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ANALYSIS OF LOW STREAMFLOWS ON CAPE BRETON ISLAND NOVA SCOTIA

WATER PLANNING AND MANAGEMENT BRANCH
INLAND WATERS DIRECTORATE,
ATLANTIC REGION,
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Abstract

1, 3, 7, 10 and 30-day, annual and summer low-flow frequency analyses were performed for 11 hydrometric stations on Cape Breton Island, Nova Scotia. A Gumbel III theoretical frequency distribution was employed with the parameters being estimated by the method of maximum likelihood. When this method failed to give a solution then the method of smallest observed drought was used. For the three long-term stations analyses of the most recent 15 years of record were also performed for the annual and summer periods as an indication of the accuracy of using stations with short term records. The data and the 140 frequency curves are displayed on 34 linear vs probability scale plots by a CALCOMP plotter. A regression analysis may be undertaken in the future between the 1:25 and 1:100-year summer low-flow values and various physiographic and climatic parameters with a view to developing a technique for estimating low flows of various durations for ungauged watersheds.

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Introduction

From time to time requests are received from government agencies and consulting firms, to provide estimates of low streamflows for various rivers and streams in the Atlantic Provinces. In order to respond to one such request and to provide a basis for future requests, the Water Planning and Management Branch has undertaken an analysis of low streamflows on Cape Breton Island, Nova Scotia.

Typically, the point on a stream or even the stream itself, on which estimates of low flows are required, does not have a hydrometric station at which streamflow records are kept. In order to provide estimates of streamflow a "regional analysis" is usually performed. Regional analyses can be of many forms; however, they all serve to apply hydrometric data collected, generally in the vicinity of the site under investigation, in some adjusted form to the study site(s). The mechanism of transferring this information can be extremely simple, as in utilizing a single nearby station's record adjusted solely on the basis of a comparison of drainage areas. Commonly, however, the procedure is more complex as in the cases where the streamflow characteristics of several metered watersheds are compared, perhaps through a regression analysis, on the basis of pertinent physiographical and climatological features and an equation or equations are produced into which these features of the study basin are entered to arrive at estimates of low flows.

The present study is intended to facilitate application of the latter approach at some point in the future. Individual station frequency analyses have been completed and a set of selected physiographical and climatological parameters have been compiled. This report summarizes the work that has been completed.

The portion of Nova Scotia under investigation is indicated in Figure 1. This area was considered in order to coincide with a feasibility study by Fisheries Management Service for a proposed fish culture station.

Hydrometric Data

The data from 11 hydrometric stations (1) were used. The drainage basins and the locations of the hydrometric stations are indicated in Figure 1. The largest basin, that of the Northeast Margaree River, drains 142 sq. mi. (368 km^2) and the smallest, that of April Brook, is 2.4 sq. mi. (6.2 km^2). The periods of record range from 59 years for the Northeast Margaree River to 10 years for April Brook. There are three stations with 25 years or more of record. The hydrometric stations and number of years of record available for analysis are listed in Table 1. None of the data for these stations are affected by man-made regulation; however, significant natural regulation occurs on the Southwest Margaree and Grand Rivers by the presence of Lake Ainslie and Loch Lomond respectively.

Data collected for the calendar year 1976 were the most recent considered.

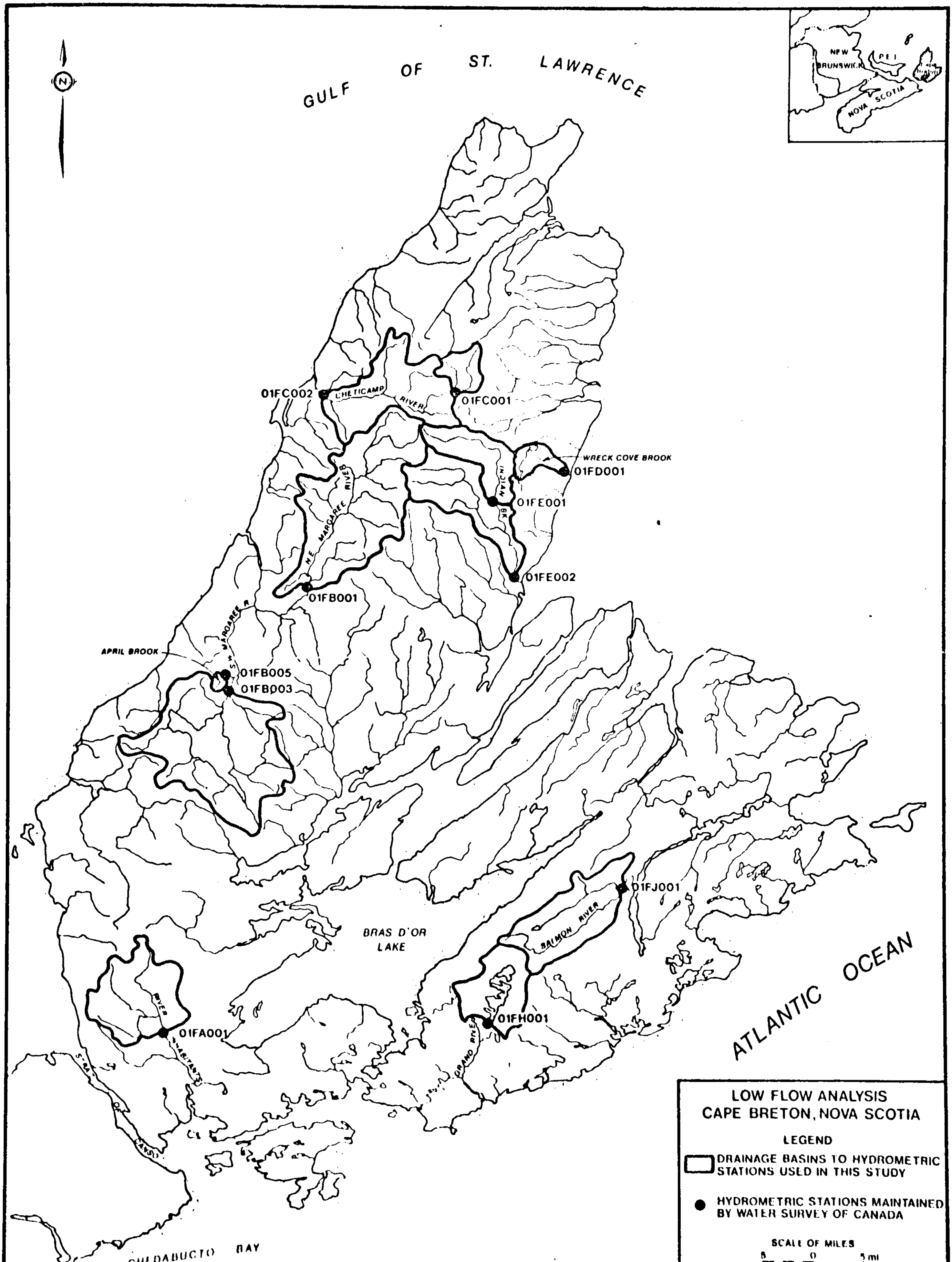
GULF OF ST. LAWRENCE
NEW BRUNSWICK
P.E.I.
NOVA SCOTIA
01FC002
CHETICAMP RIVER
01FC001
WRECK COVE BROOK
01FD001
N.E. MARGAREE RIVER
INDIAN BK
01FE001
01FE002
01FB001
MARGAREE R
APRIL BROOK
S.W. MARGAREE R
01FB005
01FB003
01FJ001
SALMON RIVER
BRAS D'OR LAKE
RIVER
01FA001
INHABITANTS
01FH001
GRAND RIVER
ATLANTIC OCEAN
CHEDABUCTO BAY
LOW FLOW ANALYSIS
CAPE BRETON, NOVA SCOTIA
LEGEND
DRAINAGE BASINS TO HYDROMETRIC STATIONS USED IN THIS STUDY
HYDROMETRIC STATIONS MAINTAINED BY WATER SURVEY OF CANADA
SCALE OF MILES

FIGURE 1

Table 1

CAPE BRETON ISLAND
HYDROMETRIC STATIONS USED IN THE STUDY

Station No.	Station Name	Years of Record
01FA001	River Inhabitants at Glenora	11
01FB001	Northeast Margaree River at Margaree Valley	59
01FB003	Southwest Margaree River near Upper Margaree	58
01FB005	April Brook at Gillisdale	10
01FC001	Cheticamp River below Cheticamp Lake	18
01FC002	Cheticamp River above Robert Brook	18
01FD001	Wreck Cove Brook near Wreck Cove	20
01FE001	Indian Brook near Matheson's Lake	16
01FE002	Indian Brook at Indian Brook	16
01FH001	Grand River at Loch Lomand	56*
01FJ001	Salmon River at Salmon River Bridge	11

*One additional year used in summer analysis

Frequency Analyses

Calendar Year

Frequency analyses were performed on the lowest 1, 3,7,10 and 30-day daily mean streamflows occurring in each calendar year. The Gumbel III theoretical frequency distribution, recommended for general application for low-flow analyses by Condie and Nix (2) was applied with the parameters being estimated by the method of maximum likelihood or, if this method failed to give a satisfactory solution, the method of smallest observed drought. The calculations were facilitiated by a computer program (3) prepared by G. A. Nix and L. G. Boone with the Inland Waters Directorate in Ottawa.

The resulting frequency curves are presented in Figures 2-1 to 2-11. For the Northeast Margaree River at Margaree Valley, the Southwest Margaree River near Upper Margaree and the Grand River at Loch Lomond hydrometric stations, the frequency curves and plotted data were too congested for one figure; therefore, separate plots 2-2A, 2-2B, 2-3A, 2-3B, 2-10A and 2-10B were prepared.

In some cases the frequency curves for the various duration periods for a given hydrometric station cross each other or appear unreasonable compared to the others, particularly for return periods of 25 or greater years. This is related primarily to the shortness of record for those stations. For the few cases where this type of problem occured, a visual adjustment was made. The troublesome portions are rectified by the dashed sections of several frequency curves.

Of particular interest in water resource studies are the extreme low flows with recurrence intervals of 25 and 100 years. The annual low-flow frequency curves display 30-day, 25-year recurrence low flows varying from 0.014 cfs/sq.mi. to 0.591 cfs/sq.mi. (0.00015 to 0.00646 $m^3/s/km^2$) for the Salmon River and Northeast Margaree River respectively and 1-day, 25 year recurrence low flows varying from 0.012 to 0.419 cfs/sq.mi. (0.00013 to 0.00458 $m^3/s/km^2$) for the Salmon River and Northeast Margaree River respectively. Annual low-flow estimates, with 25 and 100-year recurrence intervals and of 1,3,7,10 and 30-day duration, are presented in Table 2 for the 11 hydrometric stations.

In order to assess the effect of the length of record on the estimates of low flows, an analysis was also performed for the three stations having 25 years of record or more using the data for the 15 years from 1962 to 1976. The effect on the 25-year low-flow estimates is indicated on Table 3. The estimates based on the full period of record were lower for both the Northeast and Southwest Margaree Rivers but essentially equal for Grand River at Loch Lomond. A review of the mean annual total precipitation, for the only long term climatological station on Cape Breton Island, Sydney, may explain the results. In the 15-year period the mean annual total precipitation was approximately four inches higher than over the long term. It appears from this analysis that the extreme

TABLE 2

ANNUAL LOW FLOWS AND SELECTED PHYSIOGRAPHIC DATA

CFS/SQ. MI.

Metered Stream	STATION NUMBER	D. A. sq.mi	R yrs.	$Q_{1,25}$	$Q_{1,100}$	$Q_{3,25}$	$Q_{3,100}$	$Q_{7,25}$	$Q_{7,100}$	$Q_{10,25}$	$Q_{10,100}$	$Q_{30,25}$	$Q_{30,100}$
RIVER INHABITANTS	01FA001	74.5	11	.134	.121	.139	.124	.166	.153	.176	.162	.232	.219
N.E. MARGAREE RIVER	01FB001	142	59	.419	.349	.421	.349	.436	.361	.455	.380	.591	.548
S.W. MARGAREE RIVER	01FB003	133	53	.207	.143	.207	.144	.220	.161	.229	.172	.303	.259
APRIL BROOK	01FB005	2.4	10	.222	.124	.234	.174	.262	.205	.272	.225	.380	.357
CHETICAMP RIVER	01FC001	19.0	18	.229	.162	.239	.176	.265	.210	.278	.231	.373	.332
CHETICAMP RIVER	01FC002	32.5	18	.327	.294	.370	.349	.391	.366	.407	.383	.457	.419
WRECK COVE BROOK	01FD001	10.7	20	.055	.000	.068	.014	.089	.042	.095	.057	.132	.081
INDIAN BROOK	01FE001	31.8	16	.215	.203	.237	.228	.246	.234	.253	.240	.296	.266
INDIAN BROOK	01FE002	101	16	.160	.149	.175	.160	.185	.161	.213	.193	.304	.282
GRAND RIVER	01FH001	46.4	56	.012	.000	012	.000	.015	.005	.018	.007	.031	.012
SALMON RIVER	01FJ001	76.8	11	.012	.008	.013	.008	.013	.008	.014	.008	.014	.008

Metered Stream	A_S sq.mi	A_L sq.mi	A_T sq.mi	% D.A.	OB.	L mi.	D.D.	S ft/ft.	% CL.	Elev. ft.	PR. in.
RIVER INHABITANTS	1.53	0.06	1.59	2.1	1.22	75.6	1.01	.003	6.88	330	57.5
N.E. MARGAREE RIVER	1.33	0.60	1.93	1.4	1.20	113.1	0.80	.009	6.14	1200	[illegible]
S.W. MARGAREE RIVER	1.21	22.21	23.42	17.0	1.15	131.4	0.95	.0002	9.30	500	55.0
APRIL BROOK	0.0	0.0	0.0	0.0	1.25	1.65	0.69	.042	2.00	670	57.5
CHETICAMP RIVER	2.34	0.36	2.70	14.2	1.38	23.2	1.22	.032	26.06	1550	75.0
CHETICAMP RIVER	6.76	0.64	7.40	8.0	1.26	71.6	0.77	.020	13.27	1425	75.0
WRECK COVE BROOK	0.09	0.91	1.00	9.3	1.00	11.6	1.08	.034	1.34	1040	74.0
INDIAN BROOK	1.25	0.59	1.84	5.8	1.30	32.9	1.03	.005	13.75	1340	77.0
INDIAN BROOK	3.98	1.24	5.22	5.2	1.20	69.6	0.89	.012	7.20	1280	75.0
GRAND RIVER	2.51	6.42	8.93	19.2	1.06	65.7	1.42	.002	6.11	230	63.5
SALMON RIVER	2.51	4.98	7.49	9.8	1.08	74.3	0.97	.003	5.49	230	63.5

$Q_{x,y}$ - Low Flow For "x" Days Recurring Every "y" Years

D. A. - Drainage Area

R. - Period of Record

A_S - Area of Swamp

A_L - Area of Lake

A_T - Total Area of Lakes and Swamps

%D. A. - Percentage of Drainage Area Covered by Lakes and Swamps

O. B. - Overburden Index

L - Total Length of Stream

D. D. - Length of Stream Divided by Drainage Area

S - Average Slope of Main Stem

% CL. - Percentage of Drainage Area Which is Cleared, Dry Land

Elev. - Average Elevation of the Basin

PR. - Mean Annual Precipitation

Table 3

COMPARISON OF THE 25-YEAR ANNUAL LOW-FLOW ESTIMATES** FOR THE LONG-TERM HYDROMETRIC STATIONS WITH ESTIMATES BASED ON DATA FOR 1962-1976 ONLY

Station Number	Station Name	Years of Record	25-Year Low-Flows (cfs/sq.mi.) 1 Day PR*	1 Day 15yr.	3 Day PR*	3 Day 15yr.	7 Day PR*	7 Day 15yr.	10 Day PR*	10 Day 15yr.	30 Day PR*	30 Day 15yr.
01FB001	N.E. Margaree River at Margaree Valley	59	0.42	0.57	0.42	0.59	0.44	0.62	0.46	0.63	0.59	0.70
01FB003	S.W. Margaree River Near Upper Margaree	58	0.21	0.26	0.21	0.27	0.22	0.29	0.23	0.29	0.30	0.36
01FH001	Grand River at Loch Lomond	56	0.01	0.00	0.01	0.00	0.02	0.00	0.02	0.00	0.03	0.06

*PR = Period of Record

** = Estimates Have been Rounded to Two places of Decimal low-flow estimates for the short-term hydrometric stations may be high.

A correlation analysis of the data for all stations included in the study was performed. This analysis indicated that record extensions could not be carried out for any significant number of years.

Frequency Analyses

Summer Period

It became evident during the course of the investigation that the maximum water demand for the proposed fish culture station could be during the months of June to September; therefore, since some of the low flow data used in the annual analysis occurred during the winter, an independent summer analysis was performed.

The period June 1 to November 30 was selected and a new low-flow data set was prepared. The resulting summer-period frequency curves as well as the data points are presented in Figures 4-1 to 4-11. As was required for the annual analysis, the data and frequency curves for the Northeast Margaree River at Margaree Valley; Southwest Margaree River near Upper Margaree; and the Grand River at Loch Lomond had to be displayed on separate pages to relieve congestion. In a few cases, as in the annual analysis, minor visual adjustments were made. The adjusted portions of the frequency curves are indicated by dashed lines.

The summer low-flow frequency analysis indicates that the 30-day, 25-year recurrence summer low flows may vary from 0.015 to 0.666 cfs/sq.mi. (0.00016 to 0.00728 $m^3/s/km^2$) while the 1-day, 25-year recurrence summer low flows vary from 0.012 to 0.502 cfs/sq.mi. (0.00013 to 0.00549 $m^3/s/km^2$) for the Salmon River and Northeast Margaree River respectively based on the available data. Summer low-flow estimates with 25 and 100 year recurrence intervals and of 1,3,7,10 and 30-day durations are presented in Table 4.

A comparison of the low-flow estimates on Tables 2 and 4 reveals that only the Northeast Margaree River and April Brook have extreme summer low flows significantly larger than annual low flows (about 0.10 cfs/sq.mi. and 0.18 cfs/sq.mi. higher respectively), implying that extremely low flows usually occur on the Northeast Margaree River and April Brook during the winter months. This phenomenon may in part be due to the following: colder average winter temperatures on the western side of the Cape Breton Highlands topographic divide, the occurrence of moderate to thick depths of overburden material, and large baseflow from bedrock aquifers.

