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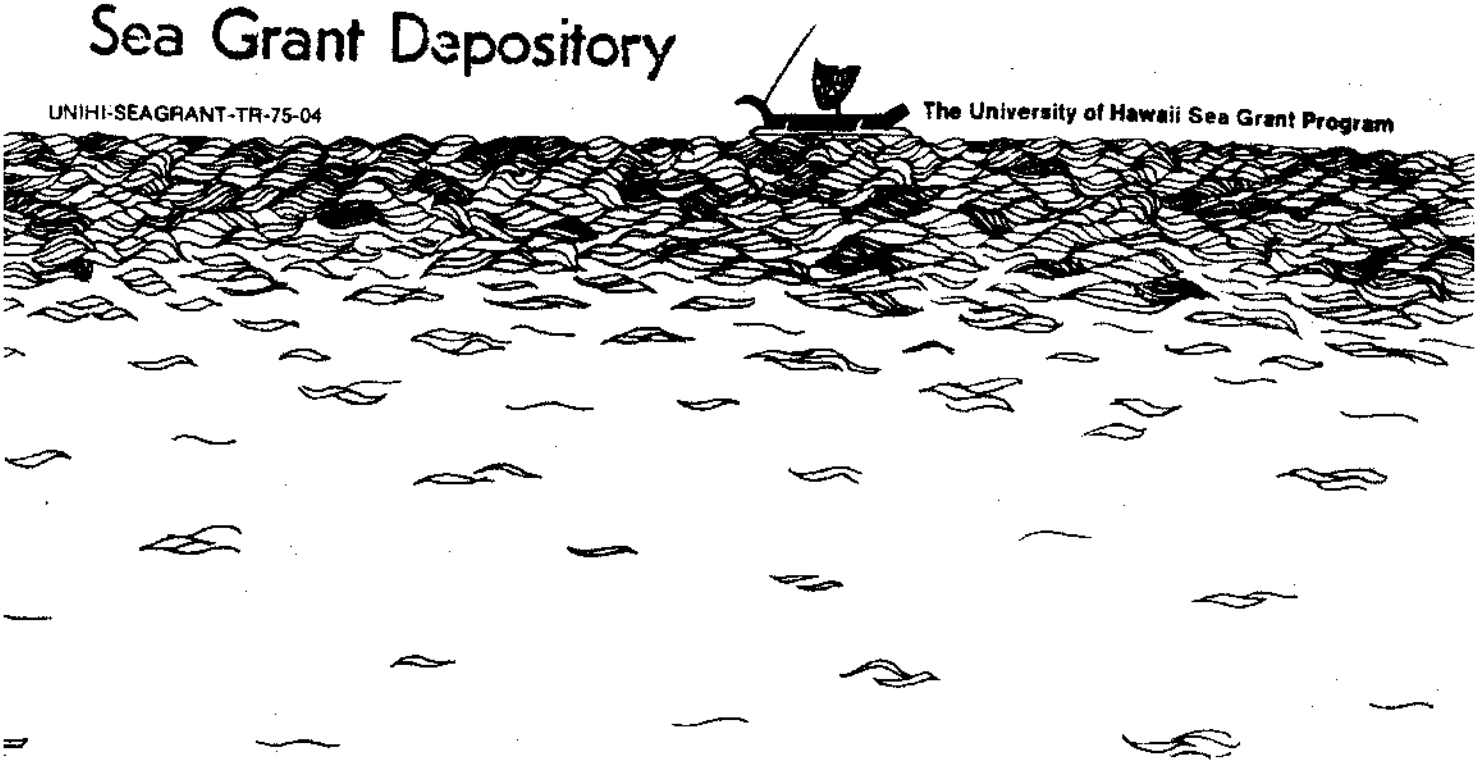

The University of Hawaii Sea Grant Program

Engineering Investigation of Marine Alternatives for Rapid Transit in Oahu, Hawaii

Theodore T. Lee and Steven A. Nicinski

August 1975

ENGINEERING INVESTIGATION OF MARINE ALTERNATIVES FOR RAPID TRANSIT IN OAHU, HAWAII

by

Theodore T. Lee
Steven A. Nicinski

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ABSTRACT

This report covers the preliminary study of the Marine alternatives to the land-based rapid transit system for the City and County of Honolulu to be operational by 1979.

The marine alternative, known as the Oceanic Express System, was originally initiated in 1972 by Dr. John P. Craven, State Marine Affairs Coordinator and Dean of Marine Programs, University of Hawaii. It is intended to serve as a complementary or a major aspect of the mass transportation system on Oahu, Hawaii. The Oceanic Express System will consist of a water-based mass transit system linked together with multiple loops via inland waterways, which are to be constructed with the existing drainageways, to serve high-density locales and suburbs in Honolulu. It can be considered as an interim and/or supplementary transportation system to the land-based system.

The objective of this study is to determine, particularly from engineering viewpoints, the feasibility of the inland waterways system which will convert the existing canals and drainage streams into navigable channels.

Major efforts under this study include study of: the hydrological and oceanographic constraints; dredging requirements; canal feeder boat requirements; and preliminary cost data involving initial construction, operation, and maintenance of the waterway potential of four selected drainageways on Oahu--Ala Wai Canal and Manoa-Palolo Stream, Nuuanu Stream, Kapalama Drainage Channel, and Kalihi Stream. These waterways will be related to four local route systems, namely Hawaii Kai, Kahala, Ala Wai, and Moanalua-Kapalama-Nuuanu.

A total of 23 feeder boats will be required. The total capital cost for the feeder boats, terminals, stop stations, initial dredging, maintenance facilities, reconstruction of road bridges, and land acquisition was estimated to be $23 million (1972). Additional capital and replacement costs over a 30-year period are estimated to be $7 million. During the 30-year period, the operational and maintenance costs would be $95 million. The annual cost was estimated at about $4 million. Reconstruction of road bridges and annual maintenance dredging in each waterway are the most expensive items. The total waterway system will be 16 miles long and the annual cost will be about $271,000 per mile per year.

It was concluded that the construction, operation, and maintenance of the four selected waterways seem to be technically feasible; but their economic feasibility cannot be determined until the entire Oceanic Express System is thoroughly analyzed. This analysis is beyond the scope of this study.

The Ala Wai route is considered to have the best potential for being converted into a waterway for navigational purposes.

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INTRODUCTION

A land-based rapid transit system has been under serious consideration by the City and County of Honolulu to be operational by 1979. The proposed rapid transit system consists of electrically-powered, automatically-controlled vehicles operating in trained units on a fixed guideway as the main trunk line element of the recommended trunk line feeder concept by Daniel, Mann, Johnson, and Mendenhall of Hawaii (DMJM, 1972).

The marine alternatives to land-based mass transit, as either a complementary or a major aspect of the system, have not been fully explored. The State Marine Affairs Coordinator, Dr. John P. Craven, initiated the Oceanic Express System study. The total Oceanic Express System will consist of a water-based mass transit system linked together with multiple loops via inland waterways, which are to be constructed with the existing canals and streams, to serve high-density locales and suburbs in the City and County of Honolulu. It was estimated that the marine transit system could be developed by 1975, as compared with 1979 for the land-based system. More recently, Lulejian and Associates, under sub-contract with DMJM, made an initial exploratory evaluation of the feasibility of a water transportation system (DMJM, 1972). Its tentative conclusion was that the marine system may be considered as an interim and/or supplementary transportation system to the land-based system. However, DMJM (1972) later studied briefly the costs, service characteristics, and the environmental impacts of several marine alternatives of the integrated transit system and concluded that the marine transportation system is not feasible.

The objective of this study is to determine, particularly from the viewpoints of engineering aspects, the feasibility of the inland waterways subsystem which will convert the existing canals and drainage streams into navigable channels.

This study was initiated in March 1972 as an 04 midyear start, with Program Management funds of the Sea Grant Program at the University of Hawaii. This resulted in a pilot study (Nicinski et al., 1972) involving site selections of those existing canals and streams which could be improved as inland waterways, requirements of canal dimensions, criteria for the feeder boats, local route systems, and patronage characteristics.

This report covers the preliminary findings of the 05 Year study during the period from September 1972 to January 1973. Major efforts include study of hydrological and oceanographic constraints, canal feeder boat requirements, and preliminary cost data for four selected local route systems--Hawaii Kai, Kahala, Ala Wai, and Moanalua-Kapalama-Nuuanu. Special attention was paid to the Ala Wai route. Information for the other routes was provided from approximations based on the Ala Wai system; therefore, it should be re-examined following the similar procedure as for the Ala Wai, particularly in the determination of maintenance dredging requirements. The estimated costs were based on the best information currently available and, in many cases, reference was made to the unit cost information from the report by DMJM (1972).

WATERWAYS POTENTIAL OF FOUR DRAINAGEWAYS ON OAHU, HAWAII

Craven (1972) proposed an inland waterway system utilizing the existing drainage channels. Pertinent hydrological and oceanographic data are scarce. Basic surface water records are maintained by the U.S. Geological Survey, Hawaii for selected streams; but they are not in a form suitable for evaluation of the hydrological and oceanographic constraints which include runoff, water level variations, sedimentation involving initial and maintenance dredging to maintain desirable water depth, and water current velocities during normal and flood conditions.

Preliminary investigation has shown that the following local canal feeder systems merit detailed engineering investigation: Hawaii Kai, Kahala, Ala Wai Canal and Manoa-Palolo Stream, and Moanalua-Kapalama-Nuuanu. This report is concerned with the potential, as a navigable waterway, of the Ala Wai Canal and Manoa-Palolo Stream, Nuuanu Stream, and the Kapalama Drainage Channels with emphasis on the Ala Wai Canal and Manoa-Palolo Stream. Included are hindcasts of runoffs on a monthly basis from rainfall information and watershed characteristics. Representative hydrographs have been developed and are used to predict the annual sediment yield in the drainageways from which the cost of maintenance dredging is estimated.

Included are the results of bathymetric surveys of the four drainageways and their analysis to determine the initial dredging requirements.

Several attempts were made to measure the currents in the Ala Wai Canal. These were not successful due to the low-sensitivity of the handheld current meter even during ebb and flood tides. Surface runoff was negligible at the time of measurement. It is concluded that currents in the waterways should be measured during floods so that their effect on navigation can be assessed.

Freshwater Runoff in the Ala Wai Canal and Manoa-Palolo Stream

The Ala Wai Canal (Figure 1) is dominately a drainageway despite its label. It consists of two straight sections, each having two near-vertical, parallel sides. The shorter seaward segment is approximately 2,830 ft long and 165 ft wide. The longer leeward segment, which receives the freshwater runoffs from the Manoa and Palolo Streams, is 7,590 ft long and 250 ft wide. The freshwater runoffs into the Ala Wai Canal are from two separate drainage basins--Manoa watershed (5.72 sq mi) and Palolo watershed (3.63 sq mi)--having a total drainage area of 9.35 sq mi (Figure 1). In addition, the freshwater runoff is also discharged into the canal from the Makiki watershed (3.72 sq mi) but it has an insignificant effect on the waterways; therefore, a study of this watershed was not made.

The U.S. Soil Conservation Service (1972) "synthesis method" was used in the construction of runoff hydrographs typical of each month and for design flood conditions as shown in Figure 2. The computational procedure is given in Appendix A.

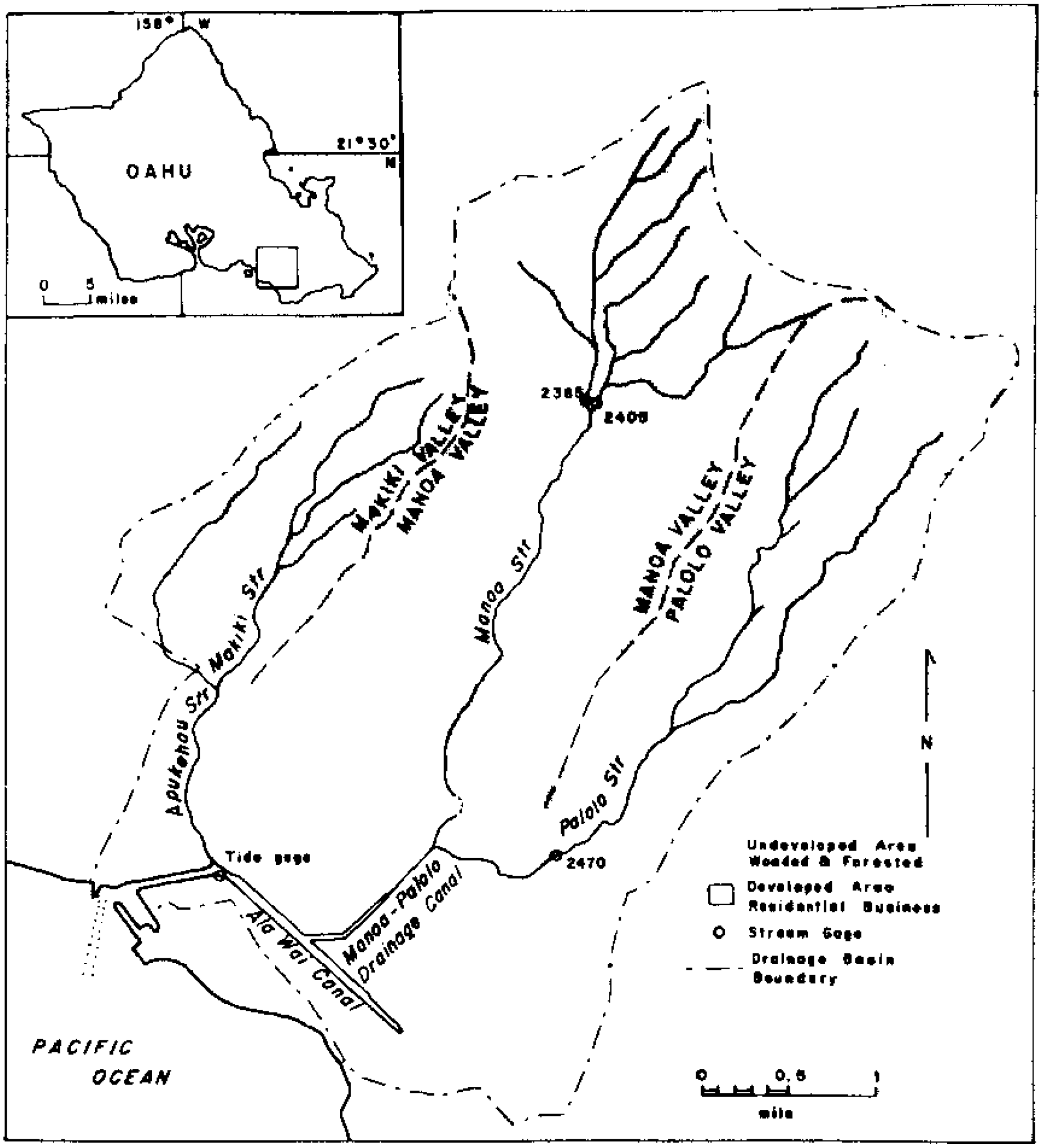

Figure 1. Ala Wai Canal and Manoa-Palolo Watersheds.

(Gonzalez, 1971)

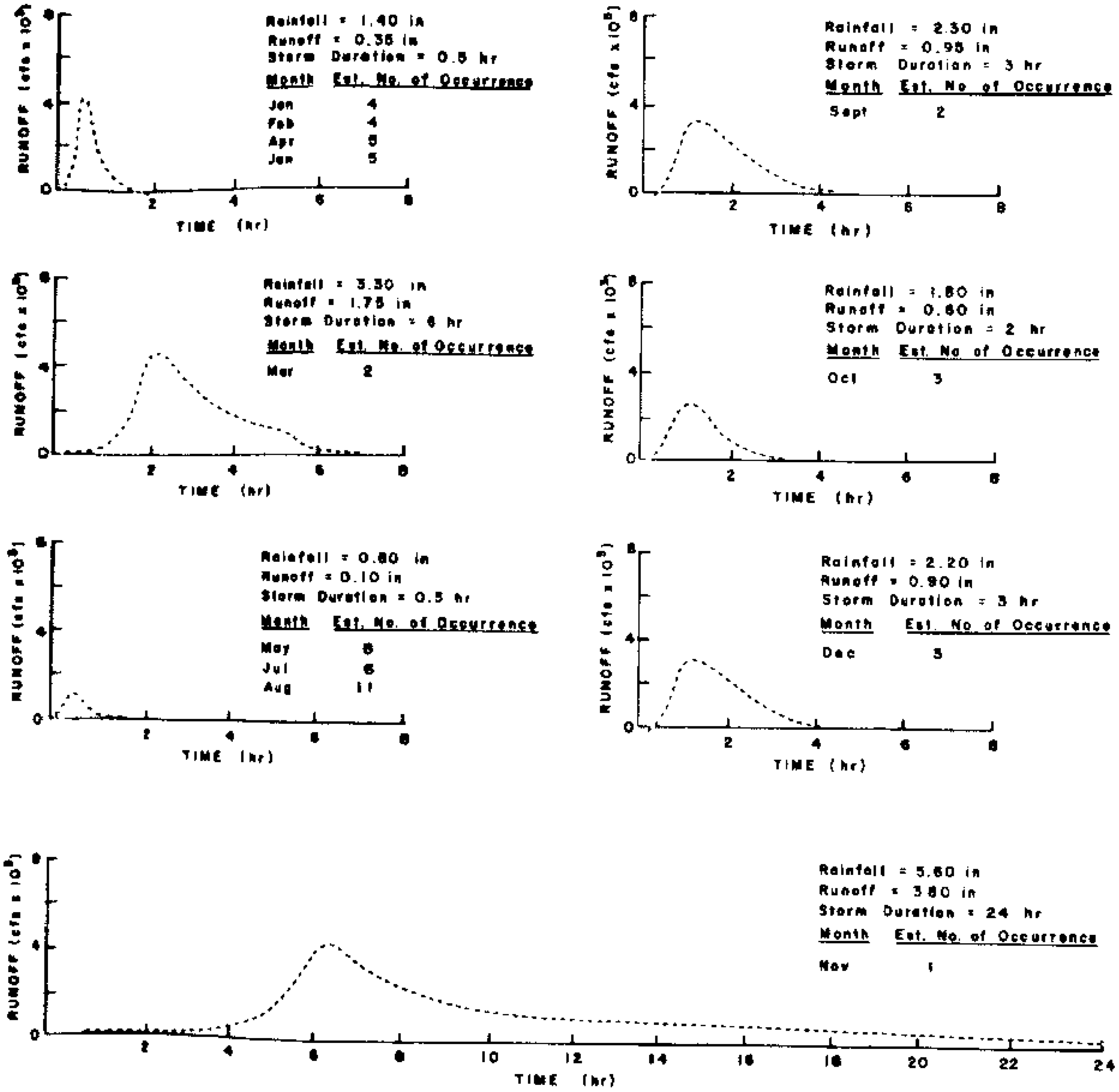

Figure 2a. Representation of monthly hydrographs predicted for Manoa-Palolo Stream based on mean monthly rainfalls and the water surface records of water year 1969.

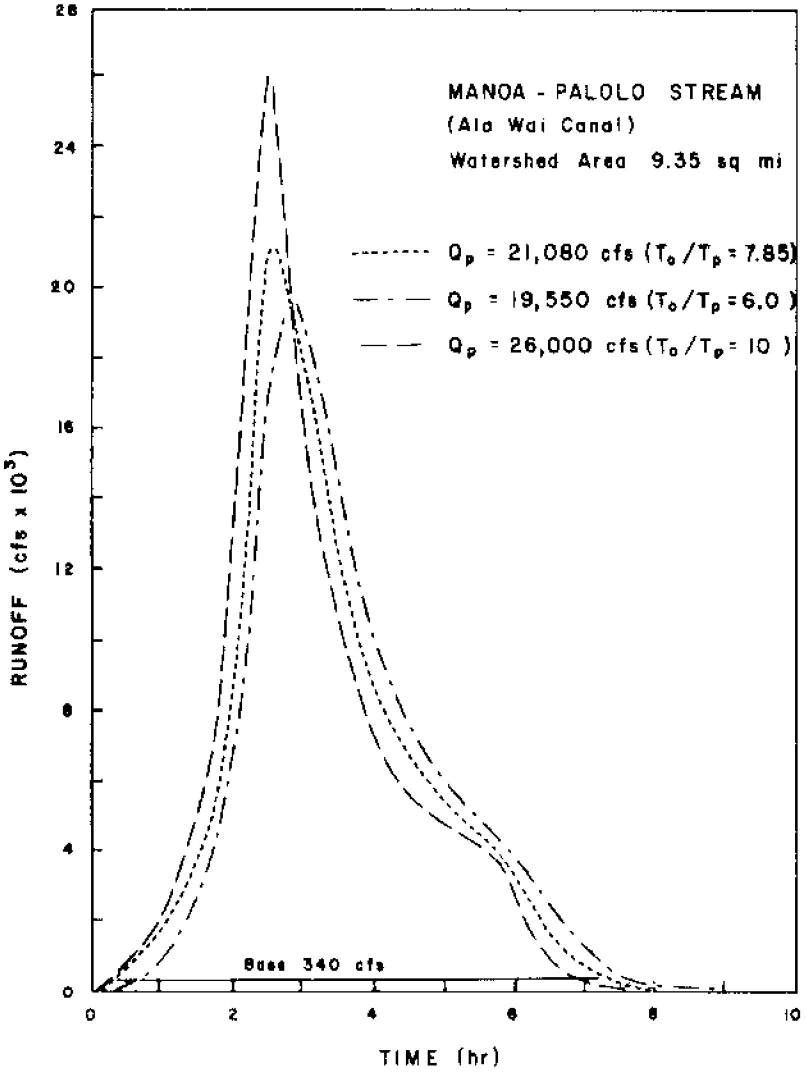

Figure 2b. Design hydrograph for 100-year storm, 1-hour rainfall of 10 inches ($T_c = 1.0$ hr) at Manoa-Palolo Stream (Ala Wai Canal).

