# EXHIBIT "I-9" PART B

**CHAPTER 3** 

# **Existing Resources & Systems**

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#### **Key Points:**

- Lana'i has an estimated 6 Million Gallons Per Day (MGD) sustainable yield. Fresh water is found only in high level dike confined compartments in the Central Sector. The Central Sector is divided into two aquifer systems, the Windward and the Leeward, with 3 MGD sustainable yield in each.
- Total pumpage during 2008 was about 2.24 MGD.
- All pumping sources but one are currently located in the Leeward aquifer system, with about 85% of total pumpage, just over 1.9 MGD, coming from this system.
- There are currently 7 pumped sources, with one pumped at only 2,000 GPD. At 2008 pumping rates and distribution, water levels in Wells 1, 9, 14, 6 and, to a lesser extent 8, were declining.
- For comparision, the 1996 document, "A Numerical Ground-Water Model for the Island of Lana'i, Hawaii" (CWRM-1, 1996) modeled withdrawals between 13 sources, 11 of them pumping. It concluded that with the modeled distribution of withdrawals, the aquifer should be able to yield 3.52 MGD without undue damage, though some additional distribution or deepening may be required.
- No surface sources remain on Lana'i, although historical evidence points to the fact that the island once had springs, streams and even taro lo'i. Lana'i has 13 ahupua'a. Of one hundred and ten kuleana claims made within these ahupua'a, fifty-six were awarded.
- Lana'i has five water systems, two drinking water systems, one brackish water system used for irrigation, and two reclaimed water systems, also used for irrigation. Collectively, these systems include about 79 miles of active pipe, 35 MG of storage, of which about 4.8 MG is potable, and about 6.394 MGD installed well capacity of which 5.04 is potable.

- Average day capacity of potable systems in use, by System Standards, equates to about 2.24 MGD.
- Existing potable water rates are \$1.10 for the first 25,000 gallons and \$1.62 for every 1,000 gallons thereafter. Although non-potable rates are higher, (provided in System Finance and Economics Section), existing rates and fees are not sufficient for the utility to be self-supporting. The cost of well operation, not including the full cost of running the system is estimated at roughly \$2.17 per thousand gallons for the Lana'i City and Koele areas, and \$1.77 for the Manele and Palawai Irrigation Grid areas. Declining water levels could exacerbate that shortfall. For example, if water levels were to reach designation trigger elevations, assuming the same pumpage rates and electricity costs, the cost of pumping wells for the Manele and the Palawai Grid could reach as high as \$3.07 per Kgal.

# Geology



FIGURE 3-1. Map of Lana'i Showing Rift Zones, Palawai & Miki Basins, & Locations of Fossiliferous Deposits. Source: MacDonald, Abbott & Peterson *Volcanoes in the Sea*: the Geology of Hawaii, University of Hawaii Press, Honolulu, 1983.

Lana'i is 18 miles (30 km) long, 12 miles (21 km) wide, and has an area of 141 sq. miles (366 sq. km). The island is 3,370' tall at its highest point. Lana'i was created by a single shield volcano during the Tertiary period. Potassium argon dating places the age of Lana'i between 0.81 and 1.46 million years.

Lana'i was built by eruptions along three rift zones, running northwest, southwest and south, with possibly a fourth, more ancient rift zone running either north or northwest.

## Geology

Near the end of volcanic activity, during the subaerial shield building stage, a major collapse occurred around the intersection of the rift zones, to the southwest of Lana'ihale. Subsequent lava flows ponded in the collapsed caldera, with some outpouring through the south rift trough. The Palawai basin is a remnant of the original caldera.

Lana'i was submerged at various times during its geologic history, with evidence of previous shorelines at the 170 meter (558') elevation, and possibly also at the 190 meter (623') elevation. Fossiliferous marine limestone as much as 45 meters (148') thick extends up to 165 meters (541') altitude in Kawaiu gulch, with calcerous conglomerate containing many shell fragments and foraminifera as high as 167 meters (548').



FIGURE 3-2. Geologic Map of Lana'i. Source: MacDonald, Abbott & Peterson Volcanoes in the Sea: the Geology of Hawaii, University of Hawaii Press, Honolulu, 1983

Harold Thornton Stearns, a well-published geologist who was in charge of Hawai'ian groundwater investigations for the United States Geological Survey in the territory of Hawai'i during the 1930s and 1940s, thought that the island had at one time been submerged to what is now the 360 meter (1,181') elevation. Evidence for this lies in thin veins of limestone in the basalt at 321 meter (1,053') altitude, which contain fragments of coral, coralline algae and marine mollusk shells, probably formed from calcerous sand which sifted into cracks in the basalt, and in the divergent nature of soils above and below the 360 meter (1,181') level. Dune formations are also found at 306 meters (1,004') high on the south-eastern shore, and 285 meters (935') high on the ridge east of Maunalei, and in Kupa'a gulch along the northeast. Some geologists have speculated that certain marine materials at high elevations could have been deposited by major tsunami events. (Source: *Volcanoes in the Sea: The Geology of Hawaii;* MacDonald, Abbott & Peterson, University of Hawaii Press; ©1983).

Lana'i lavas are theolitic basalts, theolites, oceanites and some phenocrysts of labradorite feldspar. Pahoehoe dominates near the higher elevation vents, and a'a on the lower slopes. Lana'i basalts are highly permeable, except in vertical dike formations. The south side of the island has essentially no caprock, while the north side appears to have either alluvial deposits or caprock which may serve to deter discharge to the ocean.

Lana`i soils are from the Amalu-Olokui; Jaucas-Mala-Pulehu; Kahanui-Kalae-Kanepuu; Molokai-Lahaina; and Very Stony-Rock Land soil associations, with several series within these associations. Most of the soil series are well drained, with permeabilities ranging from 0.63 to 20 inches per hour. Runoff characteristics vary from slow to very rapid.