The effect of the length of record on estimates of summer low flows was studied by performing frequency analyses on the summer low-flow data sets for the three stations having more than 25 years of record. Data for the 15-year period from 1962 to 1976 were used. The

TABLE 4

SUMMER LOW FLOWS AND SELECTED PHYSIOGRAPHIC DATA

Metered Stream	Station Number	D. A. sq.mi	R yrs.	$Q_{1,25}$	$Q_{1,100}$	$Q_{3,25}$	$Q_{3,100}$	$Q_{7,25}$	$Q_{7,100}$	$Q_{10,25}$	$Q_{10,100}$	$Q_{30,25}$	$Q_{30,100}$
				CFS/SQ. MI.									
RIVER INHABITANTS	01FA001	74.5	11	.135	.124	.138	.129	.165	.159	.176	.167	.207	.200
N.E. MARGAREE RIVER	01FB001	142	59	.502	.460	.509	.463	.524	.471	.547	.504	.666	.633
S.W. MARGAREE RIVER	01FB003	138	58	.190	.126	.206	.145	.220	.161	.229	.173	.321	.289
APRIL BROOK	01FB005	2.4	10	.396	.375	.398	.393	.442	.431	.441	.431	.478	.466
CHETICAMP RIVER	01FC001	19.0	16	.229	.173	.233	.185	.260	.210	.276	.230	.373	.348
CHETICAMP RIVER	01FC002	92.5	18	.327	.291	.371	.348	.392	.368	.409	.382	.456	.417
WRECK COVE BROOK	01FD001	10.7	20	.055	.000	.069	.016	.088	.042	.095	.057	.120	.087
INDIAN BROOK	01FE001	31.8	16	.215	.202	.237	.228	.246	.234	.253	.240	.293	.269
INDIAN BROOK	01FE002	101	16	.160	.149	.174	.160	.184	.163	.212	.194	.304	.282
GRAND RIVER	01FH001	46.4	57	.012	.000	.013	.000	.016	.006	.018	.007	.030	.013
SALMON RIVER	01FJ001	76.8	11	.012	.008	.013	.008	.013	.008	.015	.007	.015	.007

Metered Stream	A_S sq.mi	A_L sq.mi	A_T sq.mi	% D.A.	OB.	L mi.	D.D.	S ft/ft.	% CL.	Elev. ft.	PR. in.
RIVER INHABITANTS	1.53	0.06	1.59	2.1	1.22	75.6	1.01	.003	6.99	390	69.5
N.E. MARGAREE RIVER	1.33	0.06	1.93	1.4	1.20	113.1	0.80	.009	6.14	1200	71.0
S.W. MARGAREE RIVER	1.21	22.21	23.42	17.0	1.15	131.4	0.95	.0002	9.30	500	58.0
APRIL BROOK	0.0	0.0	0.0	0.0	1.25	1.65	0.69	.042	2.00	670	57.5
CHETICAMP RIVER	2.34	0.36	2.70	14.2	1.38	23.2	1.22	.002	26.06	1550	78.0
CHETICAMP RIVER	6.76	0.64	7.40	8.0	1.26	71.6	0.77	.020	13.20	1425	76.0
WRECK COVE BROOK	0.09	0.91	1.00	9.3	1.00	11.6	1.06	.034	1.34	1040	74.0
INDIAN BROOK	1.25	0.59	1.84	5.8	1.30	32.9	1.03	.005	13.75	1340	77.0
INDIAN BROOK	3.98	1.24	5.22	5.2	1.20	89.6	0.89	.012	7.20	1280	75.0
GRAND RIVER	2.51	6.42	8.93	19.2	1.06	65.7	1.42	.002	6.11	290	63.0
SALMON RIVER	2.51	4.98	7.49	9.8	1.08	74.3	0.97	.003	5.49	290	63.5

$Q_{x,y}$ - Low Flow for "x" Days Recurring Every "y" Years

D. A. - Drainage Area

R. - Period of Record

A_S - Area of Swamp

A_L - Area of Lake

A_T - Total Area of Lakes and Swamps

%D. A. - Percentage of Drainage Area Covered by Lakes and Swamps

O. B. - Overburden Index

L - Total Length of Stream

D. D. - Length of Stream Divided by Drainage Area

S - Average Slope of Main Stem

% CL. - Percentage of Drainage Area Which is Cleared, Dry Land

Elev. - Average Elevation of the Basin

PR. - Mean Annual Precipitation

The effect on the 25-year, low-flow estimates is indicated in Table 5. The estimates based on the 15-year period are generally higher for the Northeast and Southwest Margaree Rivers and essentially the same for Grand River at Loch Lomond. The magnitude of the difference in the low-flow estimates for a given station is approximately the same no matter whether the duration period is 1,3,7 or 10 days.

A further comparison making use of the 100-year low-flow estimates is presented in Table 6. The magnitude of difference for the 1,3,7 and 10-day duration periods is approximately the same for a given station; however, the 30-day, 100-year recurrence low-flow estimates are essentially the same, except for the Northeast Margaree River at Margaree Valley. This may be attributed to the fact that the other two long-term hydrometric stations are buffered by relatively large bodies of water, ie., Lake Ainslie and Loch Lomond.

These comparisons, as for the annual analyses, indicate that estimates of extreme low flows based on short periods of record will probably be high.

Physiographical and Climatological Features

As mentioned earlier, a regional analysis can, and in fact should, take into consideration pertinent physiographic and climatic features which may have an influence on low flows.

Table 5

COMPARISON OF THE 25-YEAR SUMMER LOW-FLOW ESTIMATES** FOR THE LONG-TERM HYDROMETRIC STATIONS WITH ESTIMATES BASED ON DATA FOR 1962-1976 ONLY

Station Number	Station Name	Years of Record	25-Year Low-Flows (cfs/sq.mi.) 1 Day PR*	1 Day 15yr	3 Day PR*	3 Day 15yr.	7 Day PR*	7 Day 15yr.	10 Day PR*	10 Day 15yr.	30 Day PR*	30 Day 15yr.
01FB001	N.E. Margaree River at Margaree Valley	59	0.50	0.58	0.51	0.60	0.52	0.62	0.55	0.63	0.67	0.71
01FB003	S.W. Margaree River near Upper Margaree	58	0.19	0.26	0.21	0.27	0.22	0.29	0.23	0.29	0.32	0.36
01FH001	Grand River at Loch Lomond	57	0.01	0.00	0.01	0.00	0.02	0.00	0.02	0.00	0.03	0.05

*PR = Period of Record

** = Estimates Have Been Rounded to Two Places of Decimal

Table 6

COMPARISON OF THE 100-YEAR SUMMER LOW-FLOW ESTIMATES* FOR THE LONG-TERM HYDROMETRIC STATIONS WITH ESTIMATES BASED ON DATA FOR 1962-1976 ONLY

Station Number	Station Name	Years of Record	100 Year Low-Flows (cfs/sq.mi.) 1 Day PR*	1 Day 15yr.	3 Day PR*	3 Day 15yr.	7 Day PR*	7 Day 15yr.	10 Day PR*	10 Day 15yr.	30 Day PR*	30 Day 15yr.
01FB001	N.E. Margaree River at Margaree Valley	59	0.46	0.54	0.46	0.56	0.47	0.58	0.50	0.60	0.63	0.66
01FB003	S.W. Margaree River near Upper Margaree	58	0.13	0.20	0.14	0.21	0.16	0.23	0.17	0.23	0.29	0.29
01FH001	Grand River at Loch Lomond	57	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.00	0.01	0.01

*PR = Period of Record

* = Estimates Have Been Rounded to Two Places of Decimal

Presented in Table 2 and repeated in Table 4 are the drainage areas, area covered by lake; area covered by swamp; percentage of drainage basin which is cleared, dry land; average elevation; total length of stream; slope of the main stream; drainage density and an overburden coefficient for the drainage to each of the hydrometric stations.

The drainage areas were provided by the Water Survey of Canada (4). The lake and swamp areas, cleared areas, total length of streams and slopes of the main streams were determined from 1:50,000 NTS maps. The main stream slopes are based on the difference in elevation between points located 15 and 90 percent of the length from the origin of the watercourse as indicated on the NTS maps.

The soil coefficients and the average elevations of the catchments were determined using data from the 10 km square grid data bank (5) developed in 1970 by the Department of Energy, Mines and Resources. The average elevation of each square is based on 9 spot elevations estimated to the nearest 50 feet from the 1:250,000 scale transverse Mercator projection maps showing 100 foot contour intervals. The overburden coefficients are an index of the soil cover. A value of 1.00 denotes bare rock and minimum soil cover and 3.00 denotes deep cover such as found in marshland and floodplains.

Table 2 and 4 also include the mean annual total precipitation over the catchment. The precipitation estimates are based on an isohyetal map recently completed by Water Planning and Management Branch, Inland Waters Directorate, Atlantic Region as part of this study.

This isohyetal map was prepared using nine years of record (1968-1976) for nine meteorlogical stations throughout Cape Breton. This map was prepared and reviewed under the guidance of the Atmospheric Environment Service, Atlantic Region.

Other physiographic variables of drainages such as mean latitudes, mean distances to the east (sea), basin perimeters and various form or shape factors could also be considered in a regional analysis. Of course, it is impossible to make use of a large number of variables in a regional analysis; however, it is important to apply those which provide the best correlation with the low flows for the metered drainages.

Some of the potential variables are not independent of each other. A specific example is the basic precipitation and the average elevation combined with location variables such as the basin latitude or the distance to the sea. There is little point including all of these in the analysis.

A close comparison of the physiographical and climatological features with the estimates of extreme summer-period unit low flows presented in Table 4 indicates a tendency to higher unit low flows for drainages with higher overburden coefficients. The effects of a variation in features such as the average elevation and precipitation, the cleared area and stream density, are not immediately evident, but may be defined through regression analyses.

Summary and Dicussion of Future Work

Many studies have shown that low flows are more difficult to estimate than other streamflow characteristics. Some investigations have even concluded that low-flow characteristics at ungauged sites on natural-flow streams cannot be estimated accurately by regression (6,7). The basis for this statement is probably one of frustration at the lack of directly applicable watershed physiographic and climatic data or at the amount of effort required to manipulate existing data bases to provide estimates of desired parameters such as indices of watershed evaporative power and drought potential during low-flow periods. Chang and Boyer (6) have obtained a standard error of estimate of 30% in estimating 7-day, 10-year low flows in a recently-completed study of 12 rivers varying in drainage area from 64 to 916 sq. mi. in West Virginia.

This investigation may be continued in the future to produce equations to estimate extreme low flows for ungauged watersheds in Cape Breton Island, Nova Scotia.

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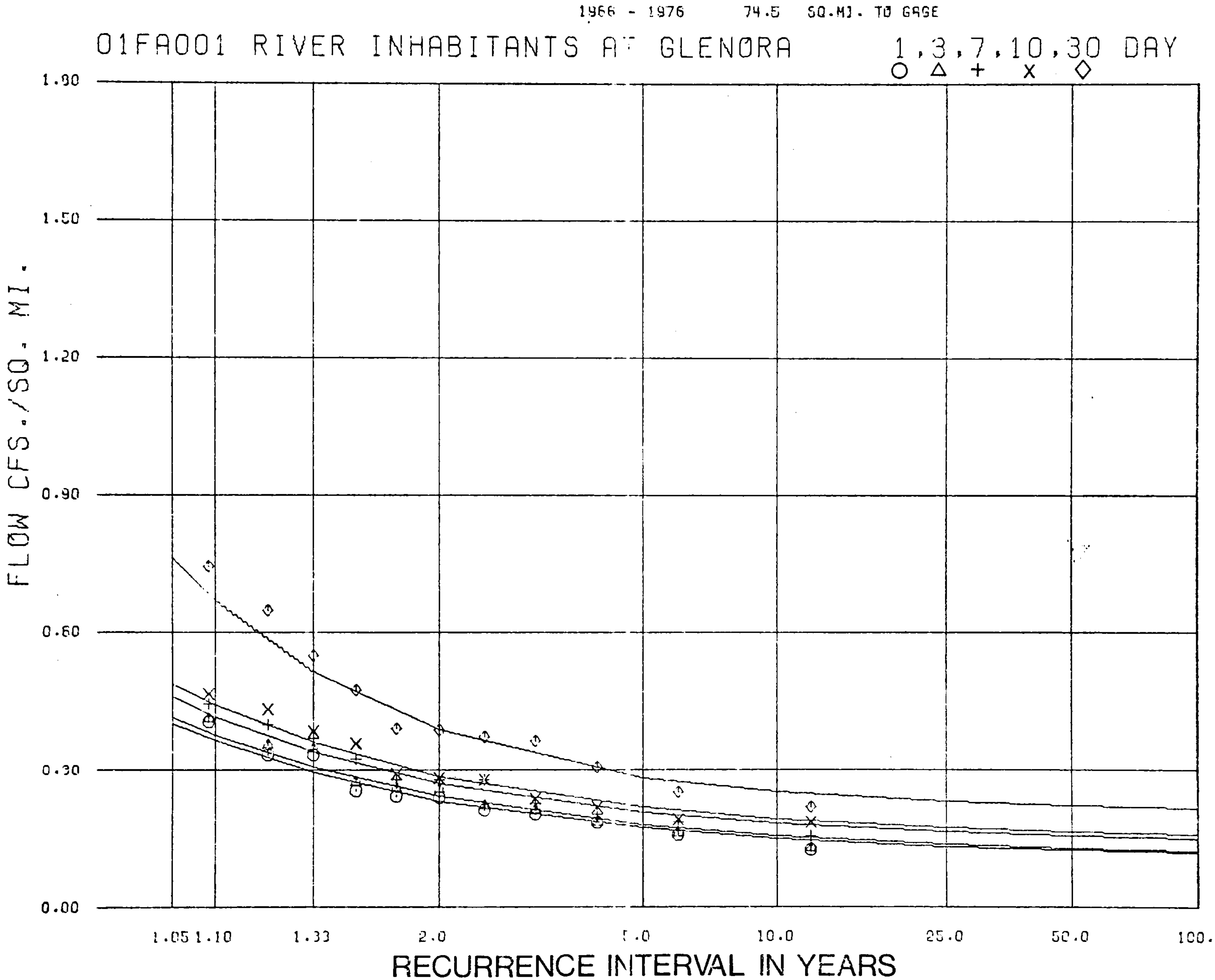
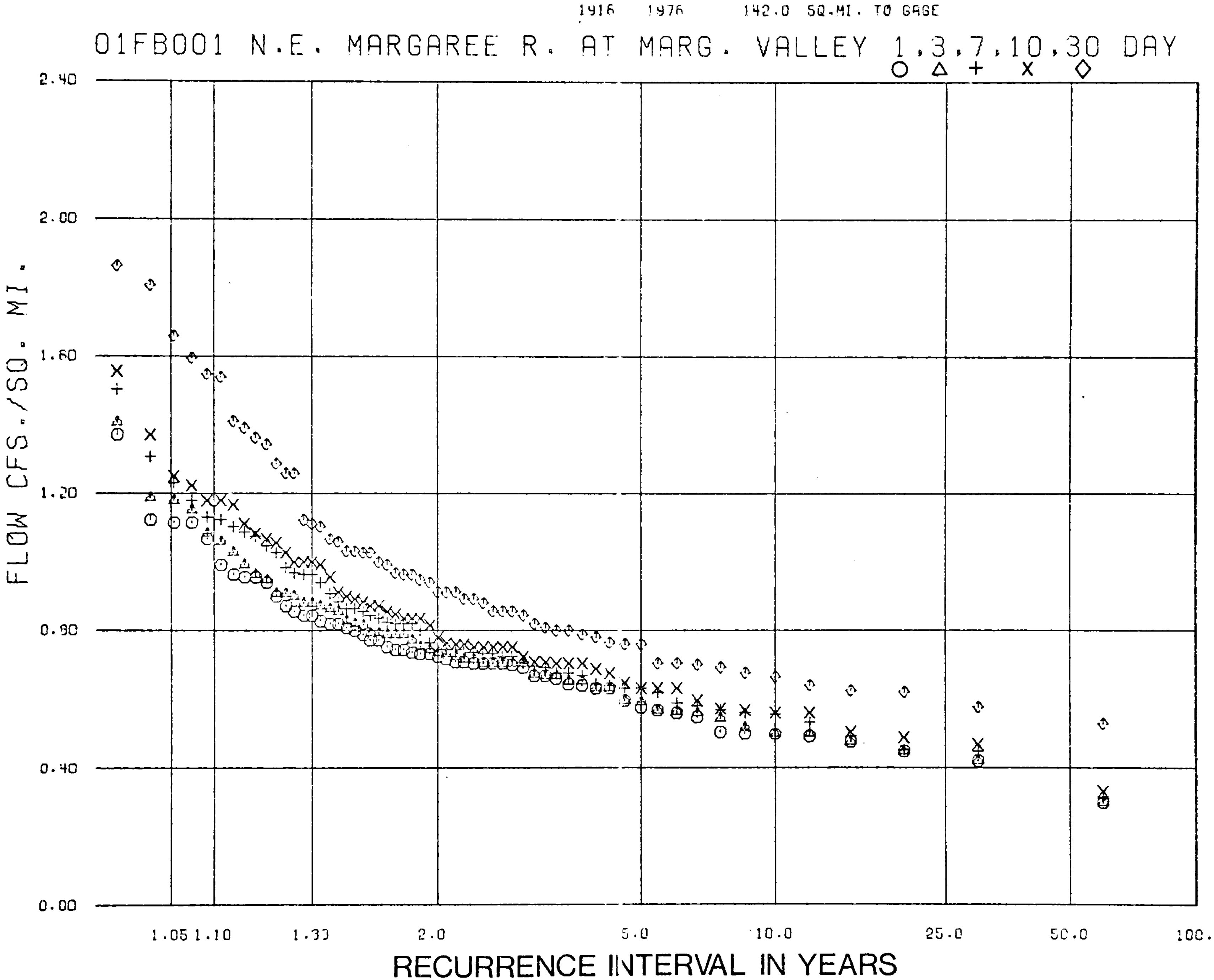
6. Chang, M. and D. G. Boyer, Estimates of Low Flows Using Watershed and Climatic Parameters, Journal of Water Resource Research, Vol. 13, No. 6, December, 1977.

7. Frye, P. M. and G. S. Runner, A proposed streamflow data program for West Virginia, U. S. Geol. Surv. Open File Rep., 61 pp, 1970 - reference made in (6).



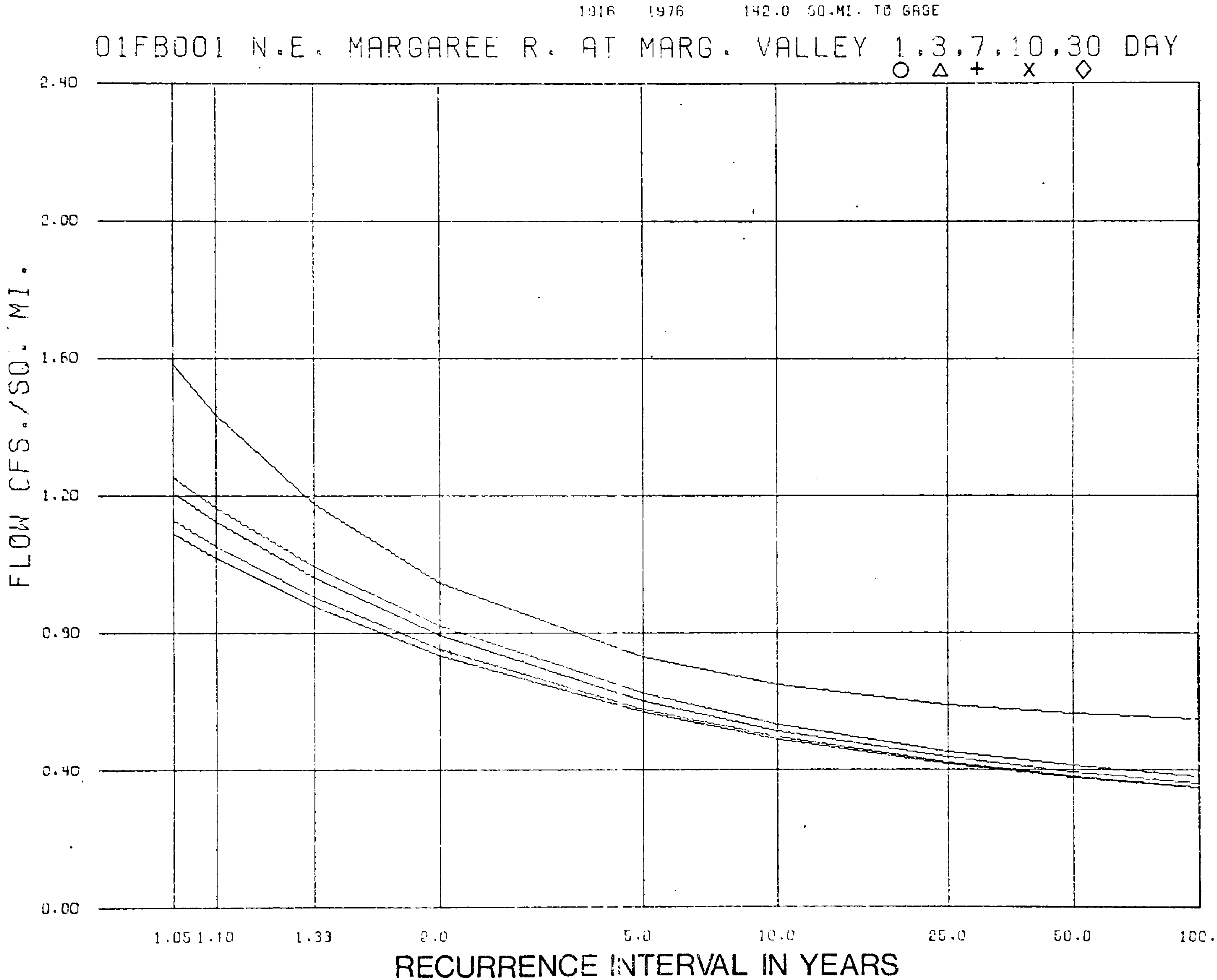
FREQUENCY ANALYSIS OF ANNUAL LOW FLOWS (PERIOD OF RECORD)

