LOW-FLOW FREQUENCY AND STOCHASTIC ANALYSIS OF IRRIGATION DITCH FLOWS FOR CENTRAL MAUI, HAWAII

FINAL REPORT

by

Yu-Si Fok

Clyde S. Miyasato

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ABSTRACT

The central portion of the island of Maui, state of Hawaii, suffered from droughts during the summers of 1971 to 1975, which resulted in heavy crop losses. In order to learn more about the frequency of droughts, a study of the irrigation water low-flow frequency was made during the earlier stage of this research, and a set of low-flow frequency curves for the central Maui area was prepared and presented in this report. Low-flow frequency curves can only provide the probability of occurrence of a drought in terms of a given magnitude of flow, its duration and its recurrence interval; therefore, their applicability is limited to an event basis, and the sequential characteristics of the droughts are not provided. In order to study the drought occurrence on an event-sequence basis, with the aim to explore the water manageability during a drought, a stochastic analysis of the low flows in the summer periods of the central Maui region was conducted. The methods and results of the stochastic analysis are presented in this report. Since most of the irrigation water is collected and delivered by ditches to the central Maui sugarcane fields, and among these ditches, the Wailoa ditch delivers about 90% of the summer months' irrigation water; therefore, the Wailoa ditch monthly flow recorded by U.S. Geological Survey for 1923 to 1972 has been used for the stochastic analysis of the summer low flows. The results obtained show very little improvement from using Pearson Type III distribution against the normal distribution of the random error term in the stochastic simulation of the summer ditch flows. Four sets of summer ditch flows for the period 1974-2020 have been generated and presented for water management references.

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INTRODUCTION

From 1971 to 1975, Maui, the second largest island of the state of Hawaii, experienced extensive drought damage in its central area. In the severe summer drought of 1973 in particular, the Maui Department of Water Supply was forced to take the emergency action of rationing and trucking water for domestic use to the drought-affected agricultural communities of Kula, Olinda, Makawao, Pukalani, Pe'ahi, and 'Ulupalakua.

A more serious consequence was the severe losses of important vegetable crops due to the irrigation water shortage. During the summer of 1973, Hawaiian Commercial and Sugar Company in Puunene, the largest sugar plantation in Hawaii, reported that 3,561 ha (8,800 acres) planted in sugarcane along the lower slopes of Haleakala were in real danger of dying (Rho 1974). In 1973, this company suffered an overall loss of 9% in sugar production, i.e., a loss of 16,780,000 kg (18,500 tons) of sugar. This loss was the direct result of the nearly 72% reduction of the irrigation water supply (diverted from East Maui to the sugarcane fields) which normally has a flow rate of 492,050 m^3/day (130 mgd). But during the 1973 drought, for a period of more than a month, only 136,260 m^3/day (36 mgd) of water was delivered.

A study of droughts on Maui was initiated in 1974 by Fok and Miyasato (1975) to investigate the drought frequencies and possible implication on water resources management in the drought-affected areas on Maui. A set of low-flow frequency curves for the central Maui region was obtained. Since low-flow frequency curves can only provide the probability of occurrence of a drought in terms of a given magnitude, duration, and recurrence interval, their applicability is limited to an event basis. In other words, the probability of a given low-flow can be obtained from a low-flow frequency curve; however, the sequential occurrence pattern of the low-flows cannot be obtained.

This study was conducted to examine the occurrence of drought on an event-sequence basis, using a stochastic analysis of the summer low-flows in central Maui. The methods applied and the results obtained are presented in this report.

GENERAL RAINFALL DISTRIBUTION ON MAUI

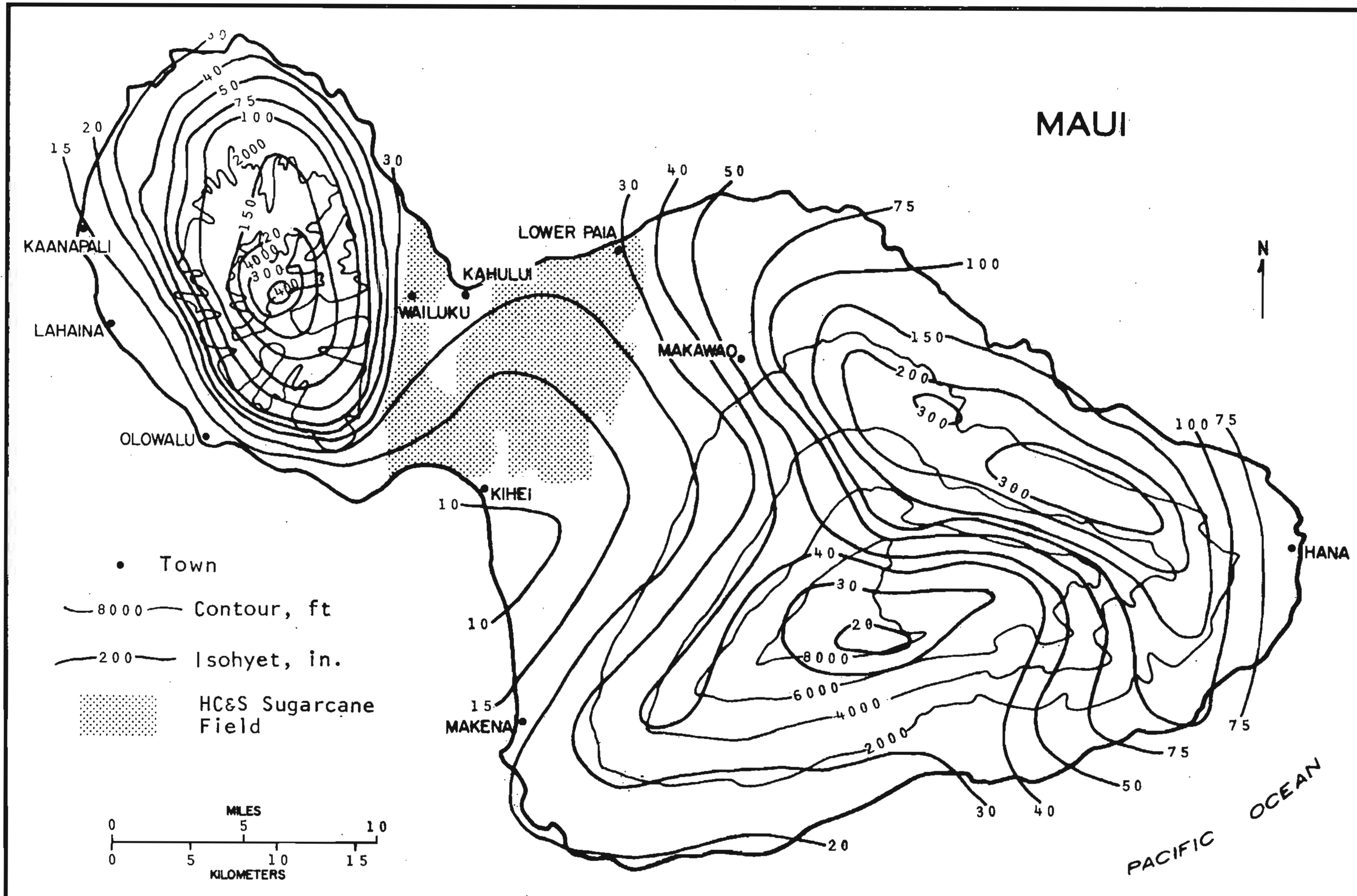
In general, the predominant northeasterly trade winds and the terrain influence the characteristics of climate in the Hawaiian Islands. Moisture-laden air carried inland from the sea by the trade winds is deflected upward by the higher mountains, resulting in cooling and condensation, and is precipitated as rain. If the Hawaiian Islands did not exist, the average annual rainfall where the islands lie would be about 63.5 cm (25 in.). Instead, the actual annual average is about 177.8 cm (70 in.).

In the study of the water resources of central Maui, the predominant parameter of climatology is the distribution of rainfall in Maui. It is recognized that steep rainfall gradients are exhibited in all the Hawaiian Islands and that Maui is not an exception. As a result of steep rainfall gradients, wide variations of water supply problems are not uncommon. In order to give a general picture of rainfall, a map showing the median annual rainfall distribution in Maui according to Taliaferro (1959) is shown in Figure 1.

Figure 1 also shows sugarcane fields located on the island's isthmus where the median annual rainfall is 88.9 cm (35 in.), whereas the windward side of northeastern Maui where water is abundant for water resources development, has a median annual rainfall of more than 381 cm (150 in.). These variations of rainfall distribution make irrigation necessary for sugarcane plantations in central Maui.

BACKGROUND OF WATER RESOURCES DEVELOPMENT FOR IRRIGATION IN CENTRAL MAUI

The largest water resources development of Maui was the construction of a major ditch system to transport water for irrigation from the wet rain forest lands of the eastern and windward slopes of East Maui (Haleakala) to the sugarcane fields. According to Rho (1974, pp. 8-17), the first ditch, the Hamakua ditch which is 27.36 km (17 miles) long with a capacity of 227,100 m^3/day (60 mgd), was completed in 1878. Other ditches were added later to the Hamakua ditch system: the Haiku, Spreckels, Center, Manuel Luis, and Lowrie ditches which were constructed before the turn of the century. The New Hamakua, Kauhikoa and Koolau ditches were completed before



SOURCE: Taliaferro (1959).

FIGURE 1. MEDIAN ANNUAL RAINFALL DISTRIBUTION FOR MAUI, HAWAII

World War I and the last major construction was the completion in 1923 of the Wailoa ditch. A map showing the general location of the ditch system is shown in Figure 2.

Initially, the various plantations shared the use of the water diverted from East Maui, this being proportional to their share of the construction costs of the ditch-tunnel water transportation system. Later the East Maui Irrigation Company (EMI) was founded to manage this vast irrigation ditch-tunnel system. Since then, the EMI has been developing and diverting water from watersheds in East Maui, 70% of which is state lands and 30% owned by EMI. In ensuing years, both the plantations and their waters were consolidated through a series of mergers. Finally in 1948, Hawaiian Commercial & Sugar Company (HC&S, a division of Alexander & Baldwin, Inc. and the largest plantation in Hawaii) became the sole plantation and, therefore, the principal user of the East Maui water. According to Rho (1974, pp. 14-20), the EMI system today includes 119 km (74 miles) of ditches and tunnels with a capacity of 1,722,175 m^3/day (455 mgd) and there are also 8 reservoirs that can store 1,097,650 m^3 (290 mil gal). Generally the EMI system collects and transports all the water available during the dry seasons; however, during the wet seasons excess stream water is allowed to flow into the ocean.

On an average annual basis, the EMI system collects 15% of the annual rainfall from the 23,066-ha (57,000-acres) East Maui watersheds. In an average summer (June to September dry season), EMI delivers about 68,130,000 m^3 (18 bil gal) of water, but drought drastically affects the actual amount of water delivered, for during the 1973 drought only 37,850,000 m^3 (10 bil gal) was supplied for the same 4-mo period. The EMI system supplies more than 50% of the irrigation water to all the HC&S sugarcane fields of more than 12,950 ha (32,000 acres), which use 126 bil gal/yr (Rho 1974, p. 13), while 45% is obtained from mountain sources and 15 deep wells and pumping stations owned by HC&S and 5% contributed by the West Maui system. In addition, there are many small reservoirs in the HC&S sugarcane fields; however, due to the steep slopes and rugged terrain, the total storage capacity of these reservoirs is about 4,049,950 m^3 (1.07 bil gal). (Reservoirs are used mainly for overnight storage; stored water will be used for irrigation the next day.)

