SOME STATISTICAL ANALYSES OF HAWAIIAN RAINFALL

by

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ABSTRACT

Monthly rainfall data of several stations in Kalihi Basin, Manoa Basin, and Kaneohe Area, all on Oahu, and the central sloping area of Molokai were correlated to watershed parameters of the areas. Distance measured from the station to a common station located seaward from all stations has proven to be the most important of the three parameters studied, the other two being the exposure and the elevation of the area. Both linear and nonlinear regression functions were developed.

The central tendency of the monthly rainfall for the high rainfall part of the southeastern part of the Island of Oahu was found to require approximately forty years of record to stabilize. The analysis also shows that mean converges to a specified level generally faster than median.

The intensity-duration relation of intense rain for specified recurrence interval for the high rainfall part of the Manoa Basin portrays accurately an inverse straight-line relationship on a plot of log-log coordinates, suggesting extension of effort to other climatically widely different regions in Hawaii. The developed relation agrees well with the reported finding of a prior Weather Bureau study employing a different approach.

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PART A. RELATION OF WATERSHED PARAMETERS TO RAINFALL

Introduction

Hawaiian rainfall studies were started more than five decades ago. Various statistical, climatological and in-place studies about rainfall from the view point of frequency analysis, geographic distribution and local distribution patterns have been made at different times by Henry (1919), Wentworth (1946, 1947), Solot (1948), Stidd and Leopold (1951), Landsberg (1951), Baer (1956), Taliaferro (1959), Mink (1960, 1962), U.S. Weather Bureau (1962), and Schwartz (1963). Nevertheless, studies of the adequacy of the existing rain gage network in Hawaii, which ranks first in the United States and third in the world in density (Chow, 1964), has not been reported.

Part A was a pilot qualitative study to examine the adequacy of the existing rain gage network in Kalihi and Manoa Basins, and in the Kaneohe area on Oahu, as well as for the sloping area on the leeward region on east Molokai with respect to the basic watershed parameters: elevation, exposure, and distance to a reference point of the rain gage stations.

Scope and Approach

The study was initiated to identify the best statistical model of the rainfall during the summer months and the dependence of the model on watershed parameters. The summer precipitation of the study areas in Hawaii can be virtually accounted for by tradewinds rain; therefore, the summer model developed may be regarded as the tradewinds component of the total precipitation for the winter precipitation which is composed of both trade and nontrade precipitation.

At the beginning of the study, the selected watersheds were limited to three leeward areas: Kalihi Basin and Manoa Basin, both on Oahu, and a central portion on Molokai. All are climatically similar areas with respect to wind. Subsequently, a windward area on Oahu, Kaneohe, was added to offer a situation for comparison.

The initial phase of the procedure involved collection, collation, and examination of data from several agencies: U.S. Weather Bureau, U.S.

Corps of Engineers, Board of Water Supply, City and County of Honolulu and the State Division of Water and Land Development, Hawaii. In the final phase, both linear and nonlinear models were tested by the multiple correlation technique using the computing facilities in the Statistical and Computing Center at the University of Hawaii.

Data Period

Inasmuch as comparative studies were to be made, the data of all stations for study had to be for the same concurrent period. After examination of data, the period from 1963 to 1966 for the month of August was selected. Consequently, 12 out of 16 stations in Kalihi Basin (Fig. 1), 6 out of 31 stations in Manoa Basin (Fig. 2), 6 out of 31 stations in Kaneohe area (Fig. 3), and 19 out of 37 stations in central Molokai (Fig. 4) were selected. It was observed that the period from 1963 to 1966 registers markedly lower mean August rainfall than other years. The basic input data for multiple correlation analysis is shown in Table 1.

Watershed Parameters

Three basic watershed parameters were included in this study: 1) Elevation of the station E, 2) Exposure X which is the sum of those sectors, centered about the station, with a 3/4-mile radius for Kalihi, Manoa, and Kaneohe and a 2-mile radius for central Molokai, not containing a mountain barrier 700 feet above the station elevation for Kalihi, Manoa, and Kaneohe and 500 feet for central Molokai, and 3) Distance D from the subject station to a common reference station which is seaward from all stations.

Each of these parameters possesses apparent close relation to the mean August rainfall for the study area as evidenced in Figures A-1 to A-8 in Appendix A.

The procedure for introducing additional parameters into the multiple correlation analysis was not identical for each study area.

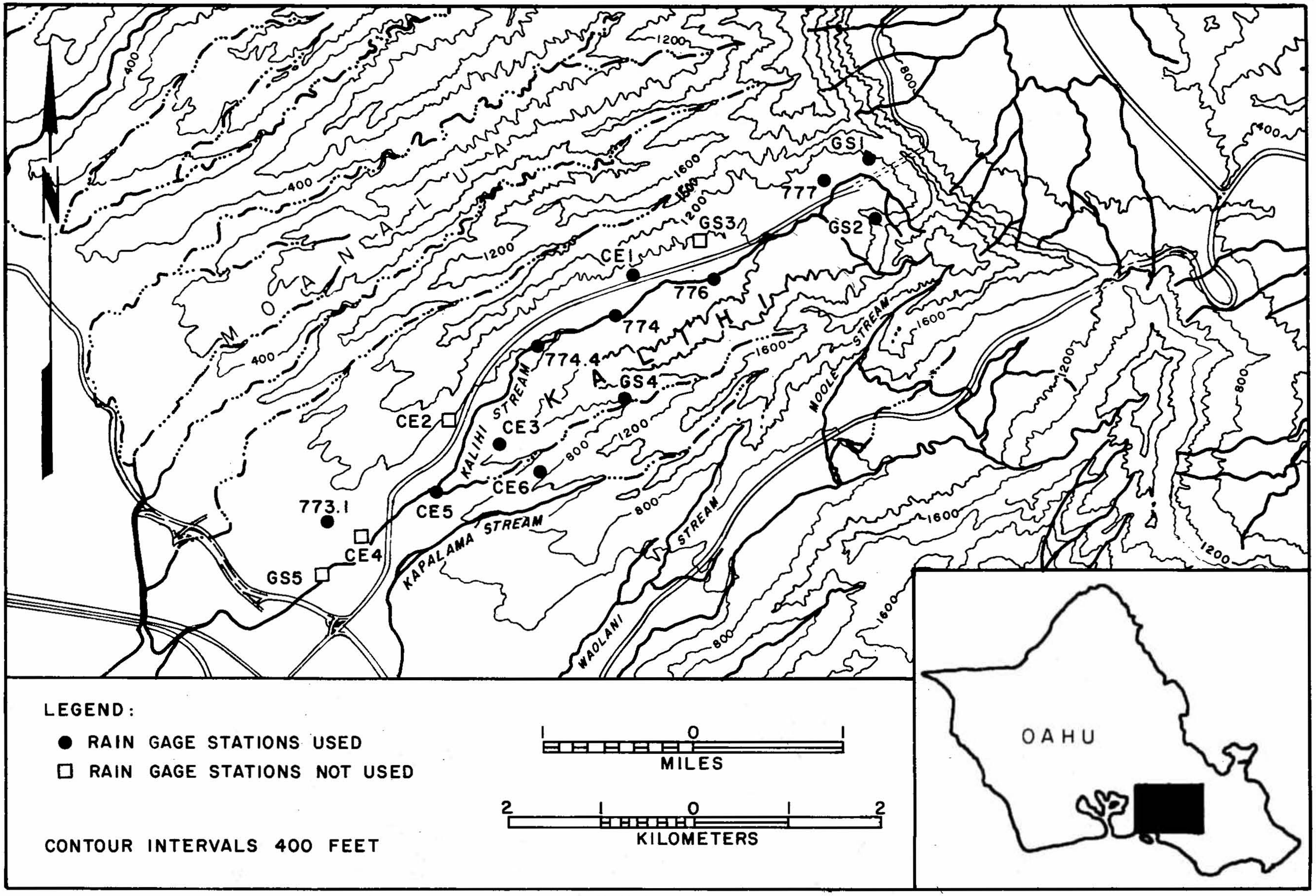

FIGURE 1. LOCATIONS OF RAIN GAGE STATIONS IN KALIHI BASIN, OAHU.

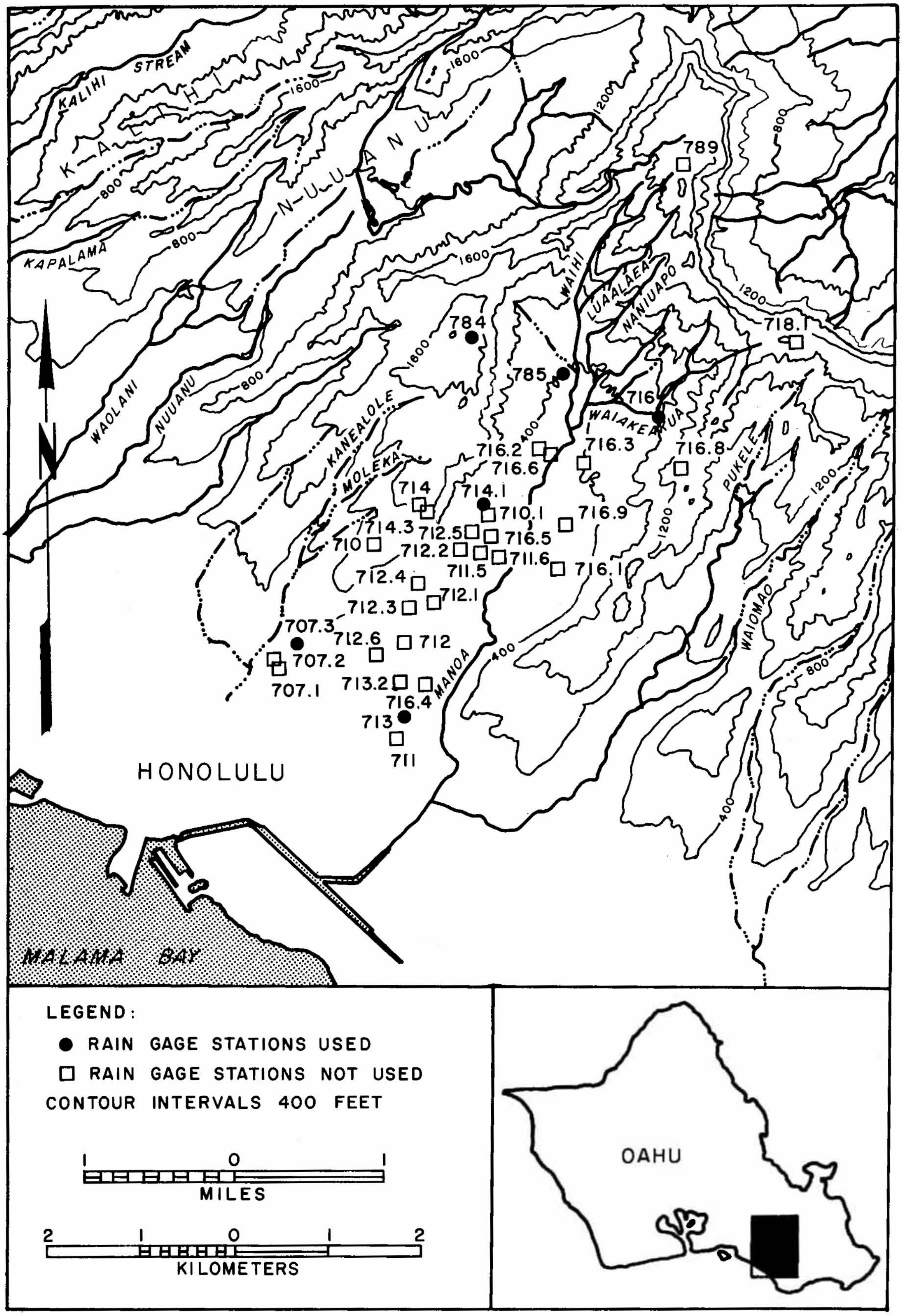

FIGURE 2. LOCATIONS OF RAIN GAGE STATIONS IN MANOA BASIN, OAHU.

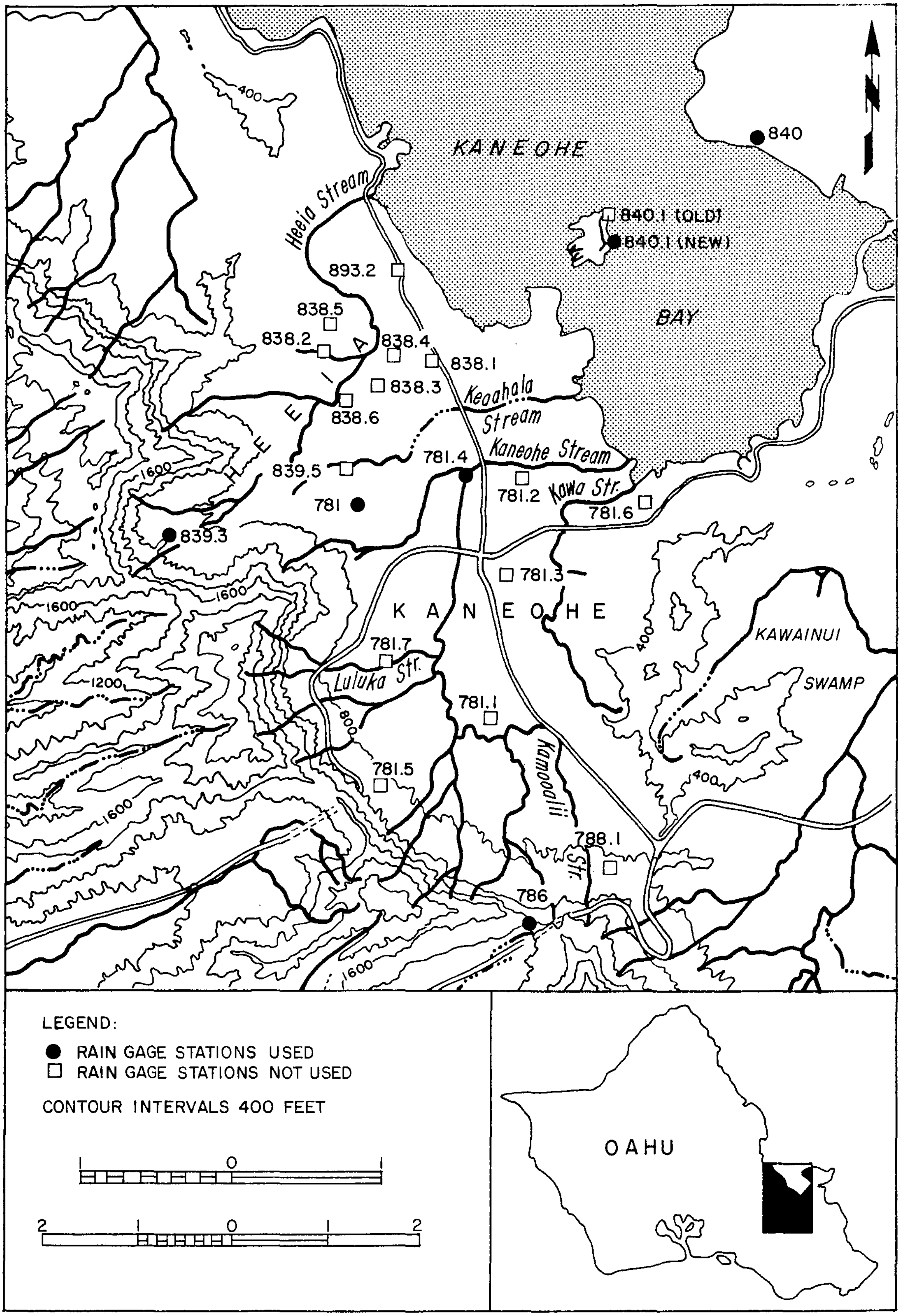

FIGURE 3. LOCATIONS OF RAIN GAGE STATIONS IN KANEOHE AREA, OAHU.

