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Streamflow Forecast of Bear River at Harer, Idaho

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STREAMFLOW FORECAST OF BEAR RIVER AT HARER, IDAHO

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AT HARER, IDAHO

by

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INTRODUCTION

Accurate forecasts of stream flow produce direct benefits for the populace of a watershed which can be measured in terms of cash income. In 1946 in Deschutes and Crook counties of Oregon, the stream flow forecast based on snow surveys indicated appreciably greater than average runoff to be anticipated during the course of the subsequent irrigation season (10). Accordingly, some 6500 acres of agricultural land in the area, normally not cropped, were seeded and successfully irrigated. The cash value of crops, grown on this usually unproductive land, was estimated to be more than half a million dollars.

Conversely, when short water supplies are indicated appropriate steps in crop planning may be intelligently undertaken. Such steps may include a reduction in the acreage of irrigated land, development of alternate water supplies, or the production of early maturing crops which do not require late season irrigations. A successful forecast also allows time for adequate planning of reservoir operation and power production. Contemporary forecasts for the Bear River at Harer, Idaho, lack the inherent accuracy for complete realization of all of the benefits accruing from reliable streamflow predictions.

At the present time (1) more than half a million acres are irrigated from the Bear River and its tributaries, of which approximately 140,600 are located upstream from Harer (figure 1). During the three hundred mile journey of the river from the Uinta Mountains through Utah, Wyoming and Idaho to Great Salt Lake, the river crosses

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At the present time (1) more than half a million acres are irrigated from the Bear River and its tributaries, of which approximately 140,600 are located upstream from Harer (figure 1). During the three hundred mile journey of the river from the Uinta Mountains through Utah, Wyoming and Idaho to Great Salt Lake, the river crosses state boundaries five times. Immediately below Harer, Bear Lake has been utilized as a storage reservoir since 1902. An extensive network of reservoirs and power plants below Bear Lake have had a profound effect upon irrigation and power development.

The interstate nature of the river has caused problems of equitable distribution which have become more complex with the passage of time. In order to utilize the flow of the Bear River in the best possible interests of all concerned the Tri-State Investigations were instituted in 1943. The investigations were to be undertaken jointly by the United States Geological Survey, the Bureau of Reclamation, the states of Utah, Wyoming and Idaho together with other water users on the river (1). Intensified river development coupled with interstate appropriation difficulties indicate the necessity of an accurate estimate of stream flow in order to facilitate annual basin wide planning of crop requirements and stream regime.

An accurate forecast for the basin above Harer would provide additional information for the operation of the largest reservoir in the Bear River system, in addition to guiding cropping programs in the watershed. This thesis has such a prediction as its primary objective. Incidental to providing main stem forecasts, tributary predictions can be realized in the determination of their contribution to the total volumetric flow at Harer, Idaho.

REVIEW OF LITERATURE

Resume of snow survey history

The earliest reported snow-water content measurements were made by C. A. Mixer at Rumford Falls, Maine, in 1901. A typical snow core was weighed to determine its water content. A similar procedure was employed by R. E. Horton at Utica, New York, in 1903, with a somewhat larger representative snow core sample. In 1909 J. E. Church, Jr. devised the Mt. Rose sampler and scales and utilized this equipment to study the relationship between forests and snow conservation. The sampler and scale devised by Church enabled rapid sampling of deep snow in the Lake Tahoe area. The tube and snow core when balanced on the Mt. Rose scales produce a direct measurement of snow-water equivalent. The utilization of easily portable direct reading equipment greatly facilitated the task of sampling and recording the accumulated winter snowfall. Clyde (5) reports that during this period Dr. Church conceived the idea of using accumulated snow cover as a basis for forecasting stream flow and to him (Church) should go the title of "Father of Snow Surveying and Stream Flow Forecasting."

While Church was conducting his work in Nevada, J. C. Alter, an employee of the Weather Bureau in Utah, suggested to the Utah state engineer that snow cover measurements be made in that state. In 1911 the United States Weather Bureau authorized the project, and that winter Alter made the first official survey of the water content of the snow cover on the Maple Creek watershed in Utah County.

Prior to 1914 the United States Weather Bureau published in its Climatological Data for Utah only descriptive generalities concerning the condition, extent and quantity of snow cover in the Wasatch and Uinta Mountains. Subsequently, an agreement was reached between the Weather Bureau and the United States Forest Service for the establishment of standard Weather Bureau stakes to measure the depth of the snow mantle. Due to the inaccessibility of the majority of stakes, readings were incomplete and as a result a large number of the stakes were abandoned.

Snow surveys patterned after the Church method were instituted in Utah in 1923-24 by Clyde (5) and Bowen (3). The snow courses were, where possible, located adjacent to Weather Bureau snow stakes. By 1930 snow surveys were being made on most of the main streams of the state, and as these data became available they were published in lieu of snow stake readings in the Climatological Data.

Methods of forecasting from snow surveys

Two methods of forecasting stream flow from snow surveys have been developed, namely the method of areas and the percentage method (4). The former requires that the forecaster determine the total volume of water in the snow cover, while the latter assumes that the percentage of seasonal normal water equivalent is indicative of the subsequent stream flow. The basic difference in these methods is fundamental.

Method of areas. The method of areas as indicated by Church (4) is difficult to apply as reflection will indicate. The chief variable to be accounted for is the variation in snow cover with elevation, area and aspect. In order to determine accurately the volumetric water equivalent, an extremely large number of samples must be taken. For most watersheds the requisite number of samples constitutes a physical and financial burden which is generally insurmountable. A second major difficulty is the determination of an infiltration index for the basin, together with an evaporation index which will yield a value of moisture excess which will appear as stream flow at down stream gaging stations. Since the drainage area of the Bear River above Harer constitutes some 2780 square miles (12) the possibilities of applying the method of areas appears remote.

The percentage method. The percentage method or method of seasonal percentages is based upon the fact that the big storms which furnish the bulk of the winter snow are comparatively uniform in character with respect to area. An average of characteristic courses over the drainage basin should yield a typical seasonal percentage for the basin as a whole. Correlation of the snow-water equivalent index thus obtained, and resulting volumetric runoff for a definite period yields a coefficient of correlation, which, generally speaking, is higher than other methods thus far discussed.

It is of interest to note that Clyde and Work (5) found no relationship between snow stake surveys and resulting runoff. They conclude their analysis with the following:

> "Snow stake readings are not snow surveys and the snow cover data from the two sources are not comparable. Therefore, when studying the relationship between snow cover and runoff snow stake readings cannot be compared with snow course data."

Factors influencing relationship between snow survey data and stream flow

Linsley *et al.* (9) point out three factors not indicated by the snow-water equivalent index which will have a pronounced affect on stream flow. These are:

1. Groundwater flow.
2. Soil moisture deficiency.
3. Precipitation during the runoff period.

Groundwater flow. In areas where groundwater flow constitutes a significant percentage of total stream flow, a resulting increase in the correlation coefficient may be realized by taking into consideration some parameter which will represent this factor. Linsley (8) suggests the use of initial flow on a fixed date of the preceding autumn or the lowest flow for the preceding year as being indicative parameters for groundwater runoff correlations. In many cases, however, the latter parameter as indicated by Linsley could not be used on streams whose regimen was such that during certain periods of the irrigation season complete appropriation and diversion was necessary. The total volume of runoff of the preceding season similarly may furnish some indication as to the quantity of base flow.

Soil moisture deficiency. Condition of the basin soil reservoir in the interval preceding runoff can also play a profound role in influencing subsequent runoff. Before surface runoff can occur the basin infiltration index must be satisfied. Not only must the soil reservoir be replenished, but depressional storage and interception requirements must be met. Linsley *et al*. (9) suggest fall precipitation or total winter discharge, or both as additional variables to be correlated in order to forecast seasonal volumes of runoff. In the western United States it is difficult to determine precisely the time base to consider in antecedent fall precipitation. If the period selected is too early, then actual soil moisture conditions will not be truly represented at the time when the permanent winter snow mantle is established. If the precipitation influence is continued too late in the year, there is a strong possibility of double counting a portion of this moisture. For example, if in an attempt to characterize soil moisture deficiencies the antecedent precipitation records are carried into December, there will be an excellent chance that some of this precipitation will be recorded again in the April 1 snow survey, thus rendering the attempt at forecast refinement impractical and misleading. It has been suggested that November 15 be used as a typical fall precipitation terminal date in studies of this nature. November 20 also may be used as a terminus, particularly if fall temperatures are significantly above normal.

Precipitation during the runoff period. The effect of precipitation during the runoff period is related to numerous variables, such as region, extent of diversions, dominant vegetal cover, and chronological distribution. Cooperrider and Sykes (6) report that although summer storms occasionally deliver important quantities of water, any seasonal comparison of flow data illustrates the relatively small percentage of average annual flow contributed by summer rains. This is extremely fortuitous from the stream flow forecasting aspect, since long range precipitation forecasting has not as yet been successfully perfected. By no means, however, should summer precipitation be neglected. Boardman (2) points out that correlating snow-water equivalent with streamflow is dependent upon the normality of all other influencing characteristics. Cooperrider and Sykes conclude that losses through evaporation and transpiration (consumptive use) account for the major difference between summer precipitation and stream yield.

There is a practical date which must be chosen in order to finalize stream flow prediction so that the forecast may be of practical value. This is the chief factor in neglecting the effect of summer precipitation generally beyond the end of May in April through September stream flow forecasts.

CORRELATION OF GAGING STATION FLOW

General method

The general method of forecast utilized in this study is presented in a flow chart (Fig. 7). Snow-water equivalent and precipitation records are used to predict the flow of Twin Creek at Sage, Smiths Fork near Border and the Bear River near Evanston. (Fig. 1) The forecast flow of the Bear River near Randolph is determined by means of a correlating equation. A prediction of flow for the Bear River at Border is calculated by substituting these intermediate forecasts in a general equation of stream flow. The flow at Harer is then forecast by means of an equation correlating these two stations.

The following sections explain this procedure in detail and present arguments for its utilization.

Zoning of watershed

Forecasts to date for the April-September flow at Harer prepared by the Federal-State Cooperative Snow Surveys and Water Supply Forecasts group have depended upon the correlation of interbasin snow courses and the resulting flow at Harer. Previous studies have not been instituted which would reflect an increased degree of correlation as a result of separating zonal influence by means of multiple correlations between independent variables throughout the drainage basin. The initial step in this analysis has been the separation of the drainage basin into zones (Fig. 1) whose water yield as measured by stream flow would be characteristic of the runoff producing variables in that section.

Flow of the main stem near Evanston, Wyoming, is taken to be characteristic of the north slopes of the Uinta Mountains. The central area of the basin above Harer has been represented by the flow of Twin Creek at Sage, Wyoming, while the northern area has been exemplified by the flow of Smiths Fork near Border, Wyoming. The flow records for Smiths Fork at Cokeville would have been more desireable by virtue of the proximity of this gaging station to the tributary confluence with the main stem, but unfortunately the station was abandoned in 1951. These stations will reflect snow cover variation with reference to aspect and areal extent. (Fig. 1) A zone representing the eastern aspect of the Wasatch range may be considered valuable, but as it will be demonstrated later a coefficient of multiple determination of 0.991 exists between the variables introduced to this point.

<u>Main stem correlations</u>

<u>Randolph-Evanston relationships.</u> The flow at the Randolph gaging station is consistently less than that recorded upstream at Evanston because of diversions during the irrigation season. In correlating stream flow between Evanston and Randolph deviations from a linear two variable regression line could probably be best accounted for by taking total diversions into consideration, or by selecting a single canal as an index which would be characteristic of seasonal diversions. Records for diversions appearing in the Bear River Hydrometric Data (1) and in the Surface Water Supply Papers (10) do not contain sufficient records for this purpose. If a diversion index could be determined the correlation between Randolph and Evanston gaging stations would undoubtedly be improved. In forecasting stream flow, the diversional index would of necessity be forecast in order to assess the differences in stream flow between the stations under discussion for the main stem. In forecasting the stream flow at Evanston, as will be demonstrated in

the Forecasting Variables section, the diversional index is assumed to be inherently contained in the snow-water equivalent index. Rationalizing this assumption presents very little difficulty, since high snow-water equivalent indices represent increased possibilities for diversion.