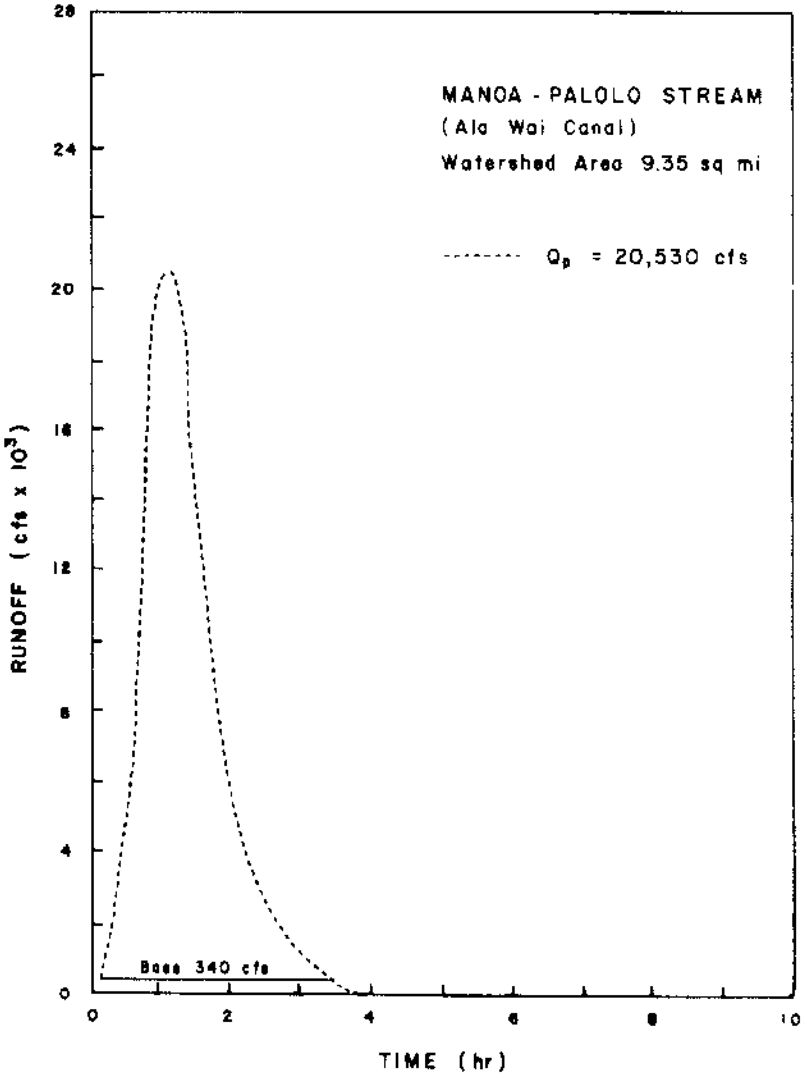

Figure 2c. Design hydrograph for 100-year storm, 1-hour rainfall of 6 inches ($T_c = 1.0$ hr) at Manoa-Palolo Stream (Ala Wai Canal).

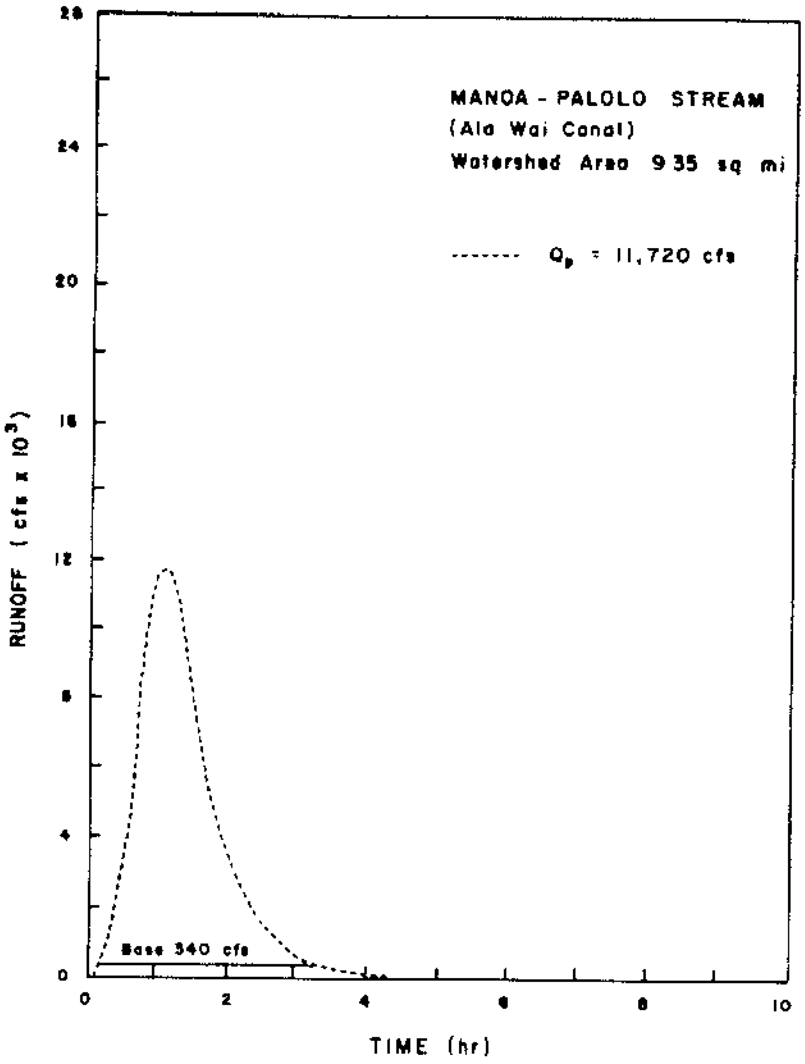

Figure 2d. Design hydrograph for 100-year storm, 1-hour rainfall of 4 inches (T_C = 1.0 hr) at Manoa-Palolo Stream (Ala Wai Canal).

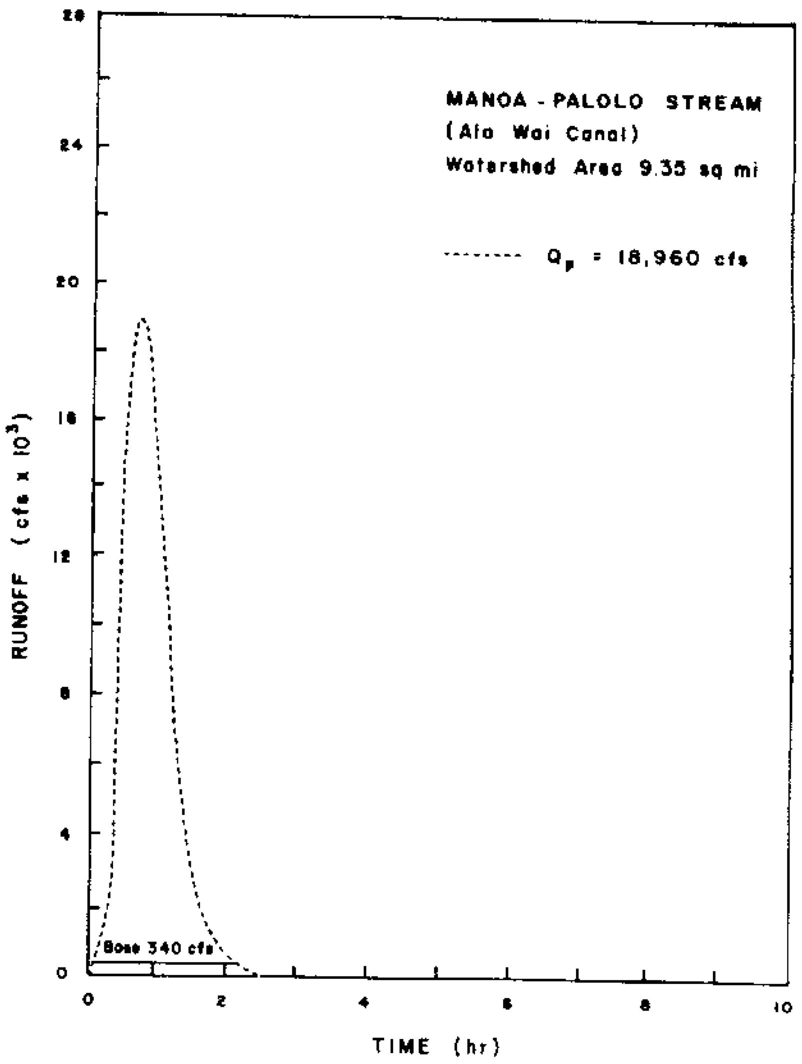

Figure 2e. Design hydrograph for 100-year storm, 1-hour rainfall of 4 inches (T_C = 0.6 hr) at Manoa-Palolo Stream (Ala Wai Canal).

The freshwater runoff into other proposed waterways is yet to be determined.

Sediment Yields

The direct freshwater runoff into the stream channels forms the bulk of the flow which generally is responsible for most of the sediment transport in the streams. This direct runoff from a given area represents the integrated effects of all characteristics of the drainage basin and of the superimposed environment upon sediment production. There are a number of empirical equations available for estimating the sediment yields from maximum yearly peak discharge, area of drainage basin, and density of cover as a percentage of the watershed area. However, they are not quite applicable to the small watersheds of the Hawaiian Islands.

For this study, sediment prediction was made from runoff-frequency data including both long-term, flow-duration curve and short-term, representative hydrograph for each month and the runoff-sediment relationship established for any given watershed from actual measurements of suspended sediments in the stream in question.

Due to lack of rating curves for Manoa-Palolo Stream, Nuuanu Stream, and Kapalama Stream, the rating curve established for the nearby Kalihi Stream was used (Figure 3). Then the sediment yields were computed for each month using the representative hydrographs respectively. The results are shown in Table 1. The sediment yields from the Manoa-Palolo Stream were estimated to be 11,900 tons per year under normal-year operational conditions. This contribution could be increased further by 3,300 up to 14,250 tons per year under extreme design flood conditions (Tables 2 and 3).

The annual sediment yield of 11,900 tons per year compares very well with 9,080 tons per year predicted with the long-range, flow-duration curve and the sediment-rating curve method used by Jones et al. (1971; Table 4) and this in turn with the estimation by Gonzales (1971; Table 4). He reported that the average rate of sediment deposition in the sill section between the intersection of Manoa-Palolo Stream and Ala Wai Canal toward the McCully Street bridge was about 0.65 ft per year, which is equivalent to 12,700 tons per year.

Based on the information from the Manoa-Palolo Stream, the sediment yield is estimated to be 4,700 and 10,400 tons per year under respectively normal and design flood conditions for the Makiki watershed, and similarly 10,750/23,600, 3,270/7,200, and 6,600/14,600 tons per year for the Nuuanu, Kapalama, and Kalihi Streams, respectively (Table 3).

For the Kalihi Stream, Jones et al. (1971) found that of the total load, approximately 60 percent is suspended sediment and 40 percent is bed load.

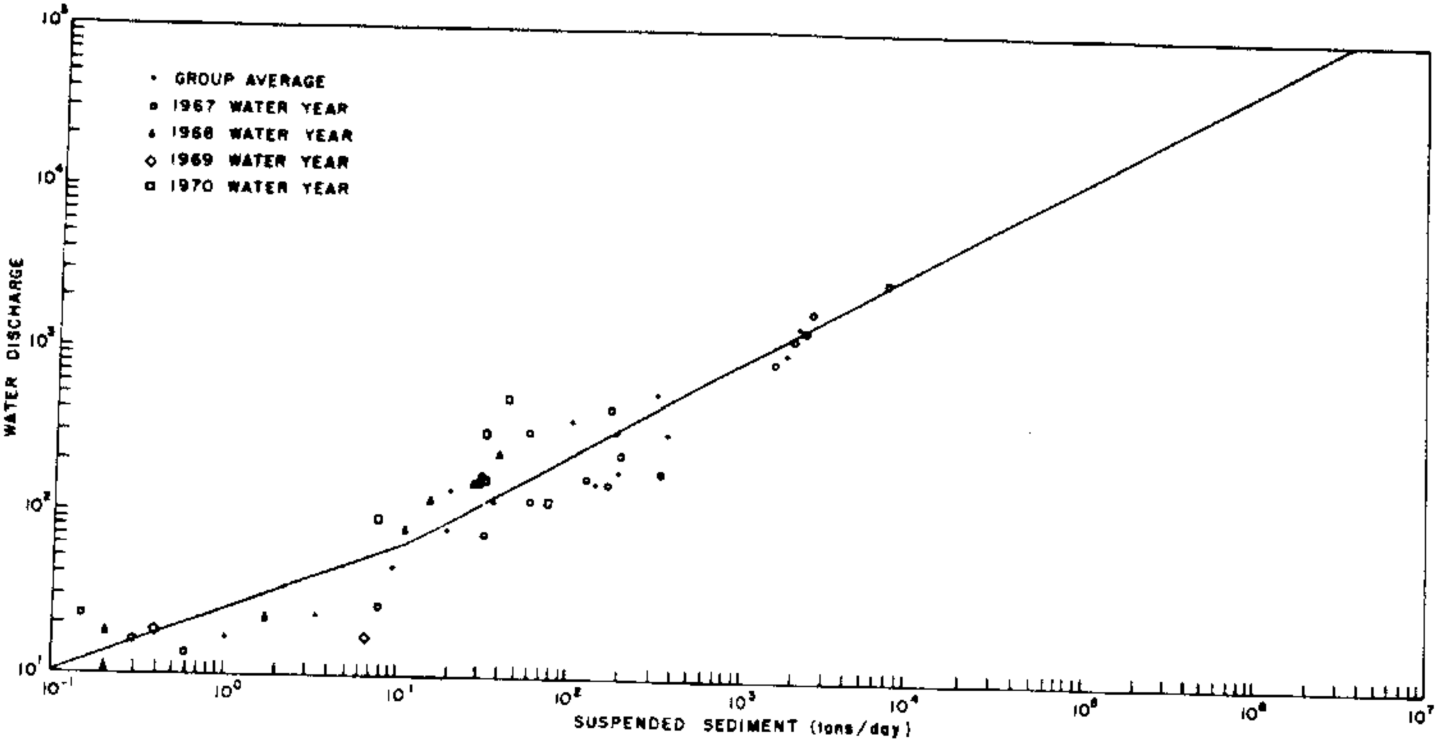

Figure 3. Relation between daily suspended sediment discharge and water discharge, Kalihi Stream, Honolulu for water years 1967 through 1970.

(Based on Jones et al., 1971 and U.S. Geological Survey, 1969 and 1970.)

TABLE 1. ESTIMATED SUSPENDED LOAD YIELD FROM MANOA-PALOLO STREAM

Month	Sediment Yield Per Storm (tons)	Estimated Number of Storms	Total Monthly Yield (tons)
Jan	220	4	880
Feb	220	4	880
Mar	1,090	2	2,180
Apr	220	5	1,100
May	30	8	240
Jun	220	4	880
Jul	30	6	180
Aug	20	11	330
Sep	520	2	1,040
Oct	290	3	870
Nov	1,880	1	1,880
Dec	480	3	1,440
TOTAL			11,900

TABLE 2. PREDICTED SUSPENDED LOAD YIELD FROM MANOA-PALOLO STREAM FROM A SINGLE STORM

Design Case	Rainfall Frequency	Q_p (cfs)	Suspended Sediment Yield (tons/year)
I	100-year, 6-hour rainfall of 10 inches (T_e = 1 hr)	21,080	14,250
II	100-year, 1-hour rainfall of 6 inches (T_e = 1 hr)	20,530	8,130
III	100-year, 1-hour rainfall of 4 inches (T_e = 1 hr)	11,720	3,330
IV	100-year, 1-hour rainfall of 4 inches (T_e = 0.6 hr)	18,960	4,690

TABLE 3. ESTIMATED SUSPENDED SEDIMENT YIELDS OF SELECTED STREAMS ON OAHU

	Major Streams			Annual Sediment Yield			
Proposed Inland Waterway	Name	Watershed Area (sq mi)	Total Drainage Area	Normal Condition		Extreme Design Flood Condition	
				(tons/year)	(tons/year/sq mi)	(tons/year)	(tons/year/sq mi)
Ala Wai	Manoa-Palolo	9.35)	13.07	11,900	1,270	26,150	2,800
	Makiki	3.72)		4,730*	1,270	10,400*	2,800
				16,630		36,550	
Nuuanu	Pauoa	1.43)	8.45	10,750*	1,270	23,600*	2,800
	Nuuanu	7.02)					
Kapalama	Kapalama	2.57	2.57	3,270*	1,270	7,200*	2,800
Kalihi	Kalihi	5.18	5.18	6,600*	1,270	14,600*	2,800

*Estimated using information developed from detailed sedimentation analysis of Manoa-Palolo Stream. Similar rigorous analysis may be necessary to obtain better information for these streams. However, the data extrapolated from Manoa-Palolo may be considered adequate for preliminary engineering purposes.

TABLE 4. PREDICTED ANNUAL SUSPENDED LOAD YIELD FROM MANOA-PALOLO STREAM

Case	Method	Suspended Sediment Yield (tons/year)
V	Hydrograph Method - mean monthly precipitation and estimated number of storms, and hindcasting of hydrographs based on rainfall and duration estimated from 1 year rainfall, duration atlas of TP-43	11,900
VI	Flow-duration curve and suspended sediment rating curve yield method (Jones et al., 1971)	9,080
V	Bathymetry Information (Gonzalez, 1971)	12,700*

*Based on 60 lb/ft^3 dry weight of sediment computed.

The total loads for each stream represent the maintenance dredging required annually (Table 5).

Bathymetry and Initial Dredging Requirements

Bathymetric surveys were made of the Ala Wai Canal, Manoa-Palolo Stream, and the Nuuanu and Kapalama Drainage Channels in November 1972 using a portable echo sounding survey recorder (Model ES-130 A/ES-130 AVF) of the States Electronics Corporation. The results are shown in Figures B1 to B3 of Appendix B. Both longitudinal profiles and cross-sections were obtained for the purpose of determining initial dredging requirements. The design depth of each waterway was selected to be 6 ft below mean lower low water (MLLW), to assure at least 3 ft clearance between the boat and channel bottom. The canal feeder boat under consideration is a converted houseboat which has the following characteristics: beam of 12 ft; length of 34 ft; draft of 3 ft.

Heavy silting due to runoff from the Manoa-Palolo Drainage Basin was found in the section between the intersection of the Manoa-Palolo Stream and the Ala Wai Canal toward the McCully Street Bridge. From the McCully

TABLE 5. PREDICTED ANNUAL MAINTENANCE DREDGING REQUIRED FOR THE PROPOSED MAJOR WATERWAYS

Proposed Inland Waterway	Estimated Annual Sediment Yields Under Normal Operational Condition					Estimated Annual Sediment Yields Under Design Flood Condition				
	Suspended Load (tons/year)		Bed Load (tons/year)		Total Load (tons/year)	Suspended Load (tons/year)		Bed Load (tons/year)		Total Load (tons/year)
Ala Wai	16,630	+	11,000	=	27,630	36,550	+	24,300	=	60,850
Nuuanu	10,750	+	7,160	=	17,910	23,600	+	15,700	=	39,300
Kapalama	3,270	+	2,180	=	5,450	7,200	+	4,800	=	12,000
Kalihi	6,600	+	4,400	=	11,000	14,600	+	9,740	=	24,340

Street bridge toward the ocean, the water depth was generally found to be adequate to meet the 6-ft design requirement. The existing water in the Manoa-Palolo, Nuuanu, and Kapalama Drainage Channels is very shallow, i.e., depths of 2 to 3 ft (MLLW). Considerable dredging is required.

The width of the Ala Wai Canal ranges from 165 to 250 ft. This is considered more than adequate to accommodate the proposed two-way feeder boat service. The width of the Manoa-Palolo, Nuuanu, and Kapalama Drainage Channels ranges from 80 to 110 ft which may still be sufficient for two-way traffic under well-maintained channel depth conditions.

The quantities of initial dredging required are listed in Table 6.

TABLE 6. INITIAL DREDGING REQUIRED OF THE PROPOSED INLAND WATERWAYS

Proposed Inland Waterway	Total Length (ft)	Width (ft)	Initial Dredging Required (cu yd)
Ala Wai Canal	7,710	250	112,000
	2,380	165	
Manoa-Palolo	2,700	80-100	25,000
Nuuanu	2,590	90-100	22,000
Kapalama	3,840	110	70,000
TOTAL			229,000

Other Constraints

Backwater

Preliminary backwater computations indicated that the water-level variations in the Ala Wai Canal due to normal flood conditions are not significant as far as their effect on the vertical clearance between the boat and the bridge. However, this may not be the case for extreme flood conditions in which case the feeder boat services would have to be suspended because of high current speeds (about 10 ft/sec) and of high water in the channel. The frequency of such floods is unusual; hence, their occurrence is very low, as is their adverse effect on the feeder service. Thus they need not be considered seriously in the design of bridges. The water level at the highest tide plus the increase due to normal flood runoff should be adequate for the determination of the minimum vertical clearance required under a bridge:

Highest tide	2.5 ft
Runoff allowance	0.5 ft
Minimum requirement from water surface to bridge underdeck for boat	9.0 ft
Safety allowance	2.0 ft
	14.0 ft

Therefore, the lowest point of the bridge should be 14 ft above MLLW.

Tide

A Stevens type water-level recorder was used to measure and record the sea level variations in the Ala Wai Canal at a point on the Ala Wai Boulevard side of the canal approximately midway between the Kalakaua Avenue bridge and McCully Street bridge (Figure 1). Approximately 20 days of records were obtained. A typical record is shown in Figure 4. Tides in the canal were found to have the same phase and amplitude as those predicted for the Honolulu Harbor (Dillingham, 1972; Table 7).

Seiche

Examination of the tidal records revealed that the predominant seiche periods are from 23 to 30 minutes with an average of 26 minutes (Table 8).

The measured seiche period of 26 minutes compares very well with that predicted by Merian's formula (Proudman, 1953):

$$T = \frac{2L}{\sqrt{gh}} = \frac{2\ (10420)}{(32.2)\ (6)\ \mathrm{x}\ 60} = 26.1 \text{ minutes}$$

where T is the seiche period in a narrow channel with vertical walls and flat bottom (10,420 ft for Ala Wai Canal) in seconds
L is the length of the channel in feet
h is the average depth in feet (6 ft for Ala Wai Canal)
g is the acceleration due to gravity: 32.2 ft/sec^2

These long oscillation periods will not affect the operation of the feeder boats because their natural period of oscillation is so much shorter, i.e., in the range of 3 to 5 seconds. The maximum seiche height is 0.38 ft with an average of 0.23 ft, i.e., the water-level oscillated approximately 0.10 ft above and below normal tidal level due to seiche action. If boats should moor at a node of the seiche then significant surge motion could be forced by the relatively fast oscillating water.

