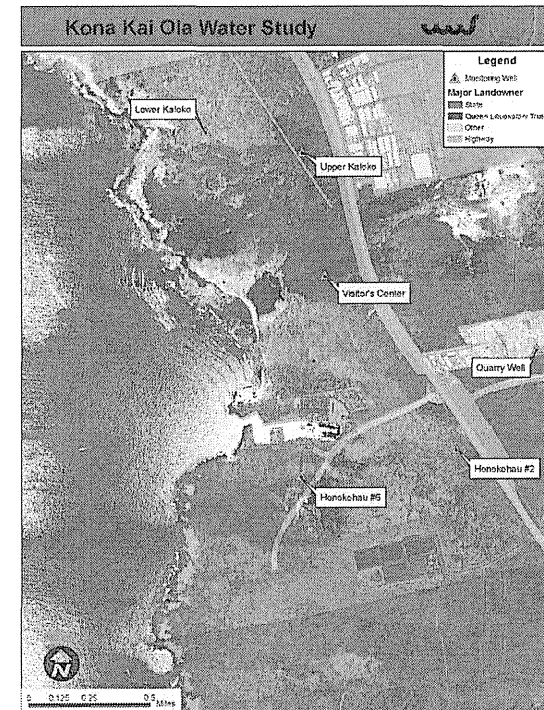


Geology and Ground-Water Hydrology in the Vicinity of Honokohau Harbor
A Field Study by Waimea Water Services, Inc.
Assisted by Mink and Yuen, Inc.
October, 2006

Introduction

A field hydrology study was conducted for the purpose of determining the ground-water regime in the immediate vicinity of Honokohau Harbor and specifically, to document the existing ground-water behavior in the area associated with the proposed Kona Kai Ola Marina expansion to the south of Honokohau.

As part of this and other activities, two observation well sites (# 2 and #6) were selected to provide data on water level and water quality for the proposed project. Additionally, three off site wells located in the nearby Kaloko-Honokohau National Park and one in the quarry located mauka of the project were included in the site study network.



However, before assessing the hydrological impacts it is important to understand the surficial and subsurface geology within the Kona Kai Ola project. The following discussion will focus on the geological conditions found in and around Honokohau Harbor.

Surface Geology

The lavas forming the area surrounding Kona Kai Ola and Honokohau Harbor were erupted from the Hualalai Volcano. The lava flows are of basaltic composition and form pahoehoe and aa lava flows within the flow units. See Figure 1. Hualalai is an active shield volcano that dominates the landscape in and around the Kailua-Kona region. The slope of the land near the Kona Kai Ola project is almost flat, dipping only 1.5 degrees. However, inland the flank of Hualalai becomes much steeper. The average slope above elevation 400 feet above mean sea level (ft., msl) is 7 degrees.

All of the lavas referred to above emanated primarily from the southwest flanks and upper southwest rift zone. Stearns and Macdonald (1946) referred to the Hualalai Volcanic Series; however, the stratigraphic nomenclature has been updated by Langenheim and Clague (1987) and renamed Hualalai Volcanics.

Recent geological mapping (Wolfe and Morris, 1996; Moore and Clague, 1991) has put the age of the pahoehoe lava flow surrounding the Honokohau area 5,000 to 10,000 years ago. This flow in turn is overlain by two pahoehoe and aa flow units that have been dated between 3,020± 150 years and 3,990± 70 years, respectively. Just south of the Honokohau Harbor is a more recent pahoehoe and aa lava flow unit dated at 1,590± 100 years (Moore and Clague, 1991). The last eruption from Hualalai was in 1801 from the southwest rift zone at Kaupulehu (Stearns and Macdonald, 1946). Wright and others (1992) placed all of Hualalai within lava-flow hazard Zone 4. This zone is defined by the frequency of eruptions, which are lower than that of Kilauea and Mauna Loa. The amount of land covered by recent lava flows is much smaller. About 5 percent of land is covered by the 1801 eruption and 15 percent of land within the past 750 years.

Subsurface Geology

As discussed above, the surficial geology has been well mapped. Only recently has the subsurface geology been studied in greater detail due to the numerous water wells that have been drilled over the last 15 years, offshore submarine mapping by the USGS, and recent geophysical studies associated with groundwater exploration (Bauer, 2003).