The relationship found to exist between these particular stations (table 12) may be represented by the regression equation:

$$Y = -61.31 + 1.226 X$$

where,

Y = April-September flow of Bear River near Randolph in thousands of acre feet.
X = April-September flow of Bear River near Evanston in thousand acre feet.

The coefficient of determination for this analysis is .947 and the standard error of estimate 14.36.

<u>Border-Harer relationships.</u> The United States Geological Survey (U.S.G.S.) relationship between the Border and Harer gaging stations based on observed flow may be stated:

$$Y = 1.25 X$$

where,

Y = April-September flow at Harer in thousand acre feet.
X = April-September flow at Border in thousand acre feet.

The value of this relationship lies in its application to determining interstate stream regime between Wyoming and Idaho in the Border-Harer area. A linear regression equation has been derived by the author principally to assist future forecast analysis in correlation of deviations between Border and Harer in an ultimate forecast refinement at Harer. An incidental purpose of this correlation is to check a linear regression equation determined by the method of least squares with the equation at utilized by the U.S.G.S.. The relationship from this analysis yields the equation (table 11):

$$Y = 2.01 \quad 1.186\ X$$

where,

Y = April-September flow in thousand acre feet at Harer.
X = April-September flow in thousand acre feet at Border.

The ratio of the seventeen year mean April-September flows between the two stations (table 11) is:

$$\frac{\text{Mean flow at Harer}}{\text{Mean flow at Border}} = \frac{264.07}{221.64} = 1.20$$

This closely approximates the U.S.G.S. factor of 1.25. The standard error of estimate in the regression equation as noted is 14.94 and the coefficient of determination is 0.987.

Tributary correlation

Smiths Fork near Border. The tributary characterizing the southern aspect of the northern drainage basin area is Smiths Fork, and the longest records available for this stream are observed at the gaging station near Border. The twelve years of record available for this tributary (table 7) indicates an April-September mean flow that constitutes 44 per cent of the equivalent mean flow at Harer. The omission of this important tributary in a correlation analysis aimed at forecasting streamflow below the confluence with the main stem would understandably detract from the overall accuracy. Using a snow-water equivalent index weighted for basin influence would certainly materially assist forecasting. If Smiths Fork itself is used as a variable in the stream flow equation, (as it is in this analysis) necessitating an independent forecast for integration with the main estimate, added benefits are evident for development from this stream. Approximately 11,500 acres are irrigated above Cokeville from Smiths Fork.

Twin Creek at Sage. The flow of Twin Creek at Sage, Wyoming, has been chosen as the index characteristic of the central portion of the drainage area above Harer. Although the twelve year mean flow or the April-September period (table 13) represents only approximately 5 per cent of the equivalent flow at Harer, the influence of Twin Creek is an important factor in writing the general streamflow equation. Reference to figure 1 will indicate that no snow course exists in the immediate vicinity of the headwaters of Twin Creek. The forecast for Twin Creek, as will be shown, bears the lowest degree of correlation in this analysis, and for that reason the establishment of a snow course in this general area would materially assist in an overall forecast of streamflow at Harer.

General equation of streamflow

Multiple correlation of the variables previously introduced yields the following equation of stream flow (table 13):

$$X_1 = -61.36 + 1.404X_2 + 1.045X_3 + 2.270X_4$$

where,

all quantities are April-September totals in thousands of acre feet

X_1 = Bear River at Border
X_2 = Smiths Fork near Border
X_3 = Bear River near Randolph
X_4 = Twin Creek at Sage

The standard error of estimate for this analysis is 10.27 and the coefficient of multiple determination is 0.991.

The analysis is based upon twelve years of record, Bear River at Border having the longest period of record for the group. Ezekial (7) has prepared a series of charts which give the true correlation coefficient corrected for the number of samples. With twelve observations and an observed correlation of 0.9911 the true correlation is found to be 0.95.

With a reliable equation of general stream flow as a basis, the next analysis required for a forecast at Harer is the prediction of flow for each gaging station involved. As pointed out previously, incidental to the primary forecast, a forecast is determined for each gaging station used in the correlation analysis.

FORECASTING FLOW AT GAGING STATIONS

Method of analysis

Many independent variables must be considered in preparing a forecast of flow at a particular gaging station. For example, not only should precipitation records be used in attempting to account for deviations from the regression line relating snow-water indices and resulting stream flow, but an attempt should be made with different weights of precipitation records in order to enhance the degree of correlation. Workers in the field of stream flow forecasting have found that in some cases use of October plus twice November 1-20 precipitation records produce better results than using simply October plus November 1-20 recorded precipitation. Similarly, in some cases twice April plus May precipitation may yield better results that simply using April plus May precipitation. Each basin is unique, and what will produce good results in one area may not necessarily yield comparable results in another basin.

Mathemetical correlations can be worked out for each possible combination devised by the ingenuity of the forecaster, but unless clerical aid is obtained the physical task of computation becomes very time consuming. For this reason, the auxiliary graphical processes for multiple correlation as described by Ezekial (7) have been adopted for this phase of the analysis.

Bear River near Evanston

Independent variables utilized. April 1 snow-water equivalent as measured at Goodman Ranch and Trial Lake, together with the April-May precipitation at Evanston constitute the variables best representing the estimated flow of the Bear River near Evanston. (figure 2a, b, c).

The year 1954 was excluded as unusually abnormal in fitting the curve for figure 2a. This is in accordance with the precepts advanced by Boardman (2) in his analysis of the Truckee and Tahoe basins in Western Nevada. The same reasoning was utilized in preparation of figure 2b in excluding the influence of 1954. Figure 2b represents deviations from figure 2a (Goodman Ranch) plotted against April 1 water equivalent as measured at Trial Lake. Below 23.5 inches of water at this snow course a corresponding decrease is indicated from the forecast flow at Evanston as indicated by the Goodman Ranch survey. Above 23.5 inches of water at Trial Lake a net increase of flow as forecast by Goodman Ranch is applicable. The falling nature of the positive limb of this curve signifies that as snow-water equivalent increases at Trial Lake above 27 inches a corresponding increase occurs at Goodman Ranch with a decreasing influence of water content at the former snow course. Low snow at Trial Lake is probably reflected as decreased late summer flow since the later flow is derived from the higher elevation snow fields. Hence, below an indicated water equivalent of 23.5 inches at Trial Lake the estimated flow should be reduced to allow for this factor (figure 2b).

Deviations from figure 2b are plotted in figure 2c against twice April plus May precipitation at Evanston. The reason for low flow in 1954 now becomes apparent as a result of unusually low spring precipitation. The years 1952 and 1950 have been omitted from positioning the precipitation influence line, since they represent maximum years of water equivalent recorded at Goodman Ranch. With much more than average water content at this station the effects of spring precipitation tend to become less and less influential in determining total irrigation season flow.

Independent variables rejected. In arriving at the selection of variables for use in forecasting the Evanston flow a number were investigated which did not exhibit satisfactory degrees of correlation. A number of possible correlations may be dismissed by casual inspection of the Summary of Snow Survey Data (11), Surface Water Supply Papers (12) and Climatological Data for the State of Utah as published by the U.S. Weather Bureau. Other interrelated variables exhibit a moderate degree of compatibility when inspected in a cursory examination and warrant more exhaustive analysis.

Three snow courses in the headwater area above Evanston indicate a fair degree of correlation at first glance. These courses are Head of Bear River, Monte Cristo and Smith Morehouse. A graphical representation of river yield versus snow-water equivalent index, however, may be interpreted as being indicative of no systematic correlation. Various combinations of precipitation indices at Evanston, Coalville, Laketown, Woodruff and Sage do not present consistent positive or negative deviation trends for the resulting stream flow at Evanston.

Trial Lake snow course for the years 1943 to 1954 indicates a moderate curvilinear relationship but again no consistent deviation trend can be established by utilization of spring or preceding fall precipitation records available for the previously noted stations.

Records for Trial Lake are available from 1932 to date, but in order to compare all aspects of the forecast relation on an equal time base only the records from 1943 have been utilized in preparing the deviation analysis to alter trends indicated from Goodman Ranch. The data available from 1932 indicate a best fit regression line which presents a reversed curvilinear form. Although this type of relationship may fit and best explain the data from a statistical standpoint it would not appear to be consistent with similar studies for other basins.

Since late season flow chiefly originates from high snow mantles it was expected that a fair degree of correlation may exist between the July-September flow and the Trial Lake snow-water equivalent index. This hypothesis was not supported by a graphical analysis.

Having utilized the forecast procedure outlined originally in this section, the corresponding flow at Randolph may be calculated from the regression equation previously described or selected from the plot of this equation (figure 3).

Smiths Fork near Border

Independent variables utilized. The average April 1 water equivalent index at Piney-La Barge, C.C.C. camp, and Snyder Basin Ranger Station corrected for antecendent and subsequent precipitation at Border are the variables selected to determine flow of Smiths Fork (figure 4a, b, c).

In placing the regression line for figure 4a the influence of the years 1947 and 1954 was omitted (after Boardman (2)). Deviations from indicated flow from figure 4a are plotted in figure 4b against the October plus twice November 1-20 precipitation. The influence of 1947 and 1954 are omitted, again, in fitting the curve.

The fall precipitation at Border for the years of record studies is a significant parameter representing antecedent soil moisture conditions before the establishment of the permanent snow mantle. Averaging the precipitation as measured at Border with another station probably would have enhanced this correlation. The most promising station appears to be Grover, Wyoming. Published data for the Grover station goes back only as far as 1947. It was noticed in the Climatological Data for Utah that the record should predate 1947 by at least twenty years. No published explanation was indicated in the Climatological Data, however. The author has learned since the preparation of his forecast procedure that the Grover station was known as Afton prior to 1947. Knowledge of this apparent record anomaly may assist other workers in the analysis of Smiths Fork.

Deviations from flow corrections from figure 4b are plotted against spring precipitation at Border in figure 4c. The reason for the years 1954 and 1947 up to this point becomes apparent when this variable is considered. 1954 appears as the lowest spring precipitation year of the period studied, while 1947 is the second highest year in the group.

As previously stated each basin is unique in character. A case in point is illustrated here. In the analysis of the flow at Evanston from the snow-water equivalent index at Goodman Ranch the spring precipitation for the years 1950 and 1952 did not appear to be a major contributing factor to April-September flow. Smiths Fork at Border, corrected from flow indicated by the snow-water equivalent index by antecedent soil moisture conditions, is significantly affected by all ranges of spring precipitation.

Independent variables rejected. The April-September flow of Smiths Fork at Border exhibits a moderate correlation with the snow-water equivalent index at Snyder Basin Ranger Station. Deviations from a trial regression line are not consistently explained by comparison with snow-water equivalent index at the Piney La Barge snow course nor the C.C.C. camp index. A similar conclusion may be drawn from comparing indicated deviations with fall and spring precipitation as measured at Border and Sage, individually or averaged.

A moderate correlation was observed between deviations from figure 4c and the mean March temperature at Border. Net probable corrections were relatively small numerically, and this final adjustment was not considered warranted with the years of record currently available at Border. Knowledge of this factor may prove of value in years to come when more observed data are available for Smiths Fork near Border.

Various combinations of antecedent flow were investigated in order to characterize base flow, but proved to be of little value. These attempts included the lowest flow of the preceding year, total flow for the past year and the average flow during December, January and February prior to the forecast date.

Twin Creek at Sage

Independent variables utilized. Prior reference has been made to the lack of snow survey courses in the headwater area of Twin Creek. The forecaster perforce must attempt to correlate snow courses some distance away from the subdrainage area proper. Bernard, in commenting on the work of Clyde and Work (5) notes a progressive decrease in correlation with increasing distance in reference to correlating runoff for Big Cottonwood Creek in Utah with precipitation stations. While it is known that extra basin indices are useful parameters in forecasting stream flow due to the general uniformity of the big storms, there is no doubt that precipitation stations or snow survey courses located in the heart of the subdrainage area are superior indicators.

