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University of Nevada

Reno

Use of Multiple Correlation for Forecasting Streamflow


A thesis submitted in partial fulfillment of the
requirements for the degree of Master of Science
in Hydrology

by

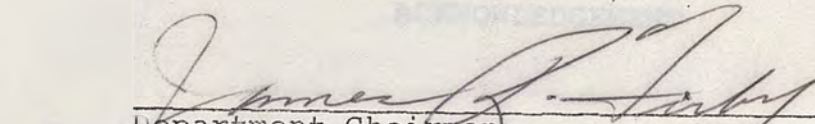
Hugo Oscar Benito

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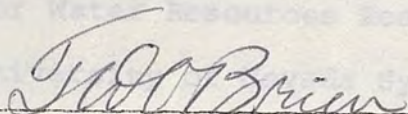
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ABSTRACT

A method is developed to derive seasonal and monthly flow regimen of large river basins where sparse amount of hydrologic data exist, utilizing techniques of multiple correlation. Reliability of the method has been illustrated with reference to Limay River Basin in Southern Argentina, in terms of reasonably sound agreement amongst predicted streamflows and observed streamflows on monthly and spring-summer seasonal basis.

Limay River Basin in Argentina is being considered for a multi-purpose water resources development. Performance objectives for total spring-summer flow, their monthly distribution, and month-to-month flow at a regulatory dam prior to the effect are of prime importance for the following reasons:

- (a) Operation analysis of dammed reservoirs;
- (b) Estimation of available water under various possibilities and timing of release; and
- (c) Scheduling the operation of agricultural and thermal power plants.

The objectives of the investigation reported in this country have been:

- (a) To determine a simple method for predicting the spring-summer flow in mountain fed rivers; and

INTRODUCTION

Development of precipitation-streamflow relationships is a significant issue in hydrologic studies. Rigorous methods for a reliable formulation demand a large amount of hydrologic and meteorologic data. Lack of adequate data in time and space is a common feature of developing countries. The problem of formulating dependable methodology to predict spring-summer flows for Limay River Basin in southern Argentina is representative of much needed hydrologic studies of large river basins where sparse amounts of data exist.

Limay River Basin in Argentina is being considered for a multi-purpose water resources development. Prediction equations for total spring-summer flows, their monthly distribution, and month-to-month flows at a significant use point on the river are of utmost importance for the following reasons:

- (a) Operation studies of Chocon Reservoir;
- (b) Alerting downstream users about water availability and timing of floods; and
- (c) Scheduling the operation of hydroelectric and thermal power plants.

The objectives of the investigation reported in the ensuing text are:

- (a) To formulate a simple method for estimating the spring-summer flows in snow-rain fed rivers; and

- (b) To assess the reliability of the method in the context of seasonal and monthly flows.

Limay River Basin covers a drainage area of about 10,000 square miles, with a mean annual flow of 25,000 cfs., and is consequently a very potential source of water resources development for Argentina. Although the Basin has a relatively large network of rain gages, only 8 of them are in continuous operation. Most of the stream gaging stations can furnish, at best, discontinuous records. Evaluation of flow quantities by methods such as water-budget studies, e.g., Stanford Watershed Model, demand dense network of gages measuring a variety of hydrologic and meteorologic events. Since Limay River Basin is not instrumented to make such data available, at the present time alternative methods, such as statistical methods, should be explored.

The main characteristics of the method developed are that it (1) does not require expensive and time-consuming water budget studies; (2) is flexible enough to accommodate all of the available and dependable stations in the basin, and future information as well. The sensitivity of the method depends upon the number of the stations included in the analysis, their location in the basin, and the quality of the data. When temperature data is available, it can be included in the analysis.

DESCRIPTION OF THE METHOD

Collection of Data

An inventory of the rain gages should be made including the ones operated on a voluntary basis. Some classification of quality of record is important in order to detect possible errors.

Since the number of independent variables is great, it is necessary to obtain the longest record possible. Some missing data could be filled by simple correlation with nearby stations or by using other methods.

Judgement was exercised at this stage of the problem. If possible, it is desirable to sacrifice some stations with short records and use a few stations with a longer period of record. Scrutiny of the data by double mass curves to verify the homogeneity of the data^{1,2} was performed.

The discharge data has to be carefully reviewed in order to correct errors. When very long records are under study and the land use pattern has been changing, corrections have to be made to the rainfall-discharge relation to account for the influence of these land use changes.¹

Weighting of the Rain Gages

If several rain gages are distributed in the basin it is possible to draw isoyetes or apply Thiessen's method in order

to obtain the mean monthly rainfall over the basin. But this situation is rarely the case in developing countries and not too common in the others.

The stations located at the mid-altitude of the basin are used as an indices of the snow accumulation in the mountain. It is expected that their relative importance varies among the stations, making it necessary to weight the stations by one of two methods.

The first method is to use a rank correlation. In this case, the weighting is made according to the reciprocal of the sum of the squares of the differences in rank. The method is equivalent to using the rank correlation coefficient for the weighting.³

The second method is to weight the stations according to the value of their multiple regression coefficient obtained through a multiple correlation computation. In this case, large negative regression coefficients need to be eliminated, and the small negative coefficients are given a small positive weight.¹ The sum of the coefficients for all stations is equal to one in both cases.

Since the regression coefficients indicate the relative importance of the stations, weights are proportioned to these coefficients. The stations are in some way correlated among themselves. A very wet year yields high values in all the stations and a dry year results in low values. For this reason the values of the regression coefficients are not too critical and can be rounded in order to simplify the computations.

The correlation equation between the annual rainfall and annual discharge was considered to be of the following form:

$$Q = (a_1 S_1 + a_2 S_2 + \dots + a_n S_n) A \pm N \quad (1)$$

where Q = Annual discharge

S_i = Annual rainfall recorded at station "i"

A_i = Weight of station "i", subject to:

$$a_1 + a_2 \dots + a_n = 1$$

A = Slope of the regression equation

N = Intercept of the regression equation.

The expression within parantheses denotes the annual rain index.

Characteristics of the Spring-Summer Discharge

The spring-summer discharge in snow-rain fed rivers is composed of three elements. The correct evaluation of each by means of appropriate parameters is the basis for meaningful correlations.

The first element of the spring-summer discharge is the recession of the winter flows, the depletion of storage in the basin. This value may be high in the case of basins with many lakes and in general depends on the geology and topography.

The second element is the discharge originating from melting snow. As previously discussed, rain gages located at

relatively low altitudes are used as in indices to snow in high mountains since data is scarce at higher elevations.

Finally, the third element is the discharge caused by the summer rains. This is the single segment of the spring-summer discharge that is unknown. When conducting the forecast, different values of the summer rain should be considered according to the demands. The method is flexible enough to permit monthly adjustments of discharge for the entire season. Each one of these elements and the parameters that correlate with them will be examined, one at a time.

Storage in the Basin

The amount of water stored in the basin at the beginning of the forecasting season is determined by the recession curve of the winter flows, which, in turn, is a function of the discharge in the preceding period.

The recession curve was drawn by combining several curves for several years.³ This method is considered to be accurate enough for this study. Once the recession curve was obtained, it was necessary to compute the volume of discharge for each year of record. In this way a curve relating discharge in the preceding season to seasonal volume stored in the basin was obtained. Thus, when a forecast is to be made, the value of storage in the basin is easily read off the curve.

The storage in the basin may also be evaluated by considering the storage in the basin to be a linear function of the discharge in the preceding season. Although the assumption of

linearity introduces some error, it is assumed to be insignificant. Errors of the forecasts for the three parts of the hydrograph tend to compensate one another.

The recession curve may be used to estimate the amount of available storage at any moment. This is equivalent to a forecast of minimum flows. In the case of a dam, this amount added to the water storage in the reservoir gives the minimum water available for power generation, irrigation, municipal and industrial water supply, etc.

Snow Melt Runoff

To evaluate snow melt runoff, rainfall in the low valleys was used as an index. Once the weights have been computed, the weighted monthly winter discharges are prepared by multiplying the monthly rain at each station by its weight and summing the weighted values. The fact that the water yield from precipitation varies with season, and within each season by month, necessitates the weighting of the winter rainfall.

A multiple correlation computation was carried out in order to determine the weights of the winter months. It is possible that one or more months give a negative coefficient. In this case, a careful judgement must be used in order to eliminate that month. Negative coefficients are likely to occur at the beginning of the season which means that the snowfall in that month melts instead of accumulating until the end of the winter season. In case it is necessary to eliminate a month, a new correlation analysis should be conducted. The weights given to

the months are set to be proportional to the multiple regression coefficients.¹

If the values of the multiple regression coefficients vary in a discontinuous manner in the season it is necessary to make some adjustments. This is made by plotting the multiple regression coefficients in a graph together with their standard errors, and adjusting the points by a smooth curve.¹ The sum of the monthly coefficients has to be equal to one, though in the case studied it was made close to three (there were three months) in order to maintain a reasonable scale of magnitude of these variables.

The Winter Precipitation Index can be obtained by an equation of the following type:

$$\begin{aligned} \text{W.P.I.} = & A_1 (a_1 S_1 + a_2 S_2 + \dots + a_n S_n)_1 + A_2 (a_1 S_1 + a_2 S_2 + \\ & \dots + a_n S_n)_2 + \dots + A_m (a_1 S_1 + a_2 S_2 \dots a_n S_n)_m \quad (2) \end{aligned}$$

where W.P.I. = Winter Precipitation Index

$A_1 \dots A_m$ = the monthly weights

where 'i' to 'm' are months.

Discharge Due to Summer Rains

The discharge due to summer rains is the only part of the spring-summer discharge that cannot be predicted on the basis of previous events. The summer rainfall is computed according to the weights of the stations. The rainfall for the entire

season should be considered, though in some instances the rainfall of the last month of the season may belong to the next water year and could add a new source of variation to the correlation.

Weighting of summer months may be convenient, but in the case studied it only contributes in a small measure to reduce the variance of the multiple correlation. To eliminate additional sources of error, spring-summer months were not weighted and the rainfall of the preceding month of the season was not considered in forecasting the entire spring-summer discharge.

Computation of Spring-Summer Discharge

The forecast for the entire spring-summer discharge is made in three stages. The first stage is evaluation of winter recession; the second stage is evaluation of the flows due to snow melt and summer rains; and the third stage is summing the two values to obtain the total discharge for the season. Total spring-summer discharge, as it is referred in this study, is the amount of water expressed in cubic hectometers gaged at the point of study during the entire forecasting season. In the case study the period is September 1st to March 31st.

Storage in the basin or discharge due to recession winter flows is the volume of water in cubic hectometers due to the recession of the winter flows and computed according to the August index flows. Net spring-summer discharge is the difference between the total spring-summer discharge and the storage in the basin. This volume of water is due to snow-melt and spring-summer rains.

First Stage:

The first stage in the computation of the spring-summer discharge forecast is the computation of the storage in the basin on the basis of recession curve and then the net spring-summer discharge. To simplify this computation, the volume of the recession curve is integrated for the seven-month period of forecasting for different values of August index flow. This value is plotted and a curve is obtained that relates August index flow to storage in the basin.

Second Stage:

The second stage of computation consists in evaluation of the net spring-summer discharge. A multiple correlation is made relating the Winter Precipitation Index and the Summer Precipitation Index to the net spring-summer discharges. In the case study the rain was expressed in millimeters and discharge in cubic hectometers.

The equation can be expressed as:

$$\text{NET S.D.} = (a) \text{ W.P.I.} + (b) \text{ S.P.I.} + d \quad (3)$$

where Net S.D. = Net spring-summer discharge (Sept. through March)

W.P.I. = Winter Precipitation Index

S.P.I. = Summer Precipitation Index.

Third Stage:

The third stage consists, as explained earlier, of summing the two components of the hydrograph in order to obtain the total spring-summer discharge.

The only source of error in this method is the correlation to compute the net spring-summer discharge. Consequently, the final relative error of the forecast will be considerably less due to the addition of the storage in the basin.

The final equation is:

$$T.D.S. = (a W.P.I. + b S.P.I. + d) + S.B. \quad (4)$$

where T.S.D. = Total spring-summer discharge

S.B. = Storage in the basin.

Monthly Distribution of the Spring-Summer Discharge

The distribution of the monthly discharge can be estimated on the basis of a statistical analysis of monthly flows. An alternative approach is to express monthly discharge as a percentage of the total spring-summer discharge. Finally a correlation between the total summer discharge and the monthly flows can be computed. The accuracy of these monthly flows is poor and it must be taken as a guide. The forecasts are corrected each month by the method to be described later.

The methodology adopted in this study was to correlate the total spring-summer discharge with the monthly discharges which were expressed as percentages of total spring-summer discharge.