FIGURE 2-1



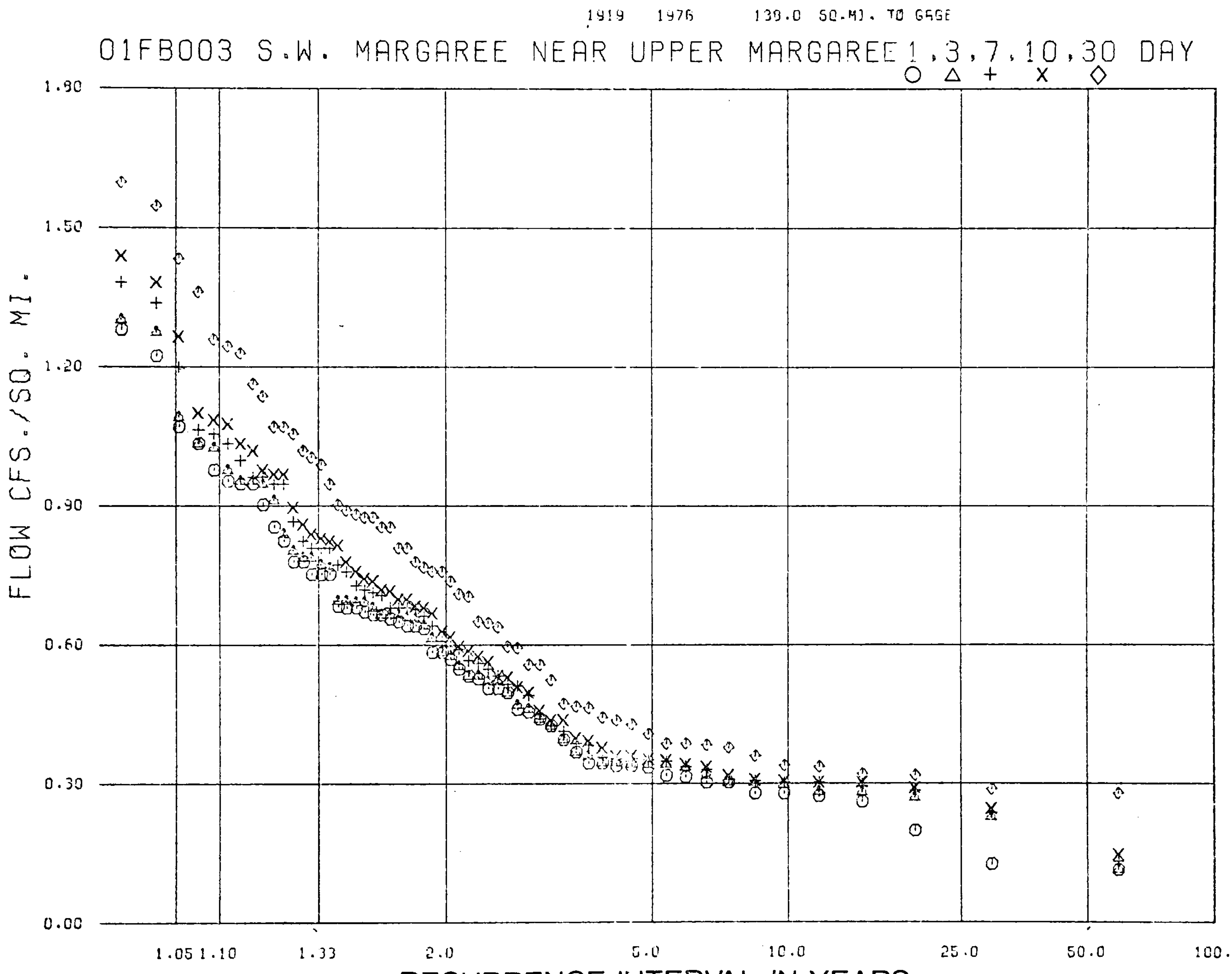
FREQUENCY ANALYSIS OF ANNUAL LOW FLOWS (PERIOD OF RECORD)

FIGURE 2-2A



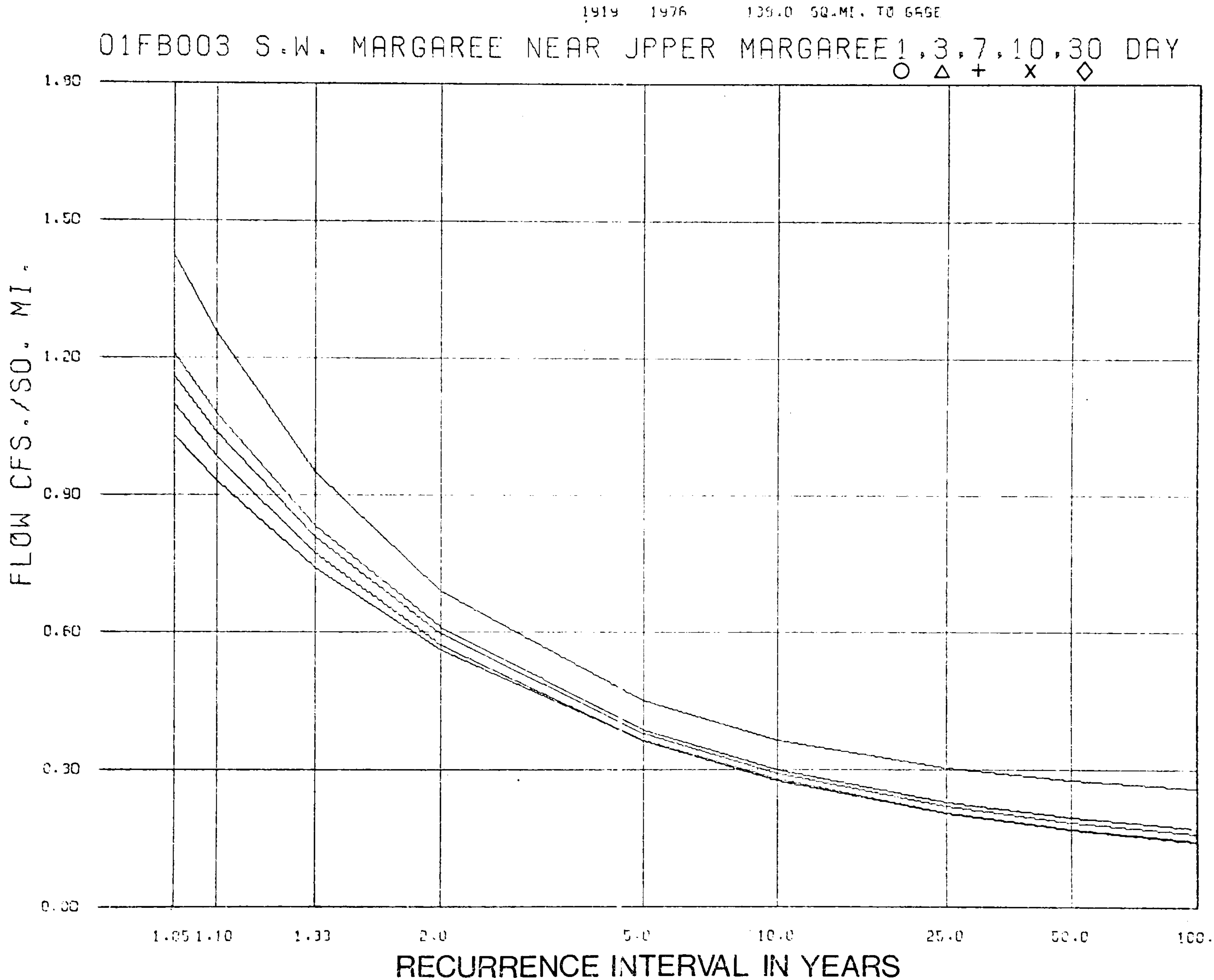
FREQUENCY ANALYSIS OF ANNUAL LOW FLOWS (PERIOD OF RECORD)

FIGURE 2-2B



FREQUENCY ANALYSIS OF ANNUAL LOW FLOWS (PERIOD OF RECORD)

FIGURE 2-3A



FREQUENCY ANALYSIS OF ANNUAL LOW FLOWS (PERIOD OF RECORD)

FIGURE 2-3B

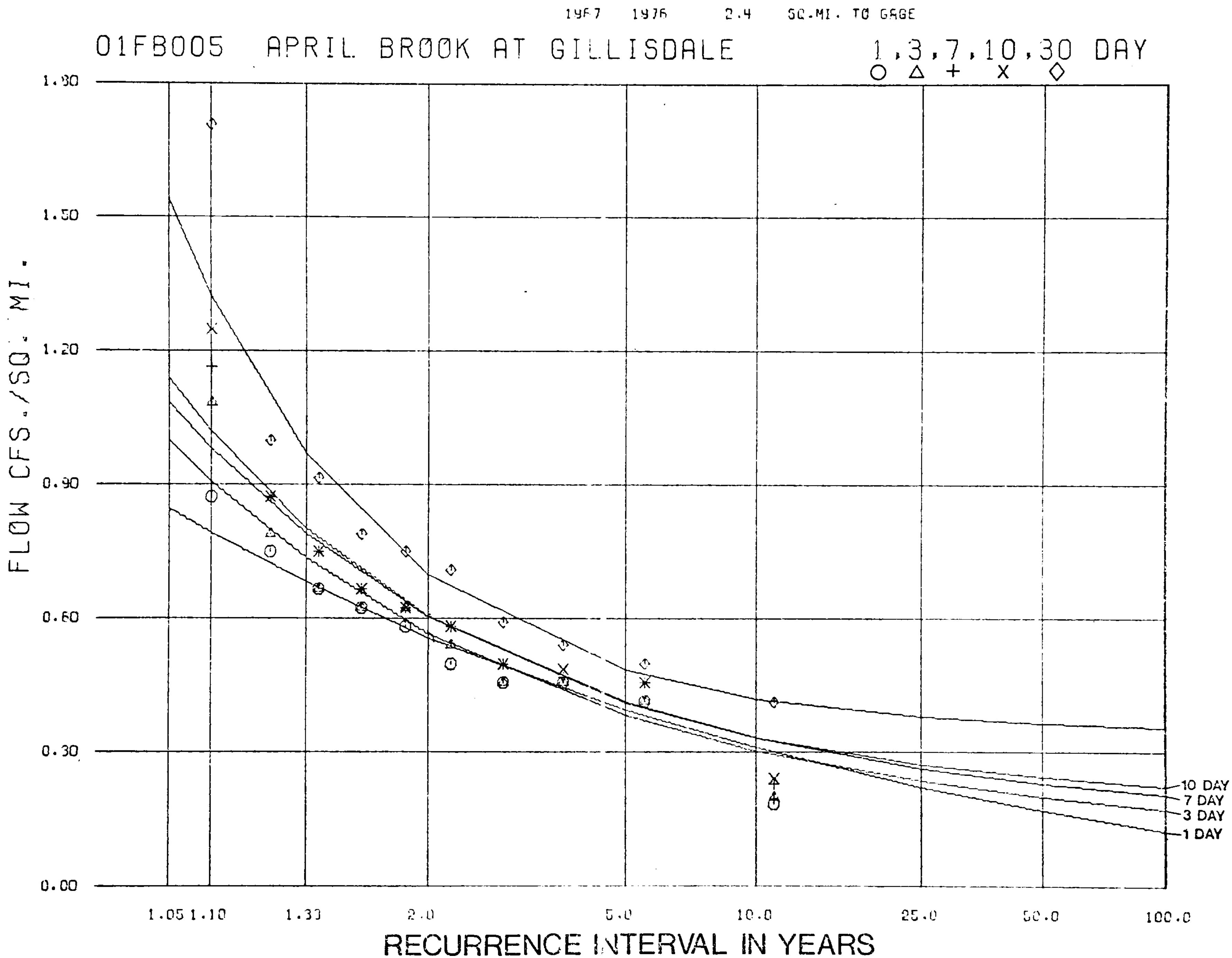
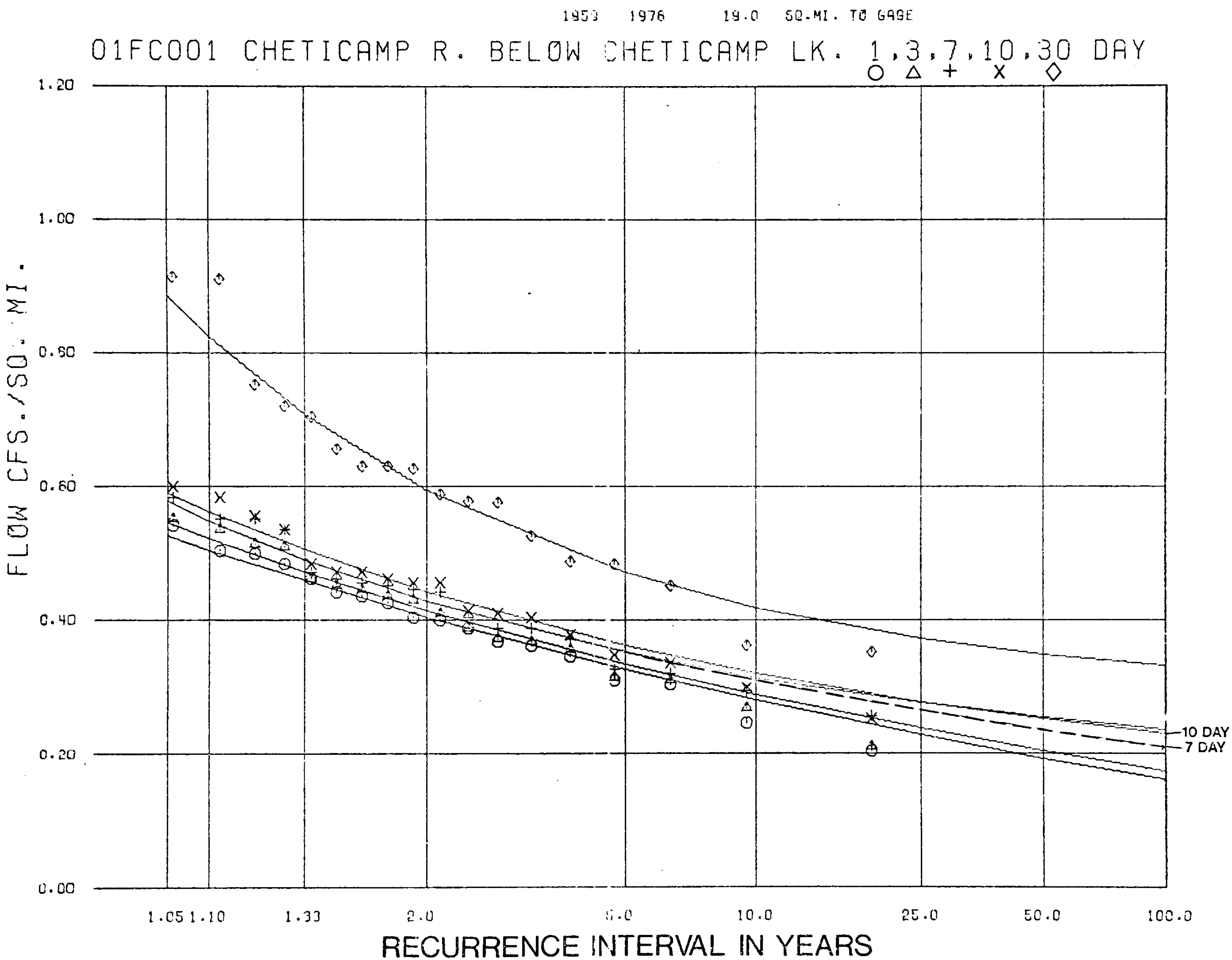


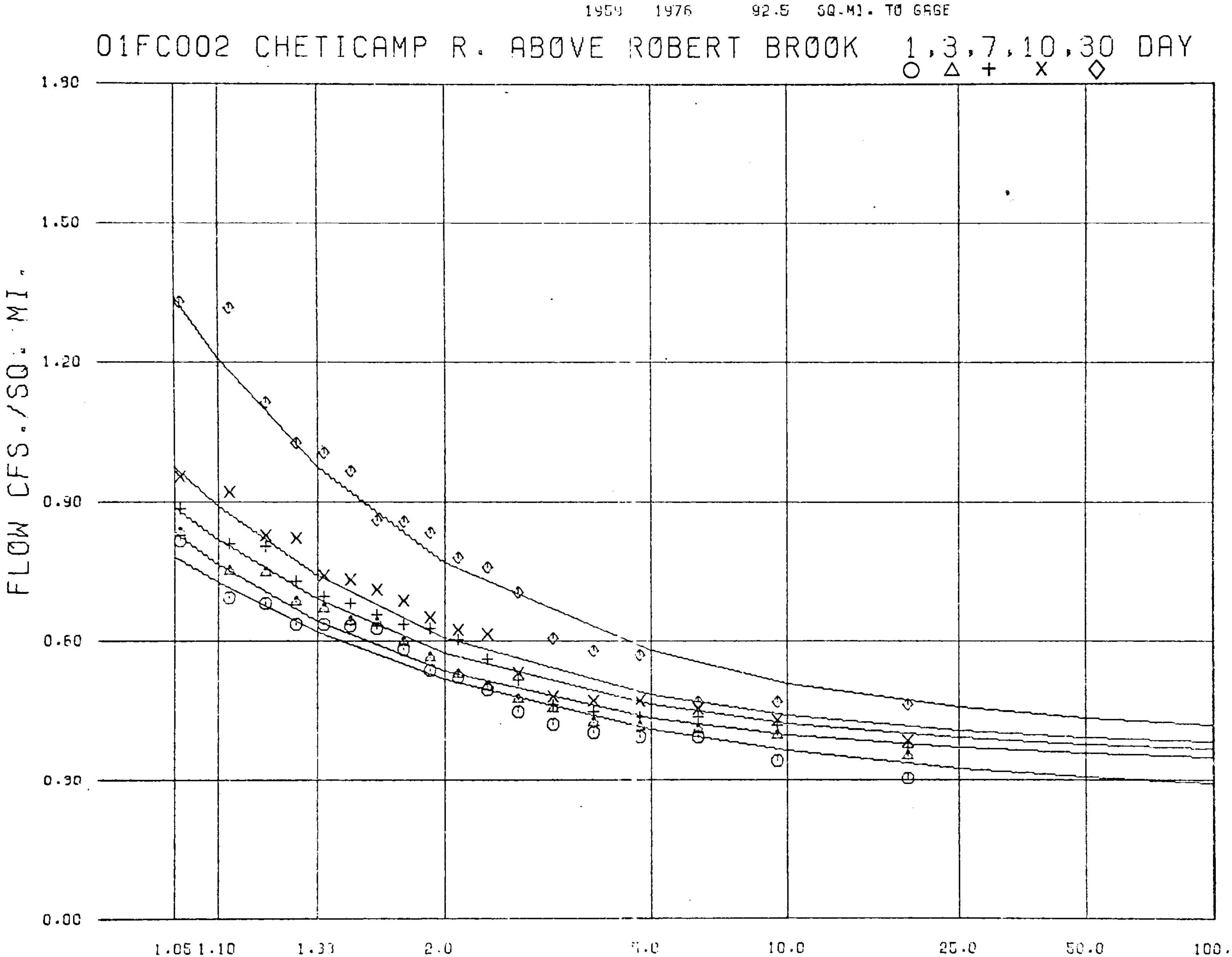
FIGURE 2-4

FREQUENCY ANALYSIS OF ANNUAL LOW FLOWS (PERIOD OF RECORD)