The USGS has employed side-scan sonar to map large and distinct submarine landslides, slumps, and debris fields west of the South and North Kona coast. The offshore bathymetry shows very abrupt changes in depth that suggest faulting and tectonic adjustments within Hualalai Volcano and Mauna Loa.

As pointed out in Moore and others (1992) and Moore and Clague (1992), the North Kona Slump, a landside older than 130,000 years, left a large escarpment that was

covered over by more recent subaerial lava flows. Understanding the nature of the subsurface geology provides an insight into the occurrence of groundwater and the groundwater flow system within the Kona Kai Ola project area.

Ground-Water Occurrence

Ground water at the project site occurs as a thin basal brackish water lens. If ground water is fresh (<250 mg/L chloride concentration) then the Ghyben-Herzberg principle holds. That is, for every foot of water above sea level there is 40 feet of water below sea level. In a situation where the ground water is brackish, the ratio of 40:1 becomes more like 30:1. A salinity profile through Ooma test well (State Well No. 4262-01) about three miles north of the project site shows the 50 percent salinity at elevation -33± ft., msl (Waimea Water Services, 1996). Using the 30:1 ratio for the thin brackish lens condition would put the Ghyben-Herzberg water level at approximately 1.3± ft., msl. The average of 38 instantaneous measurements at this well is 1.63 ft., msl (Bauer, 2003). However, this well is influenced greatly by ocean tides.

The ocean tide response in basal wells along the Kona Coast cannot be ignored when measuring water levels. In another well, Kaloko Irrigation Well No. 2 (State Well No. 4759-02), located 12,000 feet inland from the coast showed tidal and barometric amplitudes of on the order of 0.3 ft., the maximum tidal cycle (0.5 days) being 0.33 ft. over a 62 day period from December 7, 1994 to February 6, 1995 (Bauer, 2003; Waimea Water Services, 1996). Oki and others (1999) measured water levels at Kaloko-Honokohau National Historical Park as part of a numerical groundwater model and found tidal fluctuations within the test wells on the order of 0.5 to 1.5 feet daily.

The transmission of the tidal signal to water wells hundreds to thousands of feet inland is an indication of the high hydraulic conductivity (K) within the dike-free flank lava flows that comprise the Honokohau region. Employing the tidal response in the Kaloko well, Bauer (2003) estimated the K value to be between 20,000 and 40,000 ft. per day (ft./d). Because estimating K values using tidal response in wells is burdened with uncertainties, the estimated value may be too high by an order of magnitude (Bauer, 2003). Kanehiro and Peterson (1977) used similar analyses and for wells north of the project site and calculated K values between 6,000± and 12,000± ft./d.

Oki (1999) and Oki and others (1999) used a K value of 7,500 ft/d for dike-free basaltic lava flows while numerical modeling the groundwater flow system of Kona and the groundwater resources of Honokohau National Historical Park, respectively. This value was picked as one that produced the smallest errors when groundwater heads were simulated.

The high hydraulic conductivities calculated from tidal response and aquifer tests cause the groundwater gradient to shift over time. In some instances may even reverse so that the higher water level may be seaward of the inland measuring points.

Background and Methods Specifically Related to the Hydrological Data Collection

A previous study (1996) by Waimea Water Services had been conducted to attempt to trace the fate treated secondary wastewater discharge in a sump located mauka of Queen Kaahumanu Highway. That study implied that there was serious mixing of the discharge water with the underlying brackish water in the basal lens. A number of studies have shown that there is no fresh (less than 250 milligrams per liter) basal ground-water found below elevation 1200' mauka of the project area. This fact is well documented in the various studies which have been conducted.

In order to provide accurate datum control, Wes Thomas Surveyors, Inc., were contacted to insure that network wells were found to be on a common base. Accordingly, wells #2, #6, Quarry and NPS Visitor Center wells were surveyed and the Visitor Center well were found to have a total datum base difference of .08' difference which was deemed to be adequate for the purpose of this study. It was assumed that the bench marks used at the NPS Lower Kaloko and Upper Kaloko wells were on a common datum with the Visitor Center well

Water quality sampling was performed on September 15, 2006 using a peristaltic pump via Teflon tubing and analyses were performed by Aecos Laboratory. Water levels were measured with an electric, calibrated tape and reel from Solinst, Inc. and recordings using Solinst battery powered sondes.