Monthly Forecast Based on the Knowledge of the Discharge of Preceding Months

For the operation of the system, it is important to be able to forecast with as great a level of accuracy as possible, the discharge of the future month using knowledge of flow in the current month. In addition to the errors of correlation there is an additional source of error in this approach, namely the uncertainty associated with rainfall during the next month. In spite of this error the greatest part of the hydrograph is known on basis of previous parameters. The amount of rainfall in the next month should be estimated. In general, to get an average estimate, the median of the rainfall is used instead of the mean. At the same time, the first and third quartile could be the limits for a fifty percent of probability.

The correlation needed to forecast each month on basis of the previous month could be prepared in similar manner as the forecast of the discharge in the total season. The discharge due to recession of the previous months is a function of the index flow at that month. Since it uses only a small part of the recession curve it is assumed that the relationship is linear. In this way, index flows of the months are independent variables in the correlation, representing the recession flows of the previous months.

The second variable to be included is the Winter Precipitation Index. This variable represents the snow melt runoff. Since these flows are concentrated in few months of spring-summer

season discharge, it is unnecessary to include the Winter Precipitation Index toward the later months of the season.

The equations can be formulated as follows:

September

$$\text{Sep. Disch.} = a \text{ W.P.I.} + b \text{ Aug. Ix. Fw.} + c \text{ Sep. Rn} + d$$

October

$$\text{Oct. Disch.} = a \text{ W.P.I.} + b \text{ Sep. Ix. Fw.} + c \text{ Oct. Rn} + d$$

November

$$\text{Nov. Disch.} = a \text{ W.P.I.} + b \text{ Oct. Ix. Fw.} + c \text{ Nov. Rn} + d$$

December

$$\text{Dec. Disch.} = a \text{ W.P.I.} + b \text{ Nov. Ix. Fw.} + c \text{ Dec. Rn} + d$$

January

$$\text{Jan. Disch.} = a \text{ Dec. Rn} + b \text{ Dec. Ix. Fw.} + c \text{ Jan. Rn} + d$$

February

$$\text{Feb. Disch.} = a \text{ Jan. Ix. Fw.} + b \text{ Feb. Rn} + d$$

March

$$\text{Mar. Disch.} = a \text{ Feb. Ix. Fw.} + b \text{ Mar. Rn} + d$$

where W.P.I. = Winter Precipitation Index

Aug. Ix. Fw.,

Sep. Ix. Fw.,

etc.

= August index flow, September index flow,
etc., in cubic meters per second

Sep. Rn, Oct.

Rn, etc.

= September rainfall, October rainfall,
etc., in millimeters

Sep. Disch.,
 Oct. Disch.,
 etc. = September discharge, October discharge,
 etc., in cubic hectometers
 a,b,c = multiple regression coefficients.

The characteristics of the equation may vary from the beginning to the end of the season. The importance of the winter rain index (snow melt runoff) diminishes steadily while the rainfall and recession curves become more important during months of January, February, and March.

1. This would be the first step to carry important studies to the area used to determine methods of forecasting.
2. Though the main purpose of the dam under construction is hydro-power and flood prevention, studies are being carried out in order to facilitate irrigation of an area of 100,000 hectares (i.e., 1.2 million acres).
3. Other studies with similar characteristics can be found in Argentina and other countries as well, consequently the method may be applied with the same or better degree of accuracy.

Description of the Falls

The Silver River falls is located at 38°41' to 41'12" North

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CASE STUDY

The case study was chosen to be Limay River Basin in Argentina for the following reasons:

1. Data was available;
2. A large dam and reservoir with an important power plant are under construction, therefore the forecast would have the potential of immediate application;
3. The river and its tributaries are the most important reserves of hydroelectric power in the Argentine Republic, and important projects are under study to install more than 4 million KW/hr.;
4. This could be the first step to more important studies in the area aimed toward determining methods of forecasting;
5. Though the main purpose of the dam under construction is hydro-power and flood prevention, studies are being carried out in order to facilitate irrigation of as much as 500,000 hectares (i.e., 1.2 million acres);
6. Other basins with similar characteristics can be found in Argentina and other countries as well, consequently the method may be applied with the same or better degree of accuracy.

Description of the Basin

The Limay River Basin is located at 38°41' to 41°12' South

Latitude, and at $70^{\circ}20'$ to $71^{\circ}45'$ West Longitude. The basin is illustrated in Figure 1. The basin is formed by two main tributaries, the Limay River and the Collon Cura River.

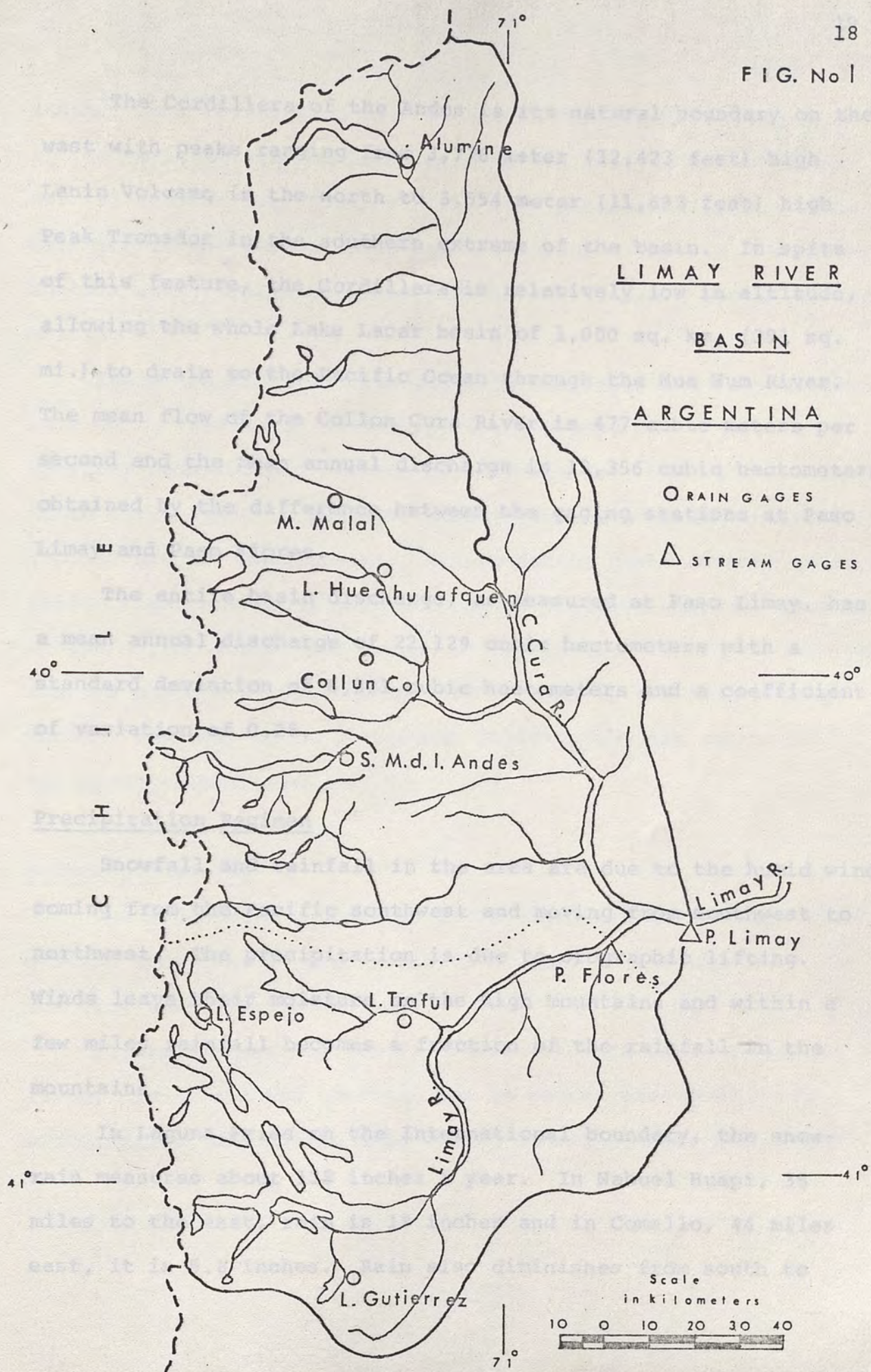
The Limay River receives runoff from the southern part of the basin. Its main characteristic is that a significant part of its drainage area is regulated by several lakes. The Limay River drainage encompasses 9,860 square kilometers of which the lakes have an area of 820 sq. km. (320 sq. mi.), i.e., 8.3% of the basin.

The Limay River at the outlet of the Nahuel Huapi Lake has a mean discharge of 210 cubic meters per second. Its main tributary, the Traful River, drains the waters of Lake Traful, and has a mean discharge of 73 cubic meters per second and a drainage area of 1,330 sq. km. The gaging station at Paso Flores records an average discharge of 283 cubic meters per second. The standard deviation of its annual discharge in cubic hectometers is 2,103, its coefficient of variation is 24%, and the mean is 8,773 cubic hectometers. It can be seen from these values that the river is highly regulated by the lakes. The average water yield is 28.7 liters per square kilometer.

The Collon Cura River drains the central and northern part of the basin and collects the runoff of a chain of lakes that reach the river from the west. The river can be considered the limit of the active basin since runoff from the east is negligible.

Its drainage area is 16,240 sq. km. (6,340 sq. mi.) with 2% covered by lakes.

FIG. No 1



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The Cordillera of the Andes is its natural boundary on the west with peaks ranging from 3,776 meter (12,423 feet) high Lanin Volcano in the north to 3,554 meter (11,693 feet) high Peak Tronador in the southern extreme of the basin. In spite of this feature, the Cordillera is relatively low in altitude, allowing the whole Lake Lacar basin of 1,000 sq. km. (391 sq. mi.) to drain to the Pacific Ocean through the Hua Hum River. The mean flow of the Collon Cura River is 477 cubic meters per second and the mean annual discharge is 13,356 cubic hectometers obtained by the difference between the gaging stations at Paso Limay and Paso Flores.

The entire basin discharge, as measured at Paso Limay, has a mean annual discharge of 22,129 cubic hectometers with a standard deviation of 6,221 cubic hectometers and a coefficient of variation of 0.28.

Precipitation Regimen

Snowfall and rainfall in the area are due to the humid winds coming from the Pacific southwest and moving from southwest to northwest. The precipitation is due to orographic lifting. Winds leave their moisture on the high mountains and within a few miles rainfall becomes a fraction of the rainfall in the mountains.

In Laguna Frias on the International boundary, the snow-rain measures about 138 inches a year. In Nahuel Huapi, 35 miles to the east, rain is 18 inches and in Comallo, 44 miles east, it is 5.8 inches. Rain also diminishes from south to

north. Rain varies from 52.6 inches in the southern extreme of the basin at Station Lake Gutierrez to 36.3 in the northern part at Station Lake Alumine. The same pattern of precipitation existing in the eastern slope of the Sierra Nevada is reproduced in this area, though the snow pack is not as heavy due to partial melting.

There are about 20 rain gages in the area, but many of them have short records or have discontinuous records. There is only one meteorologic station of second order, but it has been moved three times in the past twenty years and consequently, records are not homogeneous. Winter season marks intense rainfall. Figures 2 and 3 show the regime at three stations located at the north, south, and center of the basin. It can be inferred that 65 percent of the precipitation falls in the four winter months, and only about 20 percent falls in the six months of the spring-summer season.

Hydrologic Regime

The hydrologic regime, as it is gaged in Paso Limay Station, differs from that of precipitation because of the lag caused by the snow accumulation and melt.

Figure 4 shows the runoff characteristics of this type of river. There are two crests: one in winter caused by heavy winter rains, and one in late spring caused by snow-melt runoff.