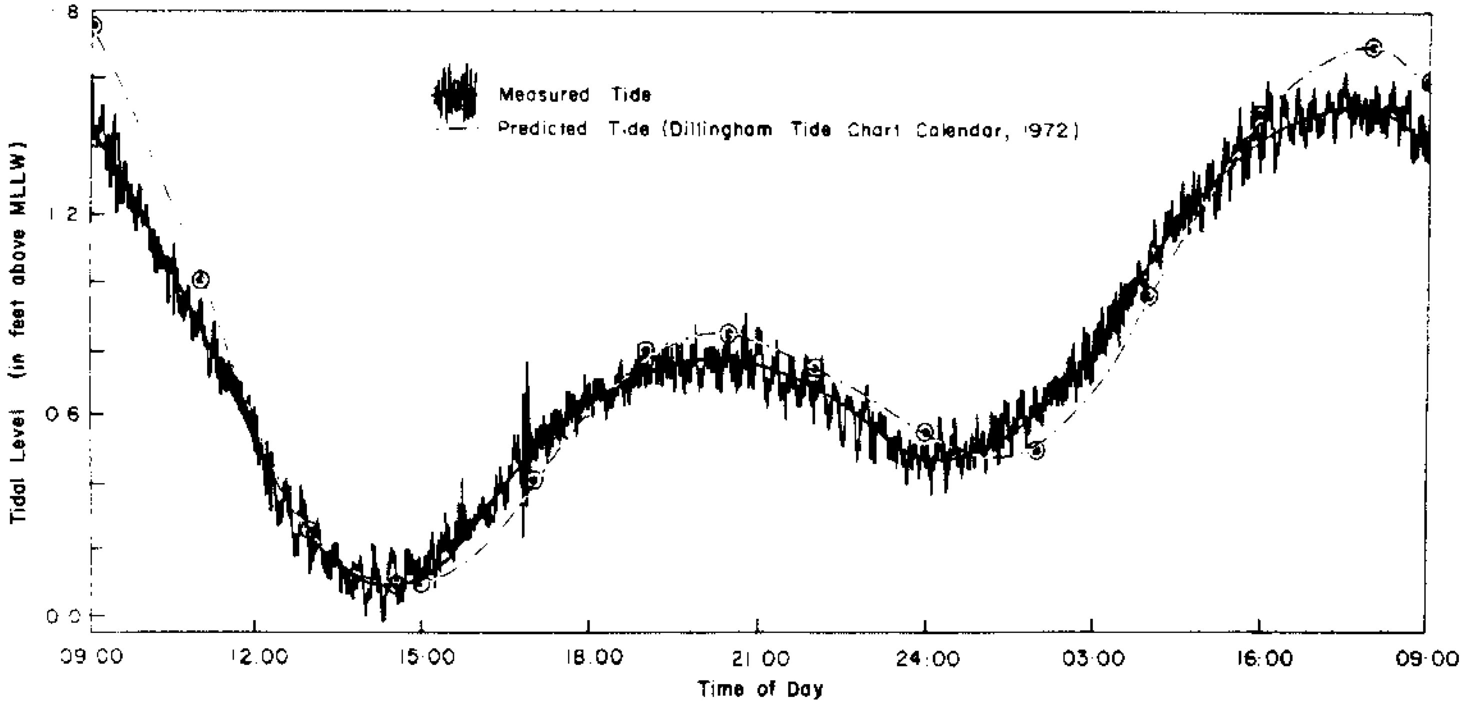

Figure 4a. Record of tide measurements taken on December 24, 1972 as compared with predicted tide by Dillingham Corporation.

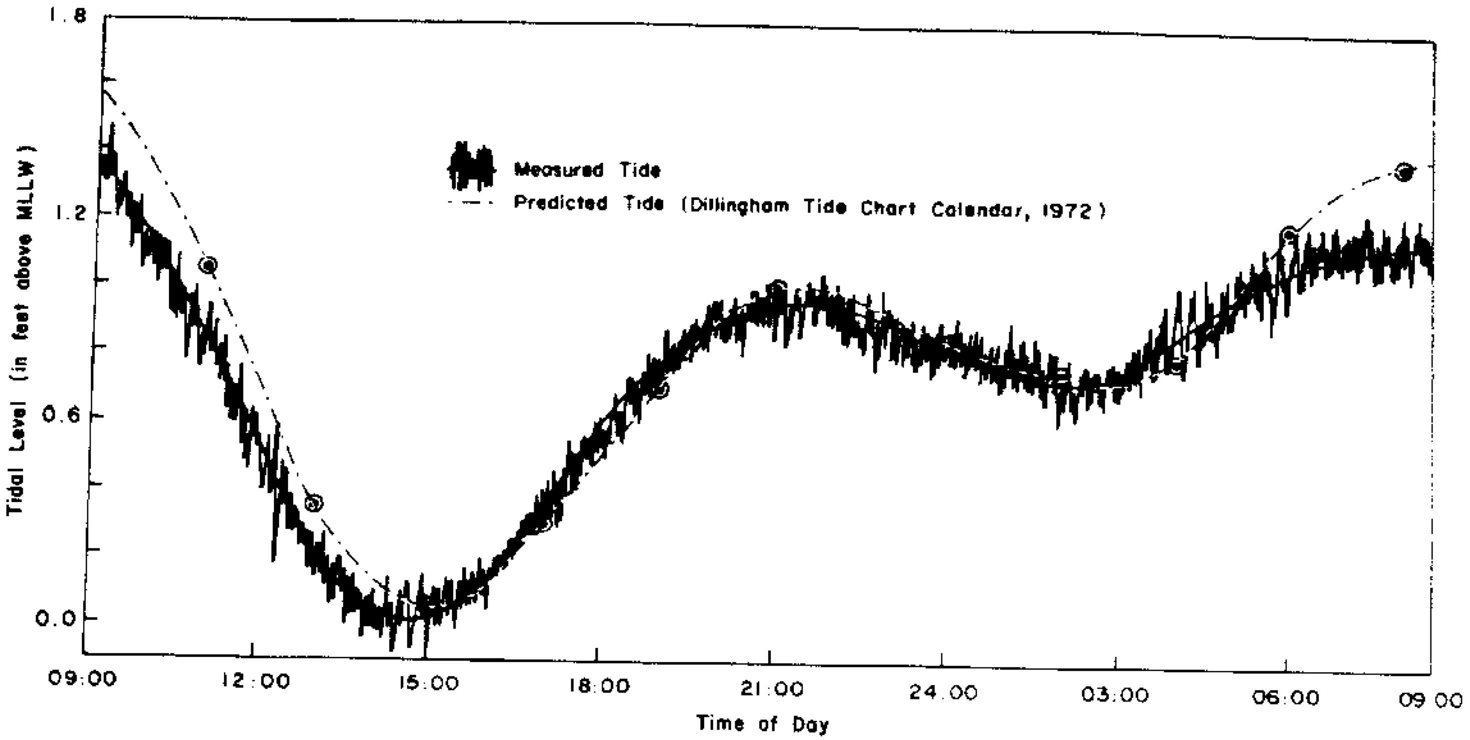

Figure 4b. Record of tide measurements taken on December 25, 1972 as compared with predicted tide by Dillingham Corporation.

TABLE 7. COMPARISON BETWEEN TIDAL HEIGHT OF DILLINGHAM TIDE CALENDAR AND STEVEN'S WATER LEVEL RECORDER

Date	(Dillingham Calendar) Tidal Height (ft)	(Steven's Water Level Recorder*) Tidal Height (ft)	Difference
8 Dec 1972	1.95	1.98	+0.03
9 Dec 1972	1.80	1.70	-0.10
14 Dec 1972	1.80	1.50	-0.30
18 Dec 1972	2.85	2.85	0.00
19 Dec 1972	2.80	2.75	-0.05
20 Dec 1972	2.85	2.85	-0.05
21 Dec 1972	2.60	2.55	-0.05
22 Dec 1972	2.25	2.25	0.00
24 Dec 1972	0.70	0.70	0.00
25 Dec 1972	0.90	0.93	0.00
26 Dec 1972	1.10	1.15	+0.05
27 Dec 1972	1.30	1.35	+0.05
28 Dec 1972	1.35	1.55	+0.20
29 Dec 1972	1.75	1.70	-0.05
30 Dec 1972	1.95	1.95	0.00
6 Jan 1973	1.95	1.90	-0.05
7 Jan 1973	1.70	1.55	-0.15

*Location of recorder: Ala Wai Canal

TABLE 8. FUNDAMENTAL SEICHE PERIODS IN THE ALA WAI CANAL

Date	Seiche Period (min)	Maximum Seiche Height (ft)
8 Dec 1972	30	0.23
9 Dec 1972	30	0.25
12 Dec 1972	25	0.18
13 Dec 1972	24	----
14 Dec 1972	24	0.38
18 Dec 1972	23	0.30
19 Dec 1972	27	0.23
20 Dec 1972	23	0.23
21 Dec 1972	26	0.35
22 Dec 1972	27	0.25
24 Dec 1972	26	0.23
25 Dec 1972	26	0.18
26 Dec 1972	27	0.20
27 Dec 1972	28	0.18
28 Dec 1972	26	0.22
29 Dec 1972	23	0.15
30 Dec 1972	26	0.22
5 Jan 1973	26	----
6 Jan 1973	26	0.18
7 Jan 1973	26	0.18
AVERAGE	26	

Canal Feeder Boat Requirements

The canal feeder boat as proposed is 34 ft long with a 12 ft beam and 3 ft draft and has a normal operating speed of 20 knots (Figure 5). It can carry 40 passengers and requires a minimum "headroom" from a waterline of 9 ft and costs about $60,000 (DMJM, 1972).

Feeder boat service on the canal can be considered as a supplementary or complementary system (as recommended by DMJM, 1972) to the existing bus feeder system in the development of either a fixed guideway rapid transit system or an oceanic express transportation system (as proposed by Craven, 1971). The vehicle requirements cannot be established easily because of a lack of information on likely patronage. However, a study of the existing bus service schedule for the Hawaii Kai area has produced very useful information. It is found that the operational period is from 6:00 a.m. to 12:00 p.m., i.e., 18 hours, and is distributed as follows:

EXISTING BUS OPERATIONAL SCHEDULE FOR HAWAII KAI

Operational Interval	Time of Operation	
	%	Hours
a. Peak hours:		
(1) 11 min (design)	10.4	1.9
b. Offpeak hours:		
(1) 20 min	11.3	2.0
(2) 33 min	21.6	3.9
(3) 40 min	56.7	10.2
	100.0	18.0

The vehicle requirement is dependent upon the total length of the local route and the time for boarding and disembarking. Based on the bus information as shown above, determination was made of requirements for canal feeder boats operating at a normal speed of 20 knots over four routes as shown on page 21.

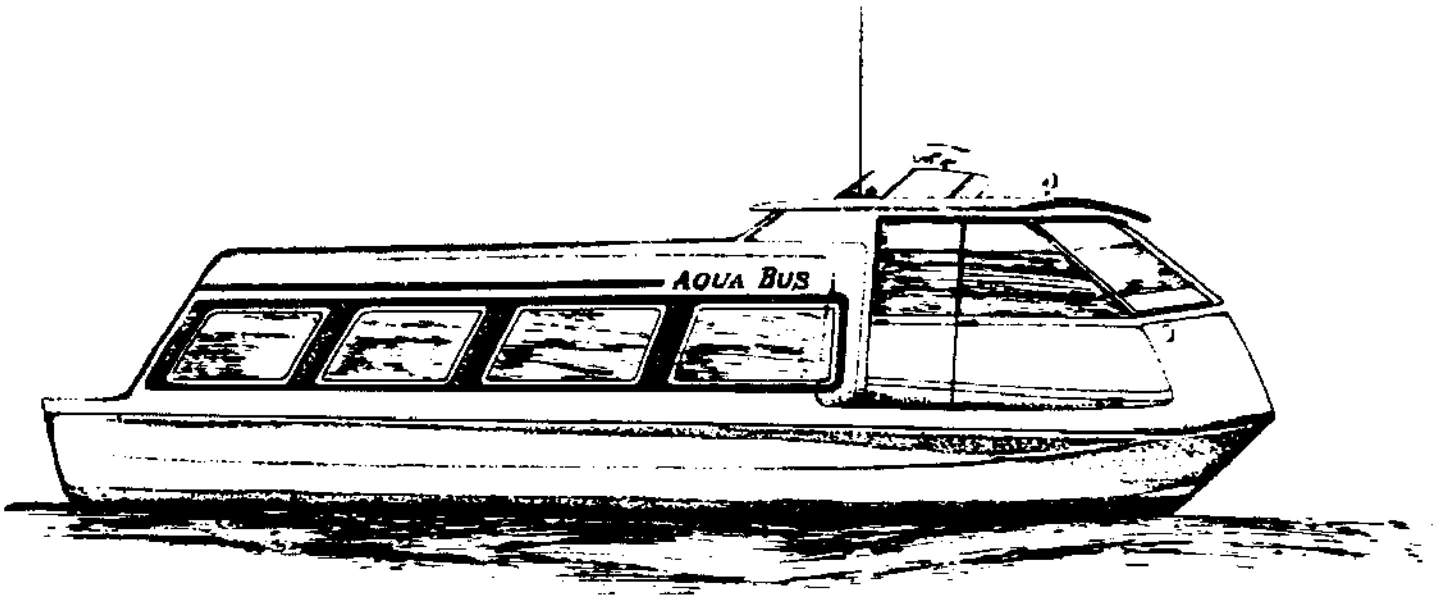

Figure 5. Proposed feeder boat for inland waterways. (Beam: 12 ft length)

(Daniel, Mann, Johnson and Mendenhall of Hawaii, 1972)

LOCAL ROUTE SYSTEMS FOR THE OCEANIC EXPRESS SYSTEM

I. Hawaii Kai Loop (Route 5)

1. Route Schedule

Station	Arrival Time	Departure Time
A Hawaii Kai Shopping Center	----	9:00
D Wailua Street bridge	9:03	9:05
B Maniniholo Street bridge	9:09	9:11
C Opihikao Place	9:14	----
	(Round Trip:	28 min)

2. Vehicle Requirement

Operational Interval	Time of Operation		Minimum Number of Vehicles Required for 2-Way Traffic
	%	Hours	
a. Peak hours:			
(1) 6 min (design)	-----	-----	3
(2) 11 min	10.4	1.9	2
b. Offpeak hours:			
(1) 20 min	11.3	2.0	1
(2) 33 min	21.6	3.9	1
(3) 40 min	56.7	10.2	1
	100.0	18.0	

II. Ala Wai/Manoa-Palolo Local

1. Route Schedule

Station	Arrival Time	Departure Time
A Magic Island	----	9:00
B Kalakaua Avenue bridge	9:02	9:04
C Lewers Street	9:055	9:075
D Waikiki-Kapahulu Library	9:095	9:12
E Date Street bridge	9:15	9:17
F University of Hawaii	9:18	----
	(Round Trip:	36 min)

2. Vehicle Requirement

Operational Interval	Time of Operation		Minimum Number of Vehicles Required for 2-Way Traffic
	%	Hours	
a. Peak hours:			
(1) 6 min (design)	-----	-----	7
(2) 11 min	10.4	1.9	4
b. Offpeak hours:			
(1) 20 min	11.3	2.0	2
(2) 33 min	21.6	3.9	2
(3) 40 min	56.7	10.2	1
	100.0	18.0	

III. Moanalua-Kapalama-Nuuanu Loop (Route 4)

1. Route Schedule

	Station	Arrival Time	Departure Time
A	Kikowaena Bridge (Moanalua)	----	9:00
B	Kamehameha Bridge (Moanalua)	9:02	9:04
C	Honolulu International Airport	9:06	9:08
D	Keehi Marina	9:10	9:12
E	Kapalama Military Reservation	9:14	9:16
F	Nimitz Highway bridge (Kapalama)	9:16	9:18
G	H-1 bridge (Kapalama)	9:20	9:22
F	Nimitz Highway bridge (Kapalama)	9:24	9:26
H	Aloha Tower	9:31	9:33
I	Nimitz Highway bridge (Nuuanu)	9:34	9:36
J	Foster Botanical Garden	9:38	----

(Round Trip: 76 min)

2. Vehicle Requirement

Operational Interval	Time of Operation %	Hours	Minimum Number of Vehicles Required for 2-Way Traffic
a. Peak hours:			
(1) 6 min (design)	-----	-----	10
(2) 11 min	10.4	1.9	4
b. Offpeak hours:			
(1) 20 min	11.3	2.0	2
(2) 33 min	21.6	3.9	2
(3) 40 min	56.7	10.2	
	100.0	18.0	

IV. Kahala Local

1. Route Schedule

	Station	Arrival Time	Departure Time
A	Waialae Beach Park	----	9:00
B	Kahala Mall Shopping Center	9:02	----

2. Vehicle Requirement

Operational Interval	Time of Operation %	Hours	Minimum Number of Vehicles Required for 2-Way Traffic
a. Peak hours:			
(1) 6 min (design)	-----	-----	1
(2) 11 min	10.4	1.9	1
b. Offpeak hours:			
(1) 20 min	11.3	2.0	1
(2) 33 min	21.6	3.9	1
(3) 40 min	56.7	10.2	1
	100.0	18.0	

Therefore, 21 canal feeder boats are required to provide necessary services over the four routes which, when added to 10 percent or two boats as spares, gives a total of 23 boats in the fleet. As the demand increases, the operational time interval may be shortened. However, these 23 boats should be designed to operate at a peak 6-min interval for each route even though this peak interval could be as low as 11 min, similar to that for the bus. Nevertheless, a more rigorous analysis of the vehicle requirements is needed.

PRELIMINARY COST ESTIMATES

The preliminary cost estimate for the four inland waterway routes are shown in Table 9. The estimated grand total for the four routes is as follows:

	1972 Dollars	1980 Dollars
Hawaii Kai	11,315,000	11,549,000
Kahala	9,444,000	10,941,000
Ala Wai	42,658,000	45,620,000
Moanalua-Kapalama	53,234,000	57,190,000
TOTAL	116,651,000	125,300,000

SUMMARY AND TENTATIVE CONCLUSIONS

Four local route systems of the inland waterways subsystem for the Oceanic Express System were studied. Included were Hawaii Kai, Kahala, Ala Wai, and Moanalua-Kapalama-Nuuanu routes. A total of 23 canal feeder boats will be the minimum number required to serve the four local routes. The total capital cost for the feeder boats, terminals, stop stations, initial dredging, maintenance facility, reconstruction of bridges and roads, and land acquisition is estimated to be about $23 million. Additional capital and replacement costs over a 30-year period will be $7 million. During this 30-year period, the operating and maintenance costs will amount to $95 million. The annual cost is estimated at about $4 million. A summary of the cost analysis is shown in Table 10. Note that the cost of maintenance dredging at each waterway is a big expenditure item. As far as capital cost is concerned, reconstruction of the bridges and roads is the most expensive item, followed by initial dredging, land acquisition, and feeder boats.

The total waterway system will be 16 miles long and the average annual cost will be approximately $271,000 per mile of waterway per year. A comparison of this annual cost with other feeder systems such as buses has yet to be made to determine the economic feasibility of the inland water subsystem.

As far as engineering feasibility is concerned, there are no major problems expected in operating such a marine feeder system. There will be

TABLE 9. PRELIMINARY COST ESTIMATES OF THE PROPOSED INLAND WATERWAYS FEEDER BOAT SYSTEM

				Subtotal	Total	
					1972*	1980†
A. INITIAL CAPITAL COSTS:						
1. Feeder Boats:						
	(23 @ $60,000) =	$ 1,380,000				
Subtotal 1		$ 1,380,000		$ 1,380,000		
2. Terminals:						
Hawaii Kai	(8,200 sq ft @ $4.40) =	$ 36,000				
Kahala	(4,500 sq ft @ $4.40) =	$ 19,000				
Ala Wai	(15,000 sq ft @ $4.40) =	$ 66,000				
Manoa-Palolo	(10,000 sq ft @ $4.40) =	$ 44,000				
Nuuanu	(4,900 sq ft @ $4.40) =	$ 22,000				
Kapalama	(4,900 sq ft @ $4.40) =	$ 22,000				
Moanalua	(4,900 sq ft @ $4.40) =	$ 22,000				
Subtotal 2		$ 231,000		$ 231,000		
3. Stations (shelters):						
Hawaii Kai	(3 @ $5,000) =	$ 15,000				
Kahala	(1 @ $5,000) =	$ 5,000				
Ala Wai	(5 @ $5,000) =	$ 25,000				
Moanalua-Kapalama-Nuuanu	(8 @ $5,000) =	$ 40,000				
Subtotal 3		$ 85,000		$ 85,000		
4. Maintenance Facilities:						
	(56,000 sq ft) =	$ 200,000				
Subtotal 4		$ 200,000		$ 200,000		
5. Initial Dredging (canal deepening and widening):						
Hawaii Kai	(none)					
Kahala (Waialae Nui)	(100,000 cu yd @ $7§) =	$ 700,000				
Ala Wai Canal	(112,000 cu yd @ $7§) =	$ 784,000				
Manoa-Palolo	(25,000 cu yd @ $7§) =	$ 175,000				
Nuuanu	(22,000 cu yd @ $7§) =	$ 154,000				
Kapalama	(70,000 cu yd @ $7§) =	$ 490,000				
Moanalua	(21,000 cu yd @ $7§) =	$ 147,000				
Subtotal 5		$ 2,450,000		$ 2,450,000		
6. Reconstruction of Bridges and Approach Roads:						
		Bridge	Approach Road#			
Hawaii Kai		0	0			
Kahala						
Kahala Beach Park	(3,200 sq ft @ $30) =	$ 96,000	$ 16,000			
Ala Wai Canal						
Ala Moana Boulevard	(16,500 sq ft @ $30) =	$ 495,000	$ 48,000			
Kalakaua Avenue	(13,500 sq ft @ $30) =	$ 405,000	$ 32,000			
McCully Street	(27,600 sq ft @ $30) =	$ 828,000	$ 32,000			
		$ 1,728,000	$ 112,000			
Manoa-Palolo						
Date Street	(6,000 sq ft @ $30) =	$ 180,000	$ 32,000			
Nuuanu						
Nimitz	(25,500 sq ft @ $30) =	$ 765,000	$ 128,000			
King	(8,000 sq ft @ $30) =	$ 240,000	$ 64,000			
Hotel	(5,250 sq ft @ $30) =	$ 158,000	$ 32,000			
Beretania	(4,000 sq ft @ $30) =	$ 120,000	$ 32,000			
Kukui	(6,180 sq ft @ $30) =	$ 186,000	$ 16,000			
		$ 1,469,000	$ 272,000			
Kapalama						
Nimitz Highway	(16,500 sq ft @ $30) =	$ 495,000	$ 64,000			
Nimitz R.R.	(6,050 sq ft @ $30) =	$ 182,000	$ 64,000			
Dillingham	(8,800 sq ft @ $30) =	$ 264,000	$ 64,000			
		$ 941,000	$ 192,000			
Moanalua#						
Nimitz		$ 240,000	$ 64,000			
Mokumoa		$ 120,000	$ 16,000			
H-1		$ 480,000	$ 128,000			
Kikowaena		$ 120,000	$ 16,000			
		$ 960,000	$ 224,000			
Subtotal 6		($ 5,374,000)	($ 848,000)	$ 6,222,000		
7. Rip-rap (canal):						
Kahala (Waialae Nui)	(7,500 ft @ $15) =	$ 113,000				
Manoa-Palolo	(10,000 ft @ $15) =	$ 150,000				
Moanalua	(9,200 ft @ $15) =	$ 138,000				
Subtotal 7		$ 401,000		$ 401,000		

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*Cost of Feeder Boat System if construction begins in 1972.

†Cost of Feeder Boat System if construction begins in 1980.

