Interpretation of 2013-14 Water Quality Data from Kaelepulu, Kailua, Hawaii.
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I. Introduction

This report reviews and interprets water quality data obtained from the City and County of Honolulu under a freedom of information act request (FOIA) made initially on March 1, 2017. The data was collected during five storm events by Cardno TEC under subcontract to AECom. AECom was initially contracted by the City in 2005 and produced a report in 2008 reviewing the City's drainage issues within the Kaelepulu watershed and providing recommendations for improvements that would reduce pollutant loads to Kaelepulu Pond (AECom, 2008). The City declined to follow the major recommendations of the report and extended the AECom contract to include additional tasks. Presumably these tasks included collecting water quality samples and compiling data to produce a runoff model of the watershed and provide revised recommendations to help lower pollutant loads delivered by City storm drains to Kaelepulu.

The purpose of this report is to review and interpret the existing water quality data, in comparison to an earlier study contracted by the State Department of Health (Babcock and Tamaru, 2012 unpublished), and compared to State water quality standards for estuaries. The review will be provided to the managers of Kaelepulu Pond, the Enchanted Lake Residents Association (ELRA), and to the broader Kailua community through the Kailua Neighborhood Board KNB).

Personnel from the City of Honolulu drainage division, AECom and Cardno TEC are all highly qualified and professional. The author has tried to corroborate details of this investigation and its interpretation with the City, Cardno TEC and AECom, however, due to the limited cooperation among parties, there may be unintentional mistakes and misrepresentations in this analysis. We welcome debate or correction in these cases.

This paper has been reviewed and modified according to comments received on 5/31/18 from the City and their consultant AECom.

II. Information Provided by the City

A summary of the water quality data provided by the City is provided in Appendix I at the end of this report. All of the information provided by the City as a result of the FOIA and from which Appedix I has been extracted is available as Appendix-II downloadable from: the web site BourkeEcology.com. The City information includes data collected during five storm events between October 2014 and February 2015. The major portion of the data is provided in five reports compiled by ALS Environmental who conducted the chemical analyses and compiled the associated field data and chain of custody sheets as supplied by Cardno TEC.

The reports include flow data, water sample time data, rainfall data, and analyses of samples including ammonia (NH3), nitrate plus nitrite (NO3+NO2), total phosphorus (TP), total suspended solids (TSS), and the results of bacteriological tests performed during two storm events. Continuous physical water quality data (4/14 thru 1/15) was also supplied as collected by an automated water quality data-sonde (YSI) suspended just below the water surface beneath Keolu Bridge at the junction of Kaelepulu Pond and Kaelepulu Stream (see Figure 1).

In addition, but not as part of the FOIA, the City provided data on water surface elevations of the pond, and other information clarifying collection locations, watershed and sub-basin areas and methods used. This information is also downloadable from the BourkeEcology.com web site.

III. Methods

This is a very generalized and simplified summary of the sample methods likely used by Cardno TEC to collect the data based upon the author's (REB) observations and experience conducting these types of studies and should not be considered to be either thorough or exacting. It is intended to give the lay-reader (ELRA and KNB) a general understanding of the methods used.

Part of the objective of the AECom study is to develop a watershed model. For the model to accurately represent the watershed, sample locations were selected, in part, to provide rainfall, drainage data (infiltration), and pollutant load data from the different types of sub-basins within the Kaelepulu watershed. The goal of each sample site is to record the total volume of water passing the site and to collect a water sample that characterizes the entire flow. The six water sample collection sites include:

> Akipola. The sample site is located in the concrete box channel running along the north-east boarder of the Kaelepulu School. This channel empties into Kaelepulu Pond through the grounds of the Kukilakila Community Association (Figure 1). The site represents drainage from 125 acres including 38 storm drain inlets within the urban neighborhood of Enchanted Lake community and also from the wetland and dry upper slopes of the hills between the homes and Kailua High School. A total of 10 nutrient samples and 2 bacteriological samples were analyzed from this site during 4 of the 5 storm events.
>
> Aleka. The sample site is located on the Old Kalanianalole Highway in a wide drainage swale with concrete side-slopes just north of the intersection with Aleka Place (Figure 1) and drains 90 acres of conservation land on the slopes of Olomana. The open swale flows to a 30-inch drain that directs the flow beneath the homes developed along Aleka Place to another open swale mauka of the State Kalanianaole Highway. From here it enters a in a DOT-Highway conduit beneath the highway and couples with the drain from the Kaopa sub-basin above its sample location. A single composite sample for nutrients and a

single bacterial sample were analyzed from this site only during the 7/20/14 rainfall event.

Hamakua. This sample site is at the end of a relatively small (10 acre) drainage area flowing from the center of Kailua Town including Hekili Street, the three-story parking structure and the relatively new "green" parking lot drain swales near First Hawaiian Bank and Whole Foods. A total of 10 samples for nutrient analyses were collected during five storms and two bacterial samples collected during two storms from this drainage.

Hele Lined Channel. This sample site is in the wide concrete channel running below Keolu Drive between the 76-Gas station and the Enchanted Lake shopping Center. The large majority of this 275-acre drainage is from the urban slopes of the earliest (1960's) housing development in Enchanted Lake, with more than 200 street storm drain inlets feeding the system. The lined channel is open for about 1500 feet above Keolu Drive as it runs between house lot back yards between Hele and Loho Streets. Above the highest residential lots, cutoff drains often intercept sheet flow from the hills above and direct it to the storm drains.

Kaopa. The sample site is from a deep concrete lined box culvert passing beneath Akaakoa Street. The culvert collects flow from the 90-acre Aleka sub-basin plus about 90-acres of the Norfolk Pines "agriculture" area and the slopes of Olomana into a culvert beneath the State DOT Kalanianaole Highway and discharges it into the Kaopa flood control basin wetlands above Akaakaawa Street. As the discharge is above the collection point for the "Keolu" site (see below), the Kaopa sub-basin (which includes the Aleka sub-basin) is part of the larger Keolu Drainage. Flow from the Kaopa wetland and grassland area is restricted by twin 30-inch culverts beneath the Kaopa flood control dam and into the top of the Keolu lined channel. This detention basin acts to even out the flow from intense rain events into the Keolu lined channel and likely also promotes settlement of much of the heavier sediment from the flow stream. This is the old course of the upper Kaelepulu Stream.

Keolu. The sample site is in the 35-foot wide concrete lined box channel about 300-feet above its terminus into the Kaelepulu wetland near the end of Akumu Street. Keolu is the largest of the drainages with about 425 acres including the last of the urbanized hills developed in Enchanted Lake (~150 street storm drain inlets) during the 1980's, portions of the Norfolk Pine "agriculture" area ("gentleman farmer" lots) and much of the slopes of Olomana including a 20+-acre parcel under development during the period of this study. Flow from about two-thirds of the area is buffered through the Keopa flood control basin which acts to decrease peak flow velocities and volumes and undoubtedly also promotes the deposition of heavier sediment entrained in the runoff.

