TOTAL MAXIMUM DAILY LOADS

KAWA STREAM
KANEOHE, HI

Final Technical Report
March 2002

Total Maximum Daily Loads of Total Suspended Solids, Nitrogen and Phosphorus for Kawa Stream Kaneohe, Hawaii

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List of Abbreviations

BMP	Best Management Practice
BOD	Biochemical Oxygen Demand
CWA	Clean Water Act
DO	Dissolved Oxygen
DOH	State of Hawaii Department of Health
EPO	DOH Environmental Planning Office
EPA	United States Environmental Protection Agency
LA	Load Allocation
MOS	Margin of Safety
NH_3	Ammonia
$NO_{2,3}$	Nitrate + Nitrite (NO_3 + NO_2)
NPS	Non-Point Source
TN	Total Nitrogen (TON + NH_3 +NO_2 + NO_3)
TP	Total Phosphorous (TOP + PO_4)
TON	Total Organic Nitrogen
TOP	Organic Phosphorus
TSS	Total Suspended Solids
PO_4	Ortho-Phosphate
SOD	Sediment Oxygen Demand
TMDL	Total Maximum Daily Load
USGS	United States Geological Survey
WLA	Waste Load Allocation
WQLS	Water Quality Limited Segment
WQS	State of Hawaii Water Quality Standards

ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

This document proposes to establish "Order of Magnitude" Total Maximum Daily Loads (TMDLs) for total suspended solids (TSS), total nitrogen, and total phosphorus in Kawa Stream. Kawa Stream drains directly into the southern portion of Kaneohe Bay, which is bounded by the only barrier reef in the United States. The stream is included on the State's Clean Water Act Section 303(d) list of impaired waters that do not meet State Water Quality Standards and is considered to be impaired by sediments, turbidity, and the nutrients nitrogen and phosphorus. These pollutants may augment unwanted algae growth in the stream and impact coral reef resources in the receiving waters of Kaneohe Bay. The water quality goal of these TMDLs is to control sources of TSS and nutrients to improve the water quality of the system, so that the designated uses for Kawa Stream will be maintained.

We conducted water quality and flow measurements in the stream to determine existing levels of water pollution. Measurements were made during periods of dry and rainy weather. Rainfall measurements and streamflow data were used to estimate runoff from multiple locations within the watershed. The watershed was divided into 8 sub-watershed basins and the land uses within each basin were determined from a Geographic Information System (GIS) database with visual groundtruthing.

Two methods are used to determine pollutant loads. One method combines a hydraulic model with pollutant concentration profiles to calculate load based upon total rainfall during an event. The other method uses a simpler matrix multiplication and mass balance approach to estimate pollutant loads. Both methods yield similar results.

Load allocations (LA) for TSS, total nitrogen, and total phosphorus entering Kawa Stream are established for both Wet and Dry (Winter and Summer) base flows and for annual storm flow conditions (Tables 5.4, 5.5 and 5.6). These load allocations represent pollution reduction guidelines associated with different land uses in the watershed, taking into account several factors including water quality standards, seasonal variations, natural loading, an environmentally conservative margin of safety (MOS), and future growth.

During base flow conditions existing loads of total phosphorus (TP) and total suspended solids (TSS) produce water quality that is presently within State Standards, but turbidity levels exceed State Standards. Turbidity is also a concern under storm conditions when TP and TSS also exceed State Standards in some stream branches. Because both turbidity and TP are correlated with TSS during storm flows, we propose implementing a TMDL for TSS during storm runoff conditions as a potential control mechanism for both turbidity and TP. Existing loads of TN produce water quality that does not meet State Standards during base flows and storm conditions, and TMDLs are established for this nutrient under all flow conditions. The major source of the nitrogen appears to be groundwater.

The desired base flow, non-point source TMDLs assume no point sources and are computed by multiplying observed rate of base streamflow by the State Standard concentrations. This gives the maximum amount of pollutants that should be allowed in the stream if the stream is expected to support its designated uses (Table 4.12). The difference between the pollutant load the stream is presently carrying and the desired base flow, non-point source TMDL becomes the load reduction goal for a particular pollutant (Table 4.13).

The dry season baseflow TMDL target for nitrogen is 55 kg per 6 months, or 0.3 kg/day. Reaching this goal will require a reduction in nitrogen input of 1.25 kg/day. The wet season base flow TMDL target for nitrogen is 113 kg per 6 months or 0.62 kg/day. Reaching this goal will require a decrease in nitrogen input of about 1.7 kg per day. No base flow TMDLs are required for TP or TSS.

Storm runoff TMDLs are required for TN, TP, and TSS. The storm runoff goal for nitrogen of 0.67 kg/day will require a total decrease in nitrogen input of about 1.17 kg/day. Achieving the phosphorus daily storm load of 0.24 kg/day will require a phosphorous load reduction of 0.22 kg/day. Meeting the TSS daily storm load requirement of 48 kg/day will require a sediment load reduction of 17 kg/day.

We also conducted a biological assessment of Kawa Stream that produced baseline information about the stream’s habitat characteristics and biotic integrity. The assessment provides an additional framework for tracking changes in stream conditions over time and for comparing conditions in Kawa Stream with conditions in high quality reference streams. Although the resulting Habitat and Biotic Integrity TMDLs are not a subject for EPA approval, they can help guide TMDL implementation towards areas where pollutant load reduction measures may best contribute to restoring stream habitat and biota.

TMDL implementation suggestions were solicited from community members and are summarized in the final section of this document. The DOH Environmental Planning Office is continuing to stimulate public participation in order to produce a Kawa Stream TMDL Implementation Plan developed with input from a range of concerned residents and responsible government agencies. The Plan is intended to guide the community and agencies in their work to improve Kawa stream and to assist them in identifying and obtaining funds to support projects that reduce stream pollution and improve stream water quality.

1.0 INTRODUCTION

1.1 Problem Definition: Conducting a TMDL Study of Kawa Stream

Section 303(d)(1)(C) of the Federal Clean Water Act directs each State to develop a list of water bodies that do not meet State water quality standards. These 303(d)-listed water bodies are termed “water quality limited segments" (WQLS) for one or more specific substances or pollutants. The State is further directed to determine, for each WQLS, the capacity of the water body to receive the listed substance and still meet water quality standards. This quantity is termed the total maximum daily load (TMDL) and must take into account seasonal variations and a protective margin of safety (MOS) to account for uncertainty. The TMDL study must also determine the origin of the listed substance within the watershed and discuss preliminary mechanisms for controlling pollutant levels that will eventually improve stream water quality to meet State Standards.

Kawa Stream was identified on the State’s 1999 list of WQLS as impaired by total suspended solids (TSS), turbidity, and nutrients - compounds of nitrogen and phosphorus. These specific substances were investigated as potential pollutants of Kawa Stream that limit beneficial uses of these and adjacent waters.

The Kawa Stream watershed is a small, largely urban basin on the windward side of Oahu (Figure 1.1). Lessons learned in this TMDL study can be applied to larger, more complex watersheds during future TMDL studies. Kawa Stream was also selected for early study because of the concern that pollutants carried by the stream could impact its receiving waters in Kaneohe Bay. Kaneohe Bay supports coral reef growth and is designated as Class "AA" coastal waters, but also contains a WQLS where coastal waters do not meet the water quality standards for the class designation.

This report investigates the levels of TSS, turbidity, and nutrients under low flow (base flow) and storm flow conditions and incorporates this information into two mathematical models of the watershed. The first creates a detailed hydrological model of the watershed that is combined with pollutant concentrations at different stages of a rainfall event. The second, simpler model uses a mass balance approach with matrix multiplication. The models assist in predicting the source, transport, and fate of water and pollutants in the watershed. We propose the establishment of wet and dry season base flow TMDLs for total nitrogen (TN) in Kawa Stream. During the course of the study, measurements of TSS and total phosphorous (TP) were within limits established by the State during base flow conditions. However, turbidity was found to be out of compliance. It is difficult to establish a TMDL for turbidity because this measurement is not a mass and cannot be computed as a load without reference and transformation to a mass-based measurement such as TSS. However, turbidity is directly related to TSS and probably also to TP associated with runoff. We propose therefore to establish TMDLs for both TSS and TP at the level of existing State water quality standards to assist in the control of turbidity. Under storm flow conditions TP slightly exceeds State standards, and both turbidity and TN are significantly above desired levels. Because of the direct relationship between TSS and turbidity/TP under storm conditions, a TMDL should also be established for TSS during storm runoff conditions.

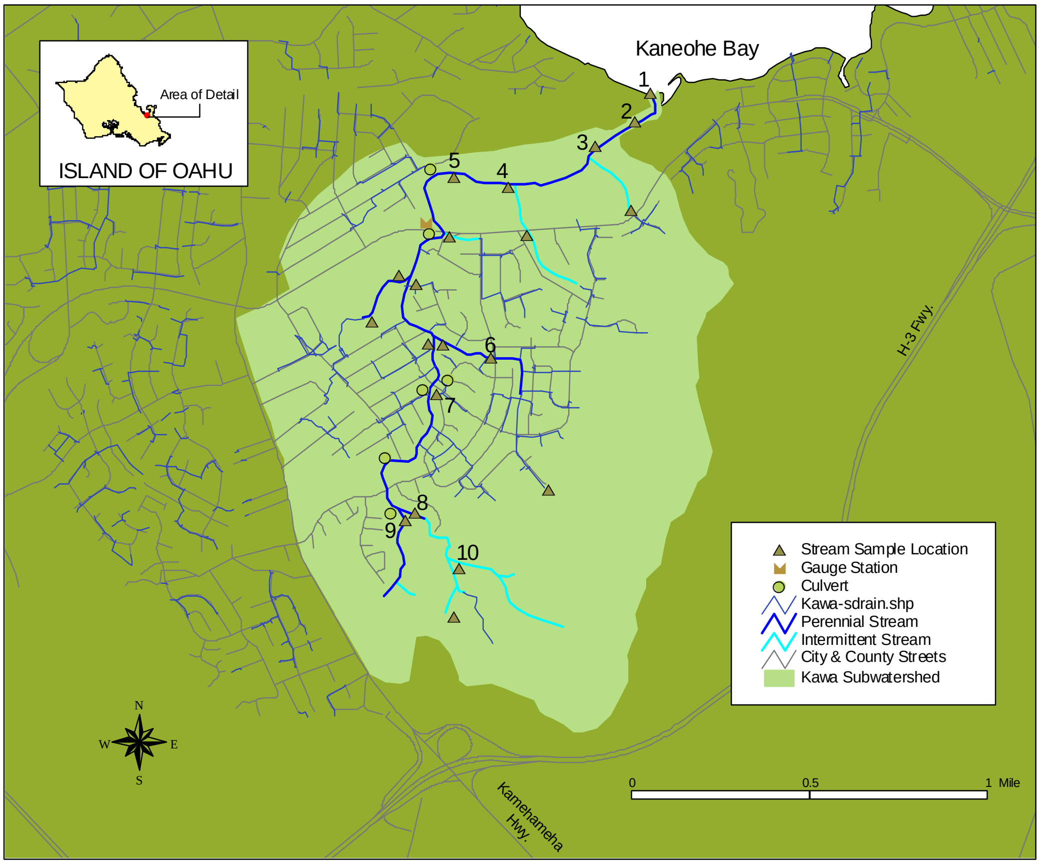


Figure 1.1: Location Map of the Kawa Stream Watershed

Once these "Order of Magnitude" TMDLs are approved by the United States Environmental Protection Agency (EPA) they will be incorporated into the State's water quality management program, and additional studies may be conducted to clarify sources of pollutants. A TMDL Implementation Plan will incorporate comments and suggestions from the community as well as any additional data collected to refine a mathematical model of the watershed. More detailed load allocations may be recommended in this Implementation Plan. In the future, the established TMDLs will support control measures needed to restore water quality in Kawa Stream and Kaneohe Bay.

1.2 Numeric Target Definition: Water Quality Standards in Hawaii

TMDLs are established to achieve and maintain water quality standards. A water quality standard is the combination of a designated use for a particular body of water, the water quality criteria designed to protect that use, and the anti-degradation policy. Kawa Stream is classified as a Class 2 Inland Water (Perennial Continuous Shallow Stream). The objectives of Class 2 waters as they apply to Kawa stream are to protect its use for recreational purposes, the support and propagation of fish and other aquatic life, and agricultural and industrial water supplies. Uses to be protected include all uses compatible with the protection and propagation of fish, shellfish, and wildlife, and with recreation in and on these waters. There are few agricultural uses and no industrial uses of Kawa Stream waters at present. Recreational use is limited to foraging (primarily by children) for small fish and crustaceans and swimming at a single deep pool.

Kawa Stream, like most perennial Hawaiian streams, is characterized by periods of relatively steady base flow and short periods of higher flow resulting from heavy rains in the watershed. Physical and chemical properties of the stream water can vary between these two types of flow, as well as between storms of different magnitudes and at different times during storm flow. The study approach requires making water quality measurements at specified locations, which permits linkage of substances carried by the flow with sources in the watershed. Historical and ongoing water quality monitoring data are used to indicate which parameters are out of compliance with their respective water quality standards. Ideally, monitoring should distribute samples across wet and dry seasons (for which different criteria may apply) and be unbiased with respect to hydrologic and polluting events occurring in the watershed.

The current specific criteria applicable to water quality standards in Hawaii streams were first adopted in 1979 and last revised in 2000 (Hawaii Administrative Rules Title 11, Department of Health Chapter 54, Water Quality Standards, §11-54-05.02). Four parameters (temperature, pH, dissolved oxygen, salinity) have numeric limits defined by specific upper or lower bounds. Nine other parameters, including turbidity, total nitrogen, total phosphorus, and total suspended solids in streams, are defined by three numeric criteria – a geometric mean and two exceedance values (10% and 2%) – for each of two seasons, wet and dry (see Table 1.1):

1.Geometric mean (GM).	The geometric mean of all time averaged samples should not exceed this value. The geometric mean is calculated as the *n*th root of the product of all samples, where *n* represents the total number of samples used.
2. 10% exceedance value.	No more than 10% of all time-averaged samples should exceed this value.
3. 2% exceedance value.	No more than 2% of all time-averaged samples should exceed this value.

Table 1.1 Hawaii State Water Quality Standards for Streams

Parameter	Geometric mean not to exceed the given value	Not to exceed the given value more than 10% of the time	Not to exceed the given value more than 2% of the time
Total Nitrogen (ug N/l)	250* 180**	520 380	800 600
Nitrate + Nitrite (ug N/l)	70 30	180 90	300 170
Total Phosphorus (ug P/l)	50 30	100 60	150 80
Total Suspended Solids (mg/l)	20 10	50 530	80 55
Turbidity (Nephelometric turbidity units)	5 2	15 5.5	25 10
* upper number = wet season ** lower number = dry season	Nov 1- Apr 30 May 1 - Oct 31		

The objective of the TMDLs established in this document is to assure that water quality standards will be attained in Kawa Stream when pollutant loads are reduced to the prescribed levels. TMDL-driven improvements in water quality will support aquatic life and recreational uses within Kawa Stream and control plankton blooms, eutrophication and sedimentation in the receiving waters of Kaneohe Bay. Specifically, the TMDL for nitrogen for Kawa Stream is intended to assure that a geometric mean level of 250 µg/l (wet season) and 180 µg/l (dry season) is not exceeded throughout the Kawa Stream system. The goal of the TSS TMDL is to reduce suspended sediment loads, primarily during storm induced flows, to within state standards as these waters enter the Kawa Stream estuary. The TMDL for TSS will limit total suspended solids to a mean of 10 mg/l during the dry season, and 20 mg/l during the wet season and storm flows.

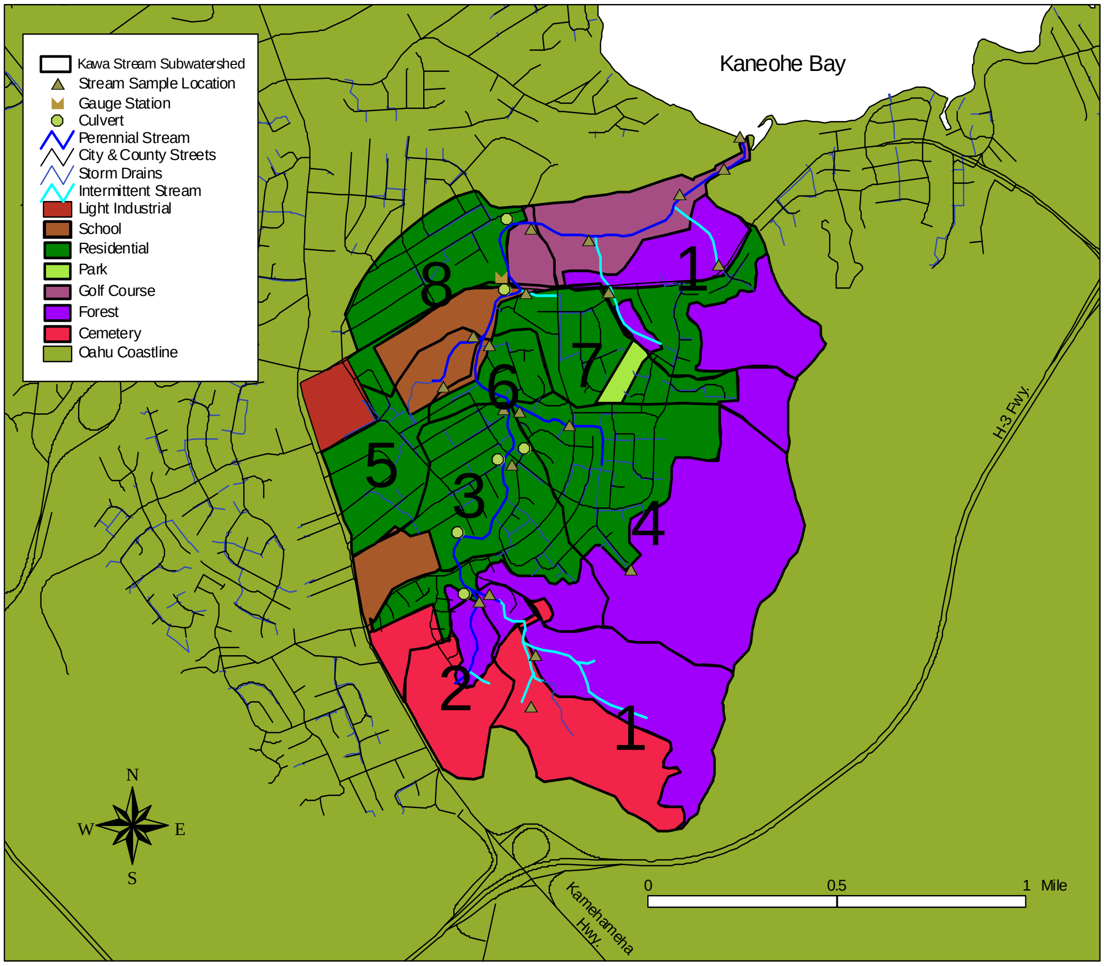


Figure 2.1: Geographic Distribution of Land Uses

Table 2.1 Relative Percentages of Land Uses in Basins

Percent Cover Per Sub-basin

Basin ID	Area (Acres)	Cemetery %	Golf %	School %	Residential %	Streets %	Park %	Forest %	Commercial %	Sum %
1	14.0	43.73	--	--	--	0.15	--	56.12	--	100.00
2	4.8	75.53	--	--	0.32	0.87	--	23.28	--	100.00
3	13.3	9.02	--	12.99	57.32	6.52	--	14.15	--	100.00
4	20.4	--	--	--	35.74	2.69	--	61.57	--	100.00
5	7.5	--	--	20.47	53.42	3.94	--	--	22.17	100.00
6	2.4	--	--	10.96	83.01	6.03	--	--	--	100.00
7	10.1	--	0.93	19.24	51.86	5.72	5.97	14.96	1.31	100.00
8	6.1	--	17.60	--	75.15	7.24	--	--	--	100.00
9	13.7	--	30.72	--	17.34	2.07	--	49.87	--	100.00
All	92.3	12.00	6.00	6.00	36.00	3.00	1.00	34.00	2.00	100.00

2.0 SETTING AND WATER QUALITY DESCRIPTION

2.1 General Physical Setting

Kawa Stream has a total length of only about 2 miles and is located in Kaneohe on the windward side of the island of Oahu. A low ridge of hills called Mahinui, which is separate from the main Koolau Mountain Range that forms the eastern ridge of Oahu, surrounds the drainage basin. Kawa Stream's headwaters originate from three perennial branches, each fed year-round by small groundwater seeps and springs at elevations from 100 to 150 feet. Above this elevation the stream is ephemeral, flowing only during periods of rain.

The Kawa Stream watershed has an area of approximately 1,000 acres (1.5 sq. miles). Land uses in the watershed consist of forest and preservation (34%), schools (6%), golf (6%), cemetery lawn (12%), urban residential (36%), commercial shopping complex (2%), park (1%), and streets (4%), based on 1999 Hawaii Office of Planning data and aerial photograph interpretation. Figures 2.1 and 2.2 and Table 2.1 show the geographic distribution of the different land uses.

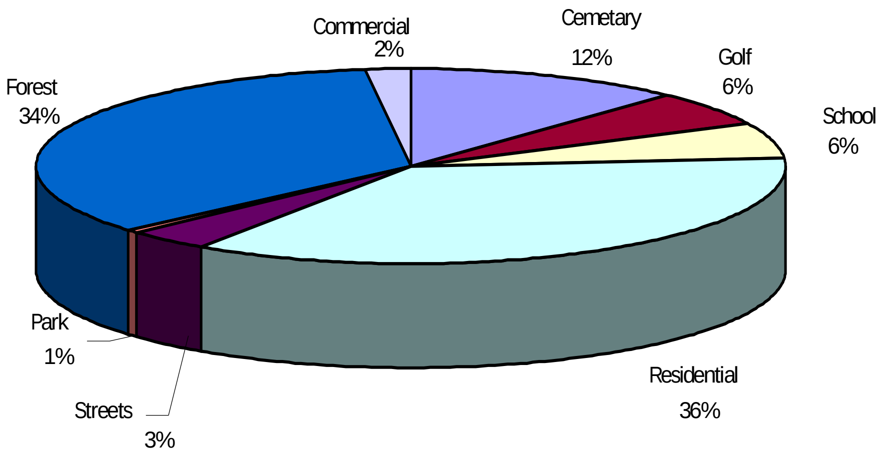


Figure 2.2: Distribution of Kawa Watershed Land Use

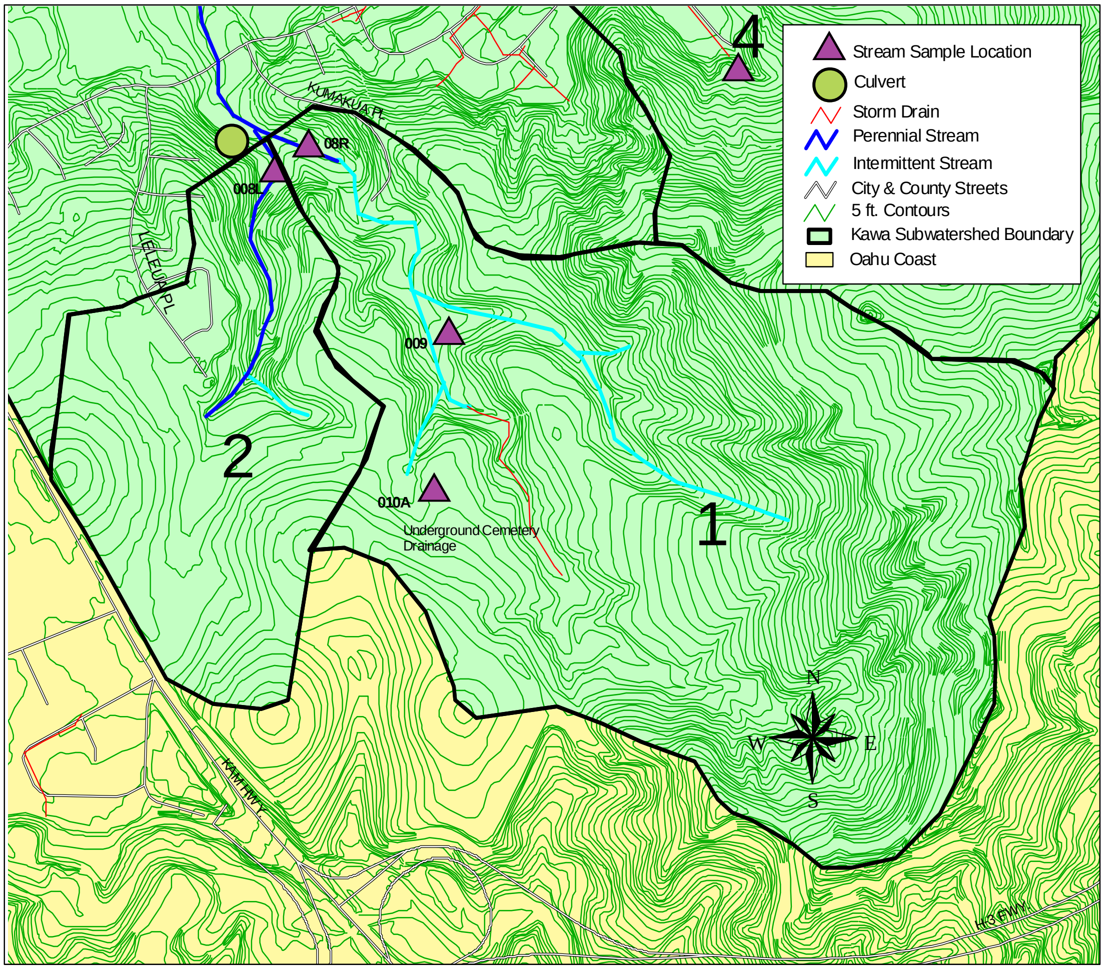


Figure 2.3: Basins 1 & 2

2.2 Description of Watershed Basins

For purposes of this study, the watershed was divided into eight sub-watershed basins. The location of each basin is noted in Figure 2.1. Physical descriptions of each basin and the associated stream reaches are as follows:

Basin 1

Basins 1, 4, 7, and 9 include the forested crest of the watershed bordering the low hills to the east of Pikoiloa subdivision. Within Basin 1 this forest (0.13 mi^2) and two cemeteries (Veterans and Hawaiian Memorial Park; 0.10 mi^2) occupy all of the land (Figure 2.1). Paved roadways within the cemeteries comprise the only other land use category present. This subwatershed includes the main or central branch of Kawa Stream and other intermittent branches draining forested lands down to the confluence with the upper west branch. Water flowing out of this basin is sampled at water quality Station 08R. Stations 009 and 010A (see Figure 2.3) are further up in the basin, and samples from Station 010A mostly represent cemetery runoff collected in underground drains.

The upper east branch of Kawa Stream drains the forested slopes immediately east of the cemetery (see Figure 2.4). This forest is dominated by large and small albizia trees (*Paraserianthes falcataria*) which provide the backdrop for the Hawaii Veterans

Cemetery. Also common and increasing in dominance downslope is Java plum (*Syzygium cumini*). The understory here is comprised of shoebutton ardisia (*Ardisia elliptica*), octopus tree (*Schefflera actinophylla*), and occasional hau (*Hibiscus tiliaceus*). Further east of this swale, the undeveloped hills behind Pikoiloa subdivision are mostly covered by an open forest of *Schefflera*. Groundcover in the albizia/Java plum forest is mostly a growth of basketgrass (*Oplismenus* sp.) and wood fern (*Dryopteris* sp.). There are also some garden plants here, including Chinese evergreen (*Aglaonema* sp.) and an unidentified heliconia (*Costus* sp.) that suggest plantings made along an old track or roadcut which parallels the normally dry swale.

Figure 2.4: The central branch of Kawa Stream rises near a water tank above the Veterans Cemetery

Figure 2.5: Upper cataract on Kawa Stream (central branch)

Figure 2.6: Central and upper west branches of Kawa Stream

Although the incision of a channel is evident in the forest floor, it lacks a distinct bed and is completely covered with basket grass. This swale is joined by at least one other from the east, then joins the central branch just above a new culvert crossing constructed for the expansion of Hawaiian Memorial Park.

The historical central branch of Kawa Stream arises near the water tank above the Veterans Cemetery. The stream channel through the small valley below the water tank is now buried beneath the cemetery lawn (Figure 2.4). Grated drains collect sheet flow from the upper parts of the lawn and roadways, directing this flow into pipe culverts and eventually to an outlet structure located just inside the Veterans Cemetery entrance.

This part of Kawa Stream may be perennial and seeps out into an open concrete box-culvert discharging vertically onto a concrete-rubble-masonry (CRM) lined channel where a pond forms behind a debris dam of mostly California grass (*Brachiaria mutica*). The "pond" is inhabited by melanid and apple snails (*Melanoides tuberculata* and *Pomacea canaliculata*). Streamflow is discontinuous (interrupted) downstream of this pool.

Scattered, small pools of water inhabited by melanid snails are present just above the new cemetery annex road and box culvert. The forest here is mostly Java plum with occasional mango (*Mangifera indica*). Again, only small, isolated pools are present below the box culvert. The channel of the stream is clearly evident as a steep-sided incision 0.5 to 1.0 m deep.

Downslope this channel disappears into a grove of hau just above Kumakua Place in Parkway subdivision. Streamflow emerging from the hau is directed around the houses on Kumakua Place between two parallel hollow-tile walls. Here, the normally dry streambed is overgrown with California grass. This "channel" terminates above a basalt rock face some 8-10 m high, partly covered by arabian balsam or busy lizzy (*Impatiens wallerana*) (Figure 2.5).

A cataract (or intermittent waterfall) below Kumakua Place marks the reestablishment of uninterrupted perennial streamflow. More or less permanent seeps contribute to small pools among boulders at the base of the cliff and the streambed is over-grown with neke fern (*Cyclosorus interruptus*). Streamflow from below the cataract is small but steady through a steep-sided gulch covered in Java plum and numerous juvenile cinnamon trees (*Cinnamomum* sp.) on one side and mostly banana (*Musa x paradisiaca*) behind houses and yards on the other. Streamflow is directed into a concrete collection chute (Figure 2.6) just behind Parkway Community Center. It is at this point that the central branch is joined by the upper west branch (Basin 2). Visual observation over a number of years suggests that base flow in the upper west branch is sometimes greater than that in the central branch.

Basin 2

The upper boundaries of Basins 2, 3, and 5 follow Kamehameha Highway and border the Kaneohe Stream watershed. Basin 2 is almost entirely cemetery (Hawaiian Memorial Park, 0.06 mi^2) except for the forested gulch (0.02 mi^2) of the upper west branch of Kawa Stream (Figure 2.2). Outflow from this basin is sampled at Station 08L (DOH Station 8).

A smaller tributary of the upper west branch arises in a swale behind the Hawaiian Memorial Park baseyard (behind the upper end of Leleua Place). The margins of the ravine at the head end are quite high and steep. This tributary joins with the branch described above at the recently constructed culvert where the cemetery road crosses to the newly opened portion of the cemetery.

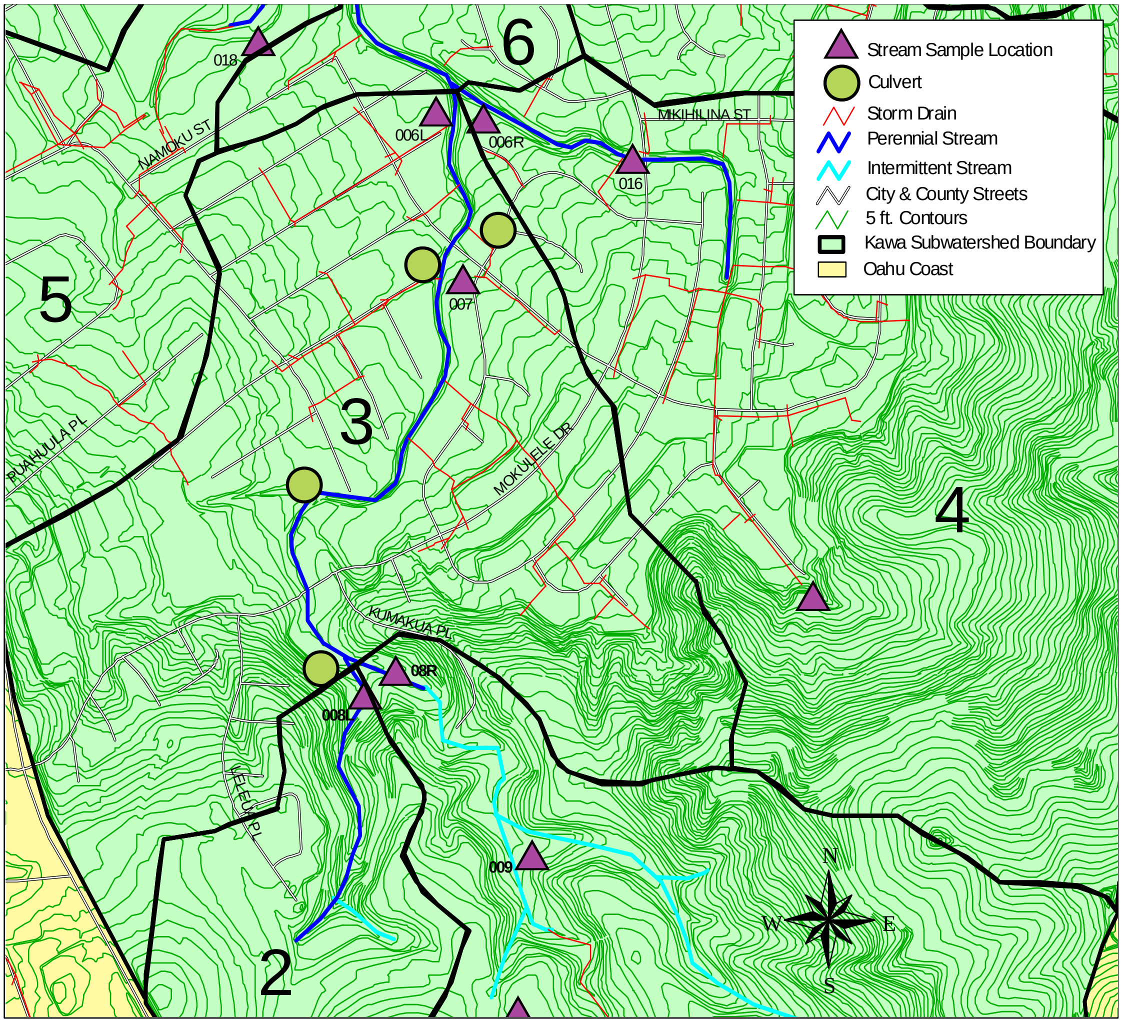


Figure 2.7: Basins 3 & 4

Basin 3

Basin 3 straddles the upper reach of Kawa Stream's central branch between its upstream confluence with the upper branches and its downstream confluence with the east branch (see Figure 2.7). Although some forested area is included (0.03 mi^2), the majority of Basin 3 is residential housing and streets (0.13 mi^2) (see Figure 2.1). The area also includes Kaneohe Elementary School (0.07 mi^2). Water quality in this segment of Kawa Stream is monitored at Station 007, although Station 06L marks the lowest point in the subwatershed. Runoff water quality during storms was measured at culverts C1, C3, and C4, all of which collect drainage from residential areas.

The concrete chute behind the Parkway Community Recreation Center (Figure 2.5) directs flow into a large box culvert that sits beneath the lawn adjacent to the Center and under Mokulele Drive. The culvert emerges uncovered around a broad turn that carries flow through the Parkway subdivision between concrete, vertical walls some 4-5 meters high (Figure 2.8). This structure can be viewed from Mokulele Street in Parkway subdivision or the end of Koa Kahiko Street in Pikoiloa subdivision.

Figure 2.8: Concrete culvert along the lower portion of the Parkway subdivision

The streambed is a flat, concrete bottom with some sediment deposition, particularly on the inside of the curve where a sandbar supports weedy growth such as primrose willow (*Ludwigia octovalvis*). Despite a base flow depth of only about 1 cm, large numbers of poeciliid fish (mostly shortfin molly -- *Poecilia mexicana*) are present, feeding on a thin coating of algae and associated insect larvae. At the curve in this massive open box culvert, a concrete pipe culvert delivers flow from the middle west branch (a short, intermittent stream draining the area around Kaneohe Elementary School). Below this point, the box culvert opens onto a stream segment characterized by bedrock bottom and steep dirt banks (see Figure 2.9).

Figure 2.9: Kawa Stream view upstream from Namoku Street Bridge

Figure 2.10: Drain inlet at the top of Lipalu Street in Pikoiloa subdivision

Water flows over low outcrops of basalt through a series of pools inhabited by large numbers of fishes: shortfin molly (*P. mexicana*), spiny armored catfish (Loricariidae), convict cichlid (*Cichlasoma nigrofasciatum*), and swordtail (*Xiphophorus helleri*). Near the lower end of this segment two species of aquatic plants (elodea -- *Egeria densa* and waterweed -- *Hydrilla verticillata*) appear in pools. The stream is now confined between steep banks of soil fill and weathered basalt, passing between house lots in the Pikoiloa tract.