§Unit cost for dredging in Ala Wai Canal was $5/cu yd in 1964 and the cost will be increased by 5% per year, therefore, 1972 cost will be $7/cu yd. The unit cost of $1.5/cu yd by Daniel, Mann, Johnson and Mendenhall of Hawaii (Lulegian & Associates), 1972, seems to be very low.

#Daniel, Mann, Johnson and Mendenhall of Hawaii (1972).

			Subtotal	Total	
				1972*	1980†
8. Barrier Wall (canal):					
Ala Wai Canal (Lewers Street to east end of canal, mauka side)	(60,000 ft @ $4)	= $ 240,000			
Subtotal 8		$ 240,000	$ 240,000		
9. Land Acquisition (terminals, new canal):					
Hawaii Kai (lease)	(8,200 sq ft @ $15)	= $ 123,000			
Kahala (Waialae Nui Stream, Golf Course land)					
Canal	(225,000 sq ft @ $6)	= $ 1,350,000			
Terminal	(4,500 sq ft @ $6)	= $ 27,000			
Ala Wai Canal	(15,000 sq ft @ $20)	= $ 300,000			
Manoa-Palolo	(10,000 sq ft @ $13)	= $ 130,000			
Nuuanu	(4,900 sq ft @ $17)	= $ 84,000			
Kapalama	(4,900 sq ft @ $15)	= $ 74,000			
Moanalua	(4,900 sq ft @ $15)	= $ 74,000			
Subtotal 9		$ 2,162,000	$ 2,162,000		
10. Contingency:					
	Contingency (15%)	= $ 2,000,000			
Subtotal 10		$ 2,000,000	$ 2,000,000		
11. Administration and Engineering:					
	Administration and Engineering (13%)	= $ 1,280,000			
Subtotal 11		$ 1,280,000	$ 1,280,000		
TOTAL INITIAL CAPITAL COSTS				$ 16,651,000	$ 23,300,000
B. ADDITIONAL CAPITAL AND REPLACEMENT COSTS (over 30 year period):					
TOTAL ADDITIONAL CAPITAL AND REPLACEMENT COSTS				$ 5,000,000	$ 7,000,000
C. OPERATING AND MAINTENANCE COSTS:					
1. Maintenance Dredging:					
Hawaii Kai	(5,000 tons/yr)	(6,200 cu yd/yr)			
Kahala	(5,000 tons/yr)	(6,200 cu yd/yr)			
Ala Wai	(27,630 tons/yr)	(34,400 cu yd/yr)			
Nuuanu	(17,900 tons/yr)	(22,300 cu yd/yr)			
Kapalama	(5,450 tons/yr)	(6,700 cu yd/yr)			
Moanalua	(5,000 tons/yr)	(6,200 cu yd/yr)			
	65,980 tons/yr	82,000 cu yd/yr			
Unit Cost					
1972	(82,000 cu yd/yr @ $ 7) = $ 570,000/yr				
1980	(82,000 cu yd/yr @ $10) = $ 820,000/yr	= $ 1,150,000/yr (ave)			
1995	(82,000 cu yd/yr @ $18) = $ 1,480,000/yr	= $ 1,640,000/yr (ave)			
2010	(82,000 cu yd/yr @ $22) = $ 1,800,000/yr				
1972					
1980	(15 years) x $1,150,000/yr (ave)	= $ 17,300,000 (15 years)			
1995	(15 years) x $1,640,000/yr (ave)	= $ 24,600,000 (15 years)			
2010					
Subtotal 1		$ 41,900,000 (30 years)	$ 41,900,000		
2. Other Indirect Operating Costs:					
General Office		= $ 100,000/yr			
Terminals (5% of Terminals; item A.2.)		= $ 12,000/yr			
Traffic (Feeder Boats)		= $ 210,000/yr*			
Personnel to Operate Feeder Boats (23 @ $15,000)		= $ 345,000/yr			
		$ 667,000/yr			
Unit Cost					
1972	$ 667,000/yr				
1980	$ 935,000/yr	= $ 1,285,000/yr (ave)			
1995	$ 1,635,000/yr	= $ 2,247,500/yr (ave)			
2010	$ 2,860,000/yr				
1972					
1980	(15 years) x $1,285,000/yr (ave)	= $ 19,300,000 (15 years)			
1995	(15 years) x $2,247,500/yr (ave)	= $ 33,800,000 (15 years)			
2010					
Subtotal 2		$ 53,100,000 (30 years)	$ 53,100,000		
TOTAL OPERATING AND MAINTENANCE COSTS				$ 95,000,000	$ 95,000,000
GRAND TOTAL				$116,651,000	$125,300,000

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*Fuel & Oil	$2,730
Engine Maintenance	$3,200
Insurance	$1,730
Hull Maintenance	$1,400

$9,160 x 23 = $210,000/yr of 2000 working hours/boat

TABLE 10. SUMMARY OF COST ANALYSIS

ROUTES / COST ITEM	Hawaii Kai Route	Kahala Route	Ala Wai Route	Moanalua-Kapalama-Nuuanu Route	Total
A. Capital Cost					
1. Feeder Boats	180,000	60,000	480,000	660,000	1,380,000
2. Terminals	36,000	19,000	110,000	66,000	231,000
3. Stations	15,000	5,000	25,000	40,000	35,000
4. Maintenance	29,000	10,000	67,000	94,000	200,000
5. Initial Dredging	---	700,000	959,000	791,000	2,450,000
6. Bridges and Roads	---	112,000	2,052,000	4,058,000	6,222,000
7. Rip Rap	---	113,000	150,000	138,000	401,000
8. Barrier Wall	---	---	240,000	---	240,000
9. Land Acquisition	123,000	1,377,000	430,000	232,000	2,162,000
SUB-TOTAL	383,000	2,396,000	4,513,000	6,079,000	13,371,000
Contingency (15%)	57,000	359,000	676,000	908,000	2,000,000
Administration & Engineering (13%)*	10,000	124,000	469,000	677,000	1,280,000
TOTAL Capital Cost, 1972	450,000	2,879,000	5,658,000	7,664,000	16,651,000
TOTAL Capital Cost, 1980	630,000	4,030,000	7,940,000	10,700,000	23,300,000
B. Additional Capital and Replacement Costs (30%) (30 years)					
1972	135,000	864,000	1,700,000	2,301,000	5,000,000
1980	189,000	1,210,000	2,380,000	3,221,000	7,000,000
C. Operating and Maintenance Cost (30 years)					
1. Maintenance Dredging	3,170,000	3,170,000	17,600,000	17,960,000	41,900,000
2. Other Indirect Cost	7,560,000	2,531,000	17,700,000	25,309,000	53,100,000
GRAND TOTAL					
1972 (30 years)	11,315,000	9,444,000	42,658,000	53,234,000	116,651,000
1980 (30 years)	11,549,000	10,941,000	45,620,000	57,190,000	125,300,000
Annual Cost					
1972 (per year)	377,000	315,000	1,422,000	1,775,000	3,888,000
1980 (per year)	385,000	365,000	1,521,000	1,906,000	4,240,000
Length of Waterways (miles) (link system)	3.0	0.6	4.05	8.0	15.65
1972 (per mile per year)	126,000	525,000	351,000	222,000	248,000
1980 (per mile per year)	128,000	608,000	376,000	238,000	271,000

*Excludes Boat and Land

no major widening of the four existing channels except for the Kahala route. The channels will be adequate in providing two-way traffic for feeder boats having 12-ft beams; however, all channels must be deepened to a minimum water depth of 6 ft in order to provide necessary passage for feeder boats of 3-ft draft. The reconstruction of the bridges and approach roads will cause some adverse effects including temporary interruption of local traffic or environmental impact on local conditions.

It is tentatively concluded that the construction, operation, and maintenance of the four selected waterways seem to be technically feasible, but their economic feasibility cannot be determined until the entire Oceanic Express System is thoroughly analyzed.

The Ala Wai route is considered to have the best potential for being converted into a waterway for navigational purposes. The Nuuanu Channel is relatively short but will involve reconstruction of five bridges; therefore, a more careful study is required to determine its feasibility as a waterway.

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APPENDICES

Appendix A. General Procedure For Preparing Runoff Hydrographs at Ala Wai Canal

GENERAL PROCEDURE FOR PREPARING RUNOFF HYDROGRAPHS AT ALA WAI CANAL

A synthesis method was used to compute the runoff hydrographs for design flood and normal flood conditions based on rainfall and watershed characteristics in the area of interest, i.e., Manoa-Palolo drainage area. Detailed procedures are described by the U.S. Soil Conservation Service (1972). Since watersheds in Hawaii are mostly small, there will be no real adjustment of rainfall amount to be used for hydrograph computations. Also, the time of concentration is very short--from 0.6 to 1.0 hours, which is much less than six hours--therefore, there will also be no duration adjustment of rainfall amount. Further, since the climatic index, C_i [$C_i = (100\ P_a)/(T_a)^2$ where C_i is the climatic index, P_a is the average precipitation in inches, T_a is the average annual temperature in °F] in the Manoa-Palolo drainage area is about 2.5 which is greater than 1; therefore, there will be no channel loss to be accounted for computing the direct runoff from rainfall. The average annual precipitation in the area is 150 inches per year and the average annual temperature is 78°F.

The runoff is determined as follows:

1. Determine the runoff curve number (CN). The runoff curve number is related to the land use characteristics, soil classification, and antecedent moisture condition in the drainage area in question. The land use classes are determined from the "Forest Map" prepared by the U.S. Forest Service (Figure A1). Code numbers are given showing land use class, forest type, and density/stand size class in each subdivided area. Based on the Forest Map and its legend, a description of the forest type of the Manoa-Palolo watershed is listed in Table A1. The soil description of the Manoa-Palolo area is obtained from the soil map prepared by the U.S. Soil Conservation Service, Hawaii. Using the map and its legend, the soil description for each sub-area was obtained as listed in Table A2. With the information on soil classification and land use characteristics, the runoff curve number for each sub-area can be determined. Following this, a weighted runoff curve number can be easily determined. In the case of the Manoa-Palolo Drainage Basin, the runoff curve number is 84 as shown in Table A2. Similarly, the CN for other drainage areas of proposed inland waterways can be determined accordingly. Note that the CN is for antecedent moisture condition II (AMC-II).

2. Determine the time of concentration, T_c. The time of concentration may be determined by the following formula:

$$T_c = \left(\frac{11.9\ L^3}{H}\right)^{0.385}$$

where T_c is the time of concentration in hours,
L is the length of the watershed in miles, and
H is the watershed height in feet.

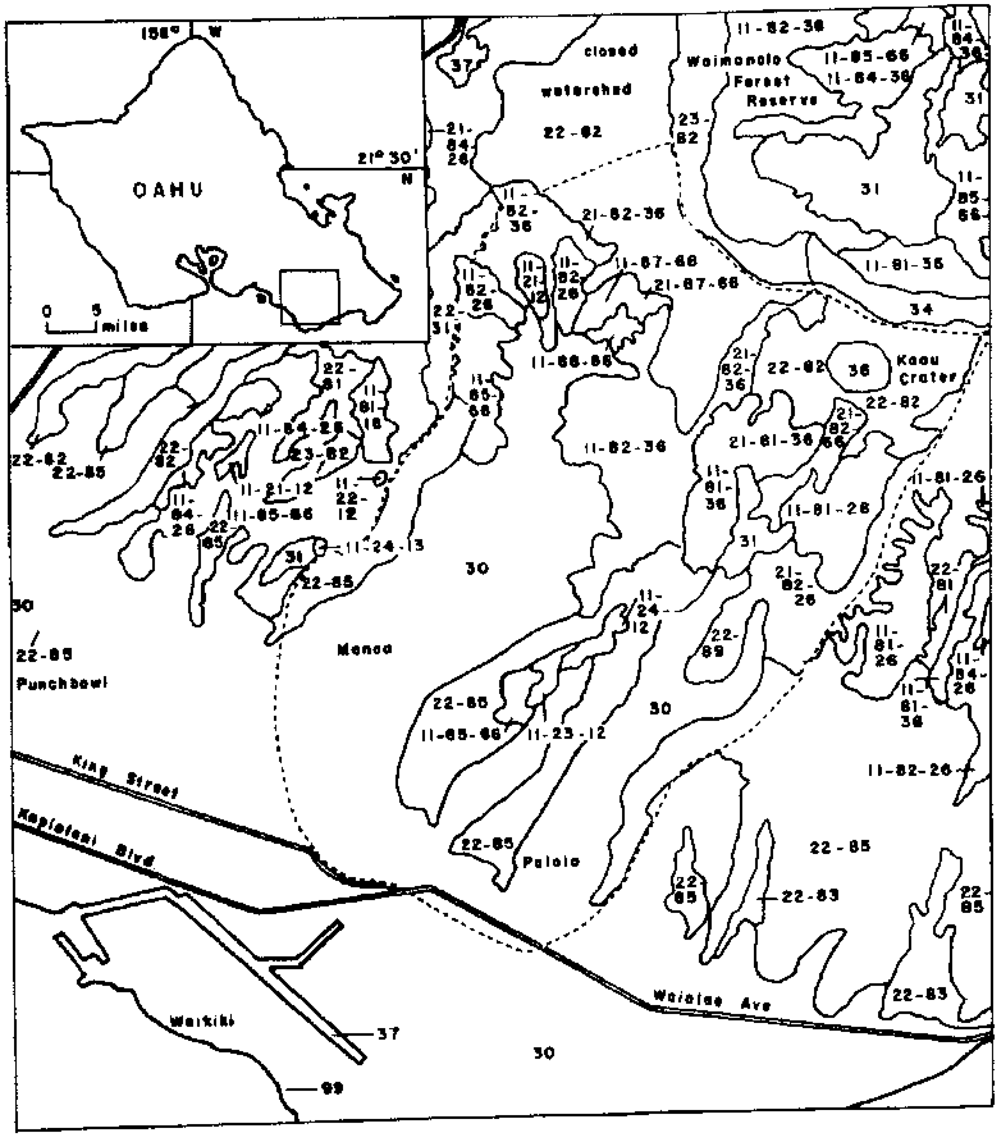


Figure A1. Manoa-Palolo Drainage Basin.

(Forest Map, U.S. Forest Service)

TABLE A1. FOREST TYPE OF MANOA-PALOLO WATERSHED

Land Use (Forest Map) Code	Land Use Class	Forest Type	Density/Stand Size Class	Area (sq mi)	
22-85	Non-Commercial	Haole-koa-Guava-Lantana Type (shrub types)	---	0.26 0.70 0.25	
11-85-66	Commercial Forest	Haole-koa-Guava-Lantana Type (shrub types)	Nonstocked	0.08 0.19 0.05	
11-82-26	Commerical Forest	Ohia-koa Type	Semidense, Nonstocked	0.08 0.09	
11-82-36	Commercial Forest	Ohia-koa Type	Open, Nonstocked	0.21	
11-82-36/ 21-82-36	Commercial Forest and Reserved Commercial	Ohia-koa Type	Open, Nonstocked	0.75	
11-21-12	Commercial Forest	Eucalyptus, planted	Dense, heavy saw timber stand	0.04	
22-82	Non-Commercial	Ohia-koa Type		0.78 0.66	Forest 5.48 sq mi 60%
11-87-66/ 21-87-66	Commercial and Reserved Commercial	Herbaceous Type (grass, herbs, etc.)	Nonstocked	0.09	
11-88-66	Commercial	Pandana, Sisal, Palms or Bamboo	Nonstocked	0.05	
11-23-12/ 11-24-12	Commercial	Hardwoods (brushbox) Conifer Species	Dense, heavy saw timber stand	0.09	
11-81-36/ 21-81-36	Commercial and Reserved Commercial	Kukui Trees	Open, Nonstocked	0.34	
21-82-36	Reserved Commercial	Ohia-koa Type	Open, Nonstocked	0.13	
21-82-26	Reserved Commercial	Ohia-koa Type	Semidense, Non-stocked	0.35	
11-81-26	Commercial	Kukui Trees	Semidense, Non-stocked	0.27	
36	Marsh Land	---	---	0.08	
31	Cultivated and Intensively Pastured Area	---	---	0.10	Honolulu 3.87 sq mi 40%
30	Housing (Urban-Industrial Areas)	---	---	3.69	
				9.35	

TABLE A2. SOIL TYPE OF MANOA-PALOLO WATERSHED

)	Area (sq mi)	Soil Description	Soil Classification A	B	C	D	for AMC-II Runoff Condition CN	CN x A	Weighted CN
	0.26	rRK Rock Land				X	79 Woods, fair		
	0.70	rRK Rock Land				X	79 Woods, fair	10?	
	0.25	rRK Rock Land				X	79 Woods, fair		
	0.08	rRK Rock Land				X	79 Woods, fair		
	0.19	LOF Lolekaa Silty Clay, 40-70% slope				X	79 Woods, fair	15	
	0.05	H_pO/PID Manana/Polmoa Silty Clay, 5-20% Slope			X		73 Woods, fair	3.6	
	0.08	LOF Lolekaa Silty Clay, 40-70% slope				X	79 Woods, fair	6.3	
	0.09	LOC Lolekaa Silty Clay, 8-15% slope		X			60 Woods, fair	9.4	
	0.21	TAE	X				45 Woods, poor	9.5	
	0.75	LOF Lolekaa and rRK Silty Clay and Rock Land, 40-70% slope				X	83 Woods, poor	62.3	
	0.04	LOC Lolekaa Silty Clay, 8-15% slope		X			55 Woods, good	2.2	
	0.78	rRK Rock Land				X	79 Woods, fair	61.6	
	0.66	rRK Rock Land				X	79 Woods, fair	52.1	
	0.09	LOF Lolekaa Silty Clay, 40-70% slope				X	84 Pasture, fair	7.5	
	0.05	rRK Rock Land				X	83 Woods, poor	4.2	
	0.09	H_pD Manana Silty Clay, 15-25% slope			X		74 Pasture, good	6.7	
	0.34	rRK Rock Land				X	83 Woods, poor	29.2	
	0.13	rRK Rock Land				X	79 Woods, fair	38.0	
	0.35							29.2	
	0.27	rRK Rock Land				X	68 Pasture, poor	12.2	
	0.08	rAAE Alakai Mucky Peat, 0-30% slope	X						
	0.10	LOB Lolekaa Silty Clay, 3-8% slope	X				92 Hard Surface	339.0	
	3.69	TCC, MIA Tantalus Clay, Makiki Clay Loam, 8-15% slope LaA LUA Lahaina Silty Clay, Lualualei Clay, 0-3% slope	(paved)			X			
			$\frac{786.0}{9.35}$ sq mi = 84.1					786.0 Say 84	

Using the nomograph (Figure A2), the T_c for the Manoa-Palolo watershed (L = 20,000 ft; H = 2,435 ft) is approximately 0.6. From consultations with the U.S. Soil Conservation Service (Whiting, 1972), T_c = 1 hour was selected for the hydrograph computations.

3. Obtain the mean monthly rainfall at Manoa-Palolo watershed from "Climates of the States - Hawaii," by Blumenstock (1961) as shown in Figure A3 and Table A3. However, rainfall duration was not given by Blumenstock. Fortunately, such information can be estimated from the "Rainfall-Frequency Atlas of the Hawaiian Islands," Technical Paper No. 43, U.S. National Weather Service (1962). Accordingly, a rainfall-duration curve was prepared for a one-year storm duration for the Manoa-Palolo watershed (Figure A4). Similar curves for other areas can be developed from the atlas. Following this, the frequency of the storm must be determined. It is assumed that 50 percent of the monthly rainfalls would generate significant direct runoff. Then, the U.S. Geological Survey's surface water records for the 1969 water year at the Manoa-Palolo gaging stations were used to determine the number of floods which would contribute 50 percent to the total discharge in each month. With this information, the average rainfall can be determined as shown in Table A3. The duration for each rainfall can be determined from Figure A4. It must be noted that this method is preliminary pending further study but it is considered reasonable for this study. Of course, one may dispute that the water year may not be representative. At least, it is the most recent information currently available to the authors. To study the effect of the design storms, the four conditions in Table A4 were selected for study.

4. Determine the direct runoff Q from the rainfall information and runoff curve number as known. (Use Figures A5 and A6.)

5. Compute hydrograph using the worksheet of the U.S. Soil Conservation Service:

   a. Compute the initial value of $T_p = 0.7\ T_c$ where T_p is time to peak discharge.

   b. Determine the duration of excess rainfall, T_o, for given rainfall and runoff curve number (Figure A7 and Tables A5 and A6).

   c. Determine the hydrograph family from known rainfall and CN (Figure A8).

   d. Compute the T_o/T_p ratio.

   e. Select a revised T_o/T_p ratio which are shown in the dimensionless hydrograph tabulations by U.S. Soil Conservation Service (1972)--their Table 21.16 and Table 21.17.

   f. Compute revised $T_p = (T_o)/(T_o/T_p)\text{rev}$.

g. Compute q_p = (484 A)/rev. T_p.

h. Compute Q_{qb} = (Q)(q_p).

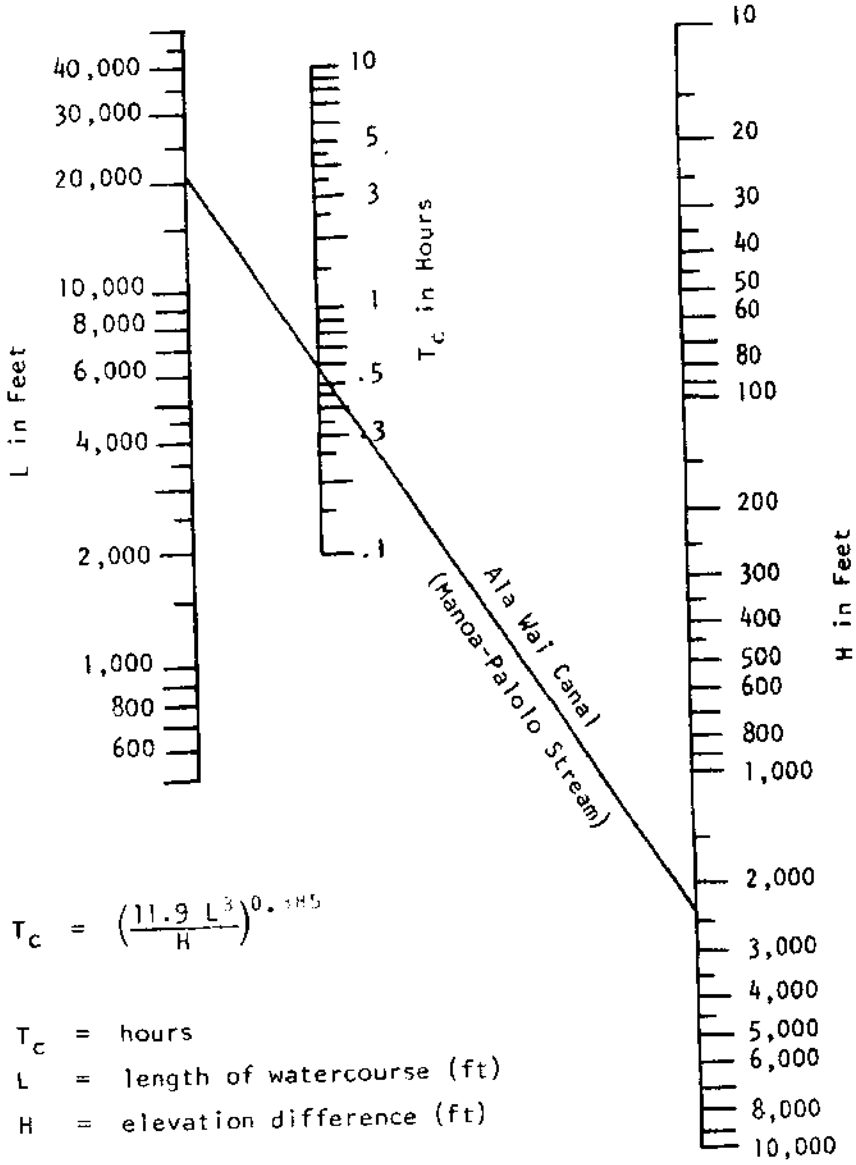
i. Compute the times for which hydrograph rates will be computed.

