**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quality data, in comparison to an earlier study contracted by the State Department of Health (Babcock and Tamaru, 2012 unpublished), and compared to State water quality standards for estuaries.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.

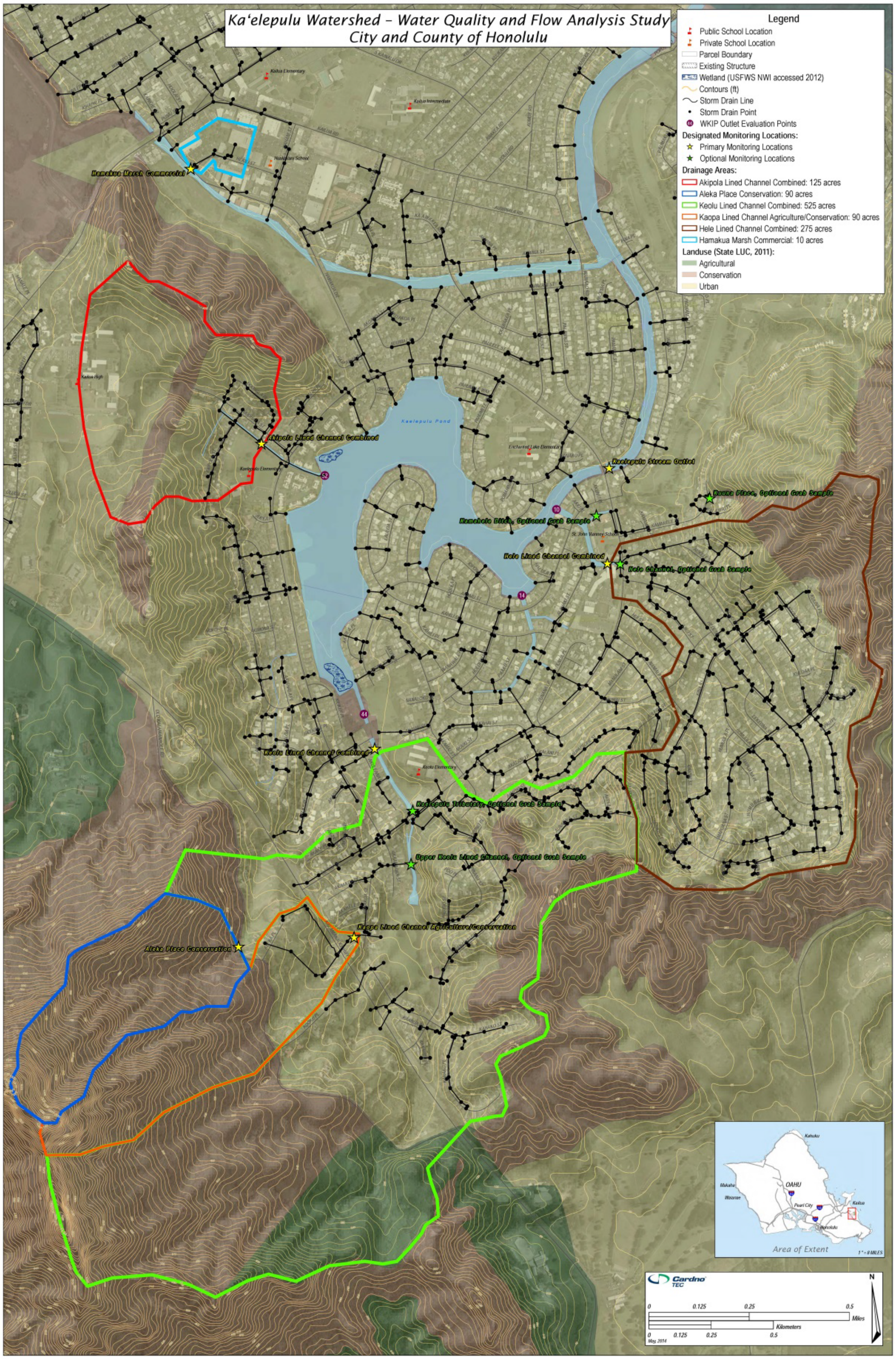


Figure 1. Kaelepulu watershed and monitored sub-basins. (AECom Graphic)

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 1/100$^{th}$ of a foot (~1/8$^{th}$ 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).