The hydrogeology of Lana'i is unusual in various respects, among them the predominance of high level water, including the presence of high-level brackish water accompanied by geothermal heating in the area of the Palawai basin. High-level water is found within 3.8 miles of the coast all around the island. Numerous dike and fault boundaries divide the main aquifer into many smaller, relatively independent compartments bounded by vertical walls of lower permeability. Evidence of relative impermeability of confining aquicludes was indicated by a 677' (206 m) difference in water levels between Wells 1 and 2 over a distance of 1 mile, and 733' (223 m) difference between Shafts 1 and 2 over a distance of two miles, noted by V.W. Thalmann in his 1954 report. (Source: *Summary of Lana'i Water Development from 1954* Report by V.W. Thalmann, in Anderson, *Water Supply Investigation, Lana'i, Hawaii*, Prepared for Hawaiian Pineapple Co. Ltd., By Keith E. Anderson, October 1957).

Lana'i is also anomalous relative to other Hawaiian Islands in that its windward side has low gradual coasts, while its leeward side exhibits high, dramatic sea cliffs such as the 300 meter (984') high Kaholo Pali, south of Kaumalapau. This is in part because Lana'i lies in the rainshadow of Western Maui and Eastern Molokai, and is relatively protected from wind and wave action on its "windward" side, whereas the "leeward", or southern - southwesterly side, has no protection for thousands of miles and is subject to southwesterly "kona" storm winds and waves. Long erosional grooves that run parallel to the prevailing wind direction on the west side attest to the fact that wind has also helped to shape Lana'i.

Large scale landslides have helped to shape the southwestern side of Lana'i, as evidenced by the  $6100 \text{ km}^2$  (2,355 sq. mile) submarine Clark Debris avalanche formation, which extends 150 km (93 miles) to the southwest of Lana'i in two branches (possibly representing two separate events).



FIGURE 3-3. Bathymetric Map & Map Showing Major Slides of Southeastern Hawaiian Ridge, Source: Moore, Clague, Holcomb, Lipman, Normark & Torresan; *Prodigious Submarine Landslides on the Hawaiian Ridge*; Journal of Geophysical Research; Volume 94, No. B12, pgs. 17,465-17,476; Dec. 10, 1989





# **Aquifer Systems and Yields**

There are nine aquifer systems in four sectors on Lana'i, as follows:

50101 - Windward	50201 - Hauola
50102 - Leeward	50202 - Maunalei
	50203 - Paomaʻi
50301 - Honopu	50401 - Kealia
50302 - Kaumalapau	50402 - Manele

Estimates of sustainable yield on the island have varied from about 5 to 10 MGD, with the current regulatory sustainable yield estimate at 6 MGD. Only the Central Aquifer sector is believed to contain fresh water. The island's entire sustainable yield of 6 MGD is found in this region, according to the sustainable yield classification system utilized by the State. By this system, the total area of this aquifer sector is about 24 square miles, (2008 *State Water Resources Protection Plan*) with water levels above 500' found in a 14 square mile area (1990 *State Water Resources Protection Plan*). Time domain elec-

tromagnetic resonance (TDEM) studies undertaken by consultants to Castle & Cooke Resorts in 1993 and 2001 indicated that the impeding structure bounding that aquifer may have an area of twice the regulatory extent. These studies are described later in this chapter. However, neither the regulatory boundary nor the estimated sustainable yield were increased in the 2008 update of the State Water Resources Protection Plan. The State's water model of Lana'i (CWRM-1, 1996), considered water level performance of existing wells using the larger recharge area indicated by TDEM studies. Neither the modeled results nor water level performance to date have appeared to indicate increased sustainable yield.

The sustainable yield of 6 MGD in the Central Aquifer sector is further divided into 3 MGD each in the Leeward and Windward aquifer sectors. All of the currently pumping wells, with the exception of Well 6, are located in the Leeward Aquifer, with a sustainable yield of 3 MGD. Figure 3-5 shows annual MAV pumpage in period 13 from Windward and Leeward aquifers from 1990 through 2008. Of a total MAV of about 2.241 MGD in December of 2008, about 1.913 MGD came from the Leeward Aquifer system, and about 0.328 came from the Windward Aquifer system.





Reasonable estimates of potential yield are also dependent upon the configuration of infrastructure and distribution of withdrawals. Here again, estimates have varied. In letters to Lana'i Land Company dated January 23, 1989 and January 25, 1989, respectively, John Mink and Keith Anderson both stated that with the configuration of approximately eight sources at the time, sustainable yield was about 3 MGD. (Sources at the time were Upper and Lower Maunalei Tunnels and Maunalei Shaft 2, and Wells 1 through 5). Both 1989 estimates anticipated an additional 0.8 MGD to be available based on the drilling of Wells 6 & 7. Mink also indicated that neither these nor Wells 9 & 10, also proposed at that time, would prevent the water table from declining to its equilibrium head. In the 1990 *State Water Resources Protection Plan*, although Mink estimated the island's sustainable yield was closer to 4 or 5 MGD. (Although Well 6

was not on-line until 1991, it had probably been tested and shown promise as of the time he wrote that document). The 1996 document, A Numerical Groundwater Model for the Island of Lana'i Hawaii, (Hardy, CWRM-1, State of Hawaii, 1996) indicated that thirteen sources existing at the time could deliver 3.52 MGD without damage to the aquifer, with the exception that both Maunalei Tunnels would run dry. This scenario included thirteen sources: free flow from the Upper and Lower Maunalei Tunnels (which would run dry in the scenario), and pumpage from Maunalei Shaft 2, Wells 1 through 9 and Well 14. This document is described further below. As of this draft, the Maunalei sources are no longer in use, and Wells 3 and 5 have also failed. Well 2 /Shaft 3 has rarely been used since 1996, though the source is still viable. Although efforts are in progress to restore or replace these sources, this leaves only six sources currently in use. The impacts of these infrastructure changes on safe yields are unclear. Plots of water levels in more recent years seem to indicate some decline, as shown on pages 60-77 of this chapter. Water levels are expected to decline in any case until equilibrium head is reached. The pace at which this occurs, and the amount of decline to equilibrium head, may or may not indicate a concern. In the case of Lana'i, it is not entirely clear whether recent declines are a concern and a function of distribution of withdrawals and aquifer yields, or whether they are simply natural equilibration or even a result of reporting methods.