$t = (t/T_p)(\text{rev. } T_p)$

t/T_p is given in Table 21.17 (SCS, 1972)

j. Compute the hydrograph rates $q = (q_c/q_p)Qq_p$ in which q_c/q_p may be obtained from Table 21.17 for the selected hydrograph family.

Based on the procedure described above, the results of hydrograph computations are shown in Tables A7 to A18. They are also plotted in Figures 2a to 2e.



$$T_c = \left(\frac{11.9\ L^3}{H}\right)^{0.385}$$

T_c = hours
L = length of watercourse (ft)
H = elevation difference (ft)

Figure A2. Nomograph for determination of time of concentration.

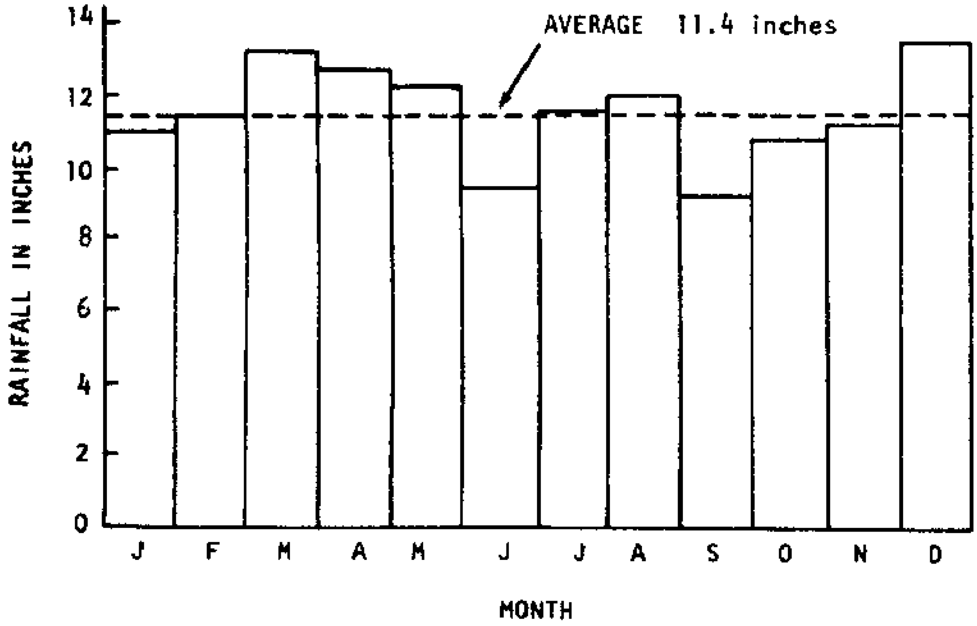


Figure A3. Mean monthly rainfall at Manoa-Palolo Stream watershed.

(Based on the averages of mean monthly rainfalls for Stations #718 Palolo Valley and #716 Manoa Tunnel 2 for period 1931 through 1955, Blumenstock, 1961.)

TABLE A3. MEAN PRECIPITATION (INCHES) ESTIMATED FOR EACH STORM DURING EACH MONTH

	Manoa Tunnel #716 (Elevation 605 ft)	Palolo Valley #718	Ave.	50% Rainfall	Significant* (days)	Rainfall (in)	Duration** (hr)
Annual	138.2	135.6					
Jan	10.9	11.1	11.0	5.5	4	1.4	1/2
Feb	11.1	11.6	11.4	5.7	4	1.4	1/2
Mar	13.2	12.9	13.1	6.6	2	3.3	6
Apr	12.8	12.6	12.7	6.4	5	1.3	1/2
May	12.6	11.8	12.2	6.1	8	0.8	1/2
Jun	9.7	9.1	9.4	4.7	4	1.2	1/2
Jul	12.1	10.9	11.5	5.8	6	1.0	1/2
Aug	12.5	11.2	11.9	6.0	11	0.5	1/2
Sep	9.4	8.8	9.1	4.6	2	2.3	3
Oct	10.4	10.9	10.7	5.4	3	1.8	2
Nov	10.8	11.3	11.1	5.6	1	5.6	24
Dec	12.9	13.6	13.3	6.7	3	2.2	3

*Based on the "Water Resources Data for Hawaii and Other Pacific Areas, 1969".

**Obtained from Figure A4 corresponding to the average rainfall estimated.

TABLE A4. CONDITIONS OF DESIGN STORMS

Frequency	Duration (hr)	Rainfall (in)
(1) 100-year (T_c = 1 hr)	6	10
(2) 100-year (T_c = 1 hr)	1	6
(3) 100-year (T_c = 1 hr)	1	4
(4) 100-year (T_c = 0.6 hr)	1	4

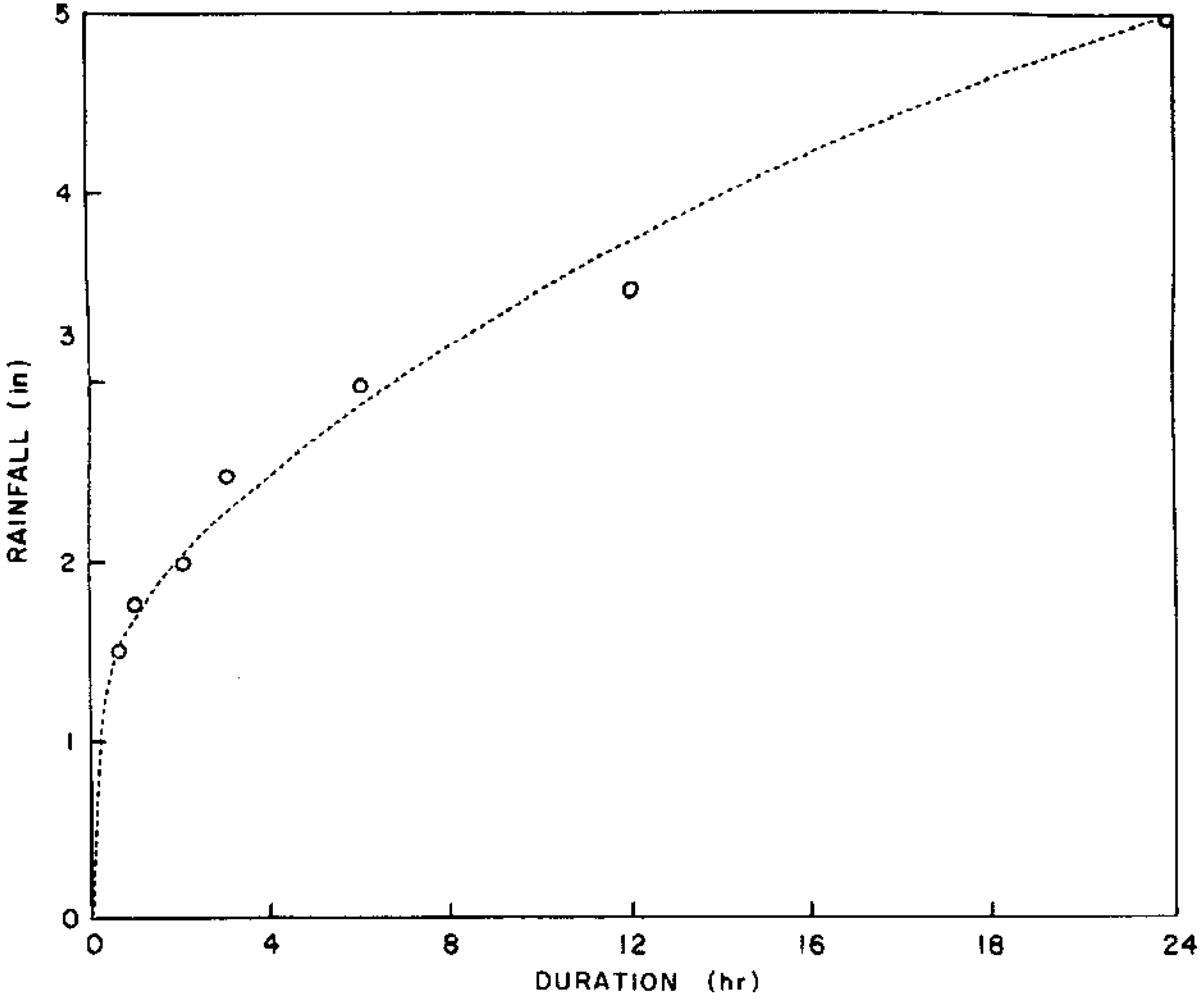


Figure A4. Manoa-Palolo Stream rainfall-frequency-duration for one year storm.

(Based on TP-43, Weather Bureau.)

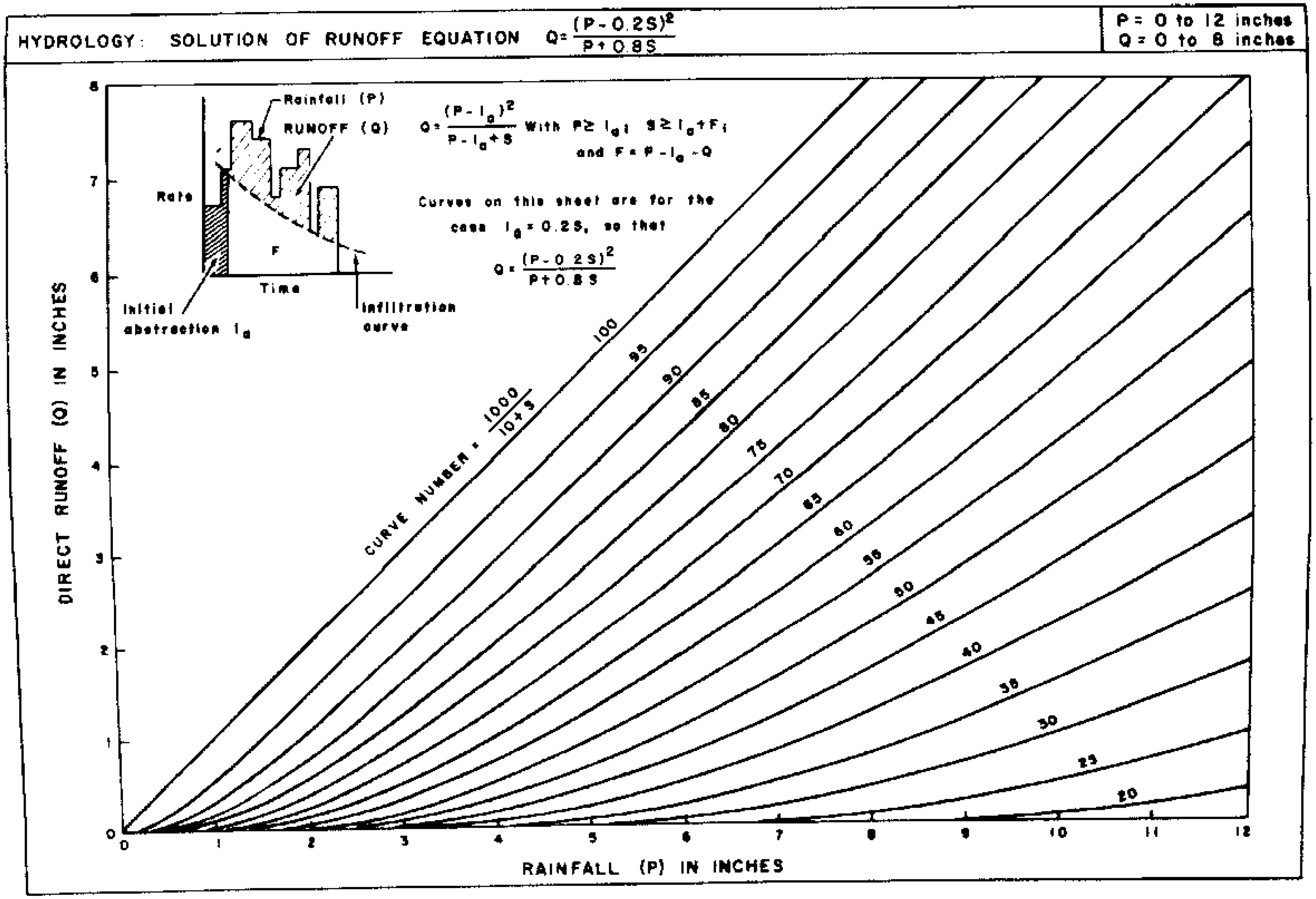


Figure A5. Relation between direct runoff and rainfall as a function of runoff curve number.

(U.S. Soil Conservation Service, 1972)

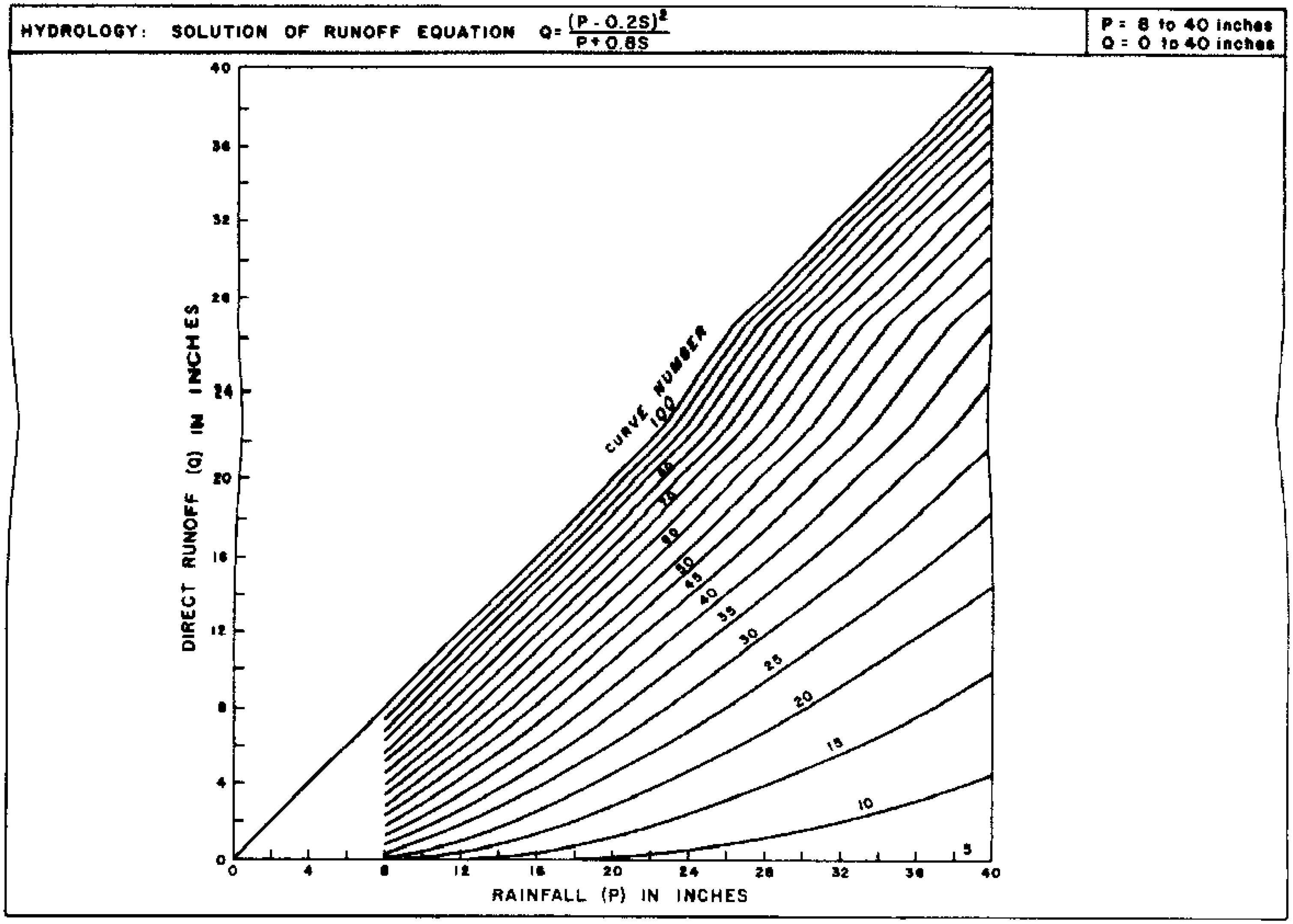


Figure A6. Relation between direct runoff and rainfall as a function of runoff curve number.

(U.S. Soil Conservation Service, 1972)

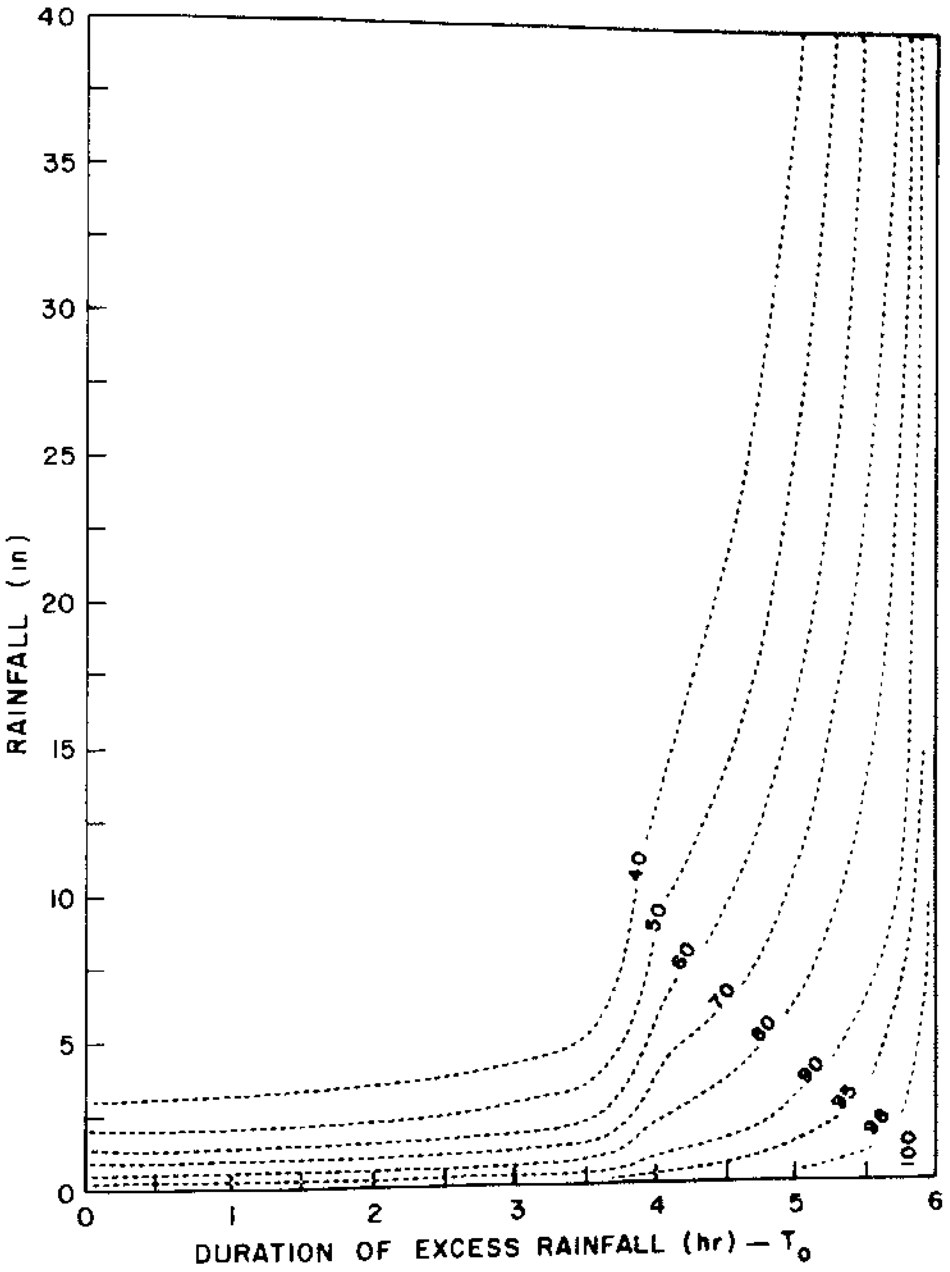


Figure A7. Duration of excess rainfall as a function of rainfall runoff curve number.

TABLE A5. RAINFALL PRIOR TO EXCESS RAINFALL (P*) VS RUNOFF CURVE NUMBER (CN)

CN	P* (in)	CN	P* (in)	CN	P* (in)	CN	P* (in)	CN	P* (in)
100	0.00	86	0.33	72	0.78	58	1.45	44	2.54
99	.02	85	.35	71	.82	57	1.51	43	2.64
98	.04	84	.38	70	.86	56	1.57	42	2.76
97	.06	83	.41	69	.90	55	1.64	41	2.88
96	.08	82	.44	68	.94	54	1.70	40	3.00
95	.11	81	.47	67	.98	53	1.77	39	3.12
94	.13	80	.50	66	1.03	52	1.85	38	3.26
93	.15	79	.53	65	1.08	51	1.92	37	3.40
92	.17	78	.56	64	1.12	50	2.00	36	3.56
91	.20	77	.60	63	1.17	49	2.08	35	3.72
90	.22	76	.63	62	1.23	48	2.16	34	3.88
89	.25	75	.67	61	1.28	47	2.26	33	4.06
88	.27	74	.70	60	1.33	46	2.34	32	4.24
87	.30	73	.74	59	1.39	45	2.44	31	4.44

(U.S. Soil Conservation Service, 1972)

Example: For Runoff Curve Number (CN) of 84 for the Manoa-Palolo Stream, the Rainfall prior the Excess Rainfall is 0.38. The Rainfall Ratio P*/P can be then computed for use in Table A6.