The character of the stream channel changes markedly below Namoku Street. An open concrete culvert with sloped banks, extending downstream from the box culvert under the street, broadens into a substantially wider channel. Here, the streambed is mostly concrete rubble for a distance of many meters, as is the left bank. This material appears to have been dumped in the past from trucks gaining access off Namoku Place, and possibly pushed up the stream by bulldozer in an attempt to reduce streambed and bank erosion below the concrete-lined section.

Basin 4

Although this is one of the larger subwatersheds, streamflow as monitored at Stations 006R and 016R tends to be small. The area is divided between an upper forested portion (0.21 mi^2) and a lower developed portion in residences and streets (0.13 mi^2) (Figure 2.1).

The middle east branch drains much of the newer section of Pikoiloa tract over to Pohai Nani. This branch is perennial in the lower part and fed by street drains as well as small, intermittent branches. Storm flow in the hills behind the suburban development is conveyed to collecting basins such as that shown in Figure 2.10.

Basin 5

Basin 5 is drained by the lower west branch, which arises as drainage culverts at the Windward City Shopping Center and flows through a modified channel at Castle High School. Output from this subwatershed is monitored at Station 012L. Station 018 monitors perennial output from the culvert outlet serving the street drainage system around the shopping center. Land uses are commercial (0.02 mi^2), school (0.02 mi^2), and residential (0.07 mi^2) (Figure 2.11).

The lower west branch joins with the lower middle reach of Kawa Stream behind Castle High School. This branch has a base flow close to that of the main or central channel, which suggests input from one or more springs that may now be buried. Immediately upstream of the confluence the stream feeds two small taro patches, apparently tended as part of school activities. Above the east bank, a small field serves as an agricultural education test field for the high school. The west bank receives drainage directly from the main high school campus including the auto shop and maintenance facilities. This bank is highly eroded due to its steep slope and lack of ground cover, probably exacerbated by periodic weed control spraying. Above the taro patch the stream emerges from a drainage culvert emanating from beneath the school's baseball diamond.

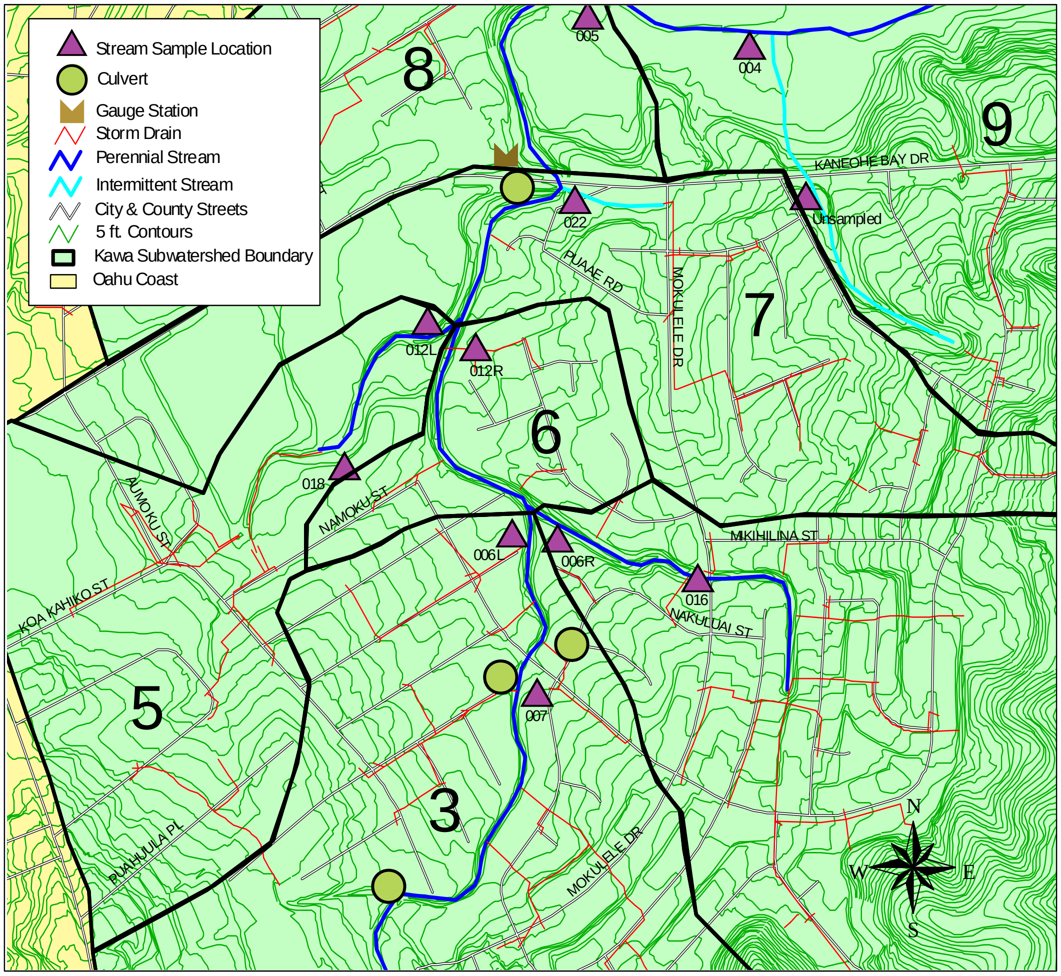


Figure 2.11: Basins 5, 6, & 7

Old topographic maps suggest that this swale was filled and leveled to create the baseball diamond and a portion of the adjacent football field. Beyond the school bounds this drain pipe receives storm runoff from the Pikoiloa Street residential community and the Windward City Shopping Center.

Basin 6

This subwatershed borders both sides of a short segment of the middle reach of Kawa Stream between stations 06L and 012R. Nearly all of the area is developed as residential neighborhood and streets (0.04 mi^2). A small area (<0.01 mi^2) in agricultural use at Castle High School is included and could be a potential source of nutrients.

The lower middle reach extends from the confluence with the east branch to the confluence with the lower west branch emanating from behind Castle High School. This segment is characterized by a series of natural and man-made drops and, in places, shows evidence of substantial bed erosion. Water flows through long pools separated by run and riffle zones, or else drops over concrete culvert structures. Much of the rocky rip-rap streambed is composed of broken and eroded concrete rocks.

Basin 7

Like the previous subwatershed, this basin consists of two areas bordering a short segment of Kawa Stream, here between stations 012R and 022 (Kaneohe Bay Drive bridge). However, street drains bring runoff in from some distance on both sides - as far away as McDonalds at Kaneohe Shopping Center to the west and the crest of the eastern hills above Pohai Nani to the east. Land uses are park (0.01 mi^2), school (0.03 mi^2), residential (0.09 mi^2), and forest (0.02 mi^2) (Figure 2.11).

This short reach begins at the junction of the lower middle reach and the Castle High School branch and flows under Kaneohe Bay Drive to an abandoned stream gauging about 100 feet below the highway. A concrete spillway opposite the Ron L. Bright Theater dumps flow onto a bedrock segment of increasing steepness as the stream turns east then north and flows under Kaneohe Bay Drive. This segment receives runoff from the urban neighborhood on its east bank, the high school and the Kaneohe Bay Drive on its west bank. The west bank adjacent to Castle High School consists of steep, bare slopes and terraces covered with low, weedy vegetation including beggar's tick (*Bidens pilosa*), sow thistle (*Sonchus oleraceus*), and prostrate spurge (*Chamaesyce prostrata*). The east bank along this segment is mostly protected by a sloped concrete wall protecting the yards of Pahikaua Estates residential lots on Puaae Place and Pouhanuu Place and Way.

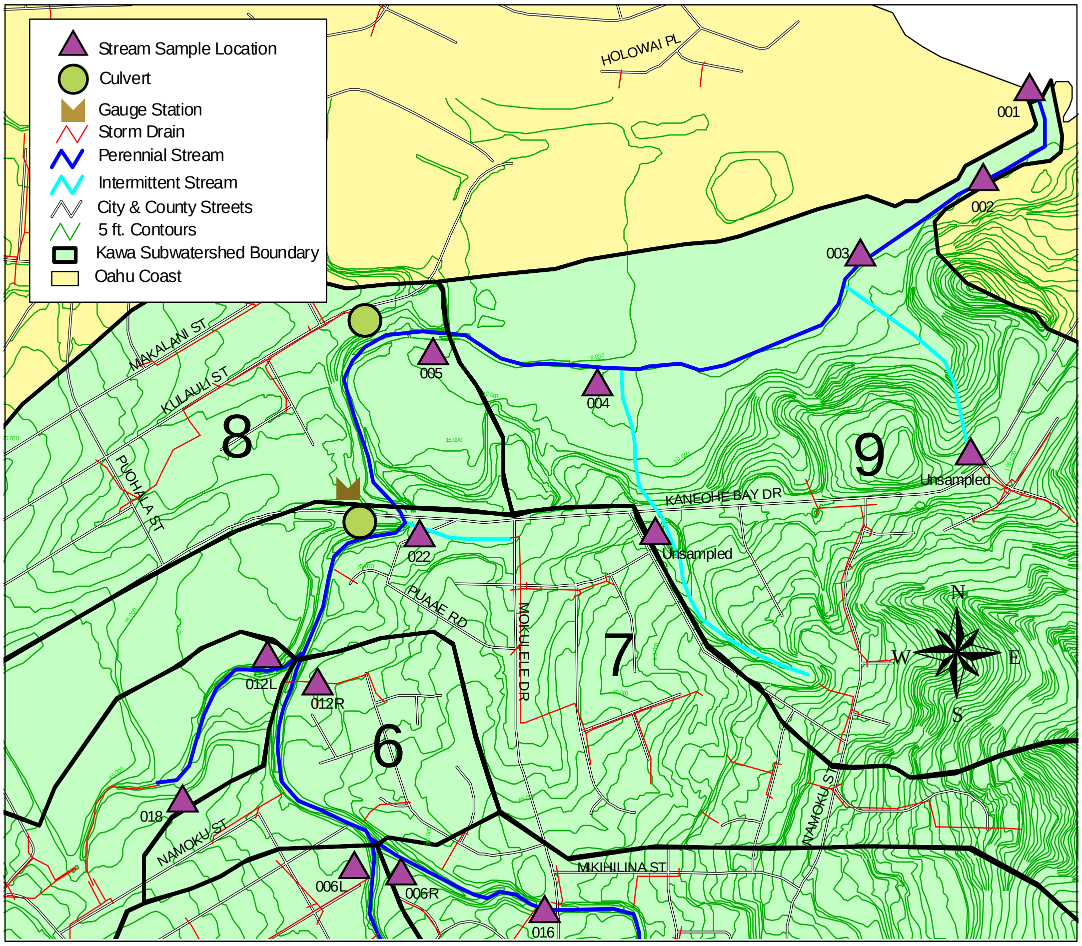


Figure 2.12: Basins 8 & 9

Basin 8

This subwatershed drains parts of the Puohala neighborhood and the upper end of the Bay View Golf Course. This basin encompasses the lower reach of Kawa Stream between Stations 022 (KAW-2) and 005 (Figure 2.10), and is comprised of residences and streets (0.07 mi^2) and golf course (0.02 mi^2) (Figure 2.12).

Below Kaneohe Bay Drive the stream tumbles down a stepped bed of basalt bedrock into a pool marking the upper end of the lower stream reach. The abandoned stream gauging station (noted above in the Basin 7 description) is located here. Hau covers the steep slopes of the gulch above the right bank of the stream and Java plum and banyan cover the slope above the left bank.

A large pool below a section of basalt outcrop has a soft sediment bottom and is deep enough to be used as a swimming hole by neighborhood kids. A sediment bar lies across the stream near this pool's upstream end. Exiting the pool, the stream flows through a channel choked by tall elephant grass (*Pennisetum purpureum*) against a high and quite steep west bank separating the stream from Puohala. The east bank descends down to the Bay View Golf Course. Kawa Stream then makes a broad turn to the east and enters a floodplain shared with Kaneohe Stream.

Basin 9

This subwatershed encompasses most of Bay View Golf Course (0.07 mi^2) and some areas upslope of Kaneohe Bay Drive, including residential developments (0.03 mi^2) and forested slopes (0.10 mi^2) that drain through street culverts and intermittent stream channels entering Kawa Stream at the golf course. The stream is confined within a man-made, mostly unlined channel through the golf course, ending in a swamp forest of red (or American) mangrove (*Rhizophora mangle*) along the south wall (here an earthen berm) of Waikalua-Loko fishpond. This channel was dredged to its present width around 1958 when wetlands here were reclaimed for building the Kaneohe WWTP. It was again dredged in 1965 to remove accumulated sediment (VTN Pacific, 1977). The channel is estuarine from the eastern edge of the Bay View Golf course between Stations 005 and 004 (Figure 2.13) to the stream mouth, a distance of about 700 m. Stations 004, 003, 002, and 001-monitor conditions in this estuary (Figure 2.10), where the channel is mostly straight, 7.0 to 9.0 m wide, and 1.0 to 1.5 m deep. A freshwater marsh lies along the south side of the man-made estuary channel, collecting the drainages coming in from upslope.

The stream discharges into Kaneohe Bay through the remnants of Waikalua fishpond, just east of Waikalua-Loko. Kaneohe Stream enters the bay along the north side of Waikalua-Loko. Maps from the mid-1800's show that both Kawa Stream and various `auwai that drained the taro lo`i located between the lower courses of Kaneohe and Kawa Streams once fed directly into Waikalua-Loko fishpond (Cultural Surveys Hawaii 1989).

Figure 2.13: Kawa Stream above the transition to an estuary below station 005

Fishes noted as present in this estuarine reach include aholehole (*Kuhlia sandwicensis*), tilapia (*Oreochromis mossambicus*), juvenile barracuda (*Sphyraena barracuda*), manini

(*Acanthurus triostegus*), and jack (*Caranx* sp.), as well as several native gobies and blennies (*Eleotris sandwicensis*, *Stenogobius hawaiiensis*, & *Awaous guamensis*). Invertebrates include oysters, barnacles (*Balanus* sp.), grapsid crab (*Metopograpsus thukuhar*), blue-pincher crab (*Thalamita* sp.) and `opae oeha`a (*Macrobrachium grandimanus*). One is likely to see red-eared slider (*Trachemys scripta elegans*) turtles in the lower and estuarine reaches of Kawa Stream.

In addition to the central branch and tributaries discussed above, an additional 4 or 5 small tributaries drain into the Kawa Stream estuary. In these intermittent streams, as in the middle east branch, swales in the hills behind Pikoiloa subdivision drain to culvert inlets at the forest/suburban boundary during storms. These freshets are then diverted through pipe culverts that discharge to channels on the seaward side of Kaneohe Bay Drive (except for the open swale forming the back boundary of the Nohonani Place subdividision between Namoku Street and Kaneohe Bay Drive at Keana Road). To the west, these small streams drain into grass-dominated wetlands that are remnants of formerly more extensive lowland marshes now surrounded by Bay View Golf Course. Drainages further east are all intermittent, with some entering a narrow mangrove belt along the southern shore of Kaneohe Bay that begins near Kokokahi YWCA.

2.3 Historical Studies and Background Information

Historical data for Kawa Stream includes water quality monitoring at several locations in the lower part of the watershed in 1991-92 (AECOS 1992) and 1996 (Marine Research Consultants 1997) and streamflow monitoring in 1999 (Nance 1999). Biological surveys were conducted by Brewer/Brandman Associates (1989) and Filbert & Englund (1995). A one-year monitoring effort (September 1999 through September 2000) by the State of Hawaii Department of Health (DOH) included stations ranging from the mouth of Kawa Stream, through the estuary, and upstream to just above the residential district. In this program, samples were collected twice a month on predetermined dates (i.e., sampling was not biased with respect to events, such as rain storms). These samples define the general, or baseline, water quality conditions in this stream system during the period of study.

Samples were analyzed at the State DOH laboratory for total dissolved nutrients, TSS, and turbidity. Because total dissolved nutrients is a fraction of the total nutrients component, we assume for the purposes of this report that the DOH data represent total nutrients, with any differences between the two adding to the margin of safety. Samples obtained by AECOS and Oceanit as part of this study typically represent storm event samples and were analyzed and reported by AECOS as total nutrients, TSS, and turbidity.

A hydrologic study of the lower stream reach was conducted in association with an application for a well pumping permit for the Bay View Golf Course (Nance 1999). Nance recorded water levels in the stream at two weirs for a period of two years, 1997 and 1998. The report provides documentation of the base flow of Kawa Stream over two winter and two summer seasons (Figure 2.14), and additional data for three events showing the stream response to small, medium and large storm events. These data provide a basis for streamflow inputs to the mathematical model and, in combination with rainfall data, estimates of percent runoff from storm events.

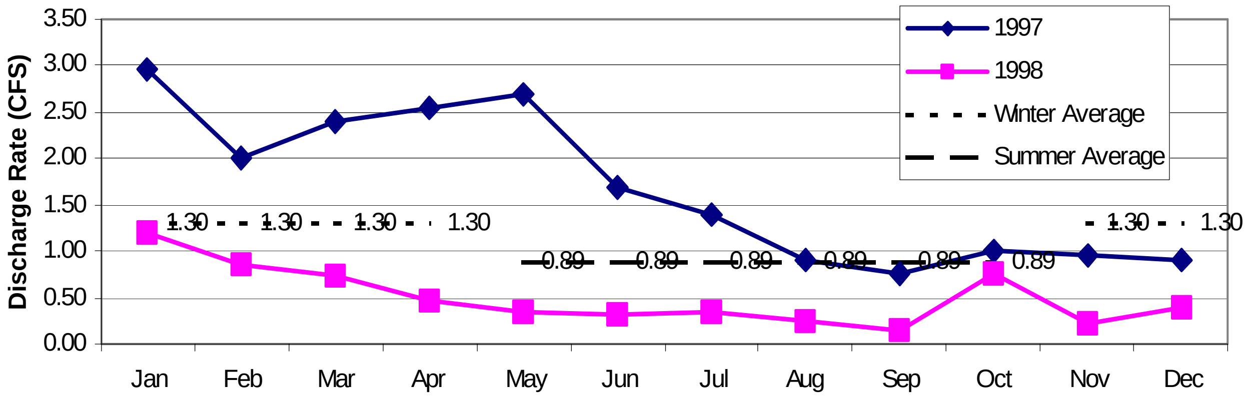


Figure 2.14: Comparison of monthly average base flows (ft^3/sec) at the Upper Kawa Stream gauging station in 1997 and 1998

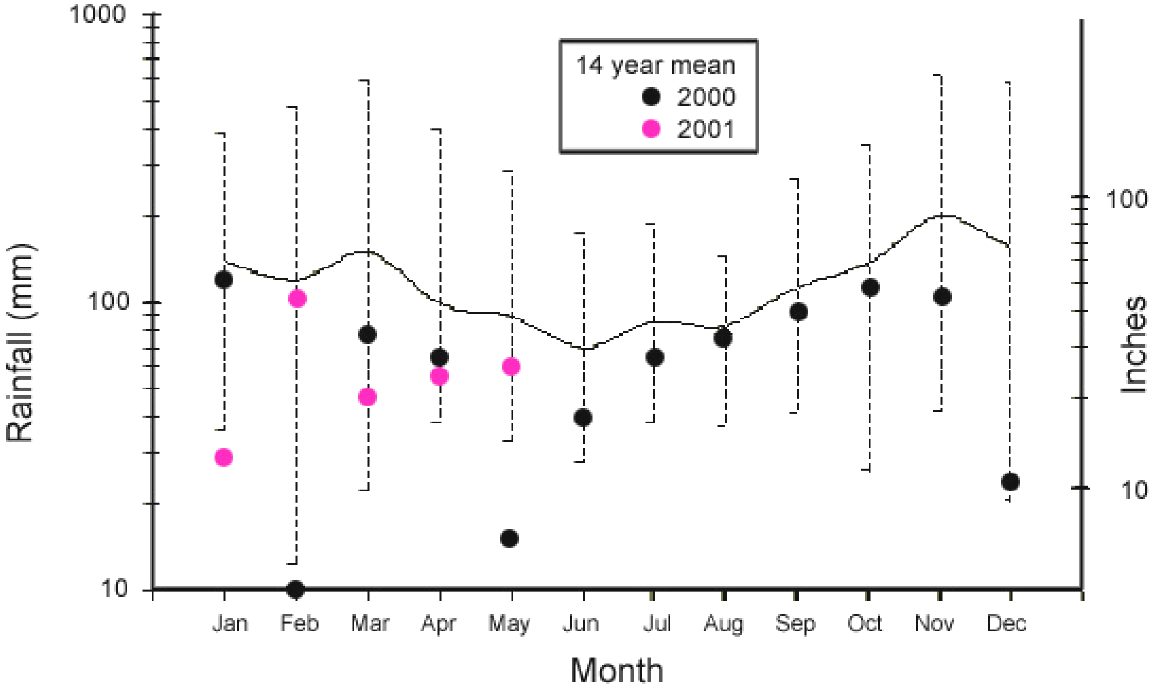


Figure 2.15: Annual rainfall at Akimala Place, Kaneohe

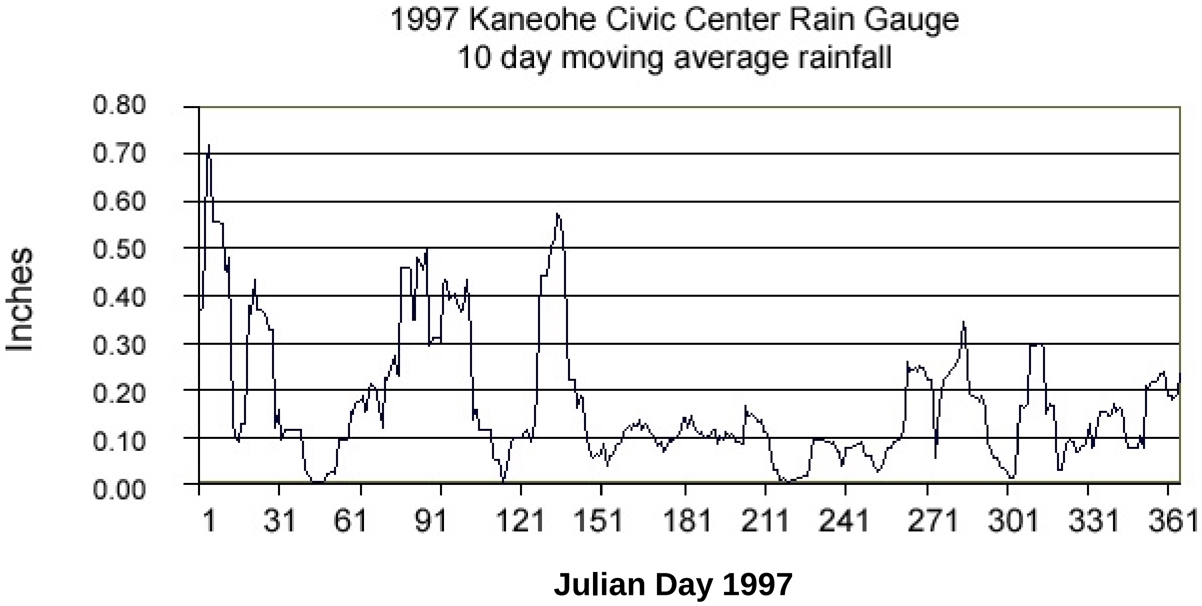


Figure 2.16: 10 day moving average rainfall at Kaneohe Civic Center gauge, 1977

2.4 General Weather Impacting Watershed

Rainfall in Hawaii is the result of five primary phenomena: 1) oceanic tradewind showers; 2) orographic lifting and thermal trapping of moisture-laden tradewinds against high mountain peaks (tradewind inversion); 3) island-wide storm fronts associated with North Pacific low pressure systems; 4) subtropical storms (Kona storms, roughly 1/yr); and 5) hurricanes (roughly 1/10yr). Of these five the subtropical storms and hurricanes are the most intense and most rare. According to the National Weather Service, Oahu typically receives four to eight major island-wide frontal system storms per winter, with each storm producing an average of 1 to 5 inches of rain over a 1 to 3 day period.

Most of Oahu's rainfall is the result of daily orographic lift along the central mountain ranges. The steep windward slope of the Koolau range (to about 2,400 feet) causes uplift of the approaching tradewind clouds, resulting in significant rainfall within about a mile of the ridge. The Kawa Stream watershed, which is no more than 900 feet high and about 3 miles away from the central island ridge, is thus beyond the effect of these typical showers and is primarily subject to rainfall resulting from oceanic tradewind showers and from large weather systems causing rainfall over the entire island. These showers tend to be most frequent in the morning and evening. They and are often intense, short-duration, and spatially limited. For example, a typical tradewind rain shower might have a diameter of a mile or two and be moving with the tradewinds at 5 to 15 mph. This event, from the perspective of a single point on land, will have a duration of 4 to 20 minutes during which time 0.1 to 0.5 inches of rain may fall.

Rainfall was measured during the entire period of the TMDL study. Data are available from three automated rain gauges - one at the center of the watershed and two outside, but near, the watershed boundary. Between November 4, 1999 and January 9, 2000, rainfall was manually recorded twice daily (7 am and 7 pm) using a TruCheck gauge located near Kawa Stream on Akimala Place in Kaneohe at the center of the watershed. Gauge elevation was approximately 30 m (100 ft) above sea level. However, during selected storms in concert with stream freshet monitoring, readings were made at 15 or 30-minute intervals. After January 9, 2000 an automated, tipping-bucket rain gauge (Onset Computer) was set up at the same location to record total rainfall at 15-minute intervals. Total annual rainfall averages about 52 inches but can vary widely from year to year. For modeling purposes, rainfall data for 1997 and 1998 were utilized to corresponded with the stream flow data collected during this period by Nance (1999).

Figure 2.15 compares mean monthly rainfall recorded at Akimala Place, Kaneohe over the past 14 years (solid line is the mean for 1985 -1999) with the monthly totals for 2000 and 2001. Vertical bars show the range of monthly totals recorded for each month of the year. The logarithmic scale on the vertical axis tends to smooth out differences between wet and dry seasons. However, the higher average rainfall and much greater variability in total rainfall during wet season months (September through April in Kaneohe) as compared with dry season months (May - August) are evident. Monthly rainfall was below average for the project period (2000-2001) at this location and at Kaneohe Civic

Center. February 2000, May 2000, and January 2001 set new records for lowest monthly rainfall since 1985.

Figure 2.16 shows the variation in daily rainfall for 1997 at the Kaneohe Civic Center using a 10-day moving average daily. 1997 was a relatively wet year with a total of 66 inches of precipitation (average = 52 in/yr). Even using the 10-day moving average to smooth the data, rainfall appears to be sporadic but corresponds well with base streamflow for this period as measured by Nance (1999).

Figure 2.17 shows another view of how daily rainfall at this gauge is distributed across time. Note that 50% of the total annual rainfall occurs in less than 0.5-inch daily increments and 80% of the total rainfall can be attributed to storms with daily rainfall of less than 1.5-inch. About a third of the total rainfall occurs on days with rainfall of 0.25-inch or less and contributes minimally to runoff as discussed below (page 26).

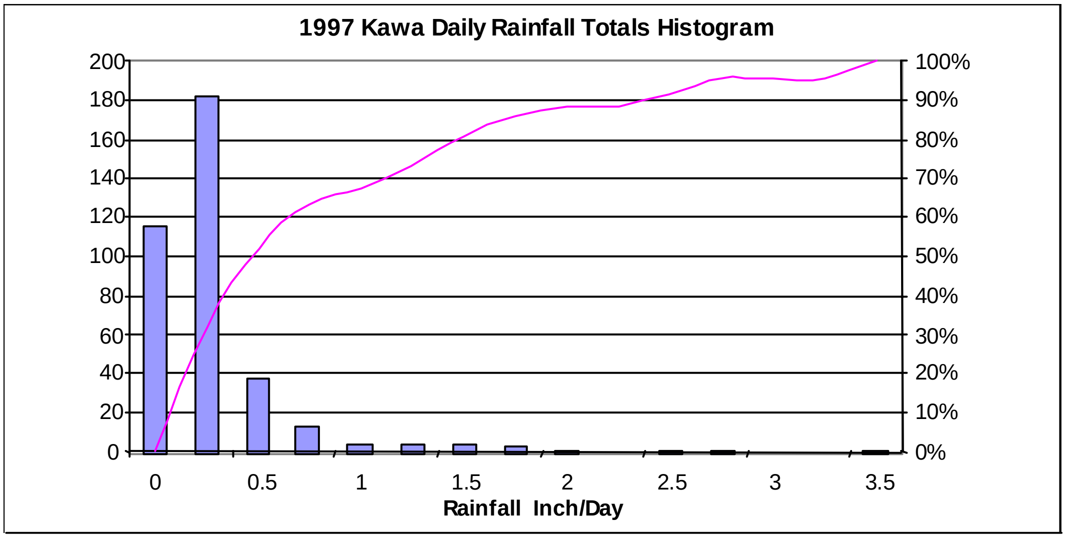


Figure 2.17: Cumulative frequency of daily rainfall at Kaneohe Civic Center, 1997

3.0 METHODS AND RATIONALE OF DATA COLLECTION

Kawa Stream has three major water sources that separately influence its water quality:

1) ground water that flows in from springs or seeps in along the stream channel;
2) overland flow that runs off of the ground during and after rainfall; and
3) human-induced overland flow that occurs independent of rainfall.

As water flows over the surface and through the soils of the watershed, it picks up numerous substances (like nutrients and sediments), dissolves some of them (e.g. nitrates), and carries the substances into the open stream channel or down to the groundwater sources. As the stream flows through the channel it erodes the streambed and stream banks, adding to the load of particulate and dissolved pollutants transported downstream. As streamflow increases, so does its capacity to pick-up and carry pollutants. However, because a heavy rain (as compared with a drier baseflow period) may contribute a volume of water that is relatively larger than the available mass of dissolvable pollutant, the actual concentration of dissolved pollutants in the stream might decrease (although the pollutant load is actually increasing) until runoff subsides.

Sources of streamflow and stream pollutants that are not directly associated with rainfall further complicate the situation. Public and private groundwater sources are used for irrigation and maintenance of school, park, and cemetery facilities, sometimes in conjunction with fertilizer applications. Runoff from these activities and from domestic water uses - such as landscape irrigation, car washing, and swimming pool maintenance - may enter storm drains and stream channels and can even return to groundwater sources. Because the entire community is sewered, there should be negligible nutrient input from cesspools. The main sewer line does cross under the stream bed in at least two locations and the possibility of occasional leakage and overflow events should be considered in the future.

Ideally we can track each substance back along its flow path to find out where excess pollutants were introduced. However, even in a small watershed like the Kawa Stream basin, this is a practical impossibility and we must resort to a sampling protocol and analytical methods to segregate pollutant sources within the watershed. Our approach was to divide the watershed into sub-basins based upon stream and watershed morphology.

Essentially each basin is its own watershed, with multiple environmental characteristics, land uses, and zoning. Our primary sampling stations were aligned at the base of each watershed to determine the impacts to stream water quality from each individual basin. Data from stations at the base of basins 1, 2, 4, and 5 characterize water quality emanating only from these specific areas, whereas data from stations at the base of basins 3, 6, 7, 8, and 9 show the cumulative effects of water quality impacts from all areas upstream, including other basins.

The State of Hawaii Department of Health (DOH) conducted twice-monthly sampling at 8 to 10 locations on Kawa Stream (the stream is intermittent at the uppermost stations) between September 1999 and September 2000 (25 events). None of these samples were collected during storm event periods when runoff would influence water quality. The DOH data are divided into two sets representing Wet Season (November-April) and Dry Season (May-October) samples.

Water quality results from regular monitoring at these stations are posted on the World Wide Web at http://www.aecos.com/jobs/kawatmdl.html. The following DOH sampling locations are shown in Figure 1.1:

Station 001 - Kaneohe Bay at mouth of Kawa Stream (Basin 9)
Station 002 - Kawa Stream estuary in mangrove upstream of mouth (Basin 9)
Station 003 - Kawa Stream estuary upstream of Waikalua-Loko (Basin 9)
Station 004 - Kawa Stream estuary at Bayview, lower golf cart bridge (Basin 9)
Station 005 - Kawa Stream at Bayview, upper golf cart bridge (Basin 8)
Station 006 - Middle east branch down from Mokulele Street bridge (Basin 4)
Station 007 - Kawa Stream just upstream of Namoku Street bridge (Basin 3*)*
Station 008 - Upper west branch above Parkway Community Center (Basin 2)
Station 009 - Kawa Stream above new culvert at Hawaiian Memorial Park (Basin 1)
Station 010 - Kawa Stream above confluence with upper west branch (Basin 1)

The station numbers assigned by the DOH (1 through 10) were maintained in our subsequent sampling plan. Additional stations sampled only by the Oceanit/AECOS team.

Oceanit/AECOS samples were collected during storm events ("runoff influenced") and periods of non-storm baseflow ("non-runoff influenced"). Interpretation of whether a sample was taken during runoff influenced or non-runoff influenced conditions was a subjective judgment based upon local rainfall data and the on-site observations of professional scientists and water quality monitoring technicians.

Data in tables labeled "HDOH" are from the DOH monthly sampling protocol only. Data labeled "non-runoff influenced" are a combination of the DOH data and Oceanit/AECOS data collected when there was no storm runoff to the stream.

4.0 EXISTING POLLUTANT LOADS AND SOURCE ANALYSIS

4.1 Overview

This section describes how the existing nutrient and TSS loads in the stream were determined and how TMDLs and load allocations were developed to guide Kawa Stream into compliance with State Water Quality Standards. The first section reviews and summarizes the water quality data collected and interprets this information in terms of loadings from the watershed. Then we describe how flow rates in the stream were obtained and interpreted. The next section describes the modeling framework for simulating nutrient loads, hydrology, and water quality responses. The assessment investigates water quality responses assuming different stream flow and nutrient loading conditions. The final section presents the modeling results in terms of TMDLs and load allocations.

4.2 Determination of Constituent Concentrations in Streamflow and Storm Runoff

Hawaii's water quality standards (Chapter 54 of Title 11 of the Hawaii Administrative Rules – see Table 1.1) provide numeric concentration criteria against which actual conditions in Kawa Stream can be assessed. These conditions were characterized by measurements obtained during a regular monitoring program that is unbiased about conditions influencing stream flow (i.e., the DOH 1999-2000 monthly monitoring program) and by measurements obtained during an event-driven monitoring program emphasizing rainy periods (AECOS stormwater monitoring). Results from both monitoring programs contribute to our understanding of where and how pollutants reach Kawa Stream. Data summaries are presented here for:

- Baseline – samples collected and analyzed by DOH
- Wet and Dry Seasonal - DOH and AECOS data obtained during periods of no rainfall and partitioned into winter wet season (wet) and summer dry season (dry)
- Storm Conditions - AECOS data collected during rain storm and runoff events

4.2.1 Water Quality Characterization

- *Suspended Solids*

Streams accomplish work in the watershed: they erode the land and move the loosened material downslope and, eventually, into the sea. This solid material is carried by the stream as bed load, suspended particles, and floating debris. Measurement of suspended particulates is usually expressed as TSS (total suspended solids). Turbidity is often used as a substitute for TSS as turbidity methods, based on light reflectance off suspended particles, agree well with visual perceptions of water clarity. However, turbidity can vary for a given TSS (weight of particulate load per unit volume of water) depending upon the size, reflectance, and color of the suspended particles. The mix of particle types may be further complicated by biological activities, which may vary with daily periodicity. For a given stream corridor, turbidity and TSS will typically vary together but the linear correlation between these measurements is often poor.