FIG. No 2

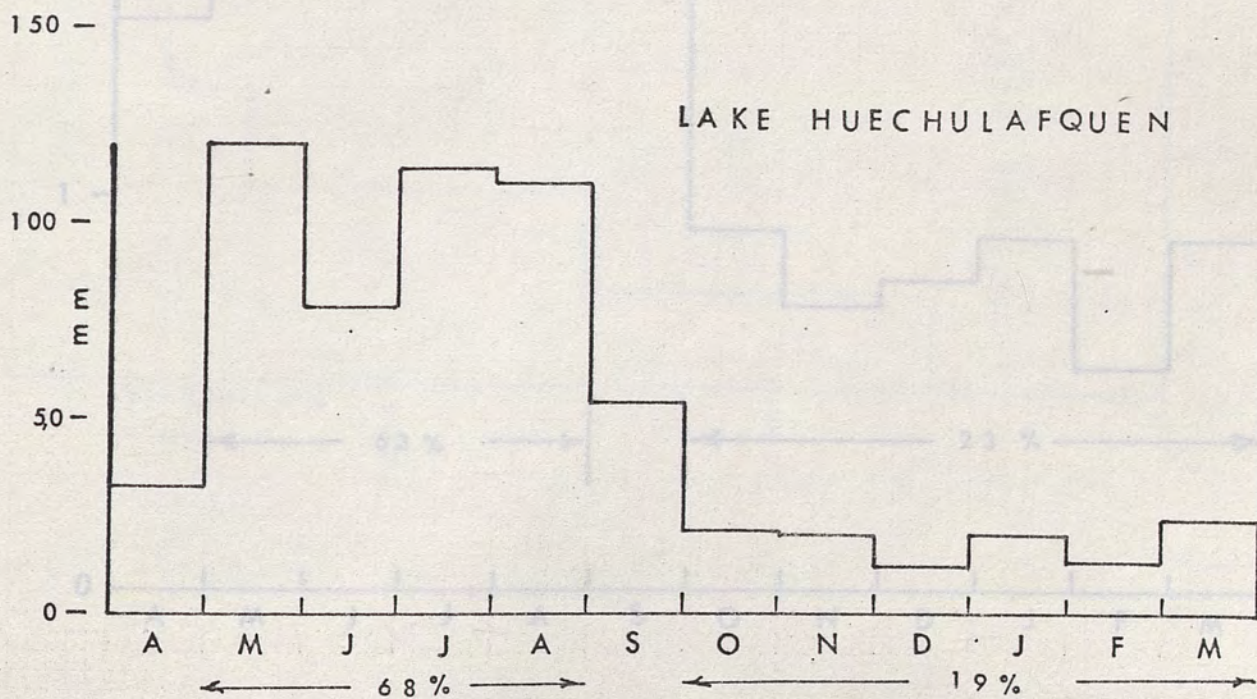
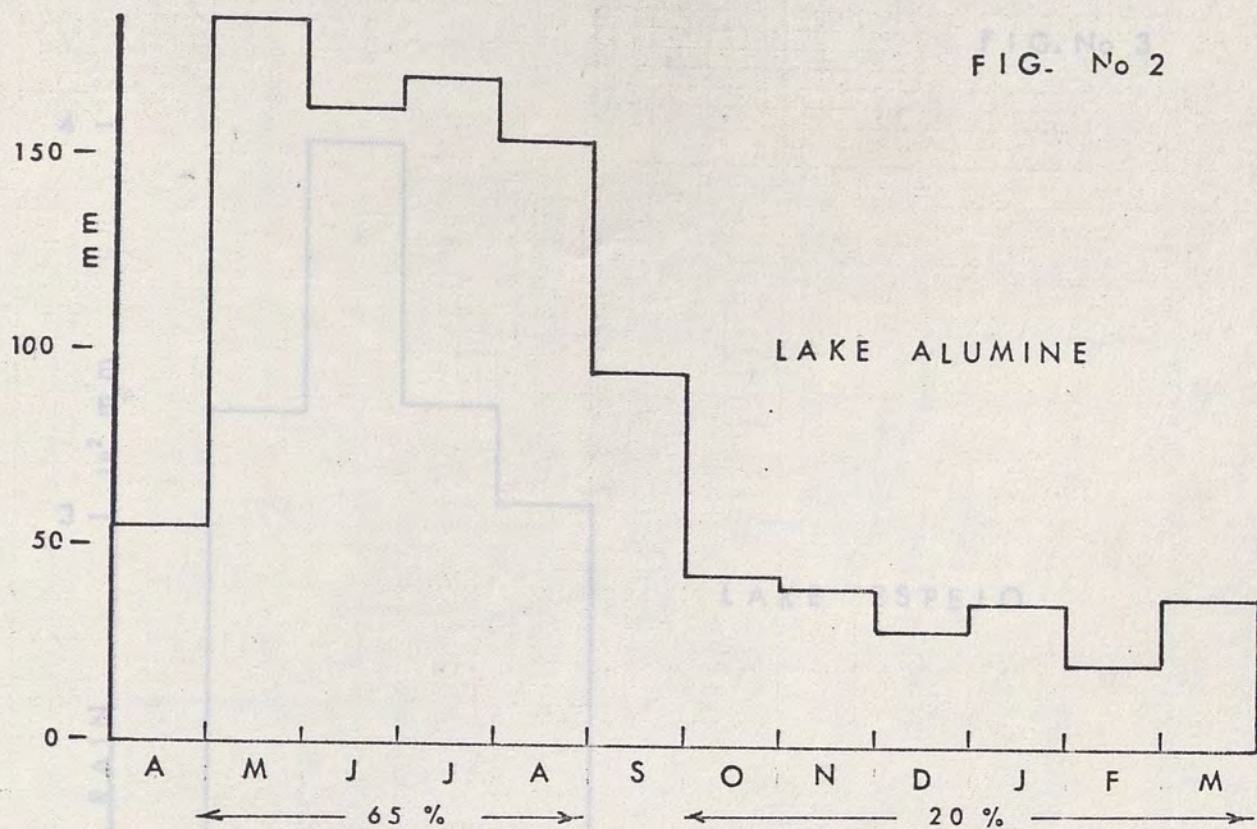
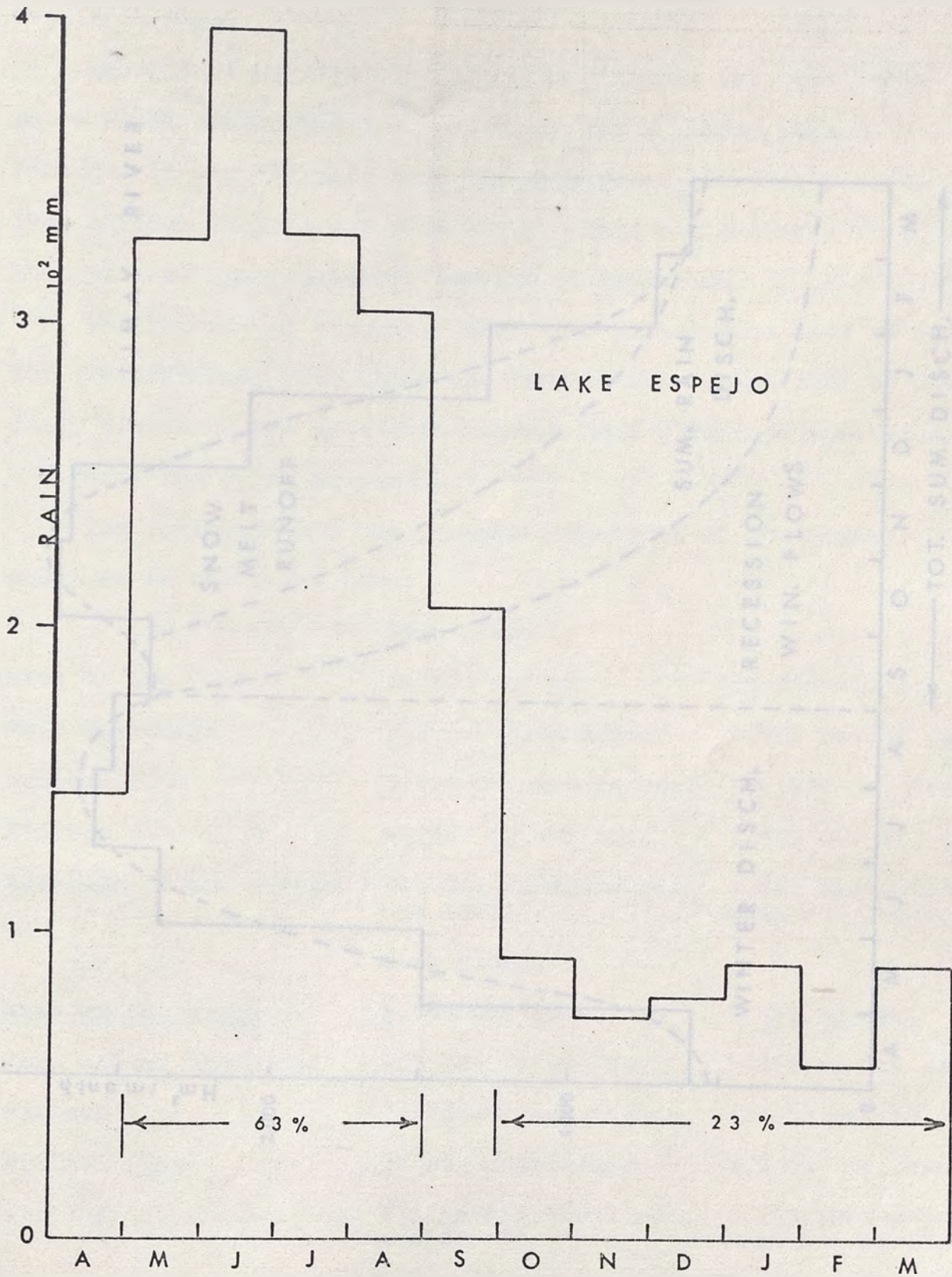


FIG. No 3



ARV 501: CUTAN TO ALBUQUERQUE

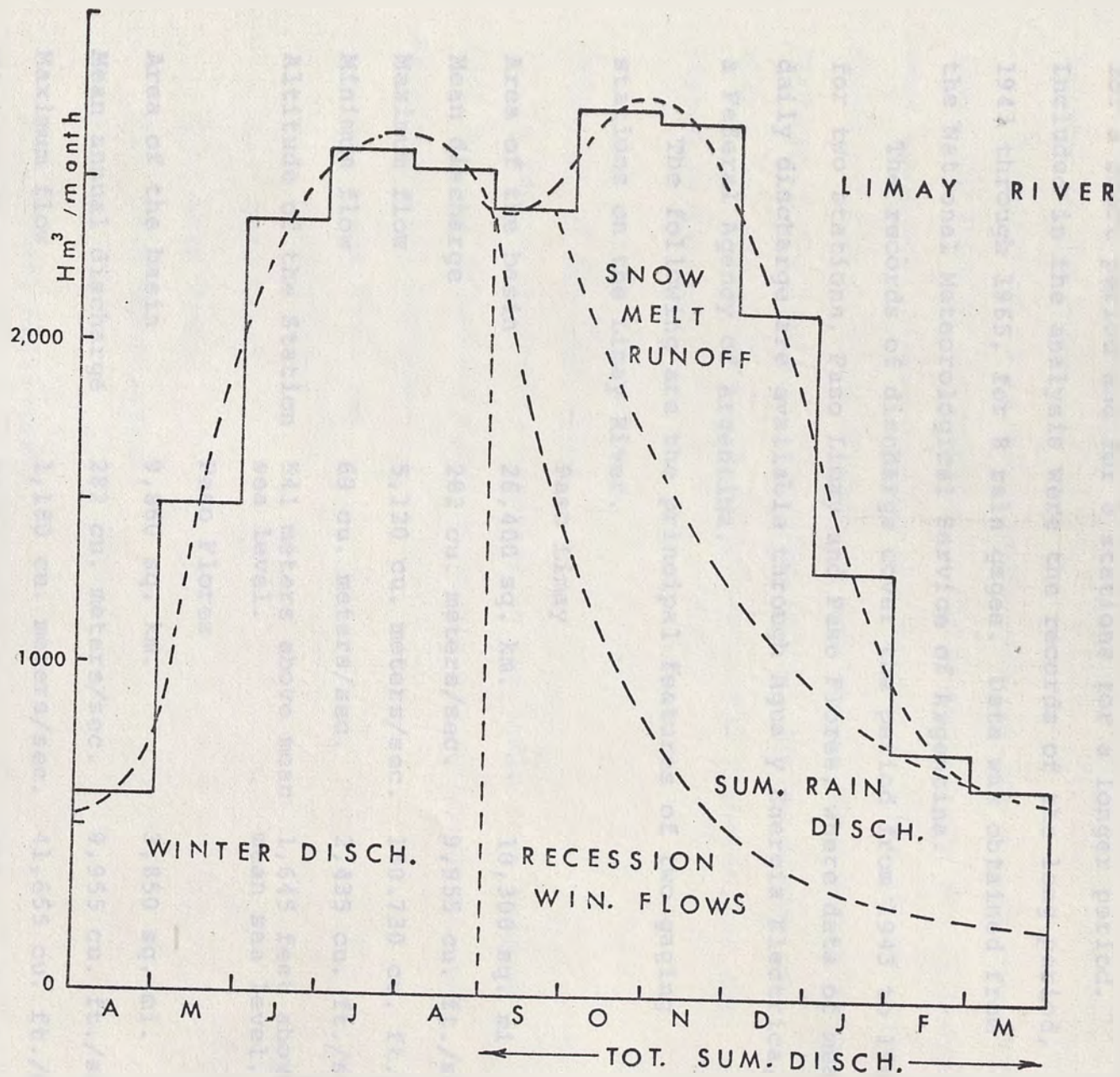


FIG. No 4

Forecast of the Spring-Summer Discharge

Available Data:

Records of rainfall for about 20 stations were available for a short period and for 8 stations for a longer period.

