Water Quality in Kaelepulu Pond

Results and Summary of Sampling from Five Storms.

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BACKGROUND

Kaelepulu Stream and Pond are "Water Quality Limited Segments" on the State's "EPA 319-List" and do not meet expected water quality standards. Kaelepulu Pond is the 90-acre estuary remnant of an ancient Hawaiian fishpond in the community of Enchanted Lake on the windward shore of Oahu, Hawaii. The Pond is central to the highly urbanized watershed and drains to the ocean across Kailua Beach through the Honolulu City owned Kaelepulu Stream. About half way to the ocean, the stream is joined by another canal, the dead-end remnant of Kawainui Stream. Kaelepulu and Kawainui canals each add about 10 acres to the water surface area of the estuary system. Kawainui, sometimes referred to as Hamakua Canal, courses through the back of Kailua Town and the Hamakua Wetland but has been separated from Kawainui Marsh by a flood control levee since about 1965. The Kawainui Stream receives only urban runoff and is essentially stagnant for much of the year. The City of Honolulu has 37 NPDES permitted storm drains entering Kaelepulu Pond and another 36 entering the Kawainui Stream and lower Kaelepulu Stream. Some of the City permitted drains also receive runoff from drains under the Kalanianaole Highway and a separate NPDES permit to the State Department of Transportation.

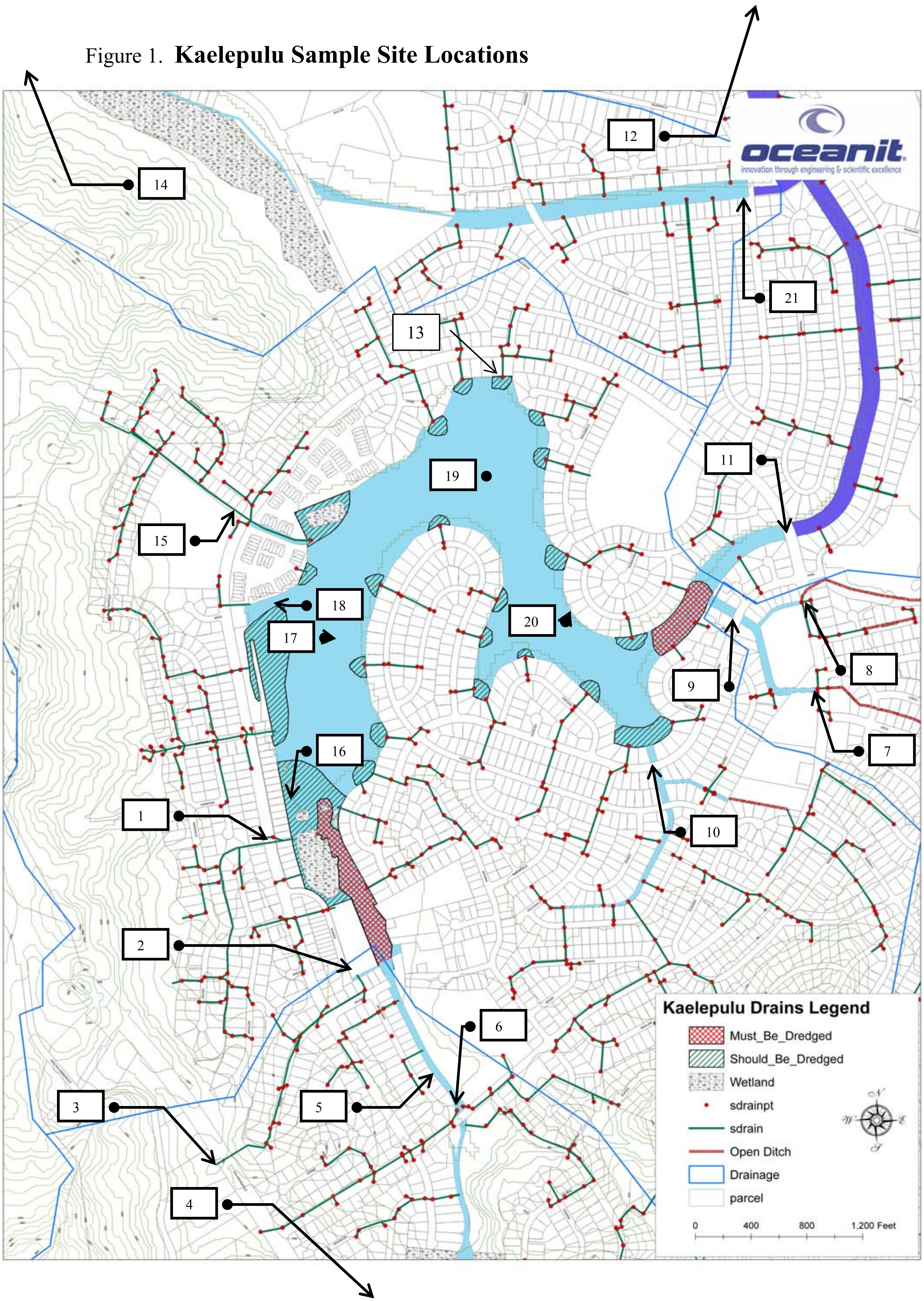
Ownership of the main portion of the pond is divided between the Enchanted Lake Residents Association and a private property owner who manages the "upper" 13 acres of the lake as wetland habitat for endangered Hawaiian waterfowl. Part of the community development agreement between the City and ELRA allows these stormwater outfalls to the pond, using the pond as a flood control basin. The Kaelepulu and Kawainui Canals are owned by the City.