FIGURE 2-5



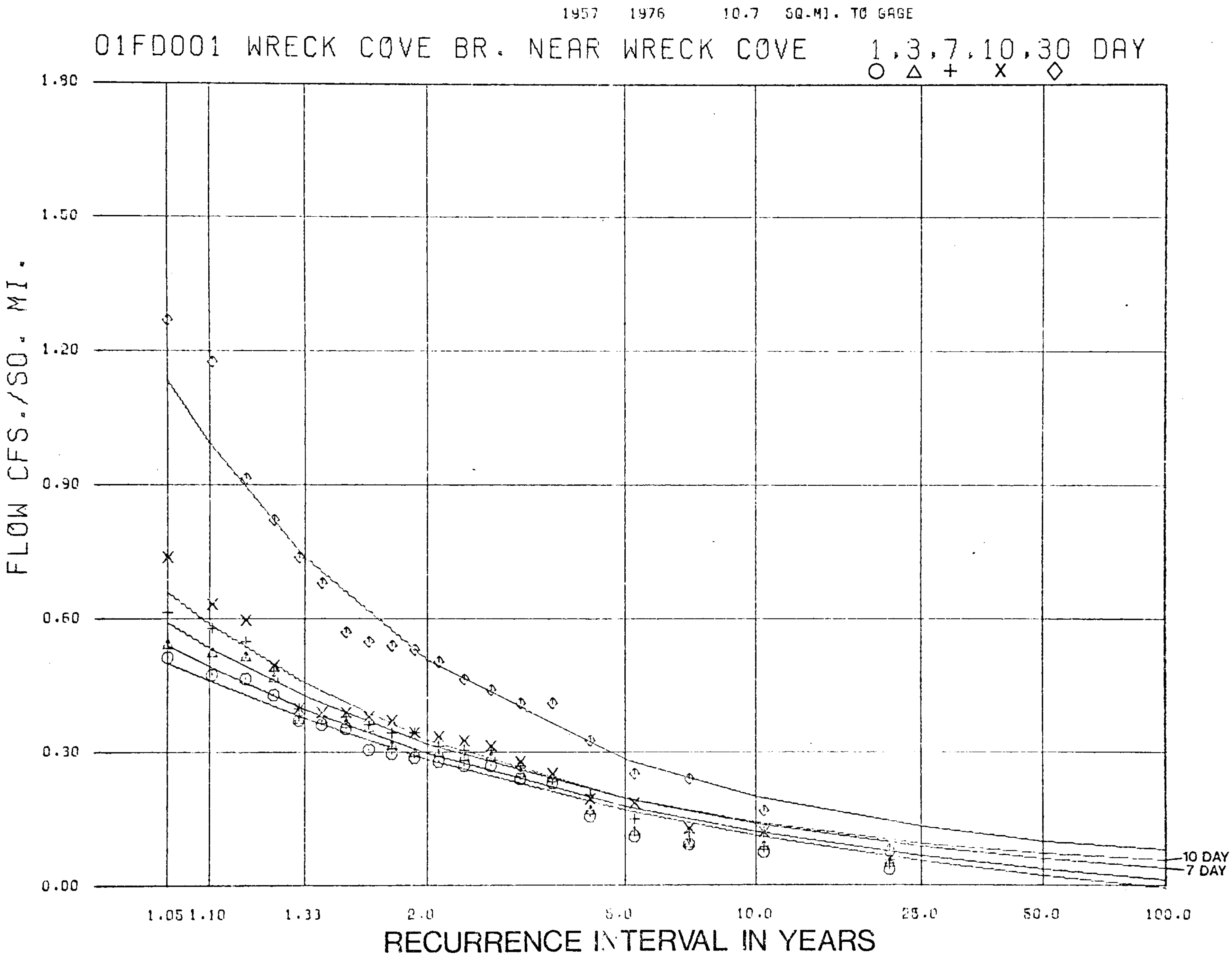
FREQUENCY ANALYSIS OF ANNUAL LOW FLOWS (PERIOD OF RECORD)



RECURRENCE INTERVAL IN YEARS

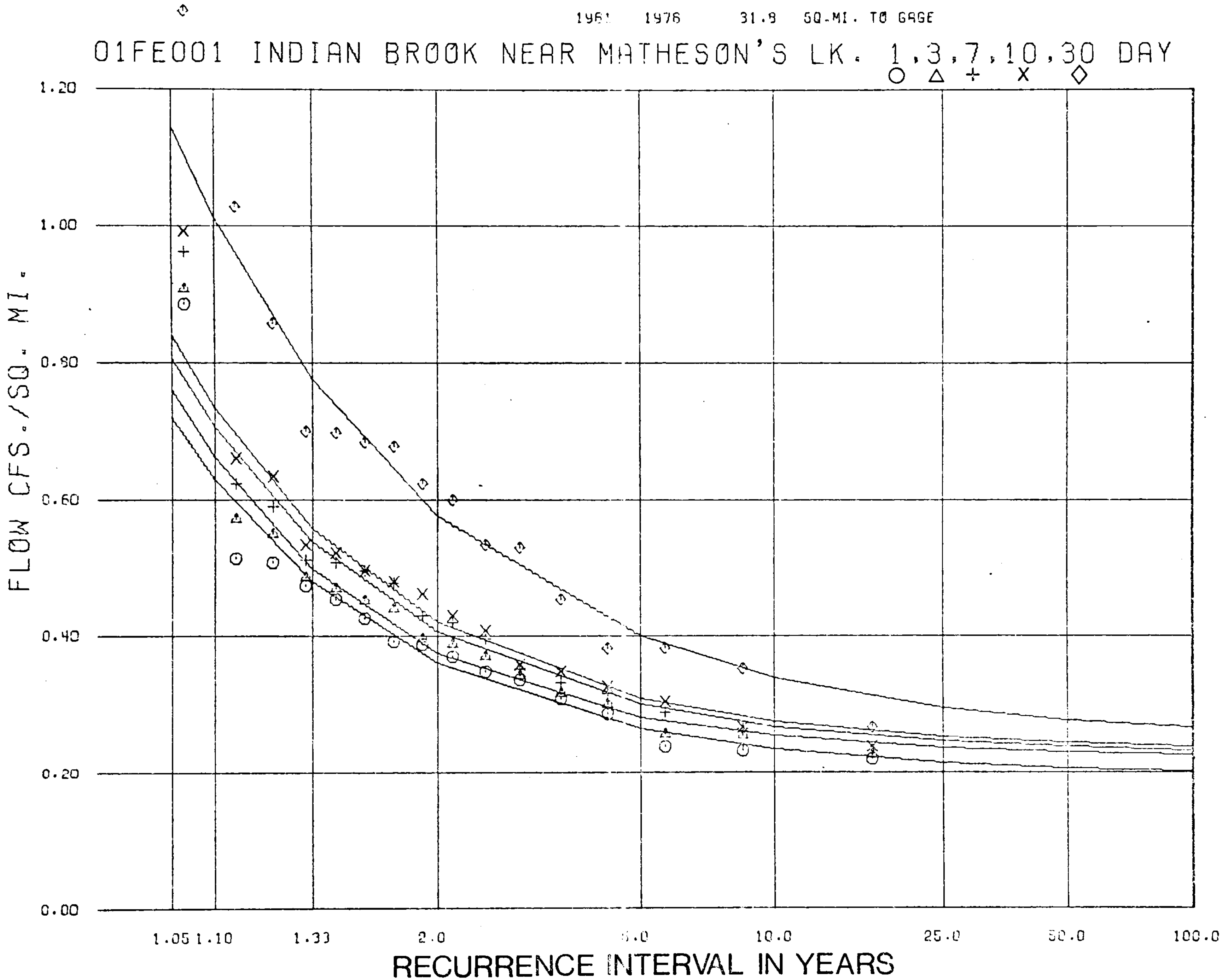
FREQUENCY ANALYSIS OF ANNUAL LOW FLOWS (PERIOD OF RECORD)

FIGURE 2-6



FREQUENCY ANALYSIS OF ANNUAL LOW FLOWS (PERIOD OF RECORD)

FIGURE 2-7



FREQUENCY ANALYSIS OF ANNUAL LOW FLOWS (PERIOD OF RECORD)

FIGURE 2-8

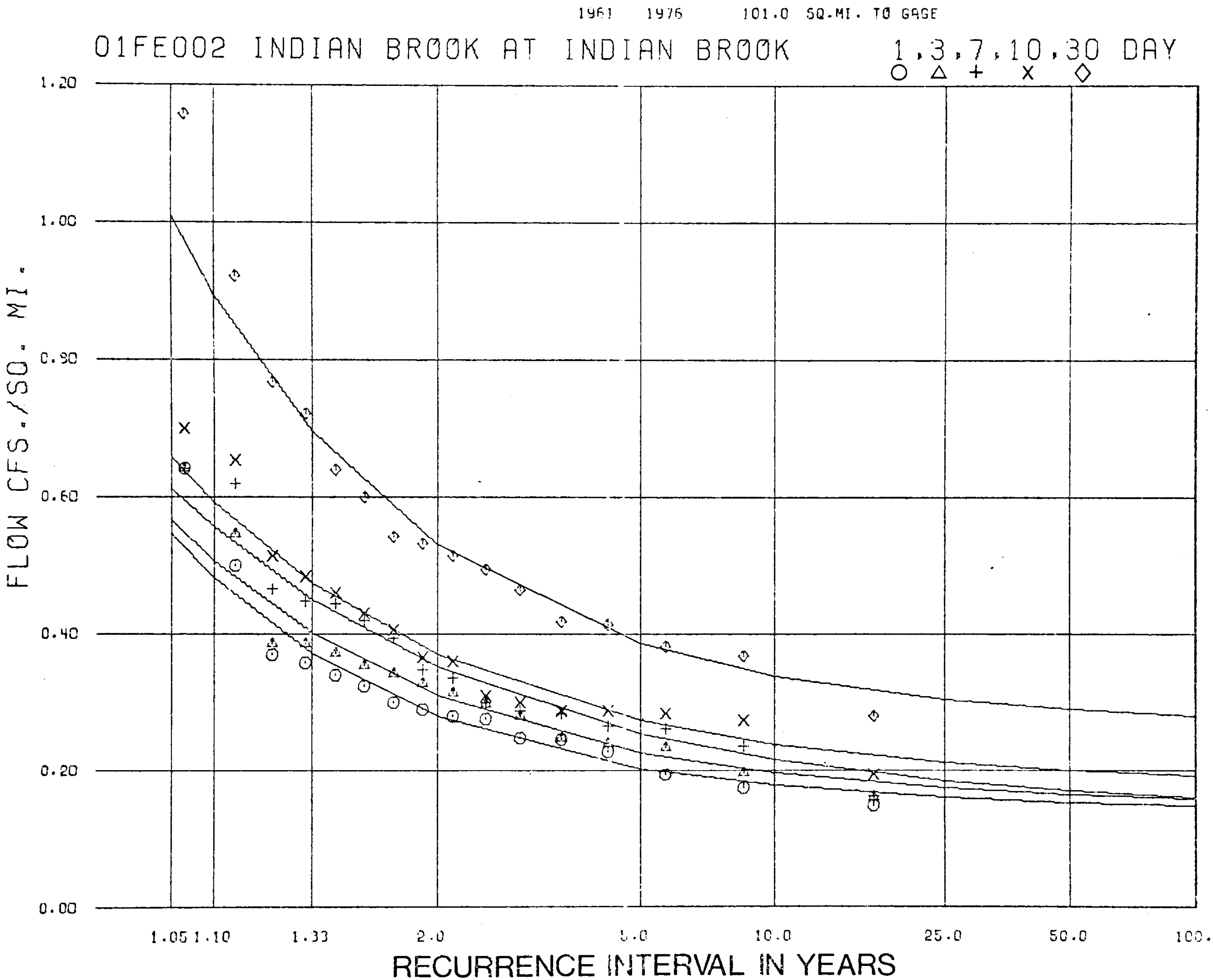
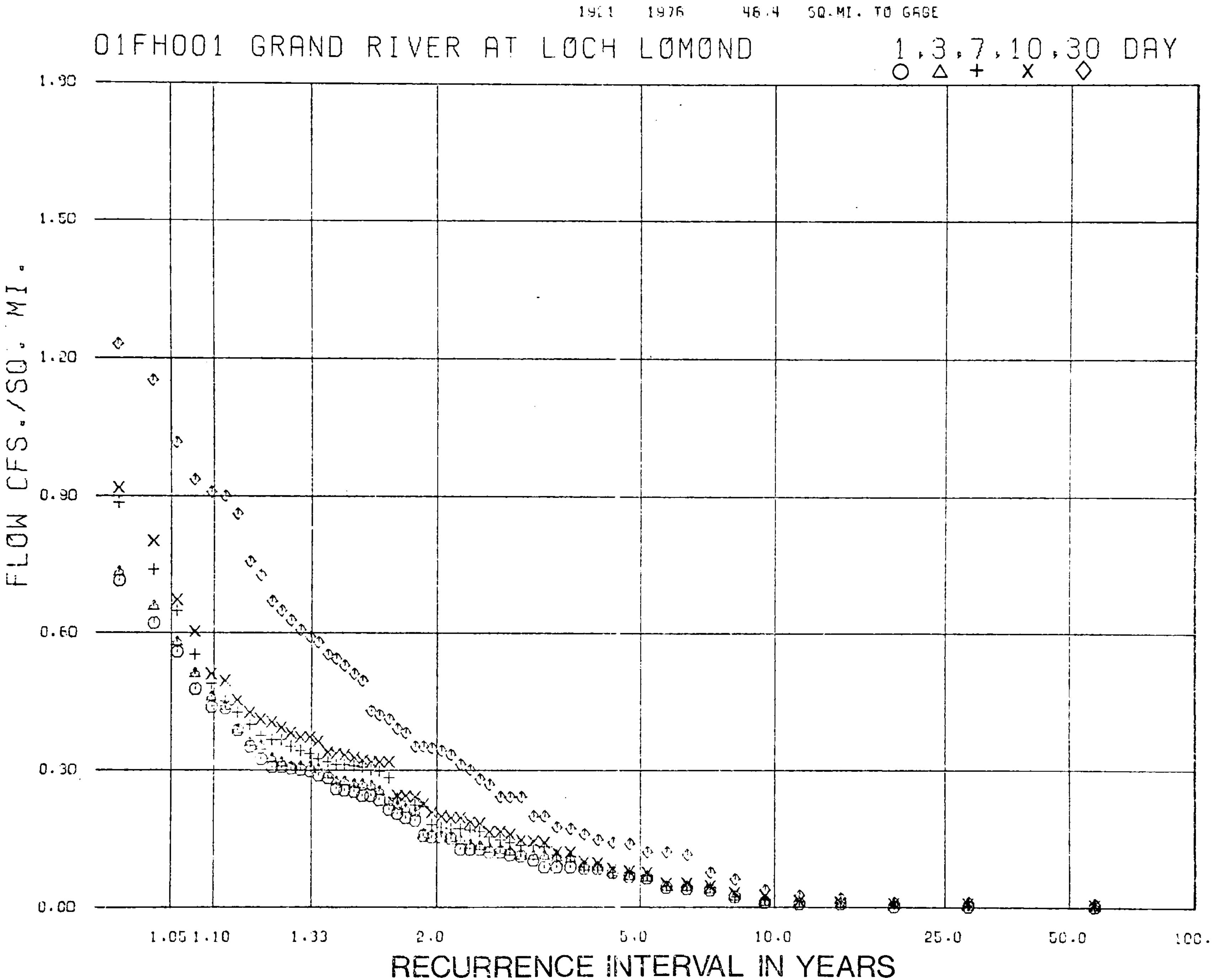


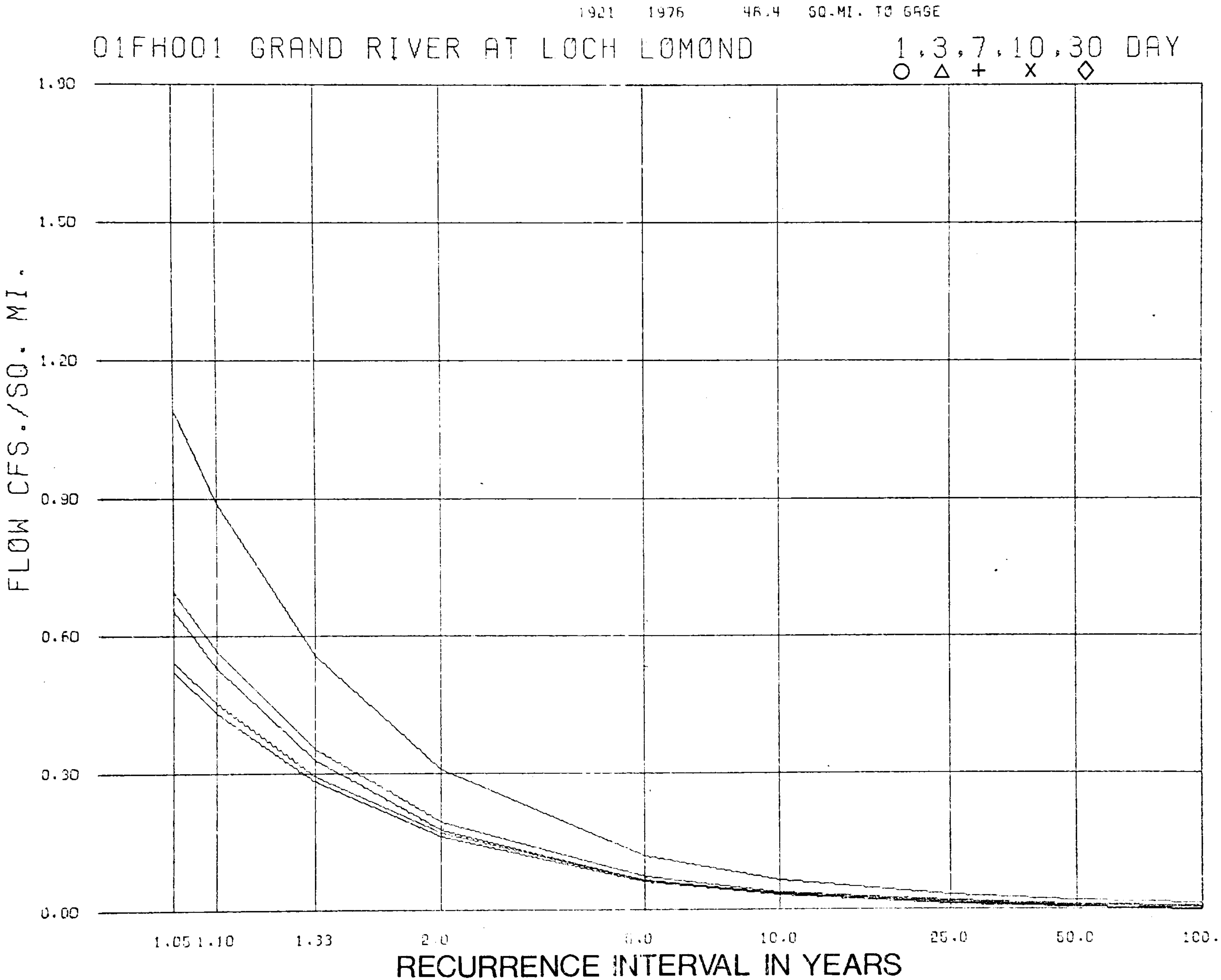
FIGURE 2-9

FREQUENCY ANALYSIS OF ANNUAL LOW FLOWS (PERIOD OF RECORD)