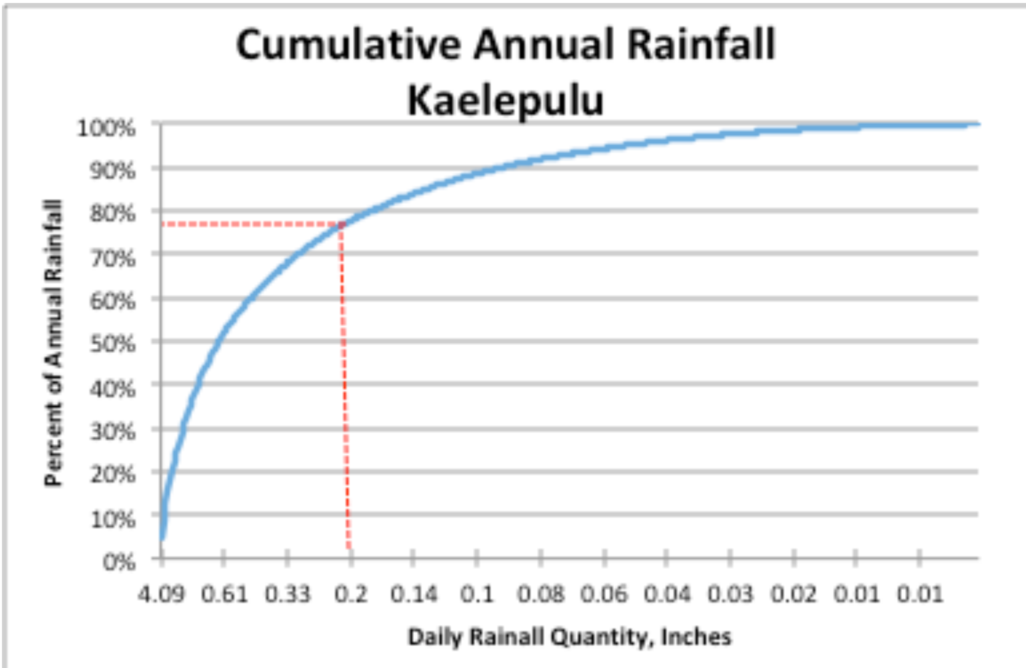


**Figure 2** Daily rainfall quantities >0.2-inch account for 77.5% of the annual rainfall. Rainfall less than 0.2-inch per day does not contribute appreciably to runoff.

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).