During the past two decades, the community has noted significant shoaling near large storm drain inlets and seen a continuous deterioration in the ecological quality of the pond. Trash from storm drains and canals entering the lake is the focus of community clean-ups two or three times every year. Once plentiful oyster beds are much depleted, but not as a result of harvesting. Occasional fish die-offs are associated with periods of stagnant odoriferous pond water. The community is working with the State and City to limit the introduction of sediment and trash from the storm drains to the pond.

Purpose for Monitoring Water Quality

This report describes the results of five sets of water quality samples and lake level measurements taken by ELRA members and associated with storms between January 2002 and March 2006. The samples were taken to help isolate the primary sources of sediment to the pond so that appropriate measures may be developed to control these sources. Measurements of pond level were taken during several of these storms to better understand the inflow and outflow dynamics of the pond from storm runoff and ocean tidal influence. This level information will be documented in a following report as it relates to the clearance rate of pollutants from the pond to the ocean. This report deals specifically with identification of primary sources of sediment to the pond with an initial attempt to quantify the sediment load.

Figure 1. **Kaelepulu Sample Site Locations**



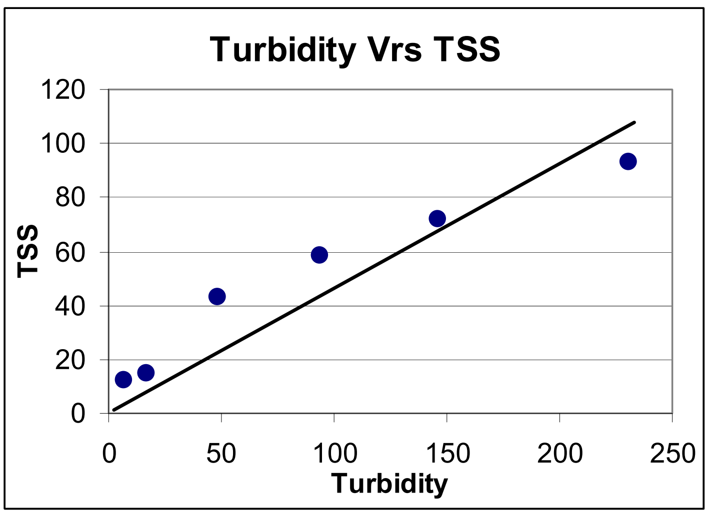
#	Site Name	Drainage Area Description
1	Cedar House	Urban + Slopes of DOT highway
1s	Keolu street gutter	Full flowing street gutter adjacent to cedar house drain
2	Go to drain outlet	Urban + DOT Highway drain +Mass grading construction Site
3	Go to drain inlet	Mass grading construction site & Olomana at DOT drain entry
4	Keopa I-2	CC box culvert draining Olomana “farm” lots thru DOT drain
5	Kaelepulu Inlet	Main concrete storm channel adjacent to Keolu School
6	Keolu Street	Urban drain along junction of Keolu and Keolu
7	76 drain	Large urban drain for upper Keolu Hills urban areas
8	Church /Golf drain	Drains golf course and urban Keolu Hills
8s	Church Constr	Drainage from church during construction
9	Main Keolu Hills	Combined flow from 7&8 at bridge just above entry to canal
10	Keolu Flats	Urban drainage from low elevation Keolu urban
11	Kaelepulu Exit	Kaelepulu Stream outflow from pond at Keolu bridge
12	Kaelepulu at Buzzes	Kaelepulu Stream at Lanikai bridge flowing to ocean
13	Kelly’s drain	Urban drain to northern portion of pond
14	Kaha	Urban 12” drain at most distal end of Kawainui canal
15	Kaelepulu School	CC box culvert draining urban, pasture, & High School
16	437 Keolu	Wetland peripheral canal at edge of pond fronting 437 Keolu Dr.
17	S pond center	Center of southern pond
18	Kukilakila	Water off of seawall fronting condo’s ~100 yd E. of boat ramp
19	Main pond center	Center of main body of pond
20	Mikes dock	Water off of dock eastern portion of pond
21	Kawainui stream	Outflow of Kawainui stream above confluence with Kaelepulu

State water quality parameters for Kaelepulu Pond, the lower course of Kaelepulu Stream to its mouth, and Kawainui Stream are defined for estuarine waters in the table below: The value of water quality parameters naturally varies over a range. The range for different water classifications has been defined from field data to vary along the classical bell-shaped curve of a log-normal distribution. Our State water quality standards take this natural variation into account by providing three levels of concentrations along this bell-shaped curve not to be exceeded more than about half the time (geometric mean – center of the bell-shaped curve), no more than 10% of the time, and no more than 2% of the time. Two-percent of one year is about 7 days, so one would not expect Turbidity to exceed 5.00 ntu more than 7 days in the year, with the year-long average value much closer to 1.5 ntu.