Table 4. 1 Baseline Turbidity and Total Suspended Solids (Geometric Means)

Station HDOH Station Number	Turbidity (ntu)	TSS (mg/l)	Turbidity/ TSS ratio
Station 10 (= 008R)	1.8	1.8	1.0
Station 8 (= 008L)	5.7	3.9	1.5
Station 007	10.1	5.6	1.7
Station 6 (= 016)	8.9	5.6	1.5
Station 005	6.2	2.8	2.1
Grand means	**6.8**	**4.1**	**1.7**
State dry season criteria *State wet season criteria*	*2.0* *5.0*	*10.0* *20.0*	
std. dev.	2.9 - 16	1.6 - 10	
n (data set) =	98	106	98

NOTE: Station 10 means based upon only 7 events (June-September 2000)

Table 4.2 Wet and Dry Season Turbidity and Total Suspended Solids Compared with State Water Quality Standards Criteria

	Turbidity (ntu)	TSS (mg/l)	Turbidity/ TSS ratio
wet season geometric mean	**7.3**	**4.4**	1.9
State criteria	*5.0*	*20*	
dry season geometric mean	**6.4**	**3.9**	1.5
State criteria	*2.0*	*10*	

[a] 13 dry period events and 12 wet period events, HDOH Stations 5, 6,7, 8, and 10

Table 4.3 Storm Condition. Suspended Particulate Measurements in Kawa Stream (Geometric Means)

Station	Turbidity (NTU)		TSS (mg/l)	
	Runoff Influenced	Non- Runoff	Runoff Influenced	Non- Runoff
Sta. 010A	**26** (4)*	----	**13** (4)	----
Sta. 009	**29** (5)	----	**19** (5)	----
Sta. 08R	**53** (6)	**2** (7)	**35** (6)	**2** (6)
Sta. 08L	**31** (6)	**5** (25)	**18** (6)	**4** (25)
Sta. 007	**73** (32)	**9** (29)	**53** (30)	**5** (28)
Sta. 016L	**52** (4)	**9** (1)	**34** (4)	**5** (1)
Sta. 016R + 006	**32** (7)	**8** (24)	**19** (7)	**5** (26)
Sta. 012R	**60** (6)	**7** (3)	**47** (5)	----
Sta. 012L	**43** (7)	**7** (3)	**39** (6)	----
Sta. 022	**47** (4)	**9** (2)	**30** (4)	**6** (2)
Sta. 005	----	**5** (25)	----	**2** (26)
GRAND MEANS	**50.7** (81)	**6.3** (118)	**34** (77)	**4** (115)
Comparable State criteria	*25.0* *wet season 2% exceedance*	*5.5* *dry season 10% exceedance*	*30.0* *dry season 10% exceedance*	*10.0* *dry season geom. mean*

* sample sizes (n)

At stations on Kawa Stream where turbidity and TSS have been monitored regularly over time, baseline values for both tend to increase with distance downstream, peaking in the middle reach around Station 007 (Table 4.1). Somewhere below Station 007, the values tend to decrease as shown by data from Station 005 at the upper end of Bay View Golf Course. Particulates could be expected to increase as one moves down gradient in the watershed due to increased competence of the stream; that is, the volume and velocity of stream water increases as a result of increasing drainage area, resulting in the stream's ability to maintain greater amounts of particulate matter in suspension. The marked decrease in both turbidity and TSS at Station 005 in the lower reach of Kawa Stream likely results from deeper, slow moving pool areas in the downstream waters where stream velocity is retarded and particulates settle out. Note that TSS between Station 007 and Station 005 decreases by about 50 percent, whereas turbidity levels decrease by only about 30 percent. These facts indicate that larger and heavier particles are settling out more readily than the very smallest particles that make the water turbid.

Table 4.2 compares the DOH turbidity and TSS data collected during wet and dry seasons with their respective state water quality standard criteria. Geometric mean turbidity levels for the stream as a whole exceed both wet and dry season criteria, while TSS concentrations are well below the State criteria. These differences raise questions about the synchronicity of State criteria for turbidity and TSS; i.e., shouldn't both parameters either be in compliance with State criteria or not? The answer is "not necessarily".

TSS and nephelometric turbidity are totally different approaches contrived to measure the “dirtiness” of water. TSS directly measures the weight of all suspended particles in the water and relates well to estimates of physical load or land erosion. Turbidity, on the other hand, is a standardized way to measure the reflectance of light by particles suspended in the water and relates well to what the human eye visualizes as the “dirtiness”, or opacity, of water. Waters with identical TSS values can exhibit very different turbidity values depending upon particle size, density, color, and reflectance. Even for a single stream passing through uniform substrate, the turbidity:TSS ratio would be expected to vary with current speed (which changes particle size distribution) and time of day (assuming photosynthetic effects). Laboratory Standard Methods for measurement of turbidity require the technician to wait until a stable reading has been achieved – thereby allowing heavier particles to fall out of the field of measurement.

Table 4.1 (DOH and AECOS data) and Figure 4.1 (AECOS data only) show the relationship between TSS and turbidity in Kawa Stream - one can only be used to predict the other to within about half an order of magnitude. A sample (from Kawa Stream) with measured TSS of 10 mg/L (the geometric mean criteria for dry season) would be expected to have a turbidity of about 18 NTU, which could actually be as low as about 8 NTU or as high as 40 NTU. Unfortunately, in either case the turbidity would be significantly above the geometric mean criteria for dry season (2 NTU). Thus in general it appears that the water quality standard for turbidity is much more stringent than that for TSS.

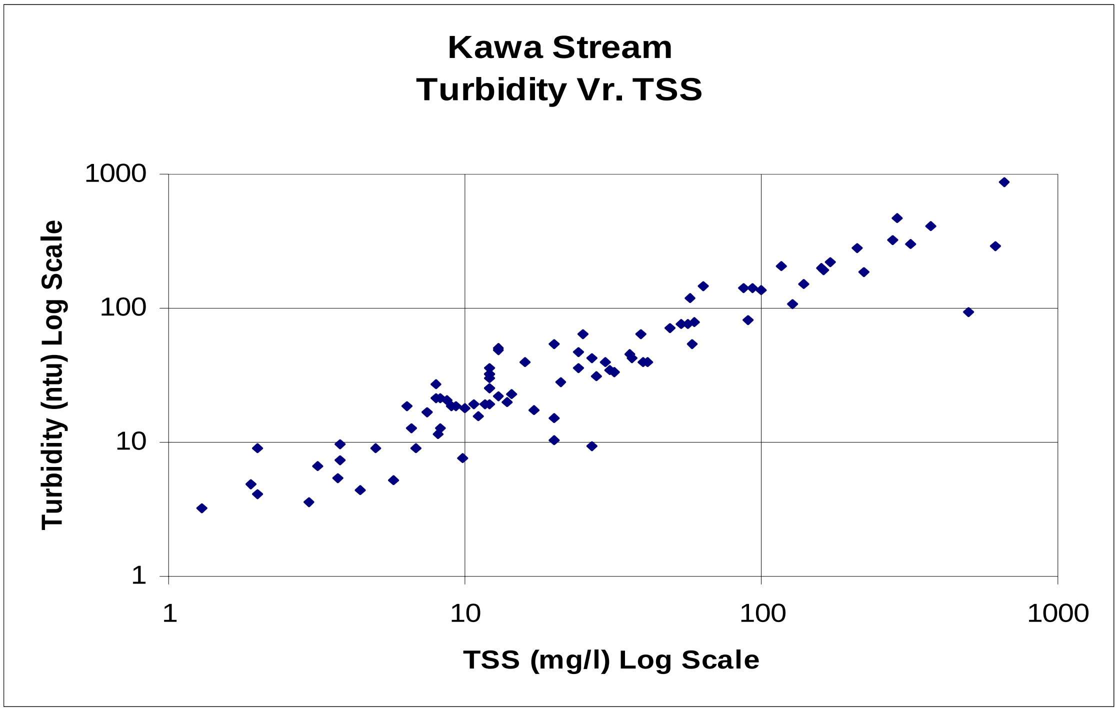


Figure 4.1: Turbidity vs. Total Suspended Solids in Kawa Stream

During high runoff periods both turbidity and TSS rise dramatically in Kawa Stream. Samples collected at various locations over time - between the onset of rainfall, through peak stream discharge, and on until water quality returns to normal - are used to assess the effects of storms of various magnitudes on suspended sediment transport (see Table 4.3). Relating these data to water quality standards requires consideration of storm frequencies for the watershed. In the main channel, measured turbidity easily exceeds all of the turbidity criteria during significant rainstorms.

Our measurements indicate that a significant source of turbidity and TSS in the stream during storms came from land grading for a construction project at Hawaiian Memorial Park Cemetery. This project straddled the intermittent upper central branch at a newly constructed culvert crossing. From November through January 2000 (at least), the steep graded and filled banks suffered significant erosion during several monitored storms. Improperly designed silt fences were partly to blame. As of May 2001 this situation was rectified and adverse water quality impacts are expected to subside as bare slopes become vegetated. What is not known is how long it will take for the soil deposited in the streambed below the project to flush out of the system.

Based on relationships between turbidity and TSS (Figure 4.1) and TSS and TP (Figure 4.2), we assume that both TSS and phosphorous levels are positively correlated with turbidity. Thus we propose that reductions in TSS and TP loads to levels where the respective numeric criteria are attained will also result in meeting the turbidity criteria.

- *Nutrients*

Although a number of chemical substances can be regarded as "nutrients" essential for growth in living organisms, two classes of chemicals are of greatest concern from a water quality standpoint - compounds of nitrogen and phosphorus.

NITROGEN

We first consider the nitrogen data obtained from the HDOH stream monitoring program as summarized in Table 4.4. These measurements reveal that the stream regularly carries high levels of nitrogen compounds. It is also evident that nitrate + nitrite (hereafter called "nitrate," but understood to include a small but unknown proportion of nitrite or NO_2) is the dominant nitrogen form. Considering that nitrate salts are very soluble, these results suggest that watershed sources regularly contribute nitrates to the stream.

Nitrate concentrations are especially high in the upper reaches of the stream and tend to decrease with distance downstream through Station 007 (middle reach). The lowest mean value (geomean = 138 ug/l) occurs at Station 016 in the middle east branch (Pohai Nani branch) of Kawa Stream that drains Basin 4. Because both streamflow and nitrate concentration here are lower than in the main branch, this subwatershed contributes much less nitrate loading than Basins 1, 2, and 3.

Nitrate levels appear to rise again in the lower reach of the stream below Kaneohe Bay Drive (Station 005). As will be shown later, much of this increase in the lower reach appears to result from inflow of the lower west branch (Castle High Branch) of Kawa Stream that arises in Basin 5, draining Windward City Shopping Center and parts of the Castle High School campus.

Table 4.4 Baseline Nutrient Concentrations (Geometric Means), 1999-2000

HDOH Station Number	NO_3 + NO_2 (ug/l)	NH_3 (ug/l)	Total Dissolved N (ug/l)	Total Dissolved P (ug/l)
Station 10	1097	2	1204	11
Station 8 (= 008L)	812	10	1015	72
Station 007	613	51	908	27
Station 6 (= 016)	138	46	533	35
Station 005	997	24	1310	37
Grand means	**538**	**23**	**928**	**37**
State dry season criteria	*30*		*180 (Total N)*	*30 (Total P)*
State wet season criteria	*70*		*250 (Total N)*	*50 (Total P)*
Comparable State exceedance criteria	*300* *wet season 2%*		*800 (Total N)* *wet season 2%*	*60 (Total P)* *dry season 10%*
std. dev.	175 - 1655	6 - 89	492 - 1747	19 - 71
n (data set) =	107	107	106	107

NOTE: Station 10 means based upon only 7 events (June-September 2000)

At every station on Kawa Stream where water samples have been collected as part of a regular monitoring program, the geometric mean of all samples exceeds all six water quality standard criteria (Table 1.1) for both total nitrogen (TN) and nitrate + nitrite in streams (Table 4.4). Table 4.5 presents a comparison of the geometric means of wet and dry season nutrient concentrations in Kawa Stream with these seasonal criteria. Note that nitrate + nitrite levels exceed State criteria by almost 7x in the wet season and nearly 20x in the dry season. Total dissolved nitrogen (TDN) levels are also well in excess of State total nitrogen criteria, but high TDN is largely the result of high nitrate + nitrite levels in this stream. Considering each individual sample (and rejecting instances of nitrate analytically exceeding TDN), nitrate is seen to constitute anywhere from 4 to 96% of total dissolved nitrogen, averaging 63% in the HDOH data.

Table 4.5 Wet and Dry Season Nutrient Concentrations (Geometric Means), 1999-2000

	NO_3 + NO_2 (ug/l)	NH_3 (ug/l)	Total Dissolved N (ug/l)	Total Dissolved P (ug/l)
wet season samples	486	27	939	41
State criteria	*70*	---	*250*	*50*
dry season samples	586	20	918	33
State criteria	*30*	---	*180*	*30*

[a] 13 dry period events and 12 wet period events, HDOH Stations 5, 6,7, 8, and 10

Table 4.6 Dissolved Inorganic Nutrient Concentrations (Geometric Means)

Station	Nitrate + Nitrite (ug/l)		Ammonia (ug/l)	
	WET	DRY	WET	DRY
Sta. 010A	**133** (3)*	----	**27** (3)	----
Sta. 009	**174** (4)	----	**53** (4)	----
Sta. 08R	**268** (3)	**1046** (8)	**5** (3)	**2** (7)
Sta. 08L	**574** (3)	**873** (26)	**13** (3)	**10** (25)
Sta. 007	----	**617** (26)	----	**49** (26)
Sta. 016L	**432** (2)	**963** (1)	**41** (2)	**21** (1)
Sta. 016R + 006	**302** (5)	**148** (26)	**61** (4)	**46** (26)
Sta. 012R	**306** (3)	**369** (3)	**58** (3)	**42** (3)
Sta. 012L	**665** (5)	**3039** (3)	**33** (4)	**15** (3)
Sta. 022	**378** (3)	**927** (1)	**66** (3)	**25** (1)
Sta. 005	----	**1054** (25)	----	**22** (25)
GRAND MEANS	**325** (31)	**585** (119)	**35** (29)	**23** (117)
State criteria	*70*	*30*	----	----

* sample sizes (n)

Table 4.7 Total and Organic Nutrient Concentrations (Geometric Means)

Station	Total N[1] (ug-N/l)		TON[1] (ug-N/l)		Total P[1] (ug-P/l)	
	Runoff Influenced	Non-Runoff	Runoff Influenced	Non-Runoff	Runoff Influenced	Non-Runoff
Sta. 010A	**711** (3)*	----	**528** (3)	----	**292** (3)	----
Sta. 009	**832** (4)	----	**532** (4)	----	**361** (4)	----
Sta. 08R	**599** (3)	**1134** (8)	**313** (3)	**81** (7)	**145** (3)	**13** (8)
Sta. 08L[1]	**883** (3)	**1487** (22)	**277** (3)	**142** (21)	**164** (3)	**76** (26)
Sta. 007[1]	----	**954** (25)	----	**220** (25)	----	**26** (24)
Sta. 016L	**1426** (2)	**981** (2)	**849** (2)	**352** (2)	**362** (2)	**57** (2)
Sta. 016R + 006[1]	**858** (5)	**559** (26)	**499** (4)	**291** (25)	**200** (5)	**35** (27)
Sta. 012R	**1165** (3)	**627** (3)	**669** (3)	**205** (3)	**309** (3)	**89** (3)
Sta. 012L	**1314** (5)	**3243** (3)	**584** (4)	**4** (3)	**208** (5)	**65** (3)
Sta. 022	**1184** (3)	**1120** (1)	**649** (3)	**168** (1)	**259** (3)	**57** (1)
Sta. 005[1]	----	**1417** (25)	----	**271** (25)	----	**36** (25)
GRAND MEANS	**956** (31)	**1038** (115)	**493** (29)	**191** (112)	**238** (31)	**39** (119)
Comparable State exceedance criteria	*800 wet season 2%*	*800 wet season 2%*			*150 wet season 2%*	*60 and 80 dry season 10% and 2%*

* sample sizes (n)

[1] Includes TDN and TDP data from HDOH which are considered as TN and TP for purposes of this analysis

In Tables 4.6 and 4.7, a division between runoff and non-runoff influenced events (see page 25) is used to compare concentrations of dissolved inorganic nitrogen (nitrate + nitrite and ammonia), total organic nitrogen, and total nitrogen. Dilution effects are suggested for nitrates – the highest nitrate values occur under conditions of no runoff into Kawa Stream, leading to a conclusion that ground water is the primary source of nitrates to the system. The middle east branch (Stations 016R and 006) appears to be an exception to this pattern. This branch is concrete lined from Station 006 to the intermittent reach. Flow declines substantially during the dry season and may not be well connected with groundwater. As an indicator of ground water quality, a sample was collected from a small seep flowing into Kawa Stream on the east bank some 10 m upstream of Station 007 (May 8, 2000). Water was allowed to flow into the pre-cleaned bottle and frozen immediately. Results obtained were: nitrate + nitrite 1240 ug-N/l and ammonia < 1 ug-N/l (AECOS Log No. 13068). This high nitrogen level may be representative of that found in shallow groundwater in the watershed.

The pattern for ammonia (Table 4.6) is less clear, although there is a tendency for all stations to show enhanced ammonia values during runoff-influenced events. Ammonia concentrations are relatively low in the upper reaches of Kawa Stream and increase to a geometric mean maximum of 51 ug/l at Station 007 near the Namoku Street bridge before decreasing further downstream. State water quality standards do not include a specific criterion for ammonia in streams.

Total N values (Table 4.7) follow the nitrate pattern (Table 4.6), which is not surprising given the fact that dissolved nitrate is a significant proportion of almost every total N measurement. Nitrate and ammonia values are subtracted from total N to derive total organic nitrogen (TON). Table 4.7 shows how TON increases during runoff-influenced periods, reflecting the additional loads of organic matter carried into the stream by runoff.

PHOSPHOROUS

Baseline concentrations of total dissolved phosphorous (TDP) concentrations measured in Kawa Stream are generally below or slightly above the State dry season geometric mean criteria for total phosphorous (Table 4.4). However, the TDP baseline at HDOH Station 008 (=08L) is double that obtained for other stream stations and exceeds the State wet season geometric mean criteria for total phosphorus (TP). This high concentration is associated with the upper west branch of Kawa Stream, which is located within a forested gulch although it may arise within Hawaiian Memorial Park cemetery.

Baseline TDP values appear slightly elevated in the wet season (Table 4.5), while the complete suite of measurements shows that TP is enhanced by runoff to levels exceeding the most liberal State criteria for TP (Table 4.7). Figure 4.2 shows the correlation between TP and TSS for runoff-influenced samples, suggesting that phosphorous loading is linked to particulate loading.

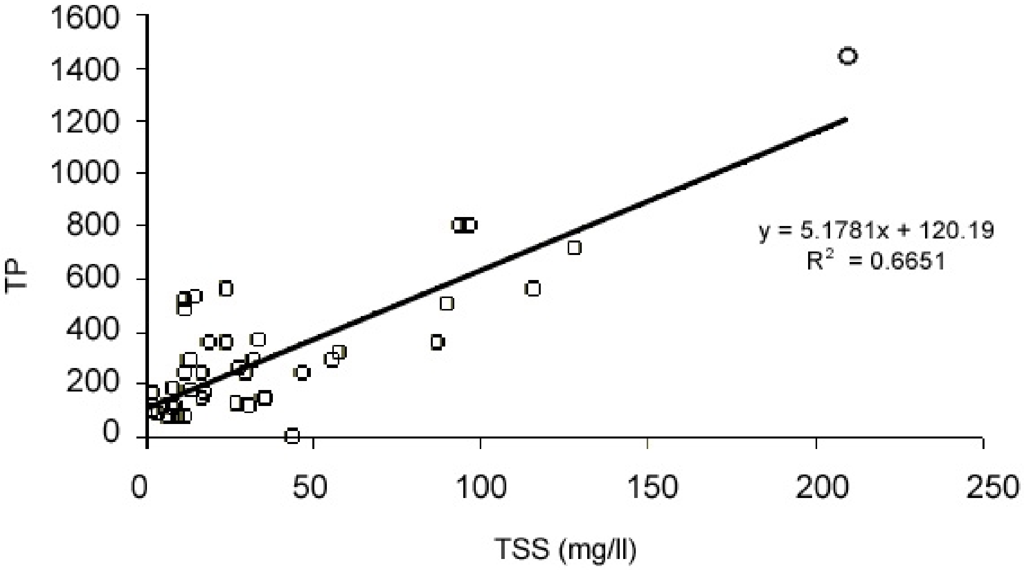


Figure 4.2: Regression of Total Suspended Solids (TSS) against runoff-influenced Total Phosphorous (TP) concentration

Historical data (AECOS 1992) suggest that soluble, inorganic phosphorus (also known as orthophosphate or ortho-P, and comparable to laboratory measurements of TDP) accounts for a significant portion of the non-runoff influenced total phosphorous values (Table 4.7). Concentrations of these dissolved forms change little over time in the lower reach of Kawa Stream, with insignificant seasonal variation (AECOS 1992; Brewer/Brandman Associates 1989; Marine Research Consultants 1997).

Soluble phosphates tend to bind with the iron-rich soil particles, and thus are not readily transported to the ground water. Therefore ortho-P is not nearly as abundant in springs and seeps as soluble nitrates, even where use of both in yard fertilizers might be considerable.

ESTUARINE WATERS

Nutrient levels in the Kawa Stream estuary are well established by numerous sampling campaigns conducted there since 1991 (AECOS 1992; Marine Research Consultants 1997; DOH monthly monitoring program 1999-2000). As Kawa Stream enters the estuary, exceedance of estuarine (not stream) geometric mean criteria for ammonia, nitrate + nitrite, and total N is the norm with DOH data showing a trend of steadily decreasing TDN in the seaward direction within the estuary. Inorganic nitrogen also appears to decrease along this gradient. These data have been evaluated for the influence of dilution with Kaneohe Bay water within the estuary (see website at http://www.aecos.com/jobs/kawa_estuary.html). When assessed against the criteria for embayments, Kawa Stream at the stream mouth (DOH Station 001) exceeds nitrate + nitrite and ammonia criteria only.

Note that because of their higher salinity, these lower estuarine stations are technically outside the boundary of this TMDL study. Pollutant loads in the estuary and bay will be the subject of future water quality management efforts following the establishment of TMDLs for other streams flowing into south Kaneohe Bay.

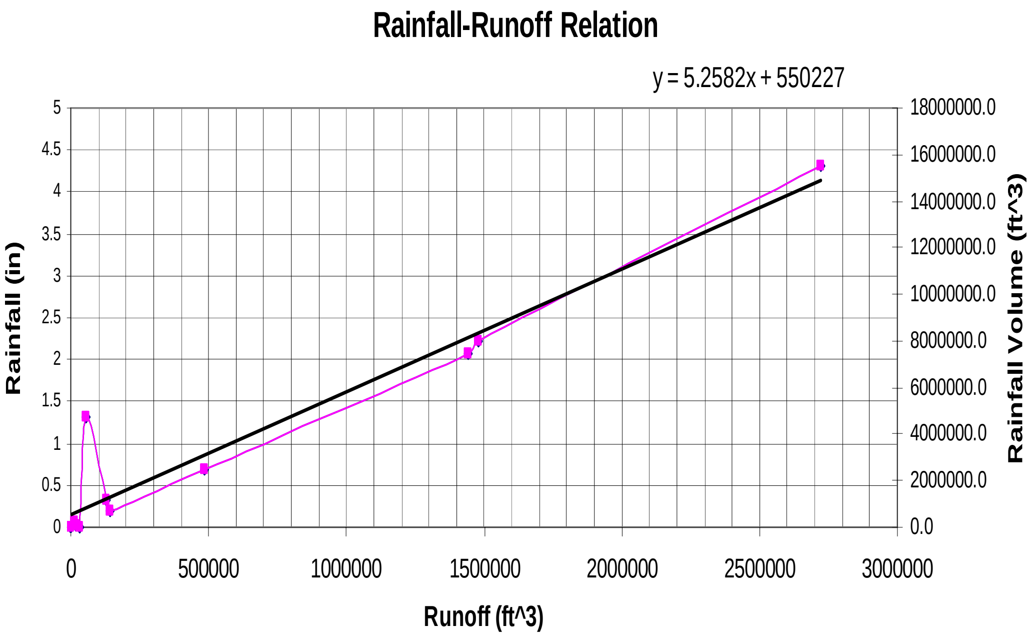
4.3 Stream Flow Analyses

Pollutant load can be calculated as the product of pollutant concentration and flow rate. Thus to calculate total pollutant load within a stream, two quantities must be known - the concentration (gm/l) of the constituent in the flow and the total volume of the flow over time (l/sec). While the sampling program yielded pollutant concentrations from numerous samples, obtaining reliable estimates of flow rate proved to be more of a challenge. Initially, we planned to derive flow rate from measurements of water height over a pre-existing weir located near the bottom of the watershed (Figure 1.1). Unfortunately this weir was washed out in a storm before any significant storm flow measurements could be obtained. To compensate for this loss of information we gained access to data previously collected at the weir during 1997 and 1998 (Nance 1999). This enabled us to characterize rates of base streamflow and storm flow and to correlate these with rainfall in the watershed.

Monthly average base flows for both 1997 and 1998 (Figure 2.14) show a summer low-flow trend and overall variation between wet (1997) and dry (1998) years. Average summer base flow (May-October) for these two years was calculated as 0.89 cfs and average winter base flow (November-April) as 1.30 cfs. Base flow is strongly correlated with a weighted rainfall averaged over the previous 60 days.

Nance provided additional data that generated hydrographs for three storm events occurring during these two years. These runoff data were correlated to rainfall data obtained from an automatic recording rain gauge (Civic Center) located in sub basin #8 of the watershed, and the correlation coefficients obtained were used to determine how total stream flow is partitioned between storm runoff and base flow (Appendix A, Rainfall-Runoff Relation). The maximum total stream flow in Nance’s data corresponds to a 4" rainfall event, and the rainfall/runoff relationship is almost linear with only about 18% of total rainfall volume contributing to storm runoff. While storms with more than 4" of rain could rapidly saturate the surface and generate nearly 100% of their volume in storm runoff, a 20% runoff coefficient is a conservative assumption for rainfall events up to 4".

Use of Nance's data (Figure 4.3 and Appendix A) allows us to make water balance calculations from rainfall data only (Table 4.10 and Section 4.5). As suggested above and in Figure 4.3, about 20 percent of rainfall is partitioned into direct runoff during storm events. Total base flow is obtained directly from Nance's data. On an annual basis, the difference between the total volume of rain falling on the watershed and base flow plus storm runoff is calculated as "Evaporation and other losses" (Table 4.10 and Section 4.5). These losses, transformed to and “Equivalent pan evaporation rate” of 1.3” to 3.2” per month (Table 4.10), compare favorably with typical evaporation on Windward Oahu (2" per month, USGS 1996) and support the accuracy of our rainfall/runoff characterizations. Another key suggestion from this water balance exercise (Table 4.10) is that direct runoff from storm events contributes about half of the total annual streamflow while ground water discharge throughout the year provides the other half.



Storm #	Total rain (in)	Duration (hrs)	Percipitation (ft^3)	Storm Runoff (ft^3)	Percent Runoff
6	0.01	0.25	36016.4	1323	4%
1	0.06	3.25	216098.3	13617	6%
11	0.02	0.75	72032.8	16481	23%
7	0.01	0.25	36016.4	30837	86%
8	1.31	3.25	4718145.6	56353	1%
3	0.32	4.25	1152524.1	127515	11%
9	0.19	1.25	684311.2	143912	21%
4	0.69	8.25	2485130.1	484404	19%
10	2.06	6.25	7419374.0	1439910	19%
5	2.22	12.00	7995636.0	1477553	18%
2	4.3	25.25	15487042.7	2721692	18%

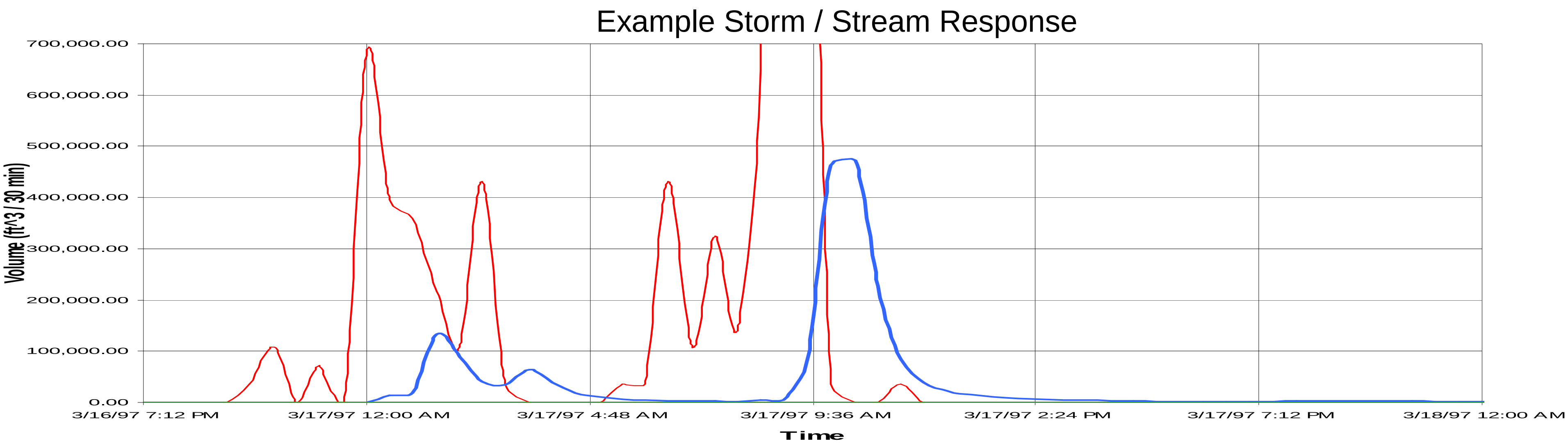


Figure 4.3 Rainfall/runoff relation in Kawa Stream with example from single storm on 03/17/1997. Lower chart shows total rainfall volume (red) and stream discharge response (blue). Highlighted storm data in table not used - these storms centered on the rain gauge or the watershed, not both. Detailed calculations for all storms in Appendix A.

The U.S. Geological Survey (USGS) previously maintained a “crest stage” gauging station at the Kaneohe Bay Drive bridge over Kawa Stream, just upstream from the weir installed by Nance. This type of gauge consists of a long chalked marker hung inside a metal pipe. The chalked marker is occasionally removed and the height to which the chalk dissolved is noted as the peak since the prior reading date (Table 4.8). The bridge culvert acted as a very large (and somewhat imprecise) discharge rating control section, allowing stream flow calculations based on peak flow height, or “crest stage.”

Because there is no overlap between the USGS and Nance data sets, there is little chance of establishing valid correlations between the two. However, comparison of USGS annual peak discharge data (Table 4.8) with Nance’s data and associated rainfall data may suggest that the USGS methods overestimate streamflow. For example, USGS estimated streamflow at about 450 cfs when peak flow height was about 6 feet (Table 4.8 entry for 10/19/85). In 1997, a 4.3" rainfall event produced a stream height 6 feet above the weir and a total discharge of 2.7 million cubic feet for a comparative streamflow of only 250 cfs. Note that this analysis is compromised by the fact that the two gauging stations are in different locations with different channel geometries, and therefore we would not expect flow heights to be the same at both stations for a given rate of streamflow.

USGS data also reveal that peak flow heights of 6 to 10 feet above datum encompass 90 percent of the recorded peak flows (Figure 4.4). Unfortunately, on very rare occasions (twice in 20 years, which is approximately the return rate for hurricanes and other extreme weather events in Hawaii) the peak height is about double this figure - 17 feet. The USGS estimates a flow rate of about 5,000 cfs at this stream height, but without time-series data it is difficult to estimate the total flow volume discharged during such events.

Table 4.8 Peak Discharge at USGS Crest Stage Station

Date	Peak Discharge	
	(cfs)	(ft above datum)
05/02/65	4750	17.0
01/27/68	2260	11.3
02/01/69	5290	17.9
01/26/70	580	6.37
04/24/71	758	6.96
04/14/72	779	7.03
01/27/74	548	6.26
05/12/77	557	6.29
10/30/78	450	6.08
01/08/80	1930	10.45
05/07/81	929	7.53
03/14/82	779	7.03
10/28/82	785	7.05
02/14/85	644	6.58
10/19/85	446	5.92
12/31/87	1460	9.11
04/04/89	902	7.44
01/16/90	440	5.93
11/13/90	1300	8.66
02/14/92	398	5.76
12/30/92	776	7.02
02/15/94	602	6.44
10/16/94	539	6.23

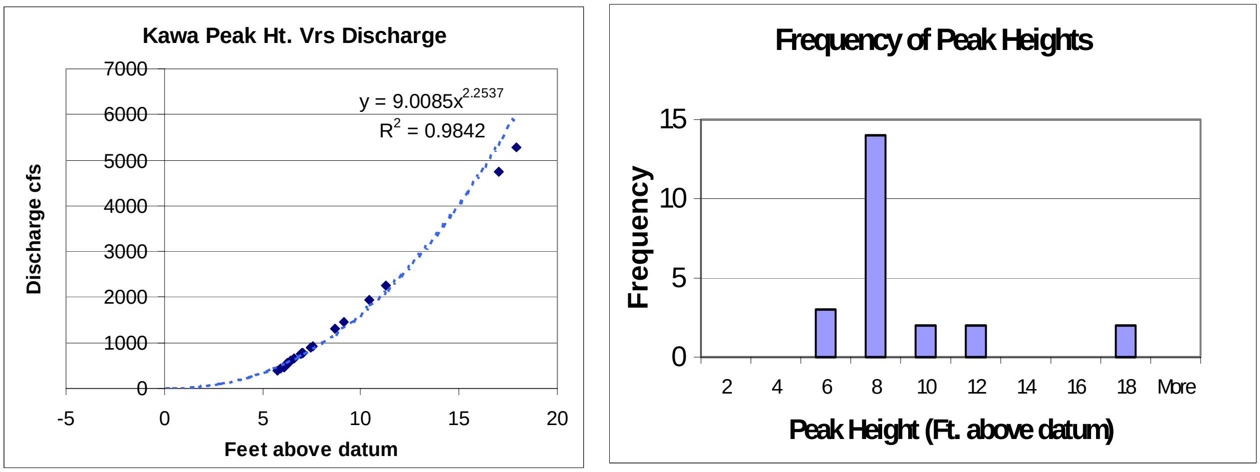


Figure 4.4: Peak Streamflows at USGS Crest Stage Station, 1965-1994

4.4 Modeling Kawa Stream Nutrient and Sediment Loads

4.4.1 Introduction

There are no universally accepted models for predicting sediment transport and nutrient loading in Hawaii's varied and unique watersheds. Environmental conditions within the islands are significantly different than anywhere in the continental U.S., where many models have been developed. In addition, climatic, topographic, and geologic conditions vary significantly from watershed to watershed on individual islands. Previous studies (e.g. Freeman 1993) suggest that that average annual discharge of sediments per unit of watershed area varies greatly in Hawaii, with no apparent correlation to location. In order to determine loading of TSS, total N, and total P from Kawa Stream to its receiving water, Kaneohe Bay, a local pollutant-loading model was created.

Sediment loading in streams is a function of a number of physical processes such as rainfall; runoff; erosion of hillslopes, gullies and stream channels; and the subsequent transport and deposition of eroded sediment. Sediment can be considered a conservative element within the watershed system. It follows the law of conservation of mass, and this mass of sediment is neither created nor destroyed within the system. The above-mentioned physical processes, modified by land use patterns and human activities within the watershed, influence the stream water column concentration profiles for sediments. While not a direct measurement of total sediment load in streams, total suspended solids (TSS) is used here as an indicator of total load.

Sediment-loading curves can be developed specific to particular stream locations. In general, pollutant concentrations rise and fall rapidly during storm events, and the concentration peak usually occurs before the stormwater discharge peak. This is mainly due to the flushing effect of the stormwater runoff, through which most pollutants are flushed out of a watershed during the early part of a storm event.

4.4.2 Pollutant-Loading Model Description

The following modeling effort relies on the combination of a deterministic hydrologic model and a pollutant-loading model based on measured pollutant concentration profiles. Coupled, these components provide a predictive model. This model is designed to accurately estimate pollutant concentration profiles throughout the watershed based on input from a streamlined scientific sampling effort.

- *Hydrologic Model*

The hydrologic model used in this study is HEC-HMS Version 2.1.1 (Hydrologic Engineering Center-Hydrologic Modeling System). It is distributed, along with a User's Manual and Technical Reference Manual, by the U.S. Army Corps of Engineers (http://www.hec.usace.army.mil) and has found widespread use and acceptance by hydrologists and engineers. It is based on established principles of watershed modeling and is simple yet complete in its analysis.

HEC-HMS has three input modules used to determine rainfall-runoff relationships - a basin model, a meteorological model, and a control specification module.

The basin model characterizes the watershed in terms of sub-basin areas, land uses, soil groups, cover types, slopes, and stream reach lengths (See Figure 4.5). All of these characteristics are combined and transformed into rainfall-runoff curves. For Kawa Stream, a standard Soil Conservation Service (SCS) runoff curve transform was used. This transform requires a lag time that is based on the above-mentioned watershed characteristics. The basin model also allows for input of base flow and loss rate. Base flow was assumed to be constant at the rate measured by Nance in 1997 and 1998. Loss rate is an additional infiltration component that can be coupled with infiltration rates calculated from soil types. For simplicity's sake the loss rate was assumed to be negligible, eliminating the need to select SCS curves for loss rate calculation.

The meteorological model allows for input of weather events. Rainfall data for storm events that occurred during the project period (1999-2001) were obtained from Oceanit rain gauges on either side of the watershed and used as model input.

The control specification allows the used to define the timeframe to be analyzed. Target dates were entered for storm events that coincided with water quality sampling during the project period (1999-2001).