The Goodman Ranch snow course was utilized in forecasting April-September flow of Twin Creek at Sage (figure 5). Attempts to account for deviations between observed flow and the regression line were unsuccessful.

Independent variables rejected. The average water index computed from Garden City Summit and Franklin Basin snow courses shows some correlation with the flow at Sage. Deviations from this curve show some correlation with the fall precipitation at Sage and Border, Wyoming. Although a comparatively long precipitation record is available at Sage the data are unusable because of several omissions. For example, in the eleven year period from 1943 to 1953 there are four omissions of April precipitation data. April admittedly is the most repeated month of omission at Sage, other months having more complete records. These missing data could doubtless be estimated from other stations but the validity of these estimates in preparing a forecast from the already short period of record for Twin Creek at Sage is questionable (table 6).

A similar degree of correlation was observed for the deviations as previously noted and the spring precipitation at the same stations. The various combinations of precipitation by months used in this analysis were October, October plus November 1-20 and October plus twice November 1-20. For the effect of spring precipitation, months used were April, May, April plus May and twice April plus May. The same analysis with comparable results was completed for precipitation records at Coalville and Woodruff.

Since spring precipitation as measured at valley stations apparently did not enhance the degree of correlation, the May 1 snow-water equivalent at Mount Logan was investigated. Although time did not permit complete exhaustion of the various May 1 survey combinations, it is felt that further investigation of this method may yield more positive results than presently realized by the author.

Deviations from the Goodman Ranch analysis were worked through exactly the same processes as have been described in this section with disappointing results.

PREPARING A FORECAST

To illustrate the use of charts and equations presented to this point assume the forecast for 1949, corrected from April 1 by spring precipitation, is made. The flow chart illustrated in figure 7 will materially assist in visualizing the requisite steps in handling each variable to predict the April-September flow of the Bear River at Harer.

The initial process requires the forecast of stream flow for each gaging station (Bear River near Randolph, Smiths Fork at Border and Twin Creek at Sage) appearing in the multiple regression equation presented in table 13.

From table 8 the April 1 snow-water equivalent at utilized snow courses is:

1.	Goodman Ranch	6.5 inches
2.	Trial Lake	32.1 inches
3.	Piney La Barge	20.7 inches
4.	C.C.C. camp	12.5 inches
5.	Snyder Basin Ranger Station	16.3 inches
6.	Average of 3, 4 and 5	16.5 inches

From figure 2a the uncorrected flow at Evanston from the Goodman Ranch index is 150,000 acre feet. A correction of plus 8000 is obtained from figure 2b using the Trial Lake index. From table 10, twice April plus May precipitation at Evanston is 2.15 inches. Figure 2c indicates a correction of minus 41,000 for this amount of precipitation. Hence the flow at Evanston is predicted to be 117,000 acre feet (150 + 8.41).

A flow of 117,00 at Evanston produces a flow of 84,00 acre feet at Randolph (figure 3).

The average index from Piney La Barge, C.C.C. Camp, and Snyder Basin Ranger Station indicates an uncorrected flow for Smiths Fork near Border of 121,00 acre feet (figure 4a). Table 9a shows that twice April plus May precipitation at Border was 2.14 inches which yields a correction of minus 11,000 (figure 4c).

The corrected flow of Smiths Fork is then 111,000 acre feet.

Figure 5 shows that for 6.5 inches of water at Goodman Ranch 12,400 acre feet may be anticipated for Twin Creek at Sage. The anticipated flow at Border may now be computed from the relationship:

$$Y = -61.36 + 1.404\ X_2 + 1.045\ X_3 + 2.27\ X_4$$

where the symbols have the meanings as previously defined. Utilization of this equation yields a forecast flow of 211,000 acre feet at Border.

Figure 6 shows that for 211,000 acre feet at Border 250,000 acre feet may be expected at Harer which is the prediction for 1949.

Observed flow at Harer was 237,000 acre feet. The forecast flow is thus 5.5 per cent in error.

COMPARISON OF FORECAST ERROR

The U.S. Geological Survey classifies the general accuracy of its streamflow records in the following terms (8):

Excellent within 5 per cent
Good within 10 per cent
Fair within 15 per cent
Poor greater than 15 per cent

These criteria may be applied in the field of stream flow forecasting as standards to compare forecast and observed flow. Table 14 lists the error between forecast flow and observed flow for the twelve years of record at each gaging station previously discussed. Included for comparison in the table are the errors obtained from the forecast method presently utilized by the Federal-State cooperating agencies for Bear River at Harer. This latter error is compared graphically with the probable error resulting from the method proposed by the author in figure 8.

Bear River at Harer

The twelve year period from 1943 to 1954 produced, by existing methods, forecasts whose average error (without regard to sign) was 31 per cent. The minimum observed error was plus 4.3 per cent while the maximum error was plus 141.2 per cent (1954). Comparing errors by existing method during this period with the criteria previously discussed there are:

7 poor forecasts
2 fair forecasts
2 good forecasts
1 excellent forecast

Utilizing the method as proposed by the author the average twelve year error is 12.7 per cent (without regard to sign) with a minimum of minus 1.4 per cent and a maximum of plus 50 per cent (1954). Comparing the errors with the criteria of accuracy there are:

2 poor forecasts
3 fair forecasts
2 good forecasts
5 excellent forecasts

The overall forecast improvement is encouraging and should serve as a basis for further study in order to bring about a more accurate prediction. The large percentage error observed in 1954, although more than halved by this analysis, is a clear indication that not all of the flow factors are being considered, or what is more probable, the flow factors are not being adequately measured throughout the basin. There may be a different combination of recorded data that would materially affect a forecast for 1954, but observing the trends of published variables, the author is convinced that a forecast for Harer would err on the positive side. Water equivalent indices were high, the fall soil moisture was apparently fair to good and, although the spring rains were light, their influence was probably not as great as the error would tend to indicate.

<u>Bear River at Border</u>

The average twelve year error at Border is 12.5 per cent (without regard to sign) with a minimum of minus 1.6 per cent and a maximum of plus 47 per cent (1945). In the twelve year period there were:

2 poor forecasts
2 fair forecasts
5 good forecasts
3 excellent forecasts

This record is seen to approximate closely that at Harer which is understandable considering the nature of the regression equation correlating the two gaging stations. Compensating errors do occur between the stations which tend to favor a forecast at Harer.

Smiths Fork near Border

The correlation established for this important tributary appears to be the most reliable of the group. As previously stated, the flow of Smiths Fork at Border averages 44 per cent of the flow of the Bear River at Harer. Future work in predicting the flow at Harer cannot fail to recognize the importance of this tributary.

The twelve year average error (without regard to sign) is 8.5 per cent with a maximum of plus 16.1 per cent in 1944 and a minimum of minus 2.3 per cent in 1954. This excellent forecast for 1954 bears out the statement made earlier regarding the error made at other stations, with regard to inadequate measurement of stream flow variables throughout the drainage basin. This statement does not infer that the numerical number of records is inadequate, but rather for the purposes of stream flow forecasting the number of recording stations strategically placed at various elevations throughout the watershed appears insufficient.

Bear River near Evanston

An average error of 14.7 per cent without regard to sign is indicated for Bear River near Evanston with a minimum error of zero and a maximum of plus 45.5 per cent (1954).

There are, for the twelve year period:

5 poor forecasts
1 fair forecast
4 good forecasts
2 excellent forecasts

The average forecast classifies as fair with 1954 being again the year of maximum error. If a typical canal diversion could be found which would serve as a parameter for diversions above Evanston this relationship probably could be improved. An inherent difficulty is apparent with handling diversions in accounting for the interplay of water rights and general cropping trends in the area reflecting a varying volume of water consumptively used.

Further work with precipitation is warranted, particularly in the search for a weighted precipitation index which would be more representative of the upper Bear River watershed than the simple use of the records at Evanston.

Bear River near Randolph

There are actually only eleven years of record at Randolph, the twelfth year having been estimated from the flow of the Bear River near Evanston for the purposes of this study. In the eleven years actually observed an average error of forecast of 32.2 per cent is indicated (without regard to sign) with a minimum of 1 per cent and a maximum of 150 per cent in 1954. The investigation of diversions between Randolph and Evanston as discussed in the preceding section is again applicable.

Table 14 shows for the period:

6 poor forecasts
3 fair forecasts
1 good forecast
1 excellent forecast

The previous section demonstrates that compensating errors between Randolph and Harer with the inclusion of the influence of Smiths Fork and Twin Creek allow for a more reliable prediction at Harer.

Twin Creek at Sage

The most disappointing aspect of this study has been the nonconformity of the relationship between recorded data and the flow of Twin Creek at Sage.

The twelve year period average error (without regard to sign) is 80.5 per cent with a minimum of 5 per cent and a maximum of 322 per cent in 1953. There are:

10 poor forecasts
2 good forecasts

Goodman Ranch evidently does not represent a true index of runoff producing characteristics in the Twin Creek drainage basin. High degrees of correlation have been shown to exist between particular snow courses and subsequent stream flow. A snow survey course located in the headwaters of Twin Creek would certainly improve the forecast accuracy. Perhaps an existing combination of currently measured courses would improve this relationship, but such a combination was not discovered in several attempts by the author.

With a truly representative snow-water equivalent index established, then the roles played by groundwater flow, soil moisture deficiencies and spring precipitation could be deduced.

THE 1955 FORECAST AS OF APRIL 1

Results of 1955 snow surveys as of April 1 indicate the following snow-water equivalent indices at courses utilized by the author:

Goodman Ranch	7.3 inches
Trial Lake	25.3 inches
Piney La Barge	16.4 inches
C.C.C. Camp	10.8 inches
Snyder Basin Ranger Station	12.2 inches

The fall precipitation index at Border, Wyoming is 1.94 inches. Consideration of these data in the manner illustrated in a preceding section will result in April-September forecasts for the several stations analyzed.

The majority of snow courses in the Bear River watershed and adjacent drainage basins indicate snow-water equivalent indices which are below the long term average. The average index for Goodman Ranch is 5.5 inches. A snow-water equivalent of 7.3 inches represents 133 per cent of this average. A basic concept of predicting stream flow from snow surveys is the uniform areal distribution of the big storms which produce the majority of precipitation for subsequent runoff. The measured snow-water equivalent as of April 1, 1955 at Goodman Ranch is evidently not characteristic of the watershed as a whole, nor particularly of existing conditions in the headwaters of the Bear River. The author learned from Mr. G. L. Pearson of the Soil Conservation Service that some of the roads in the vicinity of Goodman Ranch were bare at the time of survey. Evidently some revision of the measured index at this station is warranted. Analysis of the stations illustrated in figure 1, exclusive of Goodman Ranch, at the head of the Bear River indicate a snow-water equivalent which is probably 89 per cent of normal. Adjusting the index at Goodman Ranch, as measured for these conditions, warrants the use of an index of 4.9 inches for this variable. The adjusted value has been used in the preparation of the following April-September forecasts.

Gaging station	Forecast April-September flow in thousand acre feet
Bear River near Evanston	137
Bear River near Randolph	108
Twin Creek at Sage	7.8
Smiths Fork near Border	86
Bear River at Border	191
Bear River at Harer	245

CONCLUSIONS

1. The forecast of flow for the Bear River at Harer, Idaho, can be improved by zoning the watershed, forecasting each zonal flow and by multiple correlation arriving at the primary forecast objective. The zones investigated in this analysis are a step in the right direction, but an individual worker could scarcely hope to exhaust all of the possibilities with their subsequent ramifications. Governmental agencies with adequate clerical staff are best suited to conduct further studies of this nature.

2. A snow survey course should be established in the headwaters of Twin Creek to obtain a representative index for resulting runoff of this tributary. Establishment of such a course or series of courses would characterize flow producing conditions on the western aspect of the mountains in the east central portion of the upper Bear River drainage basin. In addition to improving the overall forecast at Harer, a reliable forecast for Twin Creek would materially assist irrigation development in that area.

3. A diversional index is desireable for that portion of the main stem above Evanston and a similar index for diversions between Evanston and Randolph. This latter parameter would materially assist in accounting for deviations between the Evanston and Randolph gaging stations.