The 1996 document mentioned above, *A Numerical Groundwater Model for the Island of Lana'i Hawaii*, (Hardy, CWRM-1, State of Hawaii, 1996) was the most recent in-depth examination of potential aquifer responses to different pumpage configurations. This document examined 6 pumping scenarios and gauged the effects of each on the aquifer. All of the scenarios assumed that the Upper and Lower Maunalei tunnels were allowed to flow freely, without pumpage. All of the scenarios but one resulted in some continued decline of water levels in the aquifer until a theoretical equilibrium would be reached. Hardy examined the anticipated drop in water levels to reach equilibrium in each scenario.

<u>Scenario One</u> involved continued pumping at a rate of about 1.707 MGD using ten sources (the Upper and Lower Tunnels, Maunalei Shaft 2, Wells 1 through 6 and Well 9). In this scenario, the aquifer would remain relatively healthy, though Upper Maunalei Tunnel would cease to flow. This scenario resulted in the second smallest decline in water levels of those tested.

<u>Scenario Two</u> involved no pumping at all, but loss of all fog drip. This scenario had greater impact overall to the aquifer than any pumpage scenario modeled, with water levels in the key recharge area dropping to about half their present levels.

<u>Scenario Three</u> involved pumping from existing wells to 6 MGD using ten sources (the Upper and Lower Tunnels, Maunalei Shaft 2, Wells 1 through 6 and Well 9). This caused regional water level decreases of concern probably due to inadequate distribution of withdrawals for this level of pumpage.

<u>Scenario Four</u> combined loss of fog drip with pumpage to 6 MGD using the same ten sources (the Upper and Lower Tunnels, Maunalei Shaft 2, Wells 1 through 6 and Well 9). This scenario would render many wells useless, with drawdowns over 1,300 feet in some areas. The worst effects were anticipated near the center of the island, in the key recharge area.



FIGURE 3-6. Water Levels as Modeled in A Numerical Groundwater Model for the Island of Lana'i, Hawaii; Hardy, CWRM-1, State of Hawaii 1996, showing cross section and aerial view of modeled area.

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<u>Scenario Five</u> examined only the effects of pumping two wells in the caldera (Wells 1 and 9). This scenario involved only 0.65 MGD of pumpage. There was little effect on upstream sources.

Finally, <u>Scenario Six</u> involved taking 3.52 MGD (CCR's proposed withdrawals at the time) from thirteen sources (the Upper and Lower Maunalei Tunnels, Maunalei Shaft 2, Wells 1 through 9 and Well 14). The Upper Maunalei tunnel would cease to flow in this scenario. Although water levels would be anticipated to drop in all sources, Hardy stated, "It appears that this pumpage scenario amongst existing wells will not harm the aquifer. However, some changes in the existing well infrastructure may still be necessary as some of the wells specified for future pumping have no track record of water level response to such stresses...".

Hardy concluded that modifications to existing well configuration, including both drilling of additional wells and deepening some, would be necessary in order to realize long term development of groundwater. Updated recharge estimates, developed as part of the modeling effort described above, were higher than those previously estimated. Nevertheless, the State elected to take a conservative approach in estimating sustainable yield, due to the absence of adequate data or studies to corroborate a potentially higher yield. Recharge estimates, though higher, were also very dependent upon the status of the mauka watershed, which has been in decline. Results are shown in Figure 3-6. Distribution of withdrawals used in the model vs. actual for 2008 and recent as of Oct, 2009 are shown in Figure 3-7.

Perhaps the most compelling conclusion resulting from this study was that the reduction of forest cover would affect groundwater levels drastically. The numerical model made a strong case for the maintenance of vegetative cover in the cloudy regions above the 2,000' elevation. The importance of watershed protection and measures contemplated in the plan are discussed further in the watershed protection section of this document.

	AS					AVG OF	
	MODELED	CWRM		* MOST	* OTHER	NON-ZERO	
	IN 1996	MODEL		RECENT	RECENT	MAVS OVER	
	CWRM	WELLS IN		ACTUAL	ACTUAL	PUMP	
	MODEL	USE NOW	2008 MAV	MAV	MAV	RECORD	Comments
Maunalei Shaft 2	500,000	0	0	0	557,385	525,980	*MAV period 13 1994. In the late 1980s, more than 600 KGal came from Maunalei sources. Shaft 2 operated until 1995 with a running MAV of around 526 KGal. Stopped in early 1995.
Well 1	270,000	270,000	393,981	378,074		291,173	*MAV period 7, 2009. Water levels appear to be declining at current pumping rates.
Well 2 / Shaft 3 future "2-A"	300,000		2,418	0	302,468	228,523	*302,468 was MAV period 13, 2006. However, there have not been 13 straight periods of pumping since 1997. Period 8, 1997 MAV was 157,140 GPD.
Well 3	300,000	0	0	0	233,991	191,281	*MAV period 6, 2006. Last 13 period with continuous non-zero pumpage.
Well 4	400,000	400,000	683,867	598,677		532,729	MAV period 7, 2009.
Well 5	400,000	0	0	0	120,030	153,557	*MAV period 12, 1992. This well started in the 200-300 KGal range for 2 years, and then dropped steadily. Period shown is last continuous non-zero MAV use.
Well 6	300,000	300,000	327,912	303,118		432,557	MAV period 7, 2009.
Well 7	200,000	0	0	0			No continuous pumpage record. One monthly number in 1992.
Well 8	300,000	300,000	276,890	255,469		121,459	*MAV period 7, 2009.
Well 9	270,000	270,000	151,440	127,851		224,302	*MAV period 7, 2009.
Well 12	0	0	0	0	14,305	10,316	*MAV period 13, 1995. Started at 17.8 KGal & declined continously. Use stopped in 1997.
Well 14	280,000	280,000	404,714	323,302		336,913	*MAV period 7, 2009.
	3 520 000	1 820 000	2 241 222	1 986 491	1 228 179	3 048 790	Average over pump record is high. These wells have not pumped at same time. Difference between 2,238,804 and 2,241,222 is less than 1%, and results from different averaging method