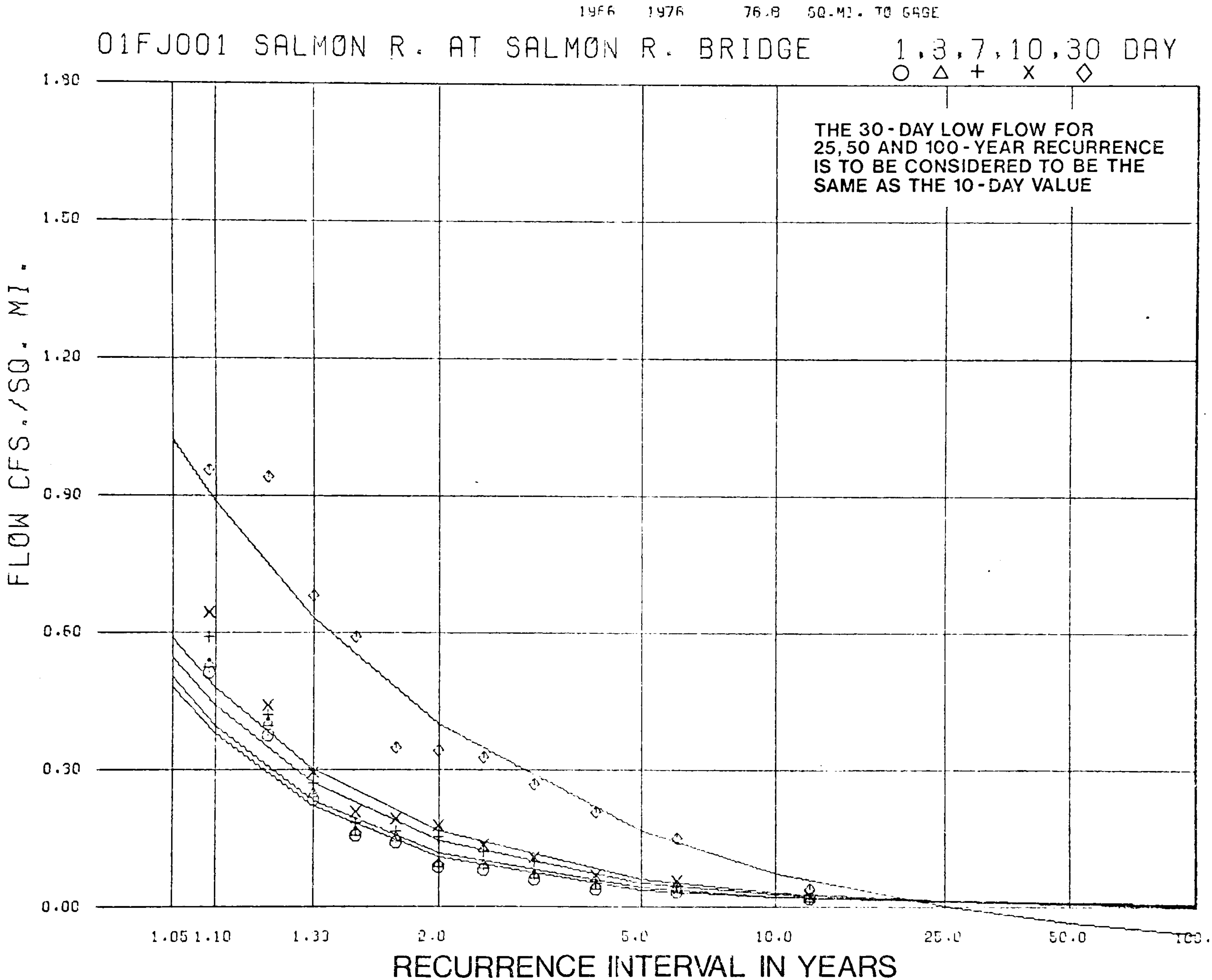
FREQUENCY ANALYSIS OF ANNUAL LOW FLOWS (PERIOD OF RECORD)

FIGURE 2-10A



FREQUENCY ANALYSIS OF ANNUAL LOW FLOWS (PERIOD OF RECORD)

FIGURE 2-10B



FREQUENCY ANALYSIS OF ANNUAL LOW FLOWS (PERIOD OF RECORD)

FIGURE 2-11

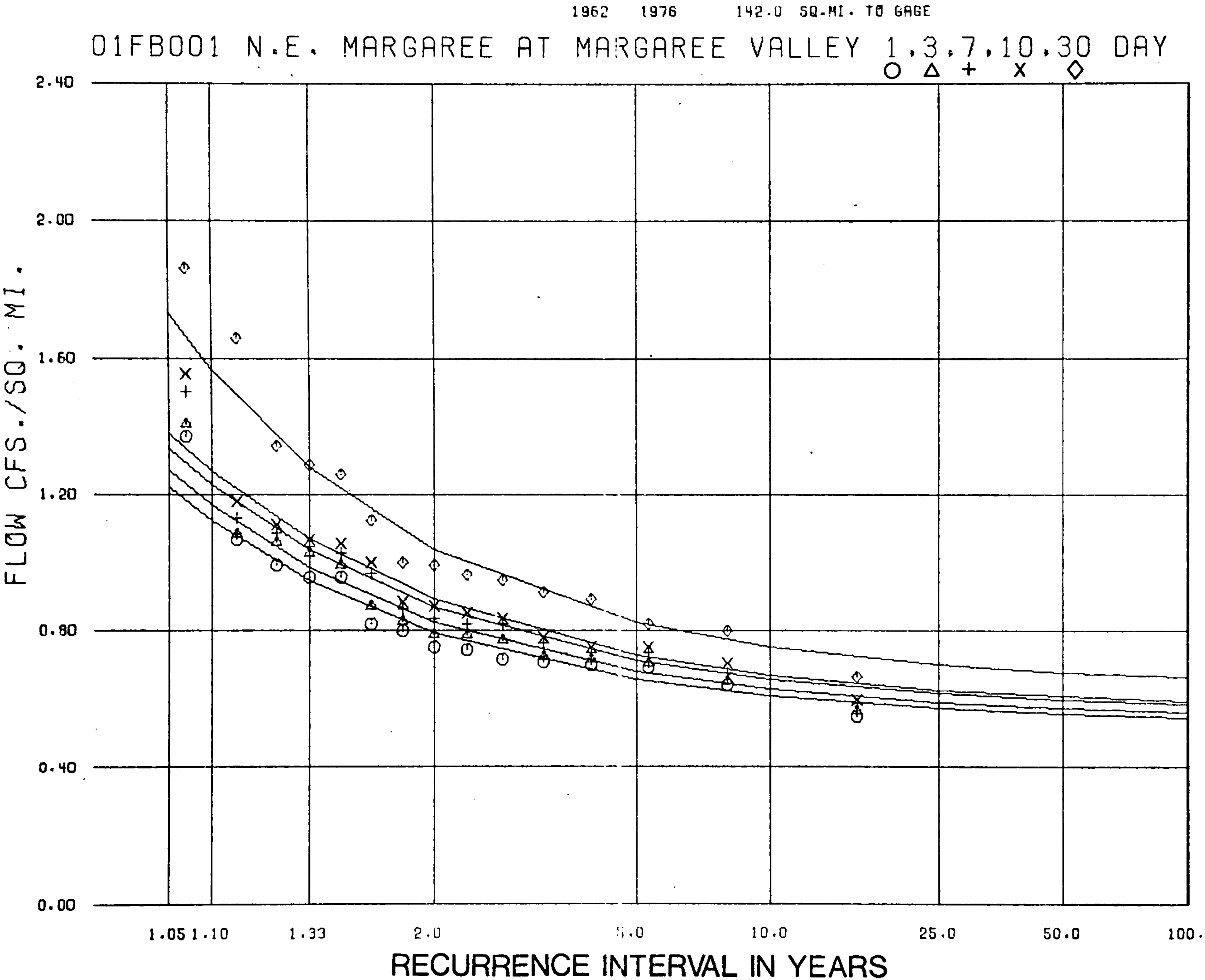
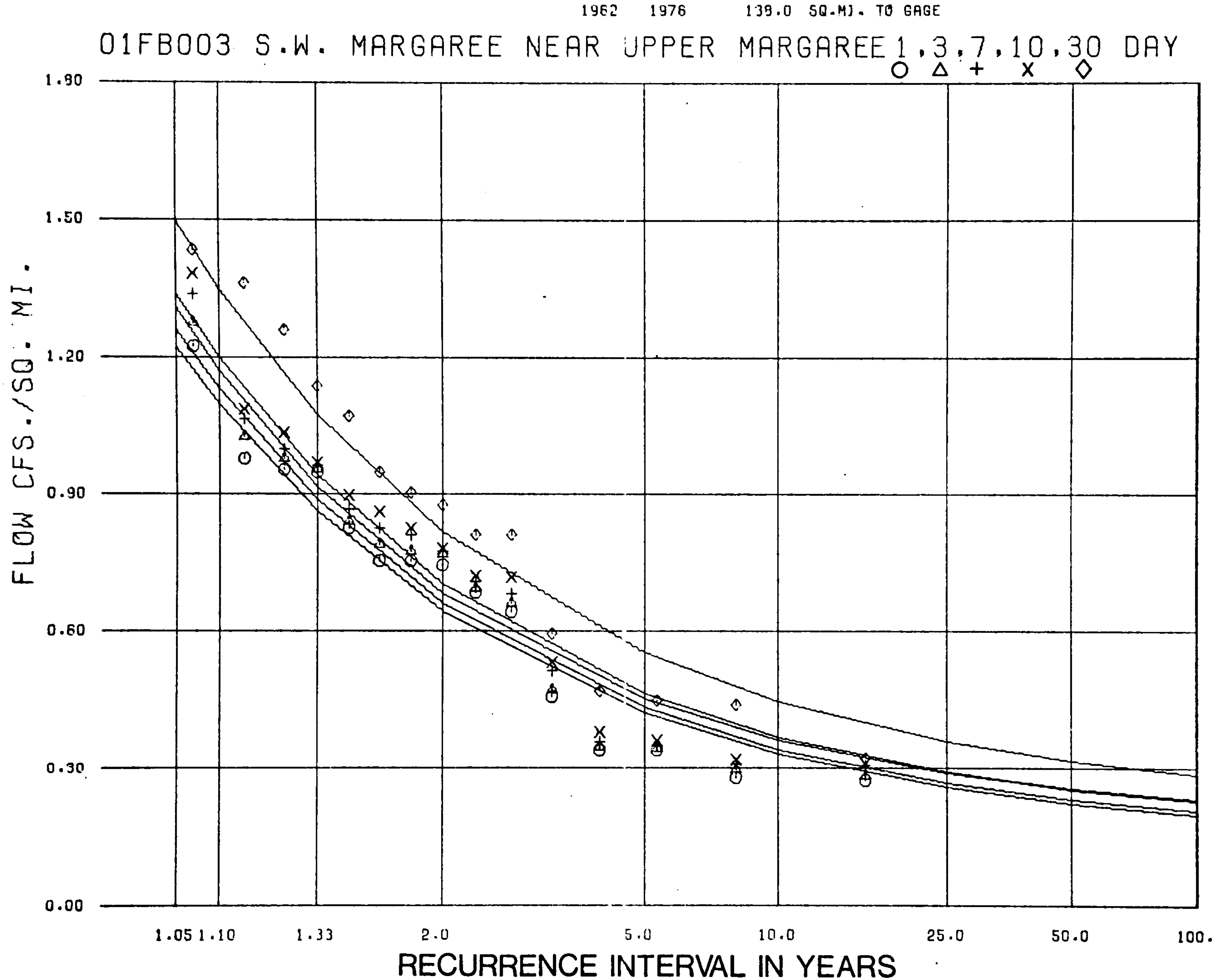


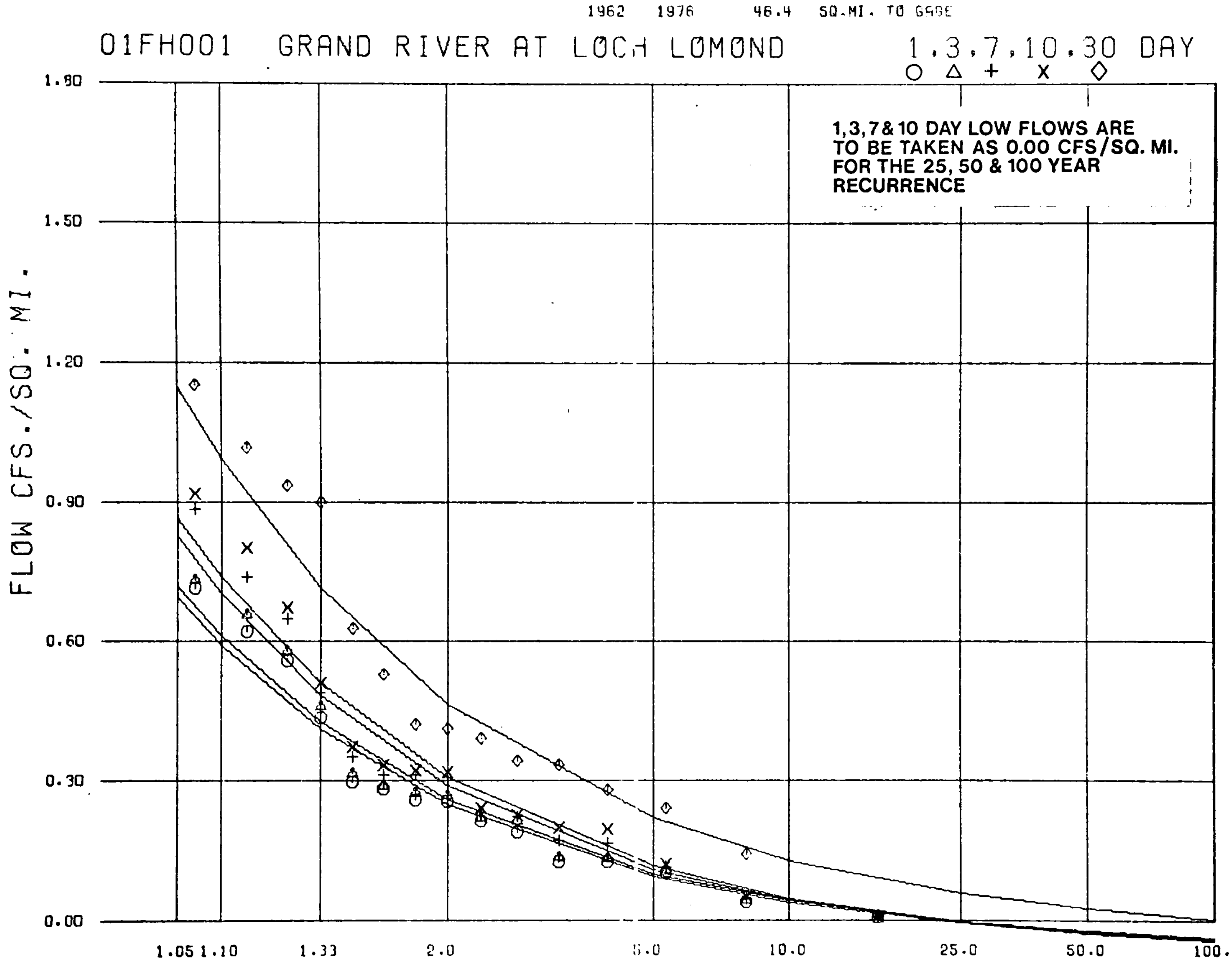
FIGURE 3-1

FREQUENCY ANALYSIS OF ANNUAL LOW FLOWS (1962 - 1976)



FREQUENCY ANALYSIS OF ANNUAL LOW FLOWS (1962 - 1976)

FIGURE 3-2



RECURRENCE INTERVAL IN YEARS

FREQUENCY ANALYSIS OF ANNUAL LOW FLOWS (1962 - 1976)

FIGURE 3-3

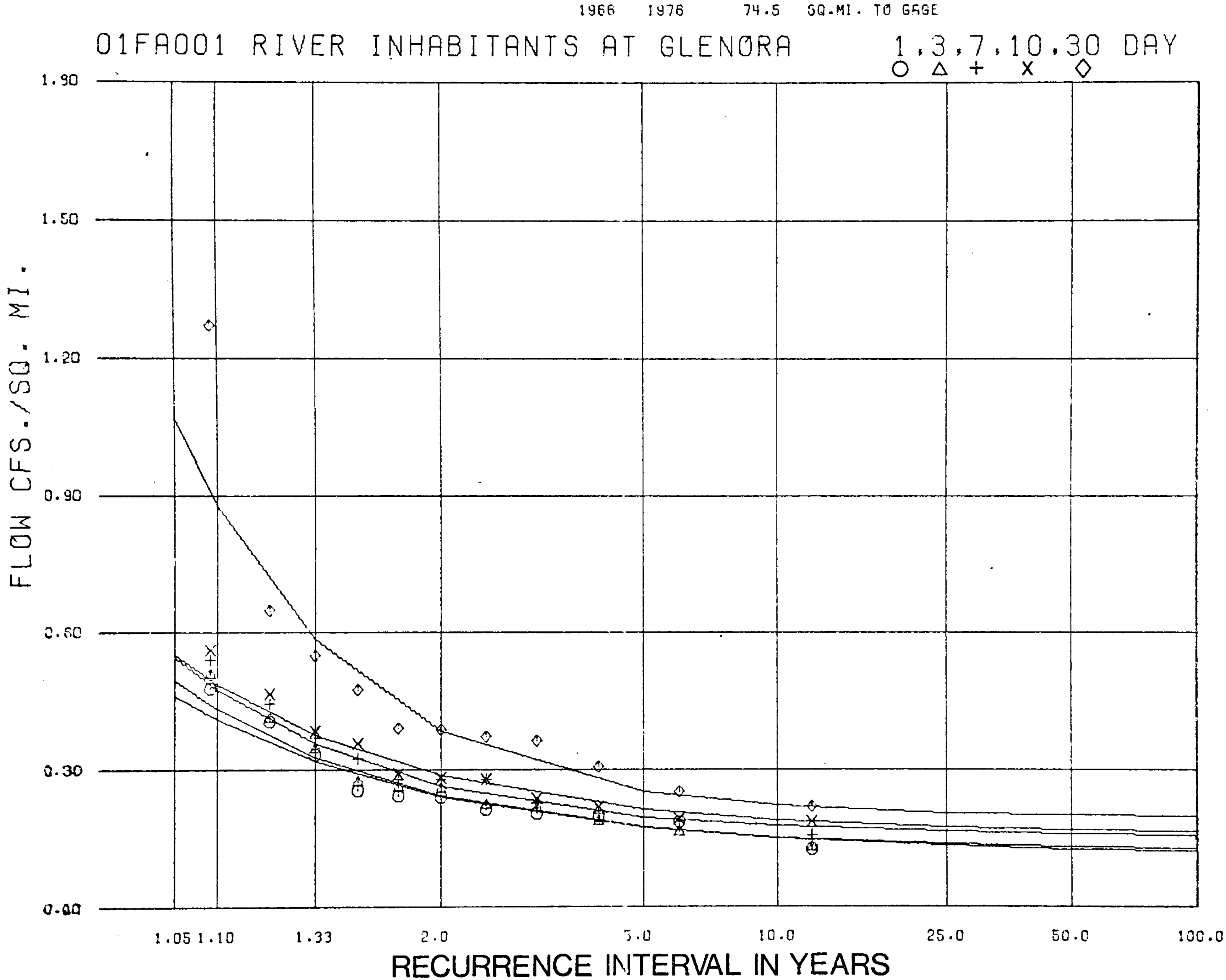
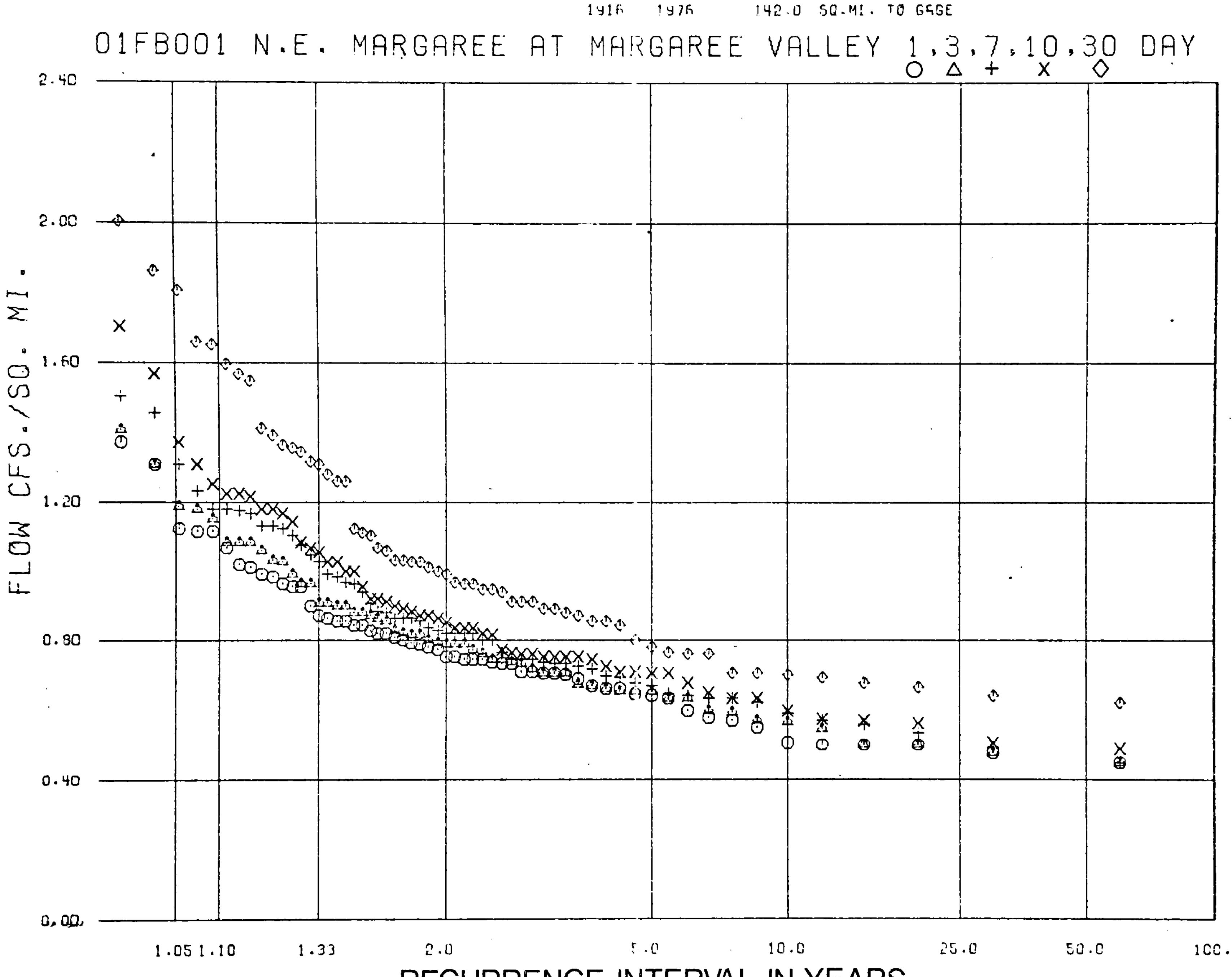