4. Rather than placing the uncorrected forecast burden on two snow courses for the flow at Evanston additional correlation should be

attempted by utilization of the newer snow courses in the headwater area. At this time too few years of record exist for this study, but Chalk Creek No. 2 appears to be a promising index.

5. The effect of antecedent and subsequent precipitation on the flow of Smiths Fork can be interpreted more reliably by utilization of a weighted precipitation index for that area. Grover, Wyoming, appears to be a promising station. Prior to 1947 this station was known as Afton.

6. The effect of groundwater contributions as measured by antecedent flow indices was not determined satisfactorily in this analysis. Trends were indicated by methods discussed herein, but in general were inconclusive. Groundwater flow is certainly a variable to be accounted for and further work in this aspect is certainly warranted.

7. For practical reasons snow courses are not all sampled on April 1. Future work in adjusting the forecast for spring precipitation should adjust this value to the actual date of survey.

Table 1. April-September discharge in acre feet of Bear River at Harer, Idaho

Year	April	May	June	July	August	September
1938	65,600	104,900	70,020	27,670	11,940	15,430
39	51,270	50,620	21,500	11,030	7,330	6,820
1940	9,390	7,900	8,990	5,850	3,620	3,710
41	16,220	25,880	54,080	22,490	12,600	10,070
42	81,570	42,540	41,060	13,390	7,500	5,780
43	90,210	92,500	68,290	34,550	17,800	12,110
44	78,700	69,770	80,430	30,460	11,350	7,800
45	25,900	42,030	66,090	36,810	22,490	17,620
46	111,100	109,000	45,530	19,110	13,540	13,170
47	45,710	97,280	103,600	40,780	21,400	16,200
48	68,690	110,200	67,800	21,160	11,220	9,010
49	49,830	68,540	69,380	28,990	12,670	7,930
1950	93,070	154,300	176,900	59,350	23,300	16,450
51	112,000	124,600	101,000	38,080	25,240	17,820
52	76,030	225,300	109,000	42,040	19,500	15,230
53	31,860	26,800	74,930	26,770	15,350	8,045
54	15,430	33,070	17,980	12,330	7,940	5,730

Table 2. April-September discharge in acre feet of Bear River at Border, Wyoming

Year	April	May	June	July	August	September
1938	56,450	88,700	63,470	21,870	8,660	11,640
39	41,920	42,130	17,040	8,350	5,550	4,890
1940	7,760	6,400	7,260	4,610	2,600	2,290
41	13,950	21,870	50,360	18,500	10,220	8,120
42	74,130	38,710	38,140	10,230	5,750	4,350
43	74,500	70,200	61,320	30,530	14,790	9,760
44	69,020	67,040	76,450	27,530	9,610	6,520
45	22,070	34,300	52,560	27,170	18,840	14,840
46	90,230	80,950	37,910	14,990	10,450	10,870
47	38,080	81,390	91,440	32,950	16,970	13,110
48	61,090	87,380	54,600	15,090	8,870	7,010
49	42,590	54,220	58,620	26,070	9,930	5,640
1950	75,460	118,500	146,400	50,510	19,480	13,330
51	90,030	95,130	85,360	32,310	22,040	15,130
52	76,280	194,200	98,230	35,790	16,820	12,610
53	25,620	19,520	70,460	20,410	11,540	6,320
54	23,160	26,800	13,230	8,970	6,400	4,550

Table 3. April-September discharge in acre feet of Bear River near Randolph, Utah

Year	April	May	June	July	August	September
1944	39,590	43,540	45,750	11,670	2,590	1,610
45	15,630	13,650	22,140	8,110	8,360	4,100
46	42,280	39,050	14,360	2,330	2,020	1,740
47	15,390	35,200	52,950	11,600	4,480	2,890
48	39,550	47,270	21,000	1,540	1,870	1,560
49	26,240	26,170	32,540	9,730	2,740	1,290
1950	45,580	64,210	80,350	15,250	6,300	2,490
51	46,290	37,450	42,250	9,200	9,240	4,020
52	59,100	113,400	63,770	15,640	8,600	4,370
53	12,610	3,980	41,890	4,530	3,490	825
54	8,430	3,290	2,100	610	480	396

Table 4. April-September discharge in acre feet of Bear River near Evanston, Wyoming

Year	April	May	June	July	August	September
1943	35,200	44,160	42,070	7,610	1,390	166
44	27,390	60,730	60,380	12,710	97	82
45	22,130	41,080	40,380	12,830	8,510	2,230
46	40,440	44,440	26,270	720	207	116
47	14,450	63,310	55,760	13,030	2,890	1,510
48	39,570	63,110	29,160	587	74	15
49	30,000	50,250	49,170	8,340	478	342
1950	43,400	69,320	85,970	17,270	2,470	2,050
51	37,920	53,680	51,610	12,360	6,900	1,960
52	52,890	108,900	82,140	15,380	6,380	2,520
53	15,570	23,430	66,930	5,200	1,810	160
54	15,520	30,240	8,610	479	19	0

Table 5. April-September discharge in acre feet of Smiths Fork near Border, Wyoming

Year	April	May	June	July	August	September
1943	19,400	37,800	40,070	23,360	11,480	7,310
44	6,180	20,180	31,600	15,060	8,330	5,990
45	4,200	25,360	35,440	19,430	10,150	7,170
46	22,930	34,460	29,310	13,690	8,440	6,350
47	10,240	48,370	38,210	19,270	11,030	7,110
48	8,080	41,190	33,770	14,090	8,370	5,920
49	11,330	33,240	29,490	13,840	8,090	5,840
1950	11,460	38,000	55,570	28,270	11,940	7,540
51	17,540	50,390	41,230	21,600	11,520	7,130
52	13,410	46,890	35,520	15,460	8,900	6,040
53	7,900	17,360	39,160	18,880	9,410	5,910
54	8,380	32,130	21,520	13,230	7,610	5,730

Table 6. April-September discharge in acre feet of Twin Creek at Sage, Wyoming

Year	April	May	June	July	August	September
1943	2,840	1,370	868	297	595	224
44	10,430	1,970	4,550	433	305	275
45	1,760	590	862	312	1,380	294
46	5,080	2,250	717	369	591	485
47	1,710	1,720	2,110	589	741	682
48	5,400	2,890	1,440	506	392	273
49	2,130	1,540	1,400	684	299	264
1950	8,600	7,770	4,440	1,710	995	721
51	7,090	3,240	1,560	697	461	447
52	6,070	6,420	2,620	1,410	950	751
53	1,070	611	428	227	174	209
54	1,270	491	411	250	168	167

Table 7. April-September discharge totals in acre feet

Year	Column					
	A	B	C	D	E	F
1938	295,560	250,790				
39	148,570	119,880				
1940	39,460	30,920				
41	141,340	123,020				
42	191,840	171,310				
43	315,460	261,100		130,596	139,420	6,194
44	278,580	256,170	144,750	161,389	87,340	17,963
45	210,940	169,780	71,990	127,160	101,750	5,198
46	311,450	245,400	101,780	112,193	115,180	9,492
47	324,970	273,940	122,510	150,950	134,230	7,552
48	288,080	234,040	112,790	132,516	111,420	10,901
49	237,340	197,070	98,710	138,580	101,830	6,317
1950	523,370	423,680	214,180	220,480	152,780	24,236
51	418,740	340,000	148,450	164,430	149,410	13,495
52	487,100	433,930	264,880	268,210	126,220	18,221
53	183,755	153,870	67,325	113,100	98,620	2,719
54	92,480	83,110	15,306	54,868	88,600	2,757

Column	Gaging station
A	Bear River at Harer, Idaho
B	Bear River at Border, Wyoming
C	Bear River near Randolph, Utah
D	Bear River near Evanston, Wyoming
E	Smiths Fork near Border, Wyoming
F	Twin Creek at Sage, Wyoming

Table 8. April 1 snow equivalent inches of water

Year	Column A	Column B	Column C	Column D	Column E	Column F
1943	15.7	29.7	23.4	22.9	5.1	36.6
44	9.3	13.2	9.9	10.8	6.6	21.7
45	10.5	15.5	9.7	11.9	4.1	24.8
46	9.0	21.8	17.9	16.3	3.2	26.6
47	10.6	17.0	11.6	13.1	3.2	27.2
48	9.5	17.1	12.8	13.1	4.4	23.5
49	12.5	20.7	16.3	16.5	6.5	32.1
1950	16.1	24.4	19.2	19.9	10.3	38.0
51	13.7	24.8	22.1	20.3	6.1	33.9
52	16.0	24.7	17.9	19.5	9.9	39.3
53	10.9	15.4	13.3	13.2	6.2	21.8
54	12.9	22.9	18.4	18.1	5.6	23.9

Column	Snow Course
A	C.C.C. Camp
B	Piney - La Barge
C	Snyder Basin
D	Average of A, B, and C
E	Goodman Ranch
F	Trial Lake

Table 9a. Fall precipitation at Border, Wyoming

Year	Forecast year	Oct. precip.	Nov. 1-20 precip.	Oct. plus twice Nov. 1-20 precip.
1942	1943	.96	.70	2.36
43	44	1.42	0	1.42
44	45	.19	.95	2.09
45	46	1.73	1.90	5.53
46	47	2.50	.43	3.36
47	48	1.12	1.25	3.62
48	49	1.28	1.37	4.02
49	1950	2.80	.39	3.58
1950	51	.73	2.62	5.97
51	52	1.39	.78	2.95
52	53	0	.24	.48
53	54	.73	.54	1.81
54	55	.90	.52	1.94

Table 9b. Spring precipitation at Border, Wyoming

Year	April precipitation	May precipitation	Twice April plus May precipitation
1943	.75	1.27	2.77
44	2.27	1.23	5.77
45	.75	2.71	4.21
46	.25	1.77	2.27
47	1.83	1.50	5.16
48	1.87	.55	4.29
49	.32	1.50	2.14
1950	.82	1.70	3.34
51	1.81	.67	4.29
52	.60	.49	1.69
53	1.46	1.72	4.64
54	.17	.55	.89

Table 10. Spring precipitation at Evanston, Wyoming

Year	April precipitation	May precipitation	Twice April plus May precipitation
1943	1.20	1.05	3.45
44	1.84	1.07	4.75
45	1.07	1.37	3.51
46	1.60	1.75	4.95
47	1.65	1.51	4.81
48	2.57	.29	5.43
49	.06	2.03	2.15
1950	.64	1.17	2.45
51	.86	1.23	2.95
52	.51	1.34	2.36
53	1.11	1.72	3.94
54	.37	.93	1.67

Table 11. Correlation analysis between
1. Bear River at Harer, Idaho (Y)
2. Bear River at Border, Wyoming (X)

(April-September thousand acre feet)

Year	Bear Border X	Bear Harer Y	X^2	XY	Y^2
1938	250.8	295.6	62,900.64	74,136.48	87,379.36
39	119.9	148.6	14,376.01	17,817.14	22,081.96
1940	30.9	39.5	954.81	1,220.55	1,560.25
41	123.0	141.3	15,129.00	17,379.90	19,965.69
42	171.3	191.8	29,343.69	32,855.34	36,787.24
43	261.1	315.5	68,173.21	82,377.05	99,540.25
44	256.2	278.6	65,638.44	71,377.32	77,617.96
45	169.8	210.9	28,832.04	35,810.82	44,478.81
46	245.4	311.5	60,221.16	76,442.10	97,032.25
47	273.9	325.0	75,021.21	89,017.50	105,625.00
48	234.0	288.1	54,756.00	67,415.40	83,001.61
49	197.1	237.3	38,848.41	46,771.83	56,311.29
1950	423.7	523.4	179,521.69	221,764.58	273,947.56
51	340.0	418.7	115,600.00	142,358.00	175,309.69
52	433.9	487.1	188,269.21	211,352.69	237,266.41
53	153.9	183.7	23,685.21	28,271.43	33,745.69
54	83.1	92.5	6,905.61	7,686.75	8,556.25
Total	3,768.0	4,489.1	1,028,176.34	1,224,054.88	1,460,207.27
Mean.	221.64	264.07	n = 17		