Parameter	Geometric mean not to exceed the given value	Not to exceed the given value more than ten per cent of the time	Not to Exceed the given value more than two per cent of the time
Total Nitrogen (ug N/L)	200.00	350.00	500.00
Ammonia Nitrogen (ug NH_4-N/L)	6.00	10.00	20.00
Nitrate + Nitrite Nitrogen (ug $[NO_3+NO_2]$-N/L)	8.00	25.00	35.00
Total Phosphorus (ug P/L)	25.00	50.00	75.00
Chlorophyll a (ug/L)	2.00	5.00	10.00
Turbidity (N.T.U.)	1.5	3.00	5.00

Unlike streams, estuaries have only a single set of water quality standards throughout the year. There is no differentiation between the wet winter season and the dry summer season. Even though the lower reaches of both Kaelepulu and Kawainui are noted on maps, and in common language, as streams there are in reality estuaries. They do not flow down gradient to the ocean, they flow both directions (with tides), and they are typically very brackish in nature.

This study focused on total suspended solids (TSS) for which a State water quality standard has not been established. TSS and turbidity are directly related, but this relationship is different for different types of sediments. The graph at the right shows the relationship between these variables for Kaelepulu as quantified with data from this study.



METHODS

The five storms sampled were "selected" based upon the perceived size of the storm and the availability of the sampler. All samples were taken manually, typically using an extendable 11-foot pole with a wide-mouth 1-liter plastic sample jar attached perpendicular to one end. This jar was cleaned between events, but was only rinsed with sample water once prior to each sample. Samples were poured into laboratory clean distilled water rinsed 1-liter bottles and held on ice or refrigerated until analyzed. Sample bottles were sequentially numbered and labeled with short descriptive names. Sample locations, times, and estimates of flow were noted in a log book.

Flow estimates were either based upon an experienced estimate, or upon crude field measurements of flow speed and depth. All of the major inlet dimensions were pre-measured. 6-inch incremental markings on the sample pole assisted in measuring flow depth. A stopwatch was used to measure flow speed between reference points of known distance.

Photos of the sample locations were taken during a subsequent storm (March 26, 2006) and are shown in the attached figures associated with sample site descriptions. Sample locations were chosen based upon prior knowledge of the watershed and represent the largest inflow points to the pond. Figure 2 shows all of the sites sampled, although not all sites were sampled during any one storm. The order and time of each sample is attached in the appendix as transcribed field notes. A sample run of eight to 12 points around the pond typically took a little more than one hour. The first and fifth storms were of long duration and it is not likely that the sample order had a great impact on water quality. However, storms 2 and 4 were of shorter duration resulting in lower flows from drains sampled at the end of the hour-long sampling period. Samples from Storm 3 were taken in the body of the lake about 16 hours after the storm to yield information on distribution of sediments within the pond and emptying to the ocean.

For the first four storms, samples were taken to AECOs laboratory for analyses of total suspended solids (TSS). Salinity and turbidity were also measured on selected samples using a refractometer. Following sampling of the fifth storm permission was given by the State Department of Health Environmental Quality Branch to have the samples analyzed at the State DOH Laboratory. Both laboratories were requested to screen the samples to exclude large particulate matter or sand from the TSS analyses. This is particularly important in the first flush samples and in samples taken from the stream mouth to the ocean where turbulence can suspend sand particles into the sample. In addition to analyses of TSS, the set of samples analyzed by the State Laboratory were also analyzed for turbidity, total dissolved nitrogen, dissolved nitrate plus nitrite, total dissolved phosphorous, and silicate. All samples were filtered prior to nutrient analyses, so the results obtained are for dissolved nutrients only, and do not include any nutrients bound to the suspended sediments.

Rainfall measurements were obtained both from a simple fence rain gauge (25 cm^2 area), and from the public rain gauge at the Olomana Fire station approximately ½ mile inland from the pond.

RESULTS AND DISCUSSION

Results of all TSS analyses and estimate flows at the time of collection are shown in the table on the following page as Table II. This information may be used to answer some basic questions concerning the source and fate of sediment loads to the pond.

Do the various inlets to the pond bring markedly different quality of water to the pond? Yes, absolutely.

#'s-> 16, 14, 1, 1s, 2, 4, 5, 6, 15, 11, 8, 7, 8c, 9, 10, 21, 12, 13 , Tap

This back-lit photograph (Credit H. deVires) of samples taken during the March 19, 2006 storm dramatically shows the difference in water quality from the various drainages entering and (third from far right, #12) leaving the system to the ocean. The bottle at the far right is tap water. Locations for each of the samples can be discerned from Figure 1.