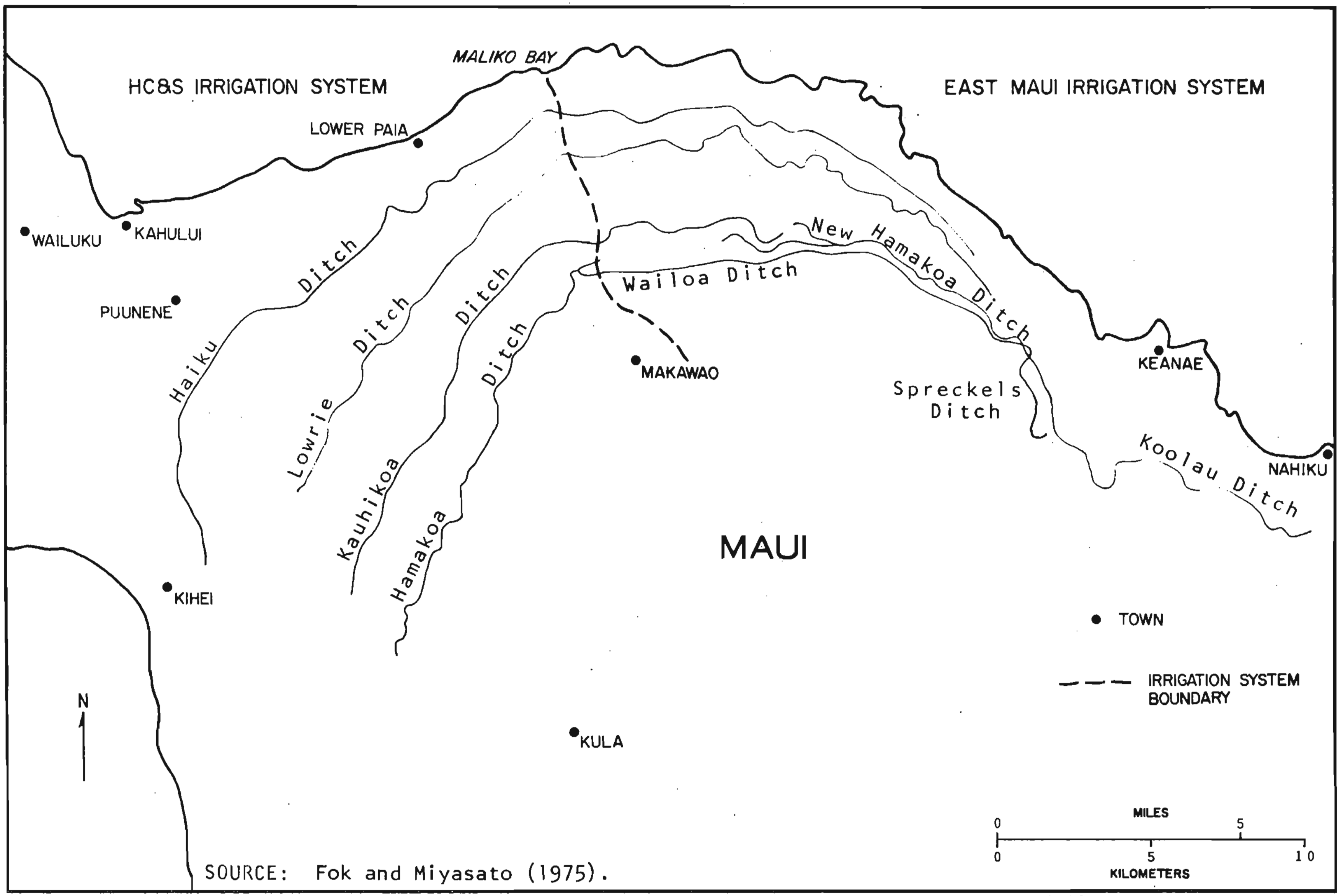


FIGURE 2. IRRIGATION DITCH SYSTEM FOR CENTRAL MAUI, HAWAII

DOMESTIC WATER SUPPLY FOR CENTRAL MAUI

Again, according to Rho (1974), Maui County has rights to purchase 3,217,250 m^3 to 3,785,000 m^3 (850 mil gal to 1 bil gal) of water per year from the EMI system to feed into the county's domestic water system. The county's water system includes the extensive Waikamoi collection facilities which are located in the same region as the EMI system and subject to the same drought conditions. The Waikamoi system includes the Upper Kula and the Lower Kula systems. In 1973, under a 20-yr contract with the Maui County government, EMI took over the management of Waikamoi's flumes and pipelines from the Maui County Water Supply Department, and as part of that agreement, EMI sells untreated water to the county at a cost of six cents per 3.785 m^3 (1,000 gal). The county will receive all the water EMI can collect from the Waikamoi system and, if necessary, EMI will provide the county with up to 60,560 m^3 (16 mil gal) of water per day from the Wailoa ditch.

LOW-FLOW FREQUENCY STUDIES OF IRRIGATION DITCH FLOWS IN CENTRAL MAUI

Although there are two recent reports (Takasaki and Yamanaga 1970; Takasaki 1972) concerning the water resources in Maui, it was found that there are very limited drought studies for the island of Maui. The only reference was a report by Hirashima (1965) concerning the flow characteristics of selected streams in Hawaii. In that report, tabulations of low flow for different durations of selected streams in Maui were reported. Unfortunately, none of the streams studied was located within the central Maui region. Therefore, an analysis of the drought frequencies was conducted by Fok and Miyasato (1975). Daily flow records of five U.S. Geological Survey (USGS) streamflow gaging stations were selected for this study. The name, the data period, and USGS gage numbers of these 5 streamflow gaging stations are as follows:

Stream Gaging Station	USGS Gage Number
Wailoa ditch (1923-1972)	5880
New Hamakua ditch (1923-1972)	5890
Old Hamakua ditch (1937-1964)	5900
Lowrie ditch (1931-1972)	5920
Haiku ditch (1931-1972)	5940

The time period of the daily streamflow records for these five stations was selected according to their availability because the data had to cover the same period for each station insofar as possible. Missing data were filled in using the standard correlation method by Searcy (1960), so that a complete set of daily streamflow data for the specified period for each streamflow gaging station was available as input data for the drought frequency analysis.

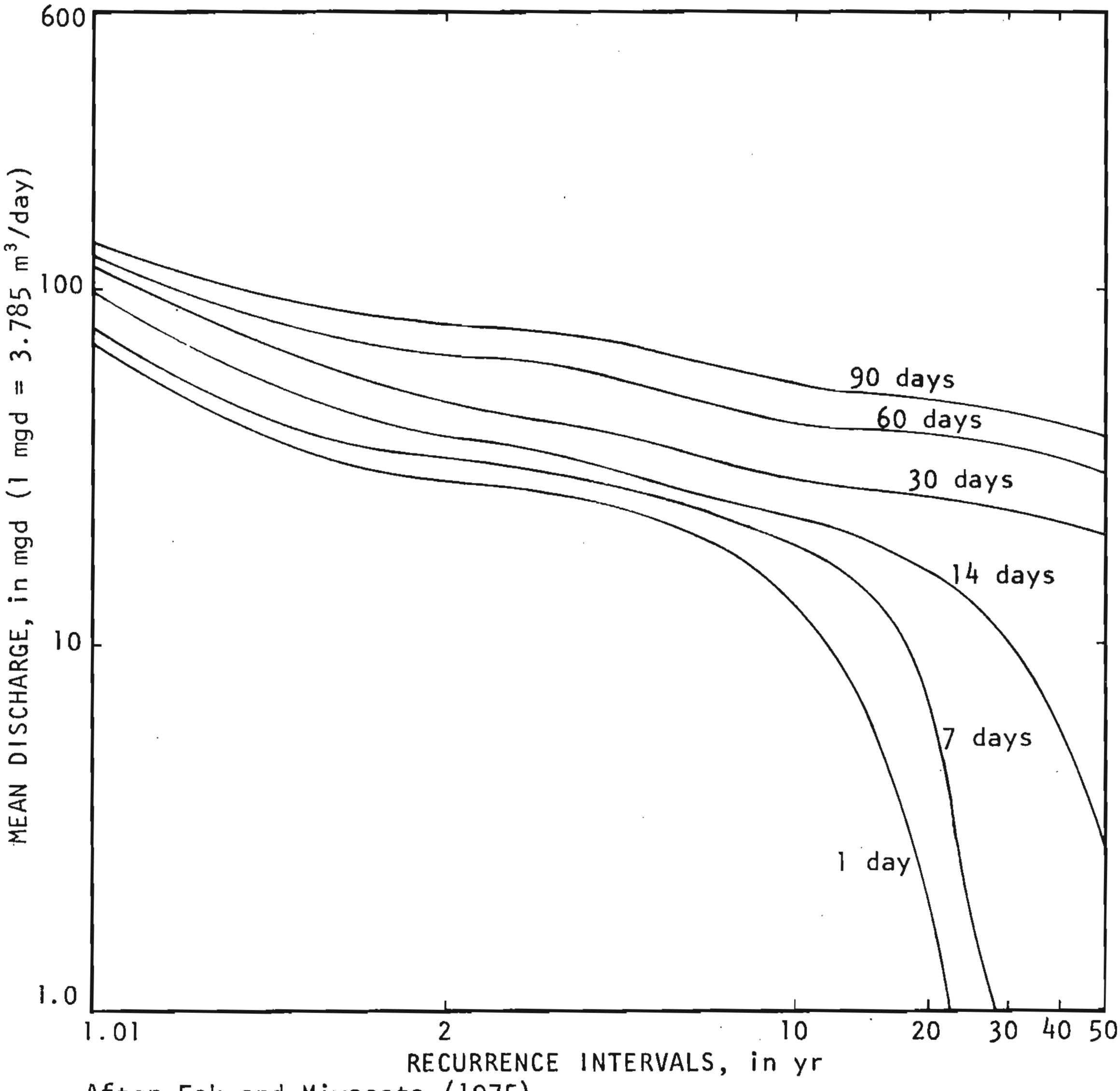
A computer program was written to identify and to rank the 1-, 7-, 14-, 30-, 60-, and 90-day lowest streamflows from the daily flow records, and to compute on an annual basis the recurrence intervals during these periods. The results of the above analysis have been plotted as low-flow frequency curves on log extreme-value probability graphs as shown in Figures 3 to 7. Judging from these low-flow frequency curves developed for the Wailoa ditch in Figure 3, droughts similar to the one that occurred in 1973 with 136,260 m^3/day (36 mgd) for 45 days are estimated to have 15-yr recurrence intervals. It must be stressed that the Wailoa ditch has been regarded as the major water collecting system among the 5 ditches studied.

STOCHASTIC ANALYSIS OF IRRIGATION DITCH FLOWS IN CENTRAL MAUI

Since the low-flow frequency curves can only provide the probability of occurrence of a low flow in terms of a given magnitude of flow with its duration and recurrence interval, their applicability is limited to an event-estimation basis. In order to study the low-flow occurrence in an event-sequence basis, with the aim of exploring the water manageability during a drought, a stochastic analysis of the ditch flows in central Maui was conducted in this study.