Included in the analysis were the records of the long period, 1943 through 1965, for 8 rain gages. Data was obtained from the National Meteorological Service of Argentina.

The records of discharge cover the period from 1943 to 1967 for two stations, Paso Limay and Paso Flores, where data of mean daily discharge are available through Agua y Energia Electrica, a Federal Agency of Argentina.

The following are the principal features of two gaging stations on the Limay River.

	Paso Limay	
Area of the basin	26,400 sq. km.	10,300 sq. mi.
Mean discharge	282 cu. meters/sec.	9,955 cu. ft./sec.
Maximum flow	5,120 cu. meters/sec.	180,730 cu. ft./sec.
Minimum flow	69 cu. meters/sec.	2,435 cu. ft./sec.
Altitude of the Station	541 meters above mean sea level.	1,645 feet above mean sea level.
	Paso Flores	
Area of the basin	9,860 sq. km.	3,850 sq. mi.
Mean annual discharge	282 cu. meters/sec.	9,955 cu. ft./sec.
Maximum flow	1,180 cu. meters/sec.	41,655 cu. ft./sec.
Minimum flow	23 cu. meters/sec.	812 cu. ft./sec.
Altitude of the Station	530 meters above mean sea level.	1,795 feet above mean sea level.

The discharge of the main tributary, the Collon Curá River, is computed as the difference between the two stations. The dam under construction is located a few miles downstream of Paso Limay in the place called Chocon.

Storage in the Basin

A recession curve and a graph relating the August Index Flow (Aug. Ix. Fw.) to the storage in the basin for the entire season were prepared. Figure 5 shows the recession curve of the winter flows and Figure 6 the storage in the basin. From Figure 6 the storage in the basin was computed and net spring-summer discharge was obtained by the difference. All these values are listed in Table 1.

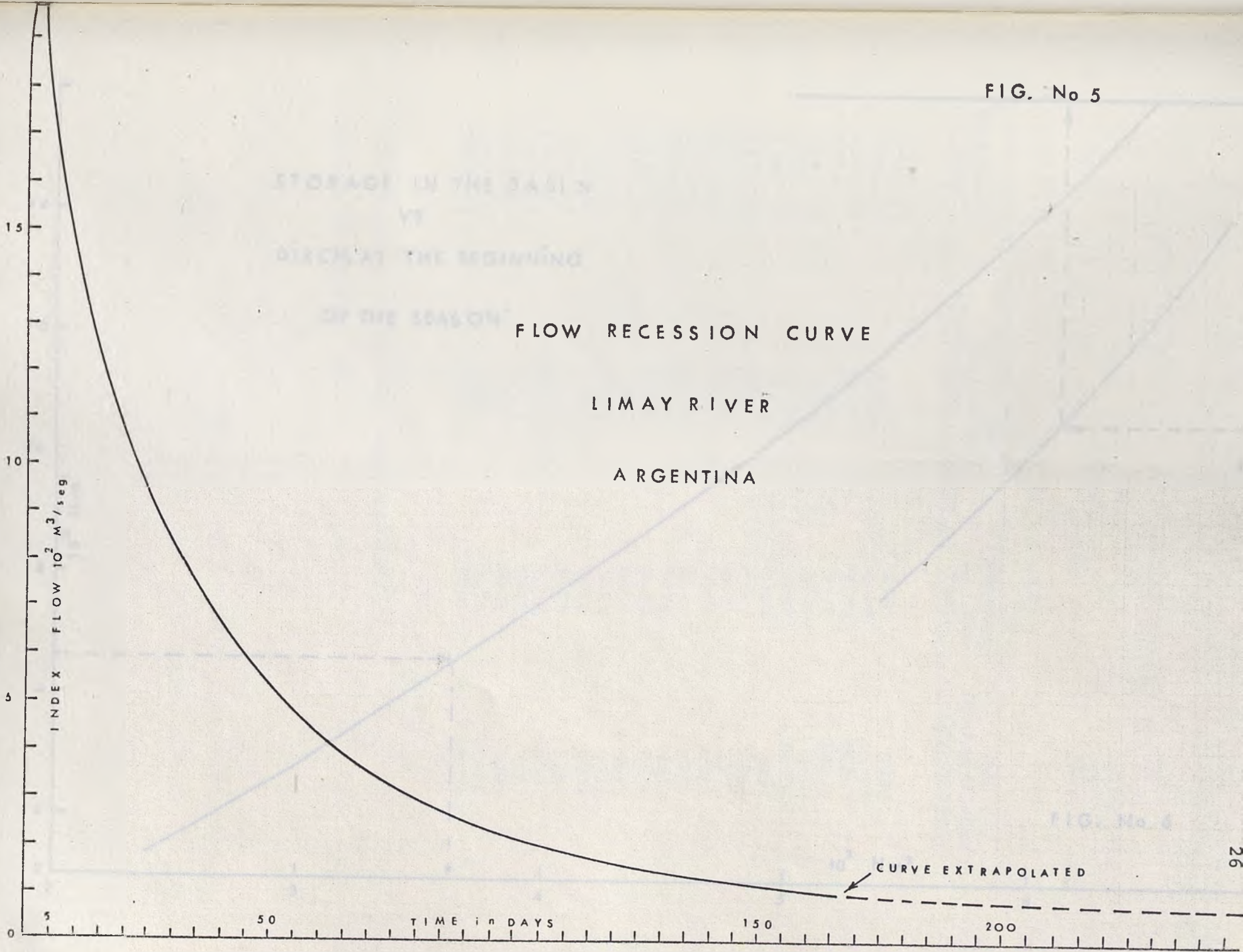
Weighting of the Rain Gages

A record of monthly rainfall is available from 1943 to 1964 for the following stations maintained by the Argentine Meteorological Service:

1. Lake Gutierrez
2. Lake Alumine
3. Lake Espejo
4. Lake Traful
5. Lake Huechulafquen
6. Collum Co. Ranch
7. Mamuil Malal Ranch
8. San Martin de los Andes.

These gages as well as the stream gages are located on Figure 1.

FIG. No 5



STORAGE IN THE BASIN
VS
DISCH. AT THE BEGINNING
OF THE SEASON

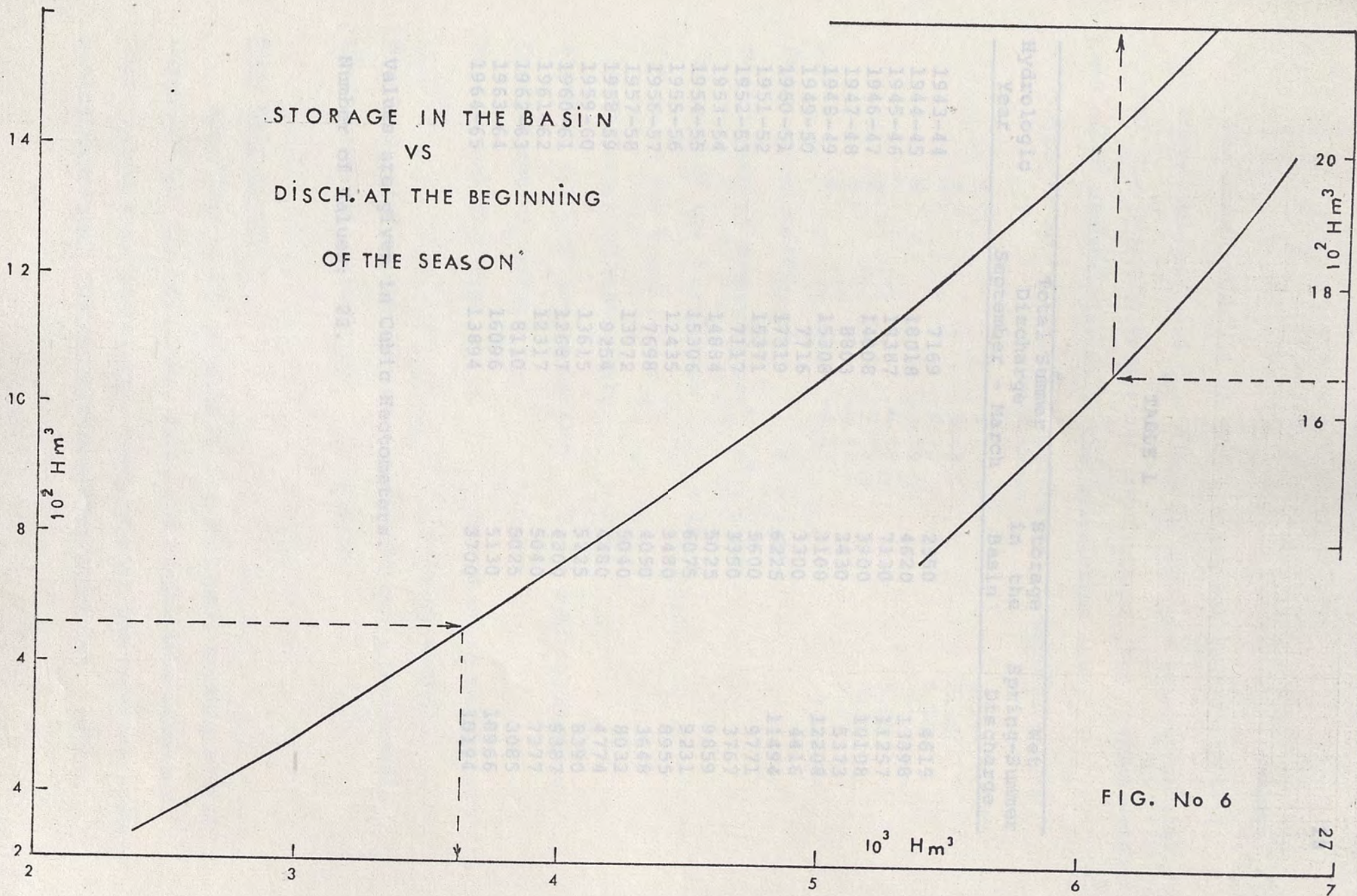


FIG. No 6

TABLE 1

Hydrologic Year	Total Summer Discharge September - March	Storage in the Basin	Net Spring-Summer Discharge
1943-44	7169	2550	4619
1944-45	18018	4620	13398
1945-46	18387	7130	11257
1946-47	14008	3900	10108
1947-48	8803	3430	5373
1948-49	15308	3100	12208
1949-50	7716	3300	4416
1950-51	17319	6225	11494
1951-52	15371	5600	9771
1952-53	7117	3350	3767
1953-54	14884	5025	9859
1954-55	15306	6075	9231
1955-56	12435	3480	8955
1956-57	7698	4050	3648
1957-58	13072	5040	8032
1958-59	9254	4480	4774
1959-60	13615	5225	8390
1960-61	12687	4300	8387
1961-62	12317	5040	7277
1962-63	8110	5025	3085
1963-64	16096	5130	10966
1964-65	13894	3700	10194

Values are given in Cubic Hectometers.

Number of Values: 22.

month of May gave a negative value, a new computation was carried out, excluding data for the month of May. The multiple regression coefficients and weights for the months are:

Month	Multiple Regression Coefficient	Rounded Weight
June	3.39	0.45
July	8.69	1.20
August	9.76	<u>1.35</u>
		= 3.00

The Winter Precipitation Index (W.P.I.) was obtained by multiplying the rainfall by the respective weights and summing.

Discharge Due to Summer-Spring Rainfall

The Summer Precipitation Index was obtained by multiplying the spring-summer rainfall at each station by its weight. A multiple correlation to weight the spring-summer months was carried out, but it contributed little in diminishing the variance of the correlation.

Computation of the Total Spring-Summer Discharge

A multiple correlation relating W.P.I. and S.P.I. to Net S.D. was computed.

The values of the gaged and computed values of the Net S.D. are listed in Table 2, as well as the differences between them.