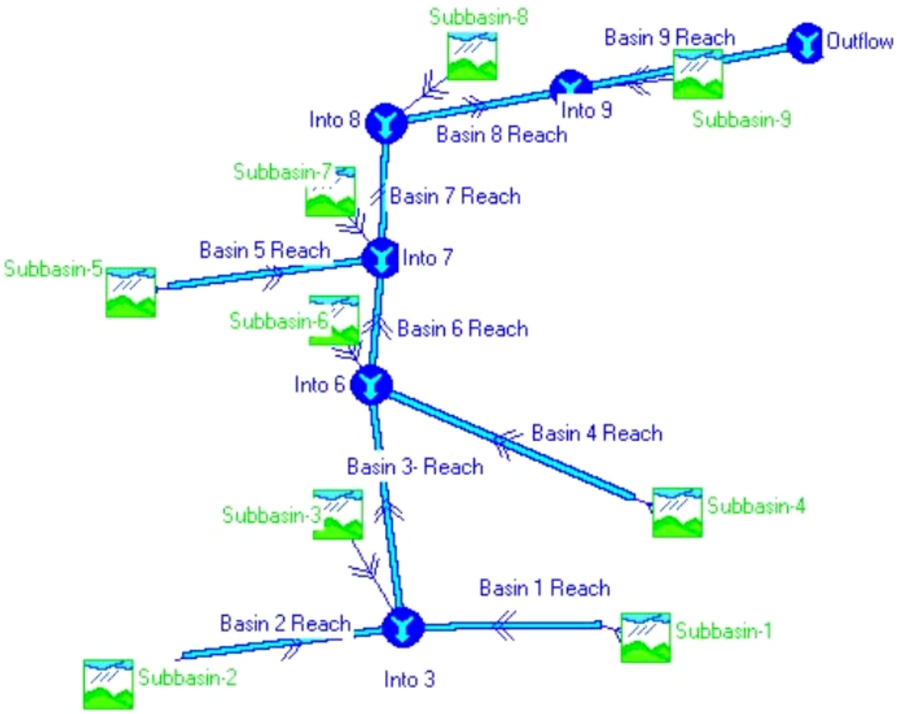


Figure 4.5: HEC-HMS model schematic

- *Pollutant Loading Model*

The model used to estimate pollutant loading for the Kawa stream was developed within the constraints of relative data scarcity. While numerous water quality samples were collected throughout the study period, they cover a wide variety of sampling locations, storm events, and runoff conditions. Although the samples represented a wide range of hydrologic and pollutant loading conditions, no storm event was sampled so comprehensively as to allow for continuous tracking of pollutant loading within the stream system.

In order to estimate pollutant loading, a framework was constructed that could be applied to the data available and also to data collected from future storm events. This involved first characterizing the pollutant-loading curve for the Kawa watershed, then applying that curve to rainfall events and water quality sampling data in order to determine the overall pollutant load delivered to the receiving water.

The characteristic pollutant-loading curve was empirically determined and then compared to conclusions drawn from other studies (Jones et. al 1971; Shade 1984). This data-based approach led to the development of a conceptual model of pollutant loadings. The model's reliability will improve with better data sets, which can be obtained through a sampling protocol capable of tracking both spatial and temporal changes within the watershed. An improved sampling protocol that utilizes automated sampling technology to track these changes is currently under development in TMDL studies of Kaneohe stream (Oahu) and Waikele stream (Oahu).

- *Calibration*

Calibration of model parameters refines the accuracy of the results generated. Hydrologic model predictions of total streamflow at the base of the watershed (in the vicinity of Station 005) were calibrated against actual stream flow data by first comparing the computer generated hydrograph to the hydrograph derived from field measurements obtained there during storm events. Streamflow data obtained from upstream sampling stations were compared on an order-of-magnitude basis to model generated hydrographs for the pertinent sub-basins. Hydrologic model inputs were then evaluated and modified to bring the modeled and measured results into better agreement.

Hydrograph calibration can also be aimed at improving our ability to sample and model the peaks of basin pollutant loading curves. To properly schedule storm event sampling, water quality monitoring analysts must predict the water level and lag time (time elapsed since the beginning of a storm event) at which the concentration curve will peak. Comparing field data with model output and adjusting both field sampling protocols and hydrologic model parameters to converge on the peak of interest can improve these predictions. Also, as the curve is calibrated for a particular location (e.g. at the base of the watershed), its shape can serve as a template for other locations where more limited concentration data are available (see Section 4.4.3 below).

4.4.3 Results for Kawa Stream Watershed

In order to characterize Kawa stream pollutant concentration curves, the water quality data archive was searched for occasions when multiple water quality samples were collected at any specific sampling location during a continuous storm event. Two were found, both at Station Number 007. Six samples were collected there during the January 19-20, 2000 storm event and four samples were collected during the February 8-9, 2001 storm event (5 cm total rainfall). When plotted out over the duration of both storm events, the TSS concentration curves rose and fell more quickly than the Station 007 storm flow hydrographs. The concentration curves also peaked earlier and exhibited shorter peak duration times than the hydrographs, further supporting the idea that sediments are quickly flushed from the watershed system (see example for February 8-9, 2001 in Figure 4.6).

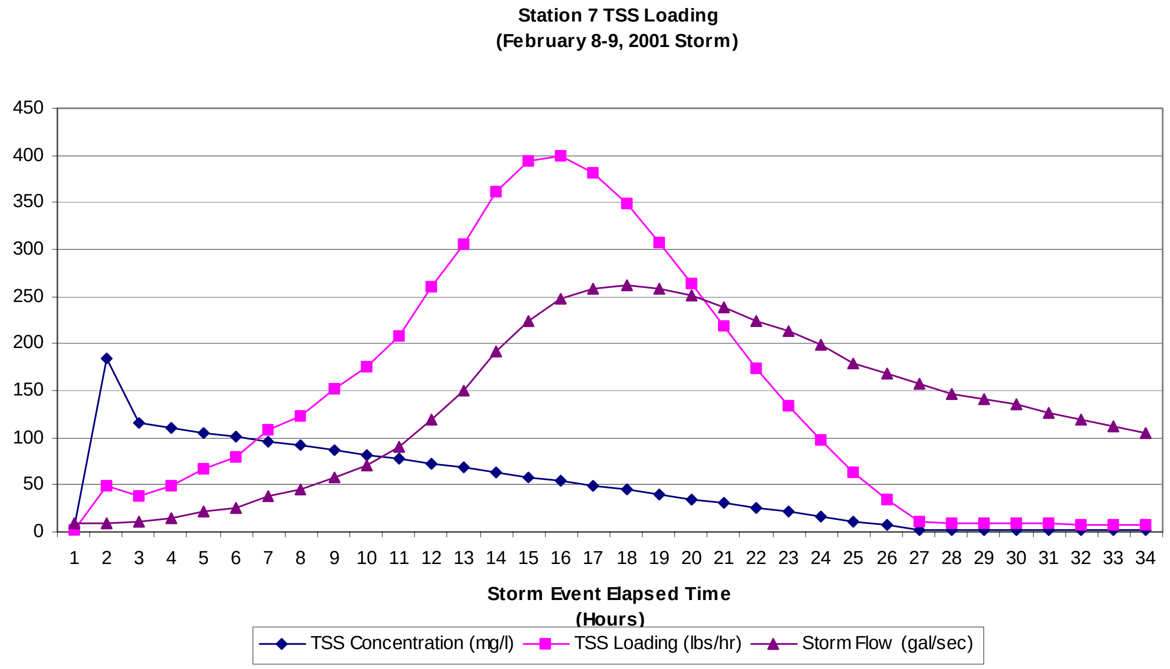


Figure 4.6: Station 007 TSS Loading

However, this scenario varies from the sampling protocol scenario developed for Station 007, where the pollutant load concentration curves were plotted from available Kawa Stream data. Station 007 lies near the lower end of the upper middle reach, well above the base of the watershed near Station 005. For the purposes of this discussion, Station022 - just upstream from Station 005 - provides a location at the base of the watershed where multiple samples were collected.

In order to estimate stream pollutant loading to the estuarine receiving water, the shape of the pollutant concentration curve from Station 007 was scaled to fit the data collected at Station 022. For example, the February 8-9, 2001 storm event yielded a single measurement of TSS at Station 22 (94 mg/l). At the corresponding point in time on the Station 007 concentration curve, measured TSS was 184 mg/l. In order to preserve the shape of the Station 007 TSS concentration curve at Station 022, its values were then scaled down for Station 022 by a factor of 184/94. The resulting concentrations were then multiplied by the hydrologic model-generated streamflow values for Station 022 to create a sediment loading curve that was integrated to determine the total sediment load delivered to the estuary for the storm event in question (See Figure 4.7). This scaling and integration process was then repeated for total nitrogen and total phosphorus (See Figure 4.8).

Table 4.9 shows the results of using this method to derive total pollutant loading for the February 8-9, 2001 storm event (5 cm total rainfall).

Table 4.9. Pollutant Loading at Kawa Stream Outlet

Pollutant	Model Output	Mass Balance Calculations
Sediments	2,300 kg	1,348 kg
Nitrogen	42 kg	38 kg
Phosphorus	13 kg	9 kg

The peak streamflow predicted by the hydrologic model for the Kawa stream outlet during this storm was 2.7 cubic meters per second with a total predicted discharge of 40,000 cubic meters of water. The predicted sediment load (2,300 kg) translates to an erosion rate of about 5 lbs of sediment per acre throughout the watershed. Model output for all pollutants is well within order-of-magnitude agreement with mass balance calculations for this storm. In the mass balance calculation, runoff-influenced storm water concentrations of TN and TP from Table 4.7 (TN = 956 ug/l, TP = 238 ug/l) and of TSS from Table 4.3 (TSS = 34 mg/l) are multiplied by the total stream discharge for the event (3.96×10^7 l of water).

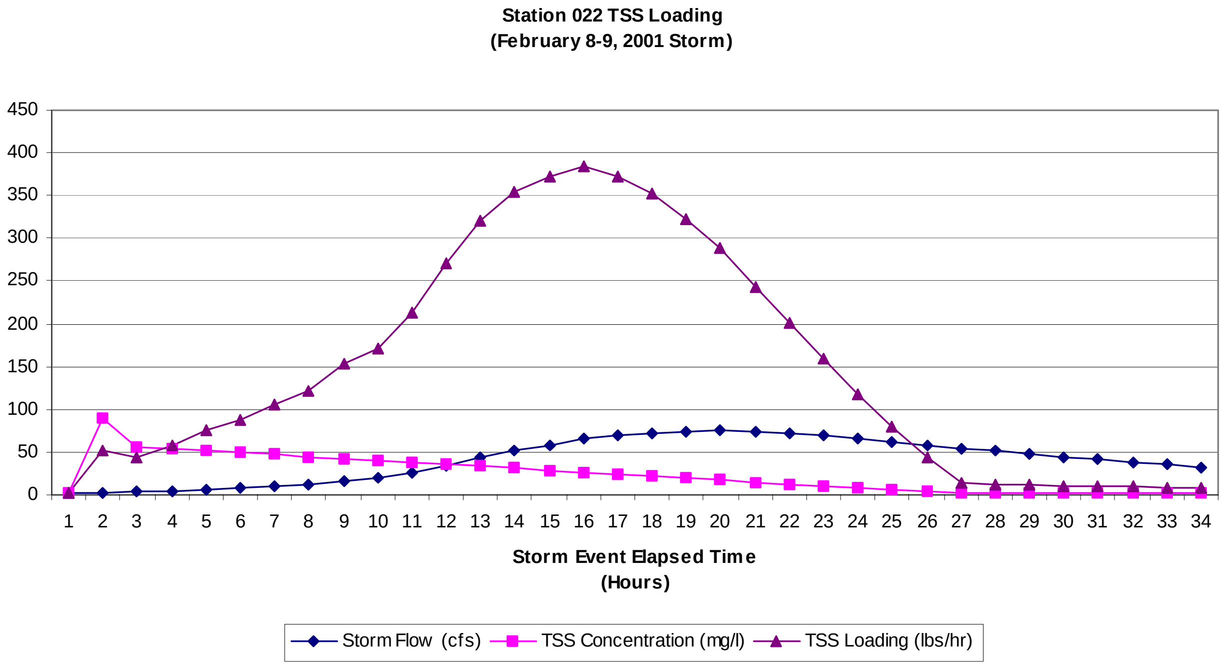


Figure 4.7: Station 022 TSS Loading

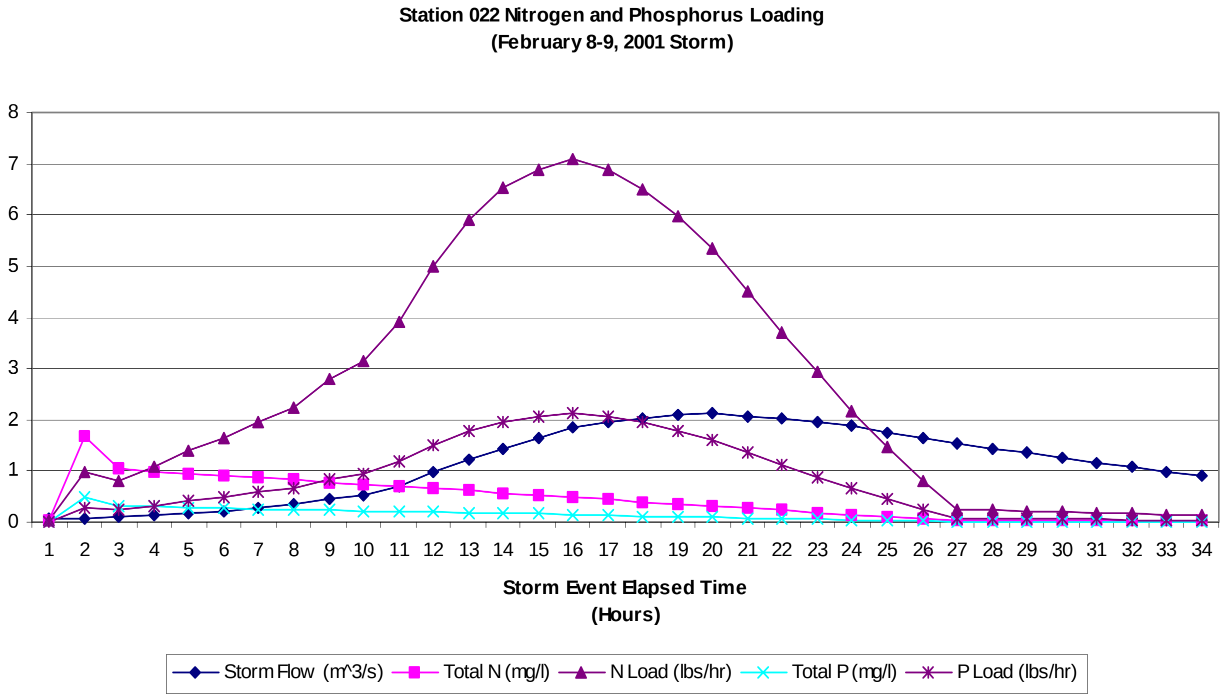


Figure 4.8: Station 022 Nitrogen and Phosphorous Loading

- *Pollutant Sources Within Watershed*

Pollutant concentrations at each of the sampling locations varied with different storm events in a way that precludes any statistically significant conclusions from the model as to the relative contribution of various basins to the overall pollutant load. However, pollutant contributions from particular basins can be suggested through areally weighted averaging of pollutant contributions typically associated with different land uses and land cover types (see Section 5.0, Load Allocations).

4.4.4 Model Strengths and Limitations

A pollutant load-estimating model as described above requires that the loading for storm events be well documented at the base of the watershed. Redundant sampling at other strategic points throughout the watershed enables accurate estimation of load allocations for various sub-basins. Coordination of the sampling procedure allows patterns within the watershed to emerge and be accounted for in the model. This approach allows us to overcome data scarcity limitations through a targeted yet comprehensive water quality data collection protocol. The model also allows for exploration of how changes to pollutant loading scenarios may be triggered by changes in land use practices or other activities.

The model has a number of limitations as well. Hydrologic model calibration relies upon considerable professional judgment. Pollutant concentration curve calibration is strictly empirical and depends upon accurate sampling of concentration peaks. The model assumes that all pollutants are conservative, which is not necessarily the case for nutrients. A related concern is that the model does not consider how pollutants accumulate in the watershed between storm events.

4.5 Mass Balance Model

As a rational check on the hydrologic pollutant-loading model, we also developed a simpler pollutant mass balance model using a basic annual water balance (Section 4.3 and Table 4.10). The water balance utilizes streamflow data from 1997-1998 and a 20% rainfall/runoff coefficient derived from streamflow and rainfall data. Ignoring any groundwater inflow (from the Koolau mountains) or outflow (to the ocean), the total rainfall over the watershed is roughly accounted for by the sum of base streamflow, stormflow, and evaporation. In Table 4.10, “Evaporation and other losses” is calculated as total rainfall volume minus total streamflow. The result - about 72.5 mcf (million cubic feet) - is equivalent to 21 inches of rain over the watershed in a year, and agrees with published pan evaporation rates of about 2 inches per month (U.S. Geological Survey 1996). Based on relationships among entries in the “Average (’97-’98)” data column (Table 4.10), we use the same percentages to calculate the total base streamflow (15.9 mcf wet season, 10.9 mcf dry season), storm runoff (24.8 mcf), and total evaporation (72.5 mcf) in the watershed during 2000 based solely on measured rainfall.

Multiplying these flow rates by average nutrient and TSS concentrations (Tables 4.2, 4.3, 4.5, and 4.7) yields the total annual flux of pollutants carried by the stream to the estuary (Table 4.11).

Table 4.10. Water Balance Calculations

	1997	1998	Average ('97-'98)	2000
Yearly Rain Total (inches)	**66.6**	**25.2**	45.9	**35.63**
Total Rain Volume over Watershed (mcf)	232	88	160	124
Direct Runoff Total (20%) (mcf)	46.4	17.6	32.0	24.8
Base Flow – Wet Season – cfs	**1.75**	**0.85**	1.30	1.01
Base Flow – Wet Season - mcf	27.6	13.4	20.5	15.9
Base Flow – Dry Season – cfs	**1.58**	**0.2**	0.89	0.69
Base Flow – Dry Season – mcf	24.9	3.2	14.0	10.9
Evaporation & other losses - mcf	133.2	53.7	93.4	72.5
Base Flow - % of total stream flow	53.1	48.5	51.9	51.9
Storm Flow - % of total stream flow	46.9	51.5	48.1	48.1
Equivalent pan evaporation rate (in/mo)	3.2	1.3	2.2	1.7
Total Stream Flow - mcf	98.9	34.1	66.5	51.6

* measured values are in BOLD type
mcf = millions of cubic feet
Total rain for 2000: 35.63"
Total Volume of rain in watershed: 124,000,000 ft^3
Total Runoff (20 % of rain over watershed): 24,800,000 1 ft^3

We also investigated mass balance model predictions for a 2-inch storm, which implies a total rainfall volume of about 7 million cubic feet over the watershed area of 1.5 square miles. At 20% direct runoff this represents about 1.4 million cubic feet of streamflow volume, or 40 million liters of water. Using mean pollutant concentrations from all stormwater samples of 956 µg/l TN and 238 µg/l TP (Table 4.7) and 34 mg/l TSS (Table 4.3), this yields a total pollutant load of 38 kg (83 lbs) TN, 45 kg (21 lbs) TP, and 1342 kg (3000 lbs) TSS entering the Kawa Stream estuary during a 2" rainfall. These results are well within order-of magnitude agreement with those developed from the pollutant-loading model (see Table 4.9).

4.6 Source Analysis and Estimation

In this section we estimate the total quantity of suspended solids and nutrients discharged into Kawa Stream from all groundwater and storm runoff sources under existing conditions. These estimates are the product of the total stream discharge in the year 2000 and the average concentration of each of the constituents of concern (see Section 4.2). Thus under existing conditions in the Kawa Stream watershed, the estimated annual total suspended solid load is 27,087 kg/yr (about 59,590 lb/yr), the total nitrogen load is 1378 kg/yr (about 3,030) lb/yr, and the total phosphorus load is 196 kg/yr (about 430 lb/yr) (Table 4.11).

We then assign these quantities to wet season base flow, dry season base flow, and storm runoff flows according to proportions established by hydrologic analysis. Table 4.11 shows that most of the existing annual pollutant load is contributed during storm runoff events (49% of TN, 85% of TP, 88% of TSS).

Most discharges of stormwater runoff into Kawa Stream are permitted under National Pollutant Discharge Elimination System (NPDES) permits issued to the City and County of Honolulu (HI0021229) and the State of Hawaii Department of Transportation (HI0021245). The State system primarily involves runoff associated with state roads and highways (mainly Kaneohe Bay Drive and Kamehameha Highway), while the City and County system accepts stormwater from a wider variety of land uses within the watershed. Locations of County storm drains are shown on the maps in Figures 2.3, 2.7, 2.11, and 2.12. There are approximately 20 storm drainpipes greater than 12 inches diameter that discharge into the stream above Kaneohe Bay. Although the storm drains are technically a point source, they receive virtually 100 percent of their input from non-point sources, and this input is incorporated in our non-point source load calculations. Thus all calculations of existing pollutant loads, TMDLs, and load allocations refer exclusively to non-point sources.

Table 4.11 Existing Pollutant Load Calculations, Year 2000

			Total Nitrogen			Total Phosphorous			Total Suspended Solids		
	Cubic Ft. x 10^6	Liters x 10^6	ug/l	Kg	Kg/da	ug/l	Kg	Kg/da	mg/l	Kg	Kg/da
Wet Season Base Flow Volume*[1]	15.9	451	939	423	2.34	41	18.5	0.10	4.4	1984	11
Dry Season Base Flow Volume*[2]	10.9	308	918	283	1.54	33	10.2	0.06	3.9	1201	7
Storm Runoff Volume**[3]	24.8	703	956	672	1.84	238	167.3	0.46	34	23902	66
Total Flow Volume[4]	51.6	1462	-	1378	3.78	-	196	0.54	-	27087	74

*** Data from DOH Baseline samples**

**** Data from AECOS runoff-influenced samples**

[1] Wet season loads (Kg) are divided by 181 days (wet season from November 1 to April 30) to obtain daily loads (Kg/da) for the seasonal period. See notes below.

[2] Dry season loads (Kg) are divided by 184 days (dry season from May 1 to October 30) to obtain daily loads (Kg/da) for the seasonal period. See notes below.

[3] Storm runoff annual loads (Kg) are divided by 365 days to obtain daily loads for the annual period.

[4] Total annual loads (Kg) are divided by 365 days to obtain daily loads for the annual period.

4.7 TMDL Loading Caps / Linkage Analysis

This section estimates the seasonal and annual capacity of Kawa Stream to receive TP, TN, and TSS loads without exceeding specific concentration criteria established in the State of Hawaii water quality standards. Given the existing conditions shown in Table 4.11, Table 4.12 presents clean water goals for the future when pollutant loads have been reduced. These goals are presented as load targets for each pollutant under various streamflow regimes - wet and dry season base flow, storm runoff, and total annual streamflow. The base flow targets were computed by multiplying the seasonal geometric mean criteria for each pollutant (Table 1.1) by the total stream discharge for the corresponding six month base flow time period.

Storm runoff targets were calculated by first constructing log-normal cumulative probability distributions fitted to the State wet season concentration criteria for each pollutant (geometric mean, 10% exceedance and 2% exceedance). We then selected the 70% cumulative probability value for TN and TP computations and the 55% cumulative probability value for TSS, and multiplied these by a representative storm runoff discharge to obtain storm runoff load targets. These selections were based on analysis of rainfall-runoff data for 1997 (Figure 2.17) in which 0.5 inches of rain per day defines the storm runoff threshold. There were 65 days of the year (82nd percentile) with rainfall above this threshold, and we assumed that this runoff did not persist over each hour of each day. Thus the 82nd percentile of the wet season criteria served as an upper limit for storm runoff criteria. Using the 80th percentile of the wet season criteria to generate storm runoff load targets raised the acceptable TP concentration to about 80 mg/l and the TN concentration to about 430 mg/l. Because this would decrease the criteria exceedance level and lower the nutrient load reduction target, we use a more conservative (70th percentile) assumption as a contribution to Total Maximum Daily Load Margin of Safety.

Table 4.12 Total Maximum Daily Loads Based on State Water Quality Standards Criteria

			Total Nitrogen			Total Phosphorous			Total Suspended Solids		
	Cubic Ft. x 10^6	Liters x 10^6	ug/l	Kg	Kg/da	ug/l	Kg	Kg/da	ug/l	Kg	Kg/da
Wet Season Base Flow Volume*[1]	15.9	451	250	113	0.62	50	22.6	0.12	20	9020	50
Dry Season Base Flow Volume*[2]	10.9	308	180	55	0.30	30	9.2	0.05	10	3080	17
Storm Runoff Volume**[3]	24.8	703	350	246	0.67	125	87.9	0.24	25	17575	48
Total Flow Volume[4]	51.6	1462	-	414	1.13	-	120	0.33	-	29675	81

* Wet and Dry Season calculations utilize State geometric mean concentration criteria

** Storm Flow calculations utilize concentrations obtained at 70% (TN and TP) and 55% (TSS) on a cumulative probability curve fitted to State wet season concentration criteria.

[1] Wet season loads (Kg) are divided by 181 days (wet season from November 1 to April 30) to obtain daily loads (Kg/da) for the seasonal period. See notes below.

[2] Dry season loads (Kg) are divided by 184 days (dry season from May 1 to October 30) to obtain daily loads (Kg/da) for the seasonal period. See notes below.

[3] Storm runoff annual loads (Kg) are divided by 365 days to obtain daily loads for the annual period.

[4] Total annual loads (Kg) are divided by 365 days to obtain daily loads for the annual period.

Cumulative annual load targets (last row in Table 4.12) result from adding wet season, dry season, and storm runoff load targets. These are presented as true “daily loads” in Table 4.14.

Each of the targets presented in Table 4.12 provides a Total Maximum Daily Load (TMDL) that can be used in developing load allocations for suspended solids, nitrogen, and phosphorus throughout the watershed. When these load targets are subtracted from corresponding existing pollutant loads in Table 4.11, the resulting “load reduction targets” (Table 4.13) show how much the existing loads must be reduced in order to hit the targets. These load reduction targets can be partitioned throughout the watershed and used to guide TMDL implementation and other pollution control and water quality improvement strategies.

Table 4.13 Pollutant Load Reduction Targets

(Difference between values in Tables 4.11 and 4.12)

			Total Nitrogen			Total Phosphorous			Total Suspended Solids		
	Cubic Ft. x 10^6	Liters x 10^6	ug/l	Kg	Kg/da	ug/l	Kg	Kg/da	ug/l	Kg	Kg/da
Wet Season Base Flow Volume*	15.9	451	689	310	1.7	-9	-4.1	-0.02	-15.6	-7036	-39
Dry Season Base Flow Volume*	10.9	308	738	228	1.2	3	1.0	0.01	-6.1	-1879	-10
Storm Runoff Volume**	24.8	703	606	426	1.2	113	79.4	0.22	9	6327	17
Total Flow Volume	51.6	1462	-	964	2.6	-	76	0.21	-	-2588	-7

Negative values indicate that existing loads correspond with pollutant concentrations that already attain State water quality standards and no load reductions are necessary to meet TMDLs established in Table 4.12. Due to cumulative effects of rounding procedures in computations, some values in this Table (obtained from subtraction of Table 4.12 from Table 4.11) do not exactly match the value that would be obtained by multiplying or dividing within this table.

Table 4.14 Total Maximum Daily Loads by Season and Storm Conditions

TMDLs	Dry Season	Wet Season	Storm (Avg. Annual)
NITROGEN TMDL	0.30 kg /day	0.62 kg /day	0.67 kg /day
PHOSPHORUS TMDL	0.05 kg /day	0.12 kg /day	0.24 kg /day
TSS TMDL	17 kg /day	50 kg /day	48 kg /day

5.0 LOAD ALLOCATIONS TO POINT SOURCES, NON-POINT SOURCES, AND NATURAL BACKGROUND SOURCES

In this section we allocate pollutant loads for the entire Kawa Stream watershed to point sources, non-point anthropogenic sources, and natural background sources. We then partition these allocations based upon land use and divide them among the basins within the watershed.

5.1 Point Sources of Pollution within the Watershed

There are two permitted point source dischargers contributing stormwater runoff to Kawa Stream – the State of Hawaii Department of Transportation (NPDES Permit HI0021229) and the City and County of Honolulu Department of Environmental Services (NPDES Permit HI0021245) (see Section 4.6). Each of these stormwater discharges may contribute significant loads of pollutants to the stream, but sufficient information to distinguish between them is not available. Moreover, we have yet to distinguish between these stormwater inputs to the stream and other storm runoff that bypasses the storm drains to flow directly into the stream channel.

Because virtually all of the known inputs to these storm drain systems have non-point source origins, the entire point source load allocation for all TMDLs is established at net zero. This means that the pollutant load exiting a storm drain system should not exceed the load entering that system, and the pollutant load entering the system is allocated, for now, entirely to natural background and non-point sources.

As part of the TMDL implementation process, we will work with the DOH NPDES permitting office and the permit holders to quantify and revise waste load allocations to these two point sources over the next two years. Anticipated tasks include strategic stormwater sampling and more detailed delineation of storm drain contributing areas. This will give the permit holders clearer targets as they focus greater attention on pollution control issues in the context of approaching NPDES permit expiration dates (September 08, 2004).

5.2 Natural Background Sources of Nutrients and Sediments

The uppermost branches of the Kawa Stream system drain undeveloped, forested lands regarded as natural sources, and the output of nutrients and sediments from these lands can be defined as background. Unfortunately, these branches are ephemeral and did not provide enough flow during the study period to allow for water quality sampling. While groundwater has been identified as a possible source of nitrates in the watershed, no wells or groundwater discharges for characterizing the chemistry of natural background groundwater inputs could be found within the forested lands.

In the absence of information about natural background sources specific to the Kawa Stream watershed, we computed geometric mean values for nutrient concentrations sampled above anthropogenic influences in other windward Hawaiian streams (Table 5.1).

Table 5.1 Water Quality from Other Hawaii Stream Systems

Stream Name	Elev. *(m)*	DIN *µg N/L*	TON *µg N/L*	TN *µg N/L*	TP *µg P/L*	Source
Kilauea, Windward Kauai	*90*	11 (2)*	138 (2)*	149 (2)*	52 (2)*	AECOS
Waihee, Windward Oahu	52	85 (9)*	92 (14)*	177 (9)*	47 (9)*	USGS
Pahehee, Hamakua Hawaii	*400*	8 (2)*	97 (2)*	105 (2)*	6 (2)*	AECOS
Kolekole, Hamakua Hawaii	*Var.*	72 (2)*	< 1 (2)*	< 1 (2)*	5 (2)*	AECOS
Waikane, Windward Oahu	~	~	~	145	45	Young (1976)

*Number of data points given in parentheses

Based upon these observations and a total annual stream discharge of 51.6 million cubic feet (1.46 x 10^9 l), nutrient loads from natural background sources in the Kawa Stream watershed are estimated at approximately 219 kg/year for TN (150 ug/l) and 36.5 kg/year for TP (25 ug/l). This represents about 67 percent of the TP and about 16 percent of the TN measured in Kawa Stream during base flow conditions.

Although the watershed is urbanized it contains several areas (particularly bare stream banks) of extensive, erosion-prone surfaces. Comparisons of sediment load calculations with observed sub-basin erosion potential were used to determine natural erosion rates. Steep, forested lands showed almost no runoff response during heavy rainfall, and therefore no erosion was occurring in these areas. Thus natural background erosion is assumed to be 10 percent of the existing 27,094 kg (or about 2709 kg/year for the entire 1000-acre watershed) as a conservative background estimate that contributes to the TMDL Margin of Safety.

No records were available for determination of background nutrient or TSS loads under stormflow conditions. Under stormflow conditions the total load is assumed, for the purpose of this report, to be anthropogenic.

5.3 Load Partitioning to Land Uses within the Kawa Watershed

In order to determine nutrient loading factors for land uses within the Kawa watershed, we utilized nutrient data for groundwater under various land use influences collected by the U.S. Geological Survey's National Water Quality Assessment program (NAWQA).

Table 5.2 Geometric Mean Values for Nutrients from U.S. Shallow Ground Water Sites (NAWQA water-quality data collected 1992-1996. Units are ug-N/L and ug-P/L.)

Land Use	NH_3	NO_3+NO_2	TN	TP
Forest	25 (39)*	217 (31)*	517 (6)*	30 (15)*
Agriculture	36 (753)*	3313 (772)*	3739 (228)*	42 (547)*
Urban	63 (232)*	1900 (216)*	2399 (92)*	54 (158)*

*Number of data points given in parentheses

While the absolute values in Table 5.2 above do not include Hawaii data, we assume that the ratio of nutrients delivered from each of the above land uses is consistent with conditions in Hawaii. This implies that the TN load from forested lands is about 1/7 of the load from agricultural lands use and 1/4 of the load from urban lands. Thus to partition total nitrogen loads within the watershed we will use weighting factors of (1) Urban, (0.25) Forest, and (1.75) Agricultural (1.75). Because of the high intensity maintenance of the cemetery lands, they are weighted as agricultural lands. School and golf course areas are weighted at 1.0. Using similar reasoning, total phosphorous weightings are assigned at (1.0) Urban, (0.55) Forest, (0.78) Agriculture/Cemetery, (1.0) golf course, and (1.0) schools (Table 5.3).

Freeman (1993, derived from Fujiwara 1973) suggests sediment concentrations in storm runoff from Residential (252 mg/l) and Commercial (142 mg/l) land uses. Thus we assign TSS weighting factors at 1.0 for residential lands and 0.56 (142/252) for commercial lands. During the TMDL study period, runoff was never observed in the forested areas (even during a 1-inch, 1-hour rainfall event) so we assign a low TSS weighting factor (0.25) to these areas. School, cemetery, and golf course lands are assigned a TSS weighting factor of 1.0 for lack of information to the contrary (Table 5.3).

Given the lack of definitive information that would enable us to better quantify the pollutant loads generated by various land uses, "1.0" can be thought of as a neutral ranking. When loads are partitioned proportionally among land use area, all land uses are equally accountable for pollution and have equal opportunity to pollute. This assumption is consistent with our objective of establishing "order of magnitude" TMDLs that provide, within a reasonable budget and timeframe, sufficient guidance for planning and implementing management measures that will reduce pollutant loads and improve water quality. During the implementation planning process that follows TMDL establishment, we anticipate the development of more detailed local information about pollutant sources that will help us to fine tune these loading factors.

Table 5.3 Relative Loading Factors for Land Use Categories

Land Use	Relative Loading Factors		
	TP	TN	TSS
Urban Residential	1.0	1.0	1.0
Streets	1.0	1.0	1.0
Cemetery	0.78	1.75	1.0
Schools	1.0	1.0	1.0
Park	1.0	1.0	1.0
Golf	1.0	1.0	1.0
Commercial	1.0	1.0	0.56
Forest	0.55	0.25	.25

5.4 Load Partitioning to Basins within the Kawa Watershed

Table 4.11 provides existing annual pollutant loads for the entire Kawa Stream watershed:

Total N	1,378 kg/yr
Total P	196 kg/yr
TSS	27,087 kg/yr

Section 6.1 shows the hydro-temporal (wet season baseflow, dry season baseflow, storm runoff) allocation of these existing annual loads and load reductions to point and non-point sources, including an explicit Margin of Safety (see Section 6.0). Note that all of the TSS load reductions and almost all of the total phosphorous load reductions are allocated to storm runoff events, while 70% of the total nitrogen load reductions are allocated to base streamflow throughout the year.

With this schedule in mind, partitioning the annual load reductions to distinct basins and land uses within the watershed provides a more detailed spatial framework for TMDL implementation. Using land use loading factors from Table 5.3 and the total area and proportional area of land use types within each basin, a weighting matrix spreadsheet was created to compute the matrix multiplication results shown in Tables 5.4, 5.5, and 5.6 for TSS, TN, and TP, respectively. There are three sub-tables for each exercise representing the annualized a) Existing Loads, b) TMDLs or Load Targets, and c) Pollutant Load Reduction Targets for hitting TMDL Targets in specific basins and/or for specific land uses.