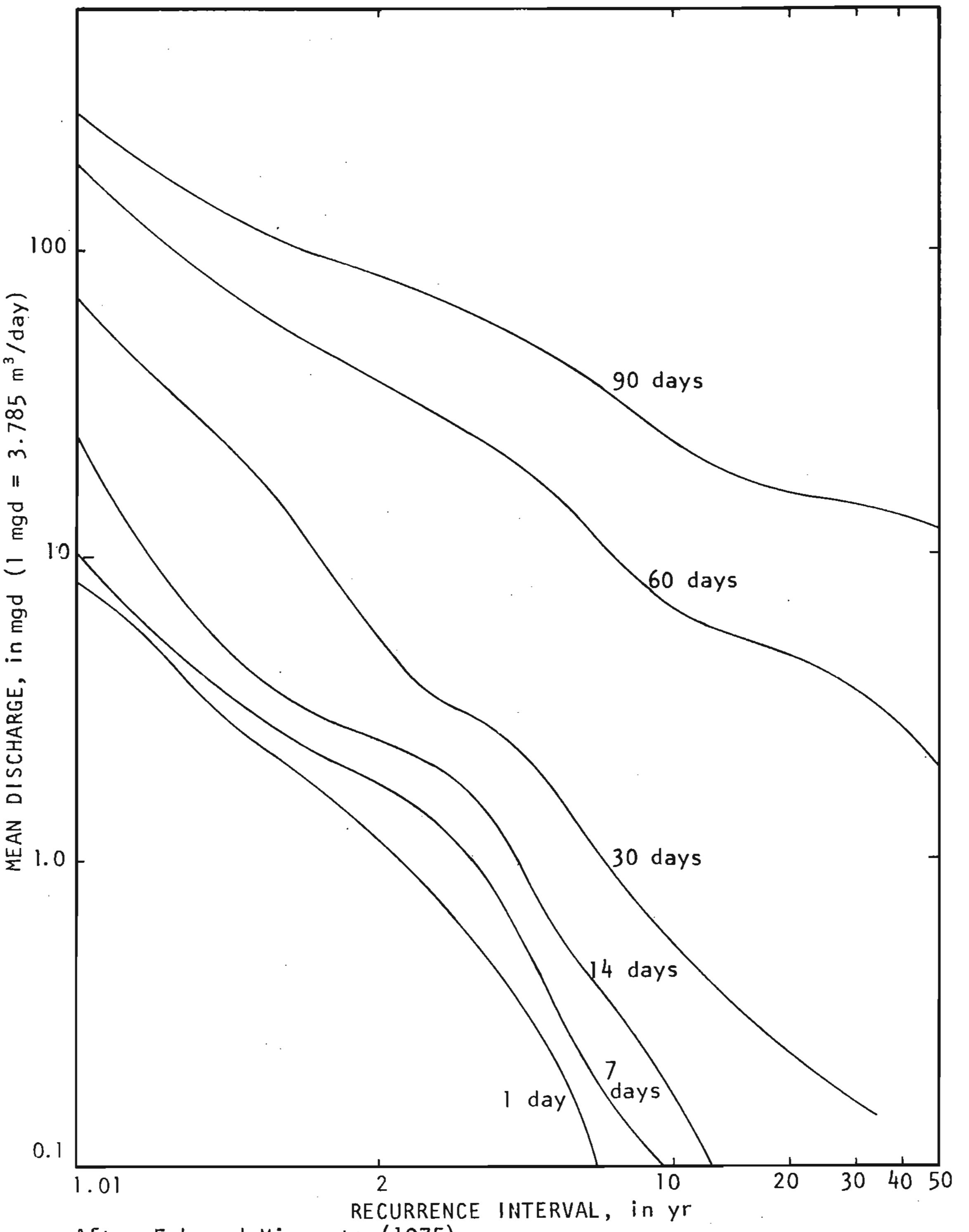
As stated by Chow (1964, pp. 8-91):

> Observed hydrologic records are usually short. Unless the record is too meager to be considered as a representative sample, the statistical parameters derived from it should enable the hydrologist to construct a stochastic model that will generate hydrologic information for as long a period of time as desired. Since the statistical hydrologic parameters of the population of the generated data are necessarily the same as those estimated from the historical data, the new information is limited by errors of measurement and sampling that are inherent in the observed record. As far as the quality of the information is concerned, the



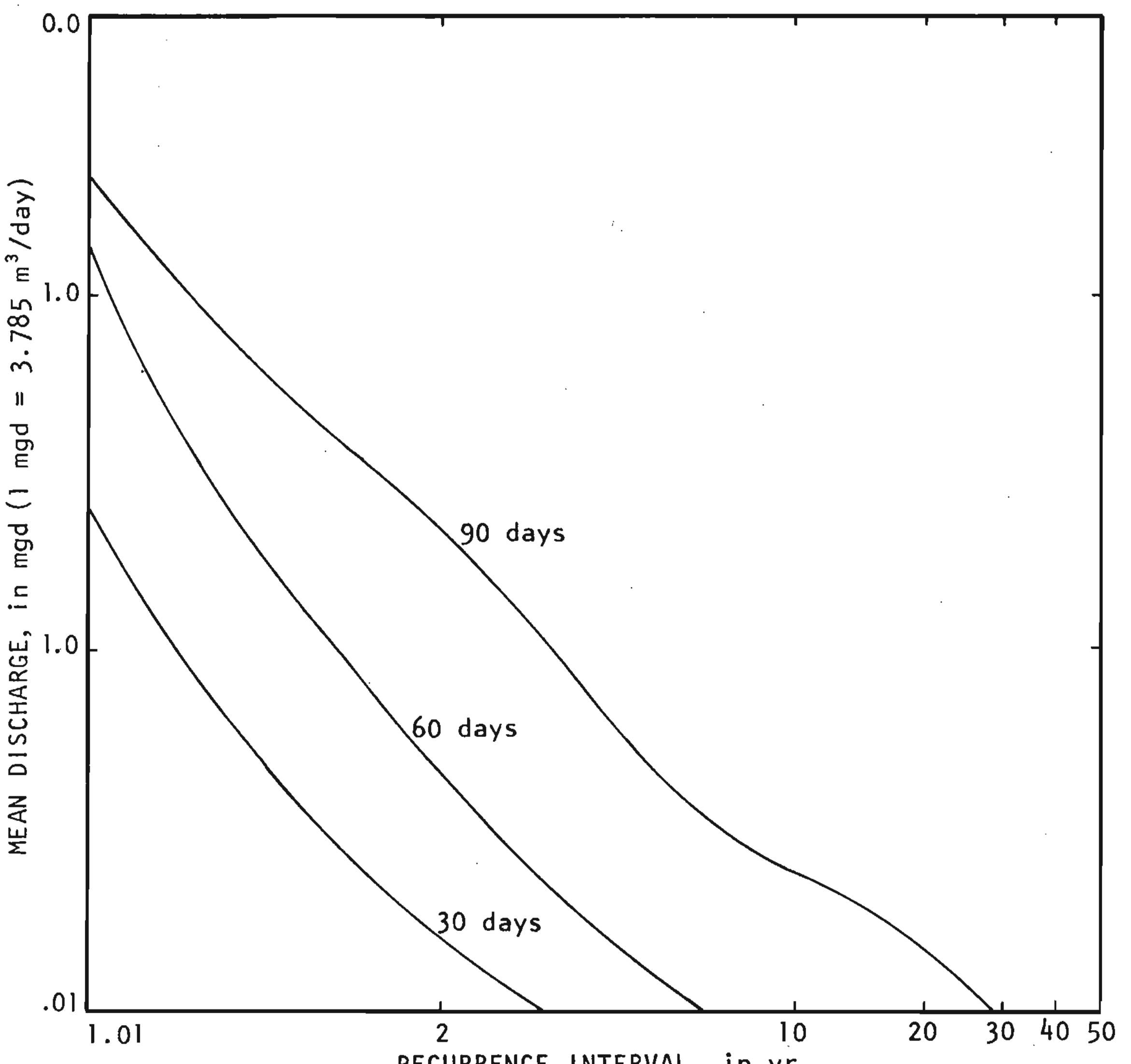
After Fok and Miyasato (1975).

FIGURE 3. LOW-FLOW FREQUENCY CURVES FOR WAILOA DITCH STATION NO. 5880, MAUI, HAWAII 1923-1972



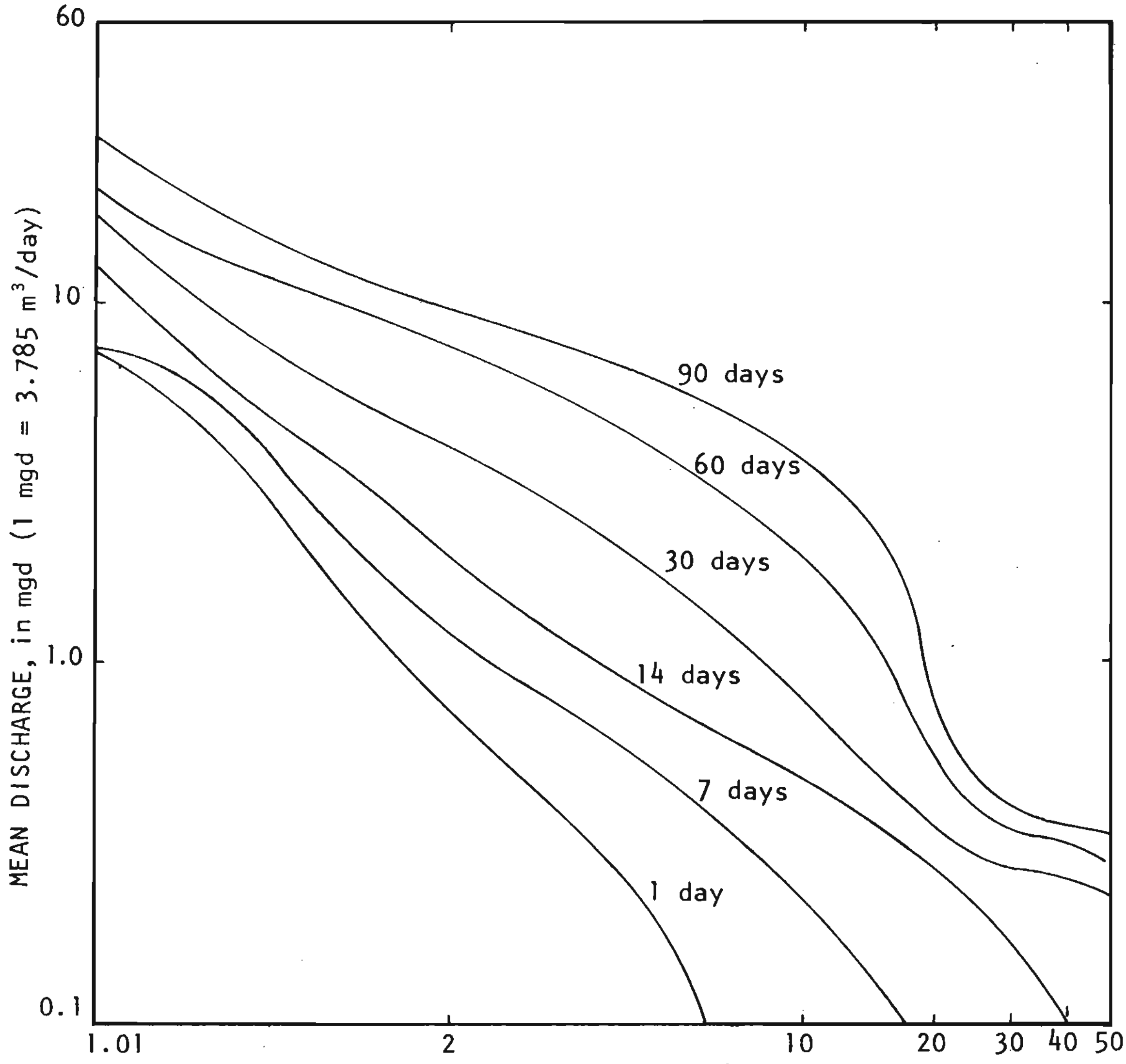
After Fok and Miyasato (1975).