The correlation equation obtained is:

$$\text{Net S.D.} = 6.858 \text{ W.P.I.} + 19.829 \text{ S.P.I.} - 1918 \quad (5)$$

TABLE 2

Year	Net Summer Disch. Gaged Cubic Hectometers	Net Summer Disch. Computed Cubic Hectometers	Residual Cubic Hectometers	Error %
43/44	4619	5113	494	9.7
44/45	13398	13214	- 184	1.4
45/46	11257	11535	278	2.4
46/47	10108	10159	51	0.5
47/48	5373	5824	452	7.8
48/49	12208	8661	-3546	40.9
49/50	4416	3574	- 842	23.6
50/51	11494	8005	-3488	43.6
51/52	9771	11499	1728	15.0
52/53	3767	4476	709	15.8
53/54	9859	9502	- 357	2.7
54/55	9231	7900	-1331	16.8
55/56	8955	6534	-2421	37.0
56/57	3648	4326	678	15.7
57/58	8032	7331	- 701	9.6
58/59	4774	7250	2476	34.2
59/60	8390	10172	1782	17.5
60/61	8387	8883	496	5.6
61/62	7277	8725	1448	16.6
62/63	3085	6114	3029	49.5
63/64	10966	10098	- 868	8.6
64/65	10194	10308	115	1.1
Mean Percent Error				17.07%
Coefficient of Correlation R				0.837
Coefficient of Determination R ²				0.70
Standard Error of the Regression				1,774 Cu. Hectometers
Coefficient of Variation				0.22
Standard Deviation of the Net Summer Discharge				3,084 Cu. Hectometers
Coefficient of Variation of Net Summer Discharge				0.38
F Test of the Correlation				22.2

After obtaining the values of the net spring-summer discharge, the total spring-summer discharge is obtained by adding the storage in the basin. All these values and the final percent of error in the forecasts are listed in Table 3. The possible errors in the forecast are considered to be lumped in the standard errors of the estimates of net spring-summer discharge.

Monthly Distribution of the Spring-Summer Discharge

Correlations between total spring-summer discharge (T.S.D.) and the monthly flows were computed. The monthly flows were computed for the mean T.S.D. and expressed as a percentage of the mean T.S.D. The standard error of the seven correlations were also expressed in percent of the T.S.D.

Month	Mean Flow	Percent of Total S.D.	Standard Error in T.S.D. Percent
Sep.	2433	19.2	+ 3.4%
Oct.	2742	21.6	+ 3.1%
Nov.	2710	21.4	+ 2.4%
Dec.	2052	16.2	+ 2.6%
Jan.	1313	10.3	+ 3.4%
Feb.	770	6.1	+ 1.6%
Mar.	657	5.2	+ 2.4%
Total	12677	100.0	-

The variation of the discharge, e.g., in the month of September, is from $19.2 \pm 3.4 = 15.8$ to 22.6 percent of the T.D.S. for 68 percent of the cases analyzed.

TABLE 3

Year	Storage in the Basin Cu. Hm.	Net S.D. Computed Cu. Hm.	Total S.D. Computed Cu. Hm.	Total S.D. Gaged Cu. Hm.	Residual Cu. Hm.	Error %
43/44	2550	5113	7663	7169	494	6.4
44/45	4620	13214	17834	18018	- 184	1.0
45/46	7130	11535	18665	18387	278	1.5
46/47	3900	10159	14059	14008	51	0.4
47/48	3430	5824	9254	8803	451	4.9
48/49	3100	8661	11761	15308	-3547	30.1
49/50	3300	3574	6874	7716	- 842	12.2
50/51	6225	8005	14230	17319	-3089	21.7
51/52	5600	11499	17099	15371	1728	10.1
52/53	3350	4476	7826	7117	709	9.0
53/54	5025	9502	14527	14884	- 357	2.4
54/55	6075	7900	13975	15306	-1331	9.5
55/56	3480	6534	10014	12435	-2421	24.2
56/57	4050	4326	8376	7698	678	8.1
57/58	5040	7331	12371	13072	- 701	5.7
58/59	4480	7250	11730	9254	2476	21.1
59/60	5225	10172	15397	13615	1782	11.6
60/61	4300	8883	13183	12687	496	3.8
61/62	5040	8725	13765	12317	1448	10.5
62/63	5025	6114	11139	8110	3029	27.2
63/64	5130	10098	15228	16096	- 868	5.7
64/65	3700	10308	14008	13894	114	0.8

Mean Percent Error	10.36 %
Coefficient of Variation ⁺	14.0 %
Mean Total Summer Discharge	12,681 Cu. Hm.
Mean Net Summer Discharge	8,145 Cu. Hm.
Mean Storage in the Basin	4,536 Cu. Hm.
Standard Deviation of Total Summer Discharge	3,696 Cu. Hm.
Coefficient of Variation of Total Summer Discharge	0.29 %
Average Summer Precipitation Index	309 millimeters
Standard Deviation of Summer Precipitation Index - Coefficient of Variation of Summer Precipitation Index	0.34 %

+ It was computed by dividing the standard error of the regression to compute the net summer discharge by the mean of the total summer discharge.

Monthly Forecast of the Discharge Based on the Discharge of the Previous Month

Multiple correlations were conducted to obtain the correlation equations and the corresponding statistics. The equations and the statistics of the correlation are given in Tables 1 through 7 of Appendix I as well as the error of each value as a percent of the computed value. To apply the equations of correlations, the rainfall of next month is unknown. For this variable, as well as for T.S.D., some value is assumed. The value recommended by the Bureau of Reclamation is the median of the rainfall. In spite of it, the assumed value will vary according to the situation.

about 17 percent while the % of deviation of the mean was 24%. This means that the forecast reduced the expected variation of the discharge from 24% to 17%. The correlations prepared in this study, after for 20% of the values was 24 and the deviation of the mean was 24%. In other words, the expected variation of the output discharges will be reduced in 20% for the forecast prepared by the Soil Conservation Service and in 24% using the value of correlation.

The effectiveness of the correlation is indicated in Figure 2. In this figure, observed discharges versus predicted discharges values were plotted. The line showing these points must be at 45°. The standard error of the correlation and of the T.S.D. were 100%. The standard error of the correlation distributed the variation of T.S.D. by 20%.

ANALYSIS OF THE RESULTS

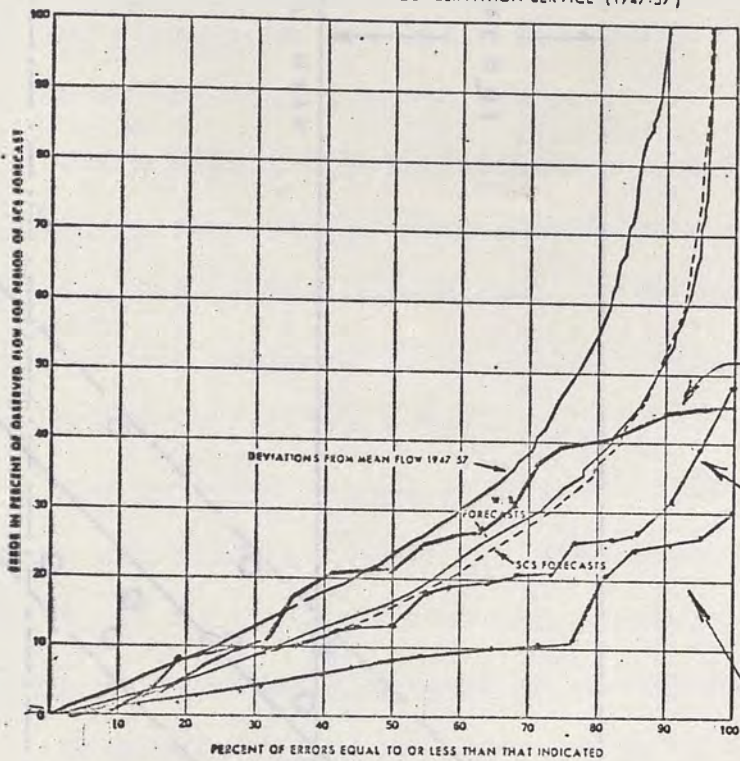
Total Spring-Summer Discharge

A duration curve of errors was prepared in order to evaluate the frequency of errors. These errors were compared with the curves given by Max A. Kohler.⁴ In Figure No. 7, taken from that report, the errors were plotted in order to compare them with those of the forecasts published by the U.S. Weather Bureau and Soil Conservation Service for the period studied by Kohler.⁴ The deviations from the mean were published in order to compare the effectiveness of the correlations.

Fifty percent of the published forecasts had an error of about 17 percent while the 50% of deviation of the mean was 24%. This means that the forecasts reduced the expected variation of the discharge from 24% to 17%. For the correlations prepared in this study, error for 50% of the values was 8% and the deviations of the mean were 21%. In other words, the expected variation of the summer discharge will be reduced in 29% for the forecast prepared by the Soil Conservation Service and in 62% using the values of correlation.

The effectiveness of the correlation is indicated in Figure 8. In this figure, computed discharge values vs. gaged discharge values were plotted. The line fitting these points must be at 45°. The standard error of the correlation and of the T.S.D. were traced. For the standard error the correlation diminishes the variation of T.S.D. by 52%.

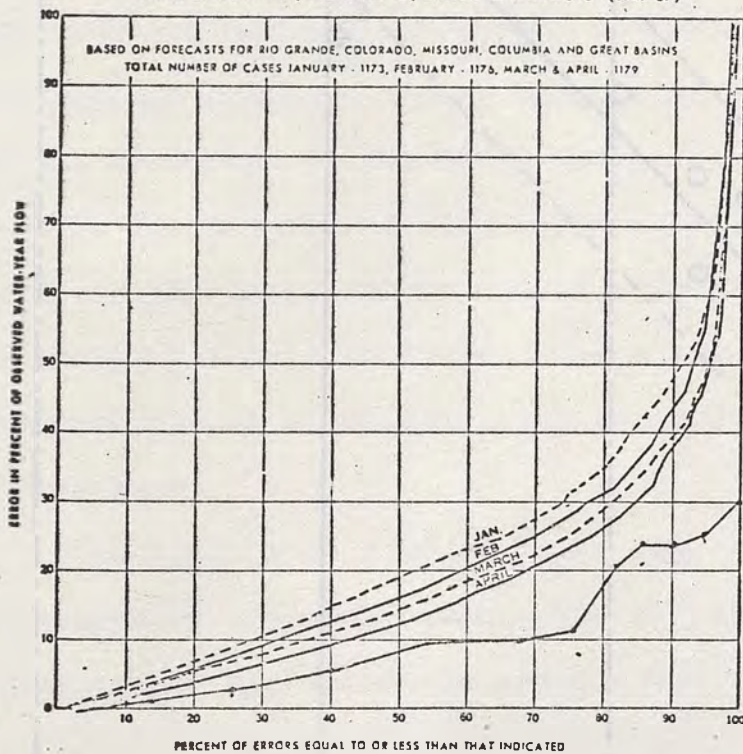
COMPARISON OF APRIL 1st WATER - SUPPLY FORECASTS PUBLISHED BY THE WEATHER BUREAU AND THE SOIL CONSERVATION SERVICE (1947-57)



DEVIATION FROM THE MEAN

FORECAST WITH MEAN S.P.I.x.

COMPARISON OF WEATHER BUREAU WATER - SUPPLY FORECASTS ISSUED AS OF JANUARY 1st, FEBRUARY 1st, MARCH 1st & APRIL 1st (1947-57)



CURVE OF ERRORS OF THE CORRELATION TO FORECAST THE T.S.D.