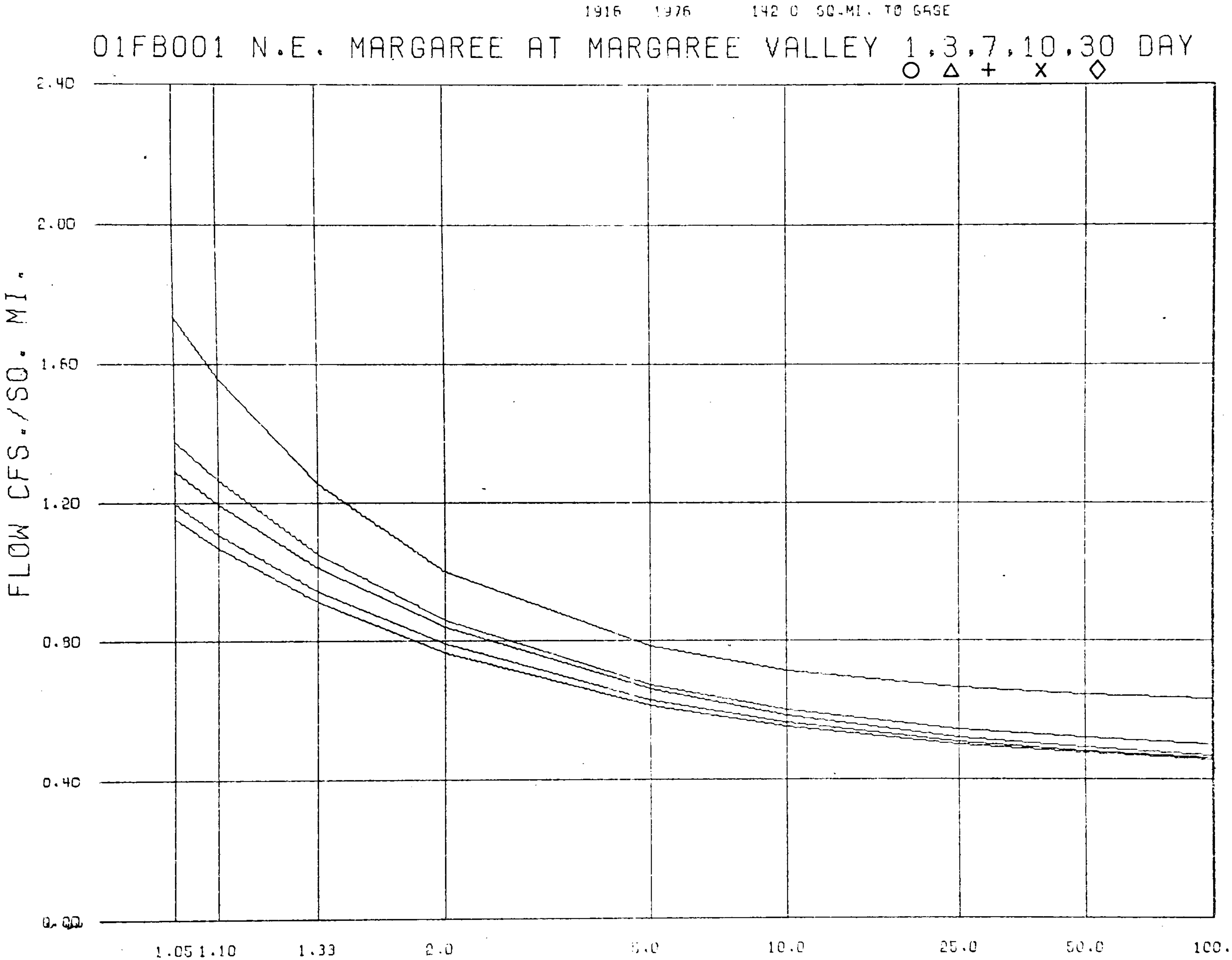
FIGURE 4-1

FREQUENCY ANALYSIS OF SUMMER LOW FLOWS (PERIOD OF RECORD)



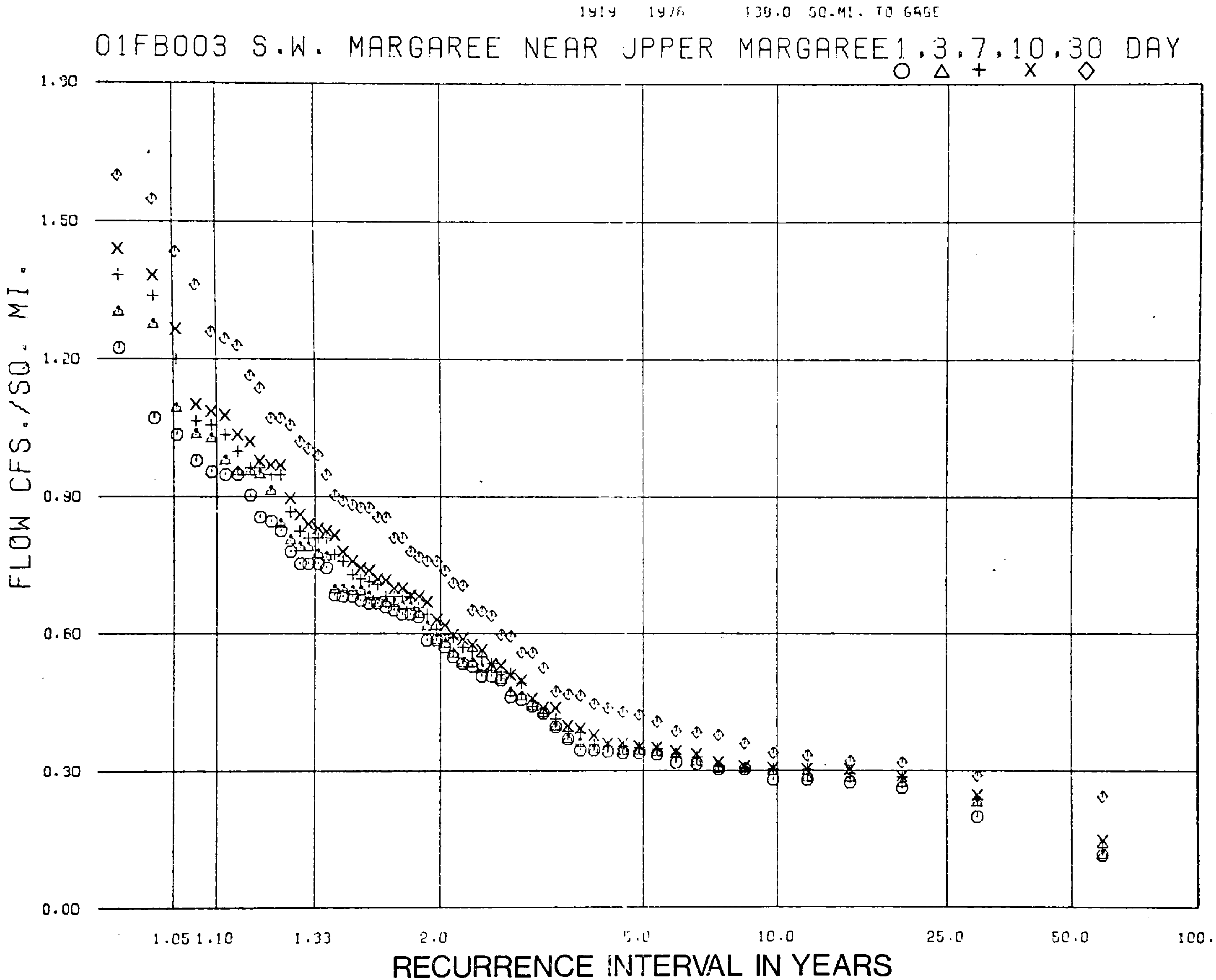
FREQUENCY ANALYSIS OF SUMMER LOW FLOWS (PERIOD OF RECORD)

FIGURE 4-2A



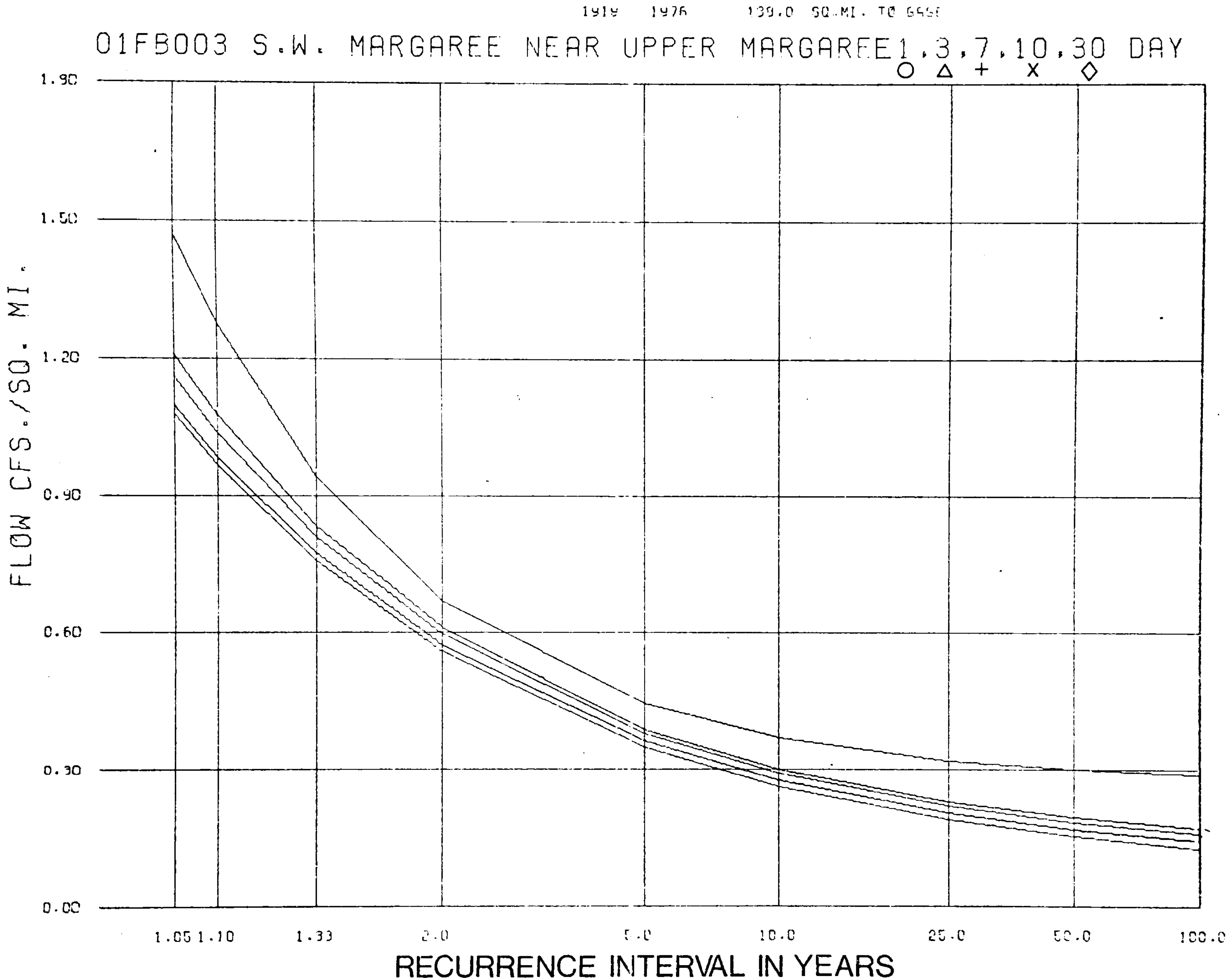
FREQUENCY ANALYSIS OF SUMMER LOW FLOWS (PERIOD OF RECORD)

FIGURE 4-2B



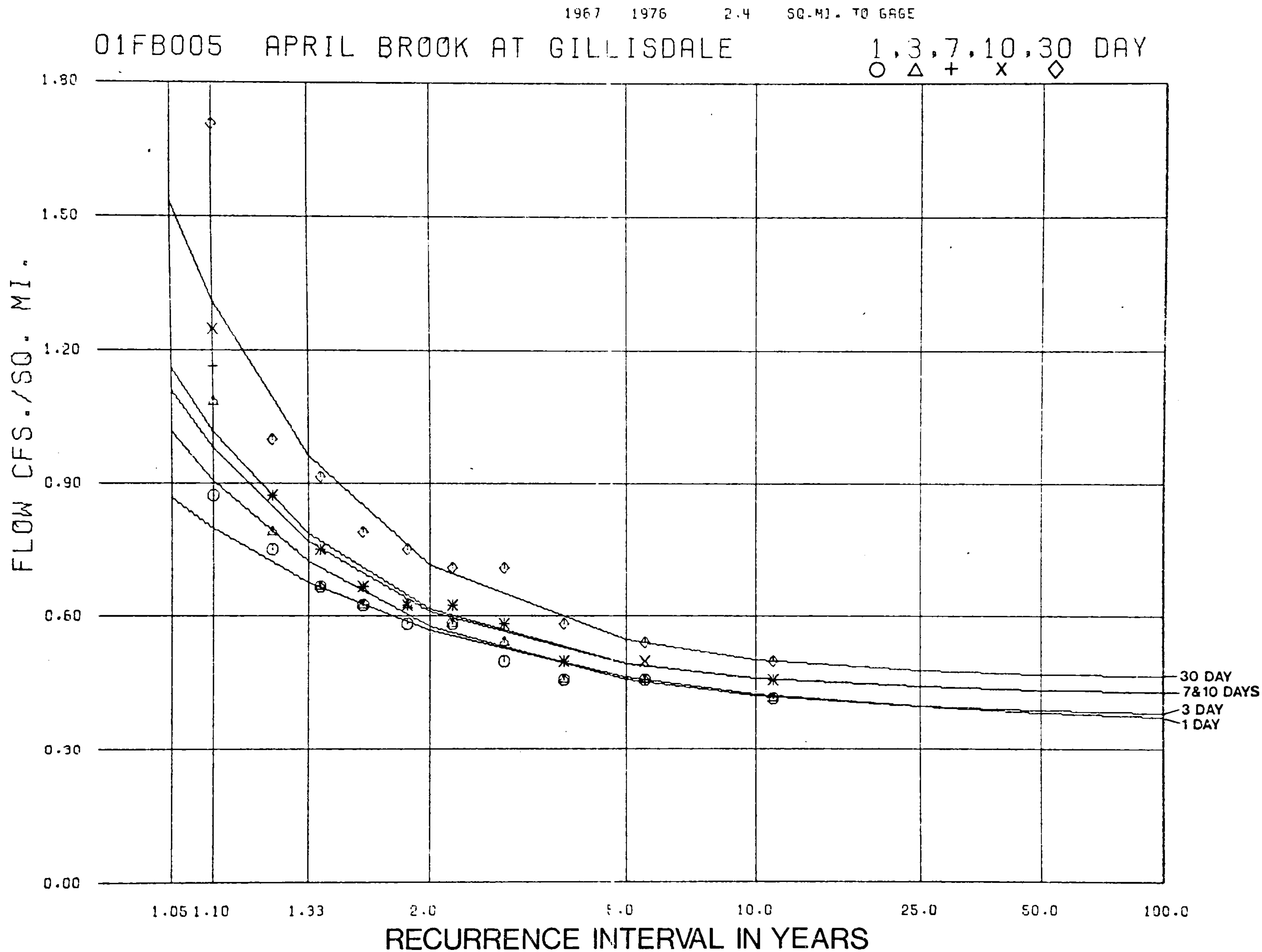
FREQUENCY ANALYSIS OF SUMMER LOW FLOWS (PERIOD OF RECORD)

FIGURE 4-3A



FREQUENCY ANALYSIS OF SUMMER LOW FLOWS (PERIOD OF RECORD)

FIGURE 4-3B



FREQUENCY ANALYSIS OF SUMMER LOW FLOWS (PERIOD OF RECORD)

