scale rift zone abandonment on a scale never before documented. What could have caused the Ninole rift zone to shut down in favor of the younger southwest rift zone ? Catastrophic landsliding may have triggered rift zone migration. Any failure surface along the west flank would now be deeply buried, but could account for the low velocities across this area (Fig. 2). Alternatively, increasing curvature of the upper rift zone reduced magma supply to the lower Ninole rift zone, causing the gradual abandonment of the original rift zone. There is no direct evidence from our velocity model showing that this transition was sudden or catastrophic.

Abandonment of the Ninole rift zone would also favor the asymmetric growth of Mauna Loa documented by others (Lipman, 1980; Lipman et al., 1990). As the new southwest rift zone grew across the former west flank, it was buttressed on the east by the great Ninole rift zone. The west flank, however, was free to deform, as demonstrated by submarine landsliding, uplift, and accretion (Morgan and Clague, 2003). Ongoing deformation of the west flank created accommodation space for in-filling lava flows, favoring west-directed flows over east-directed ones (Lipman et al., 1990).

New evidence for the truncation of the original southwest rift zone now suggests a second episode of rift zone reconfiguration that provides insight into the first. The seaward decrease in velocities observed parallel to the bend in the central southwest rift zone (Figs. 2B and 3B) suggests a buried extension of the Kahuku fault zone. The offshore Ka Lae ridge, with its detached intrusive rift complex (Garcia and Davis, 2001) could have originated along this scarp (Fig. 5). Consistent with this model, high-velocity features within the southwest flank of Mauna Loa hint of buried landslide blocks (Park et al., 2009). The incision and detachment of the old southwest rift zone would have directed subsequent intrusions along the fault scarp toward South Point (Fig. 5).

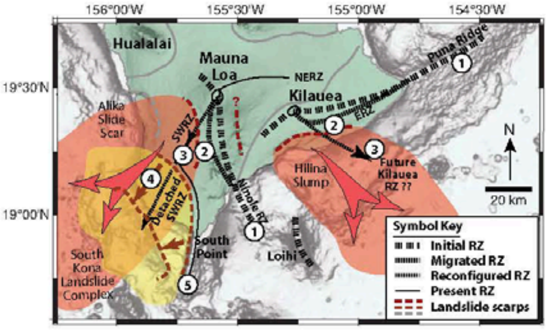

Figure 5. Interpretation of rift zone (RZ) evolution for Mauna Loa and Kilauea volcanoes. For each edifice, the oldest rift zone is indicated by wide dashed line, and younger rift zone configurations by progressively decreasing line widths. Landslide scarps are dashed, with probable regions affected by their debris fields noted by color shading. Circled numbers indicate sequence or events for a given volcano. 1: Buried rift zones, i.e., Kilauea's east rift zone (ERZ) and Mauna Loa's Ninole rift zone, extend onto submarine ridges. 2: Upper rift zones migrate seaward, introducing bends. Nearby landslides may unload rift zones. 3: New rift zones cut across landslide scars and onto submarine slopes; configuration of future Kilauea rift zone is hypothetical. 4: Mauna Loa's lower southwest rift zone (SWRZ) detaches along extension of Kahuku fault. (5) SWRZ follows trace of detachment fault, entering ocean at South Point.

Large oceanic volcanoes around the world likely hide similarly complex structures and histories, unnoticed due to a lack of data. Of great interest is the potential for younger volcanoes to undergo similar transformations in the future. In particular, Kilauea volcano appears to be in an early stage of rift zone reconfiguration. The upper east rift zone exhibits a nearly 90° bend (Fig. 1), and high gravity anomalies north of the present rift zone trace suggest the seaward migration of the rift zone over time (Swanson et al., 1976), possibly precipitated by past submarine slope failure (Morgan et al., 2003). One can see how continued rift zone migration could lead to the abandonment of Kilauea's lower east rift zone, allowing a new rift zone to propagate across the volcano's south flank (Fig. 5). If a new rift zone formed in this vicinity, the old east rift zone would serve as an upslope buttress, leading to asymmetric growth and flank spreading as documented on Mauna Loa.

Rift zone orientations are governed by regional and local stress fields, but these will change as volcanoes evolve, deform, and collapse. Thus, rift zone growth, abandonment, and reconfiguration may be the norm rather than the exception for large basaltic shield volcanoes, the formation of new rift zones opening easier pathways for magmas to reach the surface. Thus, rift zone reconfiguration can breathe new life into old edifices, potentially allowing volcanoes to grow to large size, as exemplified by Mauna Loa.

EXHIBIT 5. - Rift zone abandonment and reconfiguration in Hawaii: Mauna Loa's Ninole rift zone

Typically, this complex history is hidden from view, beneath the deceptive exterior of an active volcano, and can only be reconstructed when tools exist to look deep within the volcanic edifice, as has been achieved here.

ACKNOWLEDGMENTS

We thank Paul Okubo for help with extraction of the active source data and for sharing the earthquake data that made this joint inversion possible. Ongoing discussions with many investigators of Hawaiian geology have advanced our thinking about complex volcanotectonic evolution. We thank the reviewers, including Marco Neri, for their thoughtful comments on an earlier draft. Funding for this study was provided through National Science Foundation grants OCE-0221953 and OCE-0551750.