FIGURE 3-7. Lana'i Wells In 1996 Numerical Groundwater Model vs. Present Day

#### FIGURE 3-8. Lana'i Wells and Water Levels

Well	Initial Water Level (+MSL)	Action Level Nance	Lowest Allowable Level Nance	Trigger Levels for Designation Proceedings CWRM 3/29/1990	Current Level Period 7 2009 (except where noted *)	Notes**
1	818	550	410	414	575	
2 / Shaft 3	1,544 / 1,553	1050	750	772	1441	Initial head per Nance. "0" per CWRM database. Most recent WL reading period 13, 2002. Well rarely used since 1996. Used 8 months in '06, only few months each in '97, '02, '08.
3	1,124	750	562	562	992	Last WL reading from period 7, 2006. Well also not in operation since period 5 of 2006.
4	1,589	1100	750	794.2	1501	Initial head per Nance. "1078" per CWRM database.
5	1,570	1100	750	735	1496	Last WL reading from period 4, 2004. Well not in operation since roughly end of 1994.
6	1,005	750	500	502.5	924	
7	650			325		Initial head per CWRM. Only reported pumpage period 4 of 1992. First WL report - period 5,1999 - 980'. Last WL report period 4, 2004 973'. Not clear w hy heads are 300'+ higher than that recorded by CWRM.
8	1,014	750	500	507	944	Prior to period 6 of 2002, reported water levels were running in the mid 800s. In Period 6, 2002 they were 867. In Period 7, 2002, they jumped to 970' and have stayed in the 900s thus far. The increase may be due to a reporting method change in 2002.
9	808	550	410	404	650	Minimum reported w ater level w as 566' for periods 3, 4 and 5 of 2006. (Water level corrected by Takasaki survey per Hardy '96)
10	208			104		
11						Well missing from CWRM database or named differently there. Initial Head 95', if same as Palaw ai Exploratory. Never used.
12	5			2.5		
13	0					
14	551	400	292	275.5	497	Min high w ater level 418' - period 5, 2004.
15						Well to commence 2010.

\*\* Current and recent water levels refer to High Water Levels from the Periodic Pumpage Reports & are in elevation above Mean Sea Level. Designation triggers refer to static water levels. High water levels from pumping wells serve as a preliminary indicator for static water levels.

#### Water Levels

Figure 3-8 shows existing water levels at pumping wells versus water levels set by the CWRM as triggers for designation proceedings in its March 29, 1990 decision on designation, and action levels recommended by Tom Nance in 1996. When water levels reach triggers established by CWRM, designation proceedings are triggered. Based on Nance's 1996 proposal, when an action level is reached, pumpage data will receive a thorough public and scientific review with the aim to determine whether and what further actions, such as lowering the pump or replacing the affected well, distributing withdrawals or other measures, are indicated. When water levels reach the "lowest allowable level" proposed by Nance, pumpage of the affected well is to stop altogether until the well is able to recover. The historical and current status of individual wells are discussed on pages 60 to 77 of this chapter.



FIGURE 3-9. Side View Schematic of Well Water Levels Running North to South.

\*\*\*\* Ground elevation for Well 4 higher than tank spillway, so only ground elevation is shown. Wells 1, 9 & 14 used to pump to a control tank at 1,420' with a 1,434.5' spillway. This tank has now been bypassed, so the high point in the line, at 1,353' is the highest point to which Wells 1 & 14 now pump.

Figures 3-9 and 3-10 are recent (3-9) and historical (3-10) snapshots of water levels in pumping wells, running from north to south on Lana'i.

In Figure 3-9, lines marking elevations read top to bottom. The top black line represents the tank spillway level to which the well pumps, followed in descending order by ground elevation, high water levels in thick blue, low water levels in thin blue, pump intake levels, and the bottom of the hole. Dotted black lines represent past pump elevations. For instance, Well 8 pump level as of period 7, 2009 was 863.17'. The pump was lowered in early September of 2009 to 783.17' to avoid cavitation, as pumping water levels were within 17' of the pump.

Figure 3-10 provides the locations of the wells relative to Lana'i's topography. Although more recent data regarding depths and water levels are provided in Figure 3-9, and more recent data regarding apparent aquifer extents are provided in the next section, Figure 3-10 provides a useful reference for visualizing such data.

FIGURE 3-10. Hydrogeologic Section from Manele to Lana'ihale Illustrating the Comparative Locations of the Outer Limit of High Level Groundwater Occurrence. Source: Lana'i Company Water Resources Management Plan, 1996.



# Aquifer Extent - Time Domain Electromagnetic Resistivity Surveys

Water levels at pumping wells are described above. In addition to such measured levels, the depth, nature and extent of an aquifer can be characterized by other methods. Once such method is a time domain electromagnetic resistivity survey.