FIGURE 4-4

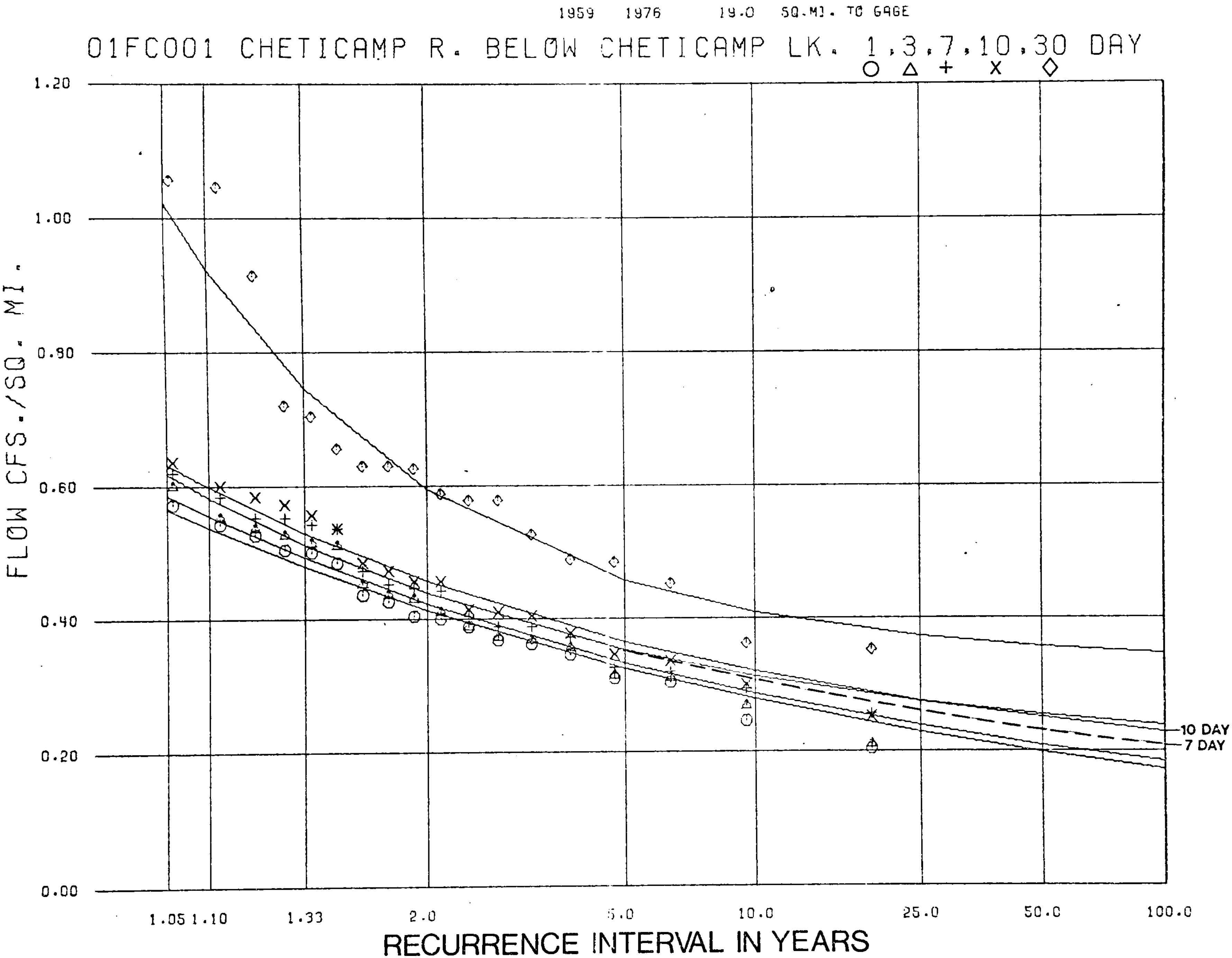
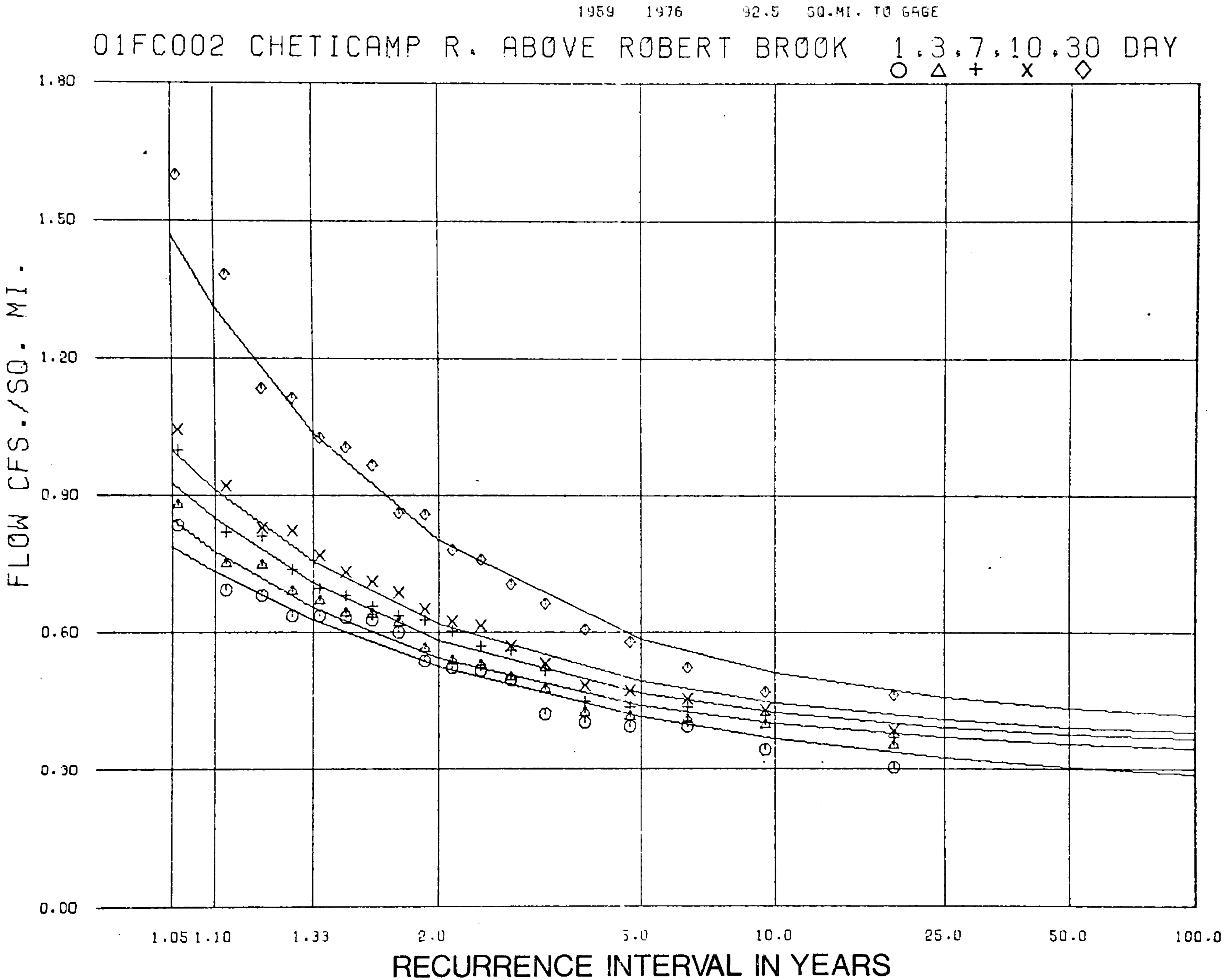


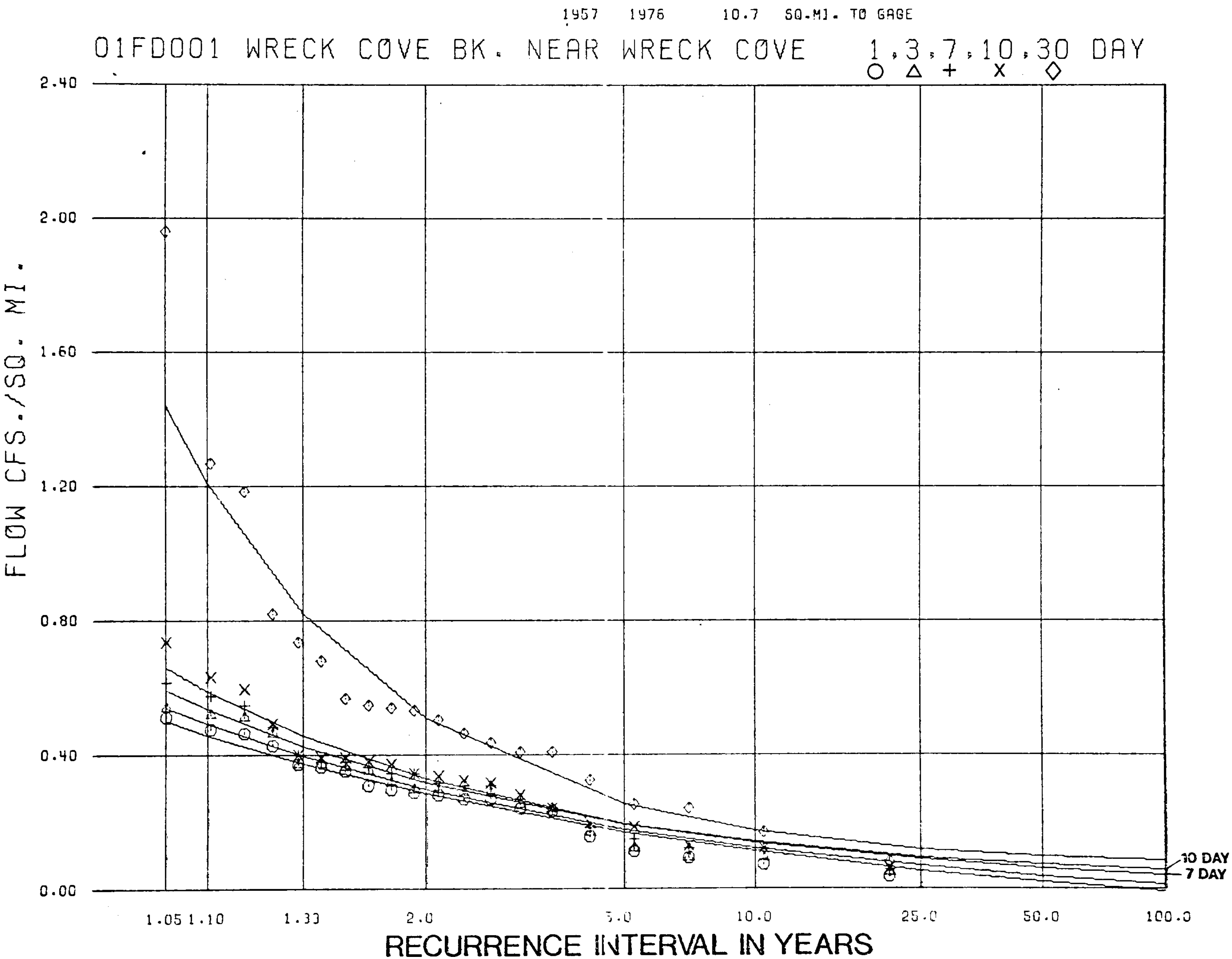
FIGURE 4-5

FREQUENCY ANALYSIS OF SUMMER LOW FLOWS (PERIOD OF RECORD)

FIGURE 4-6



FREQUENCY ANALYSIS OF SUMMER LOW FLOWS (PERIOD OF RECORD)



FREQUENCY ANALYSIS OF SUMMER LOW FLOWS (PERIOD OF RECORD)

FIGURE 4-7

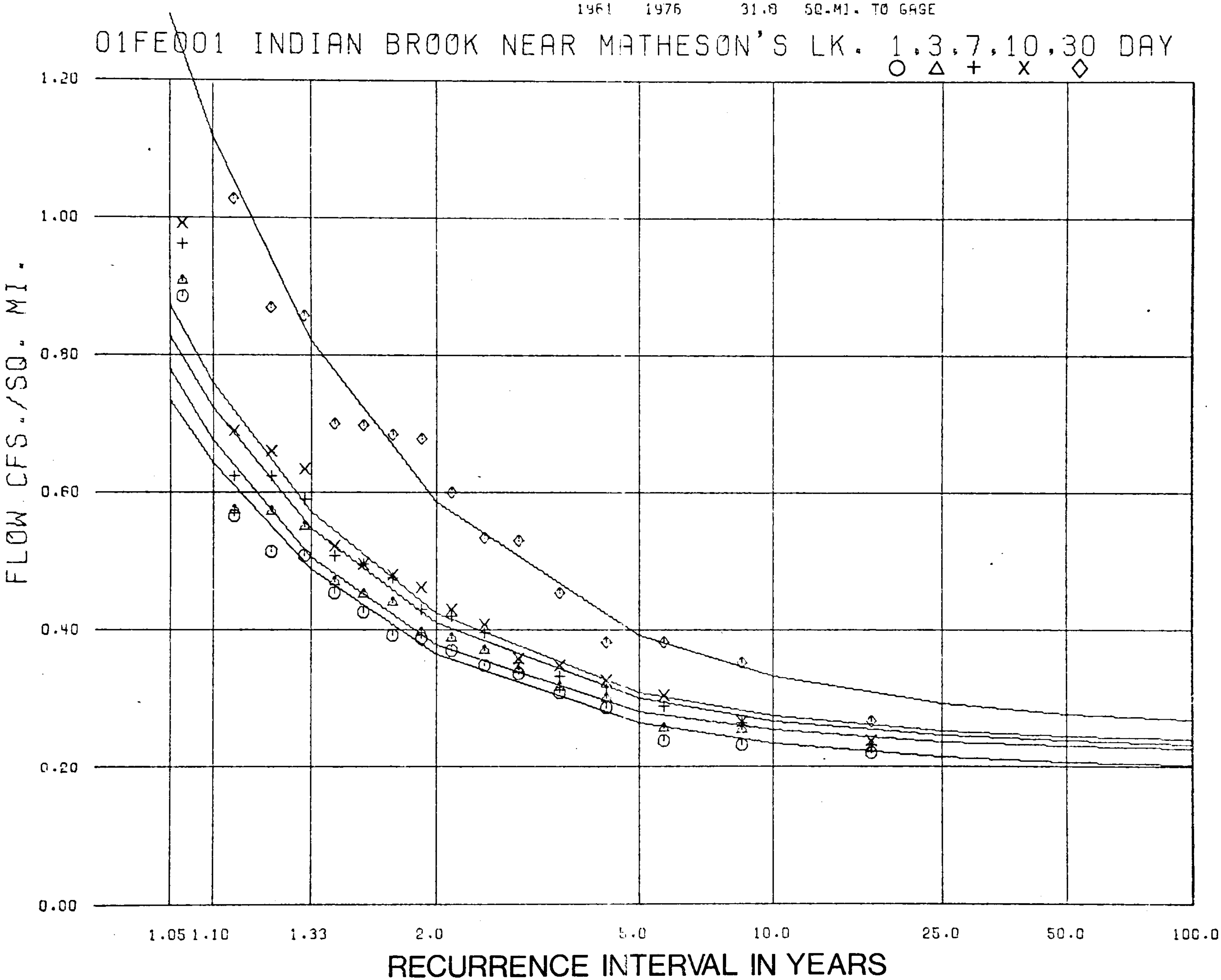


FIGURE 4-8

FREQUENCY ANALYSIS OF SUMMER LOW FLOWS (PERIOD OF RECORD)

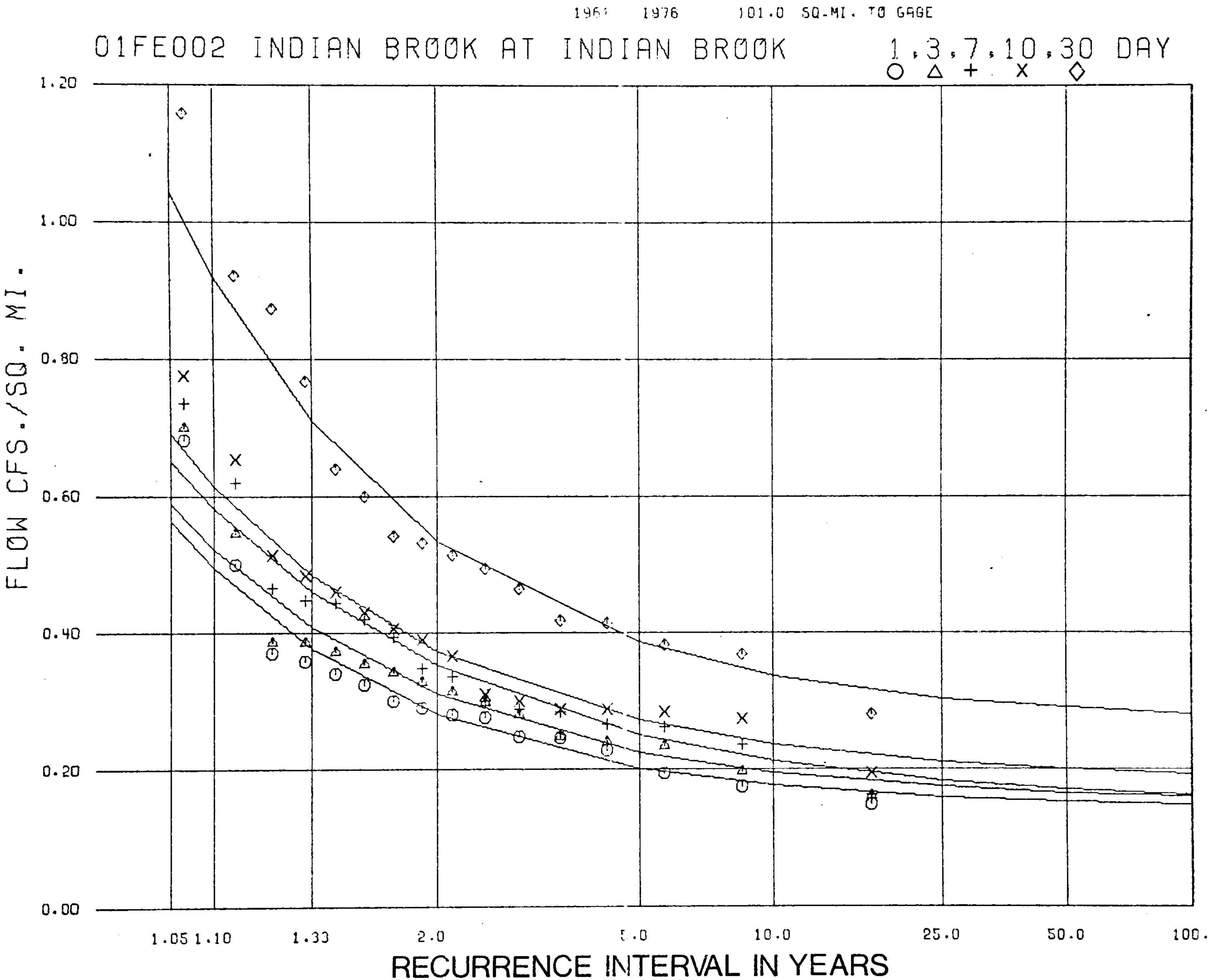
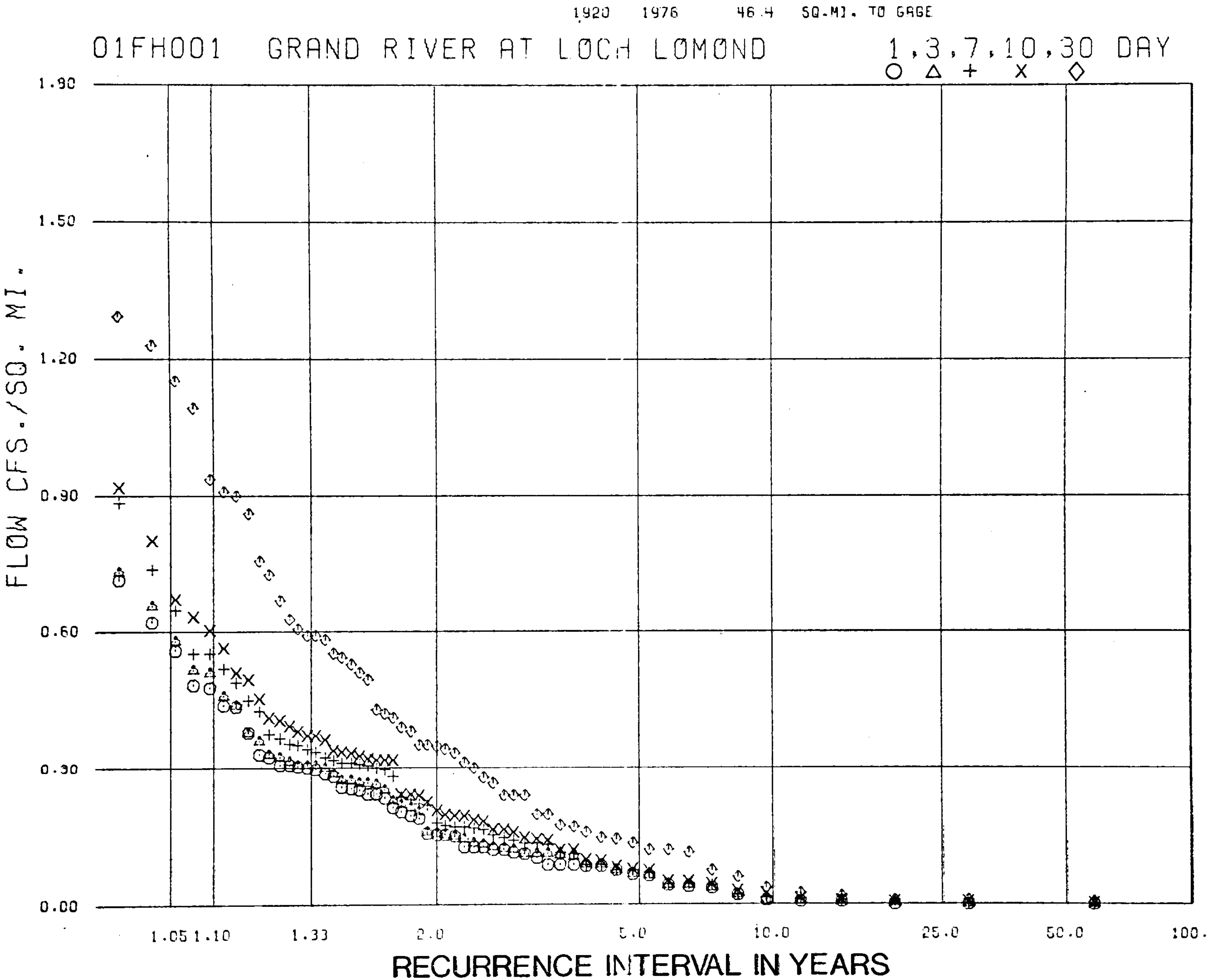