FIGURE 4. LOW-FLOW FREQUENCY CURVES FOR NEW HAMAKUA DITCH STATION NO. 5890, MAUI, HAWAII, 1932-1972



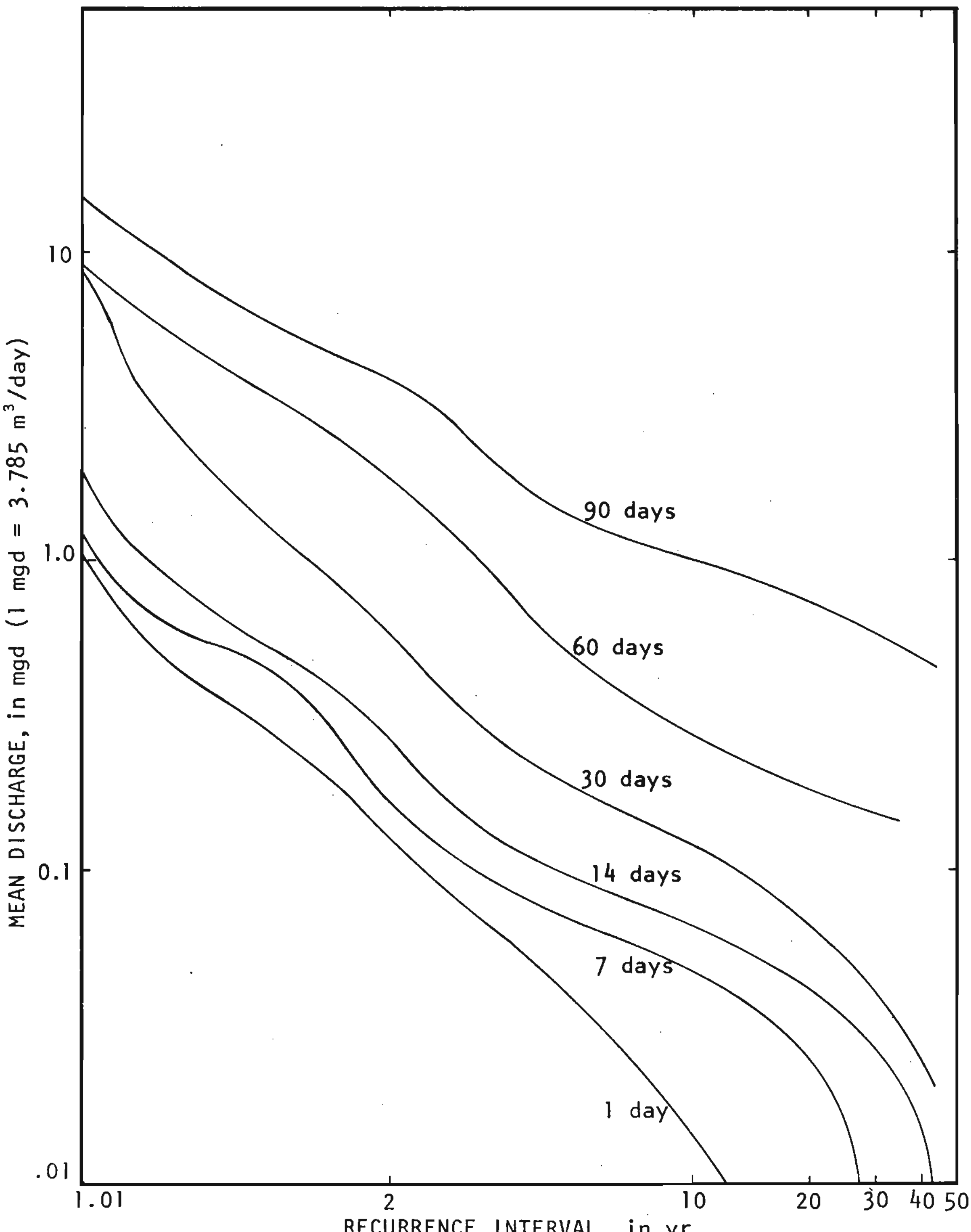
After Fok and Miyasato (1975).

FIGURE 5. LOW-FLOW FREQUENCY CURVES FOR OLD HAMAKUA DITCH STATION NO. 5900, MAUI, HAWAII, 1937-1964



After Fok and Miyasato (1975).

FIGURE 6. LOW-FLOW FREQUENCY CURVES FOR LOWRIE DITCH STATION NO. 5920, MAUI, HAWAII, 1931-1972



After Fok and Miyasato (1975).

FIGURE 7. LOW-FLOW FREQUENCY CURVES FOR HAIKU DITCH STATION NO. 5940, MAUI, HAWAII, 1931-1972

> new data is no better than the data from which it was generated. ...The major advantage of sequential generation is to create synthetic records longer than the historical....

This is the reason why this study has made no attempt to predict the exact future ditch flows. Rather, the generated ditch flow data was analyzed to show how to obtain the probable worst combination of sequential low-flows for water management decision-making purposes.

The Stochastic Ditch Flow Data Generator: The Markov Lag 1 Model

There are several models to serve as the data generater, however, the lag 1 Markov Model is selected for this study.

The rationale for using the lag 1 Markov model as the stochastic ditch flow data generator was stated by its inventor A.A. Markov (1856-1922), that the outcome of any trial depends only on the outcome of the directly preceding trial. If more preceding trials also affect the current trial outcome, more than one lag must be included, i.e., lag 2, lag 3, etc., models.

According to Bowles and Mink (1975):

> In Hawaii, streams respond quickly to rainfall and in any month both the baseflow and very high stages are likely to be recorded so that at most only the lag 1 assumption is justifiable. Actually stream flow greater than base flow reflect immediate rainfall, which means that the lag 1 correlation coefficients of the model serve also to connect rainfall dependency between succeeding months. ...If the frequency distribution, length and severity of droughts can be reasonably estimated, the long term economic feasibility of agriculture depending on surface water as its chief supply for irrigation can be assessed....

One form of the lag 1 Markov chain formula was used in this study with reference to Viessman, Harbaugh, Knapp (1972), and Linsley, Kohler, Paulus (1975, pp. 376-78):

$$Q_{i,j} = \overline{Q}_j + b_j(Q_{i,j-1} - \overline{Q}_{j-1}) + t\sigma_j(1 - r_j^2)^{\frac{1}{2}} \qquad (1)$$

in which

$Q_{i,j}$ = generated flow for month j, year i

$\overline{Q}_j$ = mean of observed flows for month j

$Q_{i,j-1}$ = generated flow for month j-1, year i

$\overline{Q}_{j-1}$ = mean of observed flows for month j-1

b_j = regression coefficient for relation of month j to month j-1, $b_j = r_j(\sigma_j/\sigma_{j-1})$

t = random number selected from normal distribution having zero mean and unit variance

σ_j = standard deviation of observed flows from month j

r_j = correlation coefficient describing relation of flows for month j to flows for month j-1

The first two terms are the deterministic part of the generated flow. And the last term in the equation, $t\sigma_j(1 - r_j^2)^{\frac{1}{2}}$, is the random part of the generated flow with a normally distributed variance.

It must be noted that j represents the calendar month of the year. Therefore, when j = 1 (January), j-1 = 12 (December) of the previous year. Hence, when j = 1, $Q_{i,j-1}$ becomes $Q_{i-1,j-1}$ where j-1 = 12 for December, and i-1 represents the previous year. It must also be noted that $b_j = r_j(\sigma_j/\sigma_{j-1})$ which must be used since $Q_j = Q_{j-1}$.

Generating Ditch Flow Data

In this study, as discussed previously, the Wailoa ditch has been regarded as the major surface water collecting and transporting system among the five irrigation ditch systems in the low-flow frequency studies. In fact, Wailoa ditch delivers about 90% of the summer months' irrigation ditch water from East Maui to central Maui; therefore the monthly Wailoa ditch flow data recorded by U.S. Geological Survey from 1923 to 1972 were used for the stochastic analysis of the summer low flows as shown in Table 1.

Utilizing the available Wailoa ditch flow data according to the Bowles and Mink (1975) method, it was determined that one month's total ditch flow correlated to some extent to that of the following month. Therefore, since any month's total ditch flow can be generated if the previous month's total flow is known, computer programs were developed for data generation. In order to examine the statistical characteristics of the Wailoa ditch flow data, the probability distribution of the flow data was analyzed without using a stepwise searching technique, first, by assuming a normal distribution for the last term of equation (1), and second, by assuming a Pearson Type III distribution for the same last term of equation (1) to make an