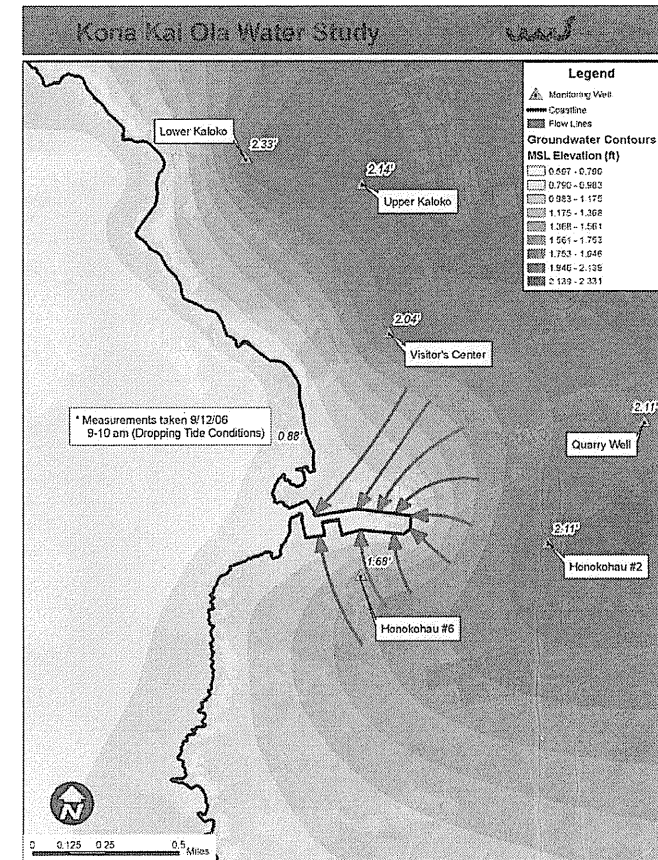
The water levels were continuously recording in the NPS wells during the period of study (September and October 2006) with data on the water level records furnished to WWS.

Ground-water Flow

The previous work by WWS in 1996 had implied that the ground-water flows might be minimal during high tide periods and accelerate at low tide. Additionally, the local recharge resulting from the wastewater discharge sump adds an average of about 1.4 mgd (personal communication – County Staff) the project area and its identity and fate, other than volume, remains a question. The ground-water quality throughout the study area is brackish and the apparent nutrient loading from the added effluent has not yet been in evidence as indicated during the sampling as evidence in Appendix A. Water Quality Data.

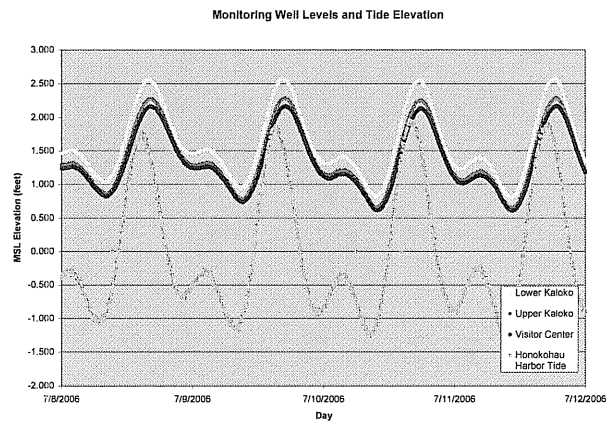
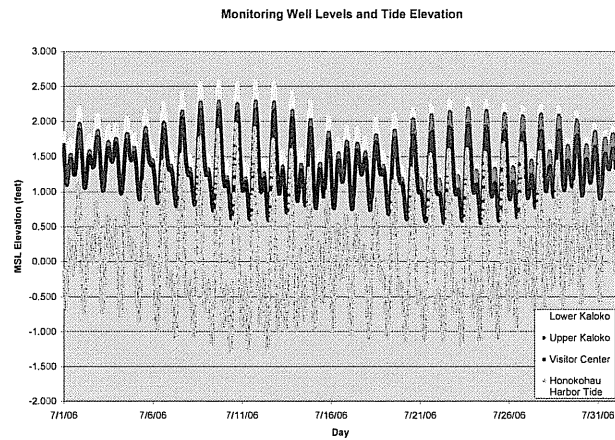
A low tide period was selected to conduct a rapid water level survey (20 minutes elapsed time) of the selected and new observation wells. Ground-water flow directions are normal to the contour lines as indicated by the flow vectors on the map. Ocean tides are in evidence in all of the wells as far inland as the Quarry well although the tidal transmission efficiency is reducing. Importantly, the existing Honokohau Harbor was acting as the drainage point at the time of the survey.