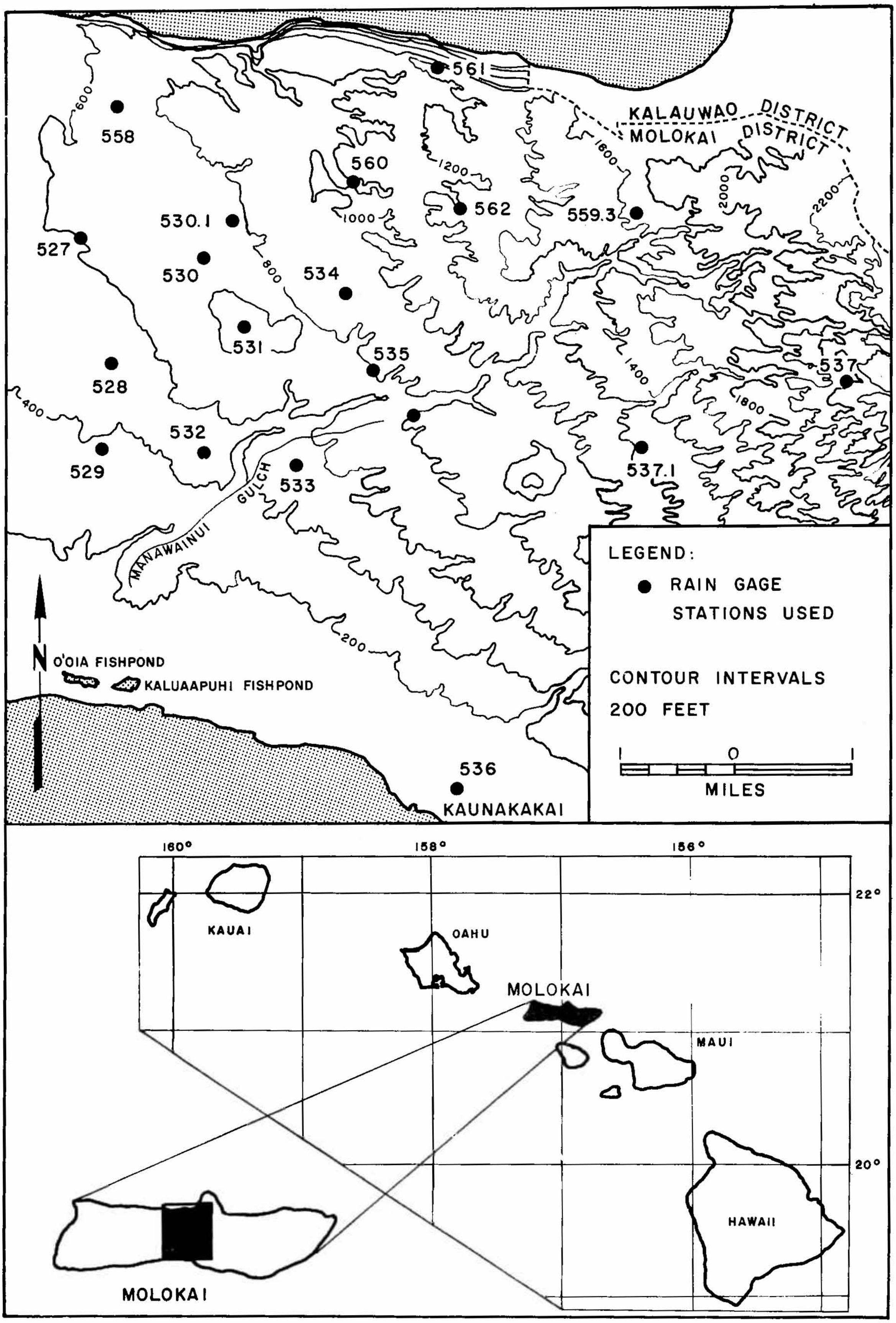

FIGURE 4. LOCATIONS OF RAIN GAGE STATIONS IN CENTRAL MOLOKAI.

TABLE 1. SUMMARIZED STATION DATA FOR KALIHI, MANOA, KANEOHE, AND CENTRAL MOLOKAI.

LOCATION	STATION (STATE NO.)	ELEVATION (FT)	EXPOSURE DEGREE	DISTANCE MAP INCH*	MEAN PRECIPITATION AUGUST 1963-66 (IN)	LOCATION	STATION (STATE NO.)	ELEVATION (FT)	EXPOSURE DEGREE	DISTANCE MAP INCH*	MEAN PRECIPITATION AUGUST 1963-66 (IN)
KALIHI	GS1**	1280	116	12.25	7.11	KANEOHE	840	10	360	1.00	1.35
	GS2	1360	95	11.78	8.47		840.1	15	360	3.81	4.44
	GS4	900	315	6.35	5.80	CENTRAL					
	CE1	700	210	7.70	7.29	MOLOKAI	527	600	360	4.13	0.56
	CE3	400	310	4.07	3.59		528	570	360	2.45	0.30
	CE5	240	330	2.50	2.61		529	320	330	1.00	0.09
	CE6	480	315	4.56	4.06		530	770	360	5.70	0.41
	777	910	90	11.30	5.83		530.1	790	360	6.90	0.46
	776	650	155	9.00	8.39		531	875	360	5.25	0.42
	774	500	152	7.00	6.06		532	475	360	2.70	0.16
	774.4	470	229	5.53	5.95		533	550	315	3.85	0.16
	773.1	155	360	1.00	1.51		533.1	820	285	6.75	0.19
MANOA	785	500	136	7.60	11.06		534	870	305	7.50	0.47
	784	1800	360	7.30	11.29		535	750	285	6.60	0.21
	716	650	170	7.70	9.75		536	10	260	1.20	0.08
	714.1	320	243	5.05	6.58		537	2150	255	14.08	1.02
	713	80	330	1.00	1.30		537.1	1230	240	9.85	0.30
	707.3	205	345	1.10	2.51		558	725	360	6.72	0.69
KANEOHE	781	198	349	10.06	3.71		559.3	1720	310	13.73	1.59
	781.4	60	360	8.63	5.63		560	1000	360	9.35	0.83
	786	1150	270	13.38	8.60		561	1250	350	12.63	1.32
	839.3	630	83	13.13	8.44		562	1230	305	10.75	0.78

* THE MAP SCALE IS 1:24000

** GS AND CE RAIN GAGE STATIONS WERE OPERATED BY U.S. GEOLOGICAL SURVEY AND U.S. ARMY CORPS OF ENGINEERS, RESPECTIVELY

Results

Kalihi basin

Linear and nonlinear multiple regression equations were developed involving different combinations of the watershed parameters for each of the two cases: Case 1 utilizing all twelve stations and Case 2 utilizing only half of the stations (Tables 2a and 2b). Selection of Case 2 stations was influenced by the figures in Appendix A to some extent.

Linear Equations:

Case 1: $P_e = 1.954 + 0.521(D)$ (1)

Case 2: $P_e = -1.769 + 0.0067(X) - 0.0042(E) + 1.294(D)$ (2)

Nonlinear Equations:

Case 1: $P_e = 1.54(D)^{0.677}$ (3)

Case 2: $P_e = 2.09(X)^{-0.0613}(D)^{0.674}$

where P_e is the estimated precipitation.

A comparison of the measured and computed rainfalls is listed in Table 3.

Manoa basin

Only linear multiple regression equations were developed for four cases as listed in Table 4. Because of the generally high multiple regression coefficients obtained for these linear cases, any additional improvement in correlation by using nonlinear equations would be of minor importance. Hence, no nonlinear analysis was made for Manoa Basin and for Molokai for similar reason as noted later.

Case 1: $P_e = 0.417 + 0.0011(E) + 1.211(D)$ (5)

Case 2: $P_e = 0.487 + 1.281(D)$ (6)

Case 3: $P_e = 0.08 + 1.265(D)$ (7)

Case 4: $P_e = -0.056 + 1.367(D)$ (8)

Table 5 summarizes the computed results for the above cases.

TABLE 2a. LINEAR REGRESSION ANALYSIS OF THE MEAN PRECIPITATION DATA FOR THE MONTH OF AUGUST IN KALIHI BASIN.

CASE	DATA PERIOD	INDEPENDENT VARIABLES	STATIONS			MULTIPLE REGRESSION COEFFICIENT					
						R			R^2		
						$P_e = f(D)$	$P_e = f(D,E)$	$P_e = f(D,E,X)$	$P_e = f(D)$	$P_e = f(D,E)$	$P_e = f(D,E,X)$
			GS1	GS2	GS4						
			CE1	CE3	CE5						
	1963 -		CE6	777	776						
1	1966	D[1]	774	774.4	773.1	0.861	---	---	0.741	---	---
	1963 -		773.1	CE5	CE6						
2	1966	X,E,D	774	776	GS2	0.978	0.996	0.998	0.956	0.993	0.997

TABLE 2b. NONLINEAR MULTIPLE REGRESSION ANALYSIS OF THE MEAN PRECIPITATION DATA FOR THE MONTH OF AUGUST IN KALIHI BASIN.

CASE	DATA PERIOD	INDEPENDENT VARIABLES	STATIONS			MULTIPLE REGRESSION COEFFICIENT			
						R		R^2	
						$P_e = f(D)$	$P_e = f(D,X)$	$P_e = f(D)$	$P_e = f(D,X)$
			GS1	GS2	GS4				
			CE1	CE3	CE5				
	1963 -		CE6	777	776				
1	1966	D	774	774.4	773.1	0.953	---	0.909	---
	1963 -		773.1	CE5	CE6				
2	1966	X,D	774	776	GS2	0.992	0.997	0.984	0.994

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[1] REFER TO PAGE 2 FOR AN EXPLANATION OF THE SYMBOLS

TABLE 3. COMPARISONS OF COMPUTED AND MEASURED PRECIPITATIONS FOR KALIHI BASIN IN THE MONTH OF AUGUST (FOUR YEARS MONTHLY AVERAGE, 1963-66).

		ESTIMATED PRECIPITATION							
		LINEAR				NONLINEAR			
		CASE 1		CASE 2		CASE 3		CASE 4	
STATION	MEAN PRECIPITATION (IN)	EQ (1)	ERROR	EQ (2)	ERROR	EQ (3)	ERROR	EQ (4)	ERROR
773.1	1.51	2.48	-0.97	1.30	0.21	1.54	-0.03	1.46	0.05
CE5	2.61	3.26	-0.65	2.68	-0.07	2.83	-0.22	2.71	-0.10
CE3	3.59	4.07	-0.48	3.80	-0.21	3.97	-0.38	3.73	-0.14
CE6	4.06	4.33	-0.27	4.25	-0.19	4.46	-0.40	4.08	-0.02
774.4	5.95	4.84	1.11	4.95	1.00	4.90	1.05	4.73	1.22
GS4	5.80	5.26	0.54	4.79	1.01	5.38	0.42	5.11	0.69
774	6.06	5.60	0.46	6.22	-0.16	5.76	-0.03	5.72	-0.34
CE1	7.29	5.97	1.32	6.66	0.63	6.13	1.16	5.96	1.33
776	8.39	6.64	1.75	8.21	0.18	6.81	1.58	6.75	1.64
777	5.83	7.84	-2.01	9.63	-3.80	7.95	-2.12	8.13	2.30
GS2	8.47	8.09	0.38	8.44	0.03	8.16	0.31	8.33	0.14
GS1	7.11	8.33	-1.22	9.48	-2.37	8.40	-1.29	8.43	1.32
SUM OF SQUARE OF DEVIATIONS ABOUT REGRESSION, SS		SS = 13.88		SS = 22.70		SS = 11.73		SS = 13.62	

TABLE 4. LINEAR REGRESSION ANALYSIS OF THE MEAN PRECIPITATION DATA FOR THE MONTH OF AUGUST IN MANOA BASIN.

				MULTIPLE REGRESSION COEFFICIENT			
				R		R^2	
CASE	DATA PERIOD	INDEPENDENT VARIABLES	STATIONS	$P_e = f(D)$	$P_e = f(D,E)$	$P_e = f(D)$	$P_e = f(D,E)$
1	1963 - 1966	E,D[1]	785 784 716 714.1 713 707.3	0.982	0.990	0.965	0.981
2	1963 - 1966	D	785 716 714.1 713 707.3	0.988	---	0.976	---
3	1963 - 1966	D	716 714.1 713	0.9997	---	0.9995	---
4	1963 - 1966	D	785 716 713	0.991	---	0.981	---

[1] REFER TO PAGE 2 FOR AN EXPLANATION OF THE SYMBOLS

TABLE 5. COMPARISONS OF OBSERVED AND COMPUTED PRECIPITATIONS FOR MANOA BASIN IN THE MONTH OF AUGUST (FOUR YEARS MONTHLY AVERAGE, 1963-66).

		ESTIMATED PRECIPITATION							
		CASE 1		CASE 2		CASE 3		CASE 4	
STATION	MEAN PRECIPITATION (IN)	EQ (5)	ERROR	EQ (6)	ERROR	EQ (7)	ERROR	EQ (8)	ERROR
785	11.06	10.17	0.89	10.22	0.84	9.68	1.38	10.33	0.73
784	11.29	11.24	0.05	9.84	1.45	9.32	1.97	9.92	1.37
716	9.75	10.45	-0.70	10.35	-0.60	9.82	-0.07	10.47	-0.72
714.1	6.58	6.89	-0.31	6.96	-0.38	6.47	0.11	6.85	-0.27
713	1.30	1.51	-0.21	1.77	-0.47	1.34	-0.04	1.31	-0.01
707.3	2.51	1.97	0.54	1.90	0.61	1.47	1.04	1.45	1.06
TOTAL	42.49								
$\bar{P} = 7.082$									
SUM OF SQUARE OF DEVIATIONS ABOUT REGRESSION, SS		SS = 1.72		SS = 3.90		SS = 6.89		SS = 4.13	

kaneohe area

Five different combinations of parameters and stations, designated as Cases 1 to 5, were studied by both linear and nonlinear multiple regression analysis (Tables 6a and 6b).

Linear Equations:

Case 1: $P_e = 1.258 + 0.492(D)$ (9)

Case 2: $P_e = 1.36 - 0.54(D)$ (10)

Case 3: $P_e = 0.761 + 0.00023(E) + 0.5686(D)$ (11)

Case 4: $P_e = 0.725 + 0.582(D)$ (12)

Case 5: $P_e = 0.719 + 0.583(D)$ (13)

Nonlinear Equations

Case 1: $P_e = 1.462(D)^{0.623}$ (14)

Case 2: $P_e = 1.436(D)^{0.688}$ (15)

Case 3: $P_e = 1.192(E)^{0.0539}(D)^{0.62}$ (16)

Case 4: $P_e = 1.337(D)^{0.696}$ (17)

Case 5: $P_e = 1.336(D)^{0.698}$ (18)

Tables 7a and 7b summarize the computed results for the above cases.

central sloping area of molokai

From the standpoint of physiography, the project areas selected for the Islands of Molokai and Oahu are quite different. Watersheds with well defined water divides similar to Manoa and Kalihi Basins on Oahu could not be found in central leeward area of Molokai. Consequently, a portion of the leeward region of east Molokai oriented to the prevailing tradewinds was selected for the study. Three cases were studied with linear regression equations developed for each case (Table 8).

Case 1: $P_e = -1.306 + 0.00357(X) + 0.0992(D)$ (19)

Case 2: $P_e = -1.291 + 0.0042(X) - 0.00072(E) + 0.1472(D)$ (20)

Case 3: $P_e = -0.235 + 0.00074(X) + 0.0729(D)$ (21)

TABLE 6a. LINEAR MULTIPLE REGRESSION ANALYSIS OF THE MEAN PRECIPITATION DATA FOR THE MONTH OF AUGUST IN KANEOHE AREA (WINDWARD SIDE OF OAHU).

				MULTIPLE REGRESSION COEFFICIENT			
				R		R^2	
CASE	DATA PERIOD	INDEPENDENT VARIABLES	STATIONS	$P_e = f(D)$	$P_e = f(D,E)$	$P_e = f(D)$	$P_e = f(D,E)$
1	1963 - 1966	X,E,D	781 781.4 786 839.3 840 840.1	0.880	---	0.768	---
2	1963 - 1966	D	781.4 786 839.3 840 840.1	0.982	---	0.964	---
3	1963 - 1966	D,E	781.4 786 839.3 840	0.9996	0.9999	0.9993	0.9997
4	1963 - 1966	D	840 781.4 839.3	0.9996	---	0.9992	---
5	1963 - 1966	D	781.4 786 840	0.9996	---	0.9991	---

TABLE 6b. NON-LINEAR MULTIPLE REGRESSION ANALYSIS OF THE MEAN PRECIPITATION DATA FOR THE MONTH OF AUGUST IN KANEOHE AREA (WINDWARD SIDE OF OAHU).

				MULTIPLE REGRESSION COEFFICIENT			
				R		R^2	
CASE	DATA PERIOD	INDEPENDENT VARIABLES	STATIONS	$P_e = f(D)$	$P_e = f(D,E)$	$P_e = f(D)$	$P_e = f(D,E)$
1	1963 - 1966	X,E,D	781 781.4 786 839.3 840 840.1	0.9140	---	0.8354	---
2	1963 - 1966	X,E,D	781.4 786 839.3 840 840.1	0.9895	---	0.9791	---
3	1963 - 1966	D,E	781.4 786 839.3 840	0.9981	0.9999	0.9963	0.9999
4	1963 - 1966	D	781.4 839.3 840	0.9982	---	0.9965	---
5	1963 - 1966	D	781.4 786 840	0.9981	---	0.9962	---

TABLE 7a. COMPARISONS OF OBSERVED AND COMPUTED PRECIPITATION (ACCORDING TO EQ. 9-13). KANEOHE AREA IN THE MONTH OF AUGUST (FOUR YEARS MONTHLY AVERAGE 1963-66).