FIG. No 7

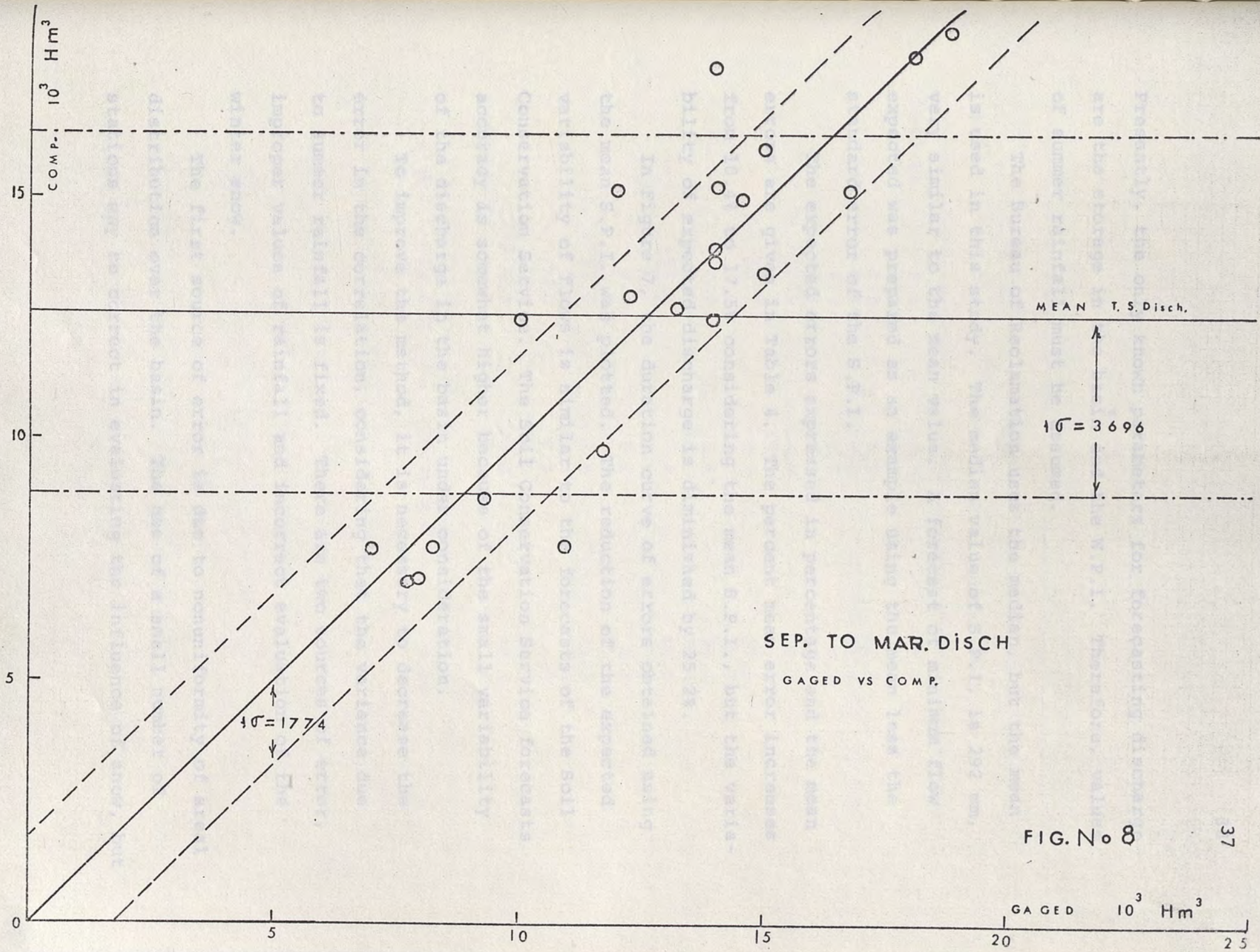


FIG. No 8

Presently, the only known parameters for forecasting discharge are the storage in the basin and the W.P.I. Therefore, values of summer rainfall must be assumed.

The Bureau of Reclamation uses the median, but the mean is used in this study. The median value of S.P.I. is 292 mm, very similar to the mean value. A forecast of minimum flow expected was prepared as an example using the mean less the standard error of the S.P.I.

The expected errors expressed in percentage and the mean errors are given in Table 4. The percent mean error increases from 10.4% to 17.5% considering the mean S.P.I., but the variability of expected discharge is diminished by 25.2%.

In Figure 7, the duration curve of errors obtained using the mean S.P.I. was plotted. The reduction of the expected variability of flows is similar to the forecasts of the Soil Conservation Service. The Soil Conservation Service forecasts accuracy is somewhat higher because of the small variability of the discharge in the basin under consideration.

To improve the method, it is necessary to decrease the error in the correlation, considering that the variance due to summer rainfall is fixed. There are two sources of error, improper values of rainfall and incorrect evaluation of the winter snow.

The first source of error is due to nonuniformity of areal distribution over the basin. The use of a small number of stations may be correct in evaluating the influence of snow, but

TABLE 4

Year	Error % S.P.I.	Error % Mean S.R.I.	Error % Mean S.R.I. 5
1943-44	6.4	21.2	- 0.5
	- 1.0	12.5	27.6
	1.5	8.9	22.6
	6.4	26.6	52.6
	4.9	12.8	0.7
	-30.1	48.1	81.1
	-12.2	18.8	0.1
	-21.7	12.3	27.9
	10.1	9.9	27.0
	9.0	26.1	- 8.1
	- 2.4	1.4	16.4
	- 9.5	10.5	28.0
	-24.2	17.8	43.5
	8.1	25.9	- 9.4
	- 5.7	8.2	5.8
	21.1	32.2	-21.2
	11.6	3.8	21.2
	3.8	0.4	17.0
	10.5	9.9	4.5
	27.2	39.0	-28.9
	- 5.7	20.6	40.4
1964-65	1.8	18.6	41.4
$\bar{m} =$	10.4	$\bar{m} =$	17.5%
		$\bar{m} + =$	20.8%
		$\bar{m} - =$	3.1%

not for summer rainfall. The rainfall may be a good estimation of local quantities of snow, but it does not account for variations in extension of the snow fields due to temperature variations. There are only broken temperature records in the area which could not be used in the correlation analysis. The large error in the correlation of 1948-49 can be explained due to it being one of the coldest winters on record. It is supposed that the accumulation of snow was greater than other years with the same precipitation. The same case was found to be true in the year 1955-56.

Monthly Forecast Based on the Previous Month

September: The previous month and the winter rainfall explain 46.6% of the variation. It also corresponds to error 16% and 37.4% to rain in September.

October: The previous month and the winter precipitation index explain 65.3% of the variability, while error accounts for 16.7% of the variability, and rainfall in October for 18%.

November: Though 20% corresponds to error and remains unexplained, only 2.7% is explained by November rainfall. The remaining source of variability is then 22.7%.

December: This month is expected to give a better forecast with only 5.7% of variability due to error and 0.1% to December rainfall. In this case,

94.2% is explained by antecedent factors. The scarce incidence of December rain is due to its small value. The mean is 33 mm against the mean of December discharge of 2,052 cubic hectometers.

January: In this month the unexplained variability begins to increase; 1.6% for January rainfall and 11.4% to error. Total variability explained by previous data is 87%.

February: Here 7.5% corresponds to February rainfall and 6.0% to error. The 86.5% of the variability is explained by previous events.

March: This is a fluctuating month at the end of the season. Error increases to leave unexplained 15% of variation and March rainfall 10.9%. Total explained by previous events is 73.6%.

The monthly correlations may be qualified as good; especially promising are the values for December. After December, the W.P.I. loses its significance and the discharges are due to withdrawal from storage and rainfall.

The partial regression coefficients were plotted in Figure 9 in order to examine their variation. The trend observed in the monthly rainfall coefficients is self-explanatory. The importance of the rainfall diminishes with the advance of the warmer season until December, and then begins again to increase.

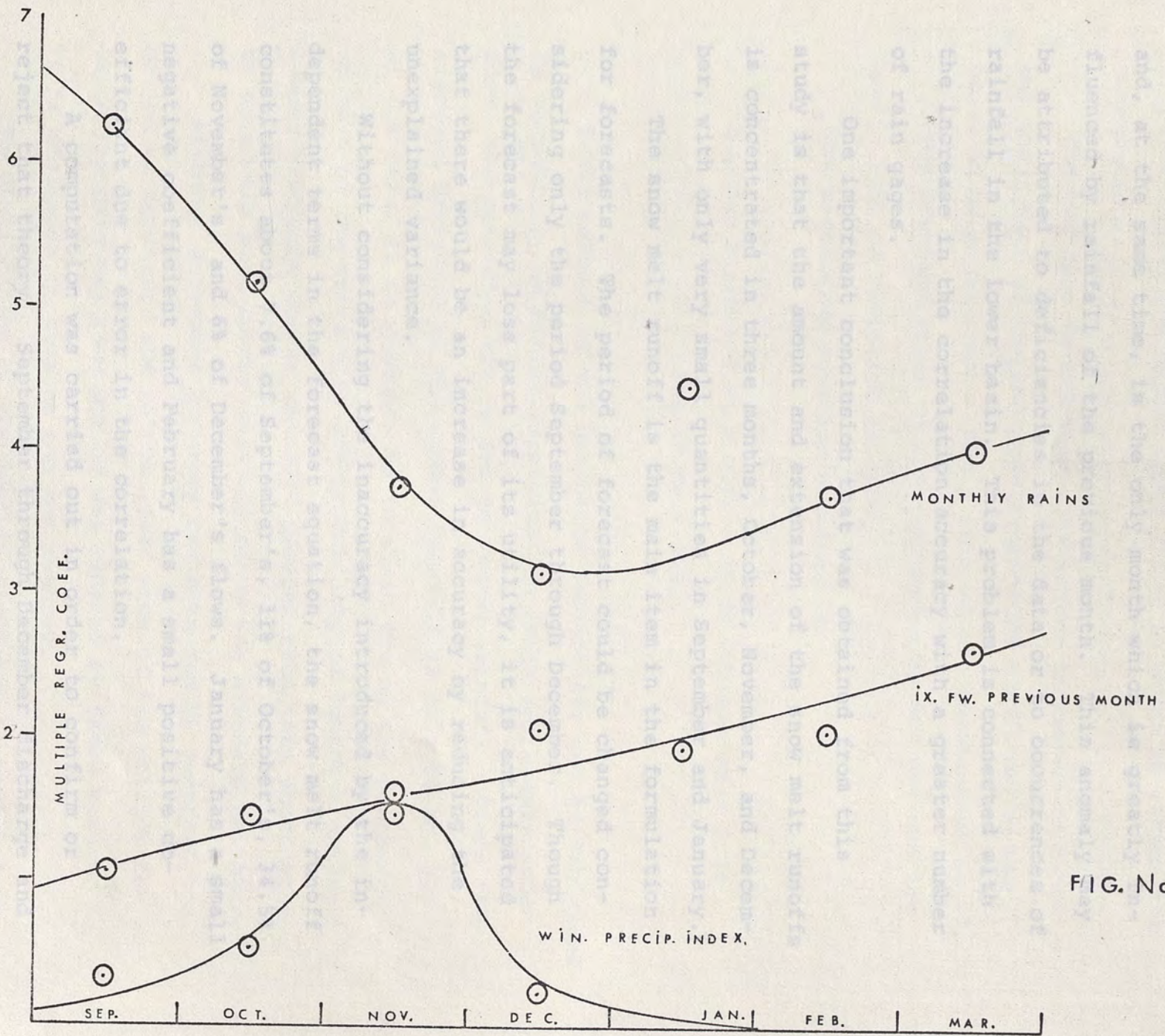


FIG. No 9

January has a coefficient of unusually high magnitude and, at the same time, is the only month which is greatly influenced by rainfall of the previous month. This anomaly may be attributed to deficiencies in the data or to occurrences of rainfall in the lower basin. This problem is connected with the increase in the correlation accuracy with a greater number of rain gages.

One important conclusion that was obtained from this study is that the amount and extension of the snow melt runoffs is concentrated in three months, October, November, and December, with only very small quantities in September and January.

The snow melt runoff is the main item in the formulation for forecasts. The period of forecast could be changed considering only the period September through December. Though the forecast may lose part of its utility, it is anticipated that there would be an increase in accuracy by reducing the unexplained variance.

Without considering the inaccuracy introduced by the independent terms in the forecast equation, the snow melt runoff constitutes about 7.6% of September's, 11% of October's, 34.5% of November's, and 6% of December's flows. January has a small negative coefficient and February has a small positive coefficient due to error in the correlation.

A computation was carried out in order to confirm or reject that theory. September through December discharge and the September through December rainfall were examined. The

W.P.I. remains the same and the recession flows were replaced by their index, the August Index Flow, in order to reduce the computations.

The multiple correlation coefficient increases to 0.954 and the t test of the multiple regression coefficients was found to be significant. The F test of the correlation is 61.

The standard error of the regression is 907 Hm^3 and its coefficient of variation is 0.09.