$nM_xM_y = 994,983.99$
$n(M_x)^2 = 835,112.93$
$n(M_y)^2 = 1,185,460.32$

TABLE II

REGRESSION EQUATION

$$BYX = \frac{\Sigma(XY) - NMXMY}{\Sigma(X^2) - N(MX)^2} = \frac{1224054.88 - 994983.99}{1028176.34 - 835112.93}$$

$$= \frac{229070.89}{193063.41}$$

$\underline{BYX = 1.186}$

$$A = MY - BMX = 264.07 - (1.186)(221.64)$$

$$= 264.07 - 262.06$$

$\underline{A = 2.01}$

$$\boxed{Y = 2.01 + 1.186\,X}$$

UNADJUSTED COEFFICIENT OF CORRELATION

$$RXY = \frac{\Sigma(XY) - NMXMY}{\sqrt{[\Sigma(X^2) - N(MX)^2][\Sigma(Y)^2 - N(MY)^2]}}$$

$$= \frac{229070.89}{\sqrt{(193063.41)(1460207.27 - 185460.32)}} = \frac{229070.89}{230311.90}$$

$\underline{RXY = 0.994}$

ADJUSTED COEFFICIENT OF CORRELATION

$$\bar{R}^2XY = \frac{1 - (1 - R^2XY)(N-1)}{N-2} = \frac{1 - (1 - .988)(16)}{15}$$

$$= \frac{1 - (.012)(16)}{15} = \underline{0.987}$$

$\underline{\bar{R}XY = .993}$

STANDARD ERROR OF ESTIMATE

$$\bar{S}YX = \sqrt{\frac{\Sigma Y^2 - N(MY)^2\ (1 - \bar{R}^2XY)}{N-1}} = \sqrt{\frac{274746.95\ (1 - .987)}{16}}$$

$\underline{\bar{S}YX = 14.94}$

COEFFICIENT OF DETERMINATION

$$\underline{\bar{D}XY = \bar{R}^2XY = 0.987}$$

Table 12. Correlation analysis between
Bear River near Randolph (y) and
Bear River near Evanston (x)

(April–September thousand acre feet)

Year	Bear Evanston x	Bear Randolph y	x^2	xy	y^2
1944	161.4	144.8	26,049.96	23,370.72	20,967.04
45	127.2	72.0	16,179.84	9,158.40	5,184.00
46	112.2	101.8	12,588.84	11,421.96	10,363.24
47	151.0	122.5	22,801.00	18,497.50	15,006.25
48	132.5	112.8	17,556.25	14,946.00	12,723.84
49	138.6	98.7	19,209.96	13,679.82	9,741.69
1950	220.5	214.2	48,620.25	47,231.10	45,881.64
51	164.4	148.4	27,027.36	24,396.96	22,022.56
52	268.2	264.9	71,931.24	71,046.18	70,172.01
53	113.1	67.3	12,791.61	7,611.63	4,529.29
Total	1,589.1	1,347.4	274,756.31	241,360.27	216,591.56
Mean	158.91	134.74	n = 10		

$nM_xM_y = 214,115.33$
$n(M_x)^2 = 252,523.88$
$n(M_y)^2 = 181,548.68$

TABLE 12
(CONTINUED—)

1. REGRESSION EQUATION

$$BYX = \frac{\mathcal{E}(XY) - NMXMY}{\mathcal{E}(X^2) - N(MX)^2} = \frac{241\,360.27 - 14115.33}{274\,756.31 - 252523.88}$$

$$= \frac{27244.94}{22232.43}$$

BYX = 1.226

$$A = MY - BMX = 134.74 - (1.226)(158.91)$$

$$= 134.74 - 196.05$$

A = 61.31

$$\boxed{Y = -61.31 + 1.226\,X}$$

2. UNADJUSTED COEFFICIENT OF CORRELATION

$$RXY = \frac{\mathcal{E}(XY) - NMXMY}{\sqrt{[\mathcal{E}(X^2) - N(MX)^2][\mathcal{E}(Y^2) - N(MY)^2]}}$$

$$= \frac{27244.94}{\sqrt{(22232.43)\ (35042.88)}} = \frac{27244.94}{27912.10}$$

RXY = .976

3. ADJUSTED COEFFICIENT OF CORRELATION

$$\bar{R}^2XY = \frac{1 - (1 - R^2XY)(N-1)}{(N-2)} = \frac{1 - (1 - .953)(9)}{8}$$

$$= 1 - \frac{(.047)(9)}{8}$$

$\bar{R}^2XY = .947$ $\bar{R}XY = .973$

4. STANDARD ERROR OF ESTIMATE

$$\bar{S}YX = \sqrt{\frac{\mathcal{E}(Y^2) - N(MY)^2}{(N-1)}(1 - \bar{R}^2XY)} = \sqrt{\left(\frac{35042.88}{9}\right)(.053)}$$

$\bar{S}YX = 14.36$

5. COEFFICIENT OF DETERMINATION

$$\bar{D}XY = \bar{R}^2XY = .947$$

Table 13. Correlation analysis between
1. Bear River at Border (x_1)
2. Smiths Fork near Border (x_2)
3. Bear River near Randolph (x_3)
4. Twin Creek at Sage (x_4)

Year	x_1	x_2	x_3	x_4	x_2^2
1944	256.2	87.3	144.8	18.0	7,621.29
45	169.8	110.8	72.0	5.2	12,276.64
46	245.4	115.2	101.8	9.5	13,271.04
47	273.9	134.2	122.5	7.6	18,009.64
48	234.0	111.4	112.8	10.9	12,409.96
49	197.1	101.8	98.7	6.3	10,363.24
1950	423.7	152.8	214.2	24.2	23,347.84
51	340.0	149.4	148.4	13.5	22,320.36
52	433.9	126.2	264.9	18.2	15,926.44
53	153.9	98.6	67.3	2.7	9,721.96
54	83.1	88.6	15.3	2.8	7,849.96
Σ	2,811.0	1,276.3	1,362.7	118.9	153,118.37
M	255.54	116.03	123.88	10.81	
Corr. item	n = 11				148,092.57
Corr. sum					5,025.80

Year	x_2x_3	x_1x_2	x_3^2	x_1x_3	x_1^2
1944	12,641.04	22,366.26	20,967.04	37,097.76	65,638.44
45	7,977.60	18,813.84	5,184.00	12,225.60	28,832.04
46	11,727.36	28,270.08	10,363.24	24,981.72	60,221.16
47	16,439.50	36,757.38	15,006.25	33,552.75	75,021.21
48	12,565.92	26,067.60	12,723.84	26,395.20	54,756.00
49	10,047.66	20,064.78	9,741.36	19,453.77	38,848.41
1950	32,729.76	64,741.36	45,881.64	90,756.54	179,521.69
51	22,170.96	50,796.00	22,022.56	50,456.00	115,600.00
52	33,430.38	54,758.18	70,172.01	114,940.11	188,269.21
53	6,635.78	15,174.54	4,529.29	10,357.47	23,685.21
54	1,355.58	7,362.66	234.09	1,271.43	6,905.61
Σ	167,721.54	345,172.68	216,825.65	421,488.35	837,298.98
M					
Corr. item	158,111.76	326,153.37	168,808.80	348,219.25	718,052.07
Corr. sum	9,609.78	19,019.31	48,016.85	73,269.10	119,246.91

Table 13 continued.

Year	x_2x_4	x_3x_4	x_1x_4	x_4^2
1944	1,571.40	2,606.40	4,611.60	324.00
45	576.16	374.40	882.96	27.04
46	1,094.40	967.10	2,331.30	90.25
47	1,019.92	931.00	2,081.64	57.76
48	1,214.26	1,229.52	2,550.60	118.81
49	641.34	621.81	1,241.73	39.69
1950	3,697.76	5,183.64	10,253.54	584.64
51	2,016.90	2,003.40	4,590.00	182.25
52	2,296.84	4,821.18	7,896.98	331.24
53	266.22	181.71	415.53	7.29
54	248.08	42.84	232.68	7.84
Σ	14,643.28	18,963.00	37,088.56	1,770.81
M				
Corr. item	13,797.13	14,730.57	30,375.45	1,285.41
Corr. sum	846.15	4,232.43	6,713.11	485.40

Correction items

$n(Mx_2)^2$	148,092.57
nMx_2Mx_3	158,111.76
nMx_1Mx_2	326,153.37
$n(Mx_3)^2$	168,808.80
nMx_1Mx_3	348,219.25
$n(Mx_1)^2$	718,052.07
nMx_2Mx_4	13,797.13
nMx_3Mx_4	14,730.57
nMx_1Mx_4	30,375.45
$n(Mx_4)^2$	1,285.41

TABLE 13 (Cont'd.)

Net Regression Coefficients

$$\Sigma x_2^2 b_2 + \Sigma (x_2 x_3) b_3 + \Sigma x_2 x_4 b_4 = \Sigma x_1 x_2$$
$$\Sigma x_2 x_3 b_2 + \Sigma x_3^2 b_3 + \Sigma x_3 x_4 b_4 = \Sigma x_1 x_3$$
$$\Sigma x_2 x_4 b_2 + \Sigma x_3 x_4 b_3 + \Sigma x_4^2 b_4 = \Sigma x_1 x_4$$

I.	$5025.8\, b_2 + 9609.78\, b_3 + 846.15\, b_4$	$= 19019.31$
I'	$-b_2 - 1.912\, b_3 - .1684\, b_4$	$= -3.7844$
II.	$+48016.85\, b_3 + 4232.43\, b_4$	$= +73269.10$
I (-1.912)	$-18,373.9\, b_3 - 1617.84\, b_4$	$= -36364.92$
Σ_2	$29642.95\, b_3 + 2614.59\, b_4$	$= 36904.18$
II'	$-b_3 - .08821\, b_4$	$= -1.2449$
III	$485.4\, b_4$	$= 6713.11$
I (-.1684)	$-142.49\, b_4$	$= -3202.85$
Σ_2(-.08821)	$-230.63\, b_4$	$= -3225.31$
Σ_3	$112.28\, b_4$	$= 254.95$
III'	b_4	$= 2.27$

II' $\quad b_3 = 1.2449 - .08821\, b_4 = 1.045$

I' $\quad b_2 = 3.7884 - 1.912 \times 1.045 - 0.1684 \times 2.27 = 1.404$

$$a = M_1 - b_2 M_2 - b_3 M_3 - b_4 M_4$$

$$a = 255.54 - 116.03 \times 1.404 - 123.88 \times 1.045 - 10.81 \times 2.27$$

$$a = -61.36$$

$$X_1 = -61.36 + 1.404\, X_2 + 1.045\, X_3 + 2.27\, X_4$$

TABLE 13 (Cont'd.)