		ESTIMATED PRECIPITATION									
		CASE 1		CASE 2		CASE 3		CASE 4		CASE 5	
STATION	MEAN PRECIPITATION (IN)	EQ (9)	ERROR	EQ (10)	ERROR	EQ (11)	ERROR	EQ (12)	ERROR	EQ (13)	ERROR
781	3.71	6.21	-2.50	6.79*	-3.08	6.53*	-2.82	6.58	-2.87	6.59	-2.88
781.4	5.63	5.50	0.13	6.02	-0.39	5.68	-0.05	5.75	-0.12	5.75	-0.12
786	8.60	7.84	0.76	8.58	0.02	8.63	-0.03	8.51*	0.09	8.68	0.08
839.3	8.44	7.72	-0.72	8.45	-0.01	8.37	0.07	8.37	0.07	8.38*	0.06
840	1.35	1.75	-0.40	1.90	-0.55	1.33	0.02	1.31	0.04	1.30	0.05
840.1	4.44	3.13	1.31	3.52	0.92	2.93*	1.51	2.94*	1.50	2.94*	1.50
SUM OF SQUARE OF DEVIATIONS ABOUT REGRESSION, SS		SS = 9.24		SS = 10.80		SS = 10.22		SS = 10.51		SS = 10.55	

TABLE 7b. COMPARISONS OF OBSERVED AND COMPUTED PRECIPITATION (ACCORDING TO EQ. 14-18). KANEOHE AREA IN THE MONTH OF AUGUST (FOUR YEARS MONTHLY AVERAGE 1963-66).

		ESTIMATED PRECIPITATION									
		CASE 1		CASE 2		CASE 3		CASE 4		CASE 5	
STATION	MEAN PRECIPITATION (IN)	EQ (14)	ERROR	EQ (15)	ERROR	EQ (16)	ERROR	EQ (17)	ERROR	EQ (18)	ERROR
781	3.71	6.37	-2.66	7.29	-3.58	6.63*	-2.92	6.67*	-2.96	6.69*	-3.00
781.4	5.63	5.61	0.02	6.32	-0.69	5.66	-0.03	6.00	-0.37	6.01	-0.38
786	8.60	7.34	1.26	8.54	0.06	8.40	-0.10	8.13*	0.47	8.16	0.44
839.3	8.44	7.27	-1.17	8.43	-0.01	8.33	0.11	8.03	0.42	8.05*	0.40
840	1.35	1.46	-0.11	1.44	-0.09	1.35	0.00	1.34	0.01	1.34	0.01
840.1	4.44	3.36	1.08	3.60	0.84	3.16*	1.28	3.40*	1.05	3.40*	1.04
SUM OF SQUARE OF DEVIATIONS ABOUT REGRESSION, SS		SS = 11.22		SS = 14.01		SS = 10.20		SS = 10.37		SS = 10.43	

TABLE 8. LINEAR REGRESSION ANALYSIS OF THE MEAN PRECIPITATION DATA FOR THE MONTH OF AUGUST IN CENTRAL SLOPING AREA OF MOLOKAI.

				MULTIPLE REGRESSION COEFFICIENT					
				R			R^2		
CASE	DATA PERIOD	INDEPENDENT VARIABLE	STATIONS	$P_e = f(D)$	$P_e = f(D,X)$	$P_e = f(D,X,E)$	$P_e = f(D)$	$P_e = f(D,X)$	$P_e = f(D,X,E)$
1	1963 - 1966	X,E,D[1]	527 528 529 530 530.1 531 532 533 533.1 534 535 536 537 537.1 558 559.3 560 561 562	0.842	0.907	---	0.701	0.823	---
2	1963 - 1966	X,E,D	527 528 529 530 530.1 531 532 533 533.1 534 535 536 537.1 558 560 561 562	0.778	0.905	0.936	0.605	0.819	0.877
3	1963 - 1966	X,E,D	528 530 530.1 531 532 534 536 560 562	0.953	0.960	---	0.909	0.921	---

[1] REFER TO PAGE 3 FOR AN EXPLANATION OF THE SYMBOLS

Estimated precipitation corresponding to the cases was computed and listed in Table 9.

Discussion

Type of regression functions

As shown in Tables 2a and 2b it is apparent that for Kalihi Basin, Oahu, the nonlinear regression function more accurately represents the recorded precipitation data than the linear functions. In contrast, studies of Manoa Basin and central Molokai indicate that the linear regression function can satisfactorily portray the measured precipitation data in these two areas (Tables 4 and 8). For Kaneohe area, as indicated in Tables 6 and 7, it appears that both linear or nonlinear regression functions can satisfactorily predict the measured precipitation data without appreciable difference.

It should be noted that in this study many cases selected for correlation analyses involve only a fraction rather than all stations. Hence, the regression equations for those cases thus obtained best represent the selected stations but not necessarily the unselected stations.

Relative importance of parameters

It is clearly evident from Tables 2, 4, 6, and 8 that distance, D, is the most important of the three parameters considered in this study. In other words, the precipitation is so highly correlated with the distance parameter, D, that involvement of additional parameters produces very minor differences. As shown in Tables 2, 4, and 6, in more than one half of the cases studied, the exposure and elevation parameters were eliminated by the F-test of significance since extremely high values of regression coefficients had already been obtained from the study. (The stepwise regression computer program computes a sequence of multiple linear regression equations in a stepwise manner. At each step one variable is added to the regression equation. But the variables are

TABLE 9. COMPARISONS OF COMPUTED AND MEASURED PRECIPITATIONS FOR CENTRAL SLOPING AREA OF MOLOKAI IN THE MONTH OF AUGUST (FOUR YEARS MONTHLY AVERAGE, 1963-66).

		ESTIMATED PRECIPITATION					
		CASE 1		CASE 2		CASE 3	
STATION	MEAN PRECIPITATION (IN)	EQ (19)	ERROR	EQ (20)	ERROR	EQ (21)	ERROR
527	0.56	0.39	0.17	0.40	0.16	0.33	0.23
528	0.30	0.22	0.08	0.18	0.12	0.21	0.09
529	0.09	0.03	0.06	0.02	0.07	0.08	0.01
530	0.41	0.54	-0.13	0.51	-0.10	0.45	-0.04
530.1	0.46	0.66	-0.20	0.67	-0.21	0.54	-0.08
531	0.42	0.50	-0.08	0.37	0.05	0.42	0.00
532	0.16	0.25	-0.09	0.28	-0.12	0.23	-0.07
533	0.16	0.20	-0.04	0.21	-0.05	0.28	-0.12
533.1	0.19	0.38	-0.20	0.31	-0.12	0.47	-0.28
534	0.47	0.53	-0.06	0.47	0.00	0.54	-0.07
535	0.21	0.37	-0.16	0.34	-0.13	0.46	-0.25
536	0.08	0.26	-0.18	0.03	0.05	0.05	0.03
537	1.02	1.00	0.02				
537.1	0.30	0.53	-0.23	0.28	0.02	0.66	-0.36
558	0.69	0.65	0.04	0.69	0.00	0.52	0.17
559.3	1.59	1.16	0.43				
560	0.83	0.90	-0.08	0.88	-0.05	0.71	0.11
561	1.32	1.20	0.12	1.14	0.18	0.94	0.38
562	0.78	0.85	-0.07	0.69	0.09	0.77	0.01
TOTAL	7.43						
$\overline{P} = 0.391$							
SUM OF SQUARE OF DEVIATIONS ABOUT REGRESSION, SS		SS = 0.566		SS = 0.207		SS = 0.543	

automatically removed when their F values become less than 0.01.) For example, the cases considered for Manoa Basin (Table 4), the multiple regression coefficient, R, was computed to be 0.982, indicating that about 96 percent of the original variance was attributable to the watershed parameter, D.

Analysis of variance

To select a proper regression equation for each case studied, analysis of variance became essential. As an illustration, Case 1 in Table 6a is discussed.

In the process of the stepwise multiple regression analysis, the addition of each new independent variable will always increase R, but it will not necessarily increase the precision of the estimate. This is because the reduction in the residual sum of squares may be less than the original residual mean square. Since, in addition, one degree of freedom is removed from the residual degrees of freedom, the resulting mean square may become larger. To illustrate this point, Case 1 in Table 6a stepwise regression analysis of variance is as follows:

STEP 1: $P_e = f(D)$; $R = 0.88$; $s = 1.52$

ANOVA: Regression Equation: $$P_e = 1.258 + 0.492(D) \tag{9}$$

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	F
Total (uncorrected)	6	212.191		
Mean	1	172.485		
Total (corrected)	5	39.706		
Regression	1	30.485	30.485	13.225
Residual	4	9.221	2.305	

Therefore, one can see that the required ratio is F = 30.485/2.305 = 13.225. By using 5 percent significance level, then F(1, 4, 0.95) = 7.71. Since the calculated F exceeds the critical F value in the table, that is,

$F = 13.225 > 7.71$, the variable D is valuable in prediction of P_e. In ANOVA the residual mean square, MS, is an estimate of the variance about the regression. From the above calculation, MS = 2.305. Therefore, the standard error of estimate, $s = \sqrt{2.305} = 1.52$.

STEP 2: $P_e = f(D,E)$; variable entered = E; R = 0.902; s = 1.58

ANOVA: Regression Equation: $P_e = 1.795 + 0.002(E) + 0.34(D)$

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	F
Total (uncorrected)	6	212.191		
Mean	1	172.485		
Total (corrected)	5	39.706		
Regression	2	32.267	16.132	6.507
Residual	3	7.439	2.480	

Since F(2, 3, 0.95) = 9.55 exceeds 6.507, the addition of the variable E has been indicated worthless. Since the extra variable produced a residual sum of squares reduction of 9.220 - 7.439 = 1.781, the value of R has increased slightly from 0.880 to 0.902. Unfortunately, the reduction in the residual sum of squares (1.781) is less than the original residual mean square (2.305), the cost of the loss of one degree of freedom is the larger resultant mean square (2.480). Consequently, a higher s value ($\sqrt{2.48} = 1.58$) is expected.

In order to make further demonstration, step 3 is continued.

STEP 3: $P_e = f(D,E,X)$, variable entered: X

ANOVA: R = 0.917; s = 1.78

Source of Variation	Degree of Freedom	Sum of Squares	Mean Square	F
Total (uncorrected)	6	212.191		
Mean	1	172.485		
Total (corrected)	5	39.706		
Regression	3	33.402	11.134	3.532
Residual	2	6.304	3.152	

Since F(3, 2, 0.95) = 19.16 exceeds 3.532, once again, the variable X has been proved meaningless.

It is also indicated from the above example that distance, D, is the only adequate parameter in simulating the rainfall data.

Relationship between variance and prediction

An examination of the statistic SS, the sum of square of deviations about regression, in Tables 3, 5, 7, and 9 indicated that the accuracy of predictions is inversely related to the magnitude of SS. If half the number of stations in a given location simulate precipitation data, the values of SS will increase from 11.73 to 13.62 (Table 3, nonlinear function Cases 1 and 2) for Kalihi, 1.72 to 4.13 (Table 5, Cases 1 and 4) for Manoa, 9.24 to 10.51 (Table 7a, Cases 1 and 4) for Kaneohe area, and 0.207 to 0.543 (Table 9, Cases 2 and 3) for central Molokai area.

Seasonal variation on the correlations between rainfall and watershed parameters in Kalihi, Oahu

Comparisons of observed and estimated precipitation which were computed according to regression functions for the Kalihi Basin during the months of August and January are listed in Table 10. The large deviations between the observed and estimated values indicate that the statistical model of precipitation for a summer month in Kalihi Valley is not applicable to a winter month. This may be attributed to the decrease in tradewinds frequency from 93 percent in August to 50 percent in January (Blumenstock and Price, 1967), and hence meteriological parameters other

TABLE 10. COMPARISONS OF OBSERVED AND ESTIMATED PRECIPITATION FOR KALIHI BASIN IN THE MONTH OF JANUARY (FOUR YEARS MONTHLY AVERAGE, 1963-66).

STATION	MEAN PRECIPITATION (IN)	ESTIMATED PRECIPITATION			
		CASE 1	ERROR	CASE 2	ERROR
GS1	9.01	9.48	-0.47	8.23	0.78
GS2	8.71	8.40	0.31	7.90	0.81
GS3	9.01	7.59	1.42	6.60	2.41
GS4	9.09	4.78	4.31	5.05	4.04
GS5	7.74	0.65	7.09	2.04	5.70
CE3	7.85	3.89	3.96	4.06	3.79
CE4	6.72	1.99	4.73	2.75	3.97
777	9.11	9.63	-0.52	7.94	1.17
776	10.53	8.19	2.34	6.77	3.76
774	8.21	6.21	2.00	5.71	2.50
774.4	9.59	4.96	4.63	4.87	4.72
773.1	5.96	1.29	4.67	2.44	3.52

CASE 1. BASED ON EQ (2) $P_e = -1.769 + 0.0067(X) - 0.0042(E) + 1.294(D)$

CASE 2. $P_e = 1.963 - 0.0007(E) + 0.585(D)$*

* REGRESSION EQUATION FOR KALIHI BASIN IN THE MONTH OF JANUARY (FOUR YEARS MONTHLY AVERAGE 1963 - 1966)

than tradewinds can be attributed to precipitation during the winter months, or during months when tradewinds are not quite as prevalent as in summer months. Under such circumstances, a study was made to determine whether precipitation could be portrayed from watershed parameters.

Six stations in Kalihi Valley, GS2, 776, 774, CE6, CE5, and 773.1, roughly evenly distributed along the valley, as indicated in Figure 1, with concurrent twelve month rainfall data during the period 1963 to 1966, were subjected to multiple regression analysis. It was found that for all twelve months extremely high correlations exist among precipitation and the three topographic parameters--exposure, elevation and distance (Fig. 5), regardless of the differences of constants of the regression functions. In other words, Figure 5 indicates that twelve regression equations of the same model with different constants can be obtained through multiple regression analysis, and, at least 86 percent of the original variance was attributable to the watershed parameters for any month of a year during the period 1963 to 1966.

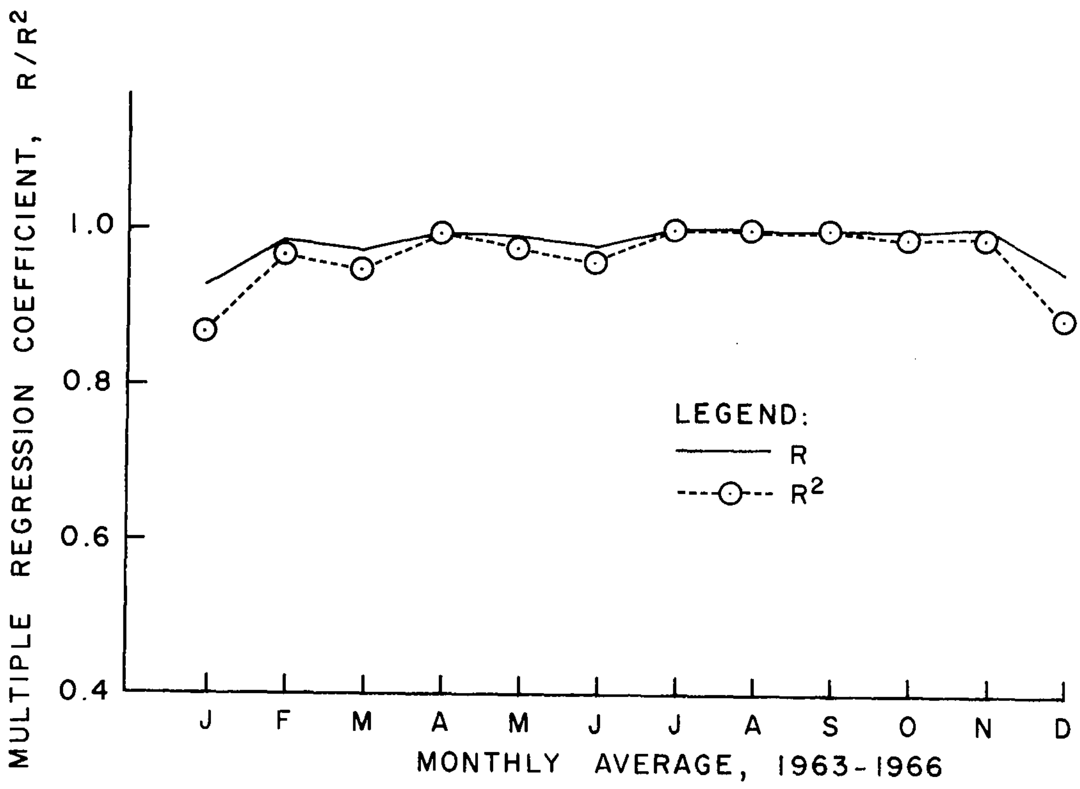

FIGURE 5. MULTIPLE CORRELATION COEFFICIENT VERSUS MONTH PLOT.