The ground-water flow direction survey clearly shows that some ground-water from within the National Park flows towards the harbor and that the flow direction from well #2 also is towards the harbor. The slope of the water table under these conditions appears to be about 2.5 feet/mile during the outgoing tide.



Ocean tides strongly influence both the ground-water flow and the water quality in the project area. The NPS maintains water level recorders on its three wells, Lower Kaloko,

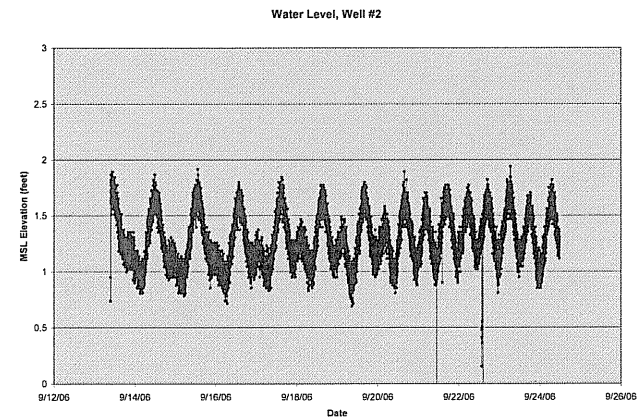
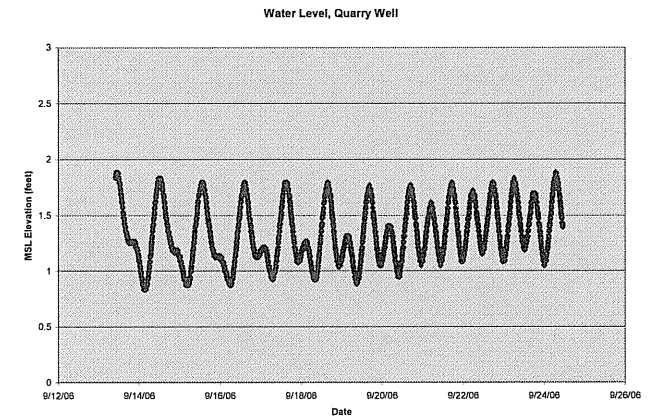
Upper Kaloko and Visitor Center. A comparison of the ocean tides within the NPS network of three wells is shown below:



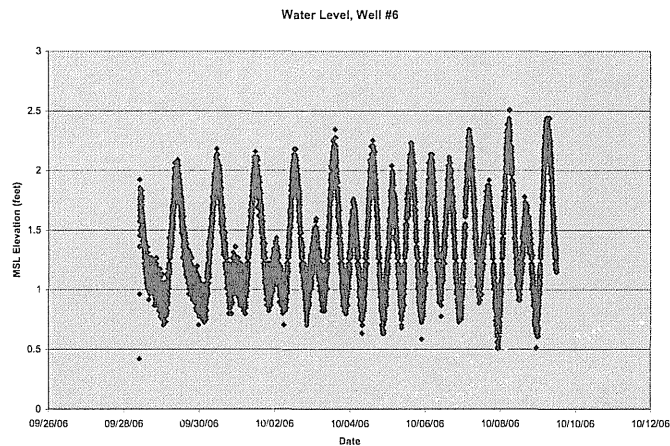
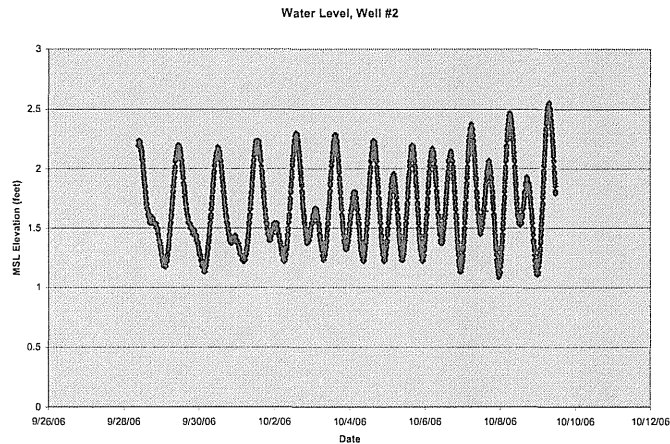
As is noted in the graph above, there are several moments when the ocean tides exceed the water table in the Lower Kaloko well, which may result in a no flow or very low flow