How much sediment enters the pond during a storm, and where does it come from? Table III shows the results of multiplying the sediment concentrations and water flow rates from Table II to arrive at a first estimate of the total amount of sediment entering Kaelepulu Pond from each of the sources. During the four storms where both flow rates and sediment concentration (TSS) were measured a total of almost 78 tons of sediment entered the pond only through the drainages we measured at a rate of just over 6 tons per hour of storm. Table I below summarizes these results by combining the drains into similar categories. Site #'s refer to the sample locations displayed on the map in Figure 1.

Table I Summary of Main Contributors of Sediment to Kaelepulu Pond

	Site #;'s	Average TSS mg/L	Average Flow CFS	Average Tons/hr
Each Street Drain	6, 13, 14	47	2	0.01
Kaelepulu School Drain	15	171	77	1.34
Mt Olomano, DOT Drains	1,2,3,4	1200	14	1.67
Keolu Canals	7,8,9,10	45	20	0.09
Kaelepulu Stream Storm Basin	5	250	133	3.39
Outflow to Ocean at Buzze's	12	26	211	0.55

As the table shows, the main Kaelepulu Storm drain entering the pond from the Keolu Hills storm basin constructed by Lone-Star Construction in the 1970's is by far the largest contributor of sediment to the pond. However, observations of this basin during storms indicate that the drainages entering this basin from the Mt. Olomana side appear to have a much higher sediment concentration as compared to the drains coming in from the more urban Keolu Hills area. This is consistent with what we see from the other storm drains that come from the Norfolk, Mt. Olomana underneath the Kalanianaole Highway. The steep slopes of Mt. Olomana combine with active grading and construction on some home sites in the area to yield very high sediment loads to the pond. The third highest source of sediment to the pond appears to be the canal adjacent to the Kaelepulu School that drains steep undeveloped lands around Kailua High School. The canals draining Keolu Hills do not appear to presently be major sources of sediment to the pond. The build up of sediments fronting the principle inlet from Keolu Hills (red-hatched area downstream from Stie 9) has been estimated at 8,500 cubic yards, assuming an original depth of only 6 feet. The present rate of sedimentation could not account for this quantity of buildup during the 50 years since the lake was initially dredged. It is likely that these sediments entered the lake when the hundreds of up-slope homes were constructed in the 1960's and 70's. The ELRA has documented the removal of large quantities of trash of urban and light industrial (tire, bikes, lawn mowers, cans, bottles, yard clippings) origin from this shallow area.

What happens to the sediment once it enters the pond?

Sediment is suspended in water by the turbulence in running water; the greater the turbulence, the heavier the particles that can be suspended. When the fast flowing storm water enters the pond it slows down and the heavier particles fall out of solution and deposit on the floor of the pond close to their point of entry….for the most part. Very fine clay-like particles can remain suspended for long periods of time and will have greater tendency to flow out to the ocean.

This is demonstrated by the results from samples taken four days after the beginning of storm 2, (24 hours after the last rainfall). At this time we conducted a transect through the lake beginning at the wetlands and ending at the ocean. Sediment concentration near the wetlands (where Kaelepulu stream and the Cedar House drain input lots of sediment) was still over 100 mg/L, whereas in the center of the pond and near the outlet, the concentration had dropped to about 30 mg/L. By the time the water had reached the outfall at Kailua beach it only contained about 20 mg/L of sediments. Photographs of the samples show the dramatic differences in water quality across the system, even 24 hours after the latest rainfall.

Figure 3. Surface water samples taken (L to R) in the pond wetland, middle of pond, far shore (Kukilakila), near the pond exit, and just before the stream enters the ocean.

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Results of Total Suspended Sediment from Water Samples in the Kaelepulu Watershed

		Storm 1		Storm 2			Storm 3		Storm 4		Storm 5				
Rainfall Total to end of sample --->		2.8"		2.5"			2.45"		1.85"		1.85"		Average	Average	Average
Site	Sample	Jan 2 04	Flow	Feb 1 05	Flow	Feb 5 05	Dec 1 05	Flow	Feb 22 06	Flow	Mar 19 06	Flow	TSS	CFS	Tons/hr
Name	Site	TSS mg/l	CFS	TSS mg/l	CFS		TSS mg/l	CFS	TSS mg/l	CFS	TSS mg/l	CFS			
Cedar House Drain	1	223	27	365	48				55	11.2	347	32	248	30	0.75
Go To Drain	2			3180	3				428	3	318	3	1309	3	0.40
DOT Go To Drain	3	6990	8										6990	8	5.72
Keopa C2 Channel	4	150	10	1556	15				159	3	632	14	624	10	0.67
Kaelepulu Inlet Channel	5	122	147	272	50		93		196	100	566	233	250	133	3.39
Urban Storm Drain 1	6	72	3						14	1	0.5	2	29	2	0.01
76 Keolu Hills Drain	7	51	52	100	48				22	1	10	21	46	30	0.14
St John Golf Course Drain	8	48.7	5	57	3				10	0.5	35	3	38	3	0.01
Large Channel Inlet (7+8)	9			120	30				28	15	22	15	57	20	0.12
Keolu Flats Drain	10								38	15	46	54	42	34	0.15
Kaelepulu Outlet Channel	11					37				200	40	300	38	250	0.98
Kaelepulu Muliwai at Buzzes	12	37	100	22	100	20					24	432	26	211	0.55
Street Drain @ Kelley's	13										10		10		
Kaha street drain to Kawainui Str	14										138		138		
Kaelepulu School Drain	15	19.6	8	440	17				54		170	205	171	77	1.34
Pond at 437 Keolu	16		na	71	na	109	72	na		na	424	na	169		
Mid pond surface	17a		na		na		58.5	na		na		na	59		
Mid pond 1.5 ft deep	17b		na		na		43.3	na		na		na	43		
Mid pond 3 ft deep	17c		na		na		15	na		na		na	15		
Mid pond 6 ft deep	17d		na		na		12	na		na		na	12		
Kukilakila Shoreline	18					7.8							8		
Pond Center	19					29.7							30		
Shore at Mike's House	20					15							15		
Kawainui at Waanao	21											72	18	72	0.13