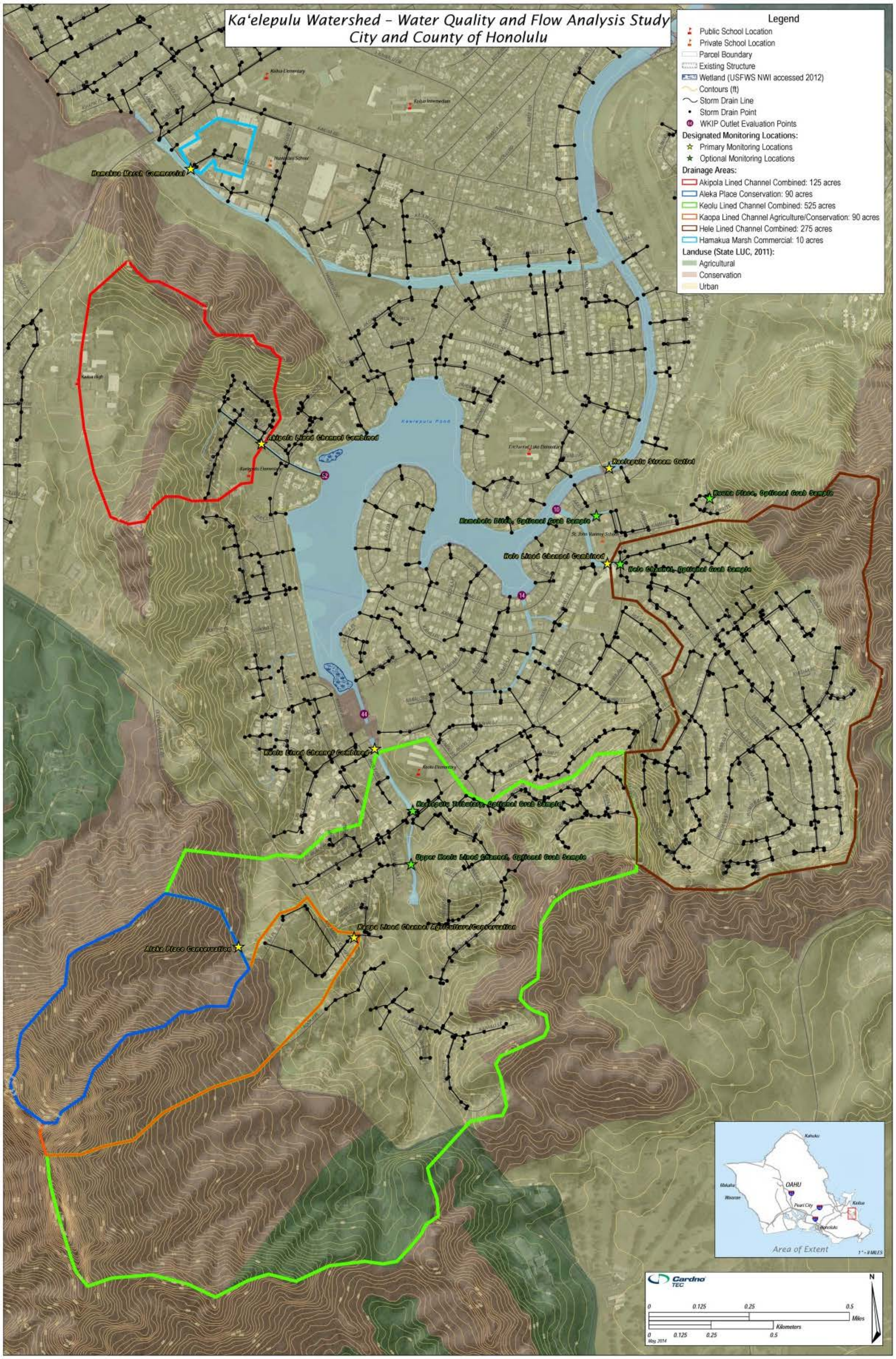

Figure 1. Kaelepulu watershed and monitored sub-basins. (AECom Graphic)

Automated samplers were set up at each of the sites. These samplers consist of a rain gauge, a water depth sensor, a sample hose reaching into the flow stream, a pump, a series of bottles into which the individual water samples can be pumped, and a chiller to keep samples cold until they are collected. All of this equipment is protected in a large (~yd^3) grey box affixed to a concrete slab at each site. The sample pump can be triggered remotely, by a level sensor, or by a timer. Once triggered, the pump fills a series of sample bottles at regular intervals over time and the bottles are chilled until they are picked up by field technicians and delivered to the laboratory. During two of the storm events, water for bacterial samples was also collected and sent to a separate laboratory for analyses.

During the 10/19/14 storm seven samples were collected at each site during the course of the storm, and during the 2/3/15 storm six separate samples were collected from the Keolu drainage. These samples were individually analyzed, and loads calculated according to the flow measured during each sample period. The remainder of the analyses were conducted on composited samples.

Composite samples were collected by an automated sampler pumping. The automated samplers obtained multiple sample volumes (typically 500 ml) into separate bottles at regular intervals during a storm event. Data loggers in the automated samplers also recorded the depth of water in the channel and in some cases water speed in the channel over time. The volume of flow during each sample period was then computed by multiplying the flow speed by the cross-sectional area of the stream, or the stream depth (or stage) was converted directly to a flow volume based on the measured slope and cross section at each sample site. These flow data are used to characterize the dynamics of storm-water movement in response to rainfall events, show the rate of stream rise and fall and estimate rates and volumes of pollutant discharge. These methods are highly sensitive to initial channel measurements (cross section, roughness, slope) and can be confounded by the buildup of debris, or backwater as the water surface level in the basin below the site rises.

For the composite analysis, a flow-volume weighted composite sample was made from the bottles collected during a storm event. Based on the flow calculated and the time that each bottle was collected, a volume proportional to its contribution to the total flow that passed the sample point during the storm event was extracted from each sub-sample bottle to make up a composite sample representative of the entire storm flow. This composite sample, representing the average constituent chemistry of the entire storm flow, was then sent for chemical analyses. The flow volume data is used to develop a flow curve for the storm and calculate the total volume of water passing the sample site. Results from this chemical analysis could be used to calculate total load for that storm event for any analyte.

This watershed is somewhat unique in providing a second method to estimate the flow volume moving past each collection point. Because the outlet from the system is typically closed to flow by the sand berm at Kailua Beach, the water surface level of the 135-acre system rises as the runoff flows in. The total runoff volume of the storm then is obtained by multiplying the water surface rise by the area of the surface (135 ac x 43560 ft^2/ac). By assuming that both the rainfall amount and infiltration (runoff) are the same across the watershed, the flow past each sensor is then related directly to the area of the sub-basin above the sample site. This method is not able to distinguish any differences in rainfall, infiltration or slope between sub-basins (which are key pieces of information for models) but it is relatively accurate in determining the total volume of the storm flow. Water surface level devices typically measure accurately to within 1/100th of a foot (~1/8th inch), and this represents about 60,000 cubic feet of water over the 135-acre estuary.

The composited or individual samples intended for nutrient analyses were packed in chilled coolers and shipped to AES Environmental Laboratories, located in Kelso, Washington. At the AES lab, samples were analyzed for ammonia nitrogen (NH3), total nitrogen (TN), nitrate plus nitrite (NO#+NO2), total phosphorous (TP) and total suspended solids (TSS). Laboratory results are reported along with a laboratory minimum report level (MRL) for each test. Samples with less than the MRL were noted as “nd”. For computation purposes these samples are assumed to contain one-half the MRL level of the measured constituent and these values are shown in the results table as underlined numbers.

An additional sensor (YSI datasonde) and sampler were installed beneath the Keolu Bridge on the center bridge support. All of the combined flow entering Kaelepulu Pond passes this site in the Kaelepulu Stream as it flows towards the ocean at Kailua Beach. Although the sampler at this site appears not to have ever been initiated, the YSI affixed to the pylon did obtain a continuous record of physical water quality parameters at this site including water surface elevation, dissolved oxygen, turbidity, pH and salinity from April 5, 2017 through January 29, 2018. This record encompasses four out of the five sample events. The equipment was removed on January 30, 2018 due to vandalism and was not present for the final February 3, 2018 sample event.

IV. Results

The YSI physical water quality data obtained at Keolu Bridge, plus the rain record, provides an excellent overview of environmental conditions surrounding 4 of the 5 sample events and is displayed in Figures 3 and 4. Figure 3(a) shows accumulated rainfall during the monitoring period with the red lines indicating storm sample dates. Note that rainfall was relatively light during the first four months, with only one significant rainfall event (>0.2”) that would warrant sample collection. The first event on July 20, 2014 was an unusual (but not rare) summer Kona Storm event that dropped 5.75 inches of rain. The second event on August 9 was a similar Kona Storm event but only produced 0.54 inch of rain. The third event on October 19 produced 3.89 inch of rain as the result of a typical north pacific front passing through the islands. The fourth event on January 3, 2015 produced 0.96 inch of rain. The final and smallest rainfall (0.28 inch) event sampled was on February 3, 2015.

Daily rainfall data collected over a period of 720 days (Nov. 1, 2013 – Oct. 11, 2015), almost 2 years, showed a total 2-year rainfall of 84.3-inches—almost precisely double the 42-inch annual rainfall predicted from the long term USWS database. Rainfall events delivering less than 0.2-inches per day rarely produce significant runoff in the watershed. Of the 84.3 inches of rain that fell during the 2-year period, about 65-inches (77.5%) accumulated on days with 0.2-inch or more rainfall (Figure 2).

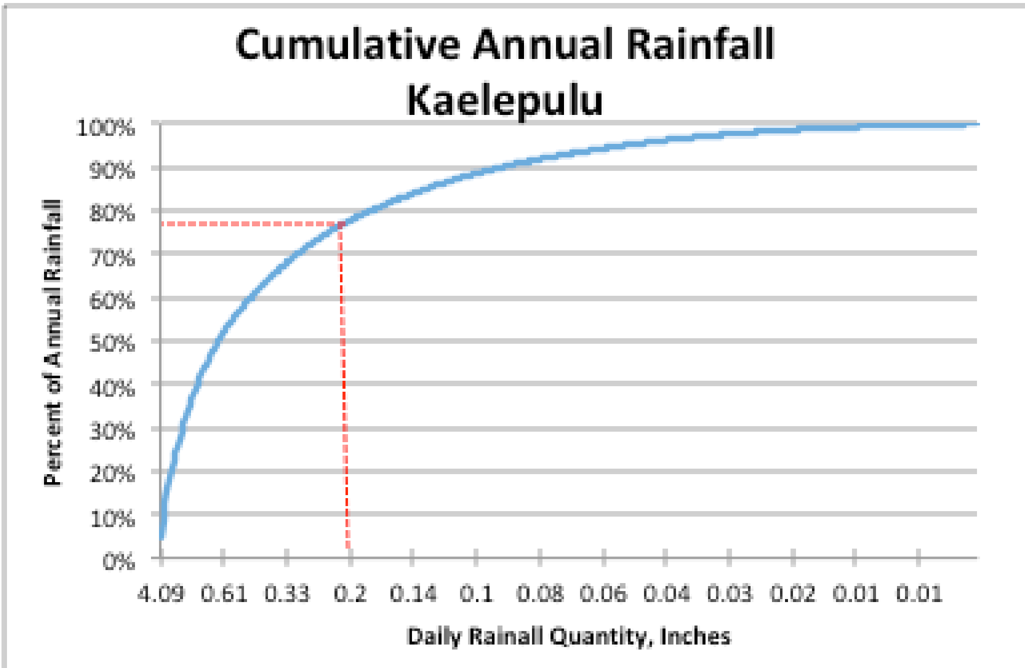

Figure 2 Daily rainfall quantities >0.2-inch account for 77.5% of the annual rainfall. Rainfall less than 0.2-inch per day does not contribute appreciably to runoff.