condition. This condition should result in a near shore mixing situation at the least and similar conditions can be expected around the perimeter of Honokohau Harbor.

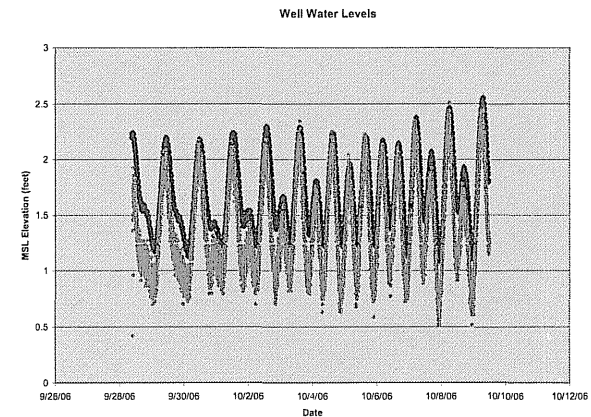
As part of this study, recorders were first placed on the Quarry well and observation well 2. Following a brief period of collection, a recorder was kept on well 2 and a recorder installed on well 6. Tides were also in evidence in Quarry well, well #2 and well #6.



A second set of recordings below were made to establish the water fluctuations within the project boundaries as presented below:



In reviewing the relationship of the water levels between well #2 and #6, although the range of the water level in well #6 is greater, the high tide peaks appear to be identical in elevation suggesting a no flow condition. To better display this feature, the water levels are superimposed below.



Well # 6 is located in what will be the main channel of the proposed marina. Although there is some brackish water at present, the tidal efficiency is nearly 100% indicating that there would be very little change if the rock were absent. The rock at the surface of the water table is providing a slight impediment to the lateral flow of the ground-water.

The natural flow of the ground-water locally to the discharge points probably remains best estimated at about 1.5 to 4 mgd/mile of aquifer width. However, with the addition of the 1.4 mgd wastewater, the total flow is likely to be towards the upper number and the total flow will increase in time as more water is discharged to the sump. Using an average slope of 1/ft.m and Oki's K of 7500 ft/d, to flow to Harbor is probably better estimated at 3 to 4 mgd.

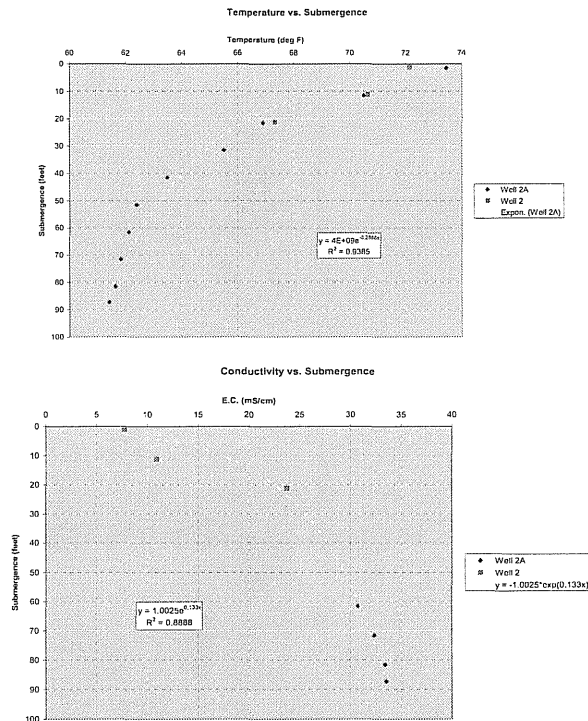
Water Quality and Temperature

Water chemistry in the project area has been reported in the past as part of the WWS 1996 study of the discharge from the Kealahou WWTP. Appendix B lists the sampling data collected during this field study. Specific conductance measurements were used as the primary indicator of the influence of ocean salts in the local ground-water. In addition, water quality (selected organic and inorganic compounds) samples were

collected from the Visitor Center, Quarry, Observation wells #2 and # 6 using a peristaltic pump to prevent any external contamination.