Standard Error of Estimate

$$\bar{S}^2 = \frac{\Sigma x_1^2 - b_2 \Sigma x_1 x_2 - b_3 \Sigma x_1 x_3 - b_4 \Sigma x_1 x_4}{n-m}$$

$$\bar{S}^2 = \frac{119{,}246.91 - 1.404 \times 19{,}019.31 - 1.045 \times 73{,}269.1 - 2.27 \times 6713.11}{11-4}$$

$$\bar{S}^2 = 105.55 \qquad \bar{S} = 10.27$$

Coefficient of Multiple Correlation (Unadjusted)

$$R^2 = \frac{b_2 \Sigma x_1 x_2 + b_3 \Sigma x_1 x_3 + b_4 \Sigma x_1 x_4}{\Sigma x_1^2}$$

$$R^2 = \frac{26{,}703.11 + 76566.21 + 15{,}238.76}{119{,}246.91}$$

$$R^2 = .9938$$

Coefficient of Multiple Correlation (Adjusted)

$$\bar{R}^2 = 1 - (1 - R^2)\frac{n-1}{n-m}$$

$$\bar{R}^2 = 1 - (1 - .9938)\frac{10}{7} = 0.9911$$

Coefficient of Multiple Determination

$$\bar{D} = \bar{R}^2 = 0.9911$$

Table 14. Comparison forecast error

Year	A				B			C		
	1	2	3	4	1	2	3	1	2	3
1943	315	300	-5.0	-11.3	261	253	-3.1	139	135	-2.9
44	279	275	-1.4	+7.7	256	233	-9.0	87	101	+16.1
45	211	220	+4.0	+4.3	170	188	+10.6	101	94	-6.9
46	311	285	-8.0	-26.1	245	241	-1.6	115	124	+7.8
47	325	280	-14.0	-44.6	274	234	-15.1	134	121	-9.7
48	288	275	-4.5	-27.1	234	230	-1.7	111	114	+2.7
49	237	250	+5.5	+20.4	197	211	+7.1	102	111	+8.8
1950	523	580	+11.0	-38.9	424	446	+5.2	153	137	-10.4
51	418	370	-11.5	-29.5	340	311	-8.5	149	172	+15.5
52	487	470	-3.5	-7.6	434	394	-9.2	126	112	-11.1
53	183	245	+34	-12.9	153	202	+32	98	91	-7.2
54	93	140	+50	+141.2	83	122	+47	88	86	-2.3

Year	D			E			F		
	1	2	3	1	2	3	1	2	3
1943	6.2	8.4	+35.4	-	101	-	131	131	0
44	18.0	12.6	-30.0	145	118	-18.6	161	145	-9.9
45	5.2	5.6	+7.7	72	99	+37.5	127	129	+1.6
46	9.5	3.0	-68.5	102	116	+13.7	112	144	28.6
47	7.5	3.0	-60.0	122	113	-7.4	151	141	-6.6
48	10.9	6.4	-41.2	113	112	-0.1	132	140	+6.1
49	6.3	12.4	+97	99	84	-15.0	138	117	-15.0
1950	24.2	23.0	-5.0	214	250	+16.8	220	256	+16.4
51	13.5	11.2	-17.1	148	101	-31.8	164	131	-20.0
52	18.2	22.2	+22.0	265	238	-10.2	268	245	-8.6
53	2.7	11.4	+322	67	104	+55	113	134	+18.6
54	2.7	9.8	+262	15	38	+150	55	80	+45.5

A. Bear River at Harer
B. Bear River at Border
C. Smiths Fork near Border
D. Twin Creek at Sage
E. Bear River near Randolph
F. Bear River near Evanston
1. Observed flow (April-September thousand acre feet)
2. Forecast flow (April-September thousand acre feet)
3. Per cent error
4. Per cent error (existing method)

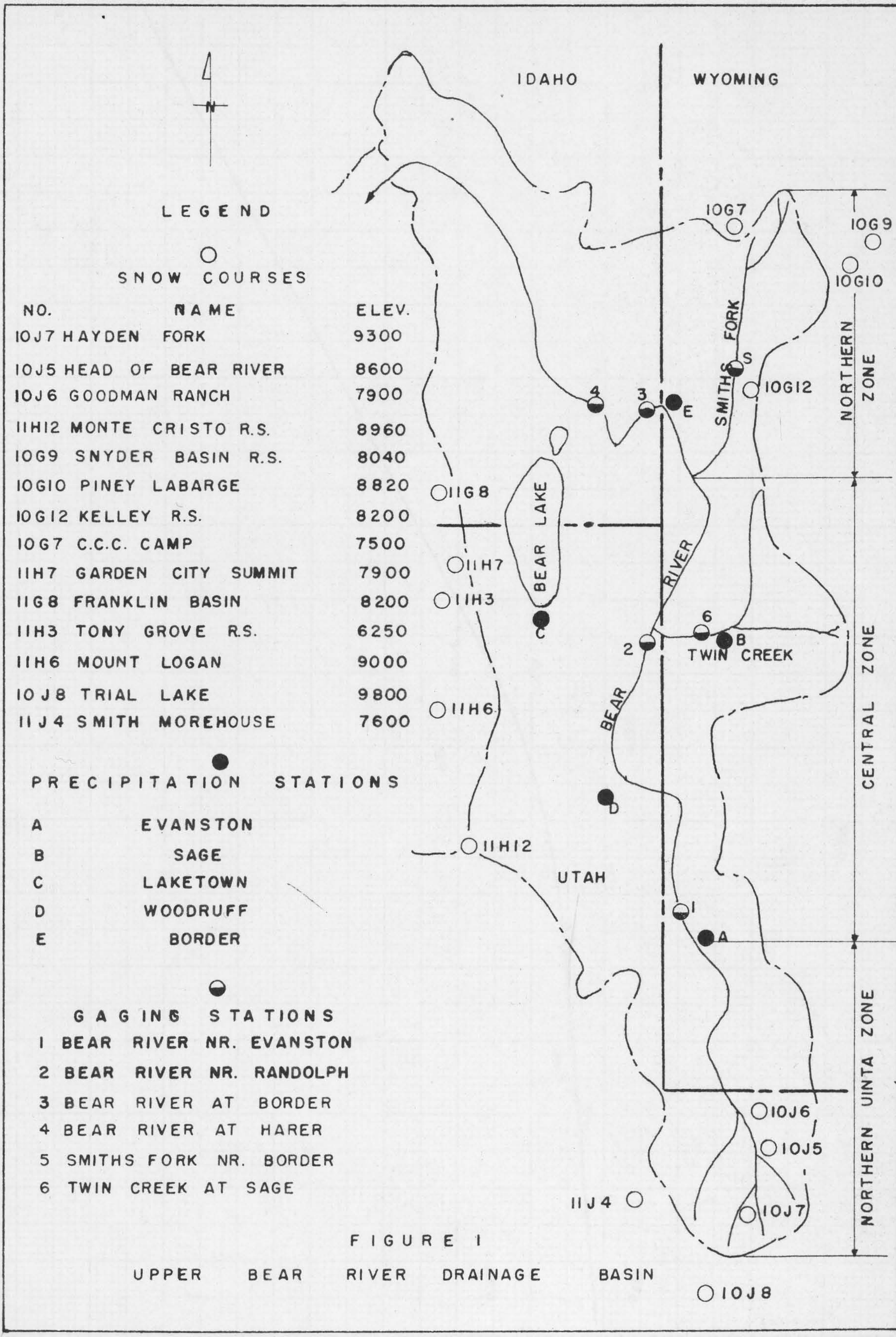

FIGURE 1

UPPER BEAR RIVER DRAINAGE BASIN

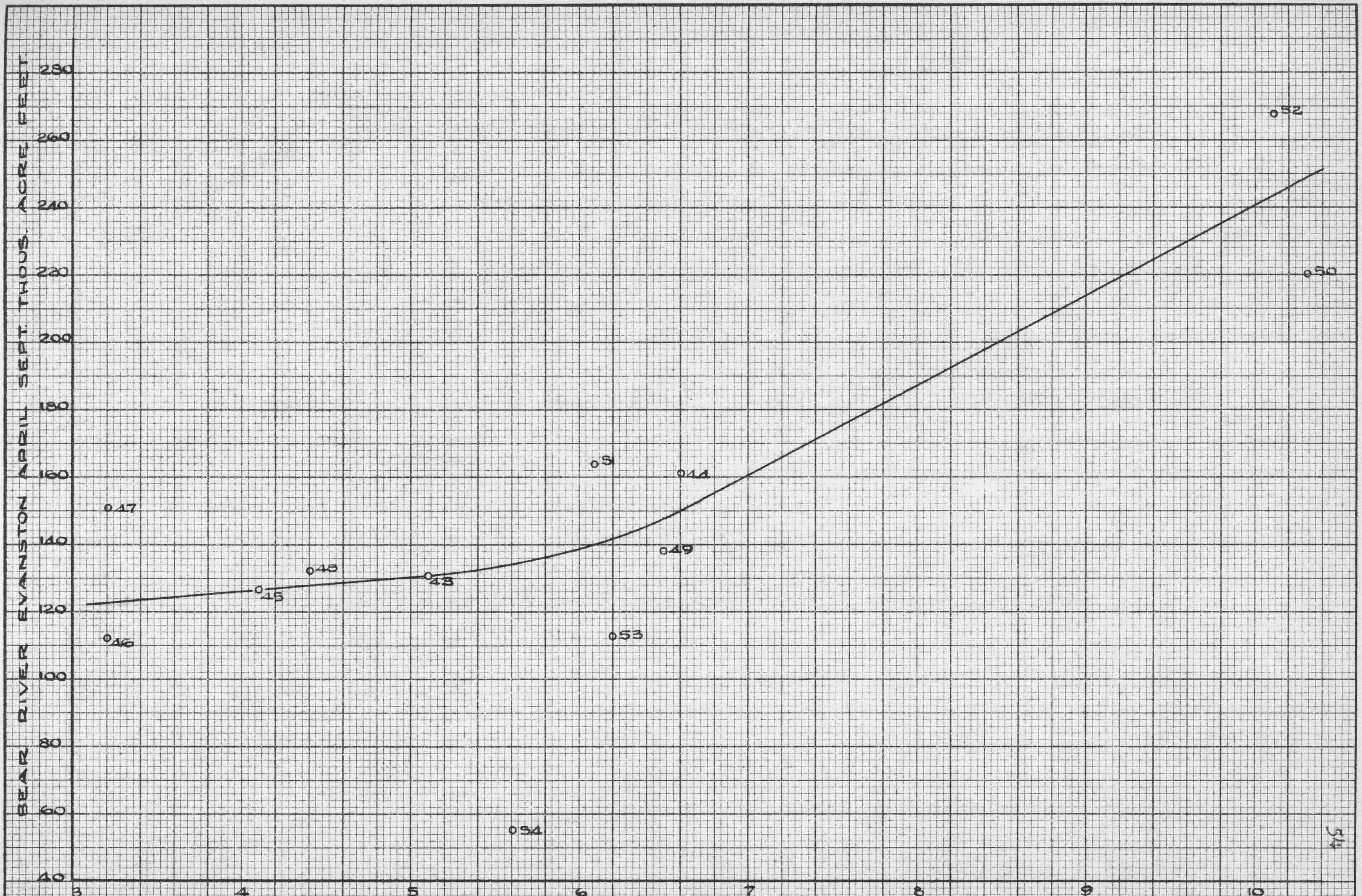

FIG. 2(a) - APRIL 1 SNOW EQUIVALENT INCHES WATER GOODMAN RANCH.