TABLE 1. MONTHLY FLOWS (in mil gal) OF THE WAILOA DITCH, STATION NO. 5880, 1923-1972

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1923	2434.00	2733.00	3303.00	3333.00	3841.00	3257.00	3878.00	2973.00	2503.00	2781.00	3737.00	3857.00
1924	2487.00	2263.00	3430.00	3488.00	3618.00	1720.00	2858.00	3892.00	2054.00	3666.00	2902.00	2599.00
1925	2987.00	2117.00	3162.00	4592.00	4562.00	4242.00	3270.00	4221.00	3942.00	3246.00	4042.00	1785.00
1926	2084.00	2016.00	1122.00	2126.00	2002.00	1953.00	1586.00	4047.00	2738.00	2838.00	2229.00	1973.00
1927	4127.00	2048.00	3595.00	4256.00	4263.00	2964.00	3687.00	4760.00	4072.00	2820.00	3142.00	4371.00
1928	3979.00	3478.00	2038.00	3390.00	4226.00	3012.00	4870.00	4667.00	4036.00	2802.00	4097.00	4625.00
1929	4513.00	3882.00	4474.00	3499.00	3369.00	2729.00	2670.00	3355.00	1767.00	2390.00	2710.00	4073.00
1930	4032.00	3069.00	4511.00	5172.00	5086.00	4759.00	4429.00	4674.00	4075.00	3650.00	3464.00	3302.00
1931	2122.00	2655.00	2215.00	3852.00	3810.00	2796.00	4260.00	4801.00	4780.00	4163.00	4535.00	3298.00
1932	4047.00	4289.00	2343.00	4781.00	4874.00	3931.00	4331.00	3556.00	2916.00	1344.00	1800.00	3212.00
1933	4347.00	3056.00	3569.00	2947.00	2574.00	2071.00	3349.00	2024.00	1499.00	790.00	1349.50	1754.00
1934	2538.00	2223.00	1972.00	4860.00	4986.00	4684.00	4832.00	3118.00	3125.00	3746.00	4661.00	3293.00
1935	4124.00	2653.00	2894.00	4591.00	3848.00	3542.00	3932.00	3439.00	3174.00	2330.00	2875.00	1902.50
1936	1726.50	1579.00	4839.00	4471.00	5142.00	4075.00	4988.00	4998.00	4544.00	3431.00	4025.00	4825.00
1937	5078.00	4543.00	5074.00	4636.00	5002.00	3953.00	4949.00	5054.00	4152.00	3753.00	4275.00	3623.00
1938	4285.00	3157.00	4512.00	4597.00	5034.00	4613.00	3387.00	4208.00	2732.00	3517.00	3398.00	4160.00
1939	4732.00	3926.00	4523.00	4599.00	4562.00	4564.00	4580.00	4207.00	3939.00	2953.00	4566.00	3836.00
1940	1625.00	2488.00	2254.00	2454.00	3691.00	2543.00	3468.00	5028.00	4520.00	3739.00	4009.00	3003.00
1941	3070.00	1556.50	4036.50	3823.00	4739.00	3623.00	4403.00	4413.00	4603.00	5344.00	4111.00	4657.00
1942	2359.00	2401.50	5452.00	5092.00	3775.00	3135.00	3400.00	3911.00	3947.00	3182.00	2058.00	2123.50
1943	2427.00	2736.00	4112.00	4752.00	4111.00	3288.00	4563.00	3731.00	2403.00	1357.00	1296.00	2978.00
1944	2162.00	1587.50	2322.50	4124.00	3531.00	3184.00	3936.00	3263.00	2706.00	2793.00	4892.00	4190.00
1945	1629.00	1714.00	4774.00	2696.00	1298.50	2444.00	2160.00	4676.00	3219.00	2149.50	3567.00	2589.50
1946	2145.00	1994.79	4683.00	4990.00	2696.00	1720.00	4504.00	2714.00	2387.00	2951.00	3449.00	4188.00
1947	3249.00	1561.00	4132.00	3546.00	4555.00	2443.00	4135.00	4072.00	3226.00	3019.00	3081.00	3962.00
1948	3024.00	2419.00	4560.00	4696.00	4026.00	2832.00	4837.00	3857.00	2583.00	3995.00	4494.00	3767.00
1949	2954.00	1892.00	3093.50	4227.00	2510.00	2151.00	3589.00	4085.00	1681.40	1987.50	3991.00	3582.00
1950	2325.50	2709.00	3861.00	4244.00	4303.00	3329.00	3911.00	3426.00	2292.00	2531.00	3394.00	3441.00
1951	3498.00	2141.00	4039.00	3031.00	1826.00	2003.00	2729.00	3598.00	2143.00	1932.50	3767.00	3190.00
1952	3571.00	3358.00	4407.00	4194.00	4580.00	4779.00	4517.00	2965.00	3056.00	3541.00	4808.00	4146.00
1953	1237.00	1860.00	3491.00	1687.50	3488.00	3010.00	2781.00	3234.00	1096.00	1377.29	2776.00	3592.00
1954	2323.00	1567.00	4299.00	2826.00	5588.00	4570.00	5819.00	5905.00	3917.00	2243.00	1626.00	3409.00
1955	2805.00	2990.00	4427.00	4660.00	5819.00	3061.00	4413.00	5449.00	3246.00	2722.00	2546.00	1802.00
1956	2510.00	2093.00	3886.00	5008.00	5567.00	5529.00	4108.00	4879.00	2243.00	3771.00	2310.00	2442.00
1957	3159.00	3092.00	2717.00	4133.00	3358.00	1331.50	3948.00	5222.00	3109.00	2712.50	3962.00	4647.00
1958	3243.00	1918.50	2351.50	2895.00	4849.00	3999.00	5390.00	5307.00	3675.00	4210.00	4315.00	4347.00
1959	2594.00	2758.00	4465.00	4479.00	4135.00	2232.00	3201.09	4578.29	3044.59	1498.89	2917.19	5243.00
1960	4129.79	3171.29	4077.50	5185.00	4165.00	3248.39	3097.54	3522.83	3627.49	2572.09	4244.11	3819.45
1961	2550.76	3280.47	2898.47	2640.61	2733.69	3489.89	2529.45	3060.08	1896.40	3659.22	4540.12	3451.08
1962	1590.99	1347.39	5039.03	2865.55	3040.68	1030.70	2720.77	2936.01	2216.65	1582.62	1491.46	2456.40
1963	1952.31	1465.69	2842.92	4081.27	5230.35	4445.11	4890.40	3304.40	2925.64	4653.20	3544.15	2349.79
1964	3801.38	2620.57	4070.27	3815.62	5240.73	2619.94	3863.43	3654.02	3352.20	4625.44	3602.93	3087.22
1965	2281.92	3079.48	3981.05	3378.70	3311.48	3422.66	4172.00	3065.00	1164.00	1985.00	4623.00	4781.00
1966	4403.00	3549.00	3378.00	4022.00	2500.00	2103.00	4000.00	4434.00	2891.00	4157.48	3669.54	3520.91
1967	4169.15	3455.63	4187.85	4673.89	3164.75	2306.45	4788.28	4315.82	1715.11	1929.71	4835.45	3983.65
1968	2500.38	962.20	3837.26	5378.35	3745.82	2808.06	2317.44	3048.45	2177.87	1663.41	1257.55	2259.95
1969	2075.75	3303.10	4653.85	5259.41	3995.92	2393.10	4982.16	5322.74	4889.76	2506.16	2146.20	2954.71
1970	3159.61	1447.72	3066.50	5137.93	4690.67	3098.87	5238.10	4847.06	4353.31	3946.14	3997.21	3164.77
1971	1392.60	1122.73	3530.56	3716.39	3690.86	1999.51	1932.92	1153.49	1771.35	1976.89	3700.56	3914.48
1972	2960.56	3407.15	1388.11	4311.97	2943.09	1806.28	3518.29	3449.80	2117.76	2752.43	3763.26	2286.44
MEAN	2971.60	2534.72	3637.80	4024.28	3953.94	3096.86	3874.37	3968.41	3004.88	2905.71	3411.84	3396.34
STD DEV	974.721	843.636	1005.379	897.289	1026.966	1020.358	953.921	936.307	992.846	994.318	1026.755	900.535
CORR COEF	0.6550	0.0348	0.2799	0.4245	0.7065	0.4676	0.4713	0.6626	0.5144	0.5005	0.5051	0.3301

NOTE: 1 mil gal = 3,785 m^3

evaluation.

NORMAL DISTRIBUTION. A testing computer program was developed to utilize equation (1) for synthetic data generation. It is well recognized that the stochastic model (eq. 1) would not correspond to the actual record. This is borne out by a test using the first 40-yr records to generate synthetic data for 10 yr and comparing with the last 10-yr data of the 1923 to 1972 record. The results, as expected, indicated that good correlation between the generated and actual data is not consistently obtained.

The next test was to use the 50-yr data to generate data for the next 10 years. Although the statistical characteristics of the generated 10-yr synthetic data are the same as those of the actual 50-yr (1923 to 1972) data, there is no way to imply that these would be the sequence of future flows. Therefore according to the test results, this data generating model should not be used as a prediction model.

PEARSON TYPE III DISTRIBUTION. It is known that many hydrologic data follow the Pearson Type III distribution rather than a normal distribution. Therefore, if the Pearson Type III distribution could be used instead of a normal distribution to test the random part of equation (1), the generated results would probably be more representative.

On the basis of this hypothesis, another sequential data generating model using the Pearson Type III distribution for the random term was developed and data were generated. According to Chow (1964, pp. 8-16), the Pearson Type III probability distribution with the origin at the mode is:

$$p(x) = p_o\left(1 + \frac{x}{a}\right)^c e^{-cx/a} \tag{2}$$

in which

$$c = \frac{4}{\beta_1} - 1$$

$$a = \frac{c}{2}\frac{\mu_3}{\mu_2}$$

$$p_o = \frac{1}{a}\frac{c^{c+1}}{e^c\Gamma(c+1)}$$

$$\beta_1 = \frac{\mu_3{}^2}{\mu_2{}^3}$$

μ_2 = second moment about the mean

μ_3 = third moment about the mean

Γ = the gamma function

The statistical parameters are: mean = mode - $\mu_3/2\mu_2$; standard deviation = $\sqrt{\mu_2}$; and Pearson skewness = $\sqrt{\beta_1}/2$. With these considered, a and c can be determined.

Equation (1) now becomes:

$$Q_{i,j} = \overline{Q}_j + b_j(Q_{i,j-1} - \overline{Q}_{j-1}) + x(1 - r_j^2)^{\frac{1}{2}} \quad (3)$$

in which x = a random number selected from the Pearson Type III distribution. All other variables are the same as those defined in equation (1).

The last term in equation (3), $x(1 - r_j^2)^{\frac{1}{2}}$ is the random term using a Pearson Type III distribution.

A test computer program was then written using the Pearson Type III distribution instead of the normal distribution. Most of the program was essentially the same except that equation (3) was substituted for equation (1) when the data skewness exceeded a certain determined limit.

Again the computer program was evaluated for its performance by using the first 40 years of actual data to generate a sequence of 10-yr data and comparing the 10-yr synthetic data with the actual last 10-yr data. As indicated by the results of the computer program, there is evidently no significant improvement in the correlation between the simulated (generated) data regardless of whether the Pearson Type III distribution or the normal distribution is used. The reason for this is the same as that explained in the first test.

As in the previous testing study, the next test was to use all the 50-yr data to generate the 10-yr data. Again, although the range of the simulated data is similar to the actual data, the simulated data cannot be taken as a sequence of future flows; therefore, this data generating model is not recommended as a prediction model.

The critical low-flow period occurs during the summer months of June, July, August, and September. Synthetic data for each of these months from 1973 to 2022 were generated for Wailoa ditch.

EXAMPLES OF GENERATING LOW FLOW SERIES. By using the two test models and computer programs developed for these models, available data for the summer months were extended to a period of 100 years (1923 to 2022). Using the first model (normal distribution), three sample program series were computed on the University of Hawaii Computer Center's plotting machine (Fortran IV computer program A in the Appendix) and these series were plotted on the graphs in Figures 8, 9, and 10. The second model (Pearson Type III distribution) was used to compute one sample series and these results were plotted in Figure 11. According to Figure 11, the generated data do not exhibit a good range of flow variation as that displayed by the normal distribution; therefore, the normal distribution is recommended for this data generation. It must be noted that for all of the graphs, the summer flow totals for the first 51 years, 1923 to 1973, are the same since they are from the same historical record of the series. On the other hand, the flow totals for the last 49 years, 1974 to 2022, are the generated portion of the series. These sample series were examined to determine if there was any long-term trend or patterns of drought (in actual practice, a sufficient number of sample series [50 or more] should be generated for examining the sequential stochastic low-flow pattern). Although there is a possibility of occurrence; no long-term trends or patterns of drought could be detected from these graphs. None of the generated low flows exhibit the same sequential low-flow combination as that experienced in 1971 and 1973, therefore, the closely spaced 1971 and 1973 recorded summer low flows would be the worst combination of sequential low flows for a long period of time.