Table 5.4 Calculation of Annual Load Reduction Targets for Total Suspended Solids

a. Existing Distribution of Total Suspended Solids in the Watershed

Pollutant Load by Basin and Land Use Sector
Total Wt of Pollutant is 27087 Kg. TSS

	/-----Land Use Category-----\								
Basin #	Cemetery	Forest	Golf	Commercial	Park	Residential	School	Streets	Grand Total
1	2450	786	0	0	0	0	0	8	3244
2	1432	110	0	0	0	6	0	16	1565
3	479	188	0	0	0	3043	690	346	4746
4	0	1259	0	0	0	2923	0	220	4403
5	0	0	0	371	0	1596	612	118	2697
6	0	0	0	0	0	807	107	59	972
7	0	151	38	30	241	2098	778	231	3567
8	0	0	432	0	0	1842	0	177	2451
9	0	685	1689	0	0	953	0	114	3441
Grand Total	4361	3180	2158	401	241	13269	2186	1290	**27087**

b. Watershed-Distributed TMDL for Total Suspended Solids

Pollutant Load by Basin and Land Use Sector
Total Wt of Pollutant is 29675 Kg. TSS

	/-----Land Use Category-----\								
Basin #	Cemetery	Forest	Golf	Commercial	Park	Residential	School	Streets	Grand Total
1	2684	861	0	0	0	0	0	9	3554
2	1569	121	0	0	0	7	0	18	1715
3	525	206	0	0	0	3334	756	379	5200
4	0	1379	0	0	0	3203	0	241	4823
5	0	0	0	407	0	1749	670	129	2954
6	0	0	0	0	0	884	117	64	1065
7	0	166	41	32	265	2298	853	254	3908
8	0	0	473	0	0	2018	0	194	2686
9	0	751	1850	0	0	1044	0	125	3770
Grand Total	4778	3484	2364	439	265	14537	2395	1413	**29675**

c. Load Reduction Allocations for Total Suspended Solids

Pollutant Load by Basin and Land Use Sector
Total Wt of Pollutant is 2588 Kg. TSS

	/-----Land Use Category-----\								
Basin #	Cemetery	Forest	Golf	Commercial	Park	Residential	School	Streets	Grand Total
1	-234	-75	0	0	0	0	0	-1	-310
2	-137	-11	0	0	0	-1	0	-2	-150
3	-46	-18	0	0	0	-291	-66	-33	-453
4	0	-120	0	0	0	-279	0	-21	-421
5	0	0	0	-35	0	-153	-58	-11	-258
6	0	0	0	0	0	-77	-10	-6	-93
7	0	-14	-4	-3	-23	-200	-74	-22	-341
8	0	0	-41	0	0	-176	0	-17	-234
9	0	-65	-161	0	0	-91	0	-11	-329
Grand Total	-417	-304	-206	-38	-23	-1268	-209	-123	**-2588**

* Note: Negative values imply that no load reductions are required to attain State water quality standards, particularly during base flow conditions. Due to rounding procedures used in data tabulation, Grand Totals may not match the sum of entries in each table column or row.

Table 5.5 Calculation of Annual Load Reduction Targets for Total Nitrogen

a. Existing Distribution of Total Nitrogen in the Watershed

Pollutant Load by Basin and Land Use Sector
Total Wt of Pollutant is 1378 Kg. TN

	Land Use Category								
Basin #	Cemetery	Forest	Golf	Commercial	Park	Residential	School	Streets	Grand Total
1	193	35	0	0	0	0	0	0	228
2	113	5	0	0	0	0	0	1	119
3	38	8	0	0	0	137	31	16	229
4	0	57	0	0	0	131	0	10	198
5	0	0	0	30	0	72	27	5	134
6	0	0	0	0	0	36	5	3	44
7	0	7	2	2	11	94	35	10	161
8	0	0	19	0	0	83	0	8	110
9	0	31	76	0	0	43	0	5	155
Grand Total	343	143	97	32	11	596	98	58	**1378**

b. Watershed-Distributed TMDL for Total Nitrogen

Pollutant Load by Basin and Land Use Sector
Total Wt of Pollutant is 414 Kg. TN

	Land Use Category								
Basin #	Cemetery	Forest	Golf	Commercial	Park	Residential	School	Streets	Grand Total
1	58	11	0	0	0	0	0	0	69
2	34	1	0	0	0	0	0	0	36
3	11	3	0	0	0	41	9	5	69
4	0	17	0	0	0	39	0	3	59
5	0	0	0	9	0	22	8	2	40
6	0	0	0	0	0	11	1	1	13
7	0	2	1	1	3	28	11	3	48
8	0	0	6	0	0	25	0	2	33
9	0	9	23	0	0	13	0	2	46
Grand Total	103	43	29	10	3	179	30	17	**414**

c. Load Reduction Allocations for Total Nitrogen

Pollutant Load by Basin and Land Use Sector
Total Wt of Pollutant is 964 Kg. TN

	Land Use Category								
Basin #	Cemetery	Forest	Golf	Commercial	Park	Residential	School	Streets	Grand Total
1	135	25	0	0	0	0	0	0	160
2	79	3	0	0	0	0	0	1	83
3	26	6	0	0	0	96	22	11	161
4	0	40	0	0	0	92	0	7	139
5	0	0	0	21	0	50	19	4	94
6	0	0	0	0	0	25	3	2	31
7	0	5	1	2	8	66	24	7	113
8	0	0	14	0	0	58	0	6	77
9	0	22	53	0	0	30	0	4	108
Grand Total	240	100	68	23	8	417	69	41	**964**

NOTE – Due to rounding procedures used in data tabulation, Grand Totals may not match the sum of entries in each table column or row.

Table 5.6 Calculation of Annual Load Reduction Targets for Total Phosphorous

a. Existing Distribution of Total Phosphorous in the Watershed

Pollutant Load by Basin and Land Use Sector
Total Wt of Pollutant is 196 Kg. Total Phosphorous

	Land Use Category								
Basin #	Cemetery	Forest Area	Golf Area	Commercial	Park Area	Res. Area	School Area	Streets	Grand Total
1	12	11	0	0	0	0	0	0	24
2	7	2	0	0	0	0	0	0	9
3	2	3	0	0	0	20	4	2	32
4	0	18	0	0	0	19	0	1	38
5	0	0	0	4	0	10	4	1	19
6	0	0	0	0	0	5	1	0	6
7	0	2	0	0	2	14	5	1	24
8	0	0	3	0	0	12	0	1	16
9	0	10	11	0	0	6	0	1	28
Grand Total	22	45	14	5	2	86	14	8	196

b. Watershed-Distributed TMDL for Total Phosphorous

Load Allocation of Constituent by Basin and Land Use Sector
Total Wt of Pollutant is 120 Kg. Total Phosphorous

	Land Use Category								
Basin #	Cemetery	Forest Area	Golf Area	Commercial	Park Area	Res. Area	School Area	Streets	Grand Total
1	8	7	0	0	0	0	0	0	14
2	4	1	0	0	0	0	0	0	5
3	1	2	0	0	0	12	3	1	19
4	0	11	0	0	0	12	0	1	23
5	0	0	0	3	0	6	2	0	12
6	0	0	0	0	0	3	0	0	4
7	0	1	0	0	1	8	3	1	15
8	0	0	2	0	0	7	0	1	10
9	0	6	7	0	0	4	0	0	17
Grand Total	13	28	9	3	1	53	9	5	**120**

c. Load Reduction Allocations for Total Phosphorous

Load Allocation of Constituent by Basin and Land Use Sector
Total Wt Reduction is 76 Kg. Total Phosphorous

	Land Use Category								
Basin #	Cemetery	Forest Area	Golf Area	Commercial	Park Area	Res. Area	School Area	Streets	Grand Total
1	5	4	0	0	0	0	0	0	9
2	3	1	0	0	0	0	0	0	3
3	1	1	0	0	0	8	2	1	12
4	0	7	0	0	0	7	0	1	15
5	0	0	0	2	0	4	2	0	8
6	0	0	0	0	0	2	0	0	2
7	0	1	0	0	1	5	2	1	9
8	0	0	1	0	0	5	0	0	6
9	0	4	4	0	0	2	0	0	11
Grand Total	9	18	5	2	1	33	5	3	**76**

NOTE – Due to rounding procedures used in data tabulation, Grand Totals may not match the sum of entries in each table column or row.

5.5 Average Annual Load Allocations

The TMDLs in Tables 5.4b, 5.5b, and 5.6b represent targets for the sum of all background, point source, and non-point source pollutant loads after cleanup/TMDL implementation has been achieved. Future action plans must aim at this target by focusing on the watershed's two point sources (City and State storm drains) and multiple non-point sources of contaminants.

As stated earlier, these two storm drain systems receive virtually all of their input from non-point pollution sources. Although there may be regulatory and public pressure on system operators to further reduce their pollutant loads, for purposes of this TMDL project we are not specifying any point source load reduction targets and the waste load allocations (WLA) are set to zero. In this manner the community may find greater incentive to address all the non-point pollution sources, not just those that avoid the storm drains to enter the stream. In the future, these storm drain waste load allocations may be increased, thereby decreasing the non-point source waste load allocation.

Table 5.7 Average Annual Load Allocations

	Total Phosphorus (kg/yr)	Total Nitrogen (kg/yr)	Total Suspended Solids (kg/yr)
Nonpoint Source	83	195	26,966
Point Source (WLA)	0	0	0
Background	37	219	2,709
Total (from Table 4.12)	120	414	29,675

6.0 MARGIN OF SAFETY AND FUTURE GROWTH

Our knowledge regarding (1) the exact nature and magnitude of pollutant loads from various land use sources and (2) the specific impacts of those pollutants on the chemical and biological quality of complex natural water bodies will always be incomplete. A margin of safety (MOS) is required as part of a TMDL in recognition of many uncertainties in the understanding and simulation of water quality in natural systems, including errors in data collection and analysis. According to EPA guidance, the MOS can be achieved through two approaches (Environmental Protection Agency 1991). One approach is to explicitly reserve a portion of the loading capacity as a separate term in the TMDL (i.e., TMDL = WLA + LA + MOS). The second approach is to implicitly incorporate the MOS through conservative assumptions used in the TMDL analysis.

The Kawa Stream TMDLs include a margin of safety that combines these two approaches. Following the first approach, the MOS was computed as 10% of the non-point source TMDLs for TP, TN, and TSS. These explicit nutrient and TSS margins of safety are summarized in Table 6.1, and are subtracted from the load allocations (LA) to achieve the TMDL goal. In addition to these explicit MOS, additional safety factors are built into the TMDL development process through the use of conservative assumptions and computational factors.

Kawa Stream watershed is quite small with an excellent record of rainfall and streamflow, allowing us to compute a water balance used in re-calibrating the HEC hydrologic model runoff coefficients. This suggested that the initially assumed runoff coefficients were off by at least a factor of two for the watershed as a whole. If the loading coefficients are even this inaccurate they become meaningless in multivariate modeling of nutrient fluxes. Therefore, we based our TMDL calculations on geometric grand means of our entire water quality data set. Examination of geometric standard deviation in these data suggests a greater degree of accuracy, to within 25 percent of actual values. The MOS is intended to account for such uncertainties in a manner that is conservative from the standpoint of environmental protection.

Our data indicate that phosphorus concentrations hover around attainment of State water quality standards in base flows, but greatly exceed concentration criteria during storm runoff events. TSS concentrations attain State water quality standards in base flows with a significant margin of safety and only slightly exceed concentration criteria during storm flows (Table 5.1). However, because (1) phosphorus and turbidity are both highly correlated with sediment-laden runoff during storm events, and (2) both exceed State criteria, particularly during storm events, we lowered the storm runoff TSS load target level to correspond with the wet season geometric mean concentration criterion. Initially we set the storm runoff TSS TMDL using concentrations obtained at 70% (35 mg/l) on a cumulative probability curve fitted to State wet season concentration criteria (parallel with the TN and TP method, see Section 4.7). However, to control TP and turbidity during storm events, it is important to also control TSS. Therefore we lowered the concentration used to that obtained at the 55% cumulative probability level (25 mg/l). This reduction generates a small exceedance of the TSS concentration criteria calculated for storm runoff events and allows us to assign meaningful TSS TMDLs for them.

Because this is a relatively old, well-established community with little developable land, the load allocations for future growth are set to zero.

Despite these known sources of uncertainty, the TMDLs establish a reasonable starting point for implementation. Subsequent monitoring during the implementation phase may be used to refine the TMDLs and should indicate whether BMPs are helping achieve better water quality.

Table 6.1 Explicit Margins of Safety (MOS)

MOS	Total Phosphorus	Total Nitrogen	Total Suspended Solids
Wet Season Base Flow	1.5 kg	5.1 kg	819.5 kg
Dry Season Base Flow	0.8 kg	2.8 kg	279.8 kg
Storm Runoff	6.0 kg	11.6 kg	1597.3 kg
Annual Total	**8.3 kg**	**19.5 kg**	**2696.6 kg**

6.1 Summary of Kawa Stream Total Maximum Daily Loads with Margin of Safety

Wet season base flow TMDLs (applicable from May 1 – October 31):

For Nitrogen:

TMDL = LA + WLA - MOS
107.90 (*kg/6 mo.*) = 113 + 0 - 5.1
0.60 *(kg/day)*
2.34 “ = Existing Load
1.74 “ = Required Decrease

For Phosphorus:

TMDL = LA + WLA - MOS
21.10 (*kg/6 mo.*) = 22.6 + 0 - 1.5
0.12 *(kg/day)*
0.10 “ = Existing Load
None = Required Decrease

For TSS:

TMDL = LA + WLA - MOS
8200.5 (*kg/6 mo.*) = 9020 + 0 - 819.5
45.3 *(kg/day)*
11.0 “ = Existing Load
None = Required Decrease

Dry season base flow TMDLs (applicable from November 1 – April 31):

For Nitrogen:

TMDL = LA + WLA - MOS
52.20 (*kg/6 mo.*) = 55 + 0 - 2.8
0.28 *(kg/day)*
1.54 “ = Existing Load
1.26 “ = Required Decrease

For Phosphorus:

TMDL = LA + WLA - MOS
8.40 (*kg/6 mo.*) = 9.2 + 0 - 0.8
0.05 *(kg/day)*
0.06 “ = Existing Load
0.01 “ = Required Decrease

For TSS:

TMDL = LA + WLA - MOS
2,800.20 (*kg/6 mo.*) = 3,080 + 0 - 279.8
15.22 *(kg/day)*
7.00 “ = Existing Load
None = Required Decrease

Storm runoff TMDLs:

For Nitrogen:

TMDL = LA + WLA - MOS
234.40 (*kg/yr*) = 246 + 0 - 11.6
0.64 *(kg/day)*
1.84 “ = Existing Load
1.20 “ = Required Decrease

For Phosphorus:

TMDL = LA + WLA - MOS
81.90 (*kg/yr*) = 87.9 + 0 - 6
0.46 *(kg/day)*
0.24 “ = Existing Load
0.22 “ = Required Decrease

For TSS:

TMDL = LA + WLA - MOS
15,977.8 (*kg/yr*) = 17,575 + 0 - 1,597.2
43.8 *(kg/day)*
65.0 “ = Existing Load
21.2 “ = Required Decrease

7.0 HABITAT AND BIOTIC INTEGRITY TMDLs FOR KAWA STREAM

The State of Hawaii is developing a biological assessment method to assess the biotic integrity of streams. Because poor water quality in streams is often linked with habitat degradation that leads to loss of biotic integrity, bioassessments play an important role in developing and implementing TMDLs for Hawaii's streams. Bioassessments extend the pollutant transport studies and demonstrate the detrimental effects of introduced species on native aquatic communities along the entire length of the stream.

Burr (2001) conducted a biological assessment of Kawa Stream, the results of which were used to develop TMDLs for habitat and biotic integrity. When the nutrient, sediment, habitat, and biotic integrity TMDLs are met, Kawa Stream should comply with Hawaii Water Quality Standards. The biological assessment for Kawa Stream can be found on EPO's web site (http://www.state.hi.us/health/eh/epo/index.htm). The *Restoration Emphasis* section in the report will be valuable when selecting appropriate implementation measures to alleviate the nutrient and sediment problems in Kawa Stream.

7.1 Methods

Four study sites were selected to assess the biological and habitat integrity of Kawa Stream (Figure 7.1). The four sites [8, 6, 12 (below both 12L&R), and 5] correspond with respectively numbered HDOH and storm sampling sites. Station 8 is in Basin 2, Station 6 in Basin 4, Station 12 in Basins 5&6, and Station 5 in Basin 8. Each assessment site is representative of a large section of the stream with respect to habitat, biological community, and expected response to human degradation. Ten characteristics representative of the quality of stream habitat and ten metrics to measure the biotic integrity from the individual, population, and community levels of ecological organization were evaluated (Table 7.1).

Table 7.1 Kawa Stream Habitat and Biotic Integrity TMDLs

Habitat Characteristics	Biotic Integrity
50-75% of Reference	30-70% of Reference

7.2 Results

The habitat scores for all sites are in the *nonsupporting* range. The biotic integrity of the two lower sites (12 and 5) score in the *moderately impaired* range and the two upper sites are *impaired* (see Figure 7.2).

Site 8 is the most *natural* site that was examined, although it is obviously negatively affected by anthropogenic influences. This section of the stream has not been heavily modified to fit in an urban setting like the other sites have, but the surrounding terrain has lost the characteristics that would give it high habitat scores.

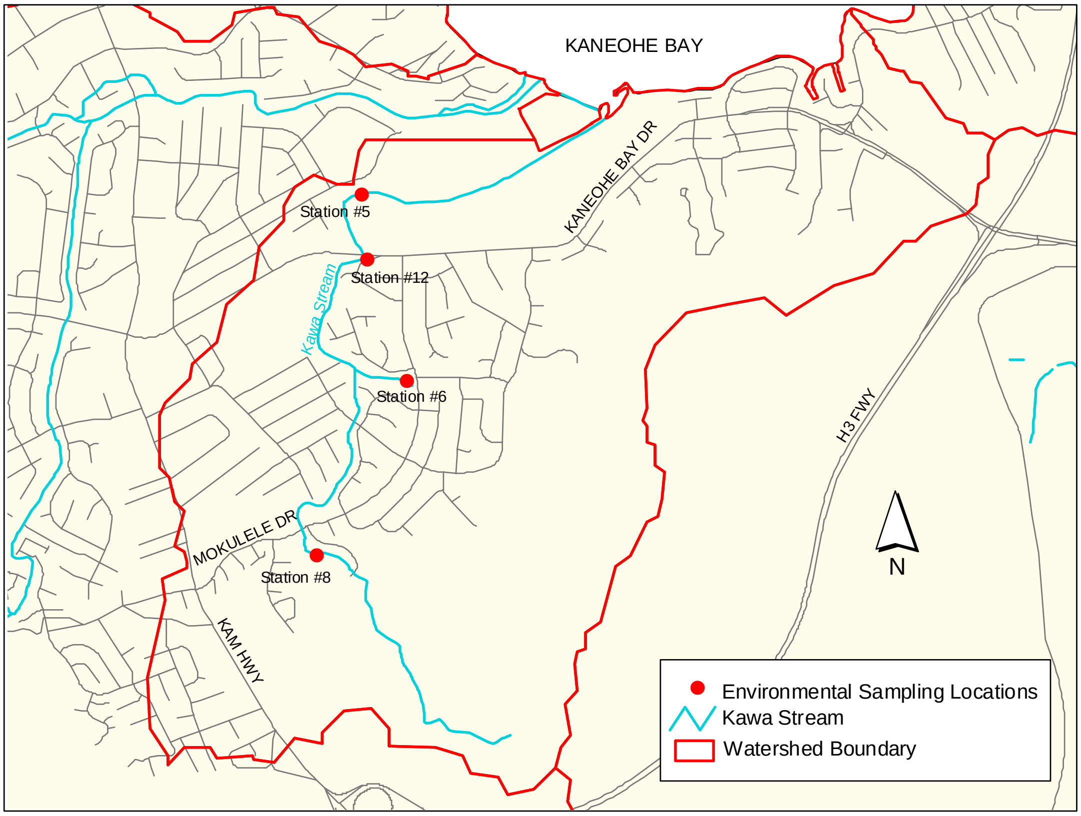


Figure 7.1 Map of Kawa Watershed

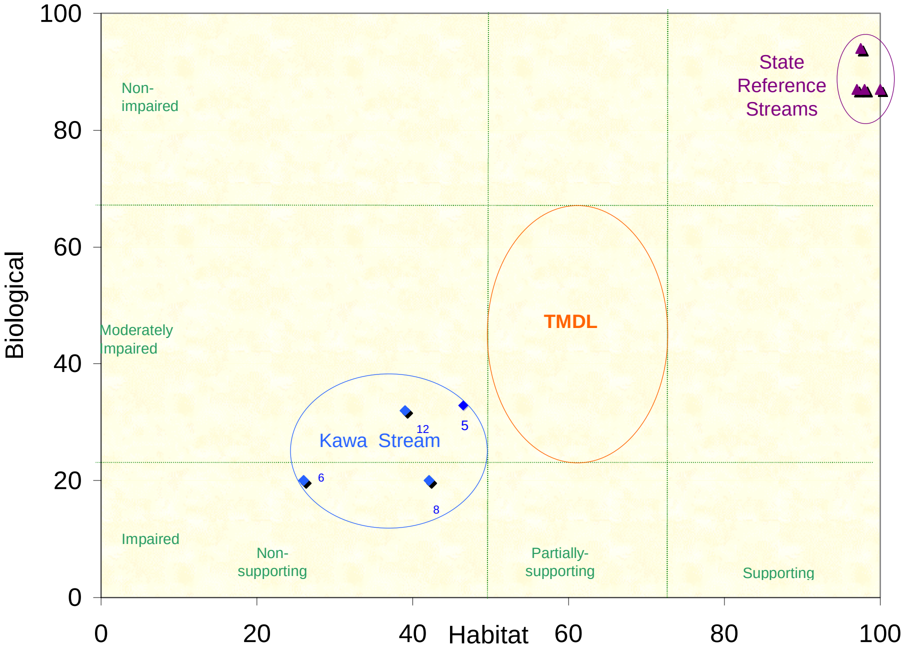


Figure 7.2 Observed, Expected (TMDLs), and Reference Values for Habitat and Biotic Integrity

Table 7.2 Current versus Expected TMDLs for Kawa Stream

Attribute	Current Score Range	Goal Score Range
Habitat Characteristics	51.7 –94.1 (26-47%)	100-150 (50-75%)
Biological Integrity	10-16 (20-32%)	15-35 (30-70%)

Site 8 scored 42% of the habitat reference score -- *nonsupporting* for aquatic life uses. The nonsupporting score can be attributed to the surrounding area where a lack of understory and unstable banks has led to high embeddedness levels in the stream. The aquatic community is *impaired*. The biological metrics score is 20% of the reference scores, due to the absence of native fish and crustaceans and dominance of alien fish tolerant of degraded conditions.

Site 6 received a lower habitat score than Site 8, 26% of reference. A hardened channel, lack of riparian zone, little habitat heterogeneity, high embeddedness, and no understory kept its habitat score low in the *nonsupporting* category for aquatic life uses.

Although this site had one native fish, numerous of fish tolerant of degraded conditions (i.e., tilapia and mollies) leave this site in the *impaired* aquatic community category at 20% of the reference scores.

The habitat score of Site 12 fell between Site 8 and Site 6, at 39% of reference – *nonsupporting* for aquatic life uses. This site has good habitat heterogeneity (the stream bed consists of natural bedrock and boulders and has varying flow regimes), but the banks are hardened or eroding and there is no riparian zone or understory. This site also had one native fish and lots of fish tolerant of degraded conditions (i.e., tilapia and mollies), but the one native fish was of breeding size, so it just makes it into the *moderately impaired* aquatic community category (32% of reference), but for all intensive purposes, can be considered *impaired*.

Site 5 had the best habitat score of the four sites (47% of reference), although it still falls within the *nonsupporting* category. Site 5 is basically one big pool; eroding bank sections and a lack of a riparian zone are all problems present at Site 5 that prevent the stream from supporting biotic integrity. This site had many more native fish than the other sites, although it was dominated by introduced fish so it remains in the *moderately impaired* community category at 32% of reference.

7.3 Habitat and Biotic Integrity TMDLs

The biological and habitat scores for Kawa Stream can be compared with expected scores representing reference conditions, and a parallel can be drawn with the definition of a TMDL as the sum of wasteload and load allocations plus a margin of safety (Table 1). If the biological and habitat target score ranges are defined as the expected load allocation, the actual stream scores as the observed sediment and nutrient-caused degradation, and the margin of error is identified by the use of target score ranges, then a TMDL model may be written in biological assessment terms as: TMDL = expected scores (load allocation) + expected score range (margin of safety).

The expected scores can be inferred from the habitat and biotic criteria for perennial streams currently proposed in the Department of Health's New Proposed Revisions to Water Quality Standards (Environmental Planning Office 2001, http://www.hawaii.gov/health/eh/epo/wqrev.htm). As a class 2a stream, Kawa would be expected to achieve a habitat score between 50% and 75% of reference condition ("partially supporting") and a biotic integrity score between 30% and 70% of reference condition ("moderately impaired").

7.4 Discussion

Kawa Stream does not meet the TMDL for habitat characteristics and only two sites achieve only the lower end of the TMDL goal score range for the biotic integrity TMDL (Table 7.2 and Figure 7.2).

Kawa Stream is a short, connected stream; upstream events are felt downstream and the ramifications of downstream conditions are felt upstream. The effect of high sediment loads entering the upper reaches of Kawa Stream can be seen throughout the entire stream in the water quality data, habitat characteristics, and ultimately, the biotic integrity. TSS levels are low in the upper reaches of Kawa Stream, although high embeddedness levels demonstrate that the large particles have settled out early. Total Phosphorus levels are also elevated in the upper reaches, corresponding with the additional sediment load in the stream. These nutrients tend to bind to the iron-rich sediments present in the stream and are available to be transported downstream during a storm event. TSS levels in the water column increase further down the stream, resulting in lower embeddedness levels. In the lowest reach of Kawa Stream, TSS levels drop again while embeddedness levels rise because the flowing water has slowed down sufficiently for the larger particles to settle out.

Poor water quality and unfavorable habitat characteristics impede the migration of native aquatic animals to and from the upper reaches, resulting in lower scores for biotic integrity at stations 6 and 8 than 5 and 12. If the middle reaches of Kawa Stream were restored, it would be likely that native aquatic macrofauna could be found throughout the stream because they are relatively abundant in the lowest reach and simple habitat improvements in the upper reaches should provide adequate habitat to support a viable native community.

The end result of implementing the habitat and biotic integrity TMDLs will be an improvement of stream channels, reduction of sediment and nutrient loads, and reduction of introduced species impacts; similar results as are also expected through implementation of the flux-based TMDLs.

Kawa Stream is the second windward Oahu stream for which TMDLs have been calculated – the first being Waimanalo Stream (Harrigan and Burr 2001). The water quality, habitat characteristics, and biological metrics are for both streams are very similar. For example, existing loads of TSS and phosphorous were below the TMDLs for both Waimanalo Stream and Kawa Stream (Waimanalo Stream: TSS – 87% and TDP – 98% and Kawa Stream: TSS – 75% and TP – 93%) but both streams exceeded allowable nitrate loads (Waimanalo Stream: 110% and Kawa Stream: 216%). Habitat characteristics and biological metrics were also similar (Waimanalo Stream: Habitat – 33% and Biological metrics – 33% and Kawa Stream: Habitat – 39% and Biological metrics – 26%). Implementation measures determined to be effective at reducing the loads and restoring the habitat for Waimanalo Stream will most likely be effective in Kawa Stream as well.

8.0 ASSURANCE OF IMPLEMENTATION

This section provides the basis for reasonable assurances that the nitrogen and TSS TMDLs will be achieved and maintained. For both TMDLs, Hawaii has several well-established programs that will be drawn upon. The EPA-sponsored Clean Water Action Plan of 1998 (CWAP) may also be utilized to assist in the implementation of these TMDLs. The State has given a higher priority for funding assessment and restoration activities to watersheds with 303(d) listed impaired waters.

It is reasonable to expect that non-point source loads can be reduced during conditions of low streamflow and small storm flows. Low flow events associated with rainfall of one inch or less account for 95% of all the rainfall events and about 75% of the total rainfall volume. While it is difficult to partition the low flow loads among specific contributing sources, the sources themselves can be identified. These include dissolved forms of nitrogen in groundwater, grading projects, pets and feral animals in the watershed, yard fertilizers, seasonal fruit fall, leaky sewers, and deposition of sediments and organic matter in the streambed from higher flow events. When these sources are controlled in combination, non-point source reductions of the magnitude identified by this TMDL allocation may be achieved.

Several activities could lead to reduced TSS, and therefore reduced turbidity and TP in the watershed. In the upper watershed, recent grading projects led to excessive sediment loads entering the stream channel. Efforts to educate landowners concerning available and effective erosion control BMPs could help reduce the sediment load to the system. Some of this loading occurs due to scouring and the highly eroded condition of the stream banks, particularly where concrete hardened banks have been undermined. Stream restoration techniques that use porous buffers and stream bank stabilization methods to cut erosion, slow the flow of storm waters, and create stream habitat would be appropriate remedies.

Control of nutrients, particularly those linked to groundwater nitrates, will involve further investigations to identify specific significant sources. These sources could include pets, feral animals, fertilizers, fruit fall and leaky sewers. While the TMDL implementation planning process and subsequent activities may include efforts to pinpoint and manage these sources, reduction of nutrient loading will require significant public education to alter behaviors that have historically led to nutrient pollution.

The City and County of Honolulu (Department of Environmental Services) and the State of Hawaii (Department of Transportation) operate storm drain systems that convey substantial portions of the existing pollutant loads entering Kawa Stream. As the NPDES permits for these systems approach their expiration date (September 08, 2004), waste load allocations for the point sources they represent will be revised, and public involvement will help these agencies find and implement solutions that reduce the pollutant loads introduced to their storm drain systems and improve the quality of water subsequently discharged into Kawa Stream.

During the TMDL development process, the City & County of Honolulu resubmitted various applications for approval of a stream channel alteration project in the middle east branch of Kawa Stream. DOH provided written comments on the proposal to the State of Hawaii

Commission on Water Resource Management, noting that “While the proposed stream channel alteration project would reduce sediment loading in the newly-lined stream channel segment, it also (1) could increase scouring and sediment loading downstream; (2) would further degrade stream habitat quality; and (3) could further impair the biotic integrity of Kawa Stream. Such changes have not been considered in the establishment of Kawa Stream TMDLs” (Department of Health 2001).

In response to these and other comments, the Water Commission required that “The applicant shall coordinate with the University of Hawaii Environmental Center, the Department of Health (TMDL Program), and the Division of Aquatic Resources to discuss the merits, additional time and costs needed, flood concerns, and feasibility of installing a low flow channel in Kawa Stream. The applicant shall provide the Commission with written findings of the information obtained from the discussion within 60 days of the receipt of the permit” (Commission on Water Resource Management 2002).

An initial meeting of this discussion group was held on February 25, 2002, resulting in a proposed recommendation that “a concrete low flow channel is not likely to be a feasible consideration for the Kawa Ditch channel lining project. Public safety and flood management (meeting drainage standards) outweigh the need for a ‘fish-friendly’ environment, since the proposed project site is located in an urbanized area with few remaining native species. While a concrete low flow channel may concentrate the base flow in a smaller cross section, there is still the potential concern for water chemistry and a physical environment that is not entirely conducive to aquatic life in the stream.”

Although this alone may not be a positive result for achieving TMDLs in Kawa Stream, the group also identified related questions and issues for further discussion (e.g. design parameters, drainage project funding, public education partnerships, and use of stream assessment data). As we continue opening lines of communication and information exchange about these issues in general, assurances that achieving and maintaining TMDLs in Kawa and other streams are expected to strengthen.

9.0 PUBLIC PARTICIPATION PROCESS

The middle branch of Kawa Stream, which borders and runs through the Castle High School campus, is one of the most highly polluted stream segments. During April 2001, a representative of Oceanit and a representative of the DOH gave presentations to four high school science classes at the school. We discussed summarized data from this report, gave the students a home survey to complete, and challenged them to conduct studies to more closely identify specific sources of nutrient and sediment pollution in "their" branch of the stream. The science teachers set up a more formal approach to this problem as part of their class curriculum beginning during the fall of 2001, and results from their efforts can be viewed on their Hawaii Department of Education website at http://www.k12.hi.us/~scyboron/ahupuaa/.

Based on field and laboratory activities, students determined that “Castle High School is adding nitrate to Kawa Stream, so my hypothesis is correct. But I can’t say where exactly that nitrate is coming from,” and suggested that “If I had more time and plenty of nitrate test kits, I would send people to sample different parts of the Ag Stream on many different days. Then we could tell whether the nitrate is coming from the athletic fields, or the ag fields, or someplace else."

During the TMDL development process, public information about the project is disseminated in numerous ways. Websites maintained by Oceanit, AECOS, and DOH provide updates about project activities, post water quality sampling and assessment results, and house electronically accessible copies of the public review document:

http://www.oceanit.com/customer_links/community/Kawa%20Stream/Default.htm
http://www.pixi.com/~isd/KawaWQ.html
http://www.state.hi.us/health/eh/epo

DOH staff held discussions with and gave presentations to numerous stakeholders including:

Kaneohe Neighborhood Board
Kaneohe Community and Family Center
Kaneohe Business Group
Koolau News
State of Hawaii Department of Transportation (Highways Division)
State of Hawaii Commission on Water Resource Management
Hawaiian Memorial Park Cemetery
Hawaii Veterans Cemetery
Windward City Shopping Center
Bay View Golf Course
Waikalua Loko Fishpond Preservation Society
Ho`omaluhia Botanical Garden
Kailua Bay Advisory Council
Ahupua`a Action Alliance

A public information meeting on the final draft of this TMDL report was held at the Kaneohe Civic Center on October 23, 2001. The meeting was attended by members of the local community and the press, and included a brainstorming exercise for Kawa Stream TMDL Implementation (results below). DOH staff is currently promoting ongoing public participation to develop a TMDL implementation plan that utilizes these results.

During the ensuing public review period, DOH received three public comment letters on the draft TMDL report. A coordinated response to these comments was mailed out and the comments and responses are incorporated in this final edition of the TMDL technical report.

Results of Brainstorming Exercise for Kawa Stream TMDL Implementation
Kawa Stream TMDL Public Information Meeting
10/30/2001

Idea	**Votes**
Educate people about alternative landscaping and construction methods. Develop residential and commercial BMPs	7
Explore alternative bank stabilization measures	5
Castle High School/Community – Pollution prevention project: Erosion, nutrients (Agriculture curriculum)	5
Fish-friendly low flow channels	4
Riparian planting demonstration/Plant sources	4
Rip out all the concrete	3
City and County of Honolulu/Castle High School - Bank stabilization	3
Reduce slope of banks	3
Alternative ways to control overgrowth of vegetation in channel/on banks	3
Public awareness campaign at Windward City Shopping Center	3
Tell the story of the stream	2
Establish erosion control and siltation basins along periphery	2
Eradicate armored catfish and other alien fishes	2
Treat street runoff	2
Appreciation through education, access, and improvement	1
Recycling of nutrient-laden water	1
Identify/advertise public access locations	0
Pathway/Greenway through stream	0
Investigate gasoline sources and reduce	0
More native species	0
Educate about new introductions of alien species	0
Reintroduce native species	0
TOTAL VOTES AVAILABLE (4 votes per person, 18 signed in to meeting)	**72**
TOTAL VOTES CAST	**50**

Ideas listed first by votes cast, then by order of submission. Participants also noted the existence of a related City and County of Honolulu Vision project in process for Kaneohe (contact Steve Kubota) and an overriding engineering and government service mandate to maintain public health and safety.

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Appendix A: Stream Flow / Rainfall Correlation

Rainfall-Runoff Relation

Tables below show the relationship between rainfall events (obtained from Oceanit's raingage data in Kaneohe, RG-3) and its associated runoff (obtained from Tom Nance's flow data). Rainfall volume is calculated as rainfall times the area of the watershed (1.55 sq mi). Rainfall-Runoff (RR) is the runoff from rain only (i.e. stream flow minus baseflow). These storm events were seperated, where possible, into individual storms (i.e. Storm 1, Storm 2, Storm n...) to provide additional data points.

For every individual storm, the base flow was determined and eliminated prior to calculating the "Storm Vol.", "Storm Runoff",and "Total Storm Runoff Vol.". This step will provide the flow from the individual storm only within the watershed and not include water from the previous individual storm.

Individual storms are seperated and shaded for visual purposes. The total rain for each individual storm is shown at the end of the storm in column "Total Rain". The total volume of percipitation at the end of each individual storm within the watershed is shown in column " Total Storm Runoff Vol.".

The data from column "Total Rain" and "Total Storm Runoff Vol." were used to plot and find an equation of line. This equation will allow us to estimate the amount of runoff for a given rainfall from a given rain storm.