Figure 3(b) shows the elevation of the water surface of Kaelepulu Stream below Keolu Bridge and can be considered representative of the entire estuary since there is typically negligible water surface "slope" within the estuary unless it is flowing to the sea. The elevation reference is set to the local mean lower low water (MLLW), corresponding to the ocean tides at Kailua Beach; this is 0.26 feet lower than the City's mean sea level survey datum. The red dotted line represents the elevation where flooding begins to occur near Buzz's Restaurant. When the system is open to the ocean at Kailua Beach, tidal influence can be seen as the rapid (daily) water surface elevation changes as measured at the Keolu Bridge. Other parameters, such as salinity and pH can also be seen to respond to this oceanic influence. Rapid increases in water surface elevation (without a corresponding immediate fall) are the direct result of inflow from storm events. Slow decreases in water surface elevation are associated with evaporation in the absence of rainfall, typically in the range of 0.25-0.33 inch/day (Bourke, 2017).

Figure 3(c) shows the percent oxygen saturation of the water. Typical diurnal fluctuations show oxygen saturation increasing during the day, during to photosynthesis, and decreasing at night due to oxygen consumption by the lake ecosystem (decomposition and respiration). Oxygen saturation less than about 20% is typically fatal to most fish (tilapia and barracuda being exceptions), and less than 50% saturation is generally considered to be a poor growth environment for fish and large invertebrates. The cause of the persistent low oxygen in late May is unknown. The slow apparent decrease in oxygen saturation (and turbidity and pH) during the last two months could be the result of instrument fouling.
Figure 3(d) shows the salinity at the sensor beneath Keolu bridge. As the system is often highly stratified, salinity is also often a function of depth (fresh water floats on salt water), so this data represent the influences of saltwater flows from the ocean, freshwater flows from rainfall, and the depth of the sensor below the surface. The periods of rapid diurnal fluctuation correspond to periods when the system is open to flow at the stream mouth. Note that the longer the stream is open to ocean flow at the mouth, the more saline the system gets with each tidal cycle (e.g. late June).

Figure 3(e) shows the turbidity, or "cloudiness" of the water. Higher turbidity can be associated with either higher sediment loads or with a higher density of plankton. Note that in general, periods of persistent increased turbidity often occur well after rainfall and ocean flow events. This is consistent with past observations that flow events (either rainfall and/or ocean flow) often precipitate plankton blooms in the Kaelepulu Pond. The persistent increase in turbidity during the final two months (as in all the other sensors) is attributed to fouling.

Figure 3(f) shows the pH, or relative acidity, of the pond water. Healthy estuary ecosystems can exhibit a broad range of pH values, but are typically expected to fall between a pH of about 7.3 and 8.4.

Figure 4 provides an expanded view of Figure 3 showing more detail of the estuary physical water quality during the June 24, 2014 (09:00), physical opening of the stream mouth conducted by the City as part of their regular maintenance. No runoff samples were collected by AECom during this period of time. The figure shows the system opening to the ocean on an incoming tide, and then remaining open for10 days. The tidal pumping over this period results in sharp increases in salinity and decreases in pH associated with ocean water inflow, and a gradual increase in salinity with each tidal cycle. Note that the increase in turbidity occurs several days after the rainfall and tidal pumping events. Personal observation (Bourke) indicates that this turbidity is associated with a bloom in phytoplankton, followed by a bloom in zooplankton (primarily rotifers and copepods).

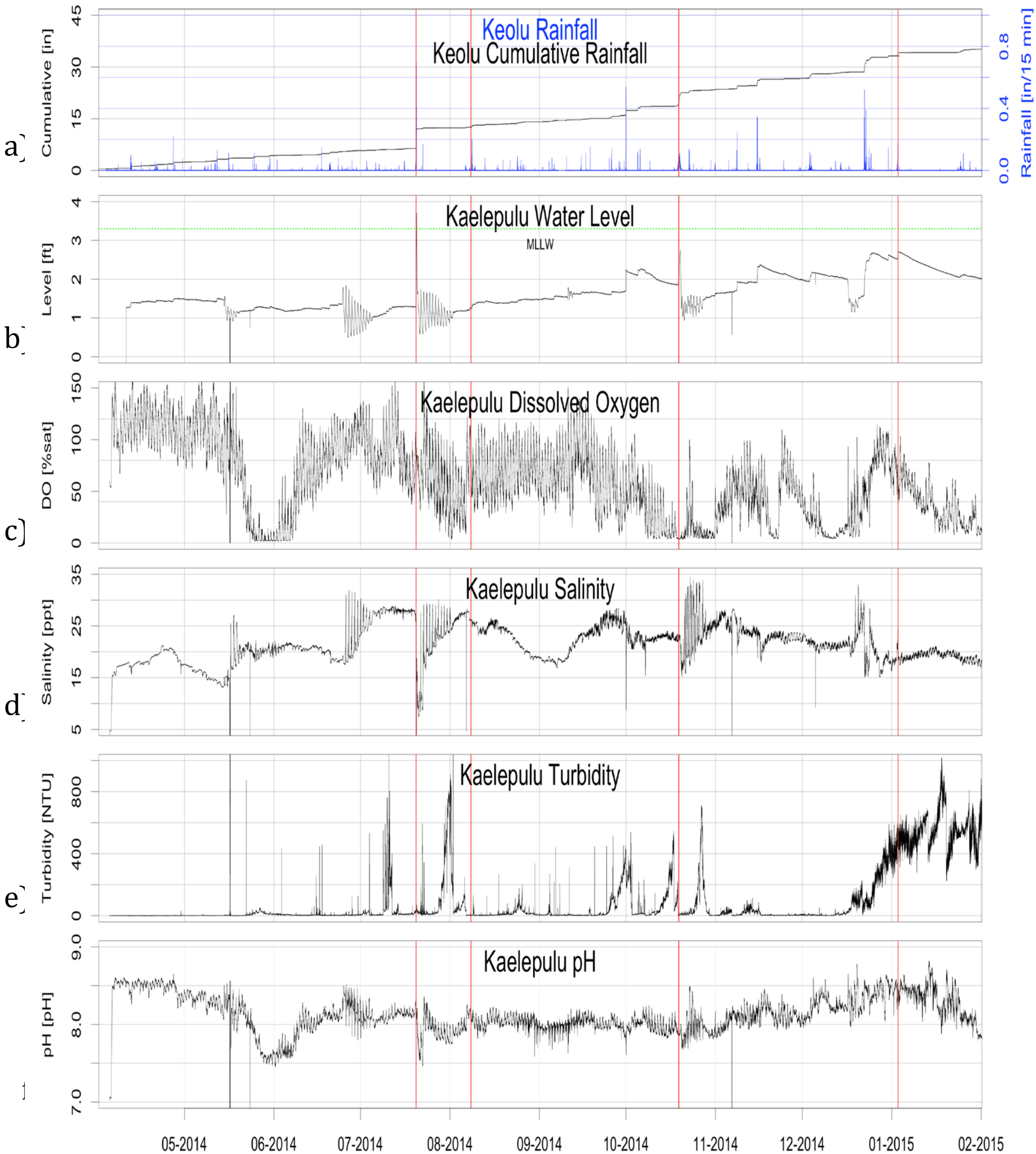

Figure 3. Cumulative rainfall and physical water quality parameters from Kaelepulu Stream at Keolu Bridge 2014-2015