The regression equation obtained is:

$$\begin{aligned} \text{Sep-Dec Disch} = & 5.61 \text{ W.P.I.} + 15.89 \text{ Sep-Dec Rn} + 2.54 \\ & \text{Aug Ix Fw} + 518. \end{aligned}$$

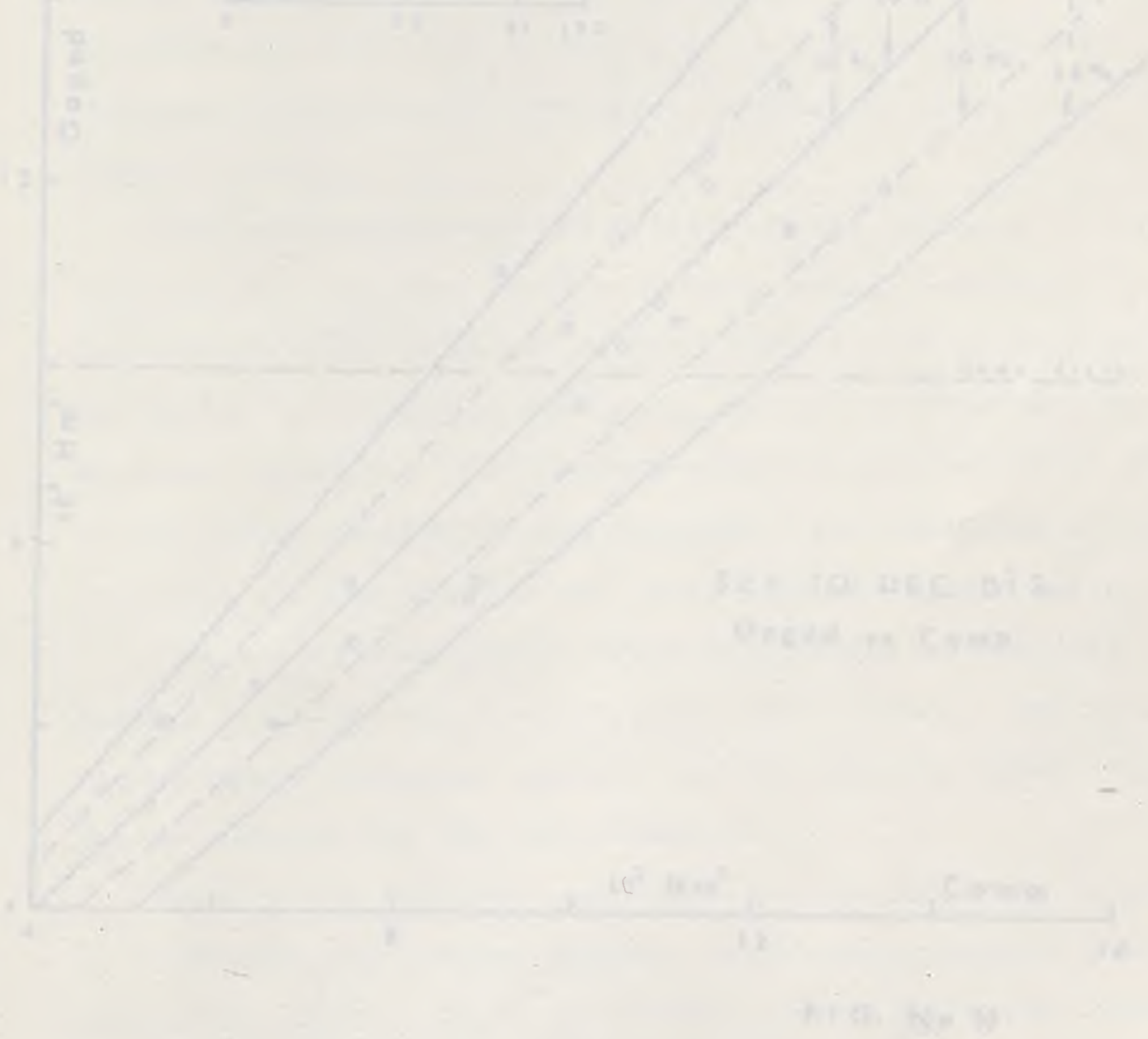
Sixty percent of the discharge variability can be explained by variability in Winter Precipitation Index and August Index Flow; the remaining 40% is due to summer rainfall. Since the standard deviation of the summer rainfall is only 81 mm, 38% of the mean, it is possible to forecast 60% of the discharge in 100% of the cases with 84% probability of having a spring-summer discharge due to rainfall greater than that forecasted by using the mean summer rainfall minus the standard deviation.

Although a greater accuracy was obtained by reducing the period of forecast, the method loses some of its utility because the original time period was reduced by three months. It is desirable to combine the two methods.

The distribution of the monthly discharge is computed in

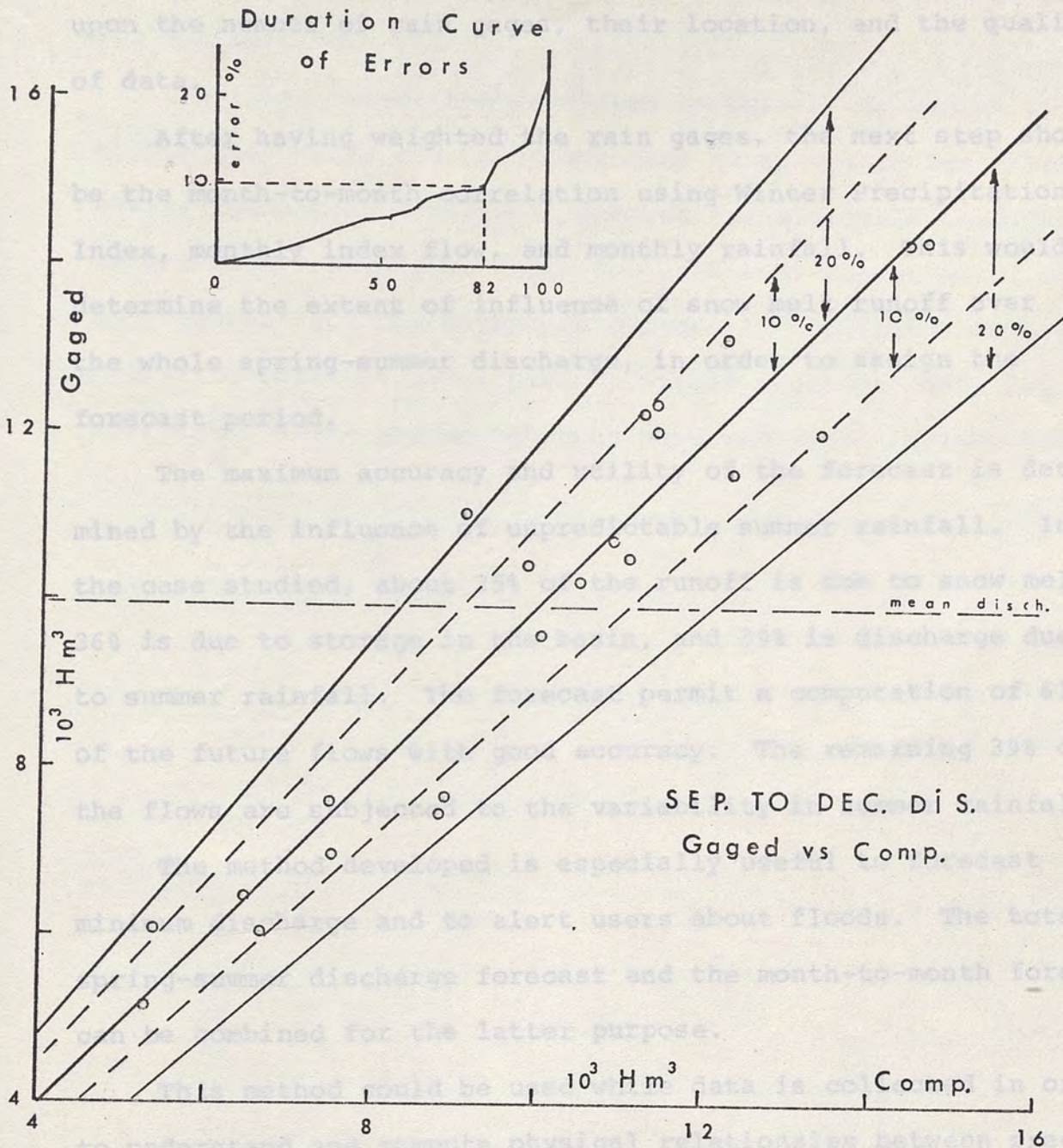
order to determine the hydrograph shape. The month-to-month forecast is valid in the two cases.

In Figure 10, the computed and gaged September through December discharge was plotted. The lines of 20% and 10% error were drawn together with the duration curve of the errors. It is believed that the correlation would be improved if temperature regime in the basin were considered in the computation.



CONCLUSIONS AND RECOMMENDATIONS

The accuracy of the method developed in this study depends upon the accuracy of the data used, their location, and the quality of data.



SEP. TO DEC. DIS.
Gaged vs Comp.

FIG. No 10

CONCLUSIONS AND RECOMMENDATIONS

The accuracy of the method developed in this study depends upon the number of rain gages, their location, and the quality of data.

After having weighted the rain gages, the next step should be the month-to-month correlation using Winter Precipitation Index, monthly index flow, and monthly rainfall. This would determine the extent of influence of snow melt runoff over the whole spring-summer discharge, in order to assign the forecast period.

The maximum accuracy and utility of the forecast is determined by the influence of unpredictable summer rainfall. In the case studied, about 25% of the runoff is due to snow melt, 36% is due to storage in the basin, and 39% is discharge due to summer rainfall. The forecast permit a computation of 61% of the future flows with good accuracy. The remaining 39% of the flows are subjected to the variability in summer rainfall.

The method developed is especially useful to forecast minimum discharge and to alert users about floods. The total spring-summer discharge forecast and the month-to-month forecast can be combined for the latter purpose.

This method could be used while data is collected in order to understand and compute physical relationships between precipitation and runoff. There are several possibilities for determining precipitation runoff relationships, though probably the

use of the "Stanford Watershed Model"⁴ with some modifications would be the best approach. In order to develop a daily hydrograph, the method developed by Rantz⁵ seems the most adequate, although the Anderson and Crawford method⁶ could be explored for application.

Finally, the method developed in this study can be applied with a reasonable degree of accuracy to snow-rain fed river basins where sparse rainfall records are available in order to estimate future discharges for efficient operation of dams and reservoirs. The method is especially applicable to new hydraulic works in developing countries where the data is scarce and dense gaging networks have yet to be implemented.

Hydrological Survey W.S.-I. - 1970-8, 1964.

5. Anderson, J.A. and W.H. Crawford, The Synthesis of Daily and Seasonal Stream Hydrographs on a Digital Computer, Stanford University, Department of Civil Engineering Technical Report No. 16, Stanford, California, 1964.

REFERENCES

1. Kohler, M.S. and R.K. Linsley, "Recent Developments in Water Supply Forecasting from Precipitation", Trans. Am. Geophys. Union, Vol. 30, pp. 427-436, 1949.
2. Searcy, J.K. and C.H. Hardison, "Double Mass Curves", Geological Survey Water Supply Paper 1541-B.
3. Wilson, Alphonse, Unpublished course in Hydrology given in Lima, Peru in 1963.
4. Kohler, Max, "A Preliminary Report on Evaluating the Utility of Water Supply Forecast", Proceedings of the Western Snow Conference, Reno, Nevada, 1959.
5. Rantz, S.E., "Snow Melt Hydrology of Sierra Nevada Streams", Geological Survey W.S.P. 1779-R, 1964.
6. Anderson, E.A. and N.H. Crawford, The Synthesis of Continuous Snowmelt Runoff Hydrographs on a Digital Computer, Stanford University, Department of Civil Engineering Technical Report No. 36, Stanford, California, 1964.



GENERAL REFERENCES

- Ezekuiel and Fox, Methods of Correlation and Regression Analysis, John Wiley and Sons, 1963.
- Snedecor, G.W., Statistical Methods, Iowa State University Press, 1965.
- Linsley, R.K., M.A. Kohler, and J.L.H. Paulhus, Applied Hydrology, McGraw Hill Book Company, 1949.
- Ford, P.M., Multiple Correlation in Forecasting Seasonal Runoff, U.S. Dept. of Interior, Bureau of Reclamation, 1959.
- Beard, Leo R., Statistical Methods in Hydrology, U.S. Corps of Engineers, 1962.



APPENDIX

Year	September Discharge (CFS)	August Discharge (CFS)	Residual	Error
41-44	1500	1847	347	20.2
44-45	2523	2413	-110	8.1
45-46	2521	2414	-107	5.0
46-47	2508	2497	-111	10.4
47-48	1557	1798	241	18.1
48-49	2334	2423	-89	10.1
49-50	2430	1814	-616	11.2
51-51	2852	2781	-71	1.8
51-52	3145	3019	-126	11.4
52-53	1461	1330	-131	5.0
53-54	2876	3011	-135	8.2
54-55	2698	2771	-73	1.4
55-56	1836	1881	-45	3.7
56-57	1882	1874	-8	45.4
58-58	2028	2307	-279	9.3
58-59	2420	2331	-89	1.3
59-60	2844	2821	-23	7.0
60-61	1864	1821	-43	8.0
61-62	2638	3181	543	28.1
62-63	2738	2417	-321	14.2
63-64	3713	3586	-127	11.1
64-65	2482	2336	-146	6.4

APPENDIX

TABLES OF MONTHLY CORRELATION

STATISTICS OF REGRESSIONS

Reg. Disch. = 0.375 W.P.F. + 1.04 Avg. Dr. Pd. + 8.27

Reg. No. = 93.