		Storm 1		Storm 2		Storm 4		Storm 5	
		2.8		2.5"			1.85		1.85
		Sediment Inflow kg/hr	Total Sediment Storm Hrs 6	Sediment Inflow kg/hr	Total Sediment Storm Hrs 2.5	Sediment Inflow kg/hr	Total Sediment Storm Hrs 2.5	Sediment Inflow kg/hr	Total Sediment Storm Hrs 3
1	Cedar House Drain	614	3683	1783	4457	0	0	396	1189
2	Go To Drain	0	0	972	2431	131	327	97	292
3	DOT Go To Drain	5700	34202	0	0	0	0	0	0
4	Keopa C2 Channel	153	917	2379	5948	49	122	895	2684
5	Kaelepulu Inlet Channel	1829	10973	1386	3466	1998	4995	13452	40355
6	Urban Storm Drain 1	22	132	0	0	1	4	0	0
7	76 Keolu Hills Drain	272	1634	489	1223	2	6	21	63
8	St John Golf Course Drain	23	139	17	42	1	1	11	32
9	Large Channel Inlet (7+8)	0	0	367	917	43	107	34	101
10	Keolu Flats Drain	0	0	0	0	58	145	252	755
11	Kaelepulu Outlet Channel	0	0	0	0	0	0	1223	3670
12	Kaelepulu Muliwai at Buzzes	377	2263	224	561	0	0	1056	3168
13	Street Drain #2	0	0	0	0	0	0	0	0
14	Street Drain #3	0	0	0	0	0	0	0	0
15	Kaelepulu School Drain	16	96	748	1869	0	0	3554	10661
Tons entering pond per hour-->		**2.2**		**3.0**		**2.1**		**17.3**	
Total Tons per Storm Entering Pond -->			**13.0**		**7.5**		**5.3**		**52.0**
Tons leaving pond per hour -->		**0.4**		**0.2**		**na**		**1.1**	
Total Tons per Storm Leaving Pond -->			**2.3**		**0.6**		**na**		**3.2**
Average tons sediment to pond for each hour of storm --				**6.1**	**tons / Hr**				
Total Sediment delivered to pond in 4 storms -->				**77.7**	**tons**				

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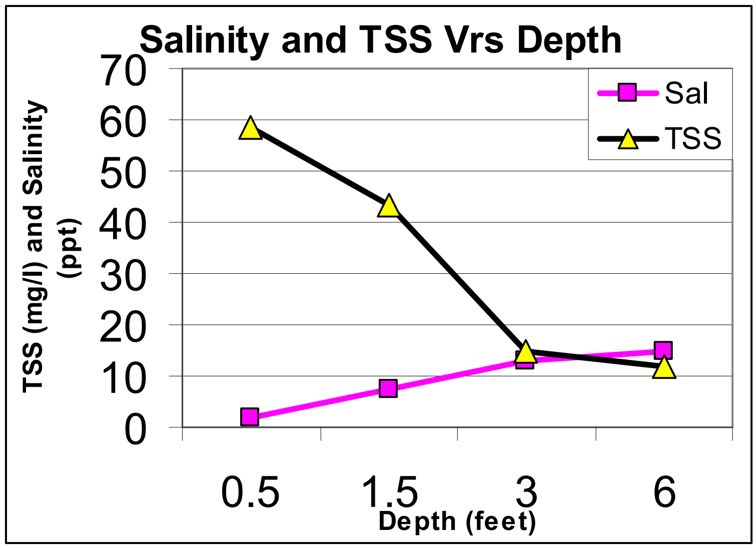
Following the third storm we again measured sediment concentrations in the area around the wetland to be between 72 and 93 mg/L, whereas in the middle of the pond the concentration had dropped to about 58 mg/L. However, at the same location where the 58mg/L was measured at the surface, we found only 43 mg/L 1.5 feet below the surface, 15 mg/L 3 feet below the surface, and only 12 mg/L at a depth of 6 feet (Figure 3). These measurements corresponded to increases in salinity (2, 7.5, 13, and 15 ppt) showing that the stormwater containing the very fine sediments was floating over a denser (and clearer) brackish water layer. Clearly the storm water in the pond is not well mixed.