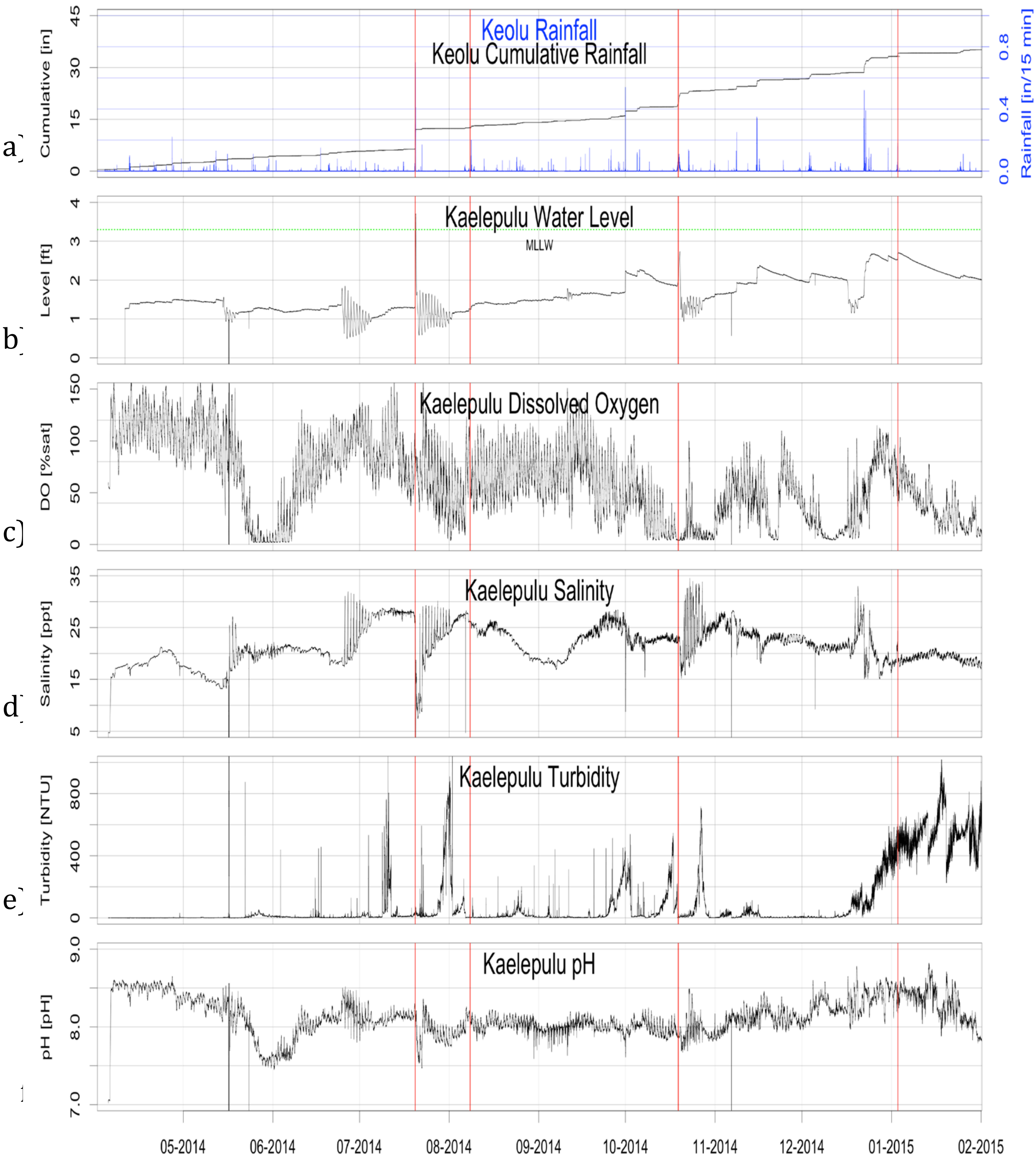


**Figure 3.** Cumulative rainfall and physical water quality parameters from Kaelepulu Stream at Keolu Bridge 2014-2015

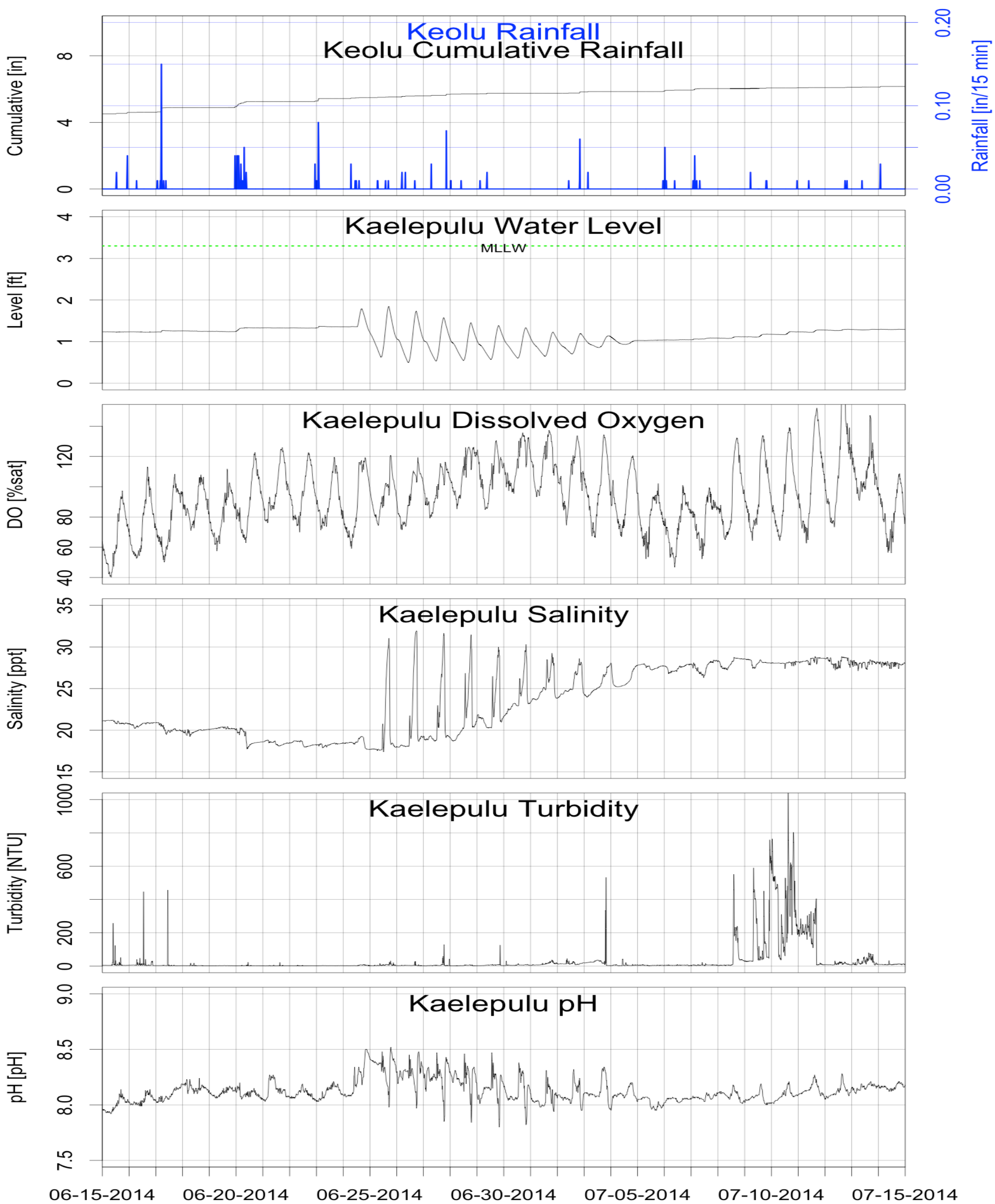


**Figure 4.** One-month detail from YSI log (Figure 3) showing estuary conditions during