PART B. LENGTH OF RAINFALL RECORD REQUIRED FOR THE DETERMINATION OF A NORMAL PERIOD OF MONTHLY RAINFALL

There is no general theory available which establishes the length of rainfall record required to establish a "normal" period of rainfall. The purpose of Part B of the study was to attempt to establish such a value. According to Conrad and Pollak (1950) considerations may be confined within three main conditions:

(1) how many years of incontestable observations at the normal station or stations are available;

(2) how long the whole period must be in order to include the periods of the series which are to be reduced;

(3) how great the variability is of the element in question.

To many scientists, a normal period should not be shorter than 35 years. Conventionally, the arithmetic mean calculated from such a period is called normal. In England, 35 years was chosen as normal of the meterological elements. Landsberg (1951) basing his study of rainfall data at one single station (Waimanalo, on the island of Oahu), concluded that the median is more adequate than the mean to define the rainfall "normal", through comparison of the length of record with the convergence of the two statistics to a respective stable value. He also stated that, "For most of the months 45 years of records would be needed to define satisfactory 'normals' for comparative studies of rainfall."

In order to understand the variability of monthly rainfall over a long period of time, seven stations, 716, 774, 776, 777, 781, and 786, located in southeastern Oahu were selected for a number of statistical tests (Fig. 6). The reason for choosing these seven stations is primarily that they have relatively long, concurrent, uninterrupted records of precipitation during the period from 1928 to the present.

For each station, the means and medians were established for the first ten years (1928-37) of the records and then successive values of these statistics were calculated by including more data, one year at a time. Thus, a series of values for the mean for successive periods 1928-37, 1928-38,..., 1928-69 was obtained and plotted in Figures 7 and 8. Similarly, a series of values for the median for these periods was plotted in Figures 7 and 8 also.

Using Landsberg's procedure, the normal period was computed for all seven station records. The results show that medians do not consistently have a faster converging rate toward a stable value than the mean for any of the twelve months. The comparison of the results was presented in Table 11.

In Landsberg's work, the criterion for the stability is that the absolute change of rainfall would vary within 0.2 inches, while the criteria for the present study are set at two levels: 5 percent and 10 percent of variation from the average values of the running means and

TABLE 11. PERIOD OF RECORD, IN YEARS, REQUIRED FOR MEANS AND MEDIANS TO REACH STABILITY AT WAIMANALO AT SPECIFIED LEVELS.

	STABILITY IS REACHED (IN NUMBER OF YEARS)					
	FOR MEAN			FOR MEDIAN		
MONTH	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 1	LEVEL 2	LEVEL 3
JANUARY	47	42	29	35	38	32
FEBRUARY	43	40	39	31	31	28
MARCH	41	40	26	37	NO	35
APRIL	50+	41	33	39	37	33
MAY	35	33	30	35	33	30
JUNE	33	42	31	27	41	21
JULY	25	21	15	23	45	45
AUGUST	23	33	18	17	16	15
SEPTEMBER	35	34	15	35	43	23
OCTOBER	43	38	32	49	NO	44
NOVEMBER	49	44	36	45	40	20
DECEMBER	45	38	23	41	NO	34

LEVEL 1: THE ABSOLUTE CHANGE WOULD DROP TO LESS THAN 0.2 INCHES AFTER H. LANDSBERG.

LEVEL 2: THE ABSOLUTE FLUCTUATION IS WITHIN ±5% ABOUT THE AVERAGE VALUE OF MEAN AND MEDIANS.

LEVEL 3: THE ABSOLUTE FLUCTUATION IS WITHIN ±10% ABOUT THE AVERAGE VALUE OF MEAN AND MEDIANS.

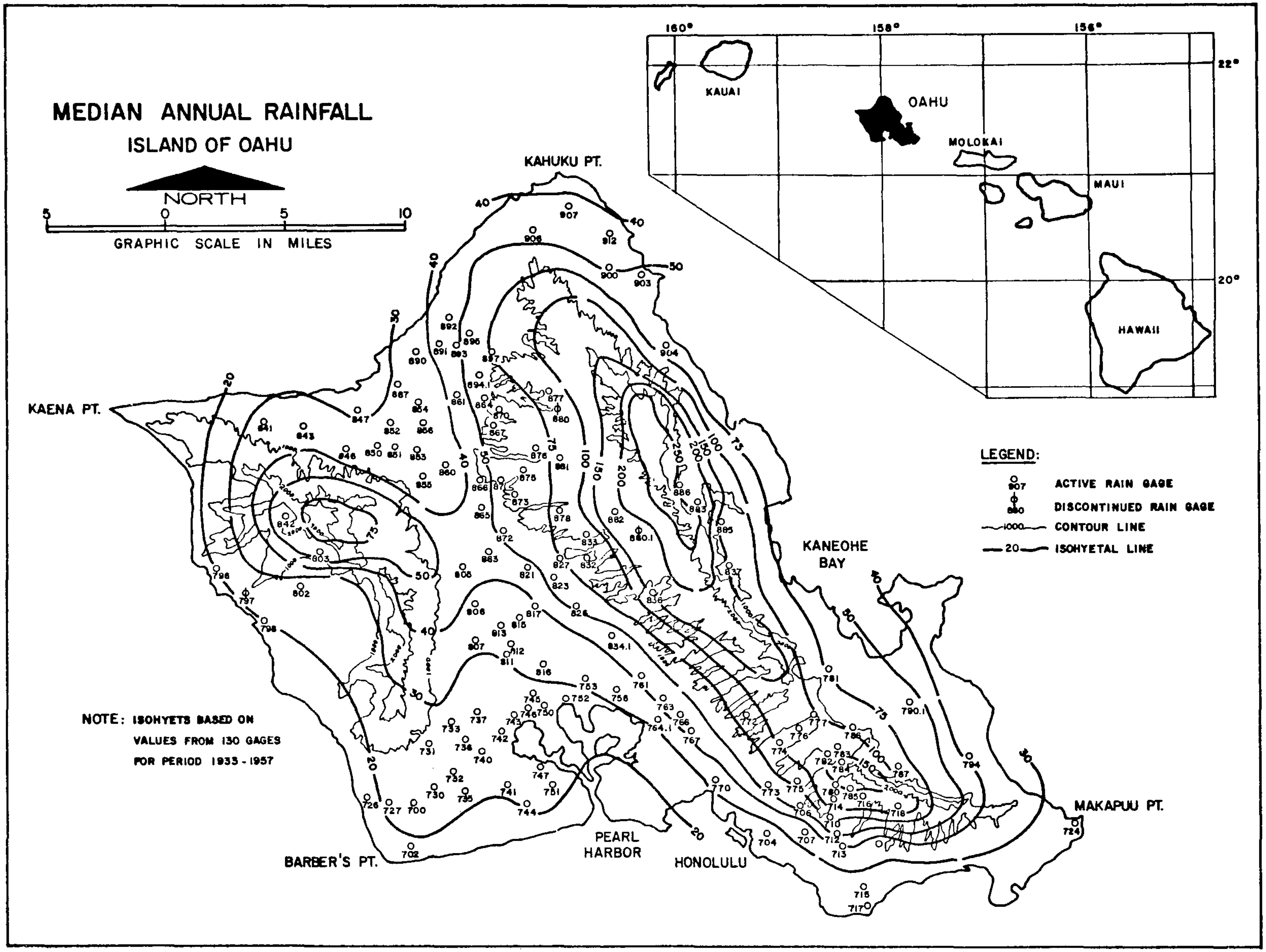

FIGURE 6. LOCATIONS OF SELECTED SEVEN RAIN GAGE STATIONS SUBJECTED TO LENGTH STUDY. (FROM: *RAINFALL OF THE HAWAIIAN ISLANDS*, W. J. TALIAFERRO, HAWAII WATER AUTHORITY, 1959.)

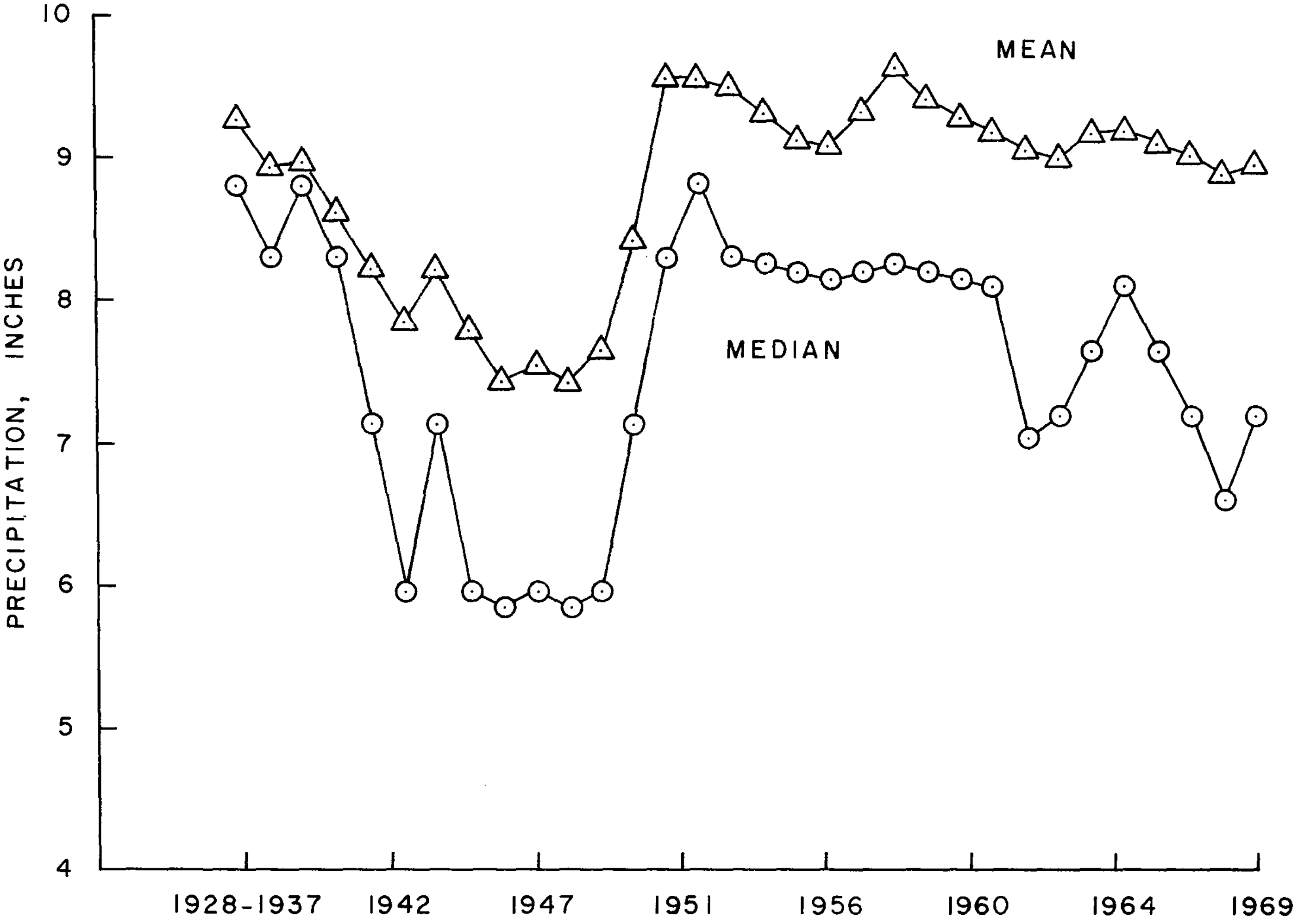

FIGURE 7. STABILITY OF MEAN AND MEDIAN VALUES OF PRECIPITATION AT STATION NO. 777 IN KALIHI BASIN FOR THE MONTH OF JANUARY, 1928-1969.

FIGURE 8. STABILITY OF MEAN AND MEDIAN VALUES OF PRECIPITATION AT STATION NO. 776 IN KALIHI BASIN FOR THE MONTH OF JANUARY, 1928-1969.

medians. It is felt that perhaps the chosen percentage of variation about the average running means and medians is more realistic than an arbitrarily chosen absolute value, and thus misleading conclusions can be avoided. As a matter of fact, the rainfall characteristic in Hawaii is so highly nonuniform, with extremely large variations of rain depth occurring from point to point and from season to season that an absolutely stable "normal" would not be expected. This is demonstrated in the results of this study. For the Waimanalo Station the annual rain variation is inherently limited and appears to be more of an exception than a rule (Figs. 7 and 8). In Table 12, in which stabilities of different levels with respect to all twelve months of the seven stations are listed (the computer program and stabilities at 5 percent and 10 percent levels of each station are present in Appendix B), it is evident that the means have a faster converging rate toward a 5 percent or 10 percent stable level than medians (for the seven stations were considered) except for November for a 5 percent level, and May, July, and November for a 10 percent level.

On the leeward side of Oahu, stability at a 10 percent level requires a period of record of 37 years for medians and 24 years for means (except March for the Manoa and Kalihi stations, respectively). On the windward side of Oahu, 37 years are needed for both means and medians (except November for means) to reach the 10 percent level of stability.

For the rainfall data period (1928-1969) studied, it is concluded that it takes about 40 years to constitute a normal period for monthly rainfall. The results also show that the mean converges to a specified level generally faster than the median.

TABLE 12. NUMBER OF YEARS REQUIRED FOR STABILITIES OF MEANS AND MEDIANS OF RAINFALL DATA FOR STATION NOS. 716, 774, 776, 777, 781, 784, AND 786 AT 5 PERCENT AND 10 PERCENT LEVELS.

	MEAN								MEDIAN							
	5%				10%				5%				10%			
MONTH	A	B	C	D	A	B	C	D	A	B	C	D	A	B	C	D
JANUARY	30	20	21	30	21	14	21	21	NO	37	34	NO	37	25	23	37
FEBRUARY	30	27	35	35	19	16	16	19	NO	27	33	NO	37	26	30	37
MARCH	NO*	NO	NO	NO	23	30	32	32	NO	14	NO	NO	37	10	36	37
APRIL	25	25	35	35	11	13	35	35	31	25	35	35	35	18	29	35
MAY	35	32	37	37	17	14	37	37	36	25	28	36	23	23	27	27
JUNE	29	25	26	29	23	20	23	23	31	NO	26	NO	21	34	25	34
JULY	35	26	30	35	19	9	26	26	35	9	36	36	21	9	23	23
AUGUST	24	16	19	24	16	13	16	16	32	14	32	32	16	9	25	25
SEPTEMBER	28	25	25	28	24	23	22	24	31	31	NO	NO	25	23	31	31
OCTOBER	35	36	35	36	16	17	17	17	36	37	NO	NO	33	32	37	37
NOVEMBER	37	37	NO	NO	37	9	NO	NO	37	30	37	37	19	9	11	19
DECEMBER	36	32	36	36	12	9	25	25	NO	36	31	NO	37	11	18	37

A: KALIHI WATERSHED (774, 776, 777)

B: MANOA WATERSHED (716, 784)

C: WINDWARD OAHU (781, 786)

D: SOUTHEAST OAHU (THE LONGEST PERIOD OF RECORD, I.E. THE LARGEST NUMBER AMONG A, B, AND C.)

* NO STABLE VALUE

PART C. INTENSITY-DURATION-FREQUENCY ANALYSIS OF RAIN STORMS, MANOA BASIN, OAHU

The purpose of Part C of this study was to derive an intensity-duration-frequency relation from rainfall records and to compare the relation with those given in the U.S. Weather Bureau Technical Paper No. 43 (1962). Rain gage stations No. 716 and No. 784 (Fig. 2), located in upper Manoa Valley, were selected for this pilot study. A frequency analysis was made for both stations, each having 40-year records (1929-1968). Both stations are recording gages operated by the Board of Water Supply, City and County of Honolulu.