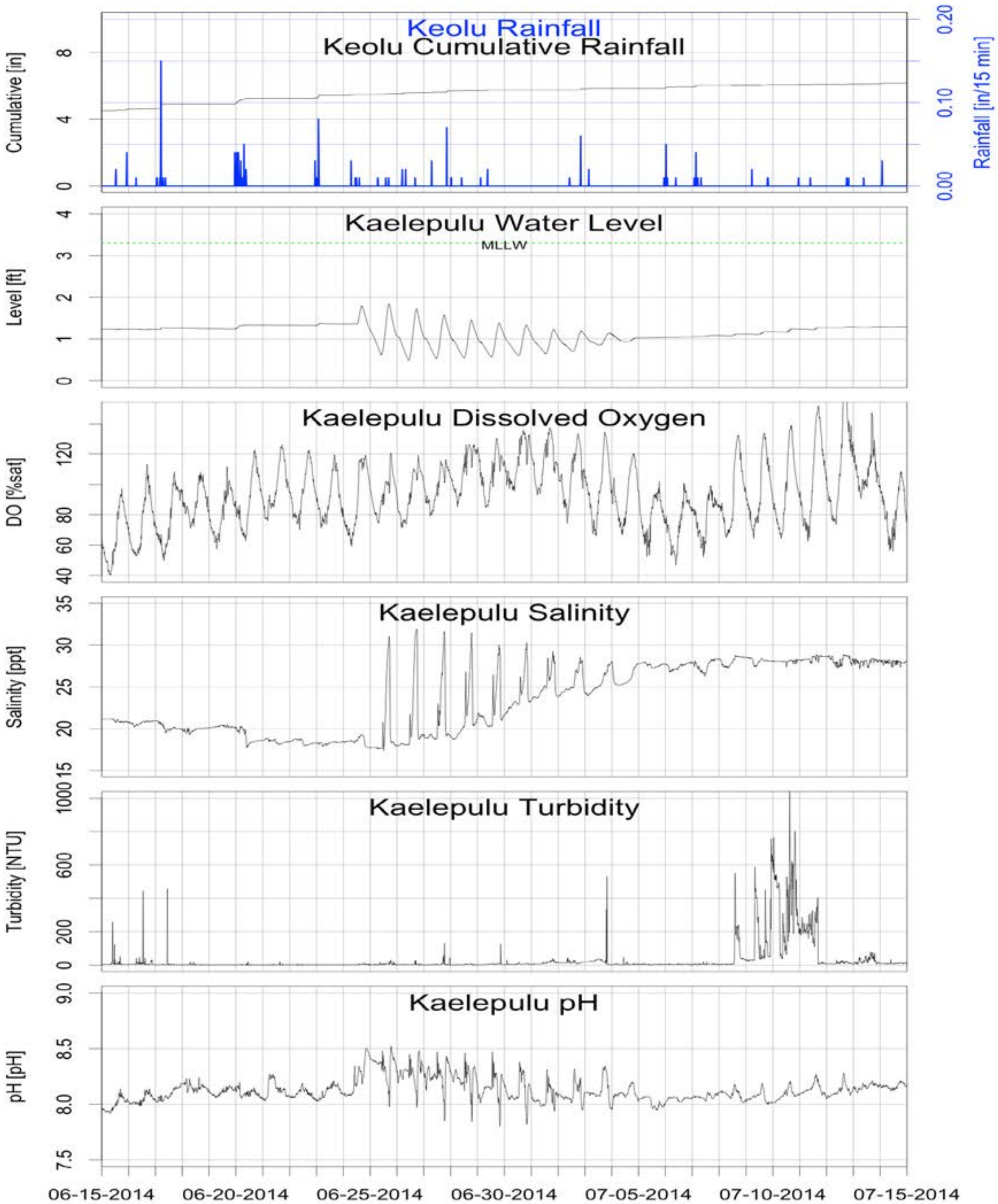

Figure 4. One-month detail from YSI log (Figure 3) showing estuary conditions during June, 2014 stream mouth opening event conducted by the City.

The basic statistics for each of the flow events are displayed in Table I. The Kaopa sub-basin (which includes the Aleka sub-basin) contributes to the Keolu sub-basin, and its flow quantities are not separately added to the flow to the estuary system.

Flow quantities measured by instruments at the individual sites are ignored here as they often led to flow calculations that were unreasonably high (would have filled the pond more than a foot higher than measured) and were inconsistent between storm events. The flows present in Table I are the result of calculating the total flow to the system based on estuary rise and surface area. This total volume is then partitioned into sub-basin contributions based exclusively on sub-basin area. This ignores differences between sub-basins in rainfall, slope, infiltration, and runoff. Plotting the rainfall quantity Vs percent runoff produces the graphic in Figure 5. Using different units (right side x-axes) the same graphic is interpreted as the Quantity of Rain Vs the Rise in the Pond and is consistent with earlier numerous records of this phenomena (Bourke 2017).

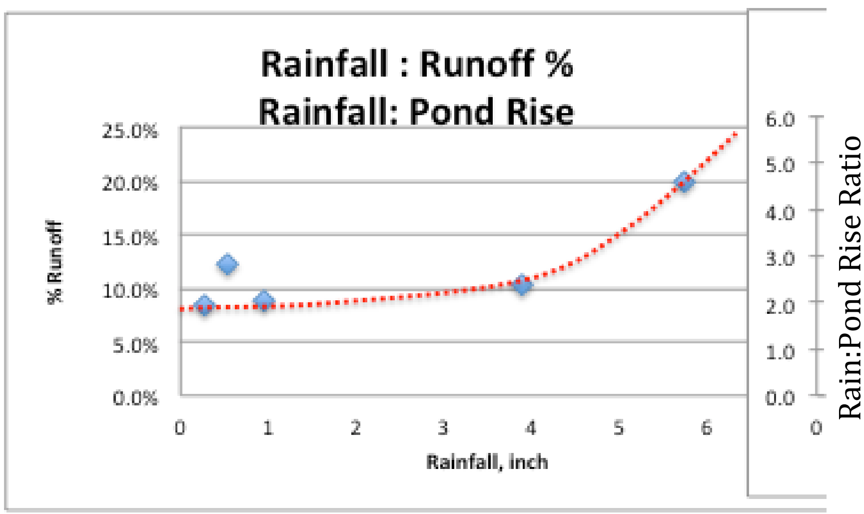

Figure 5. Rainfall and percent runoff for each sampled rainfall event. Same graphic shows the ratio of rainfall to pond rise.

Table I. Flow Volumes Per Storm

Event	Rainfall Inch	Rainfall Volume cu ft	Pond Rise, Inch	Flow Volume to Pond cuft	Rise:Rain Ratio	% Runoff
2/3/15	0.28	3,506,580	0.6	294,030	2.1	8.4%
1/3/15	0.96	12,022,560	2.16	1,058,508	2.3	8.8%
10/19/14	3.89	48,716,415	10.32	5,057,316	2.7	10.4%
8/9/14	0.54	6,762,690	1.68	823,284	3.1	12.2%
7/20/14	5.75	72,010,125	29.04	14,231,052	5.1	19.9%

CALCULATION OF SAMPLE SITE FLOW VOLUMES FROM
% WATERSHED AREA, RAINFALL VOLUME, AND RUNOFF VOLUME

Event Date -->		2/3/15	1/3/15	10/19/14	8/9/14	7/20/14
Rainfall, inch		0.28	0.96	3.89	0.54	5.75
Measured lake rise in feet -->		0.05	0.18	0.86	0.14	2.42
Total cuft flow to 135-ac pond		294,030	1,058,508	5,057,316	823,284	14,231,052
Rainfall volume cuft over watershed		3,506,580	12,022,560	48,716,415	6,762,690	72,010,125
% runoff		8.4%	8.8%	10.4%	12.2%	19.9%
Flow attributed to sampled sites, cu ft *		79,686	248,519	601,014	223,122	3,856,821
SAMPLE SITE	% Area Wtrshed	Flow, cu ft				
Akipola	3.6%	10,653	38,352	183,236	29,829	515,618
Aleka	2.6%	7,670	27,613	131,930	21,477	371,245
Hamakua	0.3%	852	3,068	14,659	2,386	41,249
Hele Ditch	8.0%	23,437	84,374	403,119	65,624	1,134,359
Kaopa	5.2%	15,341	55,227	263,860	42,954	742,490
Keolu	15.2%	44,744	161,077	769,592	125,282	2,165,595

* Total does not include Kaopa or Alika as they are part of the Keolu basin

Chemical analyses were conducted on a total of 52 samples collected from six locations during the course of five storm events. The raw data is presented in the Appendix for each sample. Table III displays the geometric mean and average water quality for each site. To avoid overrepresentation of sites or storms where multiple samples were taken, the geometric mean or average is calculated first by taking the geometric mean or average for each storm. In the lower portion of the table the geometric means and averages are calculated on all pooled data. The first method gives even weighting for each storm. The second method of averaging gives more weight to those locations where multiple samples were analyzed. The geometric mean is calculated as this is the method used for comparison to State Water Quality Standards. Figure 6 displays the average water quality for each constituent and each sample site as a graphic.

The State Water Quality Standard for the estuary into which the storm drains flow is also provided in the table. State law sets the limit of constituent concentrations desired in each type of water body. The State Standards consist of three values for each constituent 1) geometric mean not to be exceeded, 2) the value not to be exceeded more than 10-percent of the time (36.5 days/year, or 1 out of 10 samples), and 3) the value not to be exceeded (statistically the 2% nte) in any sample. This information is displayed in Table III.