Figure 4. Change in salinity and TSS with depth near the center of the pond 24 hours after rain.



How much of the sediment remains in the pond?
A first estimate of the percent of sediment that remains in the pond can be made by comparing the concentration and volume of sediments flowing out to the ocean at Kailua Beach by Buzze's, compared to what is coming in from all other sources. This is somewhat complicated by the tidal flow in <u>and</u> out of the canal at the beach, but it should make an adequate first estimate. Table II shows that the average TSS concentration flowing out to sea is only about 26mg/L whereas the storm water flowing in (even excluding all readings over 1000 mg/L) is about 113 mg/L. This suggests that about 77% of the sediment entering the pond from storm drains, remains in the pond. Table III looks at both flow and concentration. This table shows that during 4 storms a total of about 78 tons entered the pond, but only about 6 tons flowed out to sea, suggesting that the pond captured over 90% of the sediment.

How quickly do sediments fall out of suspension once they enter the pond?
To answer this question we needed to conduct another simple experiment with a sub-sample of the water collected at site-16 on March 19. The DOH lab measured the TSS of this sample at 424 mg/L. A paired 500 ml sample was taken to a laboratory, agitated, and poured into a separation funnel. This is a very steep sided 'V'-shaped flask about 10-inches tall with a valve at the bottom. This valve was opened at pre-set intervals allowing 5 mls of water and all of the settled sediments to flow into a small vial. This gives a first estimate of the quantity of the

sediment that falls (10") over time. The time intervals were distributed over half-log scale. The results were surprisingly linear in this logarithmic scale and demonstrate that half the sediment has fallen out of solution within 30 minutes, and 73% within 5 hours. Five hours is about the minimum retention time of the pond during heavy flooding events.

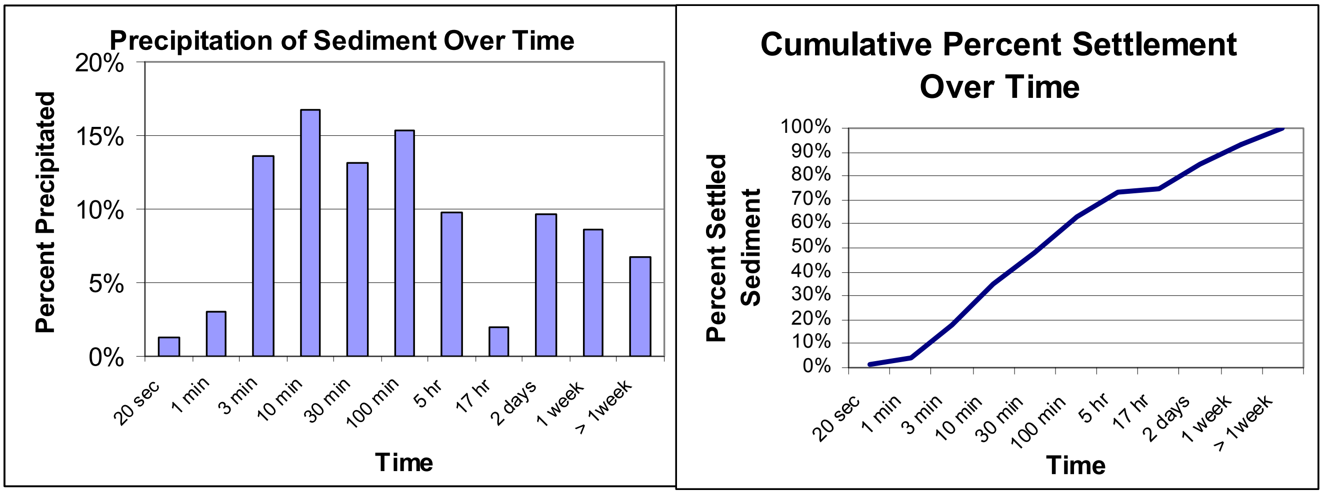


Figure 5. Shows the percent of sediment in a storm water sample that precipitated out of solution over time. Initial sample held approximately 424 mg/L sediment.

CONCLUSIONS

- A total of 78 tons of sediment entered the pond during 4 storms, only 6 tons of which left the pond to the ocean at Kailua Beach.
- In a typical intense rainstorm with rainfall from 1.5 to about 3 inches of rain will cause from 5 to about 13 tons of sediment to be deposited in the lake.
- The amount of sediment produced depends upon the intensity of the rainfall and how wet the watershed was from prior precipitation before the rainfall begins.
- Very intense rainfall events, or an event such as occurred in March 2006 can deposit upwards of 50 tons of sediment within the pond.
- An estimated 77-percent to over 90-percent of the sediment entering the pond, remains in the pond and does not flow to the ocean
- Most heavier sediments settle within minutes close to the drain where they enter the pond
- Stratification tends to float the lighter sediments over the denser brackish water
- Primary present day sources of sediment to the pond are from the urban development on slopes of Mt Olomana under Kalanianaole Highway, open lands above Kaelepulu School and the flood control basin at the top of Kaelepulu Stream.
- While inflow to the pond and canal fronting the Keolu Hills drain and the Keolu flats drain have caused significant sedimentation and shallowing of these areas in the past, the present day sediment loads from these urban drains are not nearly as high as from other drainages to the pond.