Rainfall Intensity Frequency Analysis

For both stations, maximum or peak rainfall intensities averaged for durations of 0.25, 0.50, 1, 2, 3, 6, 12, and 24 hours were deduced directly from rainfall strip charts and arranged in descending order of magnitude. Recurrence intervals for each duration are computed by the Formula:

$$T_r = \frac{n + 1}{m}$$

where T_r is the recurrence interval in years; n, the number of years of record; and m, the rank of the event. The intensity - duration curves for various recurrence intervals were then derived. The derived intensity-duration values for four recurrence intervals, 5, 10, 15 and 20 years are shown in Figures 9a and 9b. Since an inverse relation is obvious in these figures, the intensity duration values for 10-year recurrence interval follow an almost perfect straight line when plotted on a log-log paper.

It is apparent from Figures 10a and 10b that the plotted points warrant the generalization by the following relation:

$$i_{ave} = m(t_d)^{-b}$$

where i_{ave} = maximum intensity averaged for the specific duration, in inches per hour;

t_d = duration in minutes;

b = the slope of the straight line on log-log paper;

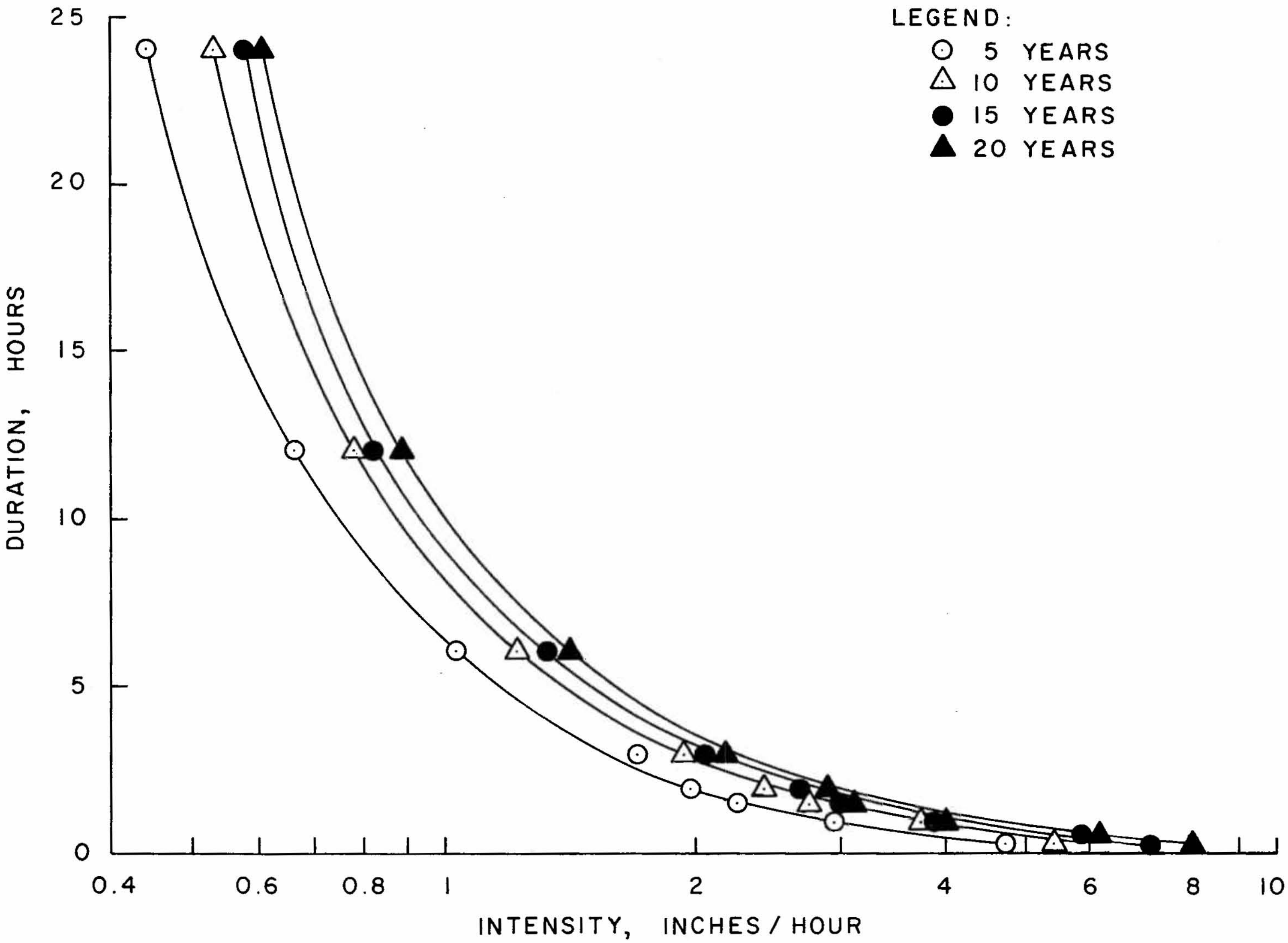

FIGURE 9 a. RAINFALL INTENSITY-DURATION CURVES FOR VARIOUS RECURRENCE INTERVALS FOR STATION NO. 716, UPPER MANOA VALLEY, OAHU, 1929-1968.

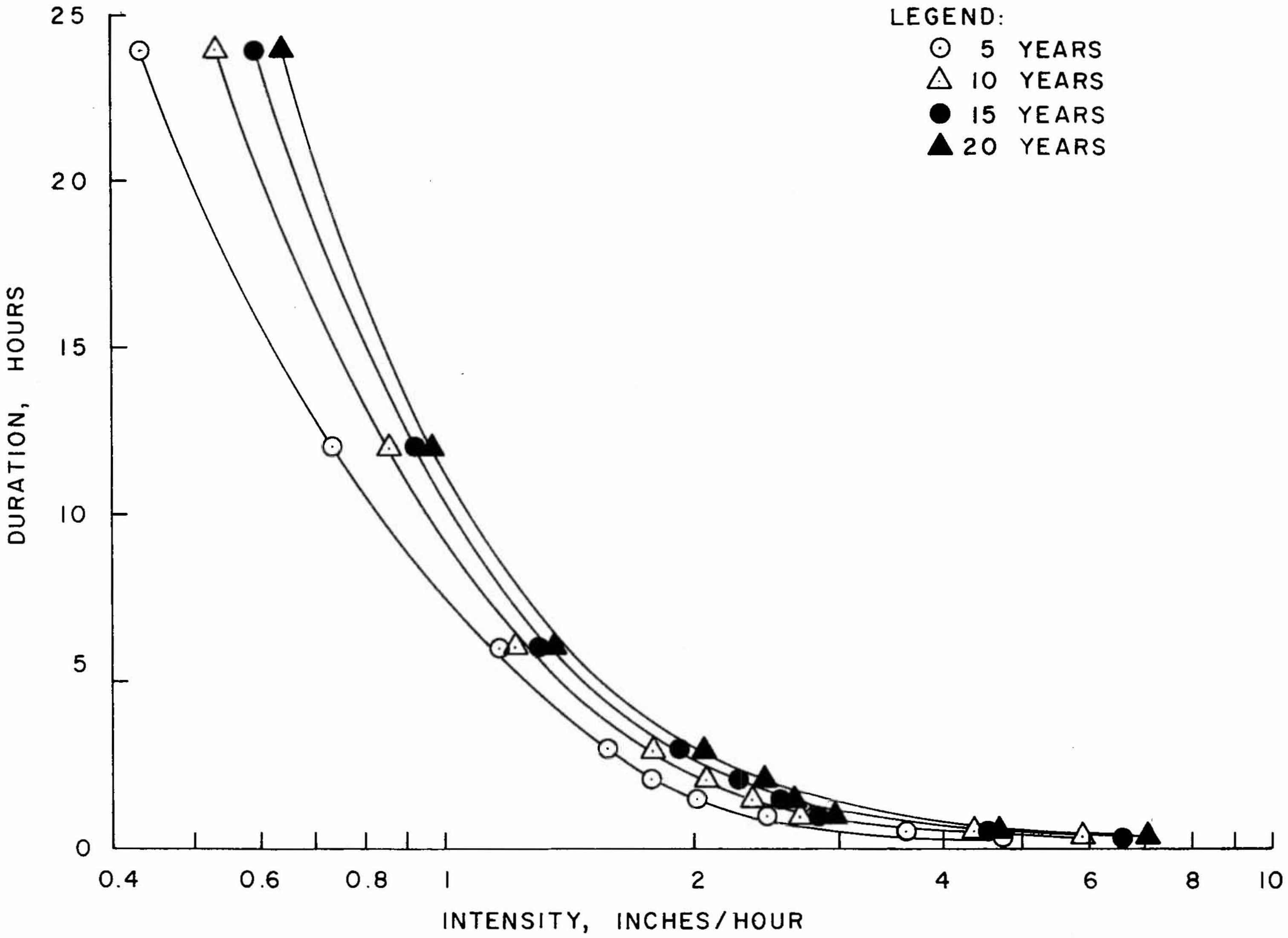

FIGURE 9b. RAINFALL INTENSITY-DURATION CURVES FOR VARIOUS RECURRENCE INTERVALS FOR STATION NO. 784, UPPER MANOA VALLEY, OAHU, 1929-1968.

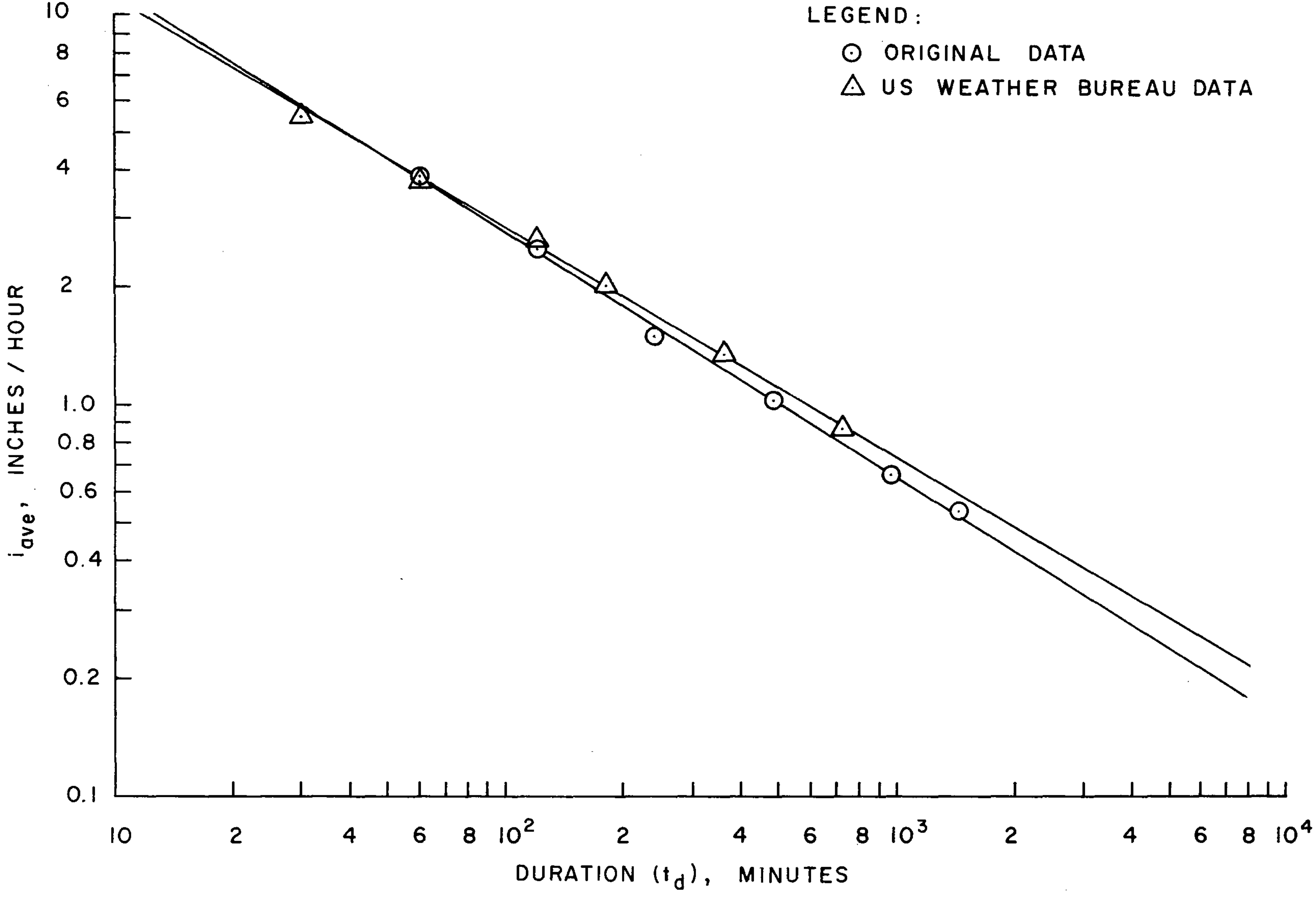

FIGURE 10a. LOG-LOG PLOT OF INTENSITY-DURATION CURVES FOR STATION NO. 716 (UPPER MANOA).

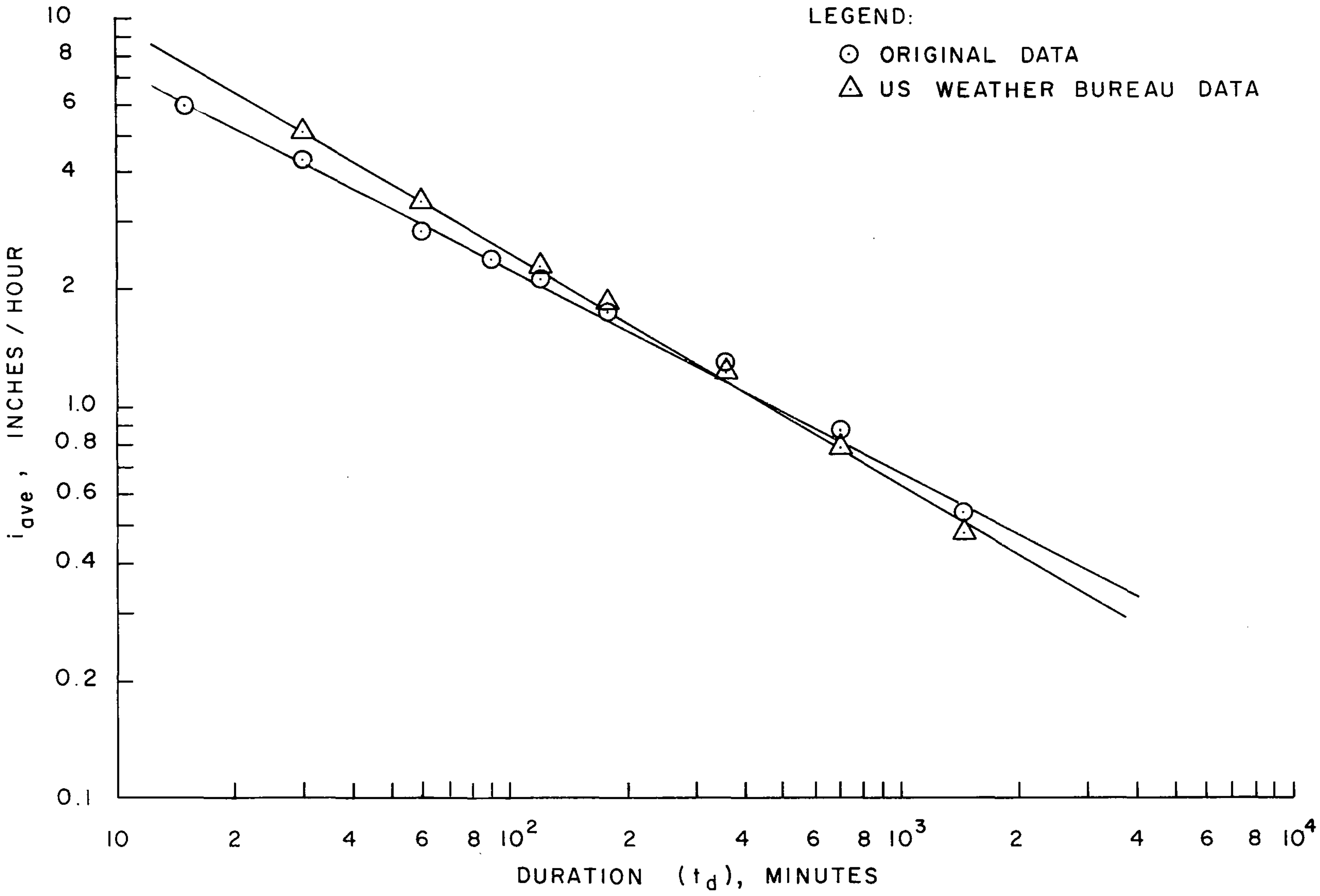

FIGURE 10b. LOG-LOG PLOT OF INTENSITY-DURATION CURVES FOR STATION NO. 784 (UPPER MANOA).

m = a constant determined for the graph.