It has been known that there is a strong temperature influence in the ground-water between Keahole point to the north and Kaiwi to the south of the marina project. To better understand to near influence to the off shore trench on the inland lens, a well (2A) was drilled within about 10 feet of well #2, which had terminated in a black sand at a depth of about -30'. Well 2A was drilled through this upper sand of volcanic origin to an elevation of -50' where a solid casing was set. A smaller diameter was then drilled to elevation -88', where a mixture of calcareous and basaltic sand was struck preventing deeper drilling to the target depth of -100'.

A conductivity/temperature survey profile was conducted and a composite of the data from wells 2 and 2A is shown in the following graphs



The top most water has an average salinity of about 12% (EC= 5.0 milliS) in the upper 10'. By an elevation of -28', the salinity is already at 50% sea water and the temperature has dropped from 73.5 degrees F to 66 degrees. By an elevation of -85', the temperature had dropped about 61.5 degrees F. It is clear that the deep ocean influence extends some distance inland. Water quality at the bottom of 2A is about 70% sea water. Wells 2 and 2A are located about 0.5 miles inland of Honokohau Harbor and it is likely that at well 6, with a surface conductance of 27 milliS (more the 50% sea water) 100% sea water will be found at a shallow depth below sea level.

The water quality sampling program (Appendix A) revealed several interesting notes, namely; that the natural ground-water in the Quarry well (up gradient) contained a total nitrogen component of 1.20 mg/L while the WWTP discharge was 5.09 mg/L. None of the down gradient sampling points indicated a concentration of N above 0.59 mg/L (well 6). While the WWTP discharge contained a total phosphorus of 3.70 mg/L, well 2 had an elevated P 2.71 mg/L. Well 6 had a very attenuated P of 0.62 mg/L while the Harbor Spring P concentration was only 0.7mg/L, just slightly below 0.09 mg/L in NPS visitor Center well and the Quarry well (natural ground-water) of 0.12 mg/L. It can reasonably be concluded that, while the quantity of 1.4 mgd of effluent is being added to the ground-water flow, the impact from nutrient addition seems to be attenuated by the efficiency of tidal mixing. This estimated flow value does not consider matters related to layered and/or density driven flows in the groundwater system.

Conclusions

The recent field study has confirmed the strong influence of ocean tides within project area and the surrounding aquifer. The result is very brackish basal lens with no evidence of fresh water (250 mg chlorides) within a 3 to 4 mile radius. The Honokohau Harbor is the dominant drainage point with the ground-water flowing from the lands of the Kaloko-Honokohau National Park and from the vicinity of the Queen Kaahumanu Highway

Average ground-water discharge into the Honokohau Harbor is on the order of 3 to 4 mgd on the outgoing tide and may approach a no flow condition during the high tide peak. This estimated flow value does not consider matters related to layered and/or density driven flows in the groundwater system.

Cold, salty water is found at a very shallow depth within the ground-water regime and is decreasing in temperature with depth below sea level as evidenced in observation well 2A.

Nutrient additions of N and P from the Kealahoe WWTP are evidenced but reduced in well 2 and apparently not detectable in the Harbor Spring discharge. This appears to be related to tidal mixing.