Time domain electromagnetic resistivity surveys are used to examine subsurface aquifer characteristics, including depth to water, lateral extent of water, degree of salinity and impeding structures or geologic features that would indicate areas where an aquifer may be present.

Electrical resistivity measurements are made by passing weak electrical currents through the ground and measuring the resultant voltage field. The behavior of the currents in the ground is sometimes compared to "smoke rings". After the initial "puff", the "smoke rings" expand, weaken, and travel down through the earth. The rate of diffusion depends on the conductivity or resistivity of the layers below. In resistive media, the currents diffuse rapidly, so the voltage drops quickly. In conductive media, they diffuse more slowly. After the initial pulse, the transmitter is turned off, and timed measurements are made of the resulting currents or "smoke rings". By making measurements at different time increments, a resistivity survey can identify variations in resistivity with depth, indicating different layers in the subsurface material. A series of soundings at different positions along a profile line can reveal lateral changes in resistivity, or changes across a section of ground. Changes in resistivity can reveal the presence of groundwater as well as provide some indication of the degree of salinity of water found.

Resistivity surveys were conducted as early as 1935. In *A Numerical Groundwater Model for the Island of Lana'i, Hawaii* (Hardy, State of Hawaii, CWRM-1996), Hardy discusses historical resistivity surveys of the island of Lana'i. Results vary but certain key points emerge. The island is characterized by high level water within 3.8 miles of the coast from any direction; the basal lens around the outside of the island is extremely thin; there is effectively no caprock on the southern side of the island but alluvium deposits on the north side may act as a sort of low permeability caprock; and finally, the presence of dikes and faulting in the main recharge area renders interpretation of resistivity studies for Lana'i a complex and uncertain undertaking. Even so, valuable data has been gained with regard to the general location of the confined high water boundary.

The most recent resistivity studies were performed in 1993 and 2001 by Blackhawk GeoSciences. Time Domain Electromagnetic Resistivity surveys (TDEM) were utilized to determine the location of the groundwater damming structure bounding the high level water, and to explore for anomalous basal groundwater occurrences. Data from the 2001 study are presented in Figures 3-11 through 3-13. Study areas referred to in Figure 3-13 are shown on the map in Figure 3-12. A larger version of this map is available on line in the large exhibits section of the Lana'i WUDP page.

Both the 1993 and 2001 TDEM surveys found that the aerial extent of the high level damming structure was broader than that originally estimated. The 2001 study also sought anomalous basal groundwater occurrences outside the damming structure. Results in the areas of Maunalei gulch, Haua gulch and an un-named gulch east of Manele Road indicated poor water resources in these areas. Possible basal lens occurrences were identified in Kahea gulch and Hauola Gulch. However, both of these sites were anticipated to yield low production wells. To date, CWRM has not elected to adjust the sustainable yield of the island based on these findings.



FIGURE 3-11. Cross Section of Lana'i showing inferred extents of high level water, basal water & damming structure

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FIGURE 3-12. Blackhawk GeoSciences TDEM Sounding Location Map, August, 2001. Red crosshatch = inferred geologic/hydrologic discontinuity. Blue = soundings in which groundwater is expected to be basal. Green = soundings interpreted to be in the groundwater barrier. Gold = soundings in which groundwater is expected to be controlled by geologic structure, or potential high-level water.





## FIGURE 3-13. 2001 TDEM Results - Blackhawk GeoSciences

	Time Dom:	ain Electron by <u>B</u> lackh	nagnetic Su <u>awk G</u> eosci	irvey of Lana`i iences, Sept 200	Groundwater 1
	Resistivity	Thickness	Elevation	Conductance	-
	(ohm-m)	(meters)	(meters)	(Siemens)	Interpretation / Comments
Area 1					North of Airport
Sounding 2			42	8	-
Layer 1	12.49	9 18.9	9 40	9 1.51	
Layer 2	1106.3	3 346.7	62.3	3 0.313	Soundings in Area 1 repositioned the
Layer 3	9.47	7			previously interpreted groundwater
Sounding 3			40:	5	damming structure 800'-1,000'
Layer 1	14.4	4 25.64	4 379	3 1.78	further seaward than had been
Layer 2	203.5	5 456.2	-76.8	6 2.24	interpreted from previous studies in
Layer 3	9.69	)			this area. This move reduced the
Sounding 4			41	7	available basal groundwater
Layer 1	23.73	3 38.58	3 378.4	4 1.62	resource estimates in the area,
Layer 2	95.45	5 198	8 180.	3 2.07	while increasing estimates of high
Layer 3	2.87	7			level water.
Sounding 5			46	0	
Layer 1	22.65	5 31.69	428.	3 1.39	
Layer 2	202.1	1 380.5	5 47.74	4 1.88	
Layer 3	10.35	5			
Area 2					Maunalei Gulch
Sounding 1			30	0	
Layer 1	13.05	5 30.29	269.	7 2.31	
Layer 2	924.5	5 290	-20.3	7 0.313	Results did not change previously
Layer 3	2.30	6			interpreted position of damming
Sounding 2			12	8	structure. However, results
Layer 1	114.6	6.97	7 12	1 0.0608	indicated a rift zone in the area,
Layer 2	15.42	2 25.89	95.1	3 1.67	and a thin brackish/fresh basal lens.
Layer 3	160.5	5 45.83	<b>49</b>	3 0.285	Basal brackish/fresh water resource
Layer 4	3.97	7			expected to be poor in this area.
Sounding 3			11	0	
Layer 1	94.87	7 7.06	5 102.9	9 0.0745	
Layer 2	21.69	9 26.14	4 76.7	8 1.2	
Layer 3	117.1	1 61.46	5 15.32	2 0.524	
Layer 4	6.13	3			
Sounding 4			10	0	
Layer 1	139	9.33	90.6	6 0.0671	
Layer 2	13.40	5 11.03	3 79.6	3 0.819	
Layer 3	83.85	5 30.43	<b>3</b> 49.2	2 0.362	