APPLICATION OF THE STUDY RESULTS

Droughts are relatively prolonged periods of abnormally dry weather where the lack of water causes a serious hydrologic imbalance in the affected areas. As a result, a creeping-type disaster develops over time and space. Therefore, decision-makers should be able to plan a strategy to alleviate damages. Oftentimes, the following questions related to drought alleviation are asked:

1. What is the current water supply and how long will this supply last under current demand?
2. What are the chances that the same drought conditions will appear in the next year, and the year after?
3. What water uses are to be curtailed in order to minimize drought damages, if the drought conditions persist for the following

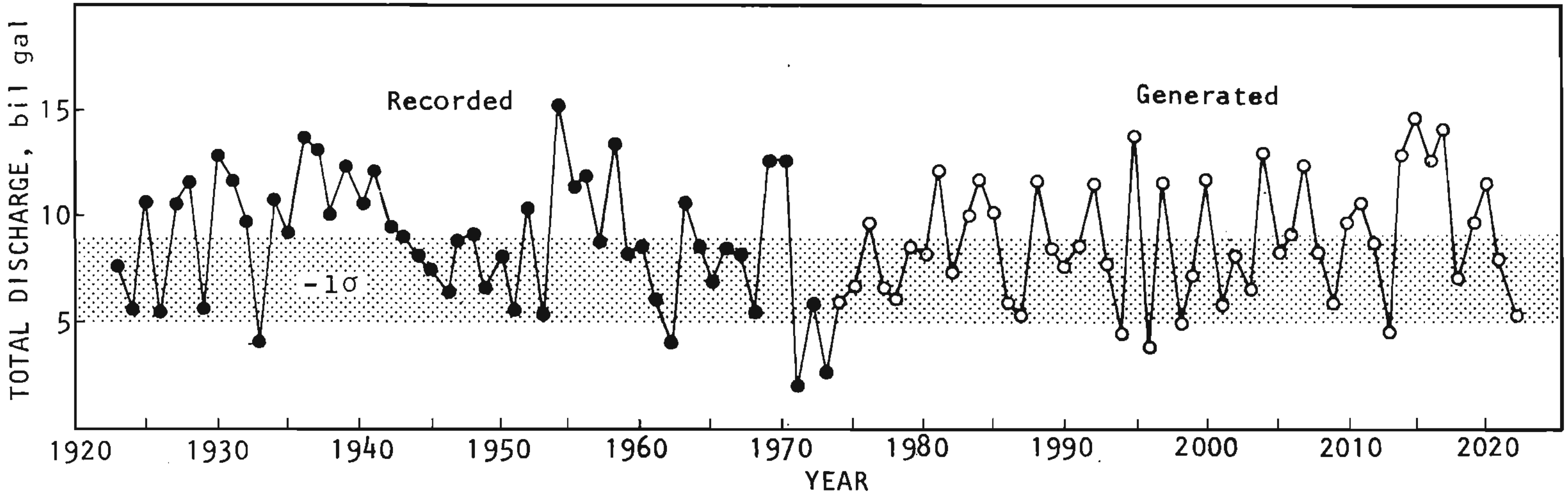


FIGURE 8. GENERATED WAILOA DITCH SUMMER FLOWS, (NORMAL-1), 1973-2022

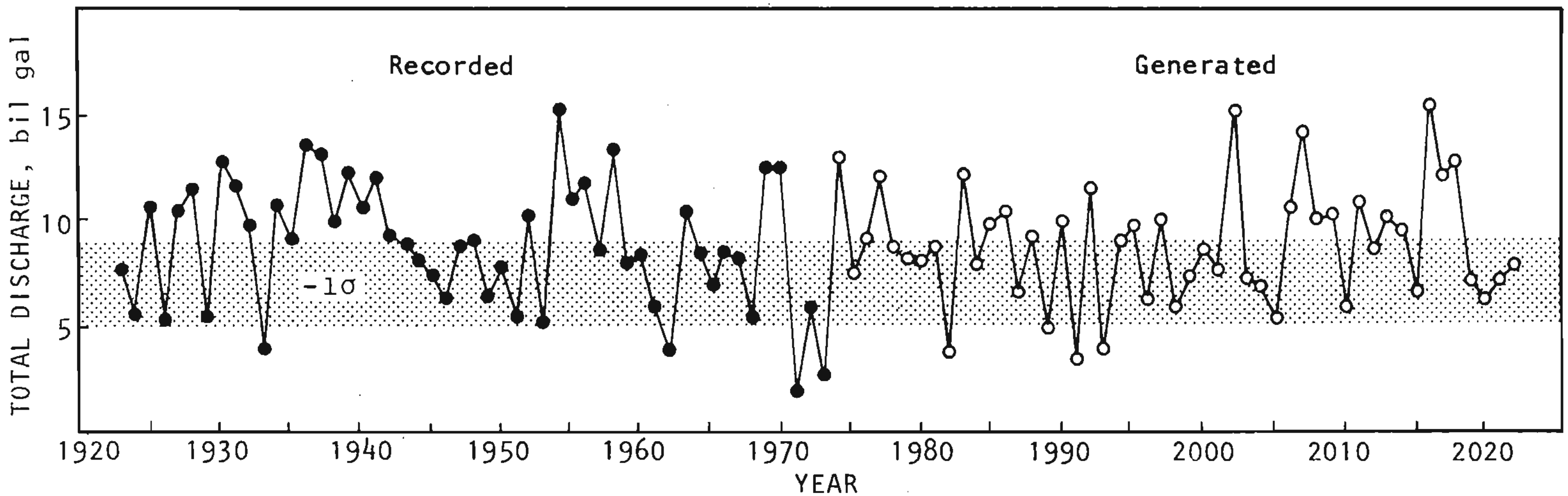


FIGURE 9. GENERATED WAILOA DITCH SUMMER FLOWS, (NORMAL-2), 1973-2022

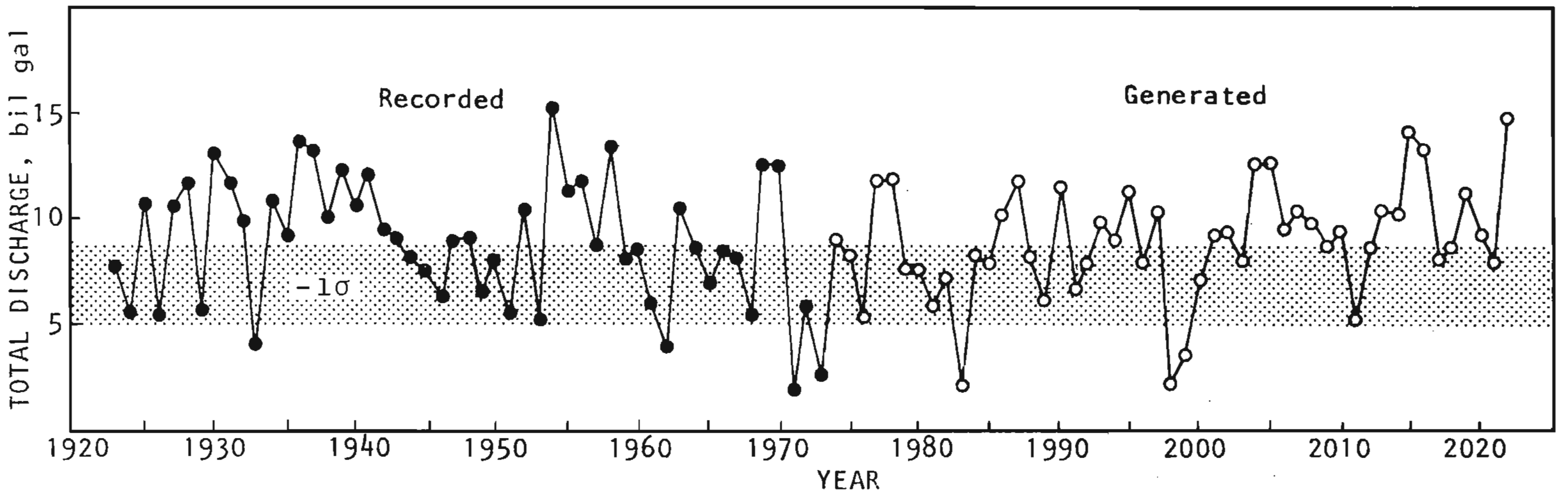


FIGURE 10. GENERATED WAILOA DITCH SUMMER FLOWS, (NORMAL-3), 1973-2022

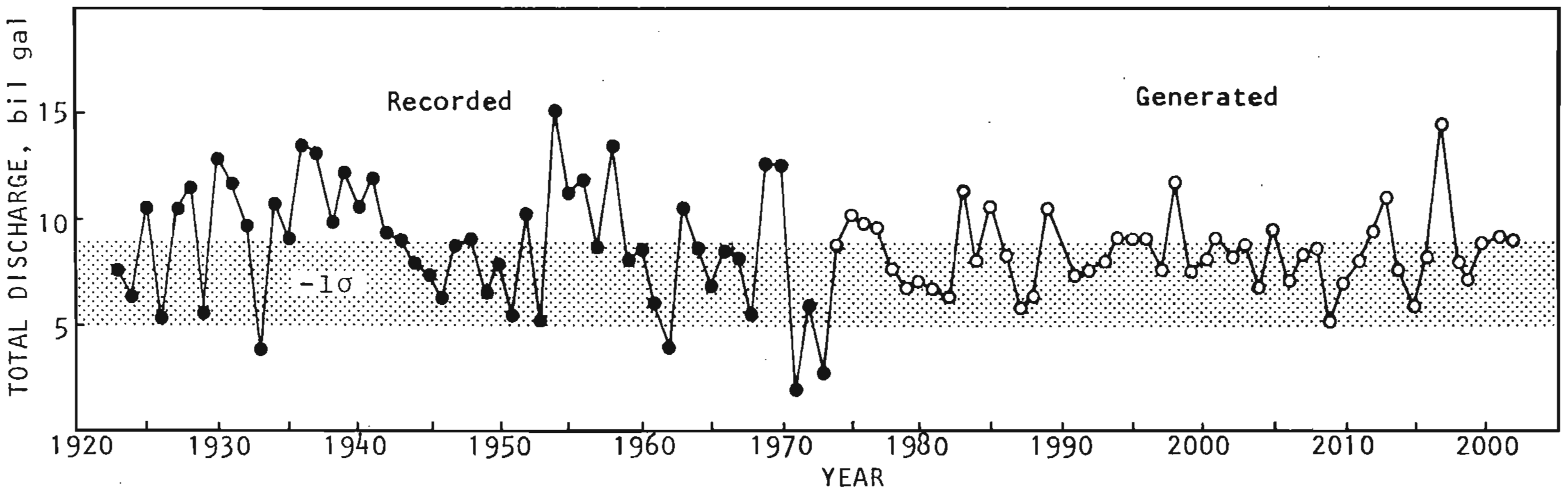


FIGURE 11. GENERATED WAILOA DITCH SUMMER FLOWS, (PEARSON TYPE III), 1973-2022

month, for the following season, and for the following year?

These questions are very difficult to answer but drought alleviating decisions are to be made based upon these answers. Some insight for the answers of the first two questions can be obtained from the results of this study, although they may not offer direct answers.

The results of this study have been presented in two major groups which are the low-flow frequency curves (Figs. 3 to 7) and the stochastic generated summer month flows for the Wailoa ditch (Figs. 8 to 11). The use of the low-flow frequency curves, such as that presented in Figure 3, are on an event basis. For example, in Figure 3, if both the magnitude and the recurrence interval are given, the duration of the corresponding low flow of the Wailoa ditch can be ascertained, and the answer for the first question is partially obtained. However, the sequential behavior of that low flow cannot be obtained from the low-flow frequency curves as shown in Figure 3. In other words, the sequential occurrence of a 15-yr recurrence interval low flow may not happen exactly at 15-yr intervals. In fact, according to recorded Wailoa ditch data, the low flow with the magnitude of a 15-yr recurrence interval occurred as close as in 1971 and 1973. In this respect, the stochastic generated low-flow data sets would offer some insight on the sequential behavior of the low flows because synthetic data can be generated to any desired period and to any desired number of data sets. For example, based upon the normal distribution, three sets of summer-month flows (Figs. 8 to 10) were generated for the period 1974 to 2022 and, based upon the Pearson Type III distribution, one set of synthetic data (Fig. 11) was also generated for the same period. By an inspection of these 4-set synthetic data, none of them exhibit a sequential combination worse than the recorded 1971 and 1973 combination. With the aid of a high speed computer, the decision-maker can study a larger number of generated data sets, so that the probability of the worst combination of low-flow sequential events may be inspected. Thus, decisions to alleviate the worst drought may be made, and the answer for the second question is partially obtained.