The total load of each constituent is obtained by multiplying the volume of flow (Tables I and II) times the concentration of each constituent associated with that flow (Table III) with the results tabulated in Table VI. Two loads are calculated, one for all sub-basins measured, and the second for only the flows to the Kaelepulu waterways (not including the Kaopa sub-basin). Only 5 storms, totaling about 11-inches of rainfall were monitored, but the annual rainfall is about 42-inches. To extrapolate to an entire year's rainfall, daily rainfall events less than 0.2-inches were ignored (see Figure 2) reducing the "significant runoff producing" rainfall events to about (.775x42) 32.5-inches. Multiplying the runoff quantities by (32.5/11.1) about 3, to obtain the annual runoff load from each monitored site. Because the monitored sub-basins account for about 27.1% of the watershed, the annual load from these sites is multiplied by (1/0.271) about 4 to yield the total load from the entire watershed as displayed near the bottom of Table IV. Figure 7 displays this information in graphic form.

The City's Federal NPDES storm drain permit does not set specific load limits for stormwater. However, it is reasonable to propose that stormwater effluent should not have higher pollutant loads than the State Standard for the waters into which it flows. The goal for stormwater loads into Kaelepulu then would be the volume of stormwater times the constituent concentration set by State Standard for estuaries as displayed in Table III. These loads are also calculated and presented at the bottom of Table IV.

Table III

Geomean calculation summed by individual storm, then averaged

GEOMETRIC MEAN CONCENTRATIONS OVER FIVE STORMS

	NH3 mg/l	NO3+NO2 mg/l	TP mg/l	TSS mg/l
Akipola	0.04	0.85	0.32	33.32
Aleka	0.07	0.97	0.73	456.00
Hamakua	0.08	0.02	0.14	13.61
Hele Ditch	0.06	0.54	0.50	71.12
Kaopa	0.03	0.55	0.25	42.17
Keolu	0.04	0.21	0.24	31.85
Average GM	0.05	0.52	0.36	108.01

AVERAGE CONSTITUENT CONCENTRATIONS OVER FIVE STORMS

	NH3 mg/l	NO3+NO2 mg/l	TP mg/l	TSS mg/l	Enterococcus MPN/dL
Akipola	0.05	1.68	0.36	114.04	4850
Aleka	0.07	0.97	0.73	456.00	2400
Hamakua	0.12	0.02	0.14	16.21	7200
Hele Ditch	0.10	0.74	0.58	89.13	13200
Kaopa	0.05	0.65	0.27	92.04	8200
Keolu	0.05	0.24	0.26	36.11	8200
Average	0.073	0.716	0.391	133.9	7342

All data points analyzed - no weighting by storm

All Sample	NH3	NO3+NO2	TP	TSS	
Average ->	0.055	0.590	0.265	60.1	7342
Geo Mean	0.032	0.222	0.221	23.4	5222

Hawaii State Water Quality Standards
Estuaries

	NH3 mg/l	NO3 +NO2 mg/l	TP mg/l	TSS mg/l	Enterococcus MPN/dL
Geo Mean	0.006	0.008	0.025	ns	35
NTE 10%	0.01	0.025	0.05		
NTE 2%	0.02	0.035	0.075		

Storm water has **X-times greater concentration** than
Hawaii State Water Quality Standard Estuaries

	NH3	NO3 +NO2	TP	TSS	Enterococcus
Geo Mean	5	28	9	ns	149
NTE 10%	3	9	4		
NTE 2%	2	6	3		

Table III. Constituent concentrations calculated from runoff in five storms sampled in the Kaelepulu watershed. Upper two tables, with individual sample locations, are calculated first as the geometric mean or average of each storm with multiple samples, then as the geometric mean or average of all storms. This avoids the problem of storms with more samples having a stronger influence on the final average. The lower table shows averages and geometric means based on all individual samples, regardless of location or storm sampled. The average in the lower table differs from that in the upper tables due to the greater representation of some storms and stations over others. Regardless of the averaging method, the results show that the constituents in the runoff are an order of magnitude higher than allowed by state water quality standards. The bacterial standard is exceeded by 149 times. There is no State Standard for TSS in estuaries.

TOTAL POLLUTANT LOADS				
	Loads from Measured Drains during Measured Storms			
	NH3	NO3+NO2	TP	TSS
	kg	kg	kg	Tons
Akipola	1.2	57.9	10.9	5.8
Aleka	0.7	10.2	7.7	4.8
Hamakua	0.2	0.1	0.3	0.03
Hele Ditch	5.3	71.8	23.6	4.4
Kaopa	1.7	25.0	11.6	7.5
Keolu	4.9	25.4	19.6	3.8
	Annual Loads Extrapolated from City 2014-15 data for monitored sites extrapolated to annual rainfall			
	NH3	NO3+NO2	TP	TSS
	Kg/Yr	Kg/Yr	Kg/Yr	Ton/Yr
Akipola	4	165	31	17
Aleka	2	29	22	14
Hamakua	0.6	0.2	0.8	0.1
Hele Ditch	15	205	67	12
Kaopa	5	71	33	21
Keolu	14	72	56	11
Annualized Total	40	543	210	75
Discharge to Kaelepulu	35	472	177	54
	Annual Load Extrapolated to Entire Watershed			
	NH3	NO3+NO2	TP	TSS
	kg	kg	kg	Tons
Watershed Total	147	2004	774	277
WS Discharge to Kaele	129	1741	652	198
	Allowed Load in Kg According to State WQ Standards			
Geo Mean -->	9	12	38	na
10% N.T.E -->	15	38	75	
2% N.T.E -->	30	53	113	

Table IV Total pollutant loads, calculated from pollutant concentrations (Table II) multiplied by the volume of water passing through the sample point (Table III) yields the total quantity of each pollutant in the flow stream at each of the six sample locations during the five storm events (top table). Because the six sampled storms represent only about 11 inches of rain, these quantities are extrapolated in the center table to represent the pollutant flow from a full year's rainfall. The six sample sites represent flow from only about one fourth of the watershed and the lower table extrapolates the annual load to the entire watershed. Note that the Aleka drainage is a sub-basin of Kaopa which is a sub-basin within the Keolu drainage and this load is not added separately to the discharge into the Kaelepulu waterway. Bottom of table shows loading if effluent met State water quality standards for estuaries at the Geometric Mean, 10% not-to-exceed (NTE) and 2%NTE levels

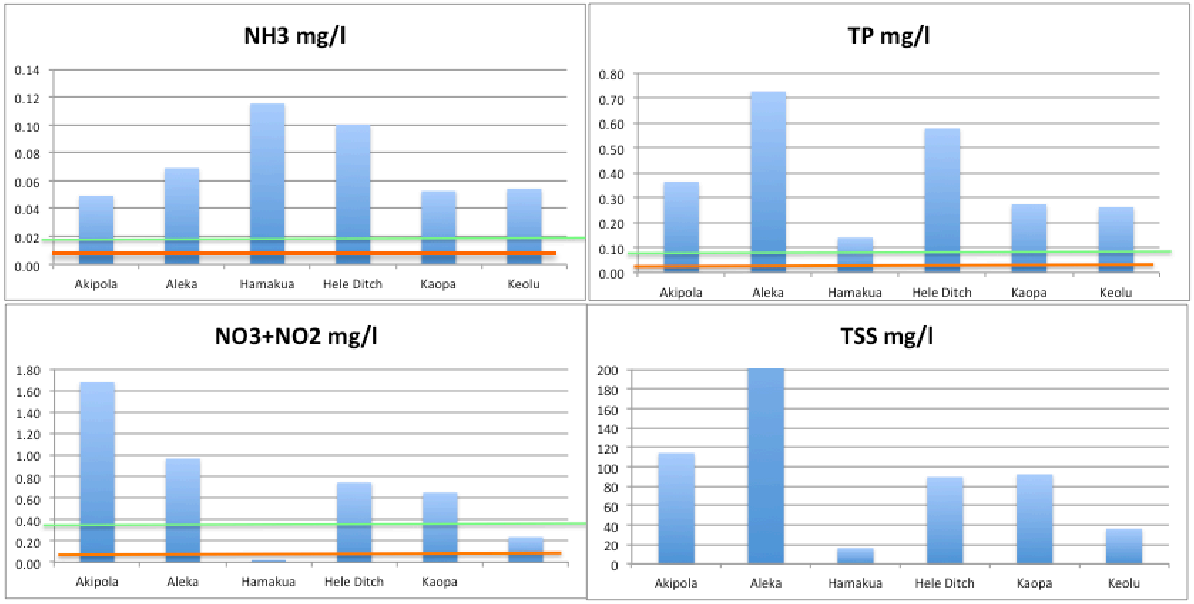

Figure 6 Average nutrient and sediment concentrations from sub-basins into Kaelepulu. Red line represents the State of Hawaii water quality standard geometric mean and the green line is the 2% nte standard for estuaries. There is no State Standard for TSS. Aleka is represented by a single sample.