APPENDIX A

Ground-water quality sample data
Prepared and analyzed by Aecos Laboratory



WATER QUALITY RESULTS FOR KONA KAI OLA MONITORING WELLS

Analyte/(Unit)	Well 2	Well 6	Kealahou WWTP	Quarry Well	NPS Well	Harbor Spring	Method	D.L.
Temp/(C)	33.0	30.8	29.6	30.5	34.2	22.9	170.1	0.1
E. Cond/(mS/cm)	8.04	29.6	3.32	9.46	21.4	39.5	120.1	0.1
Salinity/(ppt)	4.4	18.4	1.7	5.3	12.8	25.1	SM	0.1
TN/(mg/L)	0.54	0.59	5.09	1.20	0.20	0.42	353.2	0.01
Nitrate+Nitrite (ug/L)	0.54	0.59	0.44	1.20	0.20	0.42	353.2	0.01
Ammonia(ug/L)	0.005	0.002	1.950	0.003	0.004	0.003	350	0.001
Total Phosphorus(mg/L)	2.71	0.62	3.70	0.12	0.09	0.07	365.4	0.01
Silica/(mg/L)	31.3	26.8	21.3	37.9	28.9	15.8	4500-Si	0.1
Arsenic/(mg/L)	0.007	0.029	0.002	0.008	0.021	0.043	200.8	0.002
Cadmium/(mg/L)	ND	ND	ND	ND	ND	ND	200.8	0.001



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WATER QUALITY RESULTS FOR KONA KAI OLA MONITORING WELLS

Kealahou WWTP effluent, Well Bore # 6, NPS Well, Quarry Well, Bore #2 Well and the Honokohau Harbor Spring were monitored for EPA methods 602, 608, 625 and 8151A. The results for all wells was ND or Not Detected below indicated limit. Analytes for each method follow:

EPA Method 602 Purgeable Aromatics by GC

Benzene
 Ethyl Benzene
 Toluene
 Xylene, M+P
 Xylene, O
 Xylene, Total

EPA Method 608- Chlorinated Pesticides

4,4-DDD
 4,4-DDE
 4,4-DDT
 Aldrin
 Alpha BHC
 Beta BHC
 Chlordane
 Delta BHC
 Dieldrin
 Endosulfan I
 Endosulfan II
 Endosulfan sulfate
 Endrin
 Endrin baldeheaded
 Gamma BHC(Lindane)
 Heptachlor
 Heptachlor epoxide
 Methoxychlor
 PCB-1016
 PCB-1221
 PCB-1232
 PCB-1242
 PCB-1248
 PCB-1254
 PCB-1260
 Toxaphene

EPA Method 625 - BNA Extractables by GC/MS

1,2,4-Trichlorobenzene
 1,2-Dichlorobenzene
 1,2-Diphenylhydrazine
 1,2-Dichlorobenzene
 1,4-Dichlorobenzene
 2,4,6-Trichlorobenzene
 2,4-Dichlorophenol
 2,4-Dimethylphenol
 2,4-Dinitrophenol
 2,4-Dinitrotoluene
 2,6-Dinitrotoluene
 2-Chloronaphthalene
 2-Chlorophenol
 2-Methyl-4,6-dinitrophenol
 2-Nitrophenol
 3,3-Dichlorobenzidine
 4-Bromophenyl-phenylether
 3-Chloro-3-methylphenol
 4-Chlorophenyl-phenylether
 4-Nitrophenyl
 Acenaphthene
 Acenaphthylene
 Anthracene
 Benzidine
 Benzo(a)anthracene
 Benzo(a)pyrene
 Benzo(g,h,i)fluoranthene
 Benzyl butyl phthalate
 bis(2-Chloroethoxy)methane
 bis(2-Chloroisopropyl)ether
 bis(2-Ethylhexyl)phthalate
 Chrysene
 Di-n-butylphthalate
 Di-n-octylphthalate



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EPA Method 625- BNA Extractables by GC/MS

Dibenzo(a,h)anthracene
 Diethylphthalate
 Dimethyl phthalate
 Fluoroanthene
 Fluorene
 Hexachlorobenzene
 Hexachlorobutadiene
 Hexachlorocyclopentadiene
 Hexachlorethane
 Indeno(1,2,3-cd)pyrene
 Isophorone
 N-Nitroso-di-n-polyamine
 N-Nitrosodimethylamine
 Naphthalene
 Nitrobenzene
 Pentachlorophenol
 Phenanthrene
 Phenol
 Pyrene

EPA Method - 8151A Phenoxy Acid Herbicides

2,4,5-T
 2,4,5-TP(Silvex)
 2,4-D
 2,4-DB
 Dalapon
 Dicamba
 Dichloroprop
 Dinoseb
 MCPA
 MCPP