Existing Resources	& Systems				
Laver 4	17.24				
Sounding 5			78		
Layer 1	199.6	11.9	66.09	0.0596	
Layer 2	5.66	3.3	62.78	0.583	
Layer 3	422.1	60.81	1.96	0.144	
Layer 4	5.24				
Sounding 6			70		
Layer 1	153.2	5.57	64.42	0.0363	
Layer 2	42.47	50.18	14.24	1.18	
Layer 3	148.8	11.08	3.15	0.0744	
Layer 4	3.93				
Area 3					Maunalei Gulch -
Sounding 7			17		More Detailed Surveys
Layer 1	78.04	6.56	10.43	0.0841	
Layer 2	2.2	17.2	-6.77	7.81	
Layer 3	0.812				Interpreted results indicated
Sounding 8			19		streambed gravels, underlain by
Layer 1	91.6	6.13	12.86	0.0669	laterite and altered volcanics,
Layer 2	3.56	16.85	-3.98	4.72	underlain by fresh/brackish water
Layer 3	1.8				saturated volcanics below sea level
Sounding 9			15		underlain by saltwater saturated
Layer 1	85.02	2.43	12.56	0.0286	volcanics. Still indicates thin
Layer 2	3.04	16.6	-4.03	5.45	brackish/fresh water lens. Poor
Layer 3	1.23				groundwater resources anticipated.
Sounding 10			13		
Layer 1	101.3	1.74	11.25	0.0172	
Layer 2	2.4	26.53	-15.28	11.03	
Layer 3	0.973	22.51	-37.79	23.13	
Layer 4	18.09				
Sounding 11			12		
Layer 1	98.25	4.36	7.63	0.0444	
Layer 2	3.01	15.83	-8.19	5.24	
Layer 3	1.53	52.21	-60.41	34.07	
Layer 4	11.97				
Sounding 12			11		
Layer 1	74.68	2.39	8.6	0.032	
Layer 2	5.84	20.79	-12.19	3.55	
Layer 3	1.39	173.2	-185.4	124.5	
Layer 4	11.83				
Sounding 13			17		
Layer 1	39.4	9.85	7.14	0.25	
Layer 2	9.83	19.44	-12.29	1.97	

	Groundwater				
Layer 3	1.77	128.2	-140.5	72.04	
Laver 4	11.64				
Area 4					Kahea Gulch / Club Lana`i Area
Sounding 1			8		
Layer 1	36.1	44.39	-36.39	1.22	
Layer 2	2.12				Basal conductive layer found at
Sounding 2			7		unexpectedly great depth
Layer 1	6.82	2.32	4.67	0.34	considering that sites were only
Layer 2	35.78	36.89	-32.22	1.03	600'-700' inland from ocean.
Layer 3	2.13				Apparently anomolous basal lens.
Sounding 3			6		Could indicate better than usual
Layer 1	117	6.05	-0.0558	0.0517	groundwater resources. However,
Layer 2	19.08	33.93	-33.98	1.77	anomalous readings could also be
Layer 3	2.27				caused by low-permeability area or
Sounding 4			8		altered volcanics.
Layer 1	161	13.86	-5.86	0.0861	
Layer 2	25.18	30.22	-36.09	1.2	
Layer 3	2.81				
Sounding 5			15		
Layer 1	165.9	16.88	-1.88	0.101	
Layer 2	34.02	32.86	-34.74	0.965	
Layer 3	2.39				
Area 5					Haua Gulch
Sounding 1			28		
Layer 1	36.81	46.98	-18.98	1.27	
Layer 2	1.6	16.62	-35.6	10.35	Results indicate poor basal
Layer 3	2.5				groundwater resources. Basal
Sounding 2			26		conductive layer at modest depth
Layer 1	66.71	24.93	1.06	0.373	considering that the tests were
Layer 2	20.63	23.39	-22.33	1.13	2,000' inland from the ocean.
Layer 3	1.95				
Sounding 3			26		
Layer 1	41.07	42.28	-16.28	1.02	
Layer 2	2.76	42.47	-58.76	15.33	
Layer 3	9.61				
Sounding 4			29		
Layer 1	49.16	44.39	-15.39	0.903	
Layer 2	2.52	40	-55.4	15.83	
Layer 3	6.95				
Sounding 5			50		
Layer 1	343.2	64.8	-14.8	0.188	
Layer 2	2.42				

Area 6				1	Hauola Gulch
Sounding 1			20		
Layer 1	75.7	3.29	16.7	0.0435	
Layer 2	15.95	29.27	-12.56	1.83	Unexpected depth to basal seawater
Layer 3	1.78				may indicate better than normal
Sounding 2			18		basal brackish/fresh groundwater
Layer 1	85.02	5.57	12.42	0.0655	resources in this area. However,
Layer 2	13.29	31.79	-19.36	2.39	this could also be caused by a low-
Layer 3	1.93				permeability formation or altered
Sounding 3			16		volcanics.
Layer 1	83.91	3.89	12.1	0.0464	
Layer 2	14.82	33.02	-20.91	2.22	
Layer 3	1.84				
Sounding 4			14	_	
Layer 1	85.24	4.67	9.32	0.0548	
Layer 2	15.75	32.72	-23.4	2.07	
Layer 3	1.95				
Sounding 5			12		
Layer 1	78.22	3.79	8.2	0.0485	
Layer 2	13.99	33.04	-24.84	2.36	
Layer 3	1.5				
Sounding 6			12		
Layer 1	57.71	1.32	10.67	0.0229	
Layer 2	18.6	33.9	-23.23	1.82	
Layer 3	1.45				
Sounding 7			20		
Layer 1	172.6	8.71	11.28	0.0504	
Layer 2	18.65	29.22	-17.94	1.56	
Layer 3	1.61				
Area 7					Gulch East of Manele Road
Sounding 1			102		
Layer 1	79.4	113.2	-11.23	1.42	
Layer 2	0.117				Significant geologic structure
Sounding 2			101		identified in this area. Groundwater
Layer 1	380.7	102.3	-1.39	0.268	resources expected to be poor.
Layer 2	3.42				
Sounding 3			95		
Layer 1	60.37	59.79	35.2	0.99	
Layer 2	0.0152				
Sounding 4			85		
Layer 1	176.9	86.06	-1.06	0.486	