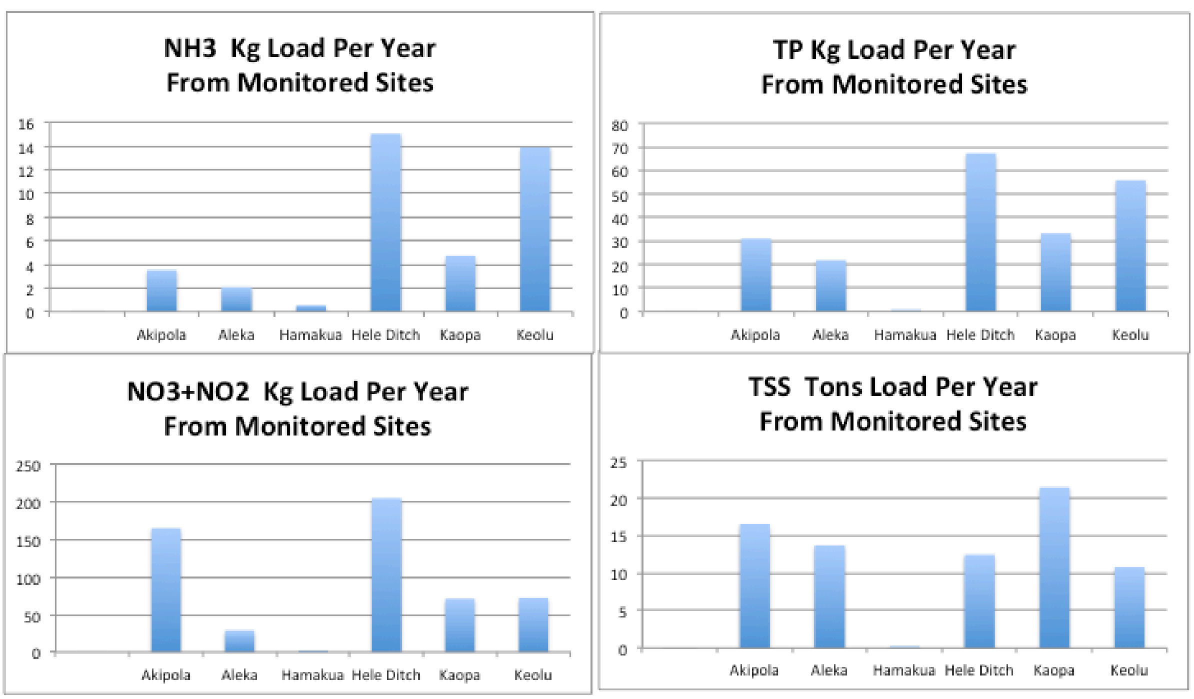

Figure 7 Total annual load from monitored sites extrapolated from 11-inches measured rainfall to the annual rainfall for the whole watershed.

V. Discussion

Water quality samples were obtained during five storm events in 2014 and 2015 from six sub-basins in the Kaelepulu watershed on the windward shore of Oahu, Hawaii. The five storms spanned the effective range of annual storm events ranging from 0.28-inch to 5.75-inch of rain. In this watershed rainfall less than 0.2-inch per day does not produce significant runoff, and the 5.75-inch rainfall is only about an inch greater than the expected annual 24-hour rainfall event. The six sub-basins sampled covered about 27% of the watershed and were representative of the land-use types including town-center commercial, urban residential, small "gentleman farmer" farm lots on the lower slopes of Olomana and the steeper slopes above within conservation land.

Equipment used to measure flow in each of the drainages appears to have provided inaccurate results, with the calculated flows being much higher than reasonable according to the measured increase in pond water surface elevation. In addition the relative flows measured from one site to another were not consistent between storms which is unusual in such a small watershed where rainfall patterns are expected to be reasonably consistent. Fortunately estimating total storm flow volume by measuring the rise of the water surface in the pond and then ascribing flows to each sub-basin based upon the area of each sub-basin overcame this problem. Unfortunately this method does not produce information such as infiltration differences between sub-basins necessary for the runoff model AECom intends to develop.

Two of the drainages, Keolu and Hele carried the greatest runoff volumes and also had generally higher constituent concentrations than the other drainages. The concentrations of nutrients ammonia (NH3), nitrate plus nitrite (NO3+NO2), and total phosphorus (TP) in the storm water runoff were 7 to 32 times higher than allowed for the estuary waters into which the drains flow. Although there is no State water quality

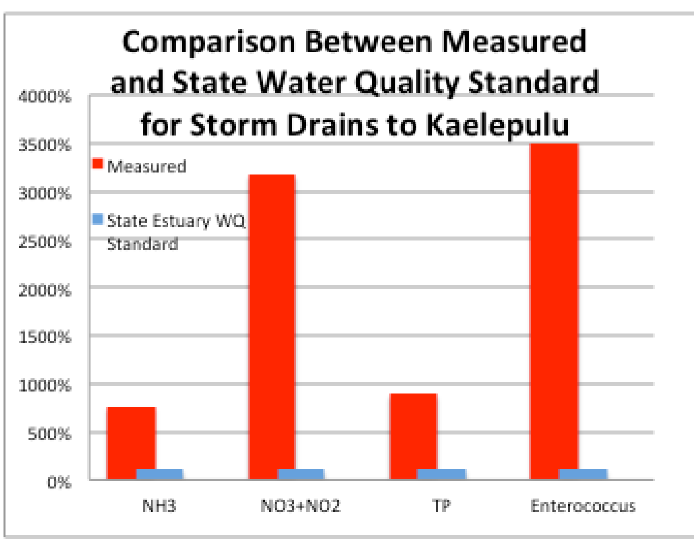

Figure 8. Constituent concentrations measured compared to Geometric Mean State water quality standards set at 100% of desirable concentration.

standard for TSS in estuaries, the total quantity of sediment (203 tons) entering the 135-acre estuary on an annual basis is extremely high.

The State water quality standard for estuaries applies only to estuaries, and not to runoff from the City's NPDES permitted point source storm drains. It may not be reasonable to apply a standard intended to characterize the estuary 50% of the time (the geometric mean water quality standard) and use this to apply to rainfall events – particularly heavy rainfall events, which are relatively rare in occurrence. For storm events, it may be more reasonable to attempt to attain water quality limits that reflect both the rarity of the rainfall event and the type of water body into which the flow outfalls. To this end we used the 2-year rainfall data collected in 2014-2015 to help identify storm intensities that might be expected 10% and 2% of the time (Figure 9). In Figure 9, a rainfall event of 0.29-inches occurs about 10% of the time, and a rainfall event of 1.29-inches occurs about 2% of the time.

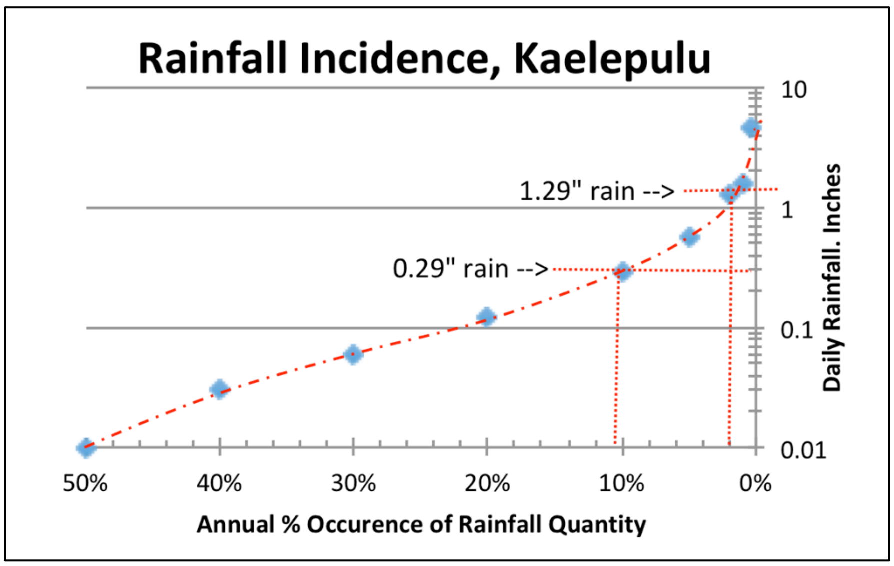

Figure 9. Annual incidence of storm events by daily rainfall quantity. Rainfall events of 0.29-inches are exceeded 10% of the time (36 days/year). Rainfall of 1.29" is exceeded 2% of the time (7 days/year). The one-year event (0.027%) is 4.5-inches.

As the magnitude of a storm increases, it is reasonable to lower expectations about the ability of BMPs to control pollutants in the flow stream. But it is not reasonable to discount adverse water quality impacts just because a watershed receives a "big" storm. Linking the relative magnitude of the storm to an expected level of control would seem to be a reasonable approach. Linking the sub-year return rate of a storm, (its annual expected incidence or expected percent occurrence) to the same "not to exceed" incidence of water quality set by State standards sets a rubric for reasonable control expectations. The water quality in the Kaelepulu system is controlled primarily by the quality of water flowing out of the City's storm drain system. The quality of water flowing out of this system into Kaelepulu should be expected to meet the State water quality standard at a "not to exceed" level equal to the annual incidence of the rainfall event. Examination of Table III shows that the storm water quality exceeds the 2% nte by a factor of 2 to 7, depending upon the constituent considered. While meeting this standard would still require a much greater degree of control by the City on the quality of the storm water effluent, this may be a more attainable goal than attempting to meet the geometric mean water quality for estuaries.