CONCLUSIONS

Based upon the study results of this project, the following conclusions were obtained:

1. Low-flow frequency curves can only provide the probability of occurrence of a drought in terms of a given magnitude of flow, its duration and its recurrence interval. It cannot, however, provide the sequential occurrence of the low flow for decision-making purposes.
2. Stochastic lag 1 Markov Model generated Wailoa ditch low-flow data should not be used as predicted future low-flow data; in other words, the lag 1 Markov Model is not a prediction model.
3. For the Wailoa ditch data generating purpose, the use of the normal distribution for the random term is recommended. The Pearson Type III distribution displays poorer simulation than the normal distribution.
4. The stochastic lag 1 Markov Model is capable of generating large numbers of stochastic sequential low-flow patterns of the Wailoa ditch for decision-makers to detect the probable worst combinations of low-flow sequential patterns.
5. The closely spaced 1971 and 1973 recorded summer low flows for the Wailoa ditch was probably one of the rare combination of sequential low flows for a long period. None of the four sets of generated data displayed similar combinations.
6. Decision-makers can follow the application examples cited in this study and to apply the developed methodology for their decision-making.

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APPENDIX. COMPUTER PROGRAMS FOR DATA GENERATION AND DATA PRESENTATION BY PLOTTING

```
C      THIS PROGRAM IS A SEQUENTIAL SIMULATION MODEL.  IT UTILIZES THE
C      ONE-LAG MARKOV RECURSION FORMULA.  THIS PROGRAM USES THE NOR-
C      MAL DISTRIBUTION TO DETERMINE THE RANDOM ERROR PORTION OF THE
C      FORMULA.
C      IT GENERATES THREE SEQUENTIAL SIMULATION SERIES.
C      IT ALSO PUNCHES THE SERIES ON CARDS FOR USE OF THE PROGRAM IN-
C      VOLVING THE COMPUTER PLOTTER.
C
C
C      INPUT FORMAT
C
C
C      CARD 1 - NUMBER OF YEARS OF RECORDS, N, COLUMNS 1 - 4.
C               STATION NUMBER COLUMNS 5 - 8.
C
C      NEXT N CARDS - INPUT DATA, COLUMN 6 - 7, YEAR
C                                 COLUMNS 9 - 80, INPUT DATA FOR 12
C                                                 MONTHS, 6 COLUMNS
C                                                 PER MONTH.
C
C
C      THE LIMIT OF THE INPUT DATA IS 100 YEARS, BUT THIS CAN BE IN-
C      CREASED SIMPLY BY CHANGING THE DIMENSION AND FORMAT STATEMENTS.
C
C
       DIMENSION SD(12),IYEAR(100),Q(100,12),R(12),B(12),QTOTAL(100)
       INTEGER YEAR(100)
       REAL MEAN(12),MEAN2(12)
       IX=1162261467
C
C      IX IS THE SEED FOR THE RANDOMLY GENERATED NUMBER.
C
       S=1.0000
C
C      S IS THE STANDARD DEVIATION FOR THE NORMAL DISTRIBUTION.
       AM=0.0000
C
C      AM IS THE MEAN FOR THE NORMAL DISTRIBUTION.
C      THESE PARAMETERS ARE FED INTO THE SUBROUTINE GAUSS WHICH SE-
C      LECTS A RANDOM NUMBER FROM A NORMAL DISTRIBUTION.
C
    80 READ(5,100)N,NSTA
C
C      READ IN THE NUMBER OF YEARS OF DATA AVAILABLE AND THE STATION
C      NUMBER.
C
       IF(N.EQ.0)GO TO 99
       WRITE(6,200)NSTA
       DO 10 I=1,N
       IF(I.EQ.N)GO TO 25
```

```
            READ(5,101)IYEAR(I),(Q(I,J),J=1,12)
      C
      C     READ IN THE YEAR AND THE 12 MONTHLY VALUES FOR EACH YEAR.
      C
            YEAR(I)=1900+IYEAR(I)
            GO TO 10
         25 READ(5,101)IYEAR(I),(Q(I,J),J=1,9)
            YEAR(I)=1900+IYEAR(I)
         10 CONTINUE
            K=N-1
            CALL STAT(K,Q,MEAN,B,SD,R)
      C
      C     STAT IS A SUBROUTINE WHICH COMPUTES THE STATISTICAL PARAME-
      C     TERS OF A SAMPLE SET.  IT COMPUTES THE MEANS, REGRESSION
      C     COEFFICIENTS, STANDARD DEVIATIONS AND CORRELATION COEFFICIENTS.
      C
            CALL GAUSS(IX,S,AM,V)
      C
      C     GAUSS IS A SSP (SCIENTIFIC SUBROUTINE PACKAGE) SUBROUTINE,
      C     IT SELECTS A RANDOM NUMBER FROM A NORMAL DISTRIBUTION.
      C     WHERE:  IX = INPUT PARAMETER, IS THE SEED FOR THE RANDOMLY
      C                  GENERATED NUMBER.
      C              S = INPUT PARAMETER, IS THE STANDARD DEVIATION OF
      C                  THE NORMAL DISTRIBUTION.
      C             AM = INPUT PARAMETER, IS THE MEAN OF THE NORMAL DIS-
      C                  TRIBUTION.
      C              V = OUTPUT PARAMETER, IS THE RANDOM NUMBER SELECTED
      C                  FROM THE NORMAL DISTRIBUTION.
      C
            Q(N,10)=MEAN(10)+B(9)*(Q(N,9)-MEAN(9))+V*SD(10)*SQRT(1-R(9)
           2*R(9))
            CALL GAUSS(IX,S,AM,V)
            Q(N,11)=MEAN(11)+B(10)*(Q(N,10)-MEAN(10))+V*SD(11)*SQRT(1-R
           2(10)*R(10))
            CALL GAUSS(IX,S,AM,V)
            Q(N,12)=MEAN(12)+B(11)*(Q(N,11)-MEAN(11))+V*SD(12)*SQRT(1-R
           2(11)*R(11))
            N1=N+1
            DO 55 M1=1,3
      C
      C     THIS DO LOOP DOMPUTES 3 DIFFERENT SERIES.
      C
            DO 40 I=N1,100
            YEAR(I)=YEAR(N)+I-N
            DO 40 J=1,12
            M=J
            K=I
            IF(J,NE,1)GO TO 50
            M=13
            K=I-1
         50 CALL GAUSS(IX,S,AM,V)
            Q(I,J)=MEAN(J)+B(M-1)*(Q(K,M-1)-MEAN(M-1))+V*SD(J)*SQRT(1-R
           2(M-1)*R(M-1))
      C
```

```
C     THE ABOVE IS THE ONE-LAG MARKOV RECURSION EQUATION WITH USE OF
C     THE NORMAL DISTRIBUTION FOR DETERMINATION OF THE RANDOM ERROR
C     TERM IN THE EQUATION.  I REPRESENTS THE YEAR AND J REPRESENTS THE
C     MONTH.  THEREFORE, IT MUST BE NOTED THAT WHEN J = 1 (JANUARY),
C     J - 1 MUST BE 12 (DECEMBER) OF THE PREVIOUS YEAR.  THIS ACCOUNTS
C     FOR THE USE OF K AND M IN THE EQUATION.
C
      IF(Q(I,J).LT.0.)GO TO 50
   40 CONTINUE
      WRITE(6,201)
      DO 55 I=N1,100
      QTOTAL(I)=0.
      DO 60 J=6,9
      QTOTAL(I)=QTOTAL(I)+Q(I,J)
   60 CONTINUE
      QQQ=QTOTAL(I)/1000+.005
      WRITE(6,202)YEAR(I),(Q(I,J),J=6,9),QTOTAL(I)
      WRITE(7,203)YEAR(I),QQQ
C
C     PUNCH CARDS FOR USE OF THE PROGRAM INVOLVING THE COMPUTER PLOTTER.
C
   55 CONTINUE
      WRITE(6,210)
      GO TO 80
C
C     THE ENTIRE PROGRAM IS REPEATED IF THERE ARE MORE DATA SETS.  WHEN
C     N = 0,  WHICH MEANS THERE NO LONGER IS DATA, THE PROGRAM WILL
C     STOP EXECUTING.
C
  100 FORMAT(I4,1X,I4)
  101 FORMAT(5X,I2,1X,12F6.2)
  200 FORMAT('1',40X,'STATION NO. ',I4)
  201 FORMAT('-','YEAR',2X,'MONTHS:',3X,'JUN',5X,'JUL',5X,'AUG',5X,'SEP'
     2,5X,'TOTAL'//)
  202 FORMAT(' ',I4,9X,4(1X,F7.2),1X,F8.2)
  203 FORMAT(6X,'*',13X,I4,',',F5.2)
  210 FORMAT(1H1)
   99 STOP
      END

      SUBROUTINE STAT(L,X,AVE,B,SD,R)
C
C     SUBROUTINE STAT COMPUTES THE STATISTICAL PARAMETERS OF THE DATA
C     SET.
C     WHERE:  L = INPUT PARAMETER, IS THE NUMBER OF YEARS OF DATA.
C             X = INPUT PARAMETER, IS THE INPUT DATA
C             AVE, B, SD AND R ARE OUTPUT PARAMETERS.
C             AVE(J) = AVERAGE OF INPUT DATA FOR MONTH J
C             B(J) = REGRESSION COEFFICIENT OF DATA FOR MONTH J TO
C                    MONTH J+1
C             SD(J) = STANDARD DEVIATION OF DATA FOR MONTH J
C             R(J) = CORRELATION COEFFICIENT OF DATA FOR MONTH J TO
C                    MONTH J+1
C
```

```
      DIMENSION X(100,12),AVE(12),B(12),SD(12),R(12),A(12),C(12),D(12),
     2 E(12),VAR(12),U3(12)
      DO 10 J=1,12
      A(J)=0.
      C(J)=0.
      D(J)=0.
   10 E(J)=0.
      DO 20 J=1,12
      DO 20 I=1,L
      C(J)=C(J)+X(I,J)
      D(J)=D(J)+X(I,J)*X(I,J)
   20 CONTINUE
      DO 30 J=1,12
      AVE(J)=C(J)/L
      G=0.
      H=0.
      DO 40 I=1,L
      W=X(I,J)-AVE(J)
      H=H+W*W*W
   40 G=G+W*W
      VAR(J)=1./(L-1.)*G
      U3(J)=L/((L-1.)*(L-2.))*H
      SD(J)=SQRT(VAR(J))
   30 CONTINUE
      DO 50 I=1,L
      DO 50 J=1,12
      K=I
      M=J
      IF(J.NE.12)GO TO 55
      M=0
      K=I+1
      IF(I.EQ.L.AND.J.EQ.12)GO TO 50
   55 E(J)=E(J)+X(I,J)*X(K,M=1)
   50 CONTINUE
      E(12)=E(12)+X(L,12)*X(1,1)
      DO 60 J=1,12
      M=J
      IF(J.EQ.12)M=0
      B(J)=(E(J)-(C(J)*C(M+1))/L)/(D(J)-(C(J)*C(J))/L)
      R(J)=B(J)*SD(J)/SD(M+1)
   60 CONTINUE
      RETURN
      END

      SUBROUTINE RANDU(IX,IY,YFL)
      IY=IX*1162261467
      IF(IY)5,6,6
    5 IY=IY+2147493647+1
    6 YFL=IY
      YFL=YFL*.4646613E-9
      RETURN
      END
```

```
      SUBROUTINE GAUSS(IX,S,AM,V)
      A=0.0
      DO 50 I=1,12
      CALL RANDU(IX,IY,Y)
      IX=IY
   50 A=A+Y
      V=(A-6.)*S+AM
      RETURN
      END
```