From Figures 10a and 10b, the formula for average intensity of rainfall (Equation (22) at Station 716 (Manoa Channel No. 2) is:

$$i_{ave} = 41.44\ (t_d)^{-0.594} \quad .$$

Similarly, at Station 784 (Pauoa Flats);

$$i_{ave} = 22.0\ (t_d)^{-0.486} \quad .$$

From U.S. Weather Bureau Technical Paper No. 43, the rainfall intensity - duration curves with respect to the 10-year recurrence interval for Stations 716 and 784 were also plotted on Figure 10a and 10b. The corresponding power equations are:

$$i_{ave} = 35.2\ (t_d)^{-0.559}$$

for Station 716 and

$$i_{ave} = 35.0\ (t_d)^{-0.573}$$

for Station 784.

Discussion

It is clearly shown by Figures 10a and 10b that intensity - duration-frequency data closely follow a straight line on a log-log plot. Hence, it is justifiable to state that the intensity - duration relation for a specific frequency of rain storm in Manoa Valley can be accurately portrayed by the following type of equation:

$$i_{ave} = m(t_d)^{-b} \quad .$$

There is close concordance between the results of this study and those given by the U.S. Weather Bureau (1962). When examined in detail, the Weather Bureau's values for Station 716 are conservative for nearly the entire range of duration; they agree with results of this study for short durations but diverge for long durations to about 10 percent for 24-hour duration. Station 784 did not yield the same comparison as Station 716. The Weather Bureau's values again were conservative but for only for the range up to 3-hour duration. For durations longer than 3 hours, the Weather Bureau's values are lower than those of this study, for example the Weather Bureau's value is lower by about 15 percent for 24-hour duration. It is not easy to explain the above mentioned differences because they are influenced by many parameters and by inherent features of the methods used in analysis.

CONCLUSIONS

The results of this study lead to the following conclusions:

Part A.

1. The nonlinear regression function more accurately represents the recorded monthly precipitation data in Kalihi basin than the linear function. In contrast, the linear regression function satisfactorily portrays the recorded precipitation data in the Manoa basin and central Molokai. For the Kaneohe area it appears that both linear or nonlinear regression functions can reasonably predict the recorded precipitation data. The studies are based on concurrent monthly rainfall of all stations in these area for the period from 1963 to 1966.
2. Distance proved to be the most important among the three watershed parameters: distance, exposure, and elevation.
3. If half the number of stations in a given location are used for simulating precipitation data, the values of SS, the sum of square of deviations about regression, will increase from 11.73 to 13.62 for the Kalihi basin, 1.74 to 4.13 for the Manoa basin, 9.24 to to 10.51 for the Kaneohe area and 0.207 to 0.543 for the central Molokai area;
4. The regression functions for precipitation during a summer month in Kalihi basin are not applicable to a winter month; demonstrating the different rainfall types for different seasons.
5. High correlation exists among precipitation and watershed parameters regardless of the month of the year.

Part B.

It takes roughly 40 years of record to constitute a "normal" period of monthly precipitation. Use of the mean requires shorter periods of records than use of the median in defining the "normal" period of rainfall for the high rainfall portion of the southeastern part of the island of Oahu.

Part C.

1. The intensity - duration relation for intense rain for specified recurrence intervals for Manoa Valley, Oahu follows an inverse straight line relationship on a plot of log-log coordinates. This relation is not unexpected but the fact that the relation so accurately portrayed the data suggests a methodology for other climatically widely different regions in Hawaii.

2. The U.S. Weather Bureau's Technical Paper No. 43, "Rainfall Frequency Atlas of the Hawaiian Islands," agrees well with the results of this study, with difference being not more than 15 percent and mostly not more than 10 percent. The methods used by this study and the Bureau are basically different.

ACKNOWLEDGMENTS

This study benefited from the advice and review from Doak C. Cox, Jen-hu Chang, Paul C. Ekern, and Reginald H.F. Young of the University of Hawaii and Saul Price of the National Weather Service. The Board of Water Supply which provided many rainfall records for this study is also gratefully acknowledged.

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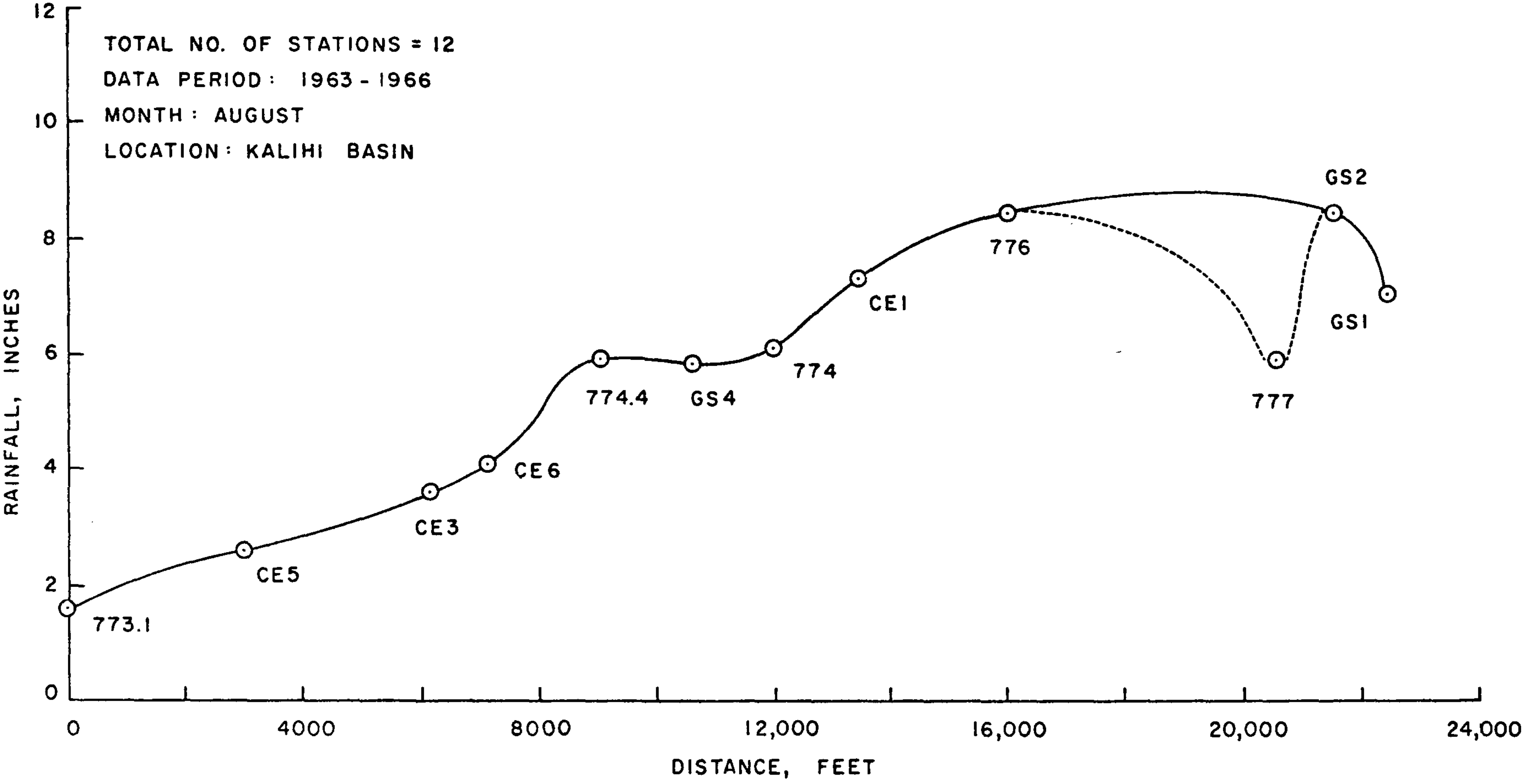
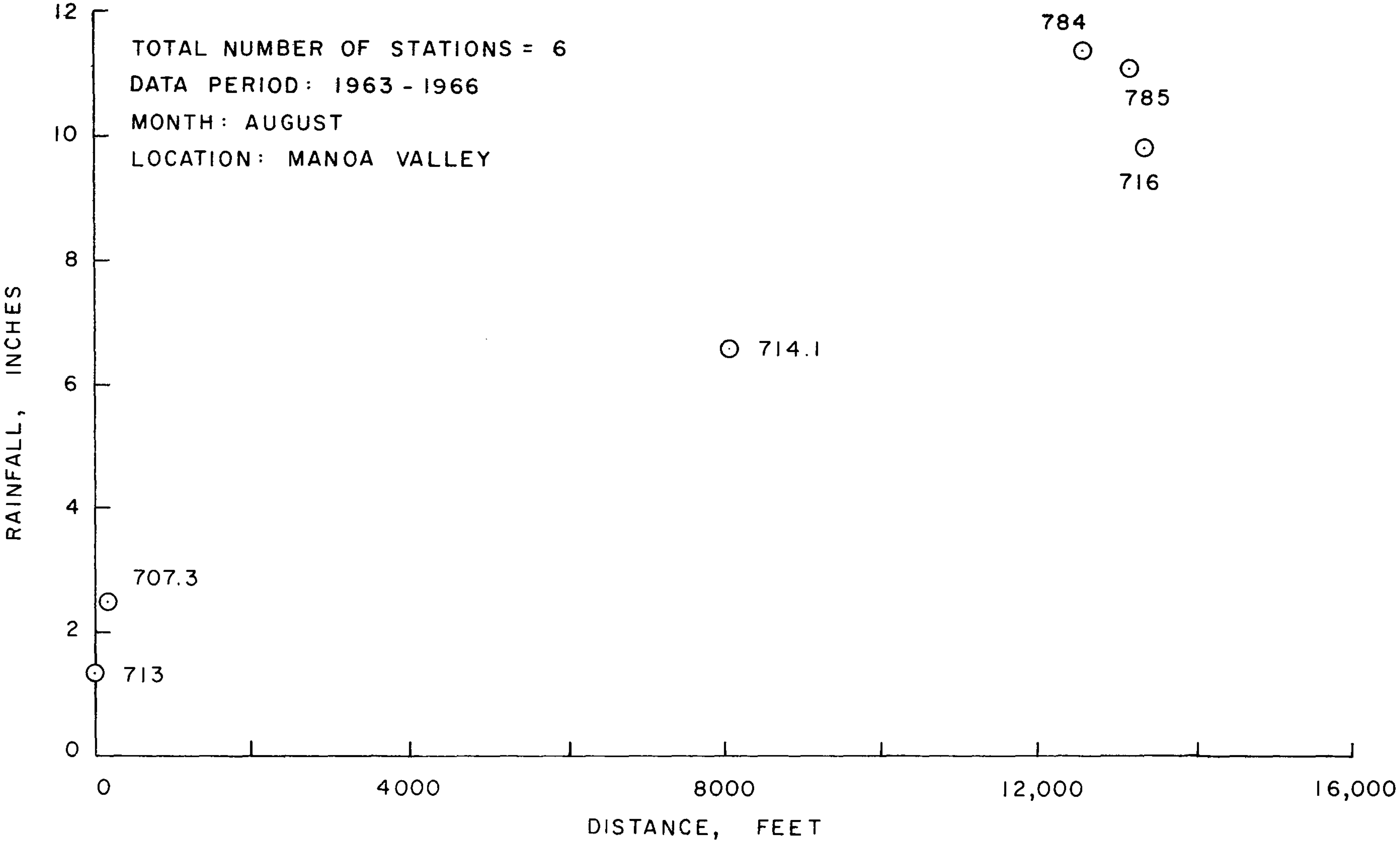
APPENDIX A:

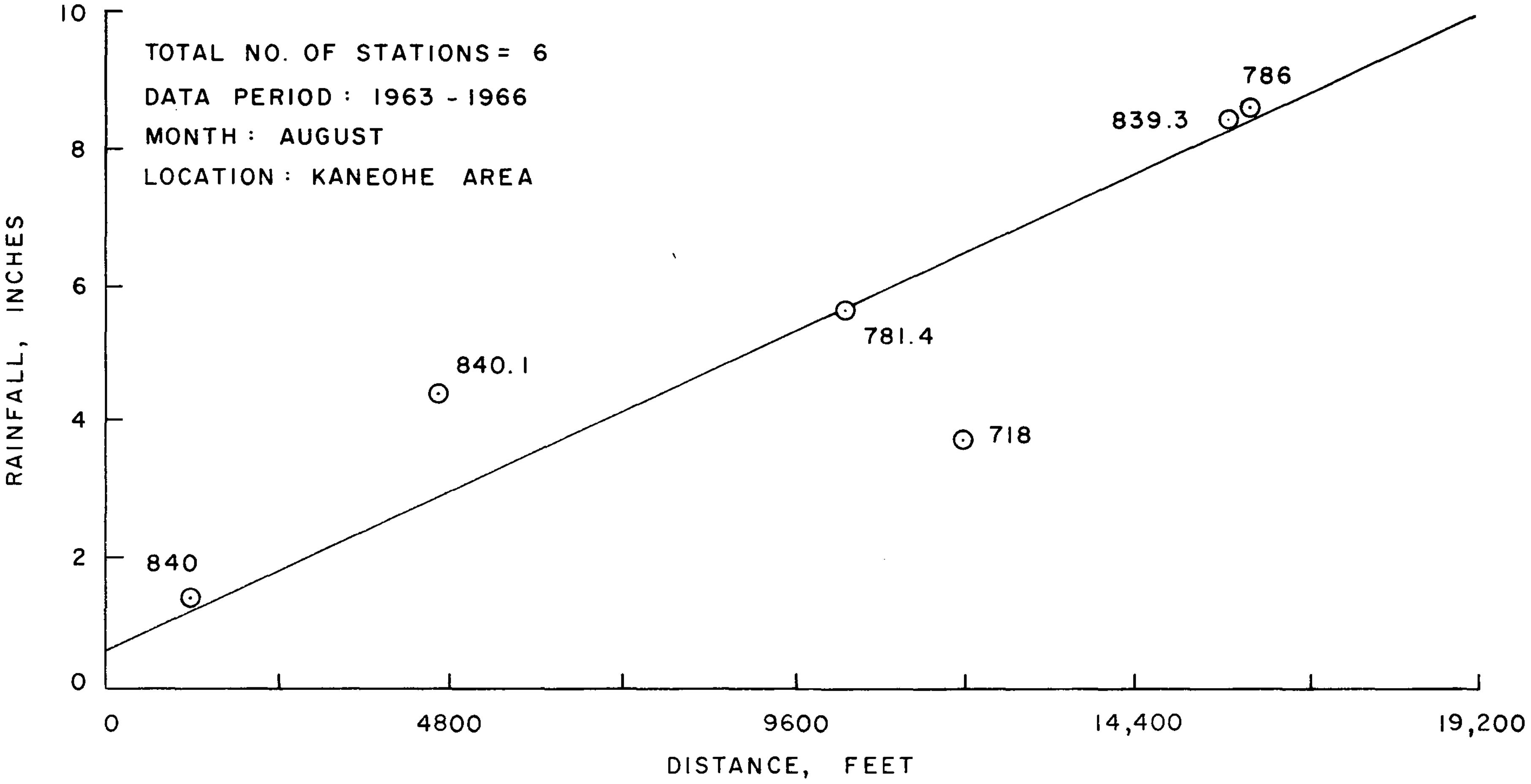
Rainfall Versus Distance and Altitude Plots for Kalihi, Manoa, and Kaneohe Basins in Oahu, and Central Sloping Area of Molokai.