The State, at the insistence of the Federal EPA, lists a surface water standard for bacteria based upon counts of the human enteric bacteria “Enterococcus” which was measured during two storm events. Across most of the United States this bacteria is a reasonably good indicator of contamination from human sewage. The standard for this indicator bacteria is 35 colony forming units per decileter. The lowest count recorded was 2.400 cfu and the geometric mean of all samples was 5,222. What the EPA does not take into account is the fact that in Hawaii this bacterium also lives in rats, mice, ducks, mongoose and many other animals and also lives freely in the soil. It is therefore an extremely poor predictor of human fecal contamination. Attempting to interpret the results of this analyses in this watershed would not be productive and could be misleading.

The nutrient and sediment concentrations found in the AECom study are similar, but somewhat higher, than those measured a few years earlier in a State funded study conducted by University of Hawaii personnel (Babcock and Tamaru, 2012). Although lower than the present study, the geometric mean of constituent concentrations in storm drain samples obtained by Babcock and Tamaru (Figure 11) were still very much higher than the State water quality standard for estuaries. In that study samples from storm drains and the open water of the estuary were taken on a monthly basis for a year, plus during three storm events. It is reasonable that the samples obtained by Babcock and Tamura, mostly during non-rainfall conditions, exhibited lower constituent concentrations as compared to the present study.

The heavy sediment loads found in this study are consistent with those described previously (Bourke, 2017) in this watershed and attributed primarily to inadequate sediment control on construction sites. No major construction activities were noted in the Hele sub-basin, although the overall TSS concentrations in Hele were similar to those measured in the Keolu sub-basin. The Hele sub-basin appears to be subject to a large “first-flush” effect (Figure 10) in which the initial flow is very turbid but clears as the surface of the watershed is cleared of built-up sediment. This contrasts to the Keolu drainage which has been observed to run red throughout the duration of most storms. The “first flush” characteristic of the Hele sub-basin opens the possibility of fitting the drainages with devices designed only to capture the initial load and not hinder the flow of larger or extended storm events.

The 425-acre Keolu sub-basin encompasses the second largest tract of housing, many of the “gentleman farmer” lots within Norfolk, the slopes of Mount Olomana, the large grassland/wetland Keopa detention basin and the DOT Kalanianaloe Highway. During the period of this study, there was active grading of a very large parcel (20+ acres) on the upper hillside of the Keolu sub-basin. Runoff that turned the entire Kaelepulu

Pond bright red-brown on multiple occasions during the period of this study was traced directly back to this construction site and did result in regulatory action by the State DOH against the developer. The presence of this development was likely a major influence on the water quality observed in the samples. The size of this sub-basin and its volume of flow are key to the high load of pollutants delivered to Kaelepulu. The presence of the Kaopa flood control basin undoubtedly has a large beneficial effect upon the portion of the Keolu flows that pass through it. However, relatively simple improvements to the structure could dramatically improve its effectiveness as a settlement basin.

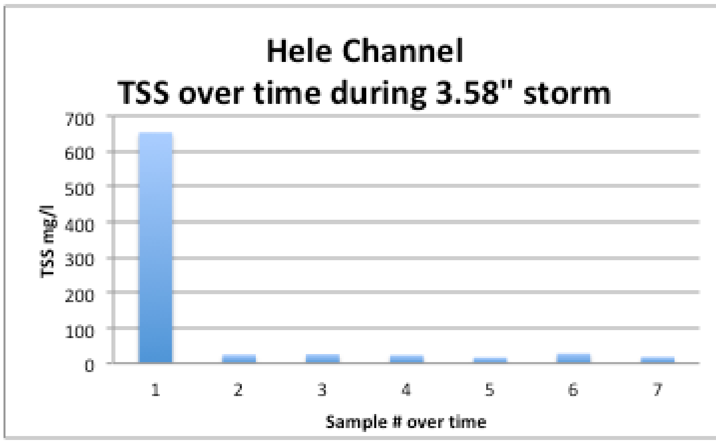

Figure 10. The Hele sub-basin is subject to a large "First Flush" effect.

The Aleka sub-basin from the slopes of Olomana was only monitored during the single storm event that had the highest rainfall (5.71"). The AECom flow volume calculated by instrumentation was very low at this site (568 cu ft) or only about one-percent of the flow instrument measured (56,939 cu ft) from the equally sized adjacent Kaopa sub-basin. The reason for the apparent extremely low runoff in this sub-basin is not known and should be investigated. The Kaopa station is downstream of the Aleka station and should include flow from both Aleka and Kaopa. Based only upon the area of these sub-basins, the flow from each should have been about 371,245 cu ft. No reason was provided for not collecting samples during subsequent storms at this site, but it is possible that rainfall of lower magnitude did not provide sufficient runoff at this site to warrant sampling. Whether this low flow rate is the result of instrument error, or there is some unique quality of this sub-basin that allows infiltration of almost 100% of the rainfall is not known. If the infiltration in this sub-basin is very high, then the flow attributed to the sub-basin by area alone (371,245 cu ft) in the calculations and graphics shown earlier in this paper would be erroneous and would grossly over-estimate the pollutant loads from this sub-basin.

Kaopa (including the 90-acre Aleka) is a 180-acre sub-basin of the Keolu drainage and empties into the lower portion of the wetland behind the Kaopa flood control basin. The Kaopa sub-basin exhibited similar ammonia and phosphorus loads to the Keolu

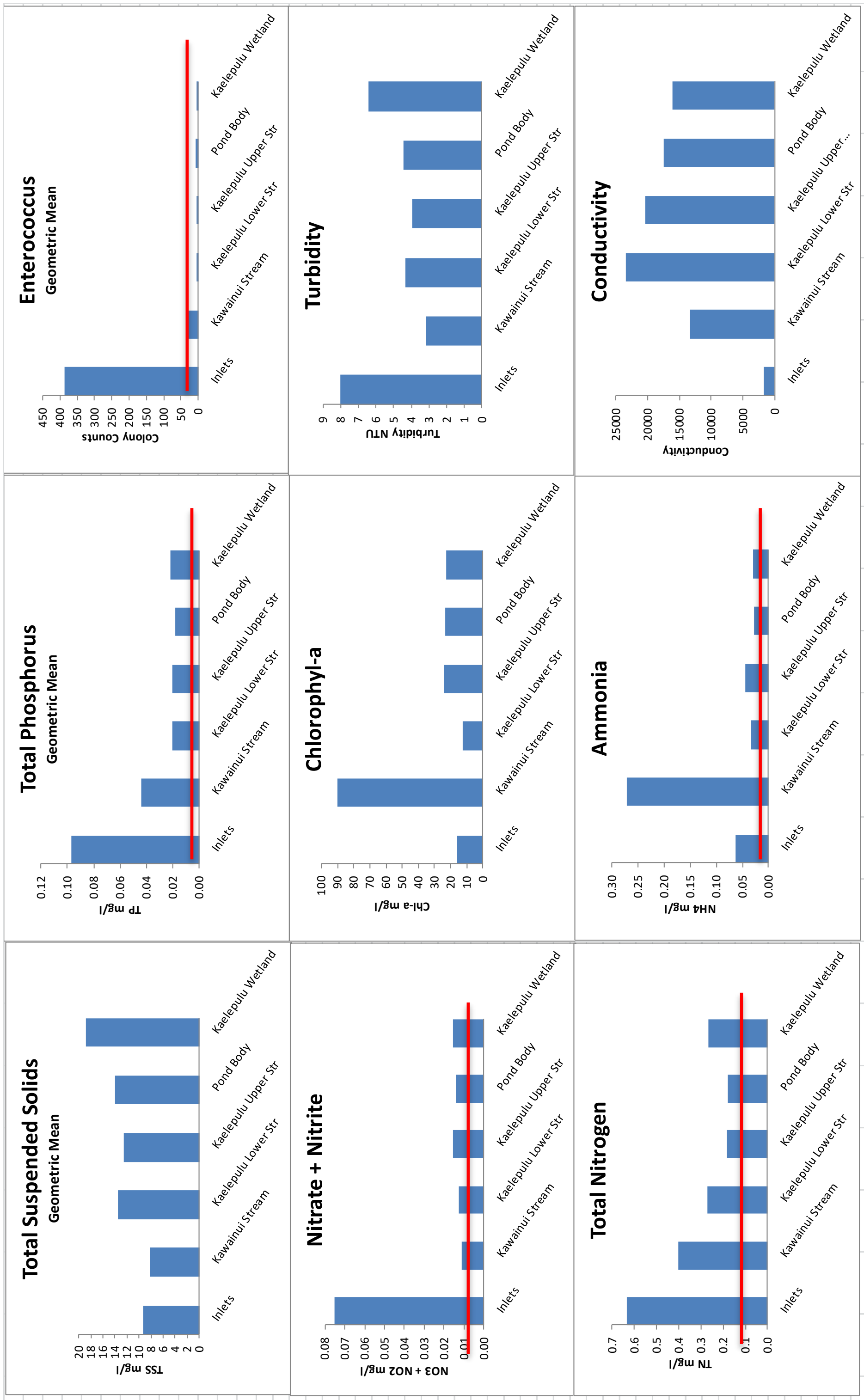

Figure 11. Data from Department of Health TMDL study by Babcock & Tamaru. Only the first column in each graphic refers to water quality from inlets to the estuary with the balance of the data referring to locations within the estuary. Red line represents the geometric mean State standard for each water quality constituent.

drainage but much higher nitrate plus nitrite and total sediment loads. It is likely that the Kaopa flood control basin acts as a settling basin removing the heavier sediments and nitrate plus nitrite associated with particulate debris in the flow. Improvements to the Kaopa flood control basin may be an effective route to reduce loads from both the Kaopa and Keolu sub-basins to the open waters of Kaelepulu.