TABLE A6. RAINFALL RATIO P*/P VS TIME RATIO (T_o/STORM DURATION)

Rain-fall Ratio	Time Ratio	Rain-fall Ratio	Time Ratio	Rain-fall Ratio	Time Ratio	Rain-fall Ratio	Time Ratio
0.000	1.000	0.070	0.852	0.140	0.746	0.210	0.684
0.002	0.995	0.072	0.848	0.142	0.744	0.212	0.682
0.004	0.990	0.074	0.844	0.144	0.742	0.214	0.680
0.006	0.985	0.076	0.841	0.146	0.740	0.216	0.679
0.008	0.981	0.078	0.837	0.148	0.739	0.218	0.677
0.010	0.976	0.080	0.833	0.150	0.737	0.220	0.675
0.012	0.971	0.082	0.830	0.152	0.735	0.222	0.673
0.014	0.967	0.084	0.827	0.154	0.733	0.224	0.672
0.016	0.962	0.086	0.824	0.156	0.732	0.226	0.670
0.018	0.957	0.088	0.821	0.158	0.730	0.228	0.668
0.020	0.952	0.090	0.818	0.160	0.728	0.230	0.667
0.022	0.948	0.092	0.815	0.162	0.726	0.232	0.666
0.024	0.943	0.094	0.812	0.164	0.724	0.234	0.666
0.026	0.938	0.096	0.809	0.166	0.723	0.236	0.665
0.028	0.933	0.098	0.806	0.168	0.721	0.238	0.665
0.030	0.929	0.100	0.803	0.170	0.719	0.240	0.664
0.032	0.924	0.102	0.800	0.172	0.717	(Change in	
0.034	0.919	0.104	0.797	0.174	0.716	tabulation	
0.036	0.915	0.106	0.794	0.176	0.714	increment.)	
0.038	0.911	0.108	0.791	0.178	0.712		
0.040	0.908	0.110	0.788	0.180	0.710	0.250	0.662
0.042	0.904	0.112	0.785	0.182	0.709	0.300	0.651
0.044	0.900	0.114	0.782	0.184	0.707	0.350	0.640
0.046	0.896	0.116	0.779	0.186	0.705	0.400	0.628
0.048	0.893	0.118	0.776	0.188	0.703	0.450	0.617
0.050	0.889	0.120	0.773	0.190	0.702	0.500	0.606
0.052	0.885	0.122	0.770	0.192	0.700	0.550	0.595
0.054	0.882	0.124	0.767	0.194	0.698	0.600	0.583
0.056	0.878	0.126	0.764	0.196	0.696	0.650	0.542
0.058	0.874	0.128	0.761	0.198	0.695	0.700	0.500
0.060	0.870	0.130	0.758	0.200	0.693	0.750	0.447
0.062	0.367	0.132	0.755	0.202	0.691	0.800	0.386
0.064	0.863	0.134	0.751	0.204	0.689	0.850	0.310
0.066	0.859	0.136	0.749	0.206	0.687	0.900	0.220
0.068	0.856	0.138	0.747	0.208	0.686	0.950	0.116

(U.S. Soil Conservation Service, 1972)

T_o = (Time Rate) (Storm Duration)

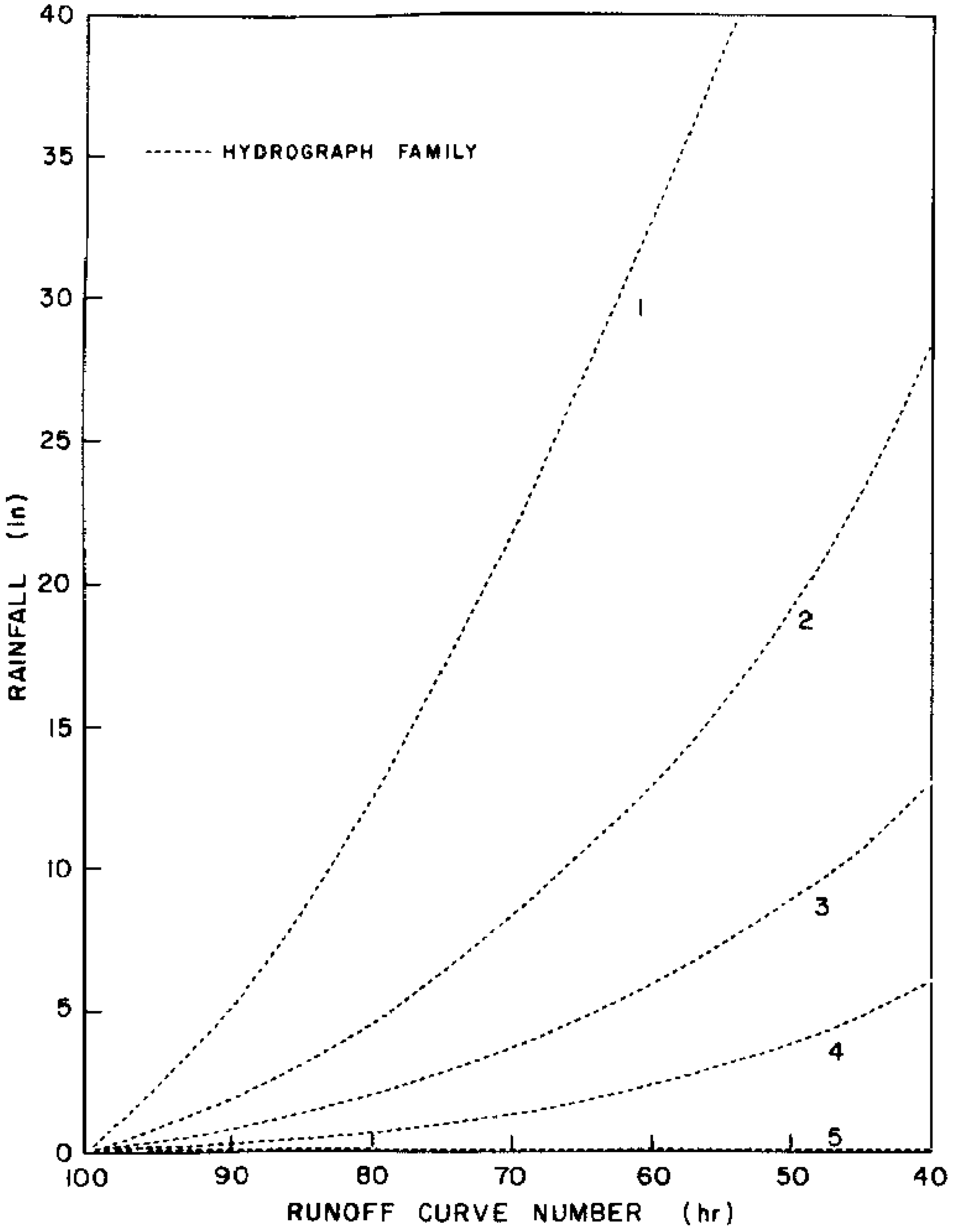


Figure A8. Hydrograph family number as a function of rainfall and runoff curve number.

TABLE A7. HYDROGRAPH COMPUTATION FOR JANUARY, FEBRUARY, APRIL, AND JUNE

SCS-ENG 319
Rev. 1-70
File Code ENG 13-14

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

HYDROGRAPH COMPUTATION

DATE ____________
COMPUTED BY ____________
CHECKED BY ____________

WATERSHED OR PROJECT Manoa-Palolo Stream

STATE Hawaii

STRUCTURE SITE OR SUBAREA Ala Wai Canal

DR. AREA 9.35 SQ. MI STRUCTURE CLASS ______

T_c 1.0 HR. STORM DURATION 0.5 HR.

POINT RAINFALL 1.4 IN.

ADJUSTED RAINFALL:

AREAL FACTOR 1 IN. 1.4

DURATION FACTOR ______ IN. ______

RUNOFF CURVE NO. 84

Q 0.35 IN.

HYDROGRAPH FAMILY NO. 4

COMPUTED T_p 0.70 HR. $(0.7\ T_c)$

T_o 0.33 HR.

(T_o / T_p) COMPUTED 0.47 USED 1

REVISED T_p 0.33

$q_p = \frac{484A}{\text{REV. } T_p}$ = 13,700 CFS.

$(Q)(q_p)$ = 4,800 CFS.

t(COLUMN) = (t / T_p) REV. T_p

q(COLUMN) = $(q_c / q_p)(Q)(q_p)$

Q(COLUMN) = $(Q_t / Q)(Q)$

Q_{peak} = 3,990 cfs

	$t = (t/T_p)(\text{Rev. } T_p)$	$q = (q_c/q_p)(Q)(q_p)$	$Q_t = (Q_t/Q)(Q)$
	t	q	Q
	HOURS	CFS	INCHES
1	0	0	0
2	0.092	241	
3	0.185	1,060	
4	0.287	2,360	
5	0.370	3,550	
6	0.462	3,990	
7	0.555	3,620	
8	0.646	2,760	
9	0.740	1,890	
10	0.831	1,250	
11	0.925	835	
12	1.017	566	
13	1.110	380	
14	1.200	250	
15	1.290	170	
16	1.380	120	
17	1.480	80	
18	1.570	50	
19	1.660	30	
20	1.760	14	
21	1.845	5	
22	1.940	0	
23			
24			
25			
26			
27			
28			
29			

	Month	Estimated Number of Occurrence
30		
31		
32	Jan	4
33	Feb	4
33	Apr	5
34	Jun	4

TABLE A8. HYDROGRAPH COMPUTATION FOR MARCH

SCS-ENG-319
Rev. 1-70
File Code ENG-13-14

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

HYDROGRAPH COMPUTATION

DATE
COMPUTED BY
CHECKED BY

WATERSHED OR PROJECT Manoa-Palolo Stream

STATE Hawaii

STRUCTURE SITE OR SUBAREA Ala Wai Canal

DR. AREA 9.35 SQ. MI. STRUCTURE CLASS

T_c = 1.0 HR. STORM DURATION 6 HR.

POINT RAINFALL 3.3 IN.

ADJUSTED RAINFALL:

AREAL FACTOR 1 IN. 3.3

DURATION FACTOR IN.

RUNOFF CURVE NO. 84

Q 1.75 IN.

HYDROGRAPH FAMILY NO. 2

COMPUTED T_p 0.70 HR. $(0.7\ T_c)$

T_o 4.67 HR.

(T_o / T_p) COMPUTED 6.67 USED 6

REVISED T_p 0.78

$q_p = \frac{484A}{\text{REV. } T_p}$ = 5,800 CFS.

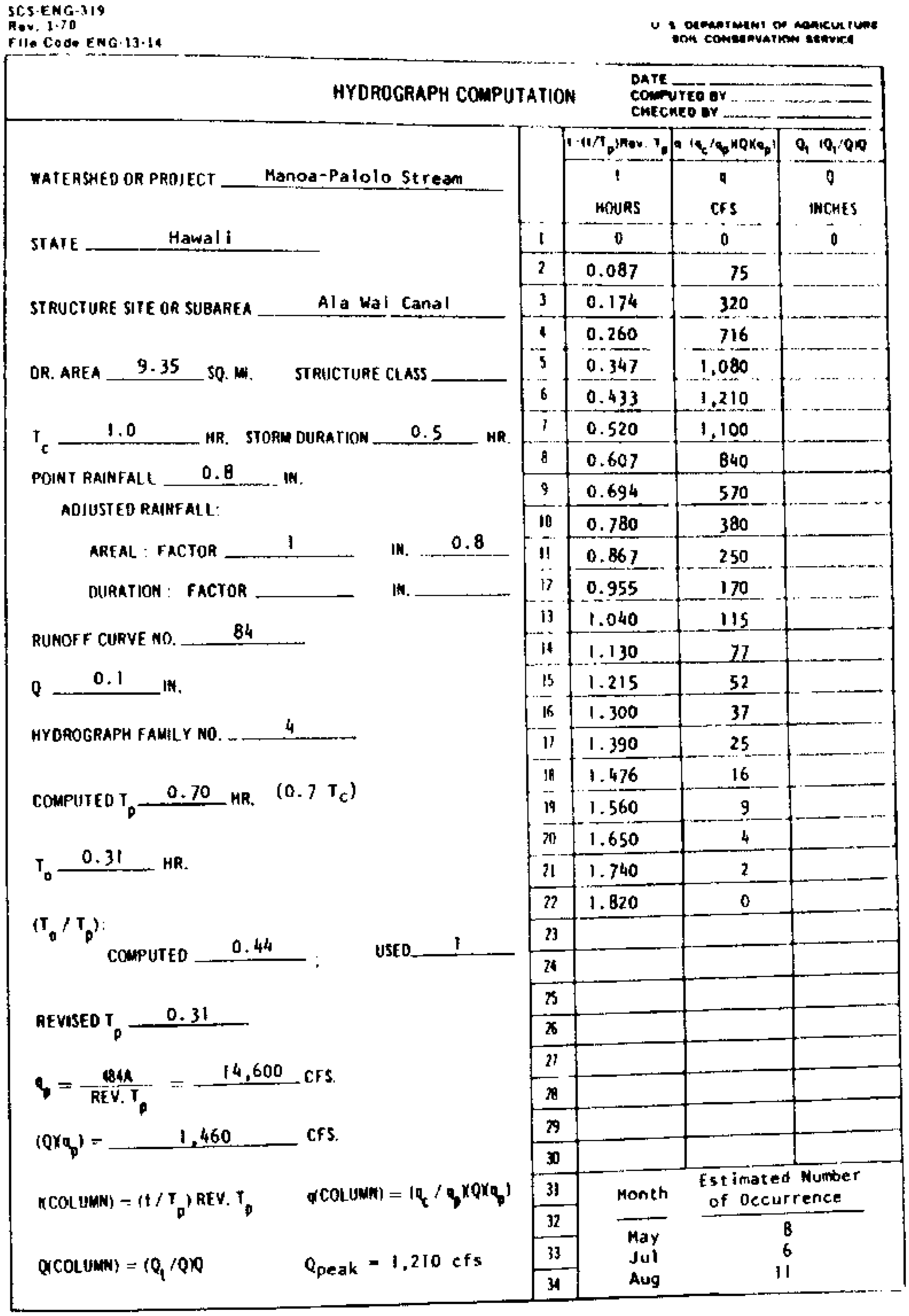
$(Q)(q_p)$ = 10,650 CFS.

t(COLUMN) = (t / T_p) REV T_p q(COLUMN) = $(q_c / q_p)(Q)(q_p)$

Q(COLUMN) = $(Q_t / Q)Q$ Q_{peak} = 4,710 cfs

	t (t/T_p)(Rev. T_p) t HOURS	q $(q_c/q_p)(Q)(q_p)$ q CFS	Q_t $(Q_t/Q)Q$ Q INCHES
1	0	0	0
2	0.265	10	
3	0.795	150	
4	1.060	380	
5	1.320	995	
6	1.590	2,480	
7	1.850	4,130	
8	2.220	4,710	
9	2.390	4,350	
10	2.650	3,720	
11	2.920	3,140	
12	3.180	2,650	
13	3.450	2,270	
14	3.720	1,960	
15	3.720	1,960	
16	3.980	1,720	
17	4.240	1,540	
18	4.510	1,410	
19	4.780	1,310	
20	5.040	1,150	
21	5.300	860	
22	5.570	560	
23	6.100	200	
24	6.370	120	
25	6.530	80	
26	6.900	50	
27	7.150	40	
28	7.420	30	
29	7.700	20	
30	7.950	10	
31	8.220	0	
32	Month	Estimated Number of Occurrence	
33			
34	Mar	2	

TABLE A9. HYDROGRAPH COMPUTATION FOR MAY, JULY, AND AUGUST



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Rev. 1-70
File Code ENG-13-14

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

HYDROGRAPH COMPUTATION

DATE ____
COMPUTED BY ____
CHECKED BY ____

WATERSHED OR PROJECT Manoa-Palolo Stream

STATE Hawaii

STRUCTURE SITE OR SUBAREA Ala Wai Canal

DR. AREA 9.35 SQ. MI. STRUCTURE CLASS ____

T_c 1.0 HR. STORM DURATION 0.5 HR.

POINT RAINFALL 0.8 IN.

ADJUSTED RAINFALL:

AREAL : FACTOR 1 IN. 0.8

DURATION : FACTOR ____ IN. ____

RUNOFF CURVE NO. 84

Q 0.1 IN.

HYDROGRAPH FAMILY NO. 4

COMPUTED T_p 0.70 HR. (0.7 T_c)

T_o 0.31 HR.

(T_o / T_p):
COMPUTED 0.44 ; USED 1

REVISED T_p 0.31

$q_p = \frac{484A}{\text{REV. } T_p}$ = 14,600 CFS.

$(Q)(q_p)$ = 1,460 CFS.

t(COLUMN) = (t / T_p) REV. T_p q(COLUMN) = $(q_c / q_p)(Q)(q_p)$

Q(COLUMN) = $(Q_t / Q)Q$ Q_{peak} = 1,210 cfs

	t (t/T_p)Rev. T_p	q $(q_c/q_p)(Q)(q_p)$	Q_t $(Q_t/Q)Q$
	t HOURS	q CFS	Q INCHES
1	0	0	0
2	0.087	75	
3	0.174	320	
4	0.260	716	
5	0.347	1,080	
6	0.433	1,210	
7	0.520	1,100	
8	0.607	840	
9	0.694	570	
10	0.780	380	
11	0.867	250	
12	0.955	170	
13	1.040	115	
14	1.130	77	
15	1.215	52	
16	1.300	37	
17	1.390	25	
18	1.476	16	
19	1.560	9	
20	1.650	4	
21	1.740	2	
22	1.820	0	
23			
24			
25			
26			
27			
28			
29			
30			
31	Month	Estimated Number of Occurrence	
32	May	8	
33	Jul	6	
34	Aug	11	

TABLE A10. HYDROGRAPH COMPUTATION FOR SEPTEMBER

SCS-ENG-319
Rev. 1-70
File Code ENG-13-14

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

HYDROGRAPH COMPUTATION

DATE ______
COMPUTED BY ______
CHECKED BY ______

WATERSHED OR PROJECT Manoa-Palolo Stream

STATE Hawaii

STRUCTURE SITE OR SUBAREA Aia Wai Canal

DR. AREA 9.35 SQ. MI. STRUCTURE CLASS ______

T_c 1.0 HR. STORM DURATION 3 HR.

POINT RAINFALL 2.3 IN.

ADJUSTED RAINFALL:

AREAL : FACTOR -- IN. --

DURATION : FACTOR ______ IN. ______

RUNOFF CURVE NO. 84

Q 0.95 IN.

HYDROGRAPH FAMILY NO. 3

COMPUTED T_p 0.7 HR.

T_o 2.2 HR.

(T_o / T_p):
COMPUTED 3.13 ; USED 3

REVISED T_p 0.73

$q_p = \frac{484A}{\text{REV. } T_p}$ = 6,200 CFS.

$(Q)(q_p)$ = 5,900 CFS.

t(COLUMN) = (t / T_p) REV. T_p

q(COLUMN) = $(q_c / q_p)(Q)(q_p)$

Q(COLUMN) = $(Q_t / Q)Q$

Q_{peak} = 3,200 cfs

	$t=(t/T_p)$Rev. T_p	$q=(q_c/q_p)(Q)(q_p)$	$Q_t=(Q_t/Q)Q$
	t HOURS	q CFS	Q INCHES
1	0	0	0
2	0.248	24	
3	0.496	520	
4	0.745	1,705	
5	0.991	2,880	
6	1.240	3,200	
7	1.490	2,990	
8	1.735	2,620	
9	1.985	2,270	
10	2.240	2,000	
11	2,480	1,730	
12	2.720	1,315	
13	2,980	880	
14	3.220	566	
15	3.480	330	
16	3.720	195	
17	3.970	112	
18	4.220	77	
19	4.470	47	
20	4.720	24	
21	4.960	18	
22	5.210	12	
23	5.460	6	
24	5.710	0	
25			
26			
27			
28			
29			
30			
31			

Month	Estimated Number of Occurrence
Sep	2

TABLE A11. HYDROGRAPH COMPUTATION FOR OCTOBER

SCS-ENG-319
Rev. 1-70
File Code ENG-13-14

U S DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

HYDROGRAPH COMPUTATION

DATE ______
COMPUTED BY ______
CHECKED BY ______

WATERSHED OR PROJECT Manoa-Palolo Stream

STATE Hawaii

STRUCTURE SITE OR SUBAREA Ala Wai Canal

DR. AREA 9.35 SQ. MI. STRUCTURE CLASS ______

T_c 1.0 HR. STORM DURATION 2 HR.

POINT RAINFALL 1.8 IN.

ADJUSTED RAINFALL:

AREAL : FACTOR 1 IN. 1.8

DURATION : FACTOR ______ IN. ______

RUNOFF CURVE NO. 84

Q 0.60 IN.

HYDROGRAPH FAMILY NO. 3

COMPUTED T_p 0.70 HR. (0.7 T_c)

T_o 1.37 HR.

(T_o / T_p):

COMPUTED 1.95 ; USED 2

REVISED T_p 0.69

$q_p = \frac{484A}{\text{REV. } T_p} =$ 6,550 CFS.

$(Q)(q_p) =$ 3,940 CFS.

t(COLUMN) = (t / T_p) REV. T_p

q(COLUMN) = $(q_c / q_p)(Q)(q_p)$

Q(COLUMN) = $(Q_t / Q)Q$

Q_{peak} = 2,590 cfs

	$t = (t/T_p)$Rev. T_p	$q = (q_c/q_p)(Q)(q_p)$	$Q_t = (Q_t/Q)Q$
	t	q	Q
	HOURS	CFS	INCHES
1	0	0	0
2	0.207	47	
3	0.414	484	
4	0.621	1,350	
5	0.827	2,240	
6	1.033	2,590	
7	1.240	2,480	
8	1.450	2,220	
9	1.655	1,910	
10	1.860	1,490	
11	2.070	1,050	
12	2.280	698	
13	2.480	457	
14	2.690	300	
15	2.900	197	
16	3.100	130	
17	3.310	79	
18	3.520	43	
19	3.730	24	
20	3.930	16	
21	4.140	8	
22	4.350	4	
23	4.560	0	
24			
25			
26			
27			
28			
29			
30			
31			
32	Month	Estimated Number of Occurrence	
33			
34	Oct	3	

TABLE A12. HYDROGRAPH COMPUTATION FOR NOVEMBER

SCS-ENG-319
Rev. 1-70
File Code ENG-13-14

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

HYDROGRAPH COMPUTATION

DATE ______
COMPUTED BY ______
CHECKED BY ______

WATERSHED OR PROJECT Manoa-Palolo Stream

STATE Hawaii

STRUCTURE SITE OR SUBAREA Ala Wai Canal

DR. AREA 9.35 SQ. MI. STRUCTURE CLASS ______

T_c 1.0 HR. STORM DURATION 24 HR.

POINT RAINFALL 5.6 IN.

ADJUSTED RAINFALL:

AREAL : FACTOR 1 IN. 5.6

DURATION : FACTOR ______ IN. ______

RUNOFF CURVE NO. 84

Q 3.8 IN.