FIGURE 4-9

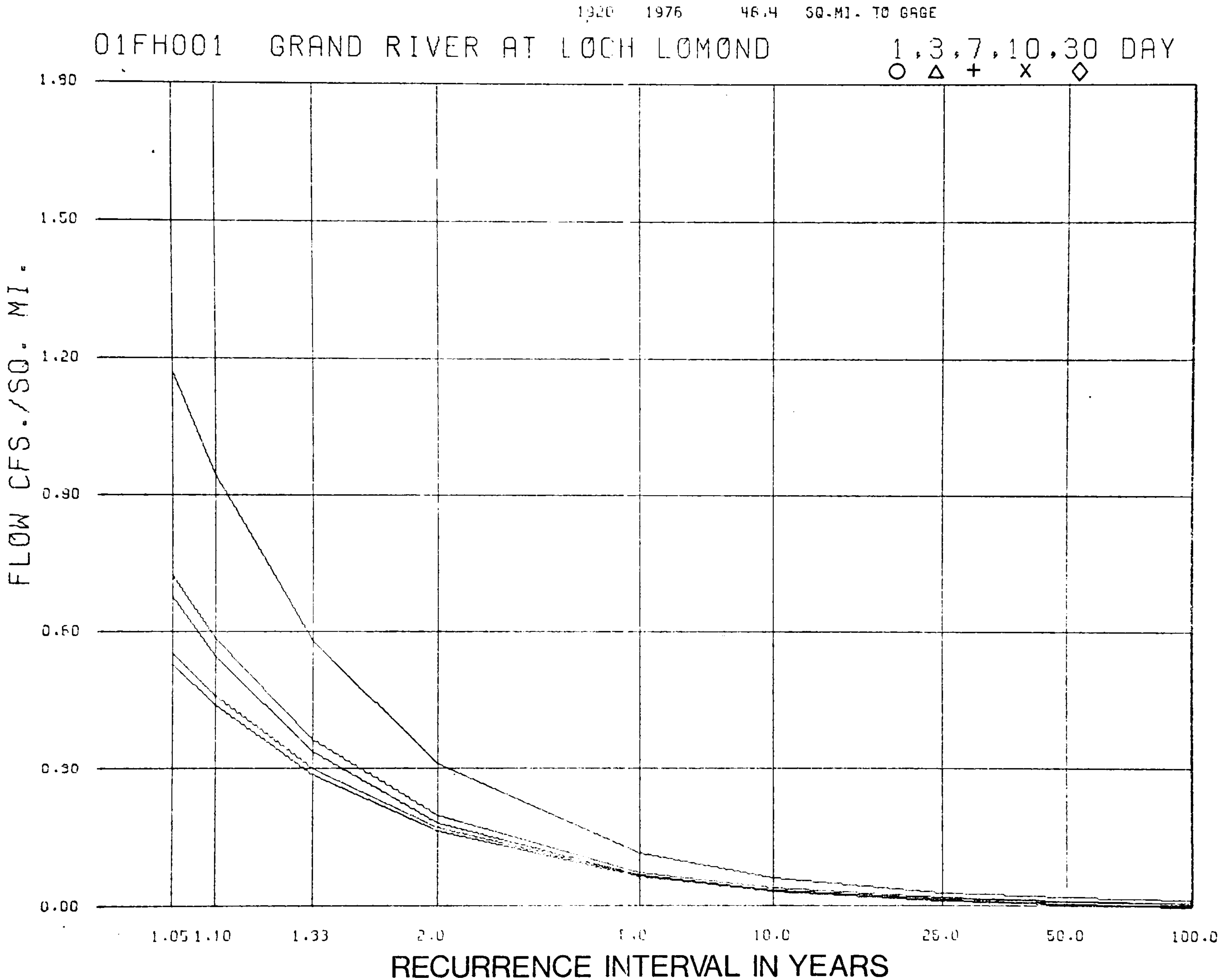
FREQUENCY ANALYSIS OF SUMMER LOW FLOWS (PERIOD OF RECORD)



FREQUENCY ANALYSIS OF SUMMER LOW FLOWS (PERIOD OF RECORD)

FIGURE 4-10A

FIGURE 4-10B



FREQUENCY ANALYSIS OF SUMMER LOW FLOWS (PERIOD OF RECORD)

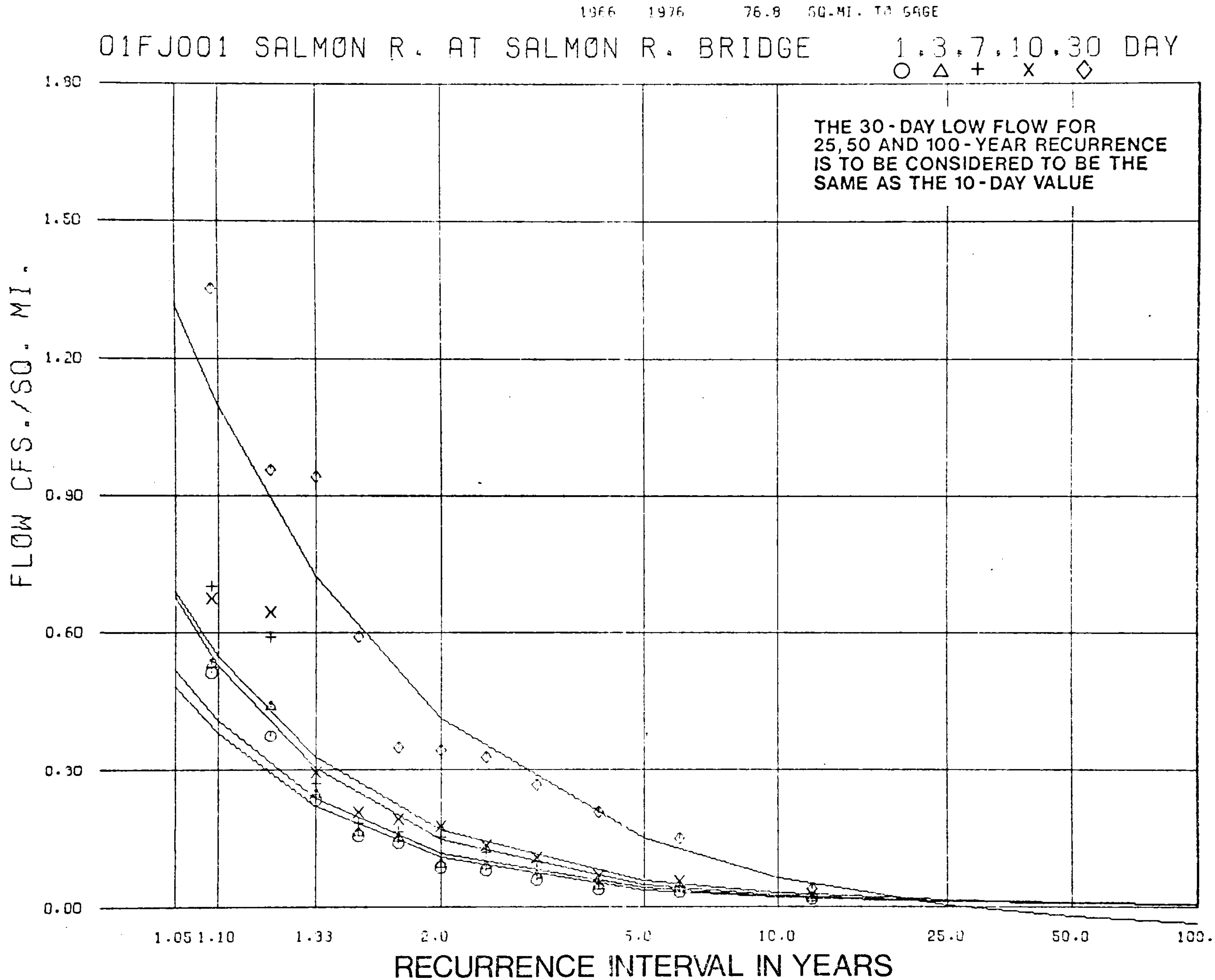
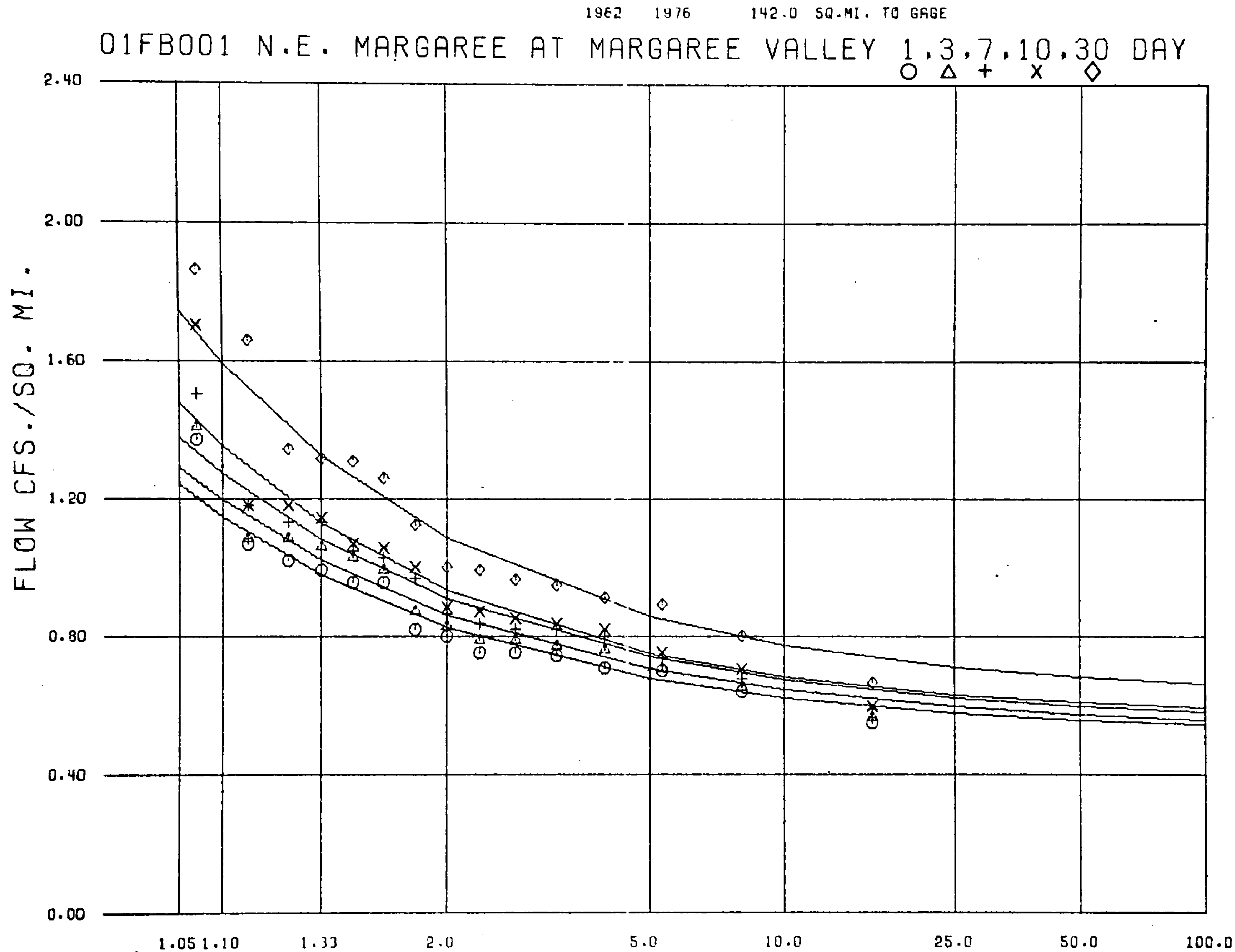


FIGURE 4-11

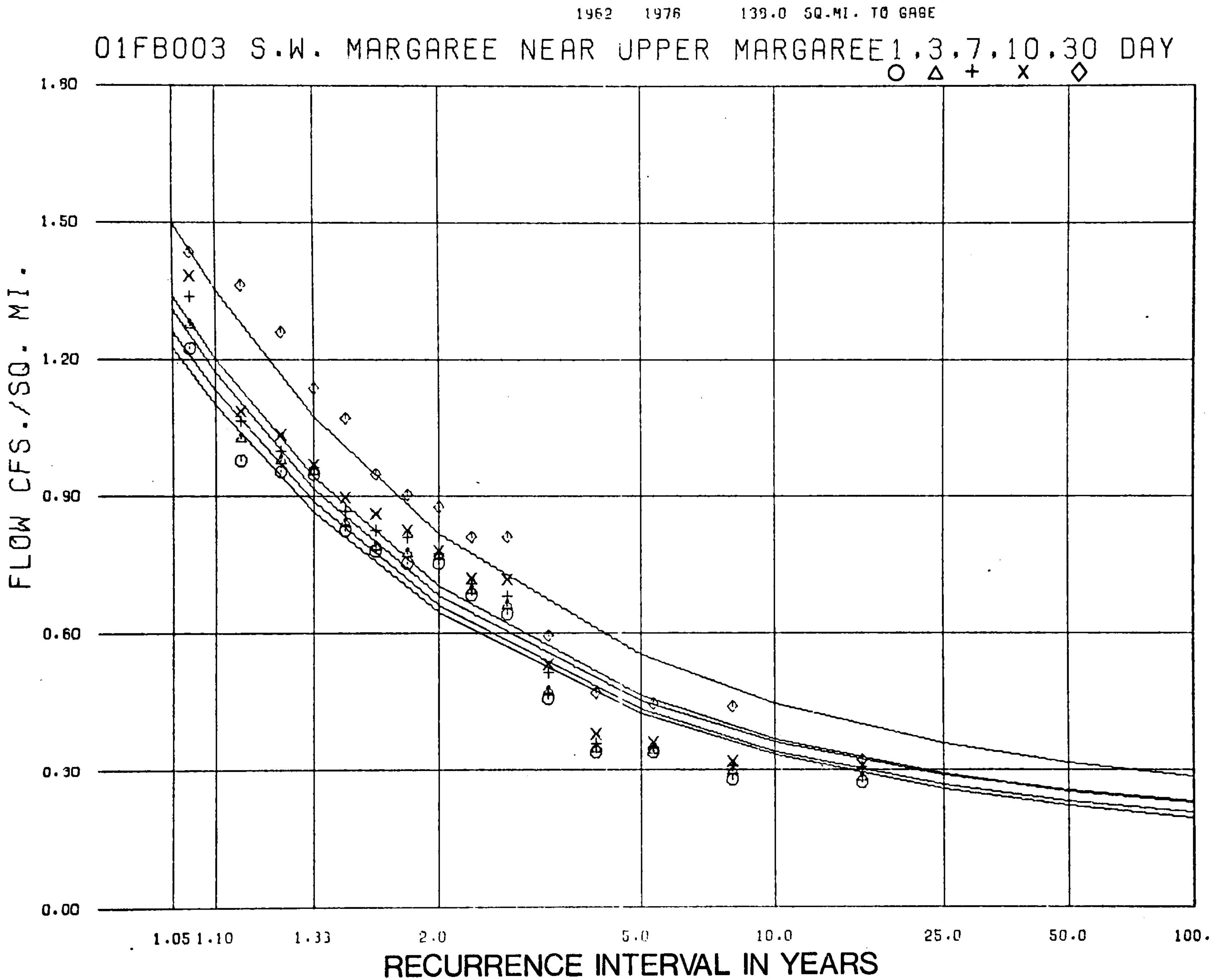
FREQUENCY ANALYSIS OF SUMMER LOW FLOWS (PERIOD OF RECORD)



RECURRENCE INTERVAL IN YEARS

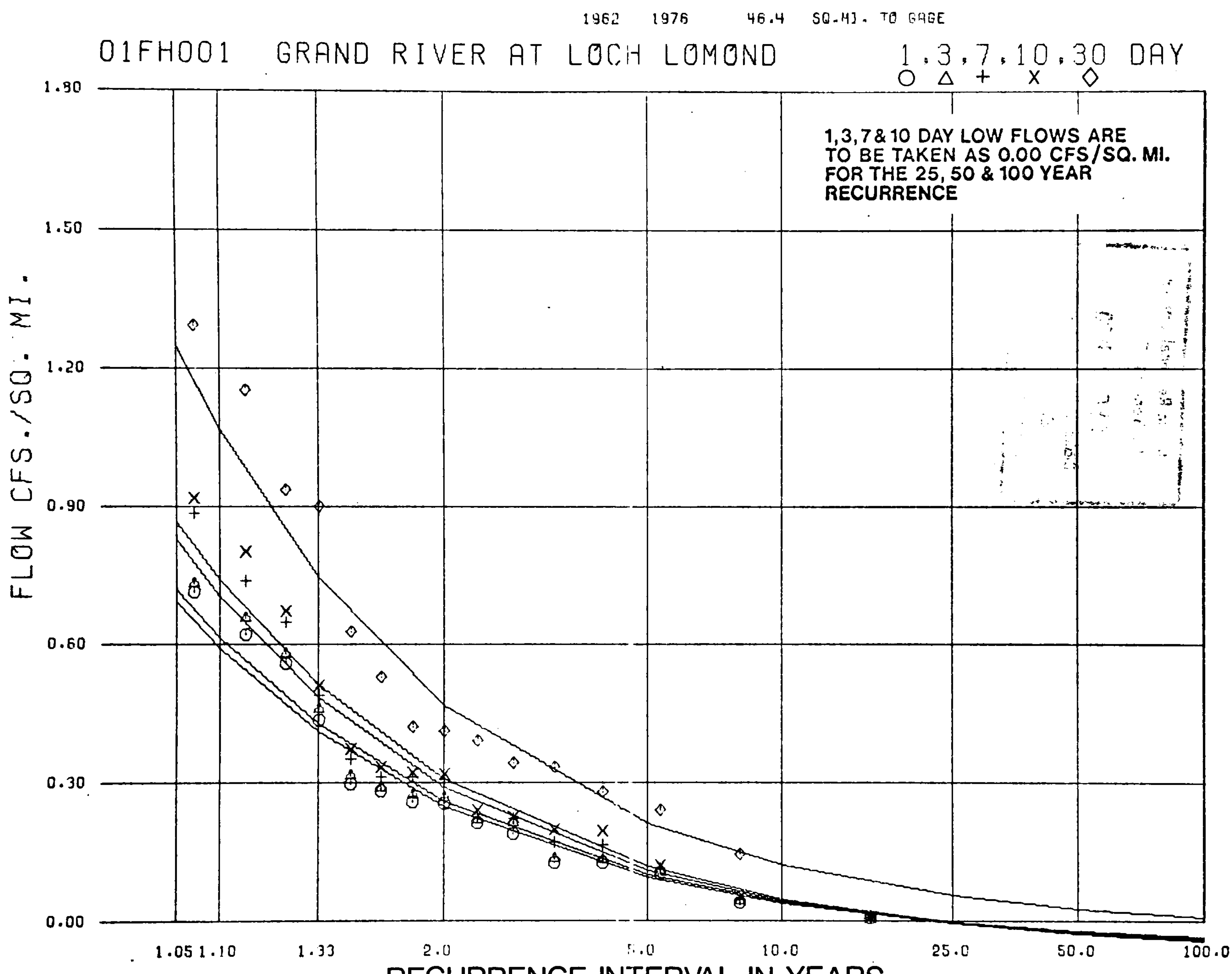
FREQUENCY ANALYSIS OF SUMMER LOW FLOWS (1962-1976)

FIGURE 5-1



FREQUENCY ANALYSIS OF SUMMER LOW FLOWS (1962-1976)

FIGURE 5-2



FREQUENCY ANALYSIS OF SUMMER LOW FLOWS (1962-1976)

FIGURE 5-3