The Akipola sub-basin around and above the Kaelepulu Grade School is a mix of residential and preservation lands, with some wetlands located above the urban area and below the high school. The lower portion of the 20-foot wide open drainage box channel, about 500-feet from Keolu Drive through the Kukilakila grounds, is below the pond water surface elevation and has in the past been subject to periods of stagnation resulting in complaints from adjacent home owners. The high TSS load from Akipola during the initial sample event (but not subsequent events) may have been partially due to a large (~1 acre) lawn that was being installed on a steep slope on private property near the back of the sub-basin. This source of sediment-colored water to the pond had been tracked to its source earlier in 2014 by lake-side residents. The wetland and forest area offers opportunities for improvements to act as a more effective settlement basin, perhaps as an improvement for a much-needed park in this area adjacent to the High School. The large size of the box channel near the sampling site, and the presence of available land near this channel provide an opportunity to install a particulate filter and/or trash entrainment BMP at this location.

Hamakua drains portions of down-town Kailua that have been subject to more regular street sweeping (by City and business owners) and have been the focus of “green” parking infrastructure construction. Hamakua sub-basin had the lowest sediment, phosphorus, and nitrate plus nitrite concentrations of the five sites. The high ammonia concentration is confusing. Emulating the street cleaning and “green” infrastructure in this small drainage to other similar areas of the watershed is warranted.

VI. Conclusion

All of the monitored sub-basins produced flows to the Kaelepulu estuary that exceed the desired loads as established by the State water quality estuary standards. Of the six basins measured, the small Hamakua sub-basin within the commercial area of Kailua exhibited the lowest pollutant concentrations, likely due to the use of BMPs within the area. The loads from the other sub-basins are all about an order of magnitude higher than they should be according to the State water quality standards for the estuary receiving waters into which they flow. Many of the problems in the watershed derive either from out-dated drainage infrastructure that make the use of standard BMPs challenging, or from poorly regulated construction activities that do not adequately control erosion on steep sites. Storm drains only act as the conduit for pollutants and are not the source. Source control in the watershed needs to be focused upon those activities and locations known to create the most significant pollutant loads. Unique opportunities exist within each sub-basin to significantly reduce these loads both at their source and at the end of pipe, but this will require the City and the public to go beyond measures that have been traditionally used in the past.

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Babcock, R., and C. Tamaru 2012 – Water quality database from unpublished TMDL study. Available from Hawaii Department of Health.

Bourke, R.E. 2017 Natural History, Hydrology and Water Quality of Enchanted Lake – Kaelepulu Pond. Downloadable from: kailuawaterways.com/web-docs/physical-water-quality-processes-kaelepulu-051617-ct.pdf

Report Appendices with data used to produce this report may be downloaded from:

www.BourkeEcology.com

DATA WITH "ND" CONVERTED TO 1/2 MRL

Kaelepulu Water Quality and Flow data extracted from files produced by City under FOIA request
Water quality data from AECom as collected by TEC Environmental

Data with "non-detect" (nd) values set at 1/2 detection MRL levels.

Date	Site	Rain Inch	Calculated Flow Volume by Lake Rise x % area M^3	NH3 mg/l (MRL 0.025)	NO3+NO2 mg/l (MRL 0.025)	TP mg/l (MRL 0.005)	TSS mg/l (MRL 2.5) <-- MRL Level
7/20/14	Akipola	5.74	14628	0.075	3.46	0.617	388.0
	Aleka		10532	0.069	0.966	0.727	456.0
	Hamakua		1170	0.129	0.068	0.182	20.5
	Hele Ditch		32182	0.105	1.88	0.492	94.5
	Kaopa		21064	0.069	0.973	0.478	348.0
	Keolu		61438	0.07	0.38	0.271	56.5
8/9/14	Akipola	0.45	846	ns	ns	ns	ns
	Aleka		609	ns	ns	ns	ns
	Hamakua		68	0.0125	0.0125	0.133	28.0
	Hele Ditch		1862	0.0125	0.427	1.24	75.0
	Kaopa		1219	0.0125	1.12	0.288	43.0
	Keolu		3554	0.0125	0.19	0.166	30.0
10/19/14	Akipola	3.89	87	0.0125	0.0125	0.294	9.0
(1)	Aleka			ns	ns	ns	ns
	Hamakua		7	0.0125	0.0125	0.111	8.0
	Hele Ditch		192	0.181	0.223	0.2	654.0
	Kaopa		126	0.0125	0.729	0.226	45.3
	Keolu		0	ns	ns	ns	ns
10/19/14	Akipola		348	0.0125	0.148	0.155	35.0
(2)	Aleka			ns	ns	ns	ns
	Hamakua		28	0.107	0.0125	0.135	1.25
	Hele Ditch		766	0.0125	0.201	0.245	25.0
	Kaopa		502	0.0125	0.286	0.215	35.0
	Keolu		0	ns	ns	ns	ns
10/19/14	Akipola		619	0.0125	1.18	0.199	14.0
(3)	Aleka			ns	ns	ns	ns
	Hamakua		49	0.073	0.0125	0.105	9.0
	Hele Ditch		1361	0.0125	0.578	0.285	26.0
	Kaopa		891	0.0125	0.52	0.134	30.0
	Keolu		0	ns	ns	ns	ns

			Flow Volume	0.025	0.025	0.005	2.5 <-- MRL Level
		Rain	by Lake Rise x	mg/l	mg/l	mg/l	mg/l
		Inch	% area M^3	NH3	NO3+NO2	TP	TSS
10/19/14	Akipola	3.89	1549	0.0125	0.239	0.133	6.5
(4)	Aleka			ns	ns	ns	ns
	Hamakua		124	0.0125	0.0125	0.089	8.5
	Hele Ditch		3408	0.0125	0.327	0.225	23.5
	Kaopa		2231	0.0125	0.507	0.138	22.5
	Keolu		0	ns	ns	ns	ns
10/19/14	Akipola		1399	0.0125	0.384	0.407	5.0
(5)	Aleka			ns	ns	ns	ns
	Hamakua		112	0.059	0.0125	0.112	25.5
	Hele Ditch		3078	0.0125	0.561	0.245	17.0
	Kaopa		2014	0.0125	0.513	0.245	16.5
	Keolu		0	ns	ns	ns	ns
10/19/14	Akipola		664	0.0125	2.24	0.287	29.5
(6)	Aleka			ns	ns	ns	ns
	Hamakua		53	0.229	0.0125	0.133	5.0
	Hele Ditch		1462	0.0125	1.17	0.342	28.0
	Kaopa		957	0.0125	0.758	0.083	1.25
	Keolu		0	ns	ns	ns	ns
10/19/14	Akipola		531	0.0125	3.78	0.327	24.5
(7)	Aleka			ns	ns	ns	ns
	Hamakua			ns	ns	ns	ns
	Hele Ditch		1169	0.0125	1.66	0.32	18.5
	Kaopa		765	0.0125	0.47	0.075	5.0
	Keolu		0	ns	ns	ns	ns
1/3/15	Akipola	0.96	1088	0.044	1.91	0.402	45.5
	Aleka		783	ns	ns	ns	ns
	Hamakua		87	0.137	0.0125	0.138	15.0
	Hele Ditch		2394	0.186	0.359	0.436	62.0
	Kaopa		1567	0.029	0.21	0.157	19.0
	Keolu		4570	0.088	0.217	0.429	35.0
2/3/15	Akipola	0.28	302	0.065	0.194	0.183	5.0
	Aleka		218	ns	ns	ns	ns
	Hamakua		24	0.216	0.0125	0.136	8.0
	Hele Ditch		7930	0.161	0.379	0.463	101.0
	Kaopa		435	0.14	0.414	0.285	28.0
	Keolu1		131	0.057	0.18	0.239	42.0
	Keolu2		183	0.039	0.1	0.194	22.0
	Keolu3		86	0.044	0.085	0.154	11.3
	Keolu4		190	0.043	0.071	0.144	8.5
	Keolu5		609	0.041	0.151	0.211	47.3
	Keolu6		70	0.055	0.358	0.166	6.5