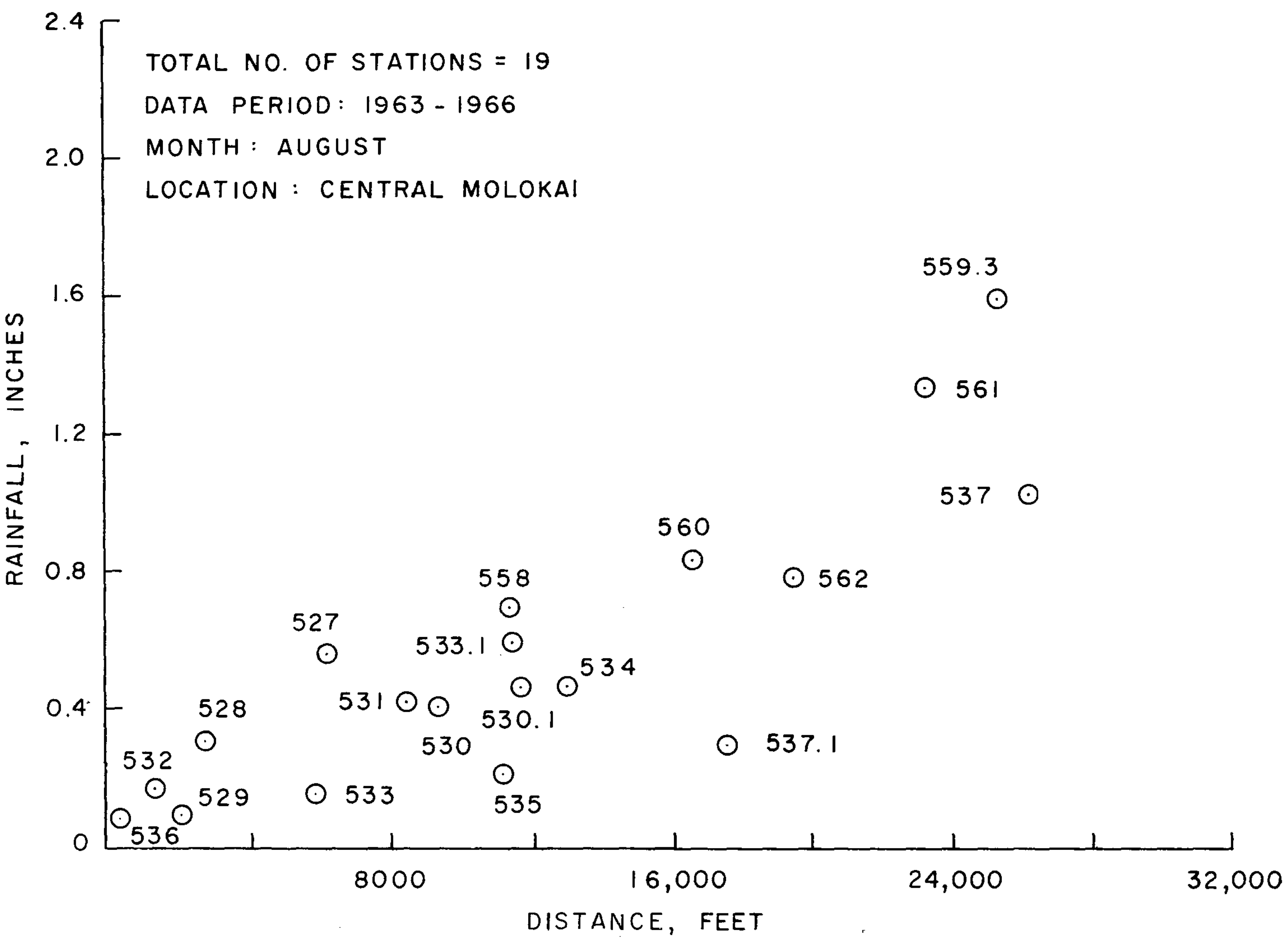
APPENDIX A-1. RAINFALL VERSUS DISTANCE PLOT ALONG KALIHI VALLEY FROM STATION NO. 773.1.



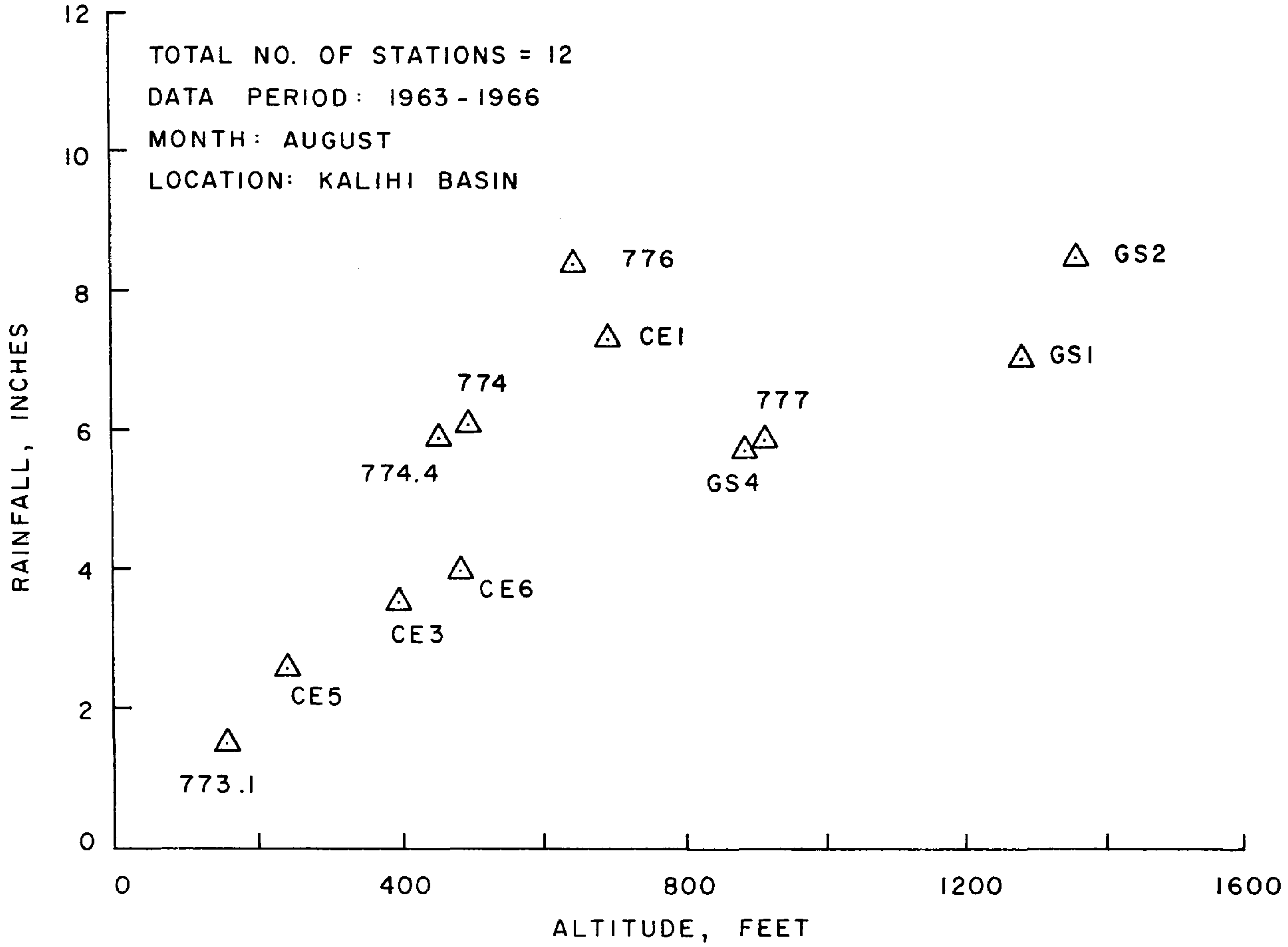
APPENDIX A-2. RAINFALL VERSUS DISTANCE PLOT ALONG MANOA VALLEY FROM STATION NO. 713.



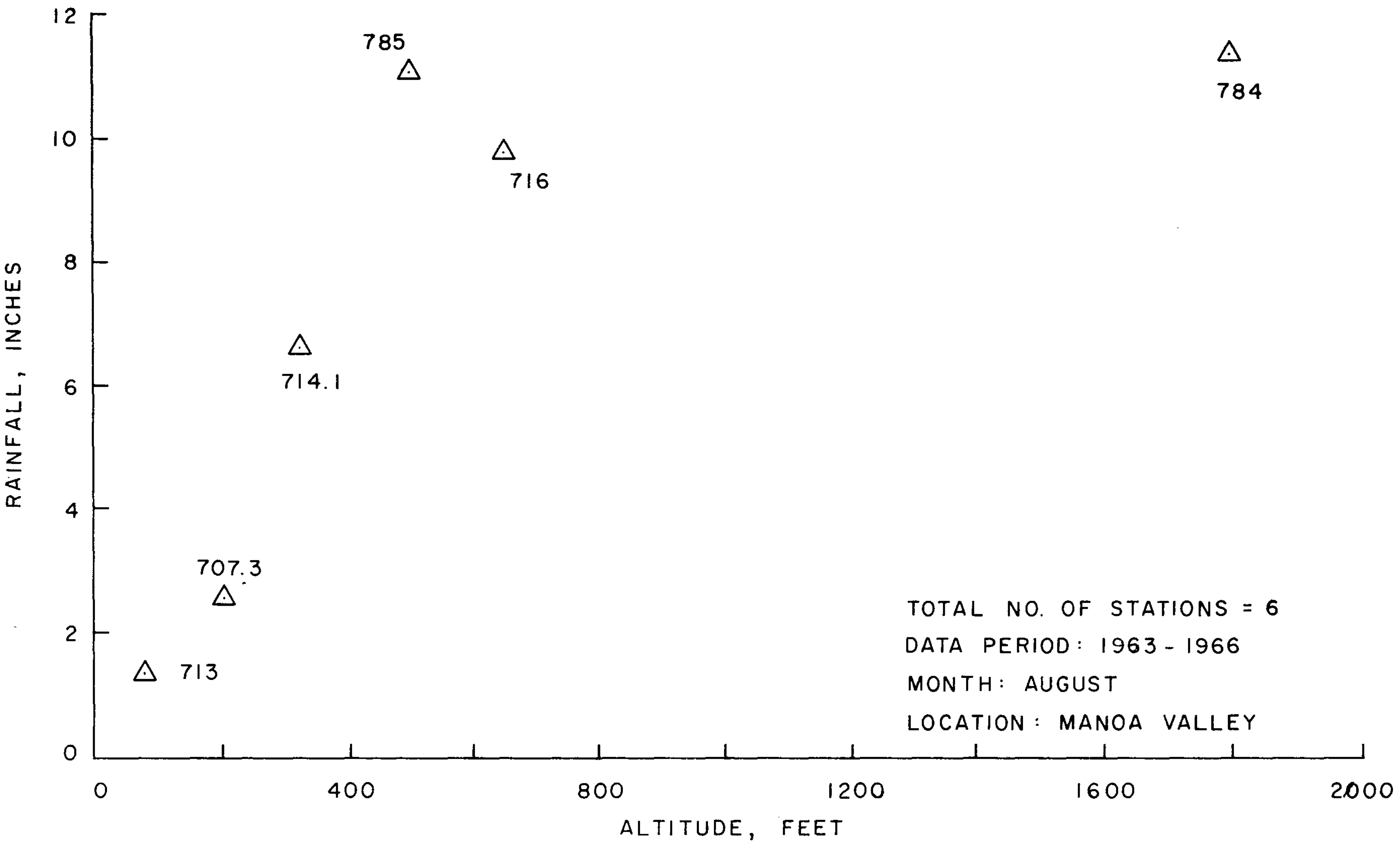
APPENDIX A-3. RAINFALL VERSUS DISTANCE PLOT ALONG KANEOHE AREA FROM STATION NO. 840.



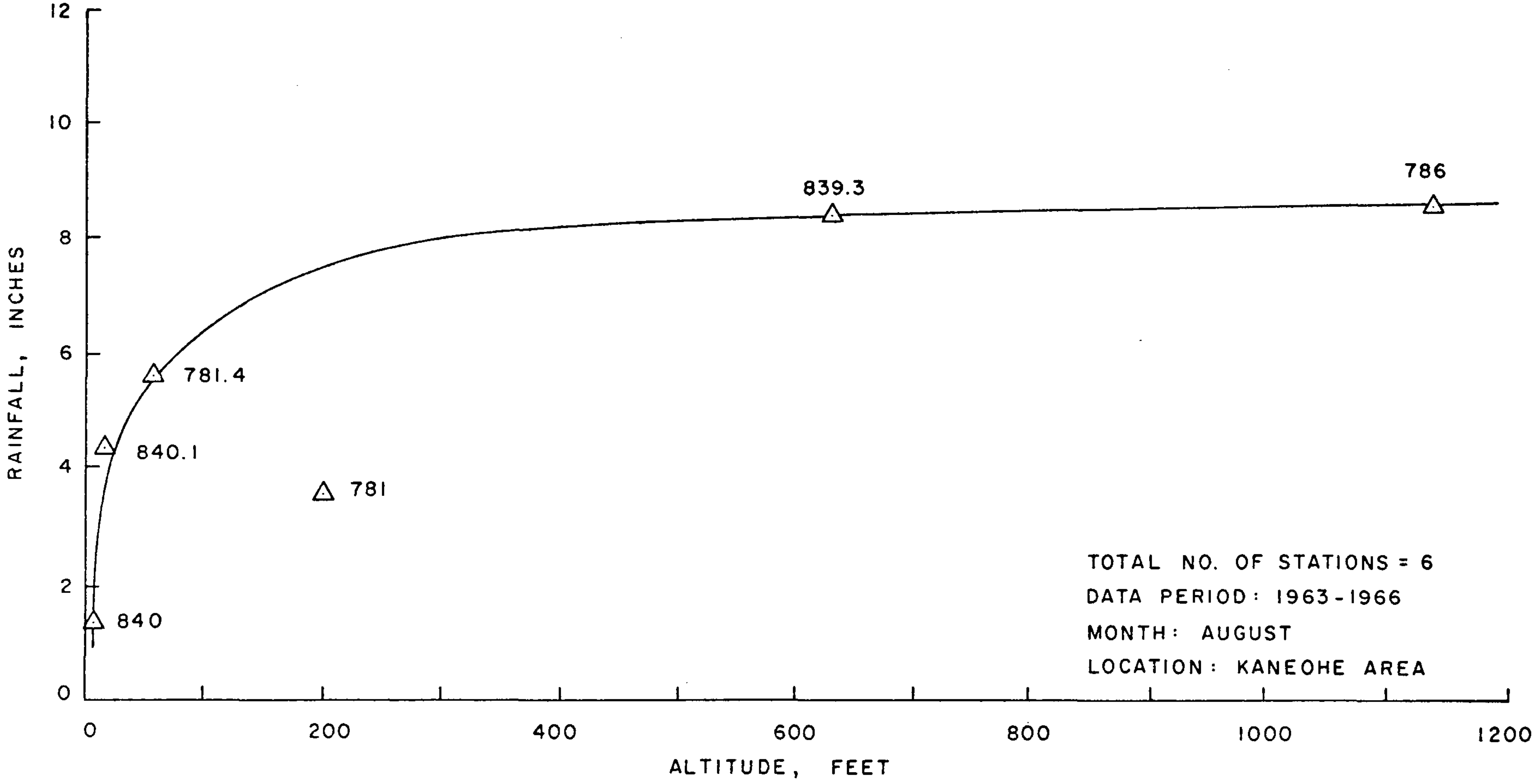
APPENDIX A-4. RAINFALL VERSUS DISTANCE PLOT ALONG CENTRAL MOLOKAI (IN THE GENERAL TRADEWIND DIRECTION) FROM STATION NO. 536.



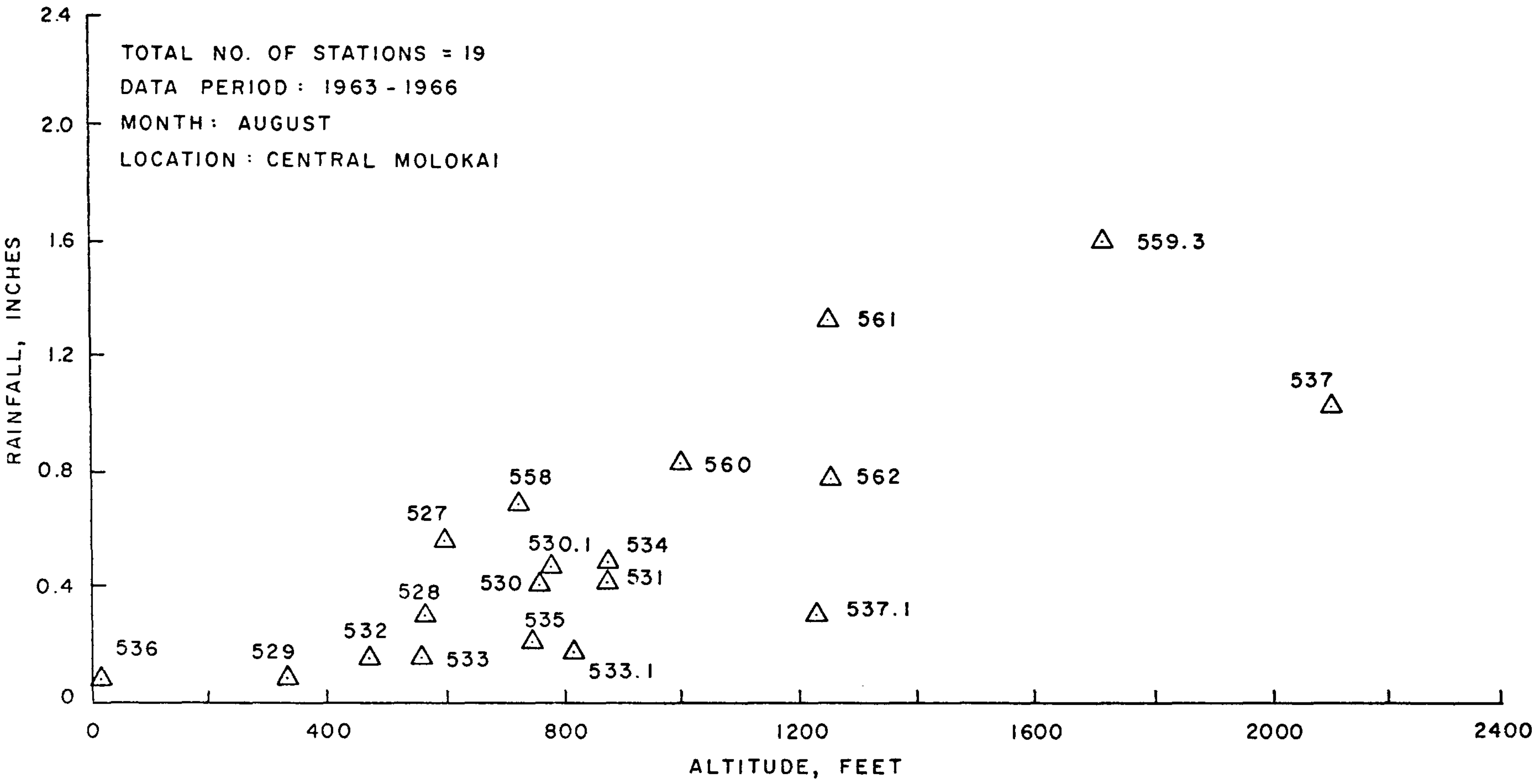
APPENDIX A-5. RAINFALL VERSUS ALTITUDE PLOT ALONG KALIHI VALLEY.