Storm Event for 1-3-97 to 1-4-97

Storm 1: Baseflow is estimated to be 2.80 cfs

Storm 2: Baseflow is estimated to be 2.76 cfs

Storm 3: Baseflow is estimated to be 7.52 cfs

DATE	TIME	RAINFALL (15 minute interval)			RUNOFF					
		RAIN (in)	Total Rain (in)	Notes	Stream Flow (cfs)	Rainfall-Runoff (cfs) Stream flow - baseflow	Storm Vol (ft^3/30min)	Storm Runoff (ft^3)	Total Storm Runoff Vol (ft^3)	Notes
1/3/97	0:00:00	0								
1/3/97	0:15:00	0			2.50	0.00				
1/3/97	0:30:00	0			2.41	0.00	0	0		
1/3/97	0:45:00	0			2.47	0.00	0	0		
1/3/97	1:00:00	0			2.41	0.00	0	0		
1/3/97	1:15:00	0			2.80	0.00	0	0		
1/3/97	1:30:00	0.01		Storm 1 (3.25 hr storm) Total Percipitation = 216098.3 ft^3	2.71	0.00	0	0		
1/3/97	1:45:00	0.01			2.71	0.00	0	0		
1/3/97	2:00:00	0.01			2.76	0.00	0	0		
1/3/97	2:15:00	0			2.86	0.09	0	0		
1/3/97	2:30:00	0			3.62	0.85	85.45	85.45		Storm 1 (3.25 hr storm) % Runoff = 6% (13617 / 216098)
1/3/97	2:45:00	0			5.43	2.66	768.26	853.70		
1/3/97	3:00:00	0			5.11	2.35	2397.13	3250.83		
1/3/97	3:15:00	0			4.44	1.68	2110.63	5361.46		
1/3/97	3:30:00	0			3.81	1.05	1508.68	6870.15		
1/3/97	3:45:00	0			3.43	0.67	941.23	7811.38		
1/3/97	4:00:00	0.01			3.48	0.72	601.62	8412.99		
1/3/97	4:15:00	0			3.74	0.98	648.56	9061.55		
1/3/97	4:30:00	0			3.62	0.85	878.75	9940.30		
1/3/97	4:45:00	0.02	0.06		3.62	0.85	768.26	10708.56		
1/3/97	5:00:00	0			3.62	0.85	768.26	11476.81		
1/3/97	5:15:00	0			3.37	0.60	768.26	12245.07		
1/3/97	5:30:00	0			3.43	0.67	543.72	12788.78		
1/3/97	5:45:00	0.01		Storm 2 (25.25 hr storm) Total Percipitation = 15487042.7 ft^3	3.01	0.25	601.62	13390.40		
1/3/97	6:00:00	0.03			2.76	0.00	226.20	13616.60	13616.60	
1/3/97	6:15:00	0			2.97	0.21	0	0		
1/3/97	6:30:00	0.09			3.55	0.79	186.88	186.88		Reset for new storm
1/3/97	6:45:00	0.07			4.66	1.90	709.79	896.67		Baseflow is eliminated
1/3/97	7:00:00	0.02			12.74	9.98	1706.16	2602.82		Storm 2 (25.25 hr storm)
1/3/97	7:15:00	0.05			21.10	18.34	8984.70	11587.53		

DATE	TIME	RAINFALL (15 minute interval)			RUNOFF					
		RAIN (in)	Total Rain (in)	Notes	Stream Flow (cfs)	Rainfall-Runoff (cfs) Stream flow - baseflow	Storm Vol (ft^3/30min)	Storm Runoff (ft^3)	Total Storm Runoff Vol (ft^3)	Notes
1/3/97	7:30:00	0.03		Storm 2 (25.25 hr storm) Total Percipitation = 15487042.7 ft^3	24.21	21.45	16502.39	28089.92		Storm 2 (25.25 hr storm) % Runoff = 18% (2721692 / 15487043)
1/3/97	7:45:00	0.01			21.80	19.04	19302.74	47392.67		
1/3/97	8:00:00	0.03			28.57	25.81	17136.26	64528.92		
1/3/97	8:15:00	0.02			21.10	18.34	23227.51	87756.44		
1/3/97	8:30:00	0			17.62	14.86	16502.39	104258.83		
1/3/97	8:45:00	0.02			20.83	18.07	13374.40	117633.23		
1/3/97	9:00:00	0.44			17.87	15.11	16266.64	133899.87		
1/3/97	9:15:00	0.27			18.39	15.63	13596.29	147496.16		
1/3/97	9:30:00	0.25			98.68	95.92	14068.39	161564.55		
1/3/97	9:45:00	0.05			112.19	109.43	86329.35	247893.90		
1/3/97	10:00:00	0.07			124.94	122.18	98490.75	346384.65		
1/3/97	10:15:00	0.05			100.86	98.10	109959.38	456344.03		
1/3/97	10:30:00	0.06			75.82	73.06	88294.46	544638.49		
1/3/97	10:45:00	0.38			49.61	46.85	65751.28	610389.77		
1/3/97	11:00:00	0.28			46.64	43.88	42168.50	652558.27		
1/3/97	11:15:00	0.25			122.91	120.15	39489.39	692047.66		
1/3/97	11:30:00	0.23			123.13	120.37	108132.27	800179.93		
1/3/97	11:45:00	0.37			154.76	152.00	108329.28	908509.22		
1/3/97	12:00:00	0.31			150.86	148.10	136800.93	1045310.15		
1/3/97	12:15:00	0.23			247.09	244.33	133287.70	1178597.85		
1/3/97	12:30:00	0.21			187.44	184.68	219901.13	1398498.98		
1/3/97	12:45:00	0.07			197.79	195.03	166216.23	1564715.21		
1/3/97	13:00:00	0.05			153.40	150.64	175529.35	1740244.56		
1/3/97	13:15:00	0.09			117.48	114.72	135572.97	1875817.53		
1/3/97	13:30:00	0.08			84.26	81.50	103247.99	1979065.53		
1/3/97	13:45:00	0.04			75.59	72.83	73354.09	2052419.62		
1/3/97	14:00:00	0.01			69.16	66.40	65544.19	2117963.81		
1/3/97	14:15:00	0			60.49	57.73	59757.32	2177721.13		
1/3/97	14:30:00	0			46.64	43.88	51960.72	2229681.85		
1/3/97	14:45:00	0			35.93	33.17	39489.39	2269171.24		
1/3/97	15:00:00	0			28.57	25.81	29854.68	2299025.92		
1/3/97	15:15:00	0			23.93	21.17	23227.51	2322253.43		
1/3/97	15:30:00	0			20.54	17.78	19054.95	2341308.39		
1/3/97	15:45:00	0			18.39	15.63	16005.95	2357314.33		
1/3/97	16:00:00	0			16.73	13.97	14068.39	2371382.72		
1/3/97	16:15:00	0.01			15.59	12.83	12570.53	2383953.25		
1/3/97	16:30:00	0			14.38	11.62	11546.29	2395499.54		
1/3/97	16:45:00	0			13.18	10.42	10457.54	2405957.08		
1/3/97	17:00:00	0			13.18	10.42	9379.76	2415336.84		
1/3/97	17:15:00	0			12.62	9.86	9379.76	2424716.61		
1/3/97	17:30:00	0			12.29	9.53	8875.86	2433592.47		
1/3/97	17:45:00	0			11.72	8.96	8573.19	2442165.66		
1/3/97	18:00:00	0			11.16	8.40	8061.58	2450227.24		
1/3/97	18:15:00	0.01			10.72	7.96	7559.26	2457786.50		
1/3/97	18:30:00	0			10.52	7.76	7168.30	2464954.80		
1/3/97	18:45:00	0			10.10	7.34	6985.20	2471940.00		
1/3/97	19:00:00	0			9.99	7.23	6603.16	2478543.16		
1/3/97	19:15:00	0			10.21	7.45	6503.65	2485046.81		
1/3/97	19:30:00	0			9.79	7.03	6703.10	2491749.91		
1/3/97	19:45:00	0.01			9.68	6.92	6325.60	2498075.52		
1/3/97	20:00:00	0			9.16	6.40	6227.29	2504302.81		
1/3/97	20:15:00	0			9.08	6.32	5761.51	2510064.32		
1/3/97	20:30:00	0			8.97	6.21	5684.87	2515749.20		

DATE	TIME	RAINFALL (15 minute interval)			RUNOFF					
		RAIN (in)	Total Rain (in)	Notes	Stream Flow (cfs)	Rainfall-Runoff (cfs) Stream flow - baseflow	Storm Vol (ft^3/30min)	Storm Runoff (ft^3)	Total Storm Runoff Vol (ft^3)	Notes
1/3/97	20:45:00	0		Storm 2 (25.25 hr storm) Total Percipitation = 15487042.7 ft^3	8.68	5.92	5589.48	2521338.67		Storm 2 (25.25 hr storm) % Runoff = 18% (2721692 / 15487043)
1/3/97	21:00:00	0			8.57	5.81	5324.76	2526663.43		
1/3/97	21:15:00	0			8.37	5.61	5231.08	2531894.52		
1/3/97	21:30:00	0			7.70	4.94	5045.11	2536939.62		
1/3/97	21:45:00	0			7.70	4.94	4444.64	2541384.26		
1/3/97	22:00:00	0.02			7.62	4.86	4444.64	2545828.90		
1/3/97	22:15:00	0			7.32	4.56	4373.26	2550202.16		
1/3/97	22:30:00	0			7.70	4.94	4108.37	2554310.53		
1/3/97	22:45:00	0			7.42	4.66	4444.64	2558755.16		
1/3/97	23:00:00	0.02			7.42	4.66	4196.18	2562951.34		
1/3/97	23:15:00	0.01			7.70	4.94	4196.18	2567147.52		
1/3/97	23:30:00	0			7.62	4.86	4444.64	2571592.16		
1/3/97	23:45:00	0			7.80	5.04	4373.26	2575965.42		
1/4/97	0:00:00	0.02			7.98	5.22	4534.29	2580499.71		
1/4/97	0:15:00	0			7.80	5.04	4696.87	2585196.58		
1/4/97	0:30:00	0.01			7.70	4.94	4534.29	2589730.87		
1/4/97	0:45:00	0			7.62	4.86	4444.64	2594175.51		
1/4/97	1:00:00	0			7.98	5.22	4373.26	2598548.77		
1/4/97	1:15:00	0.01			7.98	5.22	4696.87	2603245.64		
1/4/97	1:30:00	0			7.62	4.86	4696.87	2607942.51		
1/4/97	1:45:00	0			7.42	4.66	4373.26	2612315.77		
1/4/97	2:00:00	0			7.32	4.56	4196.18	2616511.95		
1/4/97	2:15:00	0			7.25	4.49	4108.37	2620620.31		
1/4/97	2:30:00	0			6.88	4.12	4038.47	2624658.79		
1/4/97	2:45:00	0			6.88	4.12	3710.84	2628369.62		
1/4/97	3:00:00	0			6.79	4.03	3710.84	2632080.46		
1/4/97	3:15:00	0			6.53	3.77	3625.83	2635706.29		
1/4/97	3:30:00	0			6.69	3.93	3390.53	2639096.81		
1/4/97	3:45:00	0			7.32	4.56	3541.33	2642638.14		
1/4/97	4:00:00	0			7.25	4.49	4108.37	2646746.51		
1/4/97	4:15:00	0			6.96	4.20	4038.47	2650784.98		
1/4/97	4:30:00	0			7.25	4.49	3779.21	2654564.19		
1/4/97	4:45:00	0			7.32	4.56	4038.47	2658602.67		
1/4/97	5:00:00	0			7.52	4.76	4108.37	2662711.03		
1/4/97	5:15:00	0			7.52	4.76	4284.48	2666995.51		
1/4/97	5:30:00	0			7.42	4.66	4284.48	2671279.99		
1/4/97	5:45:00	0			7.25	4.49	4196.18	2675476.16		
1/4/97	6:00:00	0			7.15	4.39	4038.47	2679514.64		
1/4/97	6:15:00	0			7.42	4.66	3951.55	2683466.19		
1/4/97	6:30:00	0			7.52	4.76	4196.18	2687662.37		
1/4/97	6:45:00	0			7.25	4.49	4284.48	2691946.84		
1/4/97	7:00:00	0.01	4.3		7.52	4.76	4038.47	2695985.32		
1/4/97	7:15:00	0			7.52	4.76	4284.48	2700269.79		
1/4/97	7:30:00	0			7.52	4.76	4284.48	2704554.27		
1/4/97	7:45:00	0.01		Storm 3 (4.25 hr storm) Total Percipitation = 1152524.1 ft^3	7.52	4.76	4284.48	2708838.75		
1/4/97	8:00:00	0.02			7.52	4.76	4284.48	2713123.22		
1/4/97	8:15:00	0.06			7.52	4.76	4284.48	2717407.70		
1/4/97	8:30:00	0.1			8.97	1.45	4284.48	2721692.18	2721692.18	
1/4/97	8:45:00	0.02			21.80	14.28	1305.48	1305.48		Reset for new storm
1/4/97	9:00:00	0.01			27.47	19.95	12852.26	14157.73		Baseflow is eliminated
1/4/97	9:15:00	0.03			25.23	17.71	17955.01	32112.74		Storm 3 (4.25 hr storm)
1/4/97	9:30:00	0			19.74	12.22	15935.99	48048.73		
1/4/97	9:45:00	0			16.73	9.21	10999.06	59047.80		

DATE	TIME	RAINFALL (15 minute interval)			RUNOFF					
		RAIN (in)	Total Rain (in)	Notes	Stream Flow (cfs)	Rainfall-Runoff (cfs) Stream flow - baseflow	Storm Vol (ft^3/30min)	Storm Runoff (ft^3)	Total Storm Runoff Vol (ft^3)	Notes
1/4/97	10:00:00	0.01		Storm 3 (4.25 hr storm) Total Percipitation = 1152524.1 ft^3	15.85	8.33	8286.53	67334.33		Storm 3 (4.25 hr storm) % Runoff = 11% (127515 / 1152524)
1/4/97	10:15:00	0			13.08	5.56	7498.11	74832.43		
1/4/97	10:30:00	0			12.29	4.77	5007.54	79839.97		
1/4/97	10:45:00	0			11.39	3.87	4289.19	84129.16		
1/4/97	11:00:00	0.03			10.63	3.11	3483.42	87612.58		
1/4/97	11:15:00	0			10.10	2.58	2802.76	90415.34		
1/4/97	11:30:00	0.01			10.52	3.00	2319.16	92734.50		
1/4/97	11:45:00	0.01			12.17	4.65	2701.20	95435.71		
1/4/97	12:00:00	0.01	0.32		13.55	6.03	4181.85	99617.55		
1/4/97	12:15:00	0			14.86	7.34	5428.80	105046.36		
1/4/97	12:30:00	0			12.62	5.10	6609.75	111656.10		
1/4/97	12:45:00	0			12.38	4.86	4591.86	116247.97		
1/4/97	13:00:00	0			11.04	3.52	4375.35	120623.32		
1/4/97	13:15:00	0			10.10	2.58	3171.80	123795.12		
1/4/97	13:30:00	0			9.08	1.56	2319.16	126114.28		
1/4/97	13:45:00	0			8.57	5.77	1400.87	127515.15	127515.15	
1/4/97	14:00:00	0.01			8.28	5.48	5195.08	132710.23		
1/4/97	14:15:00	0			7.98	5.18	4935.23	137645.47		
1/4/97	14:30:00	0			7.98	5.18	4660.87	142306.34		
1/4/97	14:45:00	0			7.80	5.00	4660.87	146967.21		
1/4/97	15:00:00	0			7.52	4.72	4498.29	151465.50		
1/4/97	15:15:00	0			7.32	4.52	4248.48	155713.97		
1/4/97	15:30:00	0			7.42	4.62	4072.37	159786.34		
1/4/97	15:45:00	0			7.25	4.45	4160.18	163946.52		
1/4/97	16:00:00	0			7.15	4.35	4002.47	167948.99		
1/4/97	16:15:00	0			7.15	4.35	3915.55	171864.54		
1/4/97	16:30:00	0.01			7.15	4.35	3915.55	175780.10		
1/4/97	16:45:00	0			7.15	4.35	3915.55	179695.65		
1/4/97	17:00:00	0.01			10.84	8.04	3915.55	183611.20		
1/4/97	17:15:00	0			10.41	7.61	7234.60	190845.81		
1/4/97	17:30:00	0			8.87	6.07	6848.07	197693.88		
1/4/97	17:45:00	0			6.96	4.16	5458.53	203152.41		
1/4/97	18:00:00	0			6.69	3.89	3743.21	206895.62		
1/4/97	18:15:00	0			6.00	3.20	3505.33	210400.94		
1/4/97	18:30:00	0			5.67	2.87	2880.24	213281.18		
1/4/97	18:45:00	0			5.51	2.71	2579.40	215860.58		
1/4/97	19:00:00	0			5.51	2.71	2439.73	218300.31		
1/4/97	19:15:00	0			5.43	2.63	2439.73	220740.03		
1/4/97	19:30:00	0			6.43	3.63	2362.93	223102.96		
1/4/97	19:45:00	0			8.76	5.96	3271.48	226374.44		
1/4/97	20:00:00	0			8.57	5.77	5364.03	231738.47		
1/4/97	20:15:00	0			8.47	5.67	5195.08	236933.56		
1/4/97	20:30:00	0			8.18	5.38	5101.86	242035.42		
1/4/97	20:45:00	0			7.90	5.10	4843.31	246878.73		
1/4/97	21:00:00	0			7.80	5.00	4588.42	251467.16		
1/4/97	21:15:00	0			8.37	5.57	4498.29	255965.45		
1/4/97	21:30:00	0			8.87	6.07	5009.11	260974.55		
1/4/97	21:45:00	0			8.37	5.57	5458.53	266433.08		
1/4/97	22:00:00	0			6.18	3.38	5009.11	271442.19		
1/4/97	22:15:00	0			6.34	3.54	3041.76	274483.94		
1/4/97	22:30:00	0			6.25	3.45	3188.96	277672.90		
1/4/97	22:45:00	0			5.67	2.87	3106.97	280779.87		
1/4/97	23:00:00	0			5.93	3.13	2579.40	283359.27		

Storm Event for 3-16-97 to 3-17-97

Observation of storm event is from 18:30:00, 3/16/97 to 04:15:00, 3/18/97. Rainfall occurred on 3/15/97, the night before. Assuming that a portion of the flow from the rainfall the night before is the recovery period, baseflow value is chosen to be at the point before where runoff from its associated individual storm starts to show.

Storm 4: Baseflow is estimated to be 1.77 cfs

Storm 5: Baseflow is estimated to be 3.11 cfs

DATE	TIME	RAINFALL (15 minute interval)			RUNOFF (30 minute interval)					
		RAIN (in)	Total Rain (in)	Notes	Stream Flow (cfs)	Rainfall-Runoff (cfs) Stream flow - baseflow	Storm Vol (ft^3/30min)	Storm Runoff (ft^3)	Total Storm Runoff Vol (ft^3)	Notes
3/16/97	18:00:00	0			1.77	0.00	0.00	0.00		
3/16/97	18:15:00	0								
3/16/97	18:30:00	0.01		Storm 4 (8.25 hr storm) Total Percipitation = 2485130.1 ft^3	1.77	0.00	0.00	0.00		
3/16/97	18:45:00	0								
3/16/97	19:00:00	0			1.77	0.00	0.00	0.00		
3/16/97	19:15:00	0								
3/16/97	19:30:00	0			1.79	0.03	0.00	0.00		
3/16/97	19:45:00	0								
3/16/97	20:00:00	0			1.79	0.03	45.46	45.46		
3/16/97	20:15:00	0								Storm 4 (8.25 hr storm) % Runoff = 19% (484404 / 2485130)
3/16/97	20:30:00	0			1.81	0.05	45.46	90.91		
3/16/97	20:45:00	0								
3/16/97	21:00:00	0			1.79	0.03	82.10	173.01		
3/16/97	21:15:00	0								
3/16/97	21:30:00	0.01			1.79	0.03	45.46	218.47		
3/16/97	21:45:00	0.02								
3/16/97	22:00:00	0.01			1.79	0.03	45.46	263.93		
3/16/97	22:15:00	0								
3/16/97	22:30:00	0			1.81	0.05	45.46	309.38		
3/16/97	22:45:00	0.02								
3/16/97	23:00:00	0			1.88	0.12	82.10	391.48		
3/16/97	23:15:00	0								
3/16/97	23:30:00	0			2.01	0.24	212.30	603.78		
3/16/97	23:45:00	0.01								
3/17/97	0:00:00	0.18			10.00	8.23	432.85	1036.63		
3/17/97	0:15:00	0.06								
3/17/97	0:30:00	0.05			12.04	10.27	14817.56	15854.19		
3/17/97	0:45:00	0.07								
3/17/97	1:00:00	0.03			75.79	74.03	18486.87	34341.06		
3/17/97	1:15:00	0.01								
3/17/97	1:30:00	0.05			51.55	49.78	133251.52	167592.58		
3/17/97	1:45:00	0.02								
3/17/97	2:00:00	0.01			24.50	22.73	89608.00	257200.58		
3/17/97	2:15:00	0.09								
3/17/97	2:30:00	0.03			20.76	19.00	40921.22	298121.80		
3/17/97	2:45:00	0.01	0.69							
3/17/97	3:00:00	0			37.73	35.97	34193.09	332314.89		
3/17/97	3:15:00	0								
3/17/97	3:30:00	0			23.25	21.48	64737.14	397052.03		
3/17/97	3:45:00	0								
3/17/97	4:00:00	0			12.04	10.27	38670.30	435722.33		
3/17/97	4:15:00	0								
3/17/97	4:30:00	0			7.67	5.90	18486.87	454209.20		
3/17/97	4:45:00	0								
3/17/97	5:00:00	0			5.67	3.91	10626.08	464835.27		

DATE	TIME	RAINFALL (15 minute interval)			RUNOFF (30 minute interval)					
		RAIN (in)	Total Rain (in)	Notes	Stream Flow (cfs)	Rainfall-Runoff (cfs) Stream flow - baseflow	Storm Vol (ft^3/30min)	Storm Runoff (ft^3)	Total Storm Runoff Vol (ft^3)	Notes
3/17/97	5:15:00	0								Storm 4 (8.25 hr storm) % Runoff = 19% (484404 / 2485130)
3/17/97	5:30:00	0.01		Storm 5 (12 hr storm) Total Percipitation = 7995636.0 ft^3	4.23	2.47	7036.84	471872.11		
3/17/97	5:45:00	0.01								
3/17/97	6:00:00	0			3.52	1.75	4443.86	476315.97		
3/17/97	6:15:00	0.1								
3/17/97	6:30:00	0.02			3.16	1.40	3150.34	479466.31		
3/17/97	6:45:00	0.03								
3/17/97	7:00:00	0			3.11	1.35	2512.11	481978.43		
3/17/97	7:15:00	0.05								
3/17/97	7:30:00	0.04			3.64	0.52	2425.71	484404.13	484404.1342	
3/17/97	7:45:00	0.03								
3/17/97	8:00:00	0.01			6.08	2.97	941.28	3366.99		Reset for new storm Baseflow is eliminated
3/17/97	8:15:00	0.06								
3/17/97	8:30:00	0.12			7.57	4.46	5342.01	8708.99		Storm 5 (12 hr storm) % Runoff = 18% (1477553 / 7995636)
3/17/97	8:45:00	0.32						0.00		
3/17/97	9:00:00	0.89			51.91	48.80	8022.32	16731.31		
3/17/97	9:15:00	0.33						0.00		
3/17/97	9:30:00	0.18			260.62	257.51	87833.37	104564.68		
3/17/97	9:45:00	0.01						0.00		
3/17/97	10:00:00	0			265.29	262.18	463512.17	568076.85		
3/17/97	10:15:00	0						0.00		
3/17/97	10:30:00	0			129.17	126.06	471925.72	1040002.57		
3/17/97	10:45:00	0						0.00		
3/17/97	11:00:00	0			50.03	46.92	226906.48	1266909.05		
3/17/97	11:15:00	0.01								
3/17/97	11:30:00	0			24.81	21.69	84451.22	1351360.27		
3/17/97	11:45:00	0								
3/17/97	12:00:00	0			15.63	12.52	39050.92	1390411.19		
3/17/97	12:15:00	0								
3/17/97	12:30:00	0			11.59	8.48	22527.83	1412939.03		
3/17/97	12:45:00	0								
3/17/97	13:00:00	0			9.09	5.97	15255.98	1428195.01		
3/17/97	13:15:00	0								
3/17/97	13:30:00	0			7.39	4.28	10753.57	1438948.58		
3/17/97	13:45:00	0								
3/17/97	14:00:00	0			6.50	3.39	7704.27	1446652.85		
3/17/97	14:15:00	0								
3/17/97	14:30:00	0			5.83	2.72	6095.82	1452748.67		
3/17/97	14:45:00	0								
3/17/97	15:00:00	0			5.43	2.32	4894.34	1457643.00		
3/17/97	15:15:00	0								
3/17/97	15:30:00	0			4.97	1.85	4177.87	1461820.87		
3/17/97	15:45:00	0								
3/17/97	16:00:00	0			4.60	1.49	3338.80	1465159.66		
3/17/97	16:15:00	0								
3/17/97	16:30:00	0			4.38	1.27	2678.22	1467837.88		
3/17/97	16:45:00	0								
3/17/97	17:00:00	0			4.23	1.12	2289.44	1470127.32		
3/17/97	17:15:00	0								
3/17/97	17:30:00	0	2.22		4.03	0.92	2018.16	1472145.48		
3/17/97	17:45:00	0								
3/17/97	18:00:00	0			3.97	0.86	1647.68	1473793.16		
3/17/97	18:15:00	0								
3/17/97	18:30:00	0			3.77	0.66	1543.89	1475337.05		
3/17/97	18:45:00	0								

DATE	TIME	RAINFALL (15 minute interval)			RUNOFF (30 minute interval)					
		RAIN (in)	Total Rain (in)	Notes	Stream Flow (cfs)	Rainfall-Runoff (cfs) Stream flow - baseflow	Storm Vol (ft^3/30min)	Storm Runoff (ft^3)	Total Storm Runoff Vol (ft^3)	Notes
3/17/97	19:00:00	0			3.64	0.52	1188.08	1476525.13		Storm 5 (12 hr storm) % Runoff = 18% (1477553 / 7995636)
3/17/97	19:15:00	0								
3/17/97	19:30:00	0			3.58	0.47	941.28	1477466.41		
3/17/97	19:45:00	0								
3/17/97	20:00:00	0			3.46	0.35	844.34	1478310.75		
3/17/97	20:15:00	0								
3/17/97	20:30:00	0			3.40	0.29	630.08	1478940.83		
3/17/97	20:45:00	0								
3/17/97	21:00:00	0			3.28	0.17	513.41	1479454.24		
3/17/97	21:15:00	0								
3/17/97	21:30:00	0			3.22	0.11	307.83	1479762.07		
3/17/97	21:45:00	0								
3/17/97	22:00:00	0			3.16	0.05	196.18	1479958.25		
3/17/97	22:15:00	0								
3/17/97	22:30:00	0			3.05		86.41	1480044.66	1477553	
3/17/97	22:45:00	0								
3/17/97	23:00:00	0			3.00		0.00	0.00		
3/17/97	23:15:00	0								
3/17/97	23:30:00	0			2.95		0.00	0.00		
3/17/97	23:45:00	0								
3/18/97	0:00:00	0			2.95		0.00	0.00		
3/18/97	0:15:00	0								
3/18/97	0:30:00	0			2.90		0.00	0.00		
3/18/97	0:45:00	0								
3/18/97	1:00:00	0			2.84		0.00	0.00		
3/18/97	1:15:00	0								
3/18/97	1:30:00	0			2.84		0.00	0.00		
3/18/97	1:45:00	0								
3/18/97	2:00:00	0			2.84		0.00	0.00		
3/18/97	2:15:00	0								
3/18/97	2:30:00	0			2.80		0.00	0.00		
3/18/97	2:45:00	0								
3/18/97	3:00:00	0			2.75		0.00	0.00		
3/18/97	3:15:00	0								
3/18/97	3:30:00	0			2.75		0.00	0.00		
3/18/97	3:45:00	0								
3/18/97	4:00:00	0			2.75		0.00	0.00		
3/18/97	4:15:00	0								

Storm Event for 5-6-97 to 5-7-97

Observation of storm event is from 0:00:00, 5/06/97 to 10:30:00, 5/07/97. Rainfall occurred on 5/05/97, the night before. Assuming that a portion of the flow from the rainfall the night before is the recovery period, baseflow value is chosen to be at the point before where runoff from its associated individual storm starts to show.

Storm 6: Baseflow is estimated to be 3.27 cfs

Storm 7: Baseflow is estimated to be 4.04 cfs

Storm 8: Baseflow is estimated to be 2.33 cfs

Storm 9: Baseflow is estimated to be 2.59 cfs

Storm 10: Baseflow is estimated to be 2.42 cfs

Storm 11: Baseflow is estimated to be 3.14 cfs

DATE	TIME	RAINFALL (15 minute interval)			RUNOFF (30 minute interval)					
		Rain (in)	Total Rain (in)	Notes	Stream Flow (cfs)	Rainfall-Runoff (cfs) Stream flow - baseflow	Storm Vol (ft^3/30min)	Storm Runoff (ft^3)	Total Storm Runoff Vol (ft^3)	Notes
5/6/97	0:00:00	0			3.82	0.00	0.00	0.00		
5/6/97	0:15:00	0								
5/6/97	0:30:00	0.01	0.01	Storm 6 (0.25hr storm) Total Percipitation = 36016.4 ft^3	3.27	0.00	0.00	0.00		
5/6/97	0:45:00	0								
5/6/97	1:00:00	0			3.82	0.56	0.00	0.00		
5/6/97	1:15:00	0								
5/6/97	1:30:00	0			3.44	0.18	1001.78	1001.78		Storm 6 (0.25hr storm) % Runoff = 19% (1323 / 36016)
5/6/97	1:45:00	0								
5/6/97	2:00:00	0			2.77	0.00	320.75	1322.54	1322.54	
5/6/97	2:15:00	0								
5/6/97	2:30:00	0			2.68	0.00	0.00	0.00		
5/6/97	2:45:00	0								
5/6/97	3:00:00	0			2.54	0.00	0.00	0.00		
5/6/97	3:15:00	0								
5/6/97	3:30:00	0			4.04	0.00	0.00	0.00		
5/6/97	3:45:00	0.01	0.01	Storm 7 (0.25hr storm) Total Percipitation = 36016.4 ft^3						
5/6/97	4:00:00	0			10.86	6.83	0.00	0.00		
5/6/97	4:15:00	0								
5/6/97	4:30:00	0			7.74	3.70	12286.20	12286.20		Storm 7 (0.25hr storm) % Runoff = 86% (30837 / 36016)
5/6/97	4:45:00	0								
5/6/97	5:00:00	0			6.20	2.16	6664.86	18951.06		
5/6/97	5:15:00	0								
5/6/97	5:30:00	0			5.95	1.91	3892.03	22843.09		
5/6/97	5:45:00	0								
5/6/97	6:00:00	0			5.77	1.74	3440.39	26283.48		
5/6/97	6:15:00	0								
5/6/97	6:30:00	0			4.83	0.79	3123.05	29406.53		
5/6/97	6:45:00	0								
5/6/97	7:00:00	0			4.04	0.00	1430.85	30837.38	30837.38	
5/6/97	7:15:00	0								
5/6/97	7:30:00	0			3.82	0.00	0.00	0.00		
5/6/97	7:45:00	0								
5/6/97	8:00:00	0			3.32	0.00	0.00	0.00		
5/6/97	8:15:00	0								
5/6/97	8:30:00	0			2.98	0.00	0.00	0.00		
5/6/97	8:45:00	0								
5/6/97	9:00:00	0			2.77	0.00	0.00	0.00		
5/6/97	9:15:00	0								
5/6/97	9:30:00	0			2.54	0.00	0.00	0.00		

DATE	TIME	RAINFALL (15 minute interval)			RUNOFF (30 minute interval)					
		Rain (in)	Total Rain (in)	Notes	Stream Flow (cfs)	Rainfall-Runoff (cfs) Stream flow - baseflow	Storm Vol (ft^3/30min)	Storm Runoff (ft^3)	Total Storm Runoff Vol (ft^3)	Notes
5/6/97	9:45:00	0								
5/6/97	10:00:00	0			2.39	0.00	0.00	0.00		
5/6/97	10:15:00	0								
5/6/97	10:30:00	0.02		Storm 8 (3.25 hr storm) Total Percipitation = 4718145.6 ft^3	2.33	0.00	0.00	0.00		
5/6/97	10:45:00	0.28								
5/6/97	11:00:00	0.6			4.83	2.50	0.00	0.00		
5/6/97	11:15:00	0.26								
5/6/97	11:30:00	0			15.64	13.31	4496.34	4496.34		Storm 8 (3.25 hr storm) % Runoff = 1% (56353 / 4718146)
5/6/97	11:45:00	0								
5/6/97	12:00:00	0.15			5.86	3.53	23956.13	28452.47		
5/6/97	12:15:00	0								
5/6/97	12:30:00	0			10.23	7.90	6346.65	34799.12		
5/6/97	12:45:00	0								
5/6/97	13:00:00	0			4.45	2.12	14215.75	49014.87		
5/6/97	13:15:00	0								
5/6/97	13:30:00	0			3.04	0.70	3818.04	52832.91		
5/6/97	13:45:00	0	1.31							
5/6/97	14:00:00	0			2.98	0.65	1267.11	54100.02		
5/6/97	14:15:00	0.01		Storm 9 (1.25 hr storm) Total Percipitation = 684311.2 ft^3						
5/6/97	14:30:00	0			2.68	0.35	1163.64	55263.66		
5/6/97	14:45:00	0								
5/6/97	15:00:00	0.11			2.59	0.26	628.73	55892.39		
5/6/97	15:15:00	0.06								
5/6/97	15:30:00	0.01	0.19		36.14	33.56	460.21	56352.60	56352.60	
5/6/97	15:45:00	0				0.00				
5/6/97	16:00:00	0			18.84	16.25	60400.30	60400.30		Reset for new storm
5/6/97	16:15:00	0				0.00				Baseflow is eliminated
5/6/97	16:30:00	0			14.18	11.59	29248.85	89649.15		Storm 9 (1.25 hr storm) % Runoff = 21% (143912 / 684311)
5/6/97	16:45:00	0				0.00				
5/6/97	17:00:00	0			10.12	7.53	20860.23	110509.38		
5/6/97	17:15:00	0				0.00				
5/6/97	17:30:00	0			6.90	4.31	13555.48	124064.86		
5/6/97	17:45:00	0				0.00				
5/6/97	18:00:00	0			5.21	2.62	7765.05	131829.91		
5/6/97	18:15:00	0				0.00				
5/6/97	18:30:00	0			4.17	1.58	4713.21	136543.12		
5/6/97	18:45:00	0				0.00				
5/6/97	19:00:00	0			3.56	0.97	2842.42	139385.54		
5/6/97	19:15:00	0				0.00				
5/6/97	19:30:00	0			3.27	0.68	1752.81	141138.34		
5/6/97	19:45:00	0				0.00				
5/6/97	20:00:00	0			3.04	0.45	1218.69	142357.03		
5/6/97	20:15:00	0				0.00				
5/6/97	20:30:00	0			2.82	0.24	806.90	143163.93		
5/6/97	20:45:00	0				0.00				
5/6/97	21:00:00	0			2.72	0.13	425.84	143589.77		
5/6/97	21:15:00	0				0.00				
5/6/97	21:30:00	0			2.63	0.05	239.73	143829.49		
5/6/97	21:45:00	0								
5/6/97	22:00:00	0			2.48	0.15	82.43	143911.92	143911.92	
5/6/97	22:15:00	0								
5/6/97	22:30:00	0			2.45	0.11	261.26	144173.19		
5/6/97	22:45:00	0.01		Storm 10 (6.25 hr storm)						
5/6/97	23:00:00	0.05			2.42	0.08	206.06	144379.25		
5/6/97	23:15:00	0.51								

DATE	TIME	RAINFALL (15 minute interval)			RUNOFF (30 minute interval)					
		Rain (in)	Total Rain (in)	Notes	Stream Flow (cfs)	Rainfall-Runoff (cfs) Stream flow - baseflow	Storm Vol (ft^3/30min)	Storm Runoff (ft^3)	Total Storm Runoff Vol (ft^3)	Notes
5/6/97	23:30:00	0.31		Storm 10 (6.25 hr storm) Total Percipitation = 7419374.0 ft^3	130.54	128.12	151.26	144530.51		
5/6/97	23:45:00	0.07								
5/7/97	0:00:00	0.1			215.99	213.58	230620.52	230620.52		Reset for new storm
5/7/97	0:15:00	0.05								Baseflow is eliminated
5/7/97	0:30:00	0.29			110.98	108.56	384436.79	615057.31		Storm 10 (6.25 hr storm) % Runoff = 19% (1439910 / 7419374)
5/7/97	0:45:00	0.16								
5/7/97	1:00:00	0.21			82.08	79.66	195411.76	810469.07		
5/7/97	1:15:00	0.07								
5/7/97	1:30:00	0.01			91.45	89.03	143386.22	953855.29		
5/7/97	1:45:00	0.05								
5/7/97	2:00:00	0.02			31.75	29.34	160251.93	1114107.23		
5/7/97	2:15:00	0								
5/7/97	2:30:00	0.04			23.81	21.39	52803.12	1166910.35		
5/7/97	2:45:00	0								
5/7/97	3:00:00	0.01			22.13	19.71	38508.50	1205418.85		
5/7/97	3:15:00	0								
5/7/97	3:30:00	0.07			12.77	10.35	35476.77	1240895.62		
5/7/97	3:45:00	0.02								
5/7/97	4:00:00	0			27.21	24.80	18631.24	1259526.86		
5/7/97	4:15:00	0								
5/7/97	4:30:00	0			19.91	17.50	44635.09	1304161.95		
5/7/97	4:45:00	0								
5/7/97	5:00:00	0.01	2.06		13.58	11.16	31492.37	1335654.32		
5/7/97	5:15:00	0								
5/7/97	5:30:00	0			10.86	8.44	20088.46	1355742.78		
5/7/97	5:45:00	0								
5/7/97	6:00:00	0			8.89	6.47	15200.43	1370943.21		
5/7/97	6:15:00	0								
5/7/97	6:30:00	0			7.17	4.75	11645.16	1382588.37		
5/7/97	6:45:00	0								
5/7/97	7:00:00	0			6.04	3.62	8556.00	1391144.37		
5/7/97	7:15:00	0								
5/7/97	7:30:00	0			5.29	2.87	6514.94	1397659.31		
5/7/97	7:45:00	0								
5/7/97	8:00:00	0			4.98	2.56	5172.72	1402832.03		
5/7/97	8:15:00	0								
5/7/97	8:30:00	0			4.59	2.18	4606.95	1407438.98		
5/7/97	8:45:00	0								
5/7/97	9:00:00	0			4.38	1.96	3917.66	1411356.64		
5/7/97	9:15:00	0								
5/7/97	9:30:00	0			4.17	1.75	3529.25	1414885.89		
5/7/97	9:45:00	0								
5/7/97	10:00:00	0			3.96	1.55	3151.37	1418037.27		
5/7/97	10:15:00	0								
5/7/97	10:30:00	0			3.82	1.41	2784.49	1420821.75		
5/7/97	10:45:00	0								
5/7/97	11:00:00	0			3.82	1.41	2529.43	1423351.18		
5/7/97	11:15:00	0								
5/7/97	11:30:00	0			3.63	1.21	2529.43	1425880.60		
5/7/97	11:45:00	0								
5/7/97	12:00:00	0			3.56	1.15	2182.61	1428063.21		
5/7/97	12:15:00	0								
5/7/97	12:30:00	0			3.44	1.03	2061.76	1430124.97		
5/7/97	12:45:00	0								
5/7/97	13:00:00	0			3.38	0.96	1848.40	1431973.37		