STATION NO. 5880 (IN MIL GAL): NORMAL 1

YEAR	MONTHS: JUNE	JULY	AUG	SEPT	TOTAL
1974	1460.17	2778.36	3957.69	2706.94	10903.16
1975	1700.57	3393.74	4299.95	2322.77	11717.02
1976	3486.16	4446.59	3431.18	3300.12	14664.05
1977	1667.95	4585.92	3397.34	2002.98	11654.20
1978	1944.68	3468.77	3878.03	1712.94	11004.41
1979	2723.38	3927.97	3189.26	3686.84	13527.45
1980	2806.94	3552.82	3453.32	3368.35	13181.42
1981	3306.05	3938.92	5813.06	4093.13	17151.15
1982	3222.95	3709.31	3083.50	2279.29	12295.04
1983	2687.55	4977.46	4166.38	3096.01	14927.39
1984	3825.33	3629.74	4834.02	4389.79	16678.87
1985	2892.97	4398.79	4590.22	3335.83	15217.81
1986	2687.70	2728.40	3225.77	2180.74	10822.60
1987	2046.85	2901.61	3435.67	1918.58	10302.71
1988	3198.77	3584.36	4956.09	4850.34	16589.56
1989	2836.42	4020.47	3309.80	3313.66	13480.35
1990	1786.97	3209.96	3434.77	4098.89	12530.58
1991	3959.82	2814.88	3723.45	3136.66	13634.81
1992	4205.42	4376.37	3623.96	3413.65	16619.39
1993	3959.80	3532.00	3493.12	1709.78	12694.70
1994	1447.67	2561.62	2871.84	2574.78	9455.90
1995	4520.93	5061.01	5549.21	3729.58	18860.73
1996	1189.57	1377.38	3705.29	2537.56	8809.80
1997	5227.89	5373.21	4157.18	1868.51	16626.80
1998	4074.28	3043.98	2119.16	568.24	9805.64
1999	2969.05	2944.10	2880.05	3493.81	12287.01
2000	4146.28	5214.48	4180.20	3195.83	16736.79
2001	2298.71	2965.77	3443.58	2066.85	10774.90
2002	3555.38	4036.52	2898.27	2581.67	13071.84
2003	3033.62	2669.56	3067.07	2724.17	11494.41
2004	4962.24	4295.15	5167.05	3609.57	18034.01
2005	2130.35	4767.82	3153.23	3152.59	13203.98
2006	4049.42	3518.08	3810.73	2762.80	14141.02
2007	3944.98	4269.07	5661.41	3656.14	17531.59
2008	3888.79	4145.85	2990.44	2263.31	13288.38
2009	2262.11	1657.73	3547.42	3407.79	10875.05
2010	2084.53	3704.76	4594.10	4220.13	14603.51
2011	4140.03	4903.26	3941.91	2634.43	15619.63
2012	3493.36	2891.33	4559.77	2851.84	13796.30
2013	2366.95	3116.18	2779.86	1117.92	9380.90
2014	4537.96	4605.25	2788.85	3987.24	17919.31
2015	5395.08	6558.11	4131.99	3613.94	19699.13
2016	4620.86	5476.09	5282.37	3254.77	17634.08
2017	3188.13	6470.55	5743.04	3755.20	19156.91
2018	2131.00	2531.73	3873.68	3506.66	12043.06
2019	2684.49	4039.26	5013.43	3095.20	14832.38
2020	3791.18	4857.13	5029.14	2845.46	16522.91
2021	2496.96	4383.42	3635.16	2492.24	13007.77
2022	1807.88	2570.62	3737.89	2204.19	10320.58

NOTE: 1 MIL GAL = 3,785 M^3

STATION NO. 5880 (IN MIL GAL): NORMAL 2

YEAR	MONTHS: JUNE	JULY	AUG	SEPT	TOTAL
1974	3376.76	5142.84	5608.78	3684.41	17812.79
1975	1765.66	3418.19	3319.02	3955.29	12458.16
1976	1341.35	3570.90	4867.62	4305.26	14085.13
1977	3394.01	5013.73	4876.96	3720.84	17005.55
1978	2482.49	3007.52	4752.78	3403.42	13646.21
1979	4120.70	4806.39	2847.64	1342.64	13117.35
1980	2841.80	3240.88	3666.28	3236.06	12985.02
1981	1662.63	3737.37	4818.80	3676.23	13895.02
1982	2414.55	3263.18	2114.03	859.93	8651.68
1983	3197.01	4358.95	5114.81	4548.53	17219.30
1984	3837.68	3221.33	2784.18	3027.59	12870.77
1985	2951.09	4404.10	4895.17	2588.57	14838.93
1986	4288.48	5082.76	4262.75	1736.63	15370.61
1987	3102.89	4239.83	2417.62	1807.32	11567.65
1988	2553.37	3945.60	4430.36	3330.29	14259.62
1989	1680.11	2418.96	3341.09	2510.78	9950.94
1990	3851.39	4451.10	3933.92	2738.18	14974.58
1991	2767.92	3507.83	2097.54	85.61	8458.89
1992	2576.50	4825.80	4573.23	4604.64	16580.17
1993	722.43	1930.06	3259.91	2979.55	8891.95
1994	2321.71	4793.15	4720.39	2261.07	14096.31
1995	5080.20	3793.52	2797.24	3206.79	48077.74
1996	2494.45	3088.35	3114.37	2653.76	11350.93
1997	2845.12	4515.07	4917.88	3022.45	15300.52
1998	1975.25	2423.37	3629.81	2979.99	11008.42
1999	4077.25	4541.50	2148.22	1668.84	12435.80
2000	3277.49	3732.54	3550.83	3227.45	13788.30
2001	2038.44	2866.62	4471.34	3231.99	12608.39
2002	3381.36	5531.48	5635.02	5745.09	20292.94
2003	1719.01	3610.99	3640.90	3443.07	12413.96
2004	1861.14	4104.10	3367.28	2656.99	11989.51
2005	1395.57	2912.01	3374.49	2728.30	10410.36
2006	3422.87	4708.85	4272.30	3371.61	15775.63
2007	3949.65	4809.85	5277.02	5224.05	19260.57
2008	3125.30	4180.04	5385.72	2507.61	15198.67
2009	3107.76	4294.36	4294.88	3710.14	15407.14
2010	2266.01	2920.53	3745.82	2106.13	11038.49
2011	4955.41	3440.62	4420.16	3258.01	16074.19
2012	4922.58	4231.21	2675.61	1945.15	13774.55
2013	4131.94	6051.60	3027.84	2064.01	15275.39
2014	4604.39	3427.73	4276.54	2428.54	14737.18
2015	2170.78	3798.45	4241.68	1581.78	11792.68
2016	5285.06	5448.34	5212.68	4592.48	20538.56
2017	3884.25	4930.99	5021.54	3426.34	17263.13
2018	4419.32	5650.47	4308.63	3570.43	17948.85
2019	3076.14	2790.01	3671.22	2736.28	12273.64
2020	3499.46	3680.69	2373.01	1826.23	11379.39
2021	2526.42	3895.56	3766.75	2064.56	12253.29
2020	2432.61	3541.11	3053.23	3818.11	12845.05

NOTE: 1 MIL GAL = 3,785 M^3

STATION NO. 5880 (IN MIL GAL): NORMAL 3

YEAR	MONTHS: JUNE	JULY	AUG	SEPT	TOTAL
1974	2108.73	4158.14	3801.86	4024.41	14093.13
1975	2837.60	4019.36	4130.64	2336.66	13324.25
1976	1463.32	2528.73	3443.72	2909.46	10345.22
1977	4059.51	4332.14	4951.57	3516.29	16859.51
1978	4864.34	5168.16	4087.75	2820.76	16941.01
1979	3968.78	3807.03	2271.89	2625.36	12673.06
1980	2344.32	3242.84	4164.99	2974.87	12727.03
1981	1791.15	3098.16	3443.57	2550.72	10883.59
1982	1840.54	3318.47	4285.48	2635.11	12079.59
1983	1655.21	795.79	2503.32	2018.85	6973.16
1984	3189.16	4212.51	3123.24	2672.88	13197.79
1985	4118.44	4026.09	2380.55	2293.61	12818.68
1986	2933.58	2461.65	5713.61	3976.42	15085.25
1987	4373.39	4948.91	4025.90	3248.65	16596.84
1988	1225.30	2911.08	4454.44	4491.86	13082.68
1989	1676.78	2549.13	4130.74	2507.28	10863.93
1990	2048.47	3667.21	5931.22	4712.38	16359.29
1991	2445.74	3148.67	2780.35	3045.47	11420.23
1992	2159.84	2201.39	4075.12	4403.44	12839.78
1993	2367.43	4172.07	4184.68	4058.50	14782.68
1994	3479.55	4131.93	4002.16	2283.77	13897.41
1995	3907.86	3482.82	4516.40	4289.38	16196.45
1996	2025.67	2400.26	4140.40	4246.39	12812.72
1997	3592.41	4761.74	4287.15	2561.26	15202.56
1998	1137.75	2403.70	2911.38	596.46	7049.28
1999	2040.44	2540.88	2248.74	1655.35	8485.40
2000	2606.28	3813.99	3504.44	2056.21	11980.92
2001	3874.51	4040.53	3846.21	2376.71	14137.95
2002	3496.52	5078.79	3598.52	2119.39	14293.21
2003	2645.93	3227.35	4273.71	2780.85	12927.84
2004	5160.54	5678.18	4646.25	2125.40	17610.37
2005	4084.26	4439.90	5171.15	3967.76	17663.07
2006	3779.65	3673.40	4147.82	3863.01	14463.88
2007	3637.83	4156.89	4542.75	2998.98	15336.44
2008	3506.05	4817.04	3161.19	3168.19	14652.47
2009	2226.21	3772.91	4314.71	3401.79	13715.61
2010	3424.40	3390.98	4030.62	3522.63	14368.63
2011	2700.30	3002.49	3164.00	1226.26	10093.05
2012	3670.86	3392.29	3705.86	2844.29	13613.30
2013	4052.80	3239.35	4664.51	3383.45	15340.11
2014	3089.69	3204.83	3956.54	4921.46	15172.52
2015	4216.91	5414.07	4759.55	4744.92	19135.45
2016	4131.04	5312.95	5152.84	3654.52	18251.35
2017	2747.50	2751.94	4068.58	3467.55	13035.57
2018	2051.69	4008.10	3875.20	3638.44	13573.43
2019	3745.33	3928.01	4589.38	3870.94	16133.66
2020	4307.77	4804.26	3543.32	1658.12	14313.47
2021	2867.31	3829.34	3589.92	2499.39	12785.95
2022	4373.41	5420.69	5619.38	4254.10	19667.58

NOTE: 1 MIL GAL = 3,785 M^3