APPENDIX A-6. RAINFALL VERSUS ALTITUDE PLOT ALONG MANOA VALLEY.



APPENDIX A-7. RAINFALL VERSUS ALTITUDE PLOT ALONG KANEOHE AREA.



APPENDIX A-8. RAINFALL VERSUS ALTITUDE PLOT ALONG CENTRAL MOLOKAI.

APPENDIX B:

(1) Period of Records in Years Required for Means and Medians to Reach Stability at Rain Gage Stations 716, 774, 776, 777, 781, 784, and 786.

(2) Listing of Computer Programs.

APPENDIX B-1A. PERIOD OF RECORD, IN YEARS, REQUIRED FOR MEANS AND MEDIANS TO REACH STABILITY AT RAIN GAGE STATION NO. 716 AT SPECIFIED LEVELS.

	STABILITY IS REACHED (IN NUMBER OF YEARS)			
	FOR MEAN		FOR MEDIAN	
MONTH	5%	10%	5%	10%
JANUARY	20	12	26	25
FEBRUARY	27	16	26	22
MARCH	NO	30	13	9
APRIL	25	13	25	18
MAY	17	14	9	9
JUNE	23	20	25	9
JULY	26	9	9	9
AUGUST	16	13	14	9
SEPTEMBER	25	23	31	22
OCTOBER	36	17	37	32
NOVEMBER	37	9	30	9
DECEMBER	32	9	36	11

APPENDIX B-1B. PERIOD OF RECORD, IN YEARS, REQUIRED FOR MEANS AND MEDIANS TO REACH STABILITY AT RAIN GAGE STATION NO. 774 AT SPECIFIED LEVELS.

	STABILITY IS REACHED (IN NUMBER OF YEARS)			
	FOR MEAN		FOR MEDIAN	
MONTH	5%	10%	5%	10%
JANUARY	21	20	10	9
FEBRUARY	30	14	34	27
MARCH	30	14	34	37
APRIL	24	11	31	9
MAY	32	11	13	9
JUNE	29	16	31	20
JULY	26	9	21	9
AUGUST	24	16	23	9
SEPTEMBER	28	24	24	24
OCTOBER	35	16	NO	33
NOVEMBER	37	11	22	19
DECEMBER	14	11	NO	37

APPENDIX B-1C. PERIOD OF RECORD, IN YEARS, REQUIRED FOR MEANS AND MEDIANS TO REACH STABILITY AT RAIN GAGE STATION NO. 776 AT SPECIFIED LEVELS.

	STABILITY IS REACHED (IN NUMBER OF YEARS)			
	FOR MEAN		FOR MEDIAN	
MONTH	5%	10%	5%	10%
JANUARY	25	14	32	16
FEBRUARY	29	15	NO	37
MARCH	NO	14	34	13
APRIL	25	9	27	26
MAY	32	17	29	23
JUNE	23	17	30	21
JULY	10	9	22	21
AUGUST	18	16	9	9
SEPTEMBER	28	24	24	23
OCTOBER	35	9	9	9
NOVEMBER	37	10	37	9
DECEMBER	24	12	NO	11

APPENDIX B-1D. PERIOD OF RECORD, IN YEARS, REQUIRED FOR MEANS AND MEDIANS TO REACH STABILITY AT RAIN GAGE STATION NO. 777 AT SPECIFIED LEVELS.

	STABILITY IS REACHED (IN NUMBER OF YEARS)			
	FOR MEAN		FOR MEDIAN	
MONTH	5%	10%	5%	10%
JANUARY	30	21	NO	37
FEBRUARY	30	19	NO	32
MARCH	NO	23	NO	10
APRIL	25	9	26	25
MAY	35	13	36	35
JUNE	29	23	29	21
JULY	35	19	35	9
AUGUST	24	15	32	16
SEPTEMBER	27	24	31	25
OCTOBER	35	14	36	28
NOVEMBER	37	37	22	9
DECEMBER	36	9	22	18

APPENDIX B-1E. PERIOD OF RECORD, IN YEARS, REQUIRED FOR MEANS AND MEDIANS TO REACH STABILITY AT RAIN GAGE STATION NO. 781 AT SPECIFIED LEVELS.

	STABILITY IS REACHED (IN NUMBER OF YEARS)			
	FOR MEAN		FOR MEDIAN	
MONTH	5%	10%	5%	10%
JANUARY	21	20	34	23
FEBRUARY	35	12	33	30
MARCH	35	30	NO	36
APRIL	35	35	35	13
MAY	37	37	16	16
JUNE	26	23	26	25
JULY	21	9	36	23
AUGUST	19	16	24	19
SEPTEMBER	25	22	NO	31
OCTOBER	35	17	NO	37
NOVEMBER	NO	NO	37	9
DECEMBER	36	25	31	18

APPENDIX B-1F. PERIOD OF RECORD, IN YEARS, REQUIRED FOR MEANS AND MEDIANS TO REACH STABILITY AT RAIN GAGE STATION NO. 784 AT SPECIFIED LEVELS.

	STABILITY IS REACHED (IN NUMBER OF YEARS)			
	FOR MEAN		FOR MEDIAN	
MONTH	5%	10%	5%	10%
JANUARY	16	14	37	10
FEBRUARY	27	16	26	26
MARCH	NO	17	14	10
APRIL	24	13	24	9
MAY	32	10	25	23
JUNE	25	16	NO	34
JULY	9	9	9	9
AUGUST	16	9	10	9
SEPTEMBER	25	23	24	23
OCTOBER	19	15	31	9
NOVEMBER	37	9	9	9
DECEMBER	14	9	19	11

APPENDIX B-1G. PERIOD OF RECORD, IN YEARS, REQUIRED FOR MEANS AND MEDIANS TO REACH STABILITY AT RAIN GAGE STATION NO. 786 AT SPECIFIED LEVELS.

	STABILITY IS REACHED (IN NUMBER OF YEARS)			
	FOR MEAN		FOR MEDIAN	
MONTH	5%	10%	5%	10%
JANUARY	21	21	16	13
FEBRUARY	26	16	20	17
MARCH	NO	32	23	18
APRIL	35	9	32	29
MAY	35	18	28	27
JUNE	20	18	22	19
JULY	30	26	20	16
AUGUST	16	15	32	25
SEPTEMBER	24	21	30	17
OCTOBER	30	17	37	32
NOVEMBER	37	22	19	11
DECEMBER	34	11	29	14

APPENDIX B-2. LISTING OF COMPUTER PROGRAMS.

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FORTRAN IV G LEVEL  18        MAIN       DATE = 71034    05/03/58     PAGE 0001

      C        COMPUTATIONS OF MEAN AND MEDIAN AND DIFFERENT LEVELS OF
              1STABILITIES ****
               DIMENSION P(200),AMEAN(100),AMED(100)
               DIMENSION  BMEAN(100),AMED(100)
               DO 6000 K=1,36
               READ(5,100) N
               READ(5,101) (P(I), I = 1, N)
       100     FORMAT (4X, I2)
       101     FORMAT (10F8.0)
               NCNT=0
               DO 10 I = 1, N
               SUM = 0.0
               NA = I + 9
               IF (NA .GT. N) GO TO 200
               NCNT=NCNT+1
      C        COMPUTATION OF MEAN ****
               DO 15 J = 1, NA
       15      SUM = SUM + P(J)
               ANA = NA
               AMEAN(1) = SUM/ANA
               NN = NA - 1
      C        SORTING WORK ****
               DO 20 II = 1, NN
               IB = II + 1
               DO 20 JJ = IB, NA
               IF (P(II).LE.P(JJ)) GO TO 20
               TEMP = P(II)
               P(II) = P(JJ)
               P(JJ) = TEMP
       20      CINTINUE
      C        COMPUTATION OF MEDIAN ***
               BNA = NA + 1
               HBNA = BNA/2.0
               LNA = (NA + 1)/2
               ALNA = LNA
               DIFF = HBNA - ALNA
               IF (DIFF.EQ.0.0) FO TO 25
               AMED (I) = (P(LNA) + P(LAN + 1))/2.0
               GO TO 10
       25      AMEN(I) = P(LNA)
       10      CONTINUE
       200     WRITE(6,105) NCNT
       105     FORMAT(1HO,'THE MEAN AND MEDIAN FOR STA.#     MON.    ,19    ,
              1NO. OF CAL.='I3/10X,'MEAN',10X,'MEDIAN')
               WRITE(6,110) (AMEAN(I),AMED(I),I=1,NCNT)
       110     FORMAT(2F15.3)
               WRITE(6,115)
       115     FORMAT(1HO)
      C        DATA REARRANGEMENT ****
               DO 600 I=1,NCNT
               IA-I-1
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FORTRAN IV G LEVEL  18      MAIN      DATE = 71034   05/03/58    PAGE 0002

                BMEAN(I)=AMEAN(NCNT-IA)
        600     BNED(I)=AMED(NCNT-IA)
        C       CRITERIA OF VARIATION OF MEAN ****
                IFLAG=1
                M=4
        650     M=M+1
                IF (M.NE.NCNT+1) GO TO 670
                GO TO (655,705),IFLAG
        655     WRITE (6,1800)
        1800    FORMAT(1HO,'STABILITY FOR MEAN AT BOTH 5 % AND 10 % LEVELS
               1START FROM THE BEGINNING YEAR')
                GO TO 4000
        705     WRITE (6,1810)
        1810    FORMAT(1HO,'STABILITY FOR MEAN AT 10 % LEVEL STARTS FROM
               1THE BEGINNING YEAR')
                GO TO 4000
        670     ASUM=0.0
                DO 700 I=1,M
        700     ASUM=ASUM+BMEAN(I)
                AM=M
                AVE=ASUM/AM
                DO 710 I=1,M
                ADIFF=(BMEAN(I)-AVE)/AVE
                Y=ABS(ADIFF)
                IF (Y.GT.0.1.AND.M.EQ.5) GO TO 1490
                IF (Y.GO.0.1.AND.M.GE.6) GO TO 1450
                GO TO (5, 710),IFLAG
        5       IF (Y.GT.0.05.AND.M.LE.5) GO TO 1400
                IF (Y.GT.0.05.AND.M.FT.5) GO TO 1350
        710     CONTINUE
                GO TO 650
        1350    JMM = 42 - (M-1)
                KMM = 1969 - (M-2)
                AJMM-JMM
                WRITE (6,1900) KMM,AJMM
        1900    FORMAT (1HO, 'STABILITY FOR MEAN AT 5% LEVEL STARTS FROM
               1'I4,2X,'IT TAKES 'F3.0,2X,'YRS TO REACH THIS LEVEL')
                IFLAG = 2
                GO TO 650
        1400    WRITE(6, 2000)
        2000    FORMAT(1HO, 'THERE IS NO STABILITY FOR MEAN AT 5% LEVEL'
                IFLAG = 2
                GO TO 650
        1450    JM=42-(M-1)
                KM=1969-(M-2)
                AJM=JM
                IF (M.EQ.6) GO TO 1455
                WRITE (6,2002) KM,AJM
        2002    FORMAT(1HO,'STABILITY FOR MEAN AT 10 % LEVEL STARTS FROM
               1'I4,2X,'IT TAKES 'F3.0.2X,'YRS TO REACH THIS LEVEL')
                GO TO 4000
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FORTRAN IV G LEVEL  18      MAIN      DATE = 71034     05/03/58     PAGE 0003

1455  WRITE (6,2003) KM,AJM
2003  FORMAT(1HO,'STABILITY FOR MEAN AT BOTH 5 % AND 10 % LEVEL
     1START FROM '14,2X,'THEY TAKE 'F3.0,2X,'YRS TO REACH THESE
     2LEVELS')
      GO TO 4000
1490  WRITE (6, 1495 )
1495  FORMAT(1HO, 'THERE IS NO STABILITY FOR MEAN AT 10 % LEVEL')
      GO TO 4000
C     CRITERIA OF VARIATION OF MEDIAN ****
4000  JFLAG=1
      L=4
1650  L=L+1
      IF (L.NE.NCNT+1) GO TO 1670
      GO TO (1655,1705),JFLAG
1655  WRITE (6,2800)
2800  FORMAT(1HO,'STABILITY FOR MED. AT BOTH 5 % AND 10 % LEVELS
     1START FROM THE BEGINNING YEAR')
      GO TO 6000
1705  WRITE (6,2810)
2810  FORMAT(1HO,'STABILITY FOR MED. AT 10 % LEVEL STARTS FROM
     1THE BEGINNING YEAR')
      GO TO 6000
1670  BUSM=0.0
      BO 800 I=1,L
800   BSUM=BSUM+BMED (I)
      BL=L
      BVE=BSUM/BL
      DO 810 I=1,L
      BDIFF=(BMED(I)-BVE)/BVE
      X=ABS(BDIFF)
      IF (X.GT.0.1.AND.L.EQ.5) GO TO 2490
      IF (X.GT.0.1.AND.L.FT.5) GO TO 2450
      GO TO (6, 810),JFLAG
6     IF (X.FT.0.05.AND.L.LT.6) GO TO 2400
      IF (X.FT.0.05.AND.L.GT.5) GO TO 2350
810   CONTINUE
      GO TO 1650
2350  JMN = 42 - (L-1)
      KMN = 1969 - (L-2)
      AJMN=JMN
      WRITE (6,2900) KMN,AJMN
2900  FORMAT (1HO, 'THERE IS NO STABILITY FOR MED  AT 5% LEVEL
     1STARTS FROM '14,2X,'IT TAKES 'F3.0,2X,'YRS TO REACH THIS
     2LEVEL')
      JFLAG = 2
      GO TO 1650
2400  WRITE(6, 3000)
3000  FORMAT(1HO, 'THERE IS NO STABILITY FOR MED  AT 5% LEVEL')
      JFLAG = 2
      GO TO 1650
2450  JN=42-(L-1)
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FORMAT IV G LEVEL  18       MAIN       DATE = 71034    05/03/58    PAGE 0004

                 KN=1969-(L-2)
                 AJN=JN
                 IF (L.EQ.6) GO TO 2455
                 WRITE (6,3002 KN,AJN
        3002     FORMAT(1HO,'STABILITY FOR MED. AT 10 % LEVEL STARTS FROM
                1'I4,2X,'IT TAKES 'F3.0,2X,'YRS TO REACH THIS LEVEL')
                 GO TO 6000
        2455     WRITE (6,3003) KN,AJN
        3003     FORMAT(1HO,'STABILITY FOR MED. AT BOTH 5 % AND 10 % LEVELS
                1START FRON 'I4,2X,'THEY TAKE 'F3.0,2X,'YRS TO REACH THESE
                2LEVELS')
                 GO TO 6000
        2490     WRITE(6, 2495 )
        2495     FORMAT(1HO, 'THERE IS NO STABILITY FOR MED. AT 10% LEVEL')
        6000     CONTINUE
                 STOP
                 END
```