DATE	TIME	RAINFALL (15 minute interval)			RUNOFF (30 minute interval)					
		Rain (in)	Total Rain (in)	Notes	Stream Flow (cfs)	Rainfall-Runoff (cfs) Stream flow - baseflow	Storm Vol (ft^3/30min)	Storm Runoff (ft^3)	Total Storm Runoff Vol (ft^3)	Notes
5/7/97	13:15:00	0								Storm 10 (6.25 hr storm) % Runoff = 19% (1439910 / 7419374)
5/7/97	13:30:00	0			3.27	0.85	1732.25	1433705.62		
5/7/97	13:45:00	0								
5/7/97	14:00:00	0			3.27	0.85	1527.64	1435233.26		
5/7/97	14:15:00	0.02								
5/7/97	14:30:00	0.01			3.38	0.96	1527.64	1436760.91		
5/7/97	14:45:00	0								
5/7/97	15:00:00	0			3.20	0.79	1732.25	1438493.15		
5/7/97	15:15:00	0								
5/7/97	15:30:00	0			3.14	0.81	1416.55	1439909.70	1439909.70	
5/7/97	15:45:00	0								
5/7/97	16:00:00	0			3.14	0.81	1458.62	1441368.32		
5/7/97	16:15:00	0								
5/7/97	16:30:00	0			3.14	0.81	1458.62	1442826.94		
5/7/97	16:45:00	0								
5/7/97	17:00:00	0			3.14	0.81	1458.62	1444285.56		
5/7/97	17:15:00	0								
5/7/97	17:30:00	0			3.14	0.81	1458.62	1445744.18		
5/7/97	17:45:00	0.02		Storm 11 (0.75 hr storm) Total Percipitation = 72032.8 ft^3						
5/7/97	18:00:00	0			3.20	0.87	1458.62	1447202.80		
5/7/97	18:15:00	0	0.02							
5/7/97	18:30:00	0			3.27	0.93	1567.81	1567.81		Reset for new storm
5/7/97	18:45:00	0								Baseflow is eliminated
5/7/97	19:00:00	0			4.38	2.04	1678.90	3246.71		Storm 11 (0.75 hr storm) % Runoff = 23% (16481 / 72033)
5/7/97	19:15:00	0								
5/7/97	19:30:00	0			4.30	1.97	3680.51	6927.21		
5/7/97	19:45:00	0								
5/7/97	20:00:00	0			3.56	1.23	3544.32	10471.53		
5/7/97	20:15:00	0								
5/7/97	20:30:00	0			3.51	1.18	2213.02	12684.55		
5/7/97	20:45:00	0								
5/7/97	21:00:00	0			3.27	0.93	2117.52	14802.08		
5/7/97	21:15:00	0								
5/7/97	21:30:00	0			3.08	0.75	1678.90	16480.98	16480.98	
5/7/97	21:45:00	0								
5/7/97	22:00:00	0			3.04	0.70	1351.41	17832.39		
5/7/97	22:15:00	0								
5/7/97	22:30:00	0			2.98	0.65	1267.11	19099.49		
5/7/97	22:45:00	0								
5/7/97	23:00:00	0			2.98	0.65	1163.64	20263.14		
5/7/97	23:15:00	0.01								
5/7/97	23:30:00	0.07			2.92	0.59	1163.64	21426.78		
5/7/97	23:45:00	0.06								

Storm #	Total rain (in)	Duration (hrs)	Percipitation (ft^3)	Storm Runoff (ft^3)	Percent Runoff	
6	0.01	0.25	36016.4	1323	4%	
1	0.06	3.25	216098.3	13617	6%	
11	0.02	0.75	72032.8	16481	23%	
7	0.01	0.25	36016.4	30837	86%	outlyer
8	1.31	3.25	4718145.6	56353	1%	outlyer
3	0.32	4.25	1152524.1	127515	11%	
9	0.19	1.25	684311.2	143912	21%	
4	0.69	8.25	2485130.1	484404	19%	
10	2.06	6.25	7419374.0	1439910	19%	
5	2.22	12.00	7995636.0	1477553	18%	
2	4.3	25.25	15487042.7	2721692	18%	

Table A1: Individual storm data

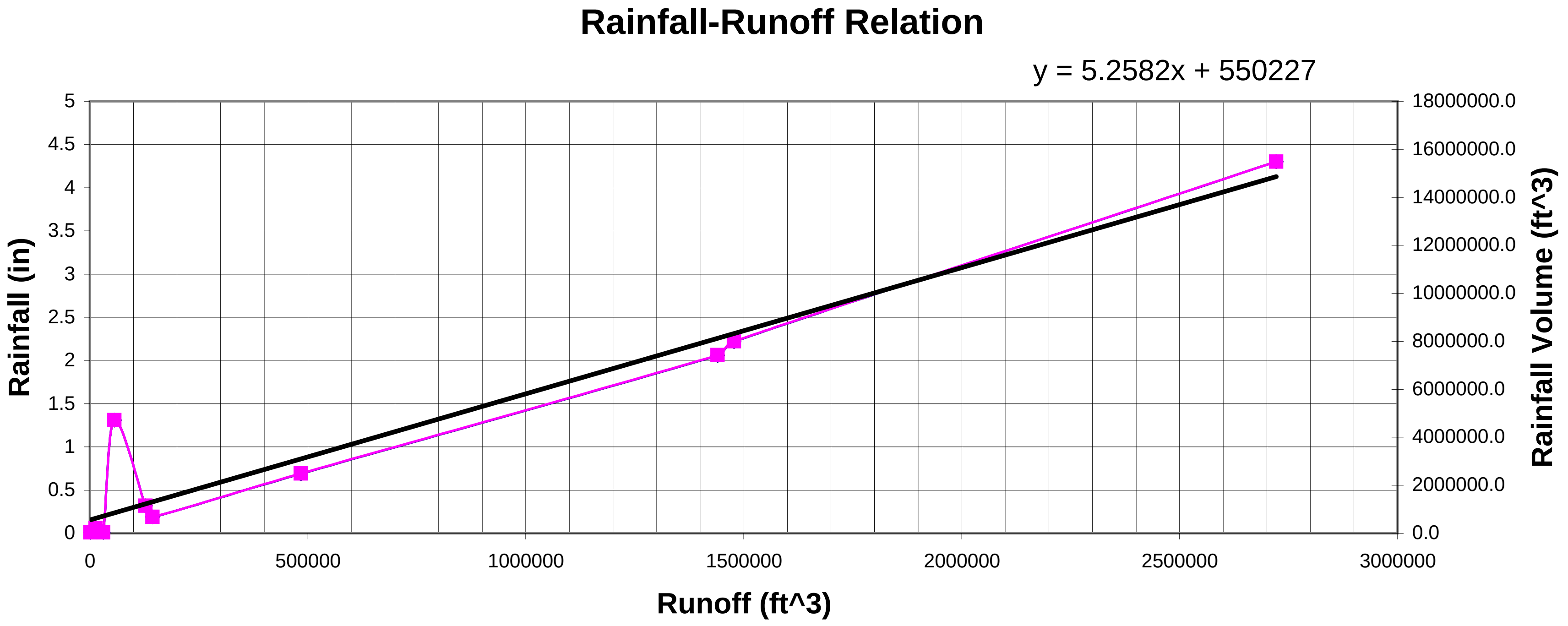

Figure A1: Rainfall vs. Runoff : Rainfall Volume vs. Runoff using Table A1.

Storm #	Total rain (in)	Duration (hrs)	Percipitation (ft^3)	Storm Runoff Vol. (ft^3)	Percent Runoff
6	0.01	0.25	36016.4	1323	4%
1	0.06	3.25	216098.3	13617	6%
11	0.02	0.75	72032.8	16481	23%
3	0.32	4.25	1152524.1	127515	11%
9	0.19	1.25	684311.2	143912	21%
4	0.69	8.25	2485130.1	484404	19%
10	2.06	6.25	7419374.0	1439910	19%
5	2.22	12.00	7995636.0	1477553	18%
2	4.3	25.25	15487042.7	2721692	18%

Table A2: Edited Individual storm data (no outlyers)

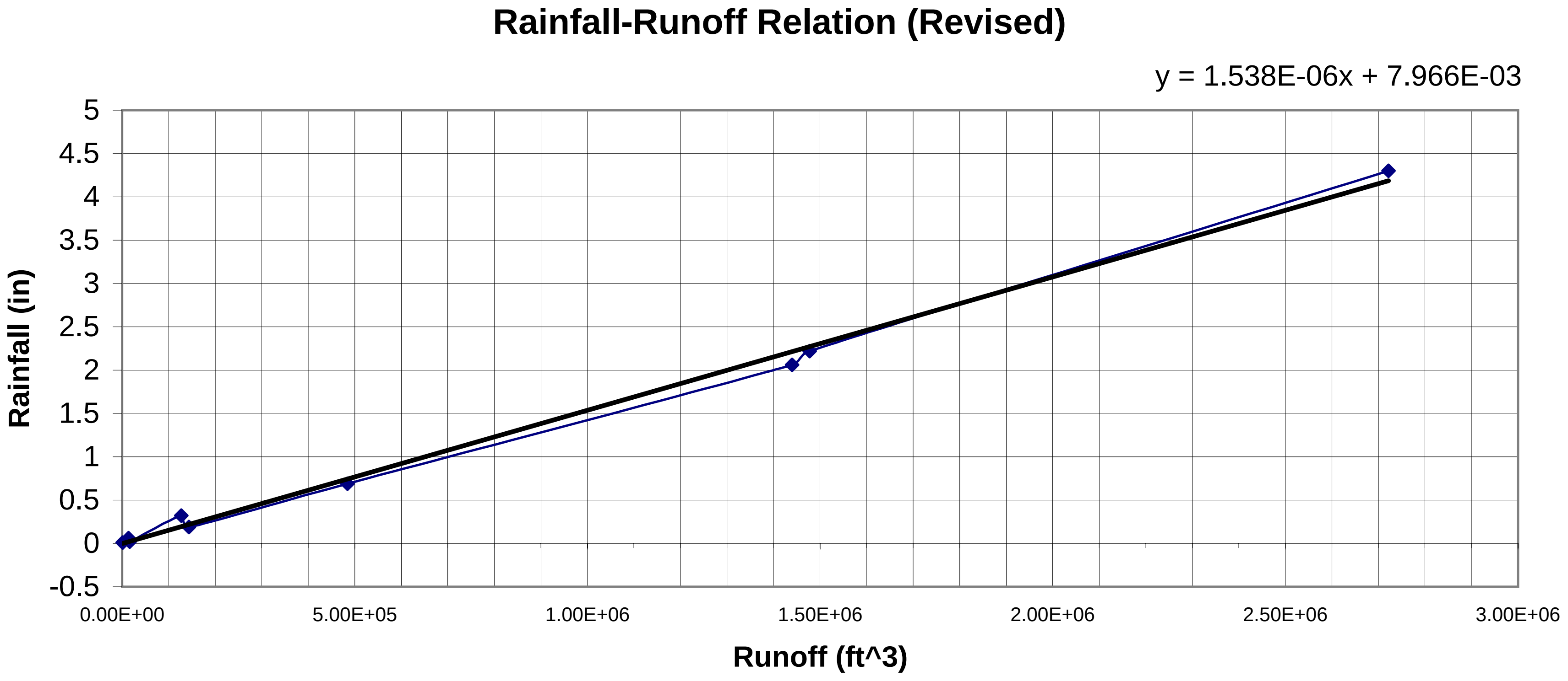

Figure A2: Rainfall vs. Runoff : Rainfall Volume vs. Runoff using Table A2.

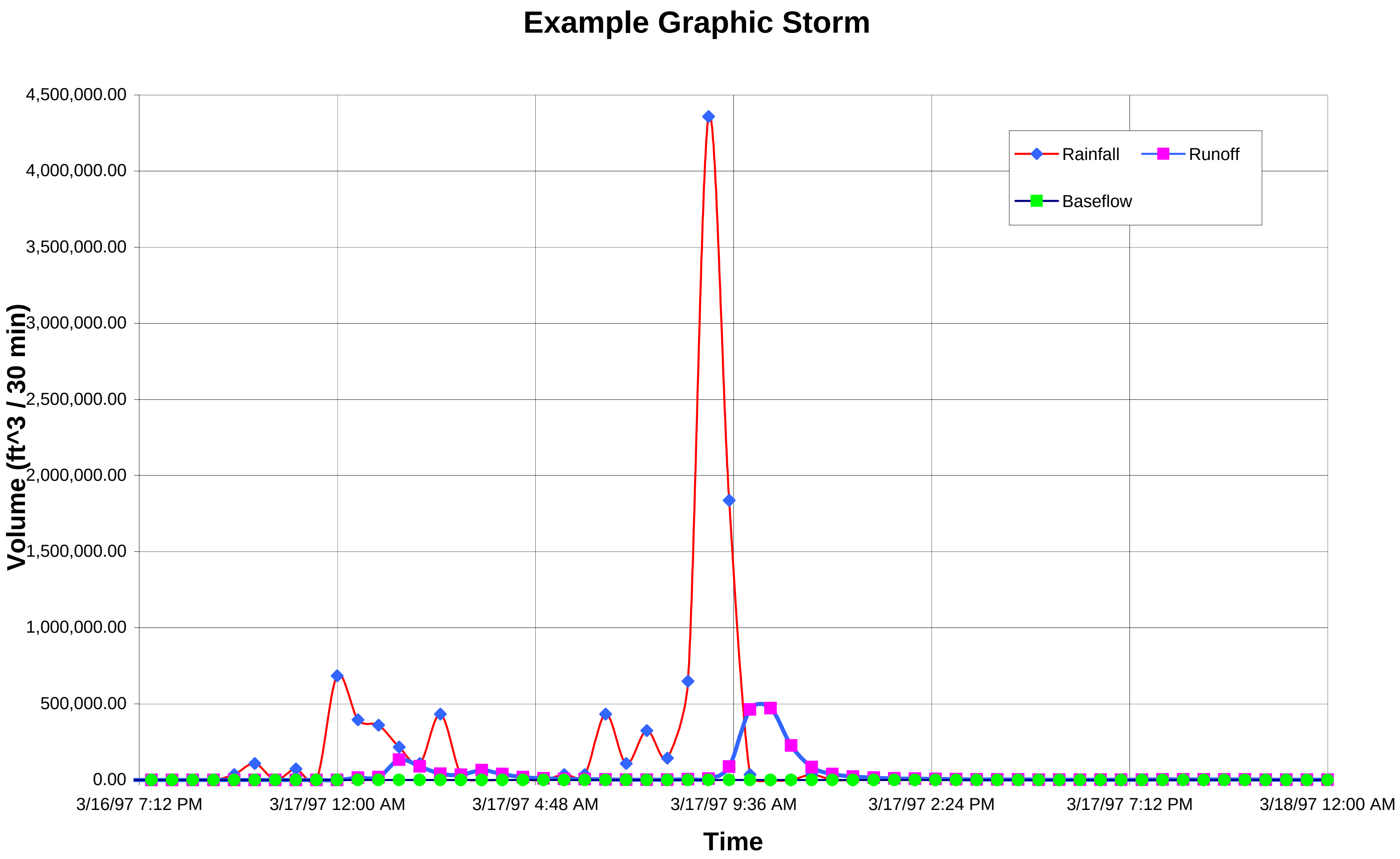

Figure A3: Volume accumulated per 30 minuntes for rainfall, runoff, and baseflow. Storm event 3-16-97 to 3-17-97 is used for this expamle.

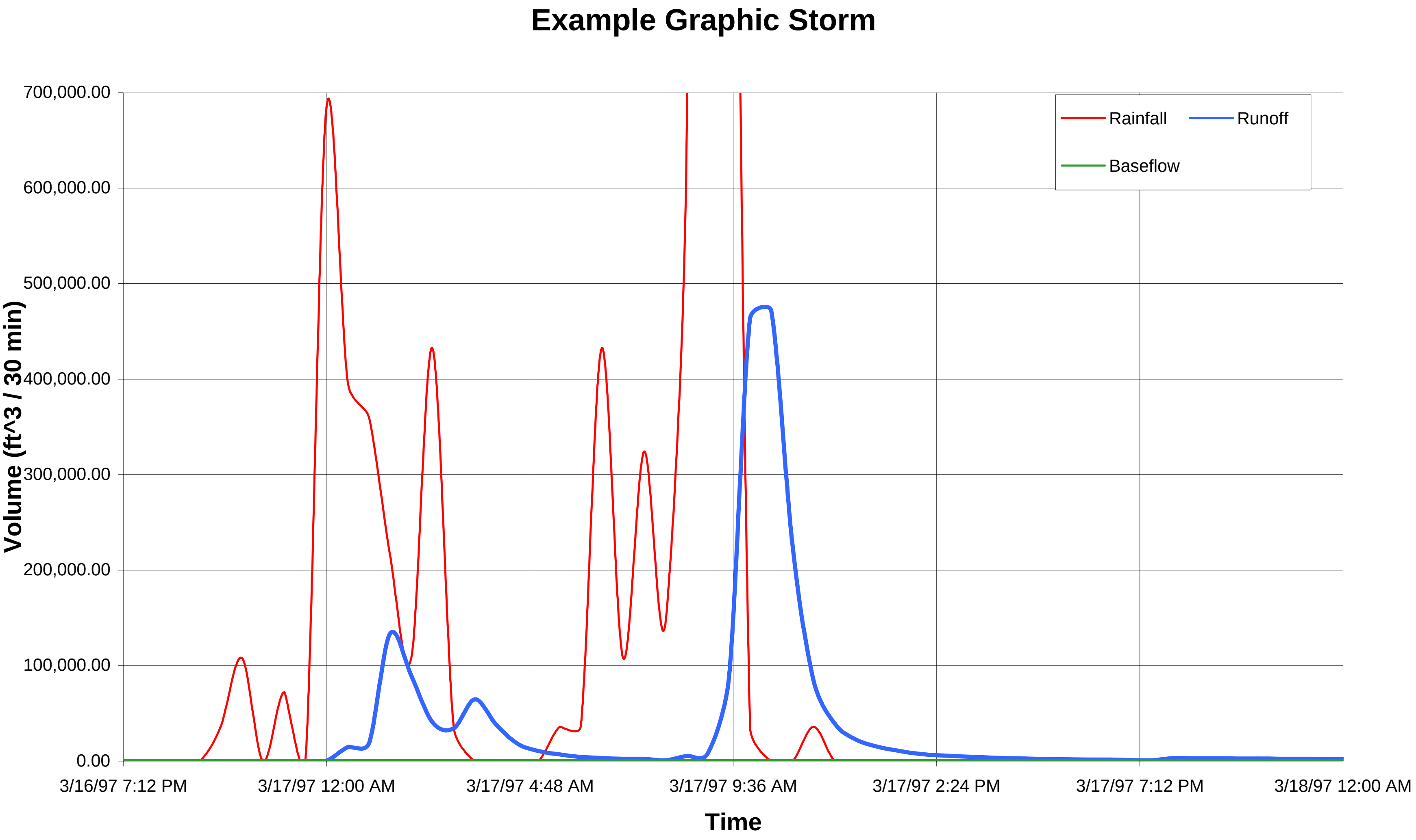

Figure A4: Volume accumulated per 30 minuntes for rainfall, runoff, and baseflow. Storm event 3-16-97 to 3-17-97 is used for this expamle.

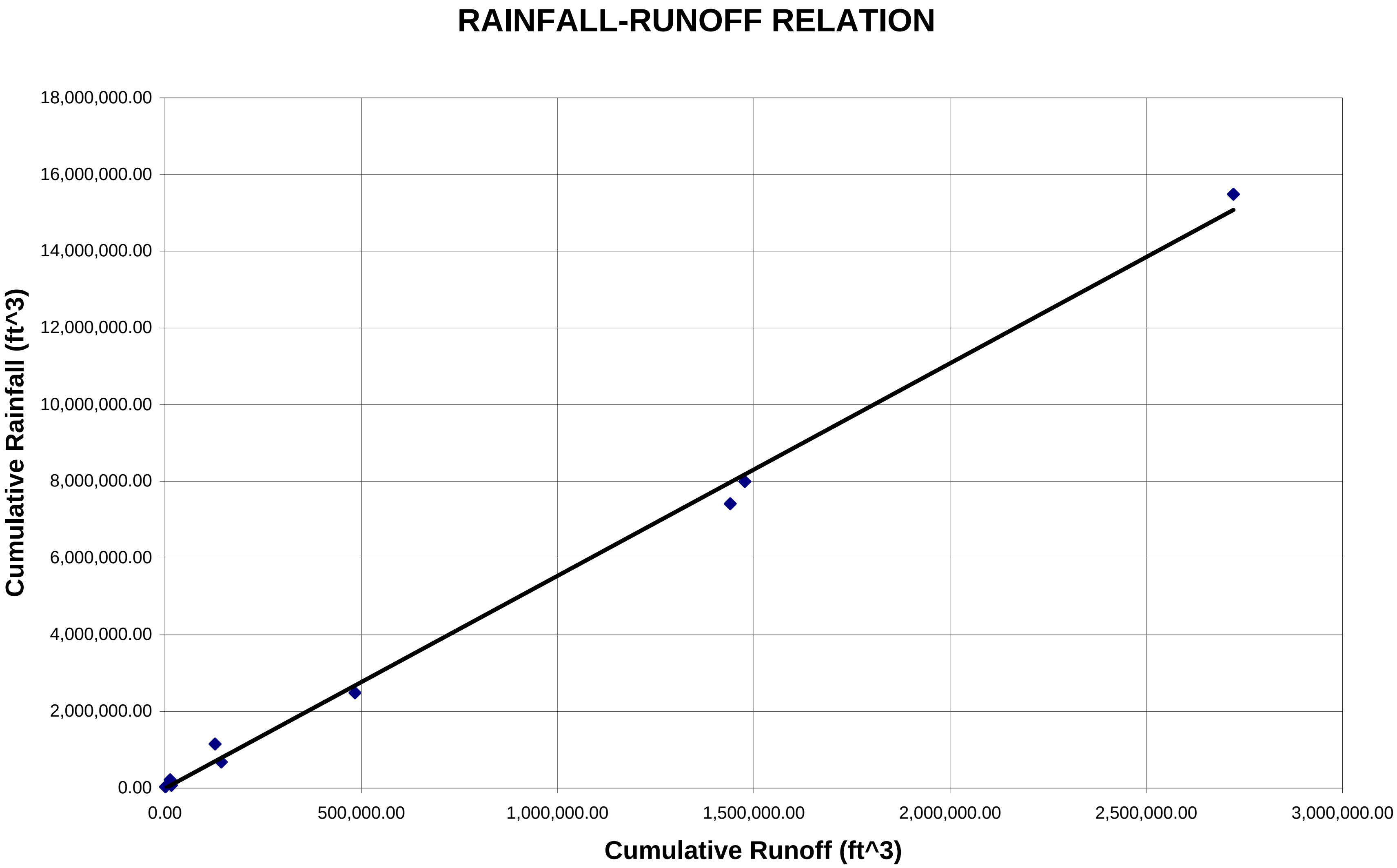

Figure A5: Total Rainfall Volume vs. Total Runoff Volume For All Storms.

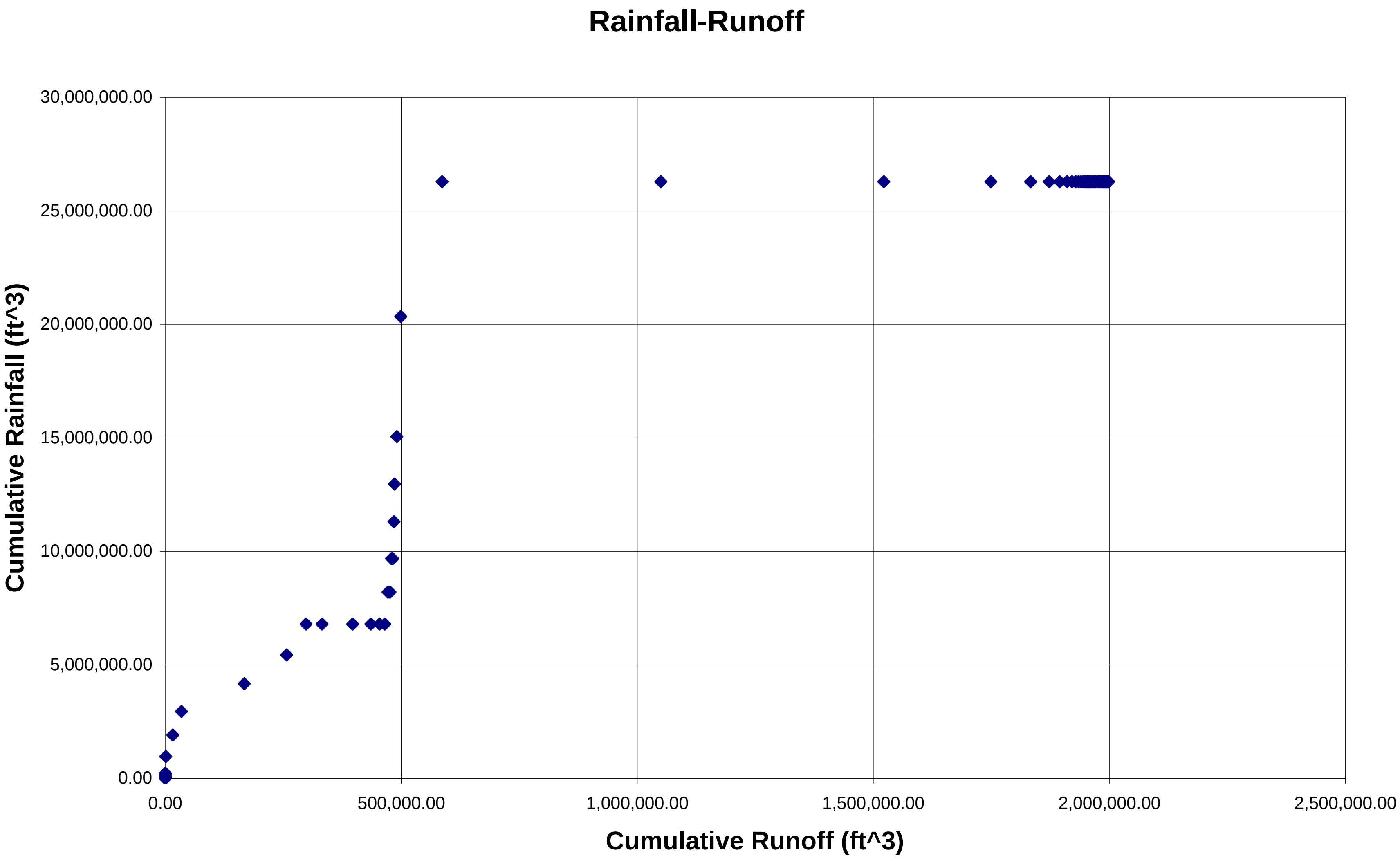

Figure A6: Cumulative Rainfall Volume vs. Cumulative Rinoff Volume For Storm Event 3-16-97 to 3-17-97.

Appendix B: Water Quality Data

APPENDIX B
WATER QUALITY DATA - KAWA STREAM

The water quality results listed here represent our effort to characterize water quality in the different reaches and branches of Kawa Stream, particularly during periods of runoff into the stream. These data are biased to rainfall events. Each sample is flagged with a small "r" following the sample date/time if influenced by rain induced runoff into the stream.

Because several samples were sometimes collected over time during a particular storm, sample event numbers may span more than one sample at a particular station (for example, event 005 at Station 007 has four separate samples collected during and after a storm on December 14; event 006 represents the next stream sampling not associated with that storm). Stream sampling stations are arranged on this page from upstream to downstream, and station numbers match HDOH station numbers where sampling locations are the same (e.g., HDOH Sta. 7 = Station 007).

Under the "Links" column appears the laboratory log number, which will match to chain of custody and other documents retained by the AECOS laboratory for the samples. Log numbers were not assigned to flow measurements made in the stream. The "+DATA" following a log number indicates that additional measurements (e.g., nutrients) were measured in the sample and are to be found elsewhere in this appendix.

STATION 010A - Central branch culvert outlet at National Veterans Cemetery (UR)

EVENT			FLOW	TEMP	DO	COND	pH	TURB	TSS	LINKS
No.	Date	Time	l/sec	°C	mg/L	umhos		ntu	mg/L	
			NC	NC	NC	NC	NC	AE	AE	
009	12/26/99	*1445* r	------	------	------	------	------	53.6	20	AE 12627
017	03/31/00	1140 r	------	------	------	------	------	22.7	14.4	AE 12886 / + DATA
020	11/02/00	1315 r	------	------	------	------	------	4.80	1.9	AE 13589 / + DATA
021	02/08/01	1705 r	------	------	------	------	------	76.8	56	AE 13932 / + DATA

STATION 009 - Central branch above Royal Construction site culvert (IUR)

EVENT			FLOW	TEMP	DO	COND	pH	TURB	TSS	LINKS
No.	Date	Time	l/sec	°C	mg/L	umhos		ntu	mg/L	
			VO	NC	NC	NC	NC	AE	AE	
007	12/20/99	*0940*	dry	------	------	------	------	------	------	
009	12/26/99	*1440* r	------	------	------	------	------	65.0	25	AE 12627
017	03/31/00	1150 r	------	------	------	------	------	25.0	12	AE 12886 / + DATA
NA	04/03/00	*1035*	pool	------	------	------	------	------	------	
020	11/02/00	1300 r	------	------	------	------	------	9.26	2.7	AE 13589 / + DATA
021	02/08/01	1645 r	------	------	------	------	------	46.2	24	AE 13932 / + DATA
**	"	1655 r	------	------	------	------	------	29.9	12	AE 13932 / + DATA

STATION 08R - Central branch above Parkway recreation center (UMR)

EVENT			FLOW	TEMP	DO	COND	pH	TURB	TSS	LINKS
No.	Date	Time	l/sec	°C	mg/L	umhos		ntu	mg/L	
			FM	NC	NC	AE	AE	AE	AE	
008	12/22/99	1740 r	------	------	------	186	------	48.0	13	AE 12626 / + DATA
009	12/26/99	1430 r	------	------	------	------	------	286	618	AE 12627
012	01/19/00	1545 r	------	------	------	133.2	------	202	159	AE 12676
015	03/06/00	0950	------	------	------	------	------	------	------	AE 12812 / + DATA
017	03/31/00	1130 r	------	------	------	------	------	35.8	24.1	AE 12886 / + DATA
NA	04/03/00	*1030*	7.4	------	------	------	------	------	------	
NA	06/07/00	1255	0.9	------	------	------	------	------	------	
020	11/02/00	1245 r	------	------	------	------	------	3.24	1.3	AE 13589 / + DATA
021	02/08/01	1525 r	------	------	------	------	------	71.1	49	AE 13932

STATION 008 (= 08L) - Upper west branch above Parkway recreation center (UMR)

EVENT			FLOW	TEMP	DO	COND	pH	TURB	TSS	LINKS
No.	Date	Time	l/sec	°C	mg/L	umhos		ntu	mg/L	
			OP	NC	NC	AE	AE	AE	AE	
007	12/20/99	0930	------	------	------	278	7.29	7.66	9.9	AE 12618
008	12/22/99	1735 r	------	------	------	186	------	21.0	8	AE 12626 / + DATA
009	12/26/99	1430 r	------	------	------	------	------	43.0	27	AE 12627
012	01/19/00	1545 r	------	------	------	83.3	-----	145	64	AE 12676
014	02/15/00	0945	------	------	------	259	------	12.8	------	AE 12747 / + DATA
015	03/06/00	0950	------	------	------	------	7.32	7.64	------	AE 12812 / + DATA
017	03/31/00	1130 r	------	------	------	------	------	39.1	29.8	AE 12886 / + DATA
NA	04/03/00	1010	4.1	------	------	------	------	------	------	
NA	06/07/00	1300	1.4	------	------	------	------	------	------	
020	11/02/00	1240 r	------	------	------	------	------	11.0	5.6	AE 13589 / + DATA
021	02/08/01	1520 r	------	------	------	------	------	39.3	40.8	AE 13932

STATION 08A - Kawa Stream at Parkway in concrete culvert (UMR)

EVENT			FLOW	TEMP	DO	COND	pH	TURB	TSS	LINKS
No.	Date	Time	l/sec	°C	mg/L	umhos		ntu	mg/L	
			NC	NC	NC	AE	AE	AE	AE	
004	12/10/99	1630 r	------	------	------	------	------	138	100	AE 12587
021	02/08/01	1630 r	------	------	------	------	------	143	94	AE 13932 / + DATA

STATION 007 - Kawa Stream above Namoku Street bridge (UMR)

EVENT			FLOW	TEMP	DO	COND	pH	TURB	TSS	LINKS
No.	Date	Time	l/sec	°C	mg/L	umhos		ntu	mg/L	
			OP	SY	NC	AE	AE	AE	AE	
001	11/29/99	1255	------	23.7	------	------	------	5.50	------	AE 12559 / +DATA
002	12/01/99	0700 r	------	19.7	------	68.9	7.07	502	1320	AE 12566
	"	0745 r	------	20.0	------	------	------	940	------	AE 12566
	"	0850 r	------	20.4	------	------	------	116	------	AE 12566
	"	1005 r	------	20.5	------	------	------	331	------	AE 12566
	"	1250 r	------	22.2	------	------	7.15	75.5	------	AE 12566
004	12/10/99	1330 r	------	23.2	------	------	------	15.2	20	AE 12587
	"	1435 r	------	23.4	------	------	------	10.4	20	AE 12587
	"	1610 r	------	22.9	------	------	------	77.6	60	AE 12587
	"	1815 r	------	22.0	------	------	------	185	220	AE 12588
	12/11/99	0835	------	22.5	------	------	------	9.69	3.8	AE 12588
005	12/14/99	1735 r	------	22.0	------	------	------	414	370	AE 12607
	"	1830 r	------	22.0	------	------	------	323	280	AE 12607
	"	2215 r	------	21.5	------	------	------	50.1	13	AE 12607
006	12/15/99	1110	------	23.2	------	------	------	6.58	3.2	AE 12609
007	12/20/99	0920	------	24.2	------	293	7.35	5.48	3.7	AE 12618
008	12/22/99	1810 r	------	20.0	------	------	------	35.3	12	AE 12626
009	12/26/99	1100 r	------	24.0	------	------	------	12.6	8.3	AE 12627
	"	1410 r	------	22.5	------	------	------	472	290	AE 12627
010	01/14/00	1150	------	22.2	------	------	------	18.6	9.0	AE 12659
011	01/15/00	0920 r	------	21.2	------	------	------	------	18.5	AE 12667
	"	1020 r	------	21.5	------	------	------	------	25.1	AE 12667
012	01/19/00	1430 r	------	20.5	------	------	------	152	139	AE 12676
	"	2015 r	------	18.3	------	------	------	863	656	AE 12679
	"	2300 r	------	19.4	------	------	------	93.7	503	AE 12679>
	1/20/00	0820 r	------	20.5	------	------	------	15.8	11	AE 12679
	"	1020 r	------	20.0	------	------	------	120	57.0	AE 12679
	"	1645 r	------	21.2	------	------	------	18.4	6.4	AE 12681
013	1/26/00	1130 r	------	21.0	------	------	------	45.9	36.2	AE 12696
	"	1250 r	------	21.4	------	------	------	22.1	13	AE 12696
NA	03/23/00	1640	8.2	24.9	------	------	------	------	------	AE 12696
016	03/27/00	0920	12	21.7	------	151.8	------	27.6	21.0	AE 12875 / +DATA
017	03/31/00	1030 r	497	21.5	------	71.3	------	42.8	36.4	AE 12886
	"	1405 r	132	22.7	------	------	------	19.3	12	AE 12892
NA	04/03/00	0950 r	32.8	21.7	------	------	------	------	------	
018	04/09/00	0735 r	------	18.7	------	------	------	302	318	AE 12914