Sample Site Descriptions

1. **Cedar House Drain** is named for the house with the natural cedar exterior under which the drain enters the Kaelepulu Wetland. At the outlet the drain enters the pond through a 6-foot diameter pipe. A grass-covered delta of approximately 150 square feet has formed in what was once a 4-foot deep 12-foot wide canal on the circumference of the wetland. Samples are taken on the uphill (west) side of Keolu Drive where the flow is confined in a concrete box channel measuring 92-inches across and 85-inches deep with a slope of about 1:10. Weep holes on the lower sides of the channel are spaced 10-feet apart and 25-inches above the base of the culvert. The box drain remains open to its twin termini on the eastern slopes of the State Kalanianaole Highway right-of-way. It receives input from street drainpipes in at least 7 locations from the residential neighborhood. The source of the mud in this flow stream has not been identified.

2. **Goto Drain** originates on the west side of the State Kalanianaole Highway as a 60-inch pipe. The entrance to the pipe is sample **site 3**, and is protected by a galvanized pipes spaced several feet apart and joined at the top with angle-iron. An active fill and grading operation on lands above this inlet is an obvious source of sediments to this drainage. During the course of this investigation, the property owner has worked with the grading contractor to grade the surfaces, add reinforced swales, and screen the inlet structure to the 60-inch storm drain. The drain receives branches of urban runoff from at least 6 locations as it courses down slope along Akumu street towards the main Kaelepulu Storm drain channel. However, about 150 feet before it reaches the channel, the pipe makes an abrupt 90-degree left turn and emerges at the back corner of a private lot. This is sample **site 2**. When the lot was graded in the 1980's a swale along the back of the lot was designated as a drainage right-of-way. According to the as-built drawings, this right of way was approximately 6 feet deep, 30 feet wide at the top, along the entire 165 foot width of the property. As of April 2006, the (30*6*165*1/2) 15,000 cubic foot volume swale was almost totally filled with silt and the invert of the pipe was at least 8 feet below the surface. On April 11, a 4-inch rainstorm forced a pile of rocks, gravel, and sand from this pipe onto the adjacent lot with a conservatively estimated volume of 50 cubic yards.

3. **Keopa I-C2 Channel** drains from above Kalanianaole Highway beginning in a concrete debris basin just below the Old Kalanianaole Highway. Below the main highway as it passes below Akakakoa Street, the concrete box culvert is 8 feet deep and 8 feet wide with a sloped bottom. During a typical intense rainfall of about 1-inch in an hour, the water in this culvert is dark red-brown. In the storm basin into which this drain enters, the water on the east side of the basin is typically gray-green in color, whereas the water on the west side, by the KeopaI-C2 is usually dark red brown.

5 **Kaelepulu Inlet Flood Control Channel** is a concrete box channel measuring 22-feet across and 6 feet deep. Weep holes along the sides are 24 inches above the bottom and spaced 10 feet apart. The channel receives flow from several urban storm drains and direct sheet flow from the Keolu School yard, but it's primary source of flow (and silt) is through the flood control dam structure constructed in the 1970's by Lone-Star Construction at the top of the culvert approximately ¼ mile above Keolu Drive.

6. **Keolu Street Drain**. Although the drainage map shows this culvert extending beneath the State Kalanianaole Highway, we have not been able to locate this inlet on the west slope of the highway. Input to this drainage appears to be completely from urban sources. The 48" culvert empties out to the main Kaelepulu drainage canal just north and west of the Keolu Drive Bridge.

7. **The "76" Canal** drains the upper Keolu hills urban area and is the largest totally urban drainage in the watershed. The drain crosses beneath Keolu drive at the northern edge of the Enchanted Lake Shopping center through twin box culverts measuring 13 feet wide and 10 feet wide with an invert about 60 inches below the sidewalk elevation. Typically the right (north) culvert is free flowing and the left culvert is slower due presumably to partial blockage. During the March 2006 storm according to gas station personnel, flood water overtopped this structure and flooded the 76-Station to a depth of about 1 foot before flowing through the perimeter chain link fence and back to the stream channel.

8. **The Church-Golf Course Drain** passes below the 76 foot wide Keolu Drive in twin 34-inch culverts plus a 24-inch drain directly from the roadway. Above the roadway the drainage splits with the larger half draining the golf course and the balance from Kamahele Street urban areas. A drain from the Church lot also enters the typically dry swale just below the roadway and was the location of a single sample (Site 8s, sample12B on 3/19/06).

9. **Main Keolu Hills Stream.** This stream channel below Akumu Street combines flow from both 7 and 8 above and empties into the City-owned portion of Kaelepulu canal just north of the ELRA boundary. The bridge confines flow to four box culverts each measuring 8 feet wide. At a typical lake height (+1.3'msl) the water is about 3 feet deep here to the soft mud bottom. During this 4-year period of measurement the silt load in this drain has not been nearly as high as in other drains. However, the delta formed in the main Kaelepulu drain is significant and does contain large quantities of trash of obvious urban origin. See attached bathymetry chart figure.