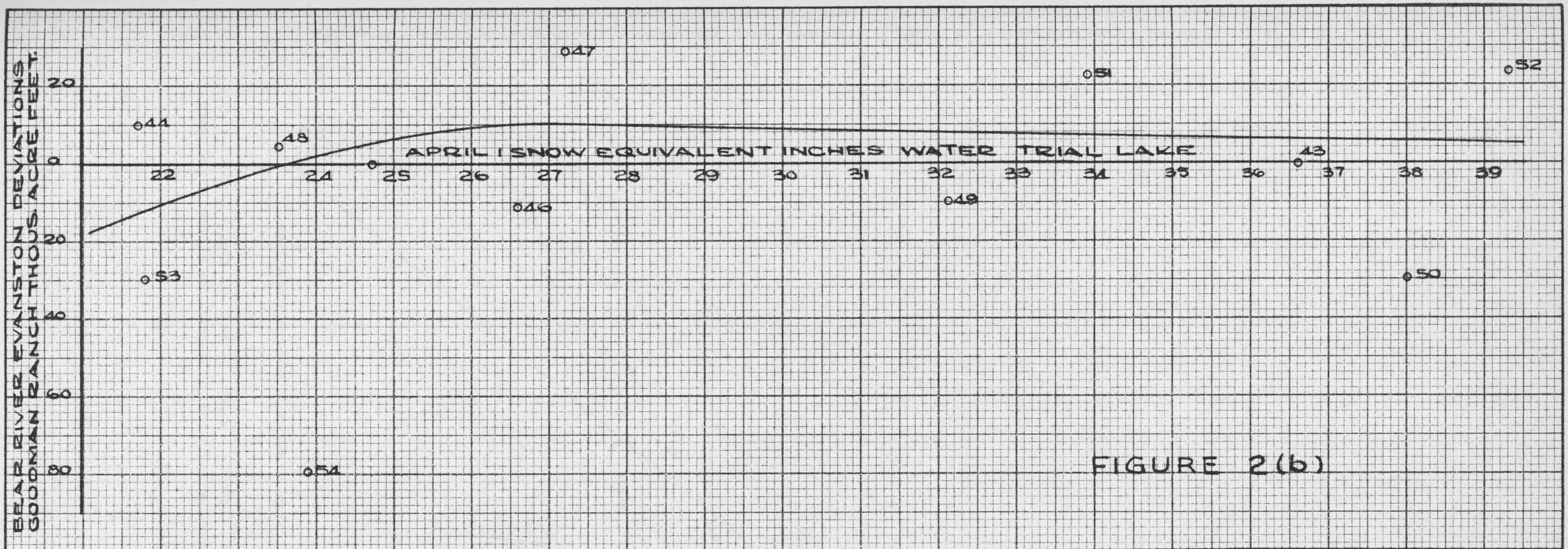

FIGURE 2(b)

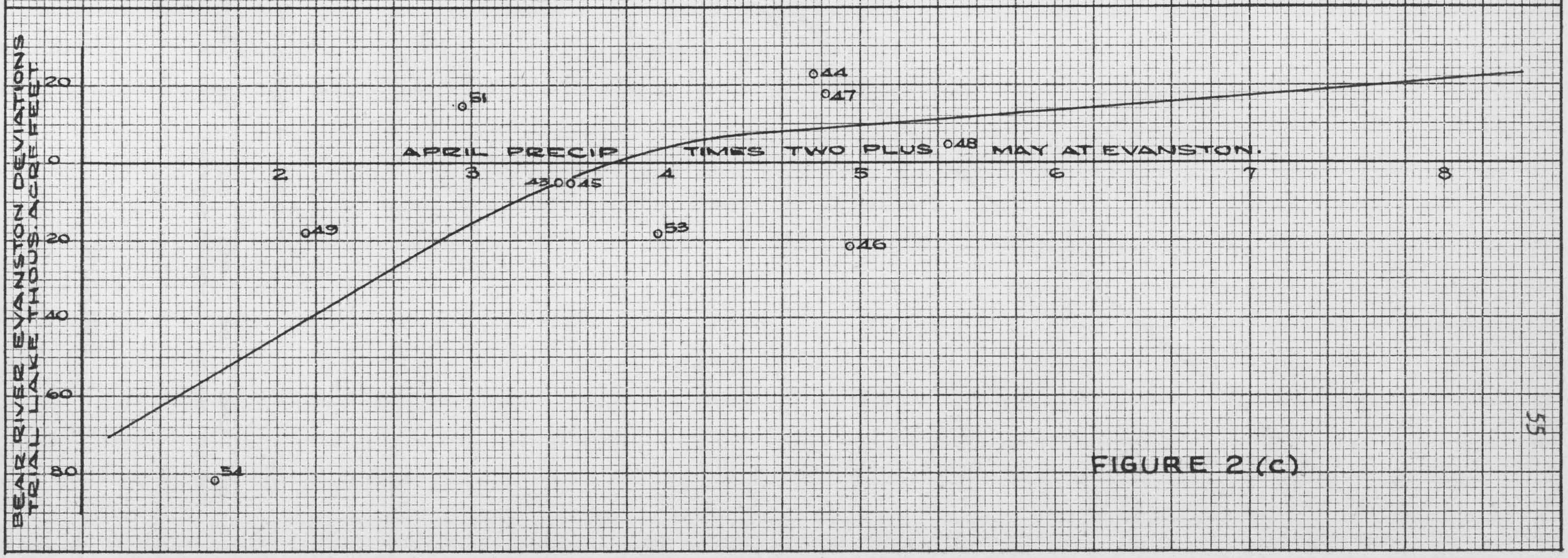

FIGURE 2 (c)

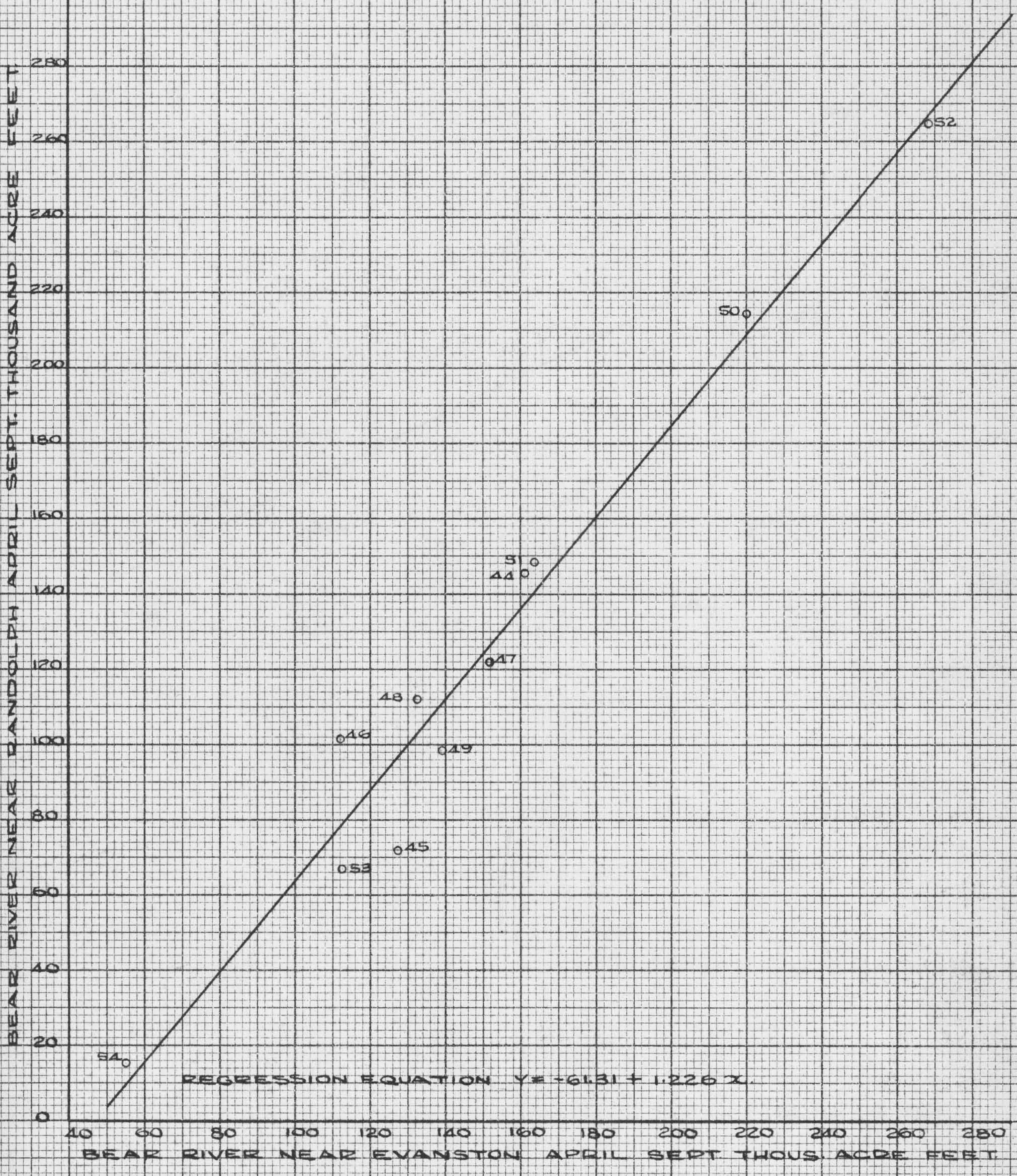
BEAR RIVER NEAR RANDOLPH APRIL SEPT. THOUSAND ACRE FEET.
BEAR RIVER NEAR EVANSTON APRIL SEPT. THOUS. ACRE FEET.
REGRESSION EQUATION Y = -61.31 + 1.226 X.
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
40
60
80
100
120
140
160
180
200
220
240
260
280
52
50
51
44
47
48
46
49
45
53
54

FIGURE 3

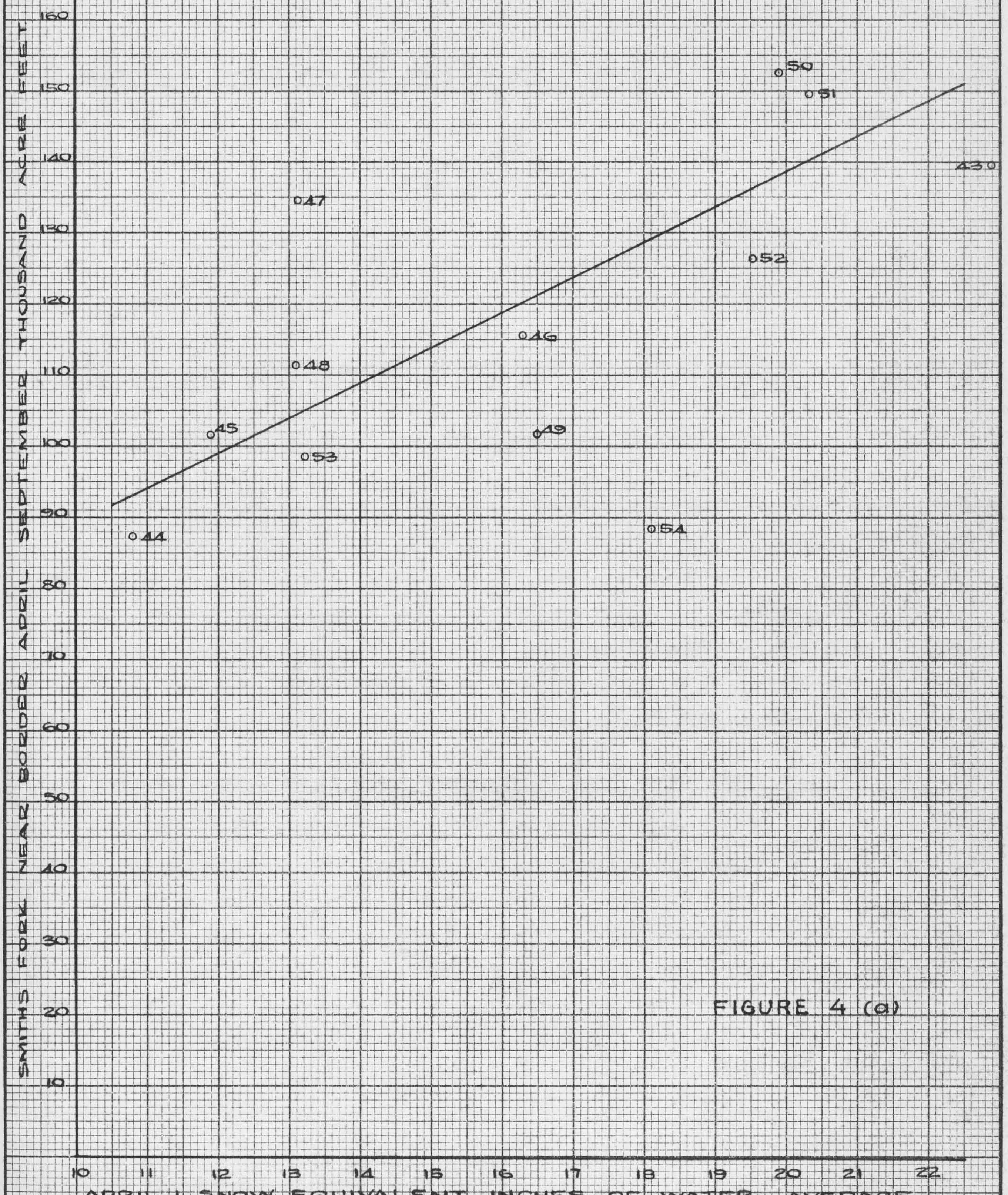
SMITHS FORK NEAR BORDER APRIL SEPTEMBER THOUSAND ACRE FEET
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
10
11
12
13
14
15
16
17
18
19
20
21
22
44
45
46
47
48
49
50
51
52
53
54
43
APRIL 1 SNOW EQUIVALENT INCHES OF WATER. AVERAGE
OF PINEY LA-BARGE, C.C.C. CAMP AND SNYDER BASIN.