Mean August Disch.	2,880
Coefficient of Correlation	0.914
Coefficient of Determination	0.835
Standard Error of the Regression	495 Cfs. Mo.
Coefficient of Variation of the Regression	0.17
F Test of the Correlation	10.8
Standard Deviation of September Discharge	637 Cfs. Mo.
Coefficient of Variation of September Discharge	0.29
Mean September Discharge	2471 Cfs. Mo.
Standard Deviation of September Disch.	415 Cfs.
Coefficient of Variation of September Disch.	0.17
Mean September Disch.	1128 Mo.

Discharge is given in cubic feet per second.

SEPTEMBER *

Year	September Discharge		Residual	Error %
	Gaged	Computed		
43-44	1509	1898	389	20.5
44-45	2823	2815	- 8	0.3
45-46	2524	3354	-169	5.0
46-47	2909	2487	-421	16.9
47-48	1537	1796	259	14.4
48-49	2530	2123	-406	19.1
49-50	1430	1410	- 20	1.4
50-51	2852	2906	53	1.8
51-52	3183	3308	127	3.8
52-53	1602	1526	- 76	5.0
53-54	2876	3052	175	5.7
54-55	2698	2857	159	5.6
55-56	1636	1532	-103	6.7
56-57	1582	1874	292	15.6
57-58	2226	2207	- 19	0.9
58-59	2020	2030	10	0.5
59-60	3180	3291	184	5.6
60-61	1884	2050	166	8.0
61-62	2656	3182	527	16.6
62-63	2738	2417	-320	13.2
63-64	3715	3068	-647	21.1
64-65	2488	2338	-150	6.4

EQUATION OF REGRESSION

$$\text{Sep. Disch.} = 0.325 \text{ W.P.I.} + 1.04 \text{ Aug. Ix. Fw.} + 6.27$$

$$\text{Sep. Rn.} + 552.$$

Mean Percent Error	8.8%
Coefficient of Correlation	0.914
Coefficient of Determination	0.83
Standard Error of the Regression	303 Cu. Hm.
Coefficient of Variation of the Regression	0.12
F Test of the Correlation	30.6
Standard Deviation of September Discharge	692 Cu. Hm.
Coefficient of Variation of September Discharge	0.28
Mean September Discharge	2433 Cu. Hm.
Standard Deviation of September Rain	60.6 mm.
Coefficient of Variation of September Rain	0.54
Mean September Rain	112.6 mm.

mm: millimeters

* Discharge is given in Cubic Hectometers.



OCTOBER *

Year	October Gaged	Discharge Computed	Residual	Error %
43-44	2049	2116	67	3.2
44-45	4021	4152	131	3.2
45-46	4019	3544	-475	13.4
46-47	2291	2819	528	18.7
47-48	2167	2146	- 21	1.0
48-49	3458	3038	-420	13.8
49-50	1883	1890	7	0.4
50-51	2672	2621	- 51	1.9
51-52	3216	3380	164	4.8
52-53	1730	1969	239	12.1
53-54	2436	2951	515	17.4
54-55	3013	2653	-360	13.6
55-56	2536	2000	-536	26.8
56-57	1904	1864	- 40	2.1
57-58	2610	2593	- 17	0.6
58-59	2397	2437	40	1.6
59-60	3311	3266	- 45	1.4
60-61	2977	2801	-176	6.3
61-62	3350	3552	202	5.7
62-63	1809	2192	382	17.4
63-64	3621	3502	-119	3.4
64-65	2861	2845	- 16	0.6

EQUATION OF REGRESSION

Oct. Disch. = 0.524 W.P.I. + 1.436 Sep. Ix. Fw. + 5.187

Oct. Rn. + 783

Mean Percent Error	7.7%
Coefficient of Correlation	0.913
Coefficient of Determination	0.833
Standard Error of the Regression	308 Cu. Hm.
Coefficient of Variation of the Regression	0.11
F Test of the Correlation	30
Standard Deviation of October Discharge	698 Cu. Hm.
Coefficient of Variation of October Discharge	0.25
Mean October Discharge	2742 Cu. Hm.
Standard Deviation of October Rain	42 mm.
Coefficient of Variation of October Rain	0.84
Mean October Rain	50 mm.

mm: millimeters

* Discharge is given in Cubic Hectometers.

NOVEMBER

Year	November Gaged	Discharge Computed	Residual	Error %
43-44	1536	1702	166	9.7
44-45	4219	4716	497	10.5
45-46	3799	3752	- 47	1.2
46-47	3856	2582	-274	10.6
47-48	2012	1976	- 36	1.8
48-49	3022	2706	-316	11.7
49-50	1668	1668	- 0	0
50-51	3402	3087	-315	10.2
51-52	3170	2891	-279	9.6
52-53	1181	1524	343	22.5
53-54	3550	2764	-786	28.4
54-55	3546	3211	-335	10.4
55-56	2071	2202	131	5.9
56-57	1986	1842	-144	7.8
57-58	3040	2756	-284	10.3
58-59	2025	2870	845	29.4
59-60	3274	3173	-101	3.2
60-61	2915	2611	-304	11.6
61-62	2909	3150	242	7.7
62-63	1371	2124	754	35.5
63-64	3517	3640	123	3.4
64-65	2563	2684	121	4.5

EQUATION OF REGRESSION

Nov. Disch. = 1.628 W.P.I. + 1.482 Oct. Ix. Fw. + 3.756

Nov. Rn. + 43.

Mean Percent Error	11.2%
Coefficient of Correlation	0.894
Coefficient of Determination	0.800
Standard Error of the Regression	413 Cu. Hm.
Coefficient of Variation of the Regression	0.15
F Test of the Correlation	24
Standard Deviation of November Discharge	855 Cu. Hm.
Coefficient of Variation of November Discharge	0.32
Mean November Discharge	2711 Cu. Hm.
Standard Deviation of November Rain	34.6 mm.
Coefficient of Variation of November Rain	0.59
Mean November Rain	41.4 mm.

mm: millimeters.



DECEMBER

Year	December Gaged	Discharge Computed	Residual	Error %
43-44	977	1008	31	3.1
44-45	3327	3847	520	13.5
45-46	3003	3139	136	4.3
46-47	2702	2849	147	5.2
47-48	1293	1315	22	1.7
48-49	2107	2242	135	6.0
49-50	1145	1202	56	4.6
50-51	3439	3025	-414	13.7
51-52	2668	2452	-216	8.8
52-53	737	744	7	0.9
53-54	3203	3118	- 85	2.7
54-55	3034	2658	-376	14.1
55-56	1408	1650	242	14.7
56-57	1025	1079	54	5.0
57-58	2639	2575	- 63	2.4
58-59	1208	1281	73	5.7
59-60	1962	2020	58	2.9
60-61	1889	1856	- 33	1.8
61-62	1672	1843	171	9.3
62-63	958	956	- 2	0.2
63-64	2370	2112	-258	12.2
64-65	2387	2180	-207	9.5

EQUATION OF REGRESSION

Dec. Disch. = 0.216 W.P.I. + 2.086 Nov. Ix. Fw. + 3.155

Dec. Rn. + 142.

Mean Percent Error	6.5%
Coefficient of Correlation	0.97
Coefficient of Determination	0.94
Standard Error of the Regression	225 Cu. Hm.
Coefficient of Variation of the Regression	0.11
F Test of the Correlation	98
Standard Deviation of December Discharge	871 Cu. Hm.
Coefficient of Variation of December Discharge	0.42
Mean December Discharge	2052 Cu. Hm.
Standard Deviation of December Rain	35.8 mm.
Coefficient of Variation of December Rain	1.07
Mean December Rain	33.5 mm.

mm: millimeters.

JANUARY

Year	January Gaged	Discharge Computed	Residual	Error %
43-44	540	382	-158	41.4
44-45	1684	1407	-277	19.7
45-46	1693	1811	118	6.5
46-47	1674	1513	-161	10.6
47-48	920	1076	157	14.6
48-49	1342	1475	133	9.0
49-50	810	1063	253	23.8
50-51	2450	2361	- 89	3.8
51-52	1493	1928	435	22.6
52-53	827	708	-119	16.8
53-54	1506	1564	58	3.7
54-55	1464	1498	34	2.3
55-56	2892	2450	-441	18.0
56-57	570	633	63	10.0
57-58	1410	1437	27	1.9
58-59	703	783	80	10.2
59-60	1070	1057	- 13	1.2
60-61	1485	1211	-273	22.5
61-62	934	955	21	2.2
62-63	596	484	-111	22.9
63-64	1288	1286	- 2	0.2
64-65	1539	1806	267	14.8

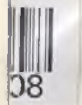
EQUATION OF REGRESSION

$$\text{Jan. Disch.} = 6.477 \text{ Dec. Rn.} + 1.663 \text{ Dec. Ix. Fw.} + 4.528$$

$$\text{Jan. Rn.} - 108.$$

Mean Percent Error	12.7%
Coefficient of Correlation	0.94
Coefficient of Determination	0.866
Standard Error of the Regression	215 Cu. Hm.
Coefficient of Variation of the Regression	0.16
F Test of the Correlation	47
Standard Deviation of January Discharge	588 Cu. Hm.
Coefficient of Variation of January Discharge	0.45
Mean January Discharge	1313 Cu. Hm.
Standard Deviation of January Rain	24.3 mm.
Coefficient of Variation of January Rain	0.53
Mean January Rain	46 mm.

mm: millimeters.



FEBRUARY

Year	February Gaged	Discharge Computed	Residual	Error %
43-44	319	288	- 31	10.8
44-45	1090	1002	- 88	8.8
45-46	1260	1234	- 26	2.1
46-47	924	971	47	4.8
47-48	521	498	- 23	4.6
48-49	885	873	- 12	1.4
49-50	414	508	94	18.5
50-51	1706	1505	-200	13.3
51-52	723	736	13	1.8
52-53	570	617	47	7.6
53-54	778	785	7	0.9
54-55	918	869	- 49	5.6
55-56	1074	1307	233	17.8
56-57	359	303	- 56	18.5
57-58	699	745	46	6.2
58-59	493	516	23	4.4
59-60	523	524	1	0.2
60-61	947	1067	120	11.2
61-62	469	444	- 25	5.6
62-63	344	334	- 10	3.0
63-64	878	781	- 97	12.4
64-65	1052	1038	- 14	1.3

EQUATION OF REGRESSION

$$\text{Feb. Disch.} = 2.075 \text{ Jan. Ix. Fw.} + 3.709 \text{ Feb. Rn.} - 101$$

Mean Percent Error	7.3%
Coefficient of Correlation	0.97
Coefficient of Determination	0.94
Standard Error of the Regression	89 Cu. Hm.
Coefficient of Variation of the Regression	0.12
F Test of the Correlation	148
Standard Deviation of February Discharge	346 Cu. Hm.
Coefficient of Variation of February Discharge	0.45
Mean February Discharge	770 Cu. Hm.
Standard Deviation of February Rain	20 mm.
Coefficient of Variation of February Rain	0.77
Mean February Rain	25.6 mm.

mm: millimeters.

MARCH

Year	March Gaged	Discharge Computed	Residual	Error %
43-44	238	195	- 42.7	21.9
44-45	853	976	122.8	12.6
45-46	1091	1326	235	17.7
46-47	652	647	- 5	0.8
47-48	353	295	- 58	19.7
48-49	1963	1380	-582	42.4
49-50	365	563	198	35.2
50-51	1149	1319	170	12.9
51-52	920	812	-108	13.3
52-53	470	493	23	4.7
53-54	536	525	- 11	2.1
54-55	633	705	72	10.2
55-56	817	837	20	2.4
56-57	273	180	- 93	51.7
57-58	448	401	- 47	11.7
58-59	406	398	- 8	2.0
59-60	365	417	52	12.5
60-61	591	644	53	8.2
61-62	324	262	- 62	23.6
62-63	293	280	- 13	4.6
63-64	709	729	20	2.7
64-65	1004	1067	63	5.9

EQUATION OF REGRESSION

March Disch. = 2.652 Feb. Ix. Fw. + 4.039 Mar. Rn. - 214.

Mean Percent Error	14.5%
Coefficient of Correlation	0.92
Coefficient of Determination	0.84
Standard Error of the Regression	166 Cu. Hm.
Coefficient of Variation of the Regression	0.25
F Test of the Correlation	52
Standard Deviation of March Discharge	401 Cu. Hm.
Coefficient of Variation of March Discharge	0.61
Mean March Discharge	657 Cu. Hm.
Standard Deviation of March Rain	28.6 mm.
Coefficient of Variation of March Rain	0.65
Mean March Rain	43.7 mm.

mm: milimeters.