HYDROGRAPH FAMILY NO. 2

COMPUTED T_p 0.70 HR.

T_o 20.6 HR.

(T_o / T_p):
COMPUTED 29.50 ; USED 25

REVISED T_p 0.825

$q_p = \frac{484A}{\text{REV. } T_p}$ = 5,500 CFS.

$(Q)(q_p)$ = 20,840 CFS.

t(COLUMN) = (t / T_p) REV. T_p

q(COLUMN) = $(q_c / q_p)(Q)(q_p)$

Q(COLUMN) = $(Q_t / Q)Q$

Q_{peak} = 4,380 cfs

	$t = (t/T_p)\text{Rev. } T_p$	$q = (q_c/q_p)(Q)(q_p)$	$Q_t = (Q_t/Q)Q$
	t HOURS	q CFS	Q INCHES
1	0	0	0
2	1.070	42	
3	2.140	125	
4	3.220	290	
5	4.290	497	
6	5.360	1,830	
7	6.440	4,380	
8	7.500	3,040	
9	8.580	2,020	
10	9.650	1,500	
11	10.700	1,187	
12	11.800	1,020	
13	12.900	915	
14	13.940	811	
15	15.000	728	
16	16.100	686	
17	17.200	645	
18	18.200	603	
19	19.300	583	
20	20.400	561	
21	21.500	290	
22	22.500	83	
23	23.600	21	
24	24.700	0	
25			
26			
27			
28			
29			
30			
31			
32			
33			
34			

Month	Estimated Number of Occurrence
Nov	1

TABLE A13. HYDROGRAPH COMPUTATION FOR DECEMBER

SCS-ENG-319
Rev. 1-70
File Code ENG-13-14

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

HYDROGRAPH COMPUTATION

DATE
COMPUTED BY
CHECKED BY

WATERSHED OR PROJECT Manoa-Palolo Stream

STATE Hawaii

STRUCTURE SITE OR SUBAREA Ala Wai Canal

DR. AREA 9.35 SQ. MI. STRUCTURE CLASS

T_c 1.0 HR. STORM DURATION 3 HR.

POINT RAINFALL 2.2 IN.

ADJUSTED RAINFALL:

AREAL : FACTOR 1 IN. 2.2

DURATION : FACTOR IN.

RUNOFF CURVE NO. 84

Q 0.9 IN.

HYDROGRAPH FAMILY NO. 3

COMPUTED T_p 0.70 HR. (0.7 T_c)

T_o 2.15 HR.

(T_o / T_p):

COMPUTED 3.08 ; USED 3

REVISED T_p 0.72

$q_p = \frac{484A}{\text{REV. } T_p}$ = 6,290 CFS.

$(Q)(q_p)$ = 15,660 CFS.

t(COLUMN) = (t / T_p) REV. T_p q(COLUMN) = $(q_c / q_p)(Q)(q_p)$

Q(COLUMN) = $(Q_t / Q)Q$ Q_{peak} = 3,070 cfs

	$t = (t/T_p)$Rev. T_p	$q = (q_c/q_p)(Q)(q_p)$	$Q_t = (Q_t/Q)Q$
	t HOURS	q CFS	Q INCHES
1	0	0	0
2	0.245	23	
3	0.490	498	
4	0.735	1,635	
5	0.980	2,760	
6	1.220	3,070	
7	1.470	2,870	
8	1.710	2,520	
9	1.960	2,180	
10	2.200	1,920	
11	2.450	1,660	
12	2.690	1,260	
13	2.940	845	
14	3.180	543	
15	3.530	317	
16	3.670	187	
17	3.920	107	
18	4.160	74	
19	4.410	45	
20	4.660	23	
21	4.900	17	
22	5.140	11	
23	5.390	6	
24	5.630	0	
25			
26			
27			
28			
29			
30			
31			
32	Month	Estimated Number of Occurrence	
33			
34	Dec	3	

TABLE A14. HYDROGRAPH COMPUTATION
(100-YR, 6-HR RAINFALL OF 10 INCHES, T_c = 1 HR, T_o/T_p = 10)

SCS-ENG-319
Rev. 1-70
File Code ENG-13-14

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

HYDROGRAPH COMPUTATION

DATE ______
COMPUTED BY ______
CHECKED BY ______

WATERSHED OR PROJECT Manoa-Palolo Stream

STATE Hawaii

STRUCTURE SITE OR SUBAREA Ala Wai Canal

DR. AREA 9.35 SQ. MI. STRUCTURE CLASS ______

T_c 1.0 HR. STORM DURATION 6 HR.

POINT RAINFALL 10 IN. (100-yr, 6-hr storm)

ADJUSTED RAINFALL:

AREAL : FACTOR -- IN. --

DURATION : FACTOR ______ IN. ______

RUNOFF CURVE NO. 84

Q 8.0 IN.

HYDROGRAPH FAMILY NO. 2

COMPUTED T_p 0.70 HR.

T_o 5.5 HR.

(T_o / T_p):
COMPUTED 7.85 ; USED 10

REVISED T_p 0.55

$q_p = \frac{484A}{\text{REV. } T_p}$ = 8,250 CFS.

$(Q)(q_p)$ = 66,000 CFS.

t(COLUMN) = (t / T_p) REV. T_p

q(COLUMN) = $(q_c / q_p)(Q)(q_p)$

Q(COLUMN) = $(Q_t / Q)Q$

Q_{peak} = 26,000 cfs

	$t=(t/T_p)\text{Rev. }T_p$	$q=(q_c/q_p)(Q)(q_p)$	$Q_t=(Q_t/Q)Q$
	t HOURS	q CFS	Q INCHES
1	0	0	0
2	0.308	130	
3	0.616	860	
4	0.295	1,780	
5	1.240	3,100	
6	1.550	4,680	
7	1.860	7,580	
8	2.170	18,350	
9	2.480	26,000	
10	2.780	21,200	
11	3.100	14,850	
12	3.410	11,500	
13	3.720	8,970	
14	4.030	7,250	
15	4.330	6,070	
16	4.650	5,210	
17	4.960	4,820	
18	5.260	4,490	
19	5.570	4,290	
20	5.880	3,500	
21	6.200	1,780	
22	6.460	790	
23	6.780	400	
24	7.070	200	
25	7.400	130	
26	7.700	70	
27	8.010	0	
28			
29			
30			
31			
32			
33			
34			

TABLE A15. HYDROGRAPH COMPUTATION
(100-YR, 6-HR RAINFALL OF 10 INCHES, T_c = 1 HR, T_o/T_p = 6)

SCS-ENG-319
Rev. 1-70
File Code ENG-13-14

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

HYDROGRAPH COMPUTATION

DATE
COMPUTED BY
CHECKED BY

WATERSHED OR PROJECT Manoa-Palolo Stream

STATE Hawaii

STRUCTURE SITE OR SUBAREA Ala Wai Canal

DR. AREA 9.35 SQ. MI. STRUCTURE CLASS

T_c 1.0 HR. STORM DURATION 6 HR.

POINT RAINFALL 10 IN. (100-yr, 6-hr storm)

ADJUSTED RAINFALL:

AREAL FACTOR 1 IN. 10

DURATION FACTOR IN.

RUNOFF CURVE NO. 84

Q 8.0 IN.

HYDROGRAPH FAMILY NO. 1

COMPUTED T_p 0.70 HR.

T_o 5.5 HR.

(T_o / T_p) COMPUTED 7.85 ; USED 6

REVISED T_p 0.92

$q_p = \frac{484A}{REV.\ T_p}$ = 4,910 CFS.

$(Q)(q_p)$ = 39,300 CFS.

t(COLUMN) = (t / T_p) REV. T_p q(COLUMN) = $(q_c / q_p)(Q)(q_p)$

Q(COLUMN) = $(Q_t / Q)Q$ Q_{peak} = 19,550 cfs

	t (t/T$_p$)(Rev. T$_p$) t HOURS	q (q$_c$/q$_p$)(Q)(q$_p$) q CFS	Q$_t$ (Q$_t$/Q)(Q) Q INCHES
1	0	0	0
2	0.410	118	
3	0.900	710	
4	1.216	1,610	
5	1.620	3,300	
6	2.020	6,910	
7	2.430	15,200	
8	2.840	19,550	
9	3.240	16,900	
10	3.640	13,200	
11	4.040	10,140	
12	4.450	7,950	
13	4.860	6,450	
14	5.260	5,470	
15	5.660	4,780	
16	6.070	3,930	
17	6.470	2,360	
18	6.880	1,300	
19	7.280	710	
20	7.770	350	
21	8.100	200	
22	8.500	120	
23	8.900	80	
24	9.310	40	
25	9.700	0	
26			
27			
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29			
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32			
33			
34			

TABLE A16. HYDROGRAPH COMPUTATION
(100-YR, 1-HR RAINFALL OF 6 INCHES, T_c = 1 HR)

SCS ENG 319
Rev. 1-70
File Code ENG 13-14

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

HYDROGRAPH COMPUTATION

DATE
COMPUTED BY
CHECKED BY

WATERSHED OR PROJECT Manoa-Palolo Stream

STATE Hawaii

STRUCTURE SITE OR SUBAREA Ala Wai Canal

DR. AREA 9.35 SQ. MI. STRUCTURE CLASS

T_c 1.0 HR. STORM DURATION 1 HR

POINT RAINFALL 6 IN.

ADJUSTED RAINFALL:

AREAL FACTOR 1 IN. 6

DURATION FACTOR IN.

RUNOFF CURVE NO. 84

Q 4.2 IN.

HYDROGRAPH FAMILY NO. 4

COMPUTED T_p 0.70 HR.

T_p 0.82 HR.

(T_o / T_p) COMPUTED 1.17 USED 1

REVISED T_p 0.82

$q_p = \frac{484A}{\text{REV. } T_p}$ = 5,510 CFS.

$(Q)(q_p)$ = 23,200 CFS.

t(COLUMN) = (t / T_p) REV. T_p

q(COLUMN) = $(q_c / q_p)(Q)(q_p)$

Q(COLUMN) = $(Q_t / Q)Q$

Q_{peak} = 20,530 cfs

	$t = (t/T_p)(\text{Rev. } T_p)$	$q = (q_c/q_p)(Q)(q_p)$	$Q_t = (Q_t/Q)Q$
	t	q	Q
	HOURS	CFS	INCHES
1	0	0	0
2	0.230	610	
3	0.460	3,940	
4	0.688	11,150	
5	0.920	18.600	
6	1.148	20,530	
7	1.378	17,860	
8	1.608	12,780	
9	1.840	8,830	
10	2.060	5,950	
11	2.300	2,850	
12	2.520	2,630	
13	2.750	1,800	
14	2.980	1,200	
15	3.220	770	
16	3.440	540	
17	3.660	350	
18	2.900	210	
19	4.120	90	
20	4.360	50	
21	4.580	20	
22	4.800	0	
23			
24			
25			
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27			
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29			
30			
31			
32			
33			
34			

TABLE A17. HYDROGRAPH COMPUTATION
(100-YR, 1-HR RAINFALL OF 4 INCHES, T_c = 1 HR)

SCS-ENG-319
Rev. 1-70
File Code ENG-13-14

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

HYDROGRAPH COMPUTATION

DATE ______
COMPUTED BY ______
CHECKED BY ______

WATERSHED OR PROJECT Manoa-Palolo Stream

STATE Hawaii

STRUCTURE SITE OR SUBAREA Ala Wai Canal

DR. AREA 9.35 SQ. MI. STRUCTURE CLASS ______

T_c = 1.0 HR. STORM DURATION 1 HR.

POINT RAINFALL 4 IN.

ADJUSTED RAINFALL

AREAL FACTOR 1 IN. 4

DURATION FACTOR ______ IN. ______

RUNOFF CURVE NO. 84

Q 2.4 IN.

HYDROGRAPH FAMILY NO. 2

COMPUTED T_p 0.70 HR.

T_o = 0.82 HR.

(T_o / T_p) COMPUTED 1.17 USED 1

REVISED T_p 0.82

$q_p = \frac{484A}{\text{REV. } T_p}$ = 5,510 CFS

$(Q \times q_p)$ = 13,250 CFS.

t(COLUMN) = (t/T_p) REV. T_p q(COLUMN) = $(q_c/q_p)(Q \times q_p)$

Q(COLUMN) = $(Q_t/Q)Q$ Q_{peak} = 11,720 cfs

	$t = (t/T_p)$ Rev. T_p	$q = (q_c/q_p)(Q \times q_p)$	$Q_t = (Q_t/Q)Q$
	t	q	Q
	HOURS	CFS	INCHES
1	0	0	0
2	0.230	350	
3	0.460	2,250	
4	0.688	6,360	
5	0.920	10,630	
6	1.148	11,720	
7	1.378	10,200	
8	1.608	7,300	
9	1.840	5,040	
10	2.060	3,400	
11	2.300	2,200	
12	2.520	1,500	
13	2.750	1,030	
14	2.980	690	
15	3.220	440	
16	3.440	310	
17	3.660	200	
18	3.900	120	
19	4.120	50	
20	4.360	30	
21	4.580	10	
22	4.800	0	
23			
24			
25			
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32			
33			
34			

TABLE A18. HYDROGRAPH COMPUTATION
(100-YR, 1-HR RAINFALL OF 4 INCHES, T_c = 0.6 HR)

SCS-ENG-319
Rev. 1-70
File Code ENG-13-14

U. S. DEPARTMENT OF AGRICULTURE
SOIL CONSERVATION SERVICE

HYDROGRAPH COMPUTATION

DATE
COMPUTED BY
CHECKED BY

WATERSHED OR PROJECT Hanoa-Palolo Stream

STATE Hawaii

STRUCTURE SITE OR SUBAREA Ala Wai Canal

DR AREA 9.35 SQ. MI. STRUCTURE CLASS

T_c 0.6 HR. STORM DURATION 1 HR.

POINT RAINFALL 4* IN. (100-yr, 1-hr storm)

ADJUSTED RAINFALL:

AREAL : FACTOR 1 IN. 4

DURATION : FACTOR IN.

RUNOFF CURVE NO. 84

Q 2.4 IN.

HYDROGRAPH FAMILY NO. 2

COMPUTED T_p 0.42 HR.

T_o 0.82 HR.

(T_o / T_p):
COMPUTED 1.95 ; USED 2

REVISED T_p 0.41

$q_p = \frac{484A}{\text{REV. } T_p}$ = 11,020 CFS.

$(Q)(q_p)$ = 26,500 CFS.

t(COLUMN) = (t / T_p) REV. T_p

q(COLUMN) = $(q_c / q_p)(Q)(q_p)$

Q(COLUMN) = $(Q_t / Q)Q$

Q_{peak} = 18,960 cfs

	$t = (t/T_p)$Rev. T_p	$q = (q_c/q_p)(Q)(q_p)$	$Q_t = (Q_t/Q)Q$
	t HOURS	q CFS	Q INCHES
1	0	0	0
2	0.115	106	
3	0.230	1,060	
4	0.344	4,500	
5	0.460	11,300	
6	0.574	17,070	
7	0.689	18,960	
8	0.804	17,900	
9	0.920	15,200	
10	1.030	12,500	
11	1.150	9,760	
12	1.260	6,550	
13	1.375	4,450	
14	1.490	2,990	
15	1.610	1,990	
16	1.720	1,320	
17	1.830	900	
18	1.950	560	
19	2.060	370	
20	2.180	210	
21	2.290	106	
22	2.400	80	
23	2.520	50	
24	2.630	30	
25	2.750	0	
26			
27			
28			
29			
30			
31			
32			
33			
34			

Appendix B. Bathymetric Survey Results

Profiles of Ala Wai Canal (Ala Moana Bridge to Lewers Street)

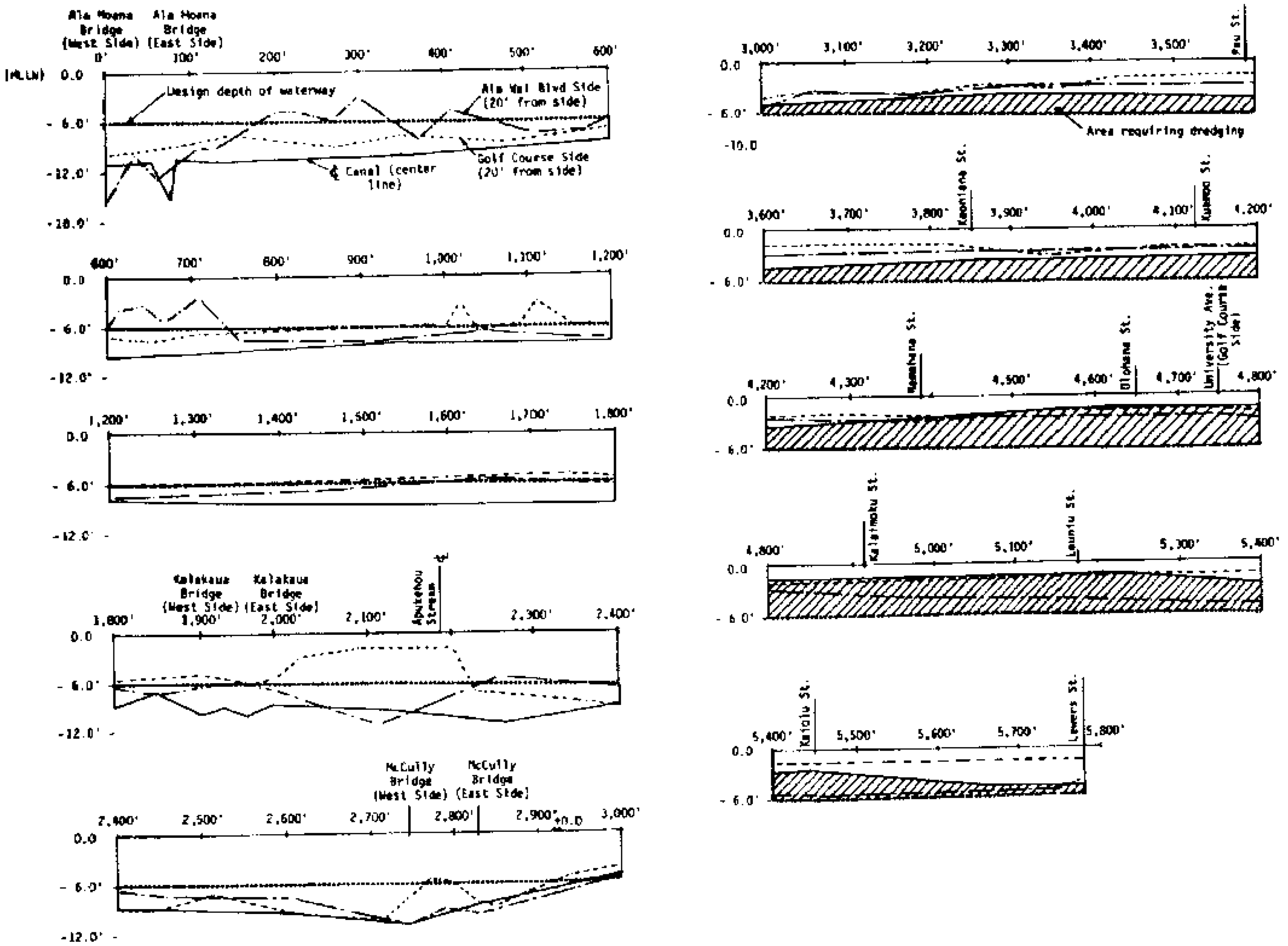


Figure B1. Bathymetric Survey Results of Ala Wai Canal

Profiles of Ala Wai Canal (Lewers Street to Ainakea Way)
November 25, 1972

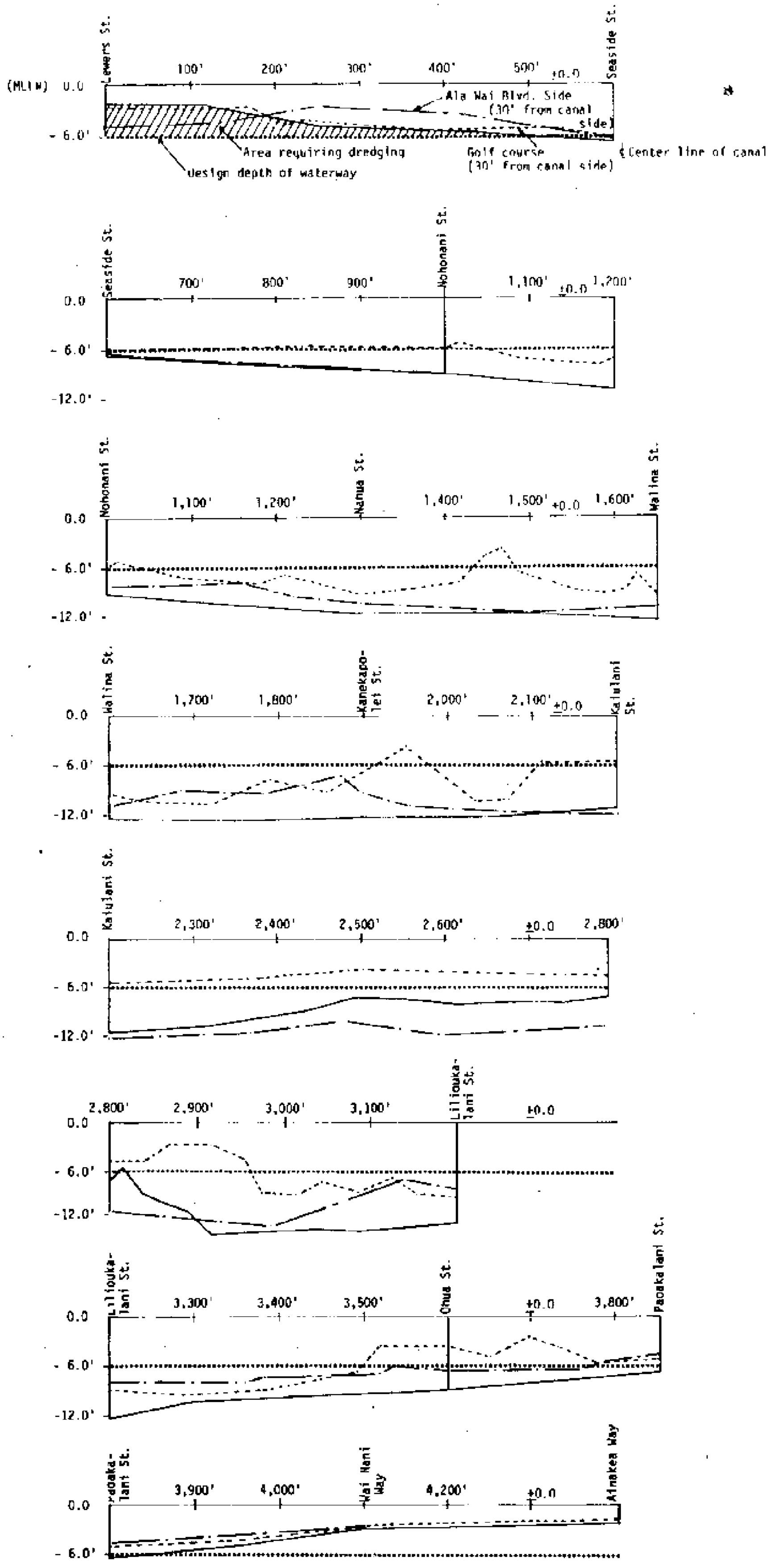


Figure B1. Bathymetric Survey Results of Ala Wai Canal (continued)