STATION 007 - Kawa Stream above Namoku Street bridge (UMR) (continued)

	"	1035 r	------	19.9	------	------	------	25.0	12	AE 12914
	"	1515 r	------	21.5	------	------	------	9.12	6.8	AE 12914
NA	05/11/00	0930	8.6	------	------	------	------	------	------	
021	02/08/01	1505 r	------	------	------	------	------	5.30	4.7	AE 13932
	"	1545 r	------	------	------	------	------	25.1	184	AE 13932
	"	1650 r	------	------	------	------	------	66.4	115	AE 13932
022	02/09/01	1625	------	------	------	------	------	*4.52*	2.2	AE 13947
023	02/12/01	1510 r	------	------	------	------	------	4.88	4.6	AE 13947
024	04/08/01	1720	------	------	------	------	------	8.12	------	AE 14175
025	04/09/01	0625	------	------	------	------	------	4.68	------	AE 14175
026	05/18/01	1105 r	------		------	------	------	434	540	AE 14320

STATION 016L - Kawa Stream above confluence with middle east branch (LMR)

EVENT			FLOW	TEMP	DO	COND	pH	TURB	TSS	LINKS
No.	Date	Time	l/sec	°C	mg/L	umhos		ntu	mg/L	
			NC	NC	NC	AE	AE	AE	AE	
006	12/15/99	1335	------	------	------	336	7.65	9.01	5.0	AE 12609 / + DATA
012	01/19/00	1450 r	------	------	------	81.4	------	189	161	AE 12676
015	03/06/00	0910	------	------	------	------	------	------	------	AE 12812 / + DATA
017	03/31/00	1440 r	------	------	------	------	------	18.2	10	AE 12892
020	11/02/00	1155 r	------	------	------	------	------	7.36	3.8	AE 13589 / + DATA
** 021	02/08/01	1615 r	------	------	------	------	------	278	210	AE 13932 / + DATA

STATION 017 - Kawa Stream middle east branch end of Lipalu Street (above residential area)(IUR)

EVENT			FLOW	TEMP	DO	COND	pH	TURB	TSS	LINKS
No.	Date	Time	l/sec	°C	mg/L	umhos		ntu	mg/L	
			OP	NC	NC	NC	NC	AE	AE	
026	05/18/01	1120 r	dry	------	------	------	------	------	------	

STATION 006 - Kawa Stream middle east branch near Mokulele Street bridge

EVENT			FLOW	TEMP	DO	COND	pH	TURB	TSS	LINKS
No.	Date	Time	l/sec	°C	mg/L	umhos		ntu	mg/L	
			OP	NC	NC	NC	NC	AE	AE	
004	12/10/99	1710 r	------	------	------	------	------	27.5	8	AE 12587
007	12/20/99	0905	------	------	------	------	------	5.28	5.7	AE 12618
014	02/15/00	0920	------	------	------	307	------	4.46	------	AE 12747 / + DATA
017	03/31/00	1450 r	22.4	------	------	------	------	------	------	
NA	04/03/00	0920	5.2	------	------	------	------	------	------	
NA	05/11/00	1015	1.3	------	------	------	------	------	------	
NA	06/08/00	---	0.6	------	------	------	------	------	------	

STATION 006 - Kawa Stream middle east branch near Mokulele Street bridge (continued)

021	02/08/01	1610 r	------	------	------	------	------	17.6	17	AE 13932 / + DATA
026	05/18/01	1125 r	------	------	------	------	------	81.1	76.0	AE 14320 / +DATA

STATION 016R - Kawa Stream middle east branch above confluence (LMR)

EVENT			FLOW	TEMP	DO	COND	pH	TURB	TSS	LINKS
No.	Date	Time	l/sec	°C	mg/L	umhos		ntu	mg/L	
			NC	NC	NC	NC	AE	AE	AE	
006	12/15/99	1330	------	------	------	223	7.49	9.14	2.0	AE 12609 / + DATA
012	01/19/00	1445 r	------	------	------	61.5	------	64.0	39.3	AE 12676
015	03/06/00	0910	------	------	------	------	------	------	------	AE 12812 / + DATA
017	03/31/00	1440 r	------	------	------	110	------	21.4	8.3	AE 12892 / + DATA
020	11/02/00	1200 r	------	------	------	------	------	20.6	8.7	AE 13589 / + DATA
021	02/08/01	1615 r	------	------	------	------	------	31.5	28	AE 13932 / + DATA

STATION 012R - Kawa Stream above Castle Highschool (LMR)

EVENT			FLOW	TEMP	DO	COND	pH	TURB	TSS	LINKS
No.	Date	Time	l/sec	°C	mg/L	umhos		ntu	mg/L	
			OP	NC	NC	AE	AE	AE	AE	
003	12/08/99	1330	------	------	------	320	8.79	6.62	------	AE 12580 / + DATA
004	12/10/99	1610 r	------	------	------	------	------	219	170	AE 12587
008	12/22/99	1800 r	------	------	------	------	------	38.0	------	AE 12626
010	01/14/00	1200	------	------	------	160	7.89	28.6	------	AE 12659 / + DATA
012	01/19/00	1500 r	------	------	------	77.2	------	208	116	AE 12676
016	03/27/00	1420	------	------	------	139.5	------	1.78	------	AE 12875 / +DATA
017	03/31/00	1510 r	------	------	------	------	------	20.0	14	AE 12892
NA	05/11/00	1130	15.8	------	------	------	------	------	------	
020	11/02/00	1135 r	------	------	------	------	------	1.29	6.6	AE 13589 / + DATA
021	02/08/01	1615 r	------	------	------	------	------	106	128	AE 13932 / + DATA

STATION 018 - Kawa Stream lower west branch at Castle Highschool culvert mouth (LMR>

EVENT			FLOW	TEMP	DO	COND	pH	TURB	TSS	LINKS
No.	Date	Time	l/sec	°C	mg/L	umhos		ntu	mg/L	
			OP	NC	NC	AE	AE	AE	AE	
021	02/08/01	1615 r	------	------	------	------	------	33.6	32	AE 13932 / + DATA
026	05/18/01	1140 r	------	------	------	------	------	92.2	68.6	AE 14320 / +DATA

STATION 012L - Kawa Stream lower west branch from Castle Highschool property

EVENT			FLOW	TEMP	DO	COND	pH	TURB	TSS	LINKS
No.	Date	Time	l/sec	°C	mg/L	umhos		ntu	mg/L	
			OP	NC	NC	AE	AE	AE	AE	
003	12/08/99	1335	------	------	------	330	8.34	6.46	------	AE 12580 / + DATA
004	12/10/99	1610 r	------	------	------	------	------	39.6	40	AE 12587

STATION 012L - Kawa Stream lower west branch from Castle Highschool property (continued)

008	12/22/99	1800 r	------	------	------	------	------	10.8	------	AE 12626
010	01/14/00	1200	------	------	------	280	7.62	2.00	------	AE 12659 / + DATA
012	01/19/00	1500 r	------	------	------	54.3	------	141	87	AE 12676
016	03/27/00	1420	7.2	------	------	259	------	23.4	------	AE 12875 / +DATA
017	03/31/00	1510 r	20.6	------	------	158	------	18.8	9.3	AE 12892 / + DATA
NA	05/11/00	1100	7.7	------	------	------	------	------	------	
020	11/02/00	1130 r	------	------	------	------	------	34.8	30.6	AE 13589 / + DATA
021	02/08/01	1610 r	------	------	------	------	------	54.2	58	AE 13932 / + DATA
026	05/18/01	1145 r	------	------	------	------	------	122	63.6	AE 14320 / +DATA

STATION 022 - Kawa Stream at Kaneohe Bay Drive (LMR)

EVENT			FLOW	TEMP	DO	COND	pH	TURB	TSS	LINKS
No.	Date	Time	l/sec	°C	mg/L	umhos		ntu	mg/L	
			OP	YS	YS	NC	NC	AE	AE	
008	12/22/99	1755 r	------	------	------	------	------	32.4	12	AE 12626
010	01/14/00	1210	------	------	------	------	------	16.9	7.4	AE 12659
016	03/27/00	1510	33	------	------	------	------	------	------	
** 019	08/01/00	1030		28.4	7.03	------	------	4.38	4.4	AE 13271 / + DATA
020	11/02/00	1115 r	------	------	------	------	------	18.9	10.7	AE 13589 / + DATA
021	02/08/01	1630 r	------	------	------	------	------	80.8	90.4	AE 13932 / + DATA
026	05/18/01	1155 r	------	------	------	------	------	99.2	68.6	AE 14320 / +DATA

STATION 005 - Kawa Stream at Bayview Golf Course (LR)

EVENT			FLOW	TEMP	DO	COND	pH	TURB	TSS	LINKS
No.	Date	Time	l/sec	°C	mg/L	umhos		ntu	mg/L	
			NC	NC	NC	NC	NC	AE	AE	
007	12/20/99	0850	------	------	------	------	------	4.07	2	AE 12618
014	02/15/00	0900	------	------	------	308	------	5.02	------	AE 12747 / + DATA
015	03/06/00	0850	------	------	------	307	7.79	3.62	3.0	AE 12812
NA	05/11/00	1210		------	------	------	------	------	------	

STATION 020 - Lower east branch (Nohonani Place) at Kaneohe Bay Drive (IR)

EVENT			FLOW	TEMP	DO	COND	pH	TURB	TSS	LINKS
No.	Date	Time	l/sec	°C	mg/L	umhos		ntu	mg/L	
			OP	NC	NC	NC	NC	AE	AE	
026	05/18/01	1200 r	dry	------	------	------	------	------	------	

STATION 004 - Kawa Estuary at Bayview Golf Course (LRE)

EVENT			FLOW	TEMP	DO	SAL	pH	TURB	TSS	LINKS
No.	Date	Time	l/sec	°C	mg/L	ppt		ntu	mg/L	
			NC	NC	NC	AE	AE	AE	AE	
007	12/20/99	1015	------	------	------	4	7.44	11.4	8.1	AE 12618
014	02/15/00	0845	------	------	------		-----	6.90	------	AE 12747 / + DATA
015	03/06/00	0830	------	------	------	8	7.35	76.6	53.8	AE 12812 / + DATA

STATION 003 - Kawa Estuary at Bayview Golf Course (LRE)

EVENT			FLOW	TEMP	DO	SAL	pH	TURB	TSS	LINKS
No.	Date	Time	l/sec	°C	mg/L	ppt		ntu	mg/L	
			NC	NC	NC	AE	AE	AE	AE	
015	03/06/00	0810	------	------	------	8	7.12	40.0	16	AE 12812

APPENDIX B
WATER QUALITY DATA - KAWA STREAM

The tables below present measurements of nutrients made by *AECOS* Inc. on Kawa Stream samples. Coded entry items in the table are as explained at the beginning of Appendix B.

STATION 010A - Central branch culvert outlet at National Veterans Cemetery (UR)

EVENT			NO_2+ NO_3	NH_4	Total N	orthoP	Total P	LINKS
No.	Date	Time	ug N/L	ug N/L	ug N/L	ug P/L	ug P/L	
			AE	AE	AE	AE	AE	
017	03/31/00	1140 r	301	28	843	-----	529	AE 12886
020	11/02/00	1315 r	121	21	708	------	163	AE 13589
021	02/08/01	1705 r	65	33	603	------	290	AE 13932

STATION 009 - Central branch above Royal Construction site culvert (UR)

EVENT			NO_2+ NO_3	NH_4	Total N	orthoP	Total P	LINKS
No.	Date	Time	ug N/L	ug N/L	ug N/L	ug P/L	ug P/L	
			AE	AE	AE	AE	AE	
017	03/31/00	1150 r	338	22	847	-----	479	AE 12886
020	11/02/00	1300 r	153	6	632	------	122	AE 13589
021	02/08/01	1645 r	312	65	991	------	555	AE 13932
**	"	1655 r	216	57	904	------	524	AE 13932

STATION 08R - Central branch above Parkway recreation center (UMR)

EVENT			NO_2+ NO_3	NH_4	Total N	orthoP	Total P	LINKS
No.	Date	Time	ug N/L	ug N/L	ug N/L	ug P/L	ug P/L	
			AE	AE	AE	AE	AE	
008	12/22/99	1740 r	215	6	627	61	172	AE 12626
015	03/06/00	0945	750	-----	750	-----	56	AE 12812
017	03/31/00	1130 r	385	27	824	-----	352	AE 12886
020	11/02/00	1245 r	232	1	417	------	50	AE 13589

STATION 008 (= 08L) - Upper west branch above Parkway recreation center (UMR)

EVENT			NO_2+ NO_3	NH_4	Total N	orthoP	Total P	LINKS
No.	Date	Time	ug N/L	ug N/L	ug N/L	ug P/L	ug P/L	
			AE	AE	AE	AE	AE	
008	12/22/99	1735 r	832	9	1200	73	182	AE 12626
014	02/15/00	0945	1880	11	1980	-----	158	AE 12747
015	03/06/00	0950	1780	-----	1780	-----	167	AE 12812
017	03/31/00	1130 r	280	14	532	-----	243	AE 12886
020	11/02/00	1240 r	812	18	1080	------	100	AE 13589

STATION 08A - Kawa Stream at Parkway in concrete culvert (UMR)

EVENT			NO_2+ NO_3	NH_4	Total N	orthoP	Total P	LINKS
No.	Date	Time	ug N/L	ug N/L	ug N/L	ug P/L	ug P/L	
			AE	AE	AE	AE	AE	
020	02/08/01	1655 r	438	37	1530	------	797	AE 13932

STATION 007 - Kawa Stream above Namoku Street bridge

EVENT			NO_2+ NO_3	NH_4	Total N	orthoP	Total P	LINKS
No.	Date	Time	ug N/L	ug N/L	ug N/L	ug P/L	ug P/L	
			AE	AE	AE	AE		
001	11/29/99	1255	695	40	937	------	------	AE 12559
016	03/27/00	0920	382	25	760	------	------	AE 12875

STATION 006 - Kawa Stream middle east branch at Mokulele Street bridge

EVENT			NO_2+ NO_3	NH_4	Total N	orthoP	Total P	LINKS
No.	Date	Time	ug N/L	ug N/L	ug N/L	ug P/L	ug P/L	
			AE	AE	AE	AE	AE	
014	02/15/00	0920	303	62	1070	-----	125	AE 12747
021	02/08/01	1610 r	328	78	900	------	241	AE 13932
026	05/18/01	1125 r	219	81	1150	------	427	AE 14320

STATION 016R - Kawa Stream middle east branch just above confluence (LMR)

EVENT			NO_2+ NO_3	NH_4	Total N	orthoP	Total P	LINKS
No.	Date	Time	ug N/L	ug N/L	ug N/L	ug P/L	ug P/L	
			AE	AE	AE	AE	AE	
006	12/15/99	1330	882	36	1190	------	66	AE 12609
015	03/06/00	0910	------	------	381	------	30	AE 12812
017	03/31/00	1440 r	408	------	747	------	104	AE 12892
020	11/02/00	1200 r	382	24	684	------	114	AE 13589
021	02/08/01	1615 r	225	92	929	------	263	AE 13932

STATION 16L - Kawa Stream central branch above confluence with middle east branch (LMR)

EVENT			NO_2+ NO_3	NH_4	Total N	orthoP	Total P	LINKS
No.	Date	Time	ug N/L	ug N/L	ug N/L	ug P/L	ug P/L	
			AE	AE	AE	AE	AE	
006	12/15/99	1335	963	21	1130	------	59	AE 12609
015	03/06/00	0910	------	------	851	------	56	AE 12812
020	11/02/00	1155 r	372	16	701	------	91	AE 13589
** 021	02/08/01	1615 r	503	104	2900	------	1440	AE 13932

STATION 012R - Kawa Stream central branch above Castle High school

EVENT			NO_2+ NO_3	NH_4	Total N	orthoP	Total P	LINKS
No.	Date	Time	ug N/L	ug N/L	ug N/L	ug P/L	ug P/L	
			AE	AE	AE	AE	AE	
003	12/08/99	1330	312	43	592	28	64	AE 12580 / + DATA
010	01/14/00	1200	340	42	627	------	96	AE 12659 / + DATA
012	01/19/00	1500 r	200	76	1040	------	563	AE 12676 / + DATA
016	03/27/00	1420	475	41	665	------	116	AE 12875 / + DATA
020	11/02/00	1135 r	460	18	710	------	74	AE 13589 / + DATA
021	02/08/01	1615 r	310	137	2140	------	711	AE 13932 / + DATA

STATION 018 - Kawa Stream lower west branch at Castle High school above farm (at culvert outlet)

EVENT			NO_2+ NO_3	NH_4	Total N	orthoP	Total P	LINKS
No.	Date	Time	ug N/L	ug N/L	ug N/L	ug P/L	ug P/L	
			AE	AE	AE	AE	AE	
021	02/08/01	1615 r	728	84	1570	------	291	AE 13932 / + DATA
026	05/18/01	1140 r	549	188	*522*	------	406	AE 14320 / +DATA

STATION 012L - Kawa Stream lower west branch at Castle High school

EVENT			NO_2+ NO_3	NH_4	Total N	orthoP	Total P	LINKS
No.	Date	Time	ug N/L	ug N/L	ug N/L	ug P/L	ug P/L	
			AE	AE	AE	AE	AE	
003	12/08/99	1335	3310	15	3470	58	60	AE 12580 / + DATA
010	01/14/00	1200	3040	22	3060	------	70	AE 12659 / + DATA
012	01/19/00	1500 r	279	37	907	------	359	AE 12676 / + DATA
016	03/27/00	1420	2790	11	3210	------	64	AE 12875 / + DATA
017	03/31/00	1510 r	1550	-----	1920	------	77	AE 12892 / + DATA
020	11/02/00	1130 r	1170	21	1530	------	117	AE 13589 / + DATA
021	02/08/01	1610 r	438	48	1480	------	321	AE 13932 / + DATA
026	05/18/01	1145 r	588	166	993	------	378	AE 14320 / +DATA

STATION 022 - Kawa Stream at Kaneohe Bay Drive (LMR)

EVENT			NO_2+ NO_3	NH_4	Total N	orthoP	Total P	LINKS
No.	Date	Time	ug N/L	ug N/L	ug N/L	ug P/L	ug P/L	
			AE	AE	AE	AE	AE	
** 019	08/01/00	1030	927	25	1120	------	57	AE 13271 / + DATA
020	11/02/00	1115 r	455	24	720	------	81	AE 13589 / + DATA
021	02/08/01	1630 r	361	112	1660	------	500	AE 13932 / + DATA
026	05/18/01	1155 r	329	105	1390	------	428	AE 14320 / +DATA

STATION 005 - Kawa Stream at Bayview Golf Course (LR)

EVENT No.	Date	Time	NO_2+ NO_3 ug N/L AE	NH_4 ug N/L AE	Total N ug N/L AE	orthoP ug P/L AE	Total P ug P/L AE	LINKS
014	02/15/00	0900	1600	18	1730	------	52	AE 12747 / + DATA

STATION 004 - Kawa Estuary at Bay View Golf Course (LRE)

EVENT No.	Date	Time	NO_2+ NO_3 ug N/L AE	NH_4 ug N/L AE	Total N ug N/L AE	orthoP ug P/L AE	Total P ug P/L AE	LINKS
014	02/15/00	0845	1150	36	1390	------	43	AE 12747 / + DATA
015	03/06/00	0830	174	83	1360	------	227	AE 12812 / + DATA

STATION "no name" - Pohai Nani property open storm drain; water running off lawn area (Basin 4)

EVENT			COND	TURB	TSS	NO_2 + NO_3	NH_4	Total N	Total P	LINKS
No.	Date	Time	umhos	ntu	mg/L	ug N/L	ug N/L	ug N/L	ug P/L	
			NC	AE	AE	AE	AE	AE	AE	
026	05/18/01		------	------	------	327	37	1560	584	AE 14321

STATION "C1" - Parkway Storm Drain: outlet into concrete culvert of Kawa Stream at Sta. 08A (Basin 3)

EVENT			COND	TURB	TSS	NO_2 + NO_3	NH_4	Total N	Total P	LINKS
No.	Date	Time	umhos	ntu	mg/L	ug N/L	ug N/L	ug N/L	ug P/L	
			AE	AE	AE	AE	AE	AE	AE	
004	12/10/99	1640	104	50	-------	-------	-------	-------	-------	AE 12587
017	03/31/00	1115	52.4	6.64	2.6	-------	-------	-------	-------	AE 12886
021	02/08/01	1630	------	19.0	12	783	176	1870	207	AE 13932

STATION "C3" - Akimala Street Drain: outlet into Kawa Stream below Sta. 007 (Basin 3)

EVENT			FLOW	COND	pH	TURB	TSS	NO_2 + NO_3	NH_4	Total N	Total P	LINKS
No.	Date	Time	L/sec	umhos		ntu	mg/L	ug N/L	ug N/L	ug N/L	ug P/L	
			FC	AE	AE	AE	AE	AE	AE	AE	AE	
002[A]	12/01/99	0655	------	39.6	7.68	174	------	------	------	------	------	AE 12566
004	12/10/99	1525	------	------	------	271	230	------	------	------	------	AE 12587
	"	1815	------	------	------	99.8	64	------	------	------	------	AE 12588
005	12/14/99	1650	------	------	------	172	213	------	------	------	------	AE 12607
	"	1730	------	------	------	280	290	------	------	------	------	AE 12607
	"	1905	------	------	------	43.6	18	------	------	------	------	AE 12607
011	01/15/00	0920	------	------	------	189	------	------	------	------	-------	AE 12667
	"	1020	------	------	------	9.3	------	------	------	------	-------	AE 12667
012	01/19/00	1430	------	------	------	47.0	27.6	------	------	------	------	AE 12676
	"	2015	------	------	------	69.6	45.7	------	------	------	------	AE 12679
	"	2300	------	------	------	12.5	2.4	------	------	------	------	AE 12679
	1/20/00	0820	------	------	------	278	246	------	------	------	------	AE 12679
	"	1020	------	------	------	11.1	2.2	------	------	------	------	AE 12679
	"	1645	------	------	------	0.96	0.6	------	------	------	------	AE 12681
013	1/26/00	1130	------	------	------	99	124	------	------	------	------	AE 12696
	"	1250	------	------	-----	2.52	0.4	------	------	------	------	AE 12696

					-							
017	3/31/00	1030	32.4	41.7	------	8.39	5.8	------	------	------	------	AE 12886
	"	1405	4.5	------	------	22.5	13	------	------	------	------	AE 12892
021	02/08/01	1540	*12.5*	------	------	24.0	51.6	408	117	1410	697	AE 13932
023	02/12/01	1510	44.3	------	------	120	216	------	------	------	------	AE 13947
	"	1535	7.2	------	------	41.0	17	------	------	------	------	AE 13947
026	05/18/01	1105	------	------	------	96.2	68.6	176	79	1390	711	AE 14320

STATION "C4" - Nakuluai Street Drain: outlet into Kawa Stream below Sta. 007 (Basin 3)

EVENT			COND	TURB	TSS	NO_2 + NO_3	NH_4	Total N	Total P	LINKS
No.	Date	Time	umhos	ntu	mg/L	ug N/L	ug N/L	ug N/L	ug P/L	
			NC	AE	AE	NC	NC	NC	NC	
023	02/12/01	1540	------	31.6	17	------	------	------	------	AE 13947

STATION "C5" - Kaneohe Bay Drive open culvert north of Castle High School (Basin 7)

EVENT			COND	TURB	TSS	NO_2 + NO_3	NH_4	Total N	Total P	LINKS
No.	Date	Time	umhos	ntu	mg/L	ug N/L	ug N/L	ug N/L	ug P/L	
			AE	AE	AE	NC	NC	NC	NC	
004[A]	12/10/99	1600	-------	209	160	------	------	------	------	AE 12587
012[A]	01/19/00	1510	34.5	88.4	53.0	------	------	------	------	AE 12676
026[A]	05/18/01	1130	------	131	105	142	67	1270	395	AE 14320

[A] Sample from off the street before entering a storm drain.

APPENDIX B (continued)
KAWA STREAM WATER QUALITY DATA – HDOH DATA SET

This part of Appendix B presents data obtained by Hawaii Department of Health (HDOH) monitoring in Kawa Stream.

Date	Time	Temp °C	pH	S/Cond (umhos/cm)	DO (mg/l)	%Sat	Turbidity (ntu)	TSS (mg/l)	Nitrate (µg/l)	Ammonia (µg/l)	Total N (µg/l)	Total P (µg/l)	Chlor a (µg/l)	Si (µg/l)
Station 10 (=008R) – Central branch above Parkway recreation center (UMR)														
06/05/00	1008	23.5		271	8.02	97	2.3	5	969	9	1100	77	0.42	9.26
06/19/00	1050	23.9	6.46	281	5.89	90	1.5	4	1070	7	1260	8	0.70	6.38
07/05/00	1020	23.5	6.59	281	5.95	70	1.4	1	1200	9	1270	9	0.11	10.0
08/01/00	1000	23.7	6.17	281	7.17	85	4.0	2	1130	5	1150	10	0.12	10.6
08/14/00	1005	23.8	6.64	277	6.78	81	1.3		1190	6	1320	10	0.02	10.4
09/05/00	1020	23.8	6.83	277	7.11	84	1.70	1	1100	3	1180	7	0.10	10.5
09/18/00	1115	23.9	6.86	273	6.30	75	1.4	1	1040	0	1160	5	0.07	10.6
Station 8 (=008L) – Central branch above Parkway recreation center (UMR)														
09/07/99	1105	23.7		243	7.53	89	5.88	5	183	5	1970	90	0.11	
09/21/99	1025	23.5		240		70	5.26	4	185	5	1470	110	0.14	
10/04/99	1145	23.5		243	5.94		4.3	3	1860	43	168	100	0.1	
10/19/99	1047	22.1		106	7.44	85	65.7	31	621	7	481	104	1.05	
11/01/99	1028						6.7	6	1560	5	1750	89	0.8	
11/16/99	1031	22.9		249	8.4	98	2.89	2	1780	4	2050	90	0.03	
12/06/99	1028						3.81	2	1750	3	2140	91	0.04	
12/20/99	0930							2	1800	28	2140	63	0.04	
01/03/00	1030	22.4		285	5.64	65	4.0	2	1790	5	1990	66	0.03	
11/08/00	0940	21.1		300	5.9	66		21	1630	17	1820	55	1.33	
02/01/00	1056	22.7		293	6.77	79	4.9	4	1510	14	1960	60	0.06	6.48
02/15/00	0950	22.4		283	6.4	74	5.69	16	637	9	2120	68	0.76	6.66
03/06/00	0945	22.6		272	6.33	73	19.0	10	1260	11	223	94	1.19	
03/20/00	1051	22.2	7.76	252	6.14	71	5.3	4	1650	9	2140	97	0.16	8.39
04/03/00	1030	21.5	7.32	210	8.30	94	7.9	2	1196	22	170	66	0.11	4.67
04/17/00	0840	21.9		282	6.90	79	8.28	9	1790	18	1900	51	0.43	4.95
05/01/00	1001	23.0	7.74	254	9.57	112	12.8	3	2000	7	835	80	0.05	
05/15/00	1000	22.8	7.46	247	8.40	98	4.2	4	1510	8	1770	77	0.08	7.61

Date	Time	Temp °C	pH	S/Cond (umhos/cm)	DO (mg/l)	%Sat	Turbidity (ntu)	TSS (mg/l)	Nitrate (µg/l)	Ammonia (µg/l)	Total N (µg/l)	Total P (µg/l)	Chlor a (µg/l)	Si (µg/l)
Station 8 (continued)														
06/05/00	0958	23.3		261	7.61	91	8.3	2	976	3	1220	68	0.10	7.57
06/19/00	1035	23.9	6.80	269	4.66	55	2.7	3	8	1	156	59	0.03	4.63
07/05/00	1005	23.6	6.96	259	6.41	76	2.8	2	43	243	269	40	0.03	10.6
08/01/00	0946	23.8	6.57	243	7.82	93	4.3	3	1060	24	1160	56	0.08	9.87
08/14/00	0955	23.7	6.76	246	8.59	102	3.5	1	1090	22	1310	60	0.06	10.5
09/05/00	1015	24.1	6.98	188	8.2	97	3.4	6.84	869	11	1070	68	0.06	6.84
09/18/00	1100	24.2	6.94	248	8.04	96	3.2	1	1260	10	1320	62	0.05	10.1
Station 7 (=007) -- Kawa Stream above Namoku Street bridge (UMR)														
09/07/99	1045	25.1		290	8.15	99	10.4	14	802	144	960	25	2.20	
09/21/99	0955	24.1		272			8.86	11	758	106	1175	37	3.17	
10/04/99	1135	25.2		269	6.17	86	7.16	10	766	54	934	24	3.13	
10/19/99	1035	22.3		93	7.12	83	186	127	365	50	613	118	7.31	
11/01/99	1000						11.7	9	750	114	1040	33	4.21	
11/16/99	1005	22		279	6.51	77	7.84	11	854	44	1080	24	1.51	
12/06/99	0955						9.44	5	793	40	1430	19	1.35	
12/20/99	0920							4	861	48	1090	8	0.73	
01/03/00	1000	21.9		296	7.31	84	5.8	2	917	29	1120	17	1.03	
11/08/00	0925	19.7		300	7.3	82		2	831	36	1110	16	0.79	
02/01/00	1035	22.9		296	8.22	96	6.2	2	883	34	1220	20	1.26	5.88
02/15/00	0935	21.6		297	7.5	85	7.14	1	1070	22	1380	23	1.34	9.69
03/06/00	0925	21.7		297	7.31	83	5.64	4	674	58	1300	36	1.66	
03/20/00	1035	22.1	8.04	293	7.91	90	37.4	10	849	66	1470	50	0.08	6.23
04/03/00	1010	21.8	7.6	246	8.35	95	7.40	3	455	79	967	36	1.29	5.14
04/17/00	0825	21.2		300	7.52	85	5.37	2	798	31	1090	16	1.94	4.84
05/01/00	0941	23.6	8.01	283	8.44	100	10.7	5	785	30	345	21	1.56	
05/15/00	0933	23.7	7.63	275	10.99	130	8.9	7	688	35	1030	28	3.44	7.32
06/05/00	0937	24.4		367	8.02	105	10.4	6	567	44	873	24	2.79	7.03
06/19/00	1018	26.3	7.05	306	8.71	108	8.8	5	155	29	481	32	1.47	3.07
07/05/00	0945	25.4	7.36	309	8.68	104	6.9	5	287	211	563	32	1.41	8.85
08/01/00	0929	24.6	6.75	291	7.84	98	11.5	6	440	86	733	34	1.59	7.87
08/14/00	0938	23.8	6.92	280	8.82	105	7.6	4	532	53	740	28	1.34	11.1

Date	Time	Temp °C	pH	S/Cond (umhos/cm)	DO (mg/l)	%Sat	Turbidity (ntu)	TSS (mg/l)	Nitrate (µg/l)	Ammonia (µg/l)	Total N (µg/l)	Total P (µg/l)	Chlor a (µg/l)	Si (µg/l)
Station 7 (continued)														
09/05/00	1000	24.8	7.07	152	9.44	113	9.6	6	221	28	474	46	2.6	4.68
09/18/00	1053	25.8	7.17	279	9.93	123	11.5	11	623	52	881	32	2.71	9.25
Station 6 (=006) -- Kawa Stream middle east branch near Mokulele Street bridge (UMR)														
09/07/99	1025	27		367	6.2	78	10.1	11	69	83	350	41	3.24	
09/21/99	0935	24.6		227			9.16	8	98	79		33	2.74	
10/04/99	1110	27.2		581	6.84	93		7	82	34	364	43	3.6	
10/19/99	1015	22.1		66	7.21	83	65.1	23	327	66	507	146	3.43	
11/01/99	0936						9.12	6	112	51	607	39	1.99	
11/16/99	0935	22.6		325	8.52	99	5.6	3	107	28	287	28	1.33	
12/06/99	0922						7.66	6	180	30	511	36	1.59	
12/20/99	0907							4	730	46	926	12	1.26	
01/03/00	0945	22.9		325	8.74	102	6.5	3	516	17	693	15	1.62	
11/08/00	0910	20.0		329	6.6	72		3	562	18	764	20	1.39	
02/01/00	1022	23.5		319	8.69	102	5.9	5	482	21	783	16	2.12	8.76
02/15/00	0920	22.4		336	5.7	66	9.33	10	166	28	647	15	2.08	9.74
03/06/00	0910	22.8		325	5.76	66	9.04	4	101	32	320	30	2.21	
03/20/00	1005	22.8	8.38	358	7.21	84	15.9	6	162	217	880	86	2.35	9.32
04/03/00	0950	22.1	7.54	205	10.64	123	12.4	4	604	106	982	42	2.42	4.26
04/17/00	0810	21.8		324	5.54	63	5.00	4	24	23	588	25	1.92	4.51
05/01/00	0920	23.5	8.37	325	7.98	99	8.1	5	155	29	1420	26	2.17	
05/15/00	0910	23.8	8.02	315	5.24	67	5.9	6	102	44	354	41	3.35	8.46
06/05/00	0915	24.9		323	7.81	95	7.1	8	50	62	338	41	4.54	8.92
06/19/00	0957	26.3	7.06	1251	3.89	48	6.3	4	83	78	345	53	5.77	5.73
07/05/00	0921	24.7	8.02	307	3.10	39	9.2	4	103	218	755	97	2.19	10.0
08/01/00	0910	25.7	7.08	322	2.76	34	11.6	10	110	139	528	38	9.97	10.9
08/14/00	0915	24.5	7.00	335	4.68	51	7.1	6	73	48	405	28	28.6	12.2
09/05/00	0935	25.4	7.14	144	9.45	115	8.1	3	46	17	303	51	2.36	4.07
09/18/00	1040	26.5	7.15	317	10.20	127	7.0	6	86	30	417	35	3.64	11.7

Date	Time	Temp °C	pH	S/Cond (umhos/cm)	DO (mg/l)	%Sat	Turbidity (ntu)	TSS (mg/l)	Nitrate (µg/l)	Ammonia (µg/l)	Total N (µg/l)	Total P (µg/l)	Chlor a (µg/l)	Si (µg/l)
Station 5 (=005) -- Kawa Stream at Bayview Golf Course (LR)														
09/07/99	0955	25		358	4.75	58	6.78	4	1020	47	1190	34	1.79	
09/21/99	0920	24.4		229			4.34	2	787	29	1056	40	1.53	
10/04/99	1045	23.8		272	6.16	73	4.33	2	1080	24	1240	35	1.91	
10/19/99	0950	22.2		134	7.45	87	291	262	397	110	734	106	26.6	
11/01/99	0912						5.13	3	987	20	1370	49	1.69	
11/16/99	0910	22.2		352	5.91	70	4	2	1250	19	1370	39	0.66	
12/06/99	0840						4.17	2	975	26	1420	43	0.53	
12/20/99	0850							1	1580	36	1720	23	0.26	
01/03/00	0917	21.9		338	6.28	71	5.1	1	1520	12	1740	36	0.68	
11/08/00	0855	20.0		330	7.3	80		2	1480	20	1680	33	0.46	
02/01/00	1005	23.3		335	6.67	78	6.2	2	1510	20	1830	29	0.76	7.86
02/15/00	0905	22.2		341	6.7	77	6.56	2	995	15	2070	30	1.16	11
03/06/00	0850	22.8		340	6.47	75	4.50	2	1230	25	1920	43	1.02	
03/20/00	0940	22.1	8.87	312	6.53	75	4.8	3	1440	20	2130	33	0.92	8.56
04/03/00	0935	21.8	7.84	211	8.07	92	13.4	3	815	44	1190	42	1.05	4.94
04/17/00	0752	21.9		323	6.44	70	4.21	2	1440	18	1770	33	0.81	5.9
05/01/00	0900	23.4	8.58	324	4.63	54	4.4	2	1500	17	1630	31	1.57	
05/15/00	0848	24.0	8.58	321	7.60	90	5.2	2	1280	19	1600	31	1.22	8.52
06/05/00	0900	24.8		301	7.74	93	23.6	12	1140	18	1590	60	1.57	7.32
06/19/00	0931	26.0	7.02	318	6.0	74	2.7	2	752	24	1310	27	1.03	4.38
07/05/00	0900	24.6	8.05	319	5.53	27	4.2	2	927	34	1250	37	0.81	9.92
08/01/00	0857	26.0	7.85	314	4.85	60	3.4	2	743	26	985	28	0.77	9.12
08/14/00	0837	24.9	7.30	322	4.94	52	3.5	2	650	43	993	26	0.83	8.93
09/05/00	0912	24.8	7.28	225	8.37	101	7.2	3	332	6	643	43	1.42	6.76
09/18/00	1025	25.8	7.34	331	5.37	66	4.5	3	821	18	1210	36	0.92	8.75