10. **Keolu Flats Drain** passes beneath Akumu Street in twin 9-foot wide culverts. At the typical +1/3ft water elevation, the water extends up stream several hundred yards well past where the channel bifurcates. The right channel (facing downstream, on the left in the photo) serves the Keolu Shoping center as well as surrounding house lots. This entire drainage serves urban areas, about half within the Keolu Drive loop boundary with low slopes, and about half on the hillside above Keolu Drive.

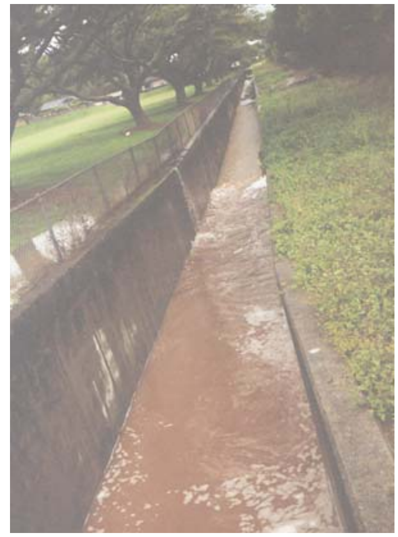
11. **Kaelepulu Exit** seen here looking up stream represents the outflow from Kaelepulu Pond as it passes beneath Keolu Drive. The bridge is supported by a single central wall that divides the stream into two equal halves. At typical water elevation of +1.3-ft msl each channel is about 40 feet wide and 5.5 feet deep. At this elevation the water level is 11.8 feet below the top cement rail on the upstream central portion of the bridge. Speed measurements are made by timing the period for flotsam to pass beneath the 75-foot wide bridge span.

12. **Kaelepulu Stream at Buzze's** marks the entry point of the stream as it crosses Kailua Beach to the ocean. The muliwai (sand beach dam) is typically breached at monthly intervals (2nd or 3rd Wed of the month at 1pm) by the C&C maintenance division using a variety of heavy equipment. If the water in the pond is significantly higher than the ocean and if the opening is made on a falling tide, then the flow is typically sufficient to carve out a channel wide and deep enough to remain open for one to several days. If the elevation difference between the pond and ocean is not great, or if the opening is made on a rising tide, or if there is significant wave action, then the opening is often closed within hours. Sampling at this site is typically conducted downstream of the bridge where there is sufficient turbulence to produce a well-mixed sample, but above the channel through the sand bar where turbulence is actively eroding sand from the bottom.

13. **Kelly's Drain** This is a small 36" urban storm drain entering the pond at its northern most extension. First flush often brings a variety of urban waste and yard clippings into the lake at this point. The only time this drain was sampled was towards the end of a storm period when the flow appeared quite clean.

14. **Kaha Drain** At the western-most dead end of Kawainui Stream, a small 12-inch drain enters from the side of the canal, apparently from the adjacent urban areas. This drain was sampled only on one occasion and at the initiation of runoff.

15. **Kaelepulu School** on the west side of the pond is bordered by a 8-foot wide 8.3 foot deep box culvert. Seepage holes in the side of the drain are 10 feet apart and 18-inches above the base of the concrete channel. The typical pond elevation causes standing water to back up into this canal 50 t0 100 feet above Keolu Drive. The channel receives sheet flow from the grasses playground area of the school as well as street drainage from the surrounding community, however the main portion of the sediment laden flow appears to be derived from the hill-side areas above the urban areas and below the Kailua High School.



16. **437 Keolu** is the residence of the primary sampler. The sample site fronts a rock retention wall and a 12-foot wide 2 foot deep channel or "moat" surrounding the wetland in the upper pond area. This site received flow primarily from the Cedar-House Drain which empties into the moat about 250 feet to the south and flows past this point to the open pond area.

17. **Southern Pond Center.** Presently the drainages with the heaviest silt load empty into the southern portion of the lake. While the periphery of this section of the lake has shallowed significantly in the past decades, the center is still relatively deep, 6 to 8 feet.

18. **Kukilakila Condos** This site represents conditions along the Kukilakila seawall north of the boat ramp area, but south of the drainage input from the Kaelepulu School Channel. Only one small storm drain enters the lake adjacent to the boat ramp near this location.

19. **Main Pond Center** represents the area of the largest surface area and greatest average depth (~9ft)

20. **Mike's Dock** is on the broad peninsula of Wanaao just before the lake funnels into the Kaelepulu Stream exit.

21. **Kawainui Stream** merges with the Kaelepulu Stream just below the bridge on Wanaao Road. At the 7 5 foot wide bridge sampling point the stream is approximately 85 feet across and 3.5 feet average depth. During periods of storm flow, the gray/green waters of Kawainui can be seen merging with the red-brown waters of Kaelepulu just downstream from the bridge.