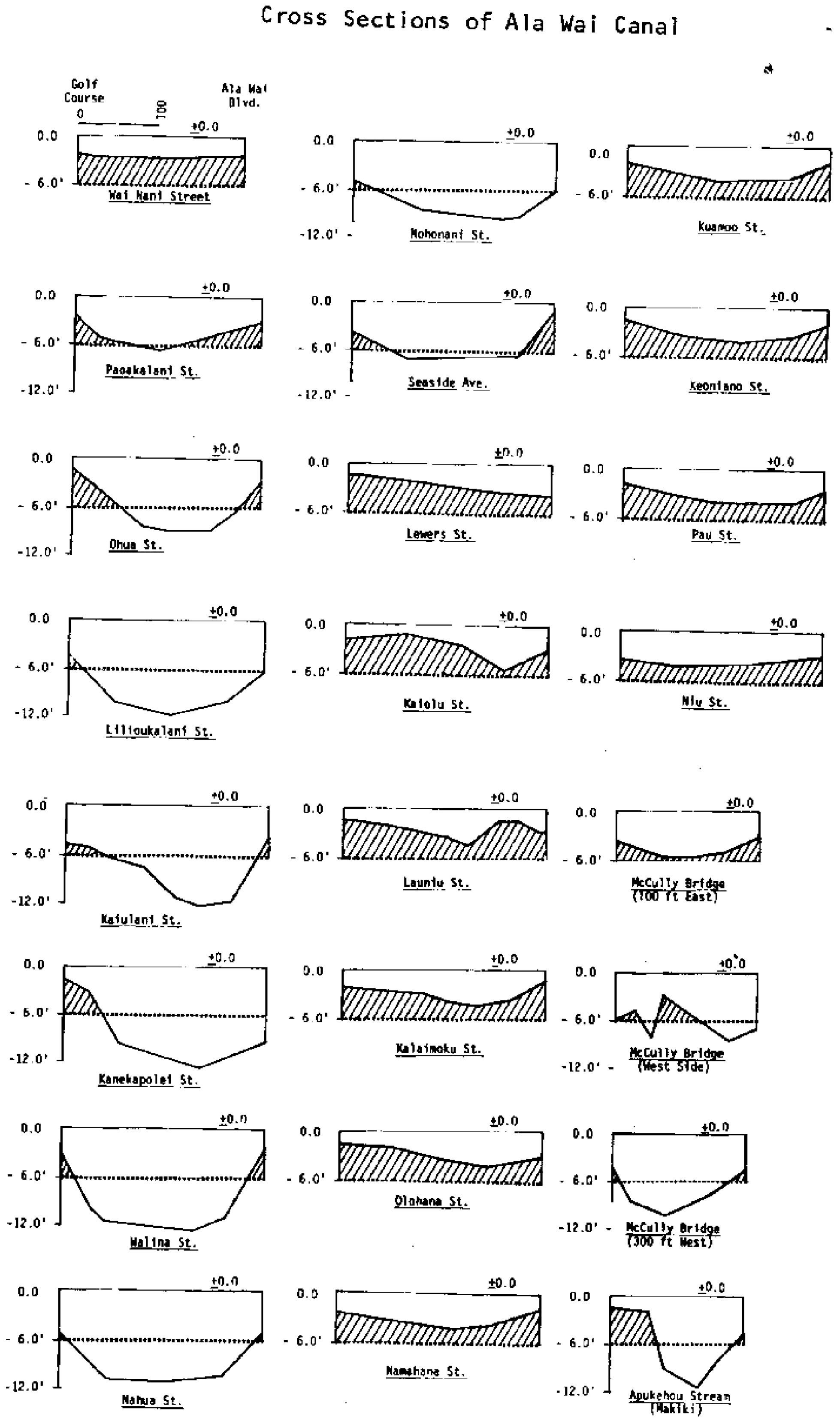


Figure B1. Bathymetric Survey Results of Ala Wai Canal (continued)

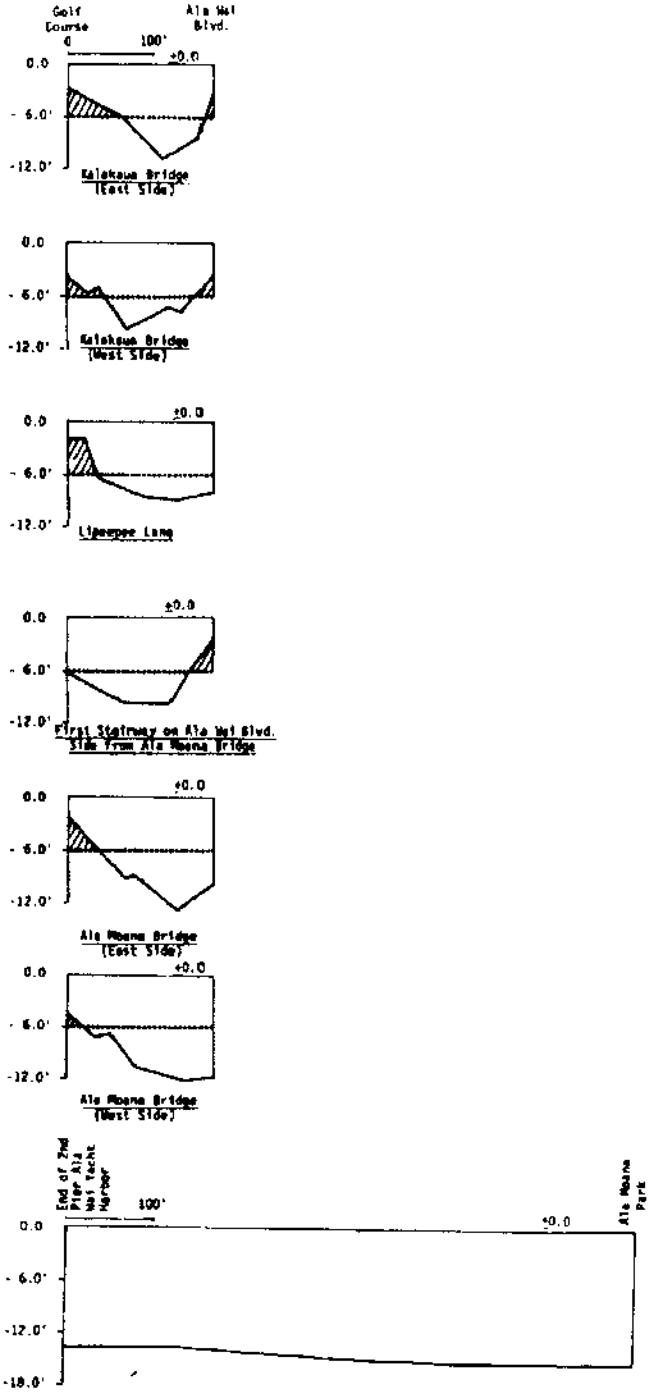
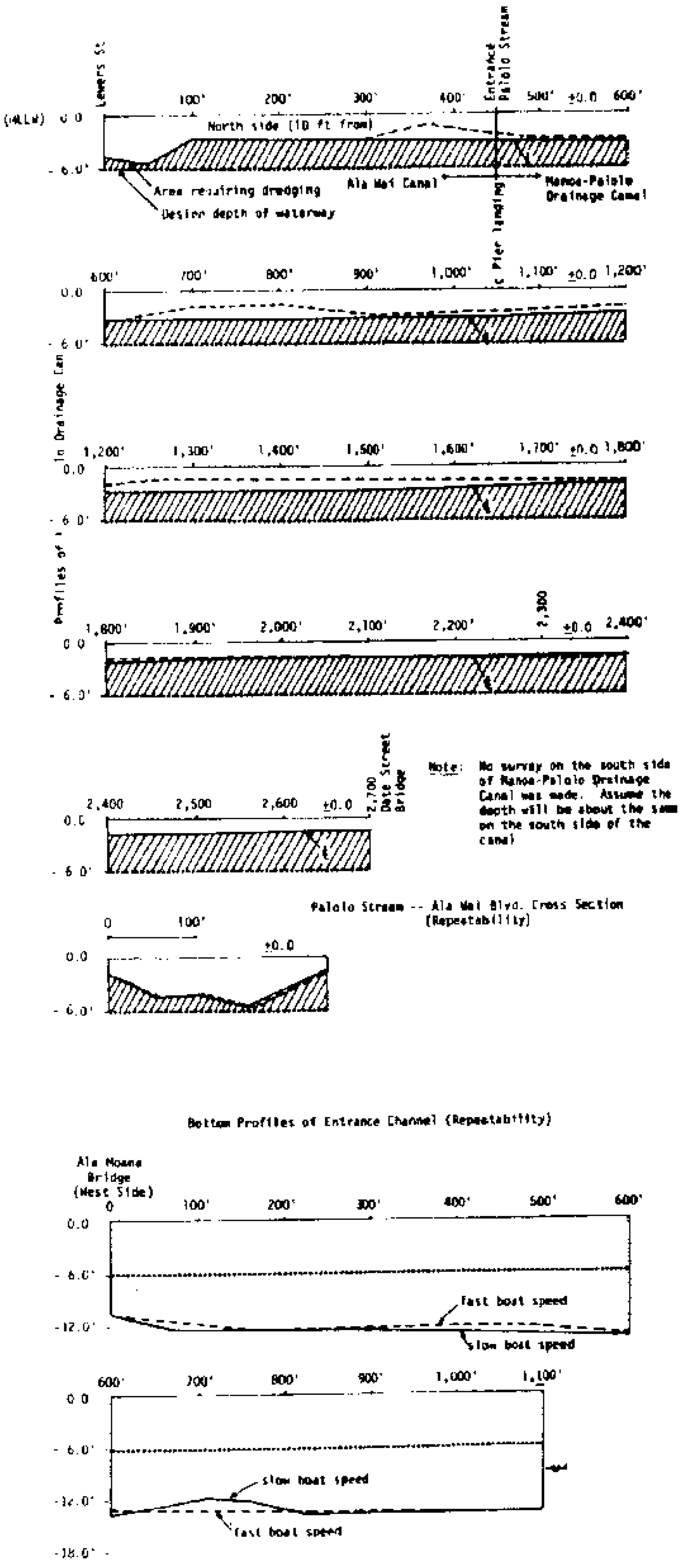


Figure B1. Bathymetric Survey Results of Ala Wai Canal (continued)



Profiles of Manoa-Palolo Drainage Canal
November 25, 1972

Note: No survey on the south side of Manoa-Palolo Drainage Canal was made. Assume the depth will be about the same on the south side of the canal

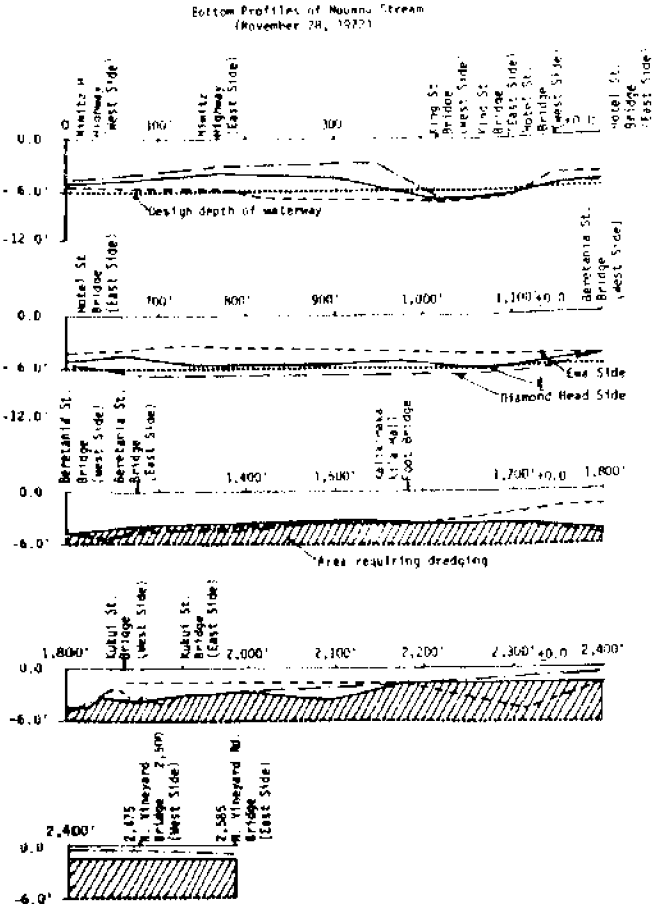
Palolo Stream -- Ala Wai Blvd. Cross Section (Repeatability)

Bottom Profiles of Entrance Channel (Repeatability)

Figure B2. Bathymetric Survey Results of Manoa-Palolo Drainage Canal

Profiles of Nuuanu Stream

November 28, 1972



Cross Sections of Nuuanu Stream

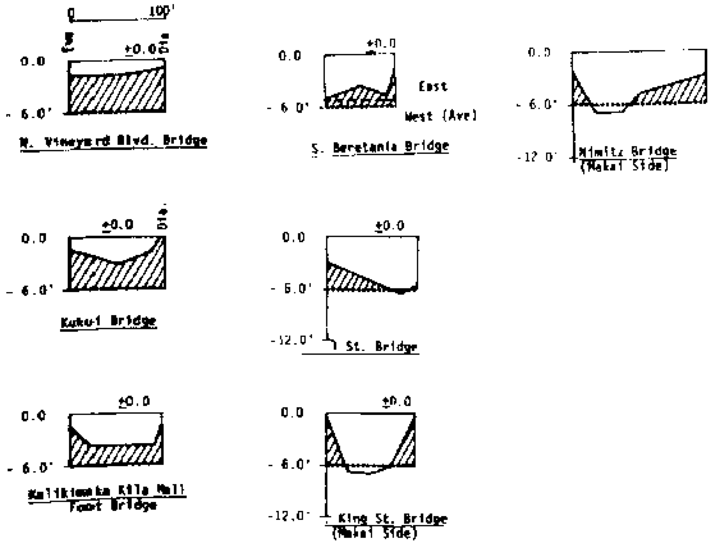
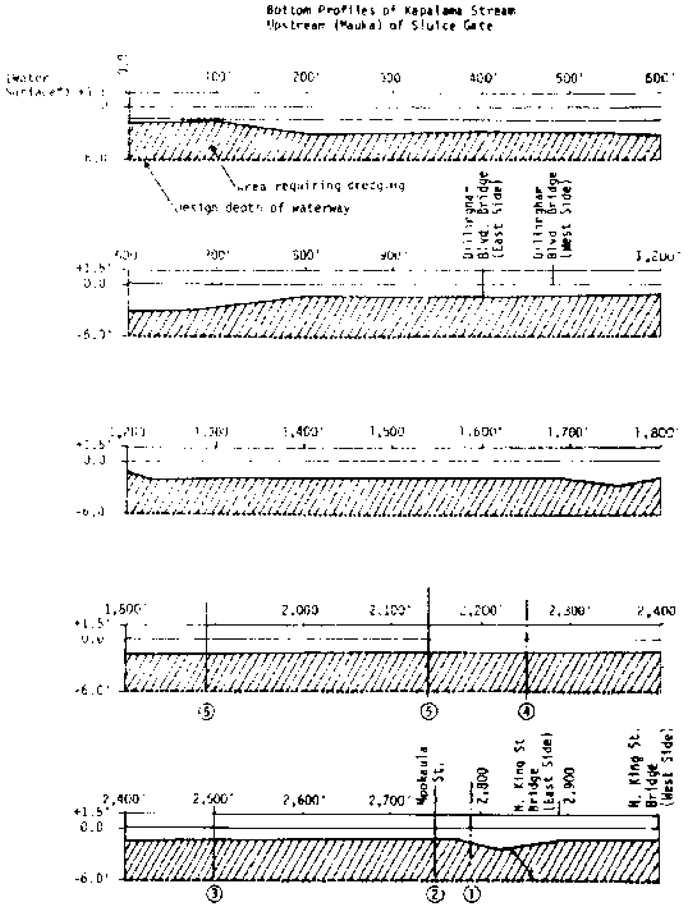


Figure B3. Bathymetric Survey Results of Nuuanu Stream

Profiles of Kapalama Stream Upstream (Mauka) of Sluice Gate



*Water surface is at +1.50 under normal condition (no runoff); the water surface is 0.40 ft higher upstream the sluice gate than the downstream side of the sluice gate. Tide at time is +1.[illegible] ft.

Figure B4. Bathymetric Survey Results of Kapalama Stream

Cross Sections of Kapalama Stream

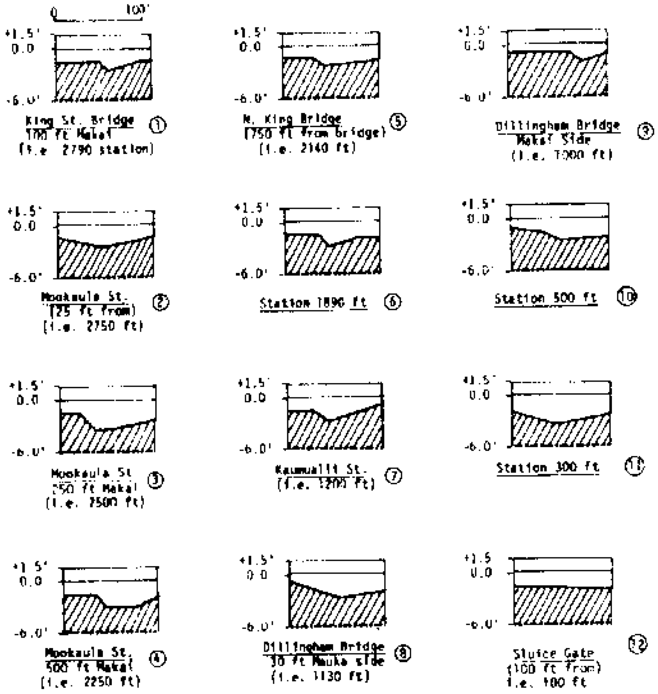


Figure B4. Bathymetric Survey Results of Kapalama Stream (continued)

Profile of Kapalama Stream Downstream (Makai) of Sluice Gate

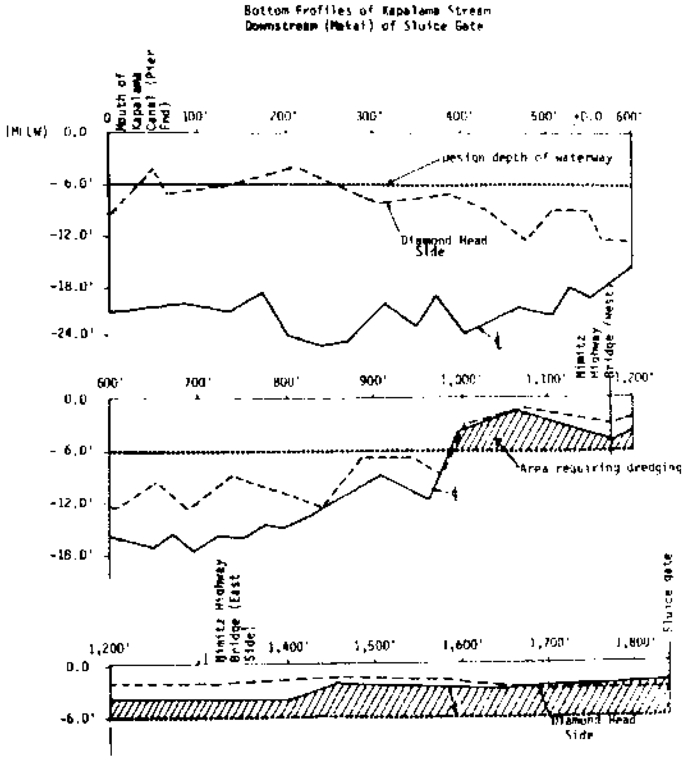


Figure B4. Bathymetric Survey Results of Kapalama Stream (continued)

Cross Sections of Kapalama Stream

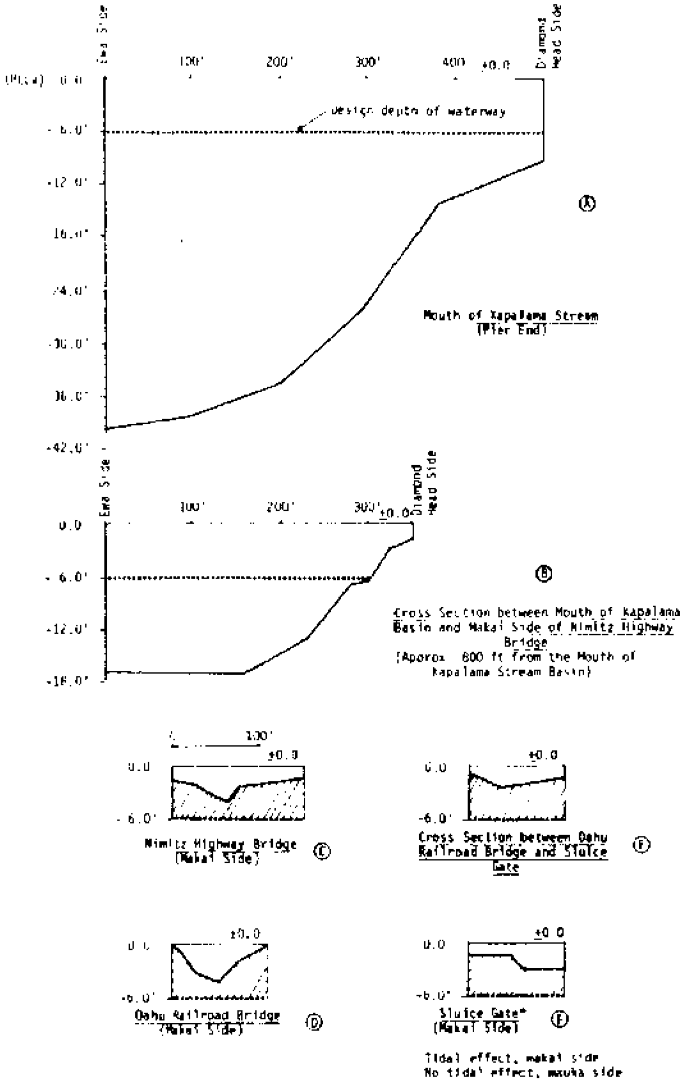


Figure B4. Bathymetric Survey Results of Kapalama Stream (continued)