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EXHIBIT 5. - Rift zone abandonment and reconfiguration in Hawaii: Mauna Loa's Ninole rift zone

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May 12, 2019

Memo To: Roy Hardy
Commission on Water resources Management

From: Donald Thomas Donald Thomas

Subject: Findings of the Humu'ula Saddle drilling project of relevance to determination of Aquifer System boundaries

The research program that was undertaken in the Humu'ula Saddle was intended to better characterize the hydrologic conditions within the interior of the Island of Hawaii where relatively little hydrologic data were previously available. The project conducted geophysical resistivity surveys across the Saddle region, both east-west and north-south, to determine the deep electrical resistivity of the subsurface (as a means of identifying areas likely to have groundwater), and drilled two boreholes to depths of approximately 1.5 km.

Very briefly stated, the findings of that research were as follows:

Geophysical surveys: The east-west electrical resistivity data showed a fairly complicated structure that included a broad conductive feature at an elevation of a little more than 1 km above sea level that extended from a vertical resistive feature, located a short distance west of the Mauna Kea access road, westward beneath the Pohakuloa Training area lands toward the west flank of the Saddle. The top of the conductive feature is at a nearly constant elevation, except for a narrow (1 – 2 km wide) ridge immediately beneath the PTA cantonment. As the western flank of the Saddle is approached, the top of the conductor begins to descend to lower elevations at about the same rate as the slope of the ground surface. The conductive formations were interpreted to represent water saturated basalts, an aquifer, that was later confirmed to be present by drilling.

The north-south trending geophysical surveys extend across the exposed Mauna Kea surface onto younger lavas produced by Mauna Loa. Those surveys likewise show conductors at about the same depth as those shown in the E-W surveys but also show a shallow lowered resistivity layer that slopes toward the south that is interpreted to reflect the now-buried Mauna Kea slope that has been encroached upon by Mauna Loa lavas. That lowered resistivity is interpreted to be the result of soil and ash accumulated on the exposed Mauna Kea surface before Mauna Loa lavas were deposited: we believe that that layer is intercepting infiltrating rainfall and partially retaining it to allow lowered resistivity.

Drilling Results:
We selected as our primary drilling target the above-noted ridge in the conductive feature present in the E-W resistivity surveys. Our borehole at that location encountered a perched groundwater

EXHIBIT 6. DON THOMAS MEMO (5/12/2019)

table at a depth of about 700' below ground surface, an elevation of ~5700' amsl, that extended to a depth of about 1200' below ground surface. At the latter depth, the perching aquifer was penetrated and water levels in the hole dropped to below the bit. Drilling continued and a second aquifer was encountered at a depth of ~1800' (about 4600' amsl). That aquifer was continuous to the total depth drilled, 5786' depth or about 630' amsl, and we believe that aquifer is the continuous regional aquifer extending to sea level and below. The second borehole was located on the western flank of the Saddle, about 1 km beyond where the elevation of the top of the cross-Saddle conductive feature begins to descend in elevation. Our drilling at that location encountered a much different hydrologic environment: a series of confined aquifers was penetrated beginning at a depth of ~1050' below the surface (~4000' amsl). Many of the confined aquifers showed substantial hydrostatic head above the depth of entry: water levels within the drill string (which were sensed each time the core tube was lowered to the bit) would rise by several hundred to several thousand feet above the depth of entry into the confined aquifer.

To date, we have only been able to conduct testing of the deep regional aquifer in the first test hole located in the PTA cantonment. We conducted a short pump test and sampled the water from the formation at a depth of ~2000' below ground surface. The water there showed an isotopic composition consistent with rainfall at an elevation of ~10,000' amsl. The apparent age of that water was ~10,000 years before present, although that age may be somewhat impacted by the presence of magmatic carbon dioxide produced by an underlying geothermal system present in Mauna Kea.

The significance of these findings to the aquifer boundary between the Waimea and Anaehoomalu aquifer boundaries is as follows;

1. The presence of perched and confined (pressurized) aquifers in these boreholes demonstrates that buried ash/soil/clay layers within Mauna Kea's slopes exert a strong control over water flow and storage within the mountain.
2. The presence of high elevation recharge in the regional aquifer encountered in the PTA cantonment test hole, which is located south of the Anaehoomalu/Waimea aquifer boundary, indicates that recharge into the upper elevations of Mauna Kea is flowing toward the southwest into Mauna Kea formations that are now covered by more recent Mauna Loa flows.
3. The Anaehoomalu/Waimea aquifer boundary is, more or less, drawn along the surface contact of the recent Mauna Loa lavas where they have encroached onto the older Mauna Kea surface but has no further geologic basis that would affect groundwater flow within Mauna Kea or Mauna Loa.

Hence, I don't believe that the subject aquifer boundary, as currently configured, is useful for, or relevant to, its intended purpose. I don't believe that the observations made in the Humu'ula Saddle are unique and am strongly of the opinion that water flow across currently designated aquifer boundaries is far more common than has generally been recognized: this would include the Kohala/Waimea aquifer boundary as well as Anaehoomalu/Hualalai boundary and many others where aquifer boundaries reflect the intersection of volcanic deposits of younger volcanoes covering those of their older sister volcanoes. I would strongly advocate a program of re-evaluating all aquifer boundaries to better align them with geologic conditions and features that do have a substantial effect on groundwater flow – both in a horizontal direction as well as in a vertical direction. The current consideration of the Waimea/Anaehoomalu aquifer boundary is one obvious example, where we have data to demonstrate that cross boundary flow is occurring.

If I can provide further data of relevance to the present discussion, please contact me at your convenience.

EXHIBIT 6. DON THOMAS, PhD MEMO (5/12/2019)