		Precipitation			
	Layer 2	2.49			
Sounding 2	5			80	
	Layer 1	118.7	37.65	42.34	0.317
	Layer 2	0.00241			
Sounding	6			90	
	Layer1	94.06	69	20.99	0.733
	Layer 2	0.0607			

# Precipitation

Rainfall is a major source of recharge to aquifers, streams and springs, as well as being an indicator of the effects of climate change. Rainfall measurements have been taken at 52 rain gauges on Lana'i since 1914. Eight rain gauge stations are still in service and are followed by the National Weather service. The longest rain station records are those for Lana'i City and Koele. (Koele station # 693, not included in Figure 3-14 below, monitored from 1949 to 1963, showed an average annual precipitation of 37.3 inches.)

			La	na`i Mon	thly Mea	n of Pred	ipitation	(01/1970	-02/2002)					
Station Name	Sta. No	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
Kanepuu	690	4.44	3.04	2.65	1.58	1.31	1.24	0.71	0.87	1.05	1.81	2.51	3.21	23.32
Kaumalapau Harbor	658	2.02	2.42	1.46	1.41	1.34	1.1	1.01	0.89	1.01	1.47	2.14	2.6	10.71
Lana`i Airport	656	2.85	2.16	1.24	0.9	0.83	0.78	0.55	0.5	0.76	1.29	2.22	3.25	15.86
Lana`i City	672	5.24	3.81	2.73	2.53	2.12	1.63	1.64	1.42	1.99	2.45	3.39	4.16	33.83
Lanai`hale	684	5.62	4.5	3.82	2.42	2.46	1.84	1.57	1.97	2.17	2.78	4.2	3.03	41.65
Mahana	694	4.51	3.29	2.65	1.27	1.19	0.79	0.44	0.42	0.82	1.71	2.74	3.06	20.69
Malauea	676	3.16	2.34	1.56	0.98	0.5	0.45	0.27	0.18	0.81	1.1	1.98	2.73	14.16
Waiakeakua	685	3.66	3.31	2.17	1.81	1.28	0.73	0.49	0.41	1.08	1.61	2.02	3.39	21.22
Source: School or	f Ocean &	Earth Scie	ence & Teo	chnology	http://w	ww.soest.	hawaii.ed	u/MET/Hs	sco/upt/pp	ot/ppt4.htr	nl	Unit: Incl	hes	
* note annual nur	nbers do r	not match	totals due	to metho	d of handli	ng missir	ng data da	vs - totals	given are	those repo	orted by S	OEST		

FIGURE 3-14. Lana'i Monthly Mean Precipitation

Most sources estimate that rainfall on Lana'i averages less than ten inches per year along the coast, (generally 6 to 8 inches), and thirty-five to forty (35-40) inches at the summit along the main ridge from Lana'ihale to Koele. Much of this rainfall comes from orographic lifting of the northeasterly trades over the central ridge.

Fog-drip is also a major contributor to recharge on Lana'i. The island experiences frequent cloud cover above the 2,000 to 2,500 foot range. Despite the relatively low rainfall, a 1967 state Land Bureau study investigating soils and vegetation on Lana'ihale concluded that they were more typical of an area receiving 60" per year than the 35" - 40" that actually fall on the summit. This seeming anomaly was attributed to the importance of fog drip from the watershed. (Mirabayashi, Ching, Kuwahara, Fujimura, Awai & Baker, *Detailed Land Classification - Island of Lana'i*, Bulletin No. 8, Land Study Bureau, 1967).

A 1964 paper by Paul Ekern reached a similar conclusion about the importance of fog drip. Ekern monitored a network of rain gauges beneath a Norfolk Island Pine tree and compared rainfall in these gauges to that collected by a network in the open for three years. (*"Direct Interception of Cloud Water on Lana 'ihale, Hawaii"*, Ekern, Paul C., Soil Physicist, Pineapple Research Institute of Hawaii, Honolulu,

<u>Soil Science Society of America Journal</u>, Wisoncsin, © 1964, & Technical Paper No. 294 of the Pineapple Research Institute of Hawaii, Honolulu.) More recent studies have borne out such statements about fog drip. The 2009 <u>Lana'i Fog Drip Study</u>, by Pacific Environmental Planning, found that precipitation caused by fog drip and through-fall under Cook Pines was substantially higher than estimated in 1964, possibly due to the increased stature of the trees, and substantially higher than precipitation from rainfall alone.





Being in the rain-shadow of Maui, Lana'i's seasonal variation is somewhat more subtle than other islands, but there is still a notable seasonal pattern as shown in Figure 3-15.

Data from the Western Regional Climate Center for Lana'i City and Lana'ihale are plotted above and below, respectively. (Source: http://www.wrcc.dri.edu/cgi-bin/cliMONtpre.pl?hi5301). Lana'i City plots seem to reveal a slight declining trend, though data from both this and the Lana'ihale gauge plotted below are inadequate to say whether such trends reach the level of statistical significance.