June, 2014 stream mouth opening event conducted by the City.

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).

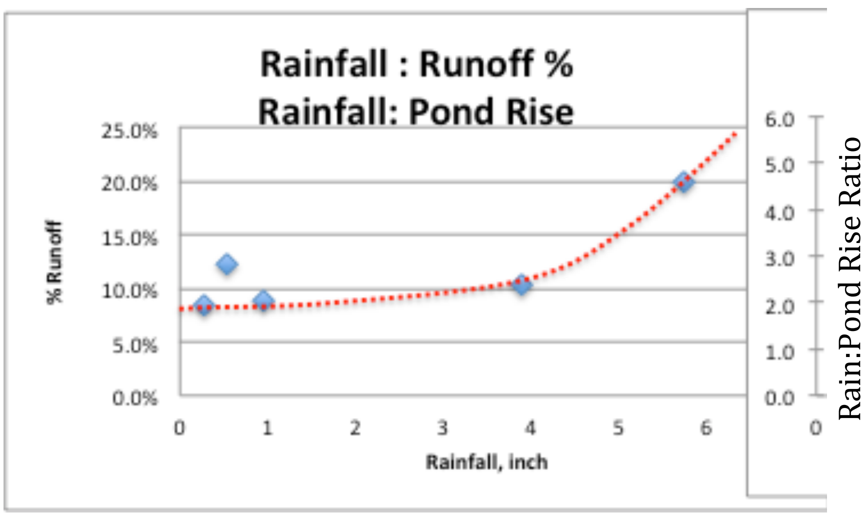


**Figure 5**. Rainfall and percent runoff for each sampled rainfall event. Same graphic shows the ratio of rainfall to pond rise.