#### Surface Water Hydrologic Units



FIGURE 3-16. Rainfall at Lana'ihale Source:Western Regional Climate Center Source: http:// www.wrcc.dri.edu/cgi-bin/cliMONtpre.pl?hi5301 Note: Although measurements at the rain gauge continued until 2004, there isan inadequate number of measured rain daysreported on the web to accurately plot this data.

# **Surface Water Hydrologic Units**

The 2008 update of the State Water Resources Protection Plan divides Lana'i into 32 hydrologic units, shown below. Despite having units identified, no stream flows, stream flow standards, diversions or gauges are present on Lana'i.

Unit	Name	Unit	Name
5001	Puumaiekahi	5017	Awehi
5002	Lapaiki	5018	Kapua
5003	Hawaiilanui	5019	Naha
5004	Kahua	5020	Kapoho
5005	Kuahua	5021	Kawaiu
5006	Poaiwa	5022	Mahanalua
5007	Halulu	5023	Manele
5008	Maunalei	5024	Anapuka
5009	Whane	5025	Palawai Basin
5010	Hauola	5026	Ulaula
5011	Nahoko	5027	Kaumalapau
5012	Kaa	5028	Kalamanui
5013	Haua	5029	Kalamaiki
5014	Waiopa	5030	Paliamano
5015	Kahea	5031	Honopu
5016	Lopa	5032	Kaapahu

FIGURE 3-17. Lana'i's Surface Water Hydrologic Units



FIGURE 3-18. Lana'i Surface Water Hydrologic Units with Isohyets Source: State Commission on Water Resource Management

The only perennial stream known to have existed on Lana'i originated in the upper reaches of Maunalei gulch where it is deeply incised into the dike complex of the northwest rift. This flow was diverted by the Maunalei tunnels. (Source: Keith Anderson, "*Water Supply Investigation: Island of Lana'i, Hawaii*", prepared for Hawaiian Pineapple Co., Ltd., and including a summary of Lana'i Water Development from a 1954 report by V. W. Thalman).

At one time there were also various seeps and springs at Kaiholena, Waipa'a and Waiakeakua, Kaohai and Paliakoa'e Gulch. There are historical accounts of growing rice in a kuleana using the watercourse from Paliakoa'e, and even of a deep water hole. (George C. Munro, <u>*The Story of Lana'i*</u>, Honolulu, 2006).

**Historical Water Resources** 

# **Historical Water Resources**

Historical and anecdotal evidence suggest that Lana'i once had more available water than it has now. Maunalei Stream was once perennial, running to the ocean. It supported taro lo'i in the upper reaches of that ahupua'a until the late 1800s. During the late 1800s taro production was discontinued because goats had so denuded the cliffs above that work in the lo'i had become hazardous. The stream stopped running with the development of Maunalei Tunnels in 1940, but even before that time it had stopped running all the way to the ocean.

John Lydgate, in his memoirs of botanizing on Lana'i with W.F. Hillebrand and W.M. Gibson, noted a small pond, the size of a dining table, that was always full of water regardless of the weather. Stearns (1940) mentioned two seeps upstream of Waipaa tunnel. Munro, in *The Story of Lana'i*, (2006, Honolulu), notes a water course at Paliakoa'e Gulch, and mentions a 5 acre kuleana growing rice with that water. He also notes seeps and springs at Kaiholena, Waipa'a, Waiakeakua and Kaohai.

Kenneth P. Emory, in "<u>The Island of Lana 'i; A Survey of Native Culture</u>"; (Bernice P. Bishop Museum Bulletin 12; Honolulu, Hawaii 1969) not only notes the historical cultivation of taro, but provides maps of historic sites which give the location of a number of springs (at least nine), and other water-related features.

Emory created a map of historical houses and heiau, which is presented in Figure 3-19. Note the number of dots, indicating home sites, near to the shore. Such settlements would not have been located at unreasonable walking distances from water. The presence of home sites, as well as several historical dug-wells seems to indicate the likelihood that water along the coast was once fresher, and that water may generally have been more readily available at one time. This is supported by various historical accounts that refer to Lana'i as a place with abundant water.

Emory also developed a gazetteer of Lana'i place names, providing translation from Hawaiian to English and mapping the location of these places. Place names are provided on the map in Figure 3-20. An 11x17 version of this map is also available on the web in the 11x17 pdf section. A list of those place names which seem to refer to water or water-related conditions (such as taro growing) is provided in Figure 3-21. These names are numbered, and can also be located on the map in Figure 3-20. Such names as "Water of the God", "Glistening Water", "Column of Rain" lead one to infer that water was indeed more plentiful at one time. Some of the higher elevation places specifically denoted as springs are shown in Figure 3-22.

A review of the map in Figure 3-22 will prompt one to note that many of the developed wells on Lana'i are sited at or near of some of these historical water features. The loss of these water features could stem from several factors, including water development, diminished forest cover causing decreased recharge, climate change, cracks in confining rock barriers allowing water to seep out, or various combinations of such factors. Bowles (1974) and Hardy (1996) both noted that a significant portion of drawdown observed in Lana'i wells may be attributed to changes in the forest cover in the cloudy regions above 2,000'. With regard to Maunalei, V.W. Thalman noted in his 1954 report to the company, "...this flow is now diverted by tunnels and provides part of the domestic water supply for Lana'i City."

More recently, data from USGS, Tom Giambelluca and others indicate a thinning of the inversion layer and decreases in stream flow and in overall precipitation, affecting all Hawaiian islands, including Lana'i.

Additional historical data on water is found in the source water protection chapter of this plan, in the table entitled, *A Chronology of Land Use, Conservation and Water in Lana'i.* 