FIGURE 4 (a)

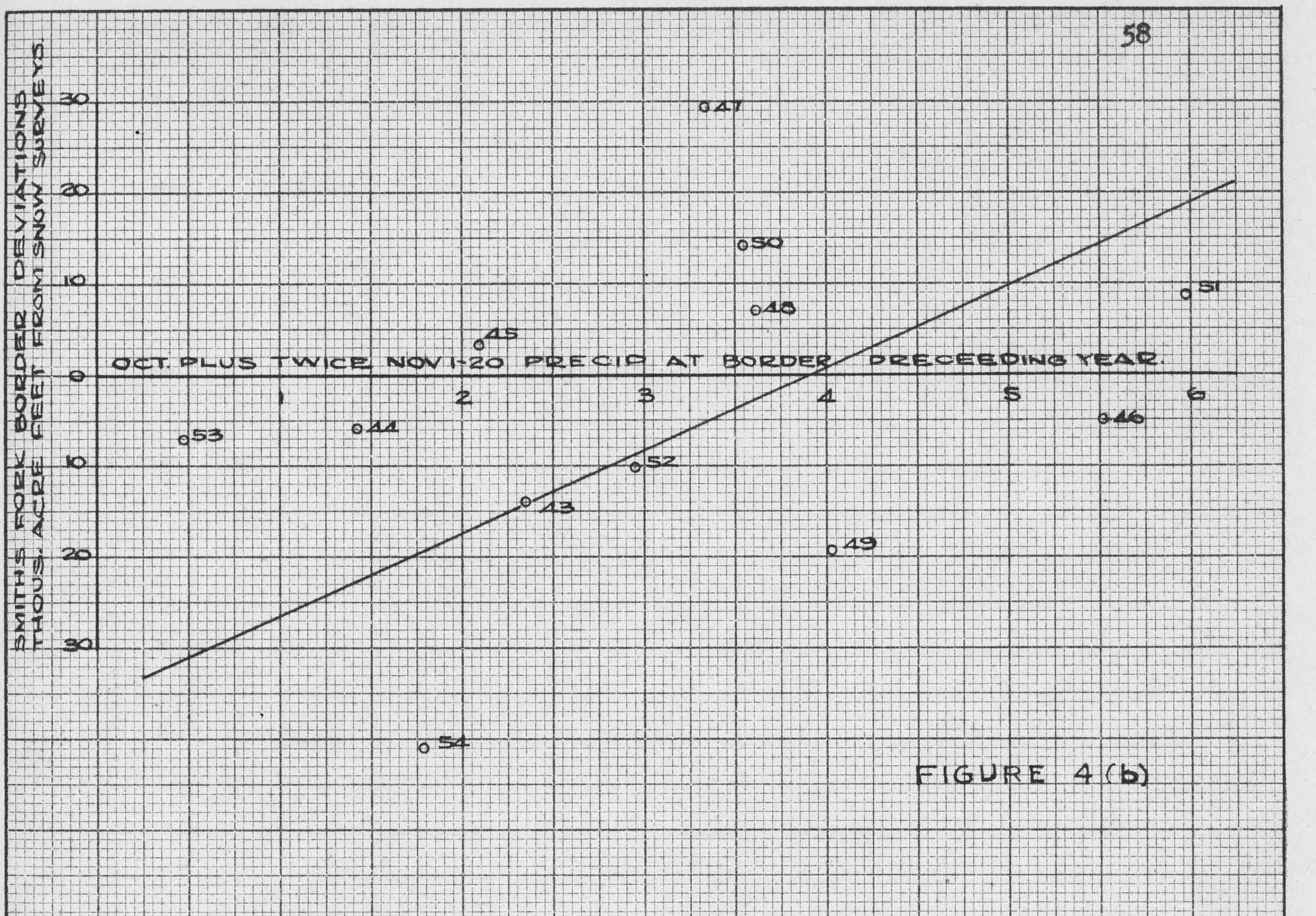

FIGURE 4 (b)

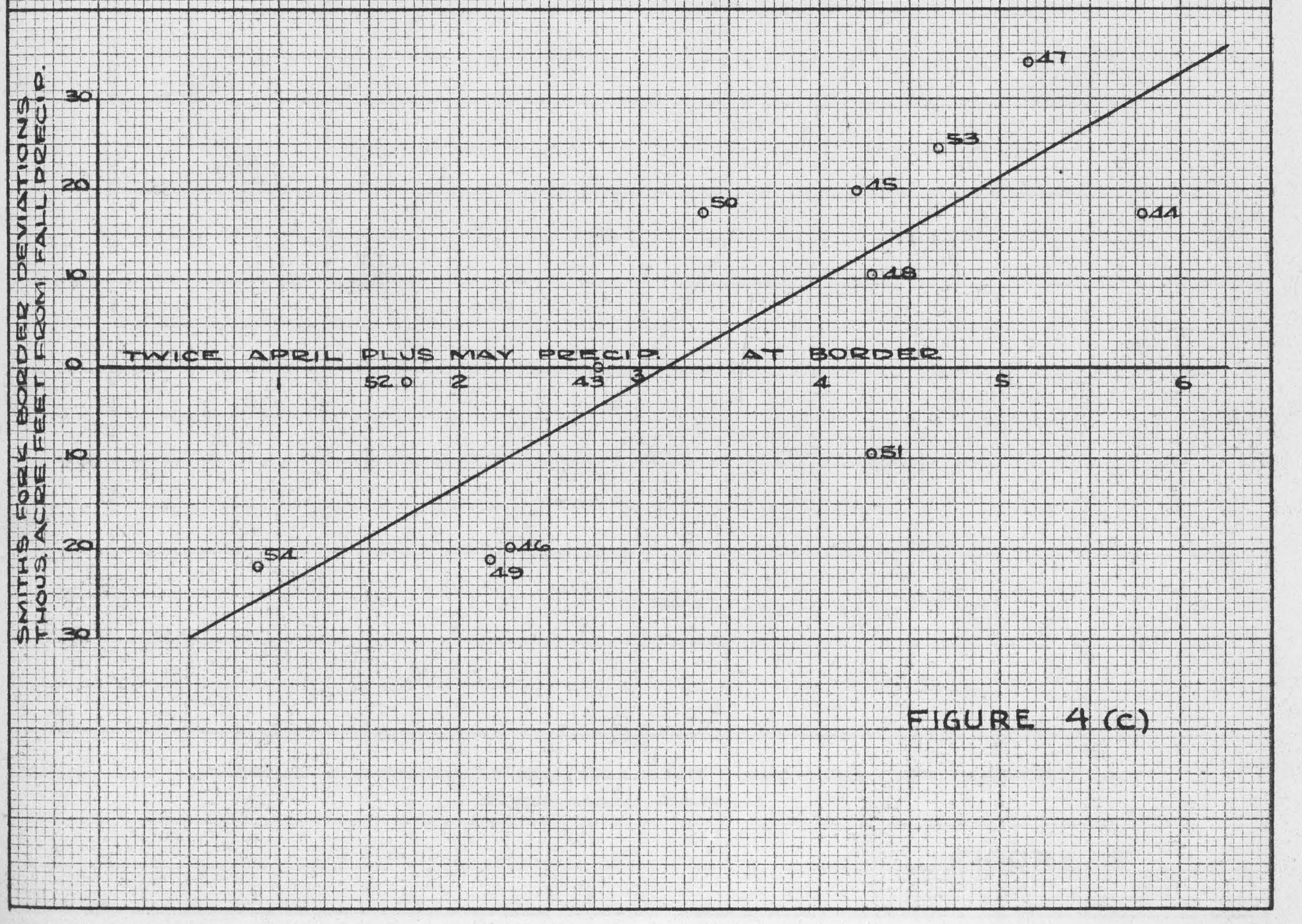

FIGURE 4 (c)

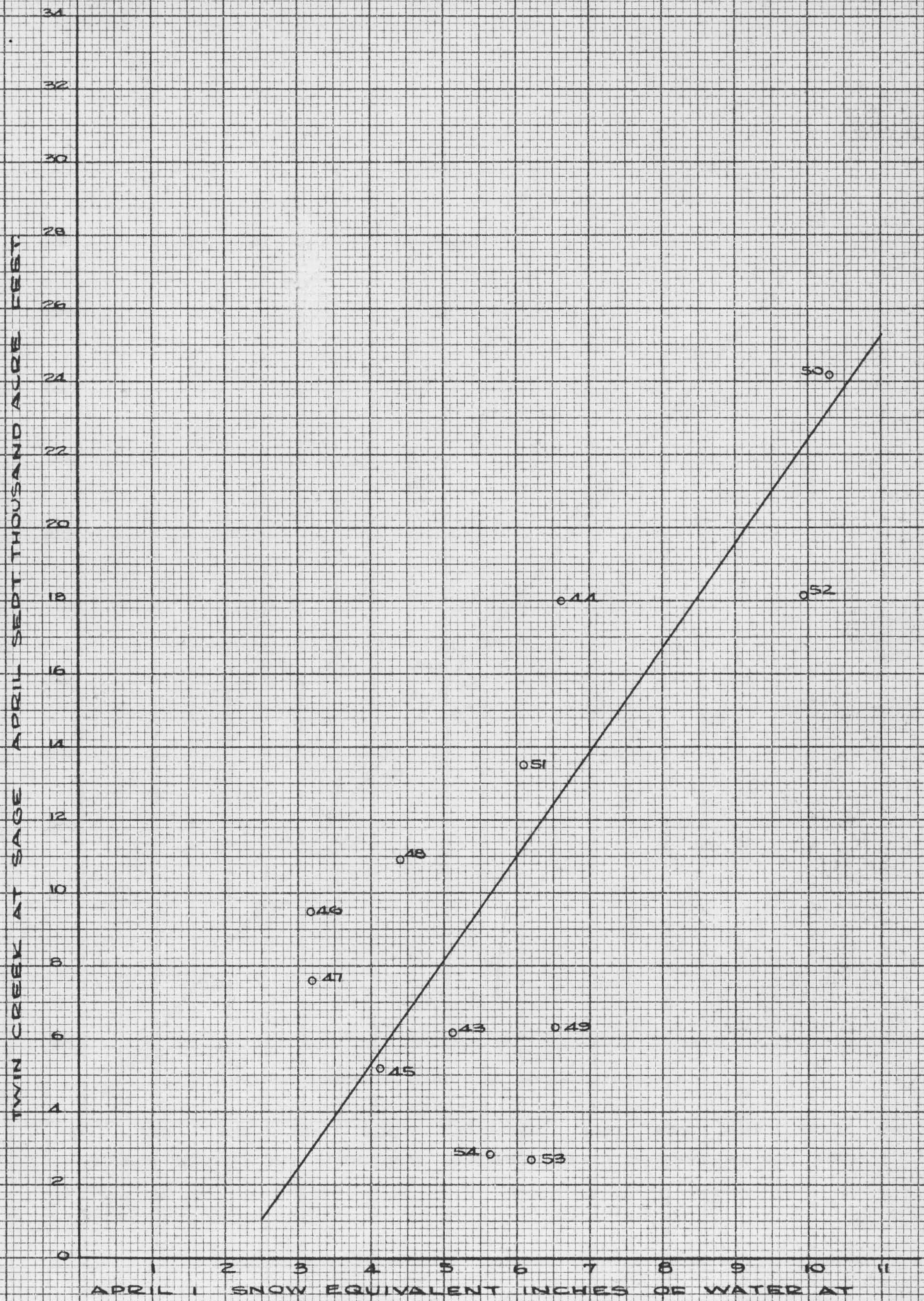
TWIN CREEK AT SAGE APRIL SEPT THOUSAND ACRE FEET
APRIL 1 SNOW EQUIVALENT INCHES OF WATER AT GOODMAN RANCH.
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
1
2
3
4
5
6
7
8
9
10
11
44
45
43
46
47
48
49
50
51
52
53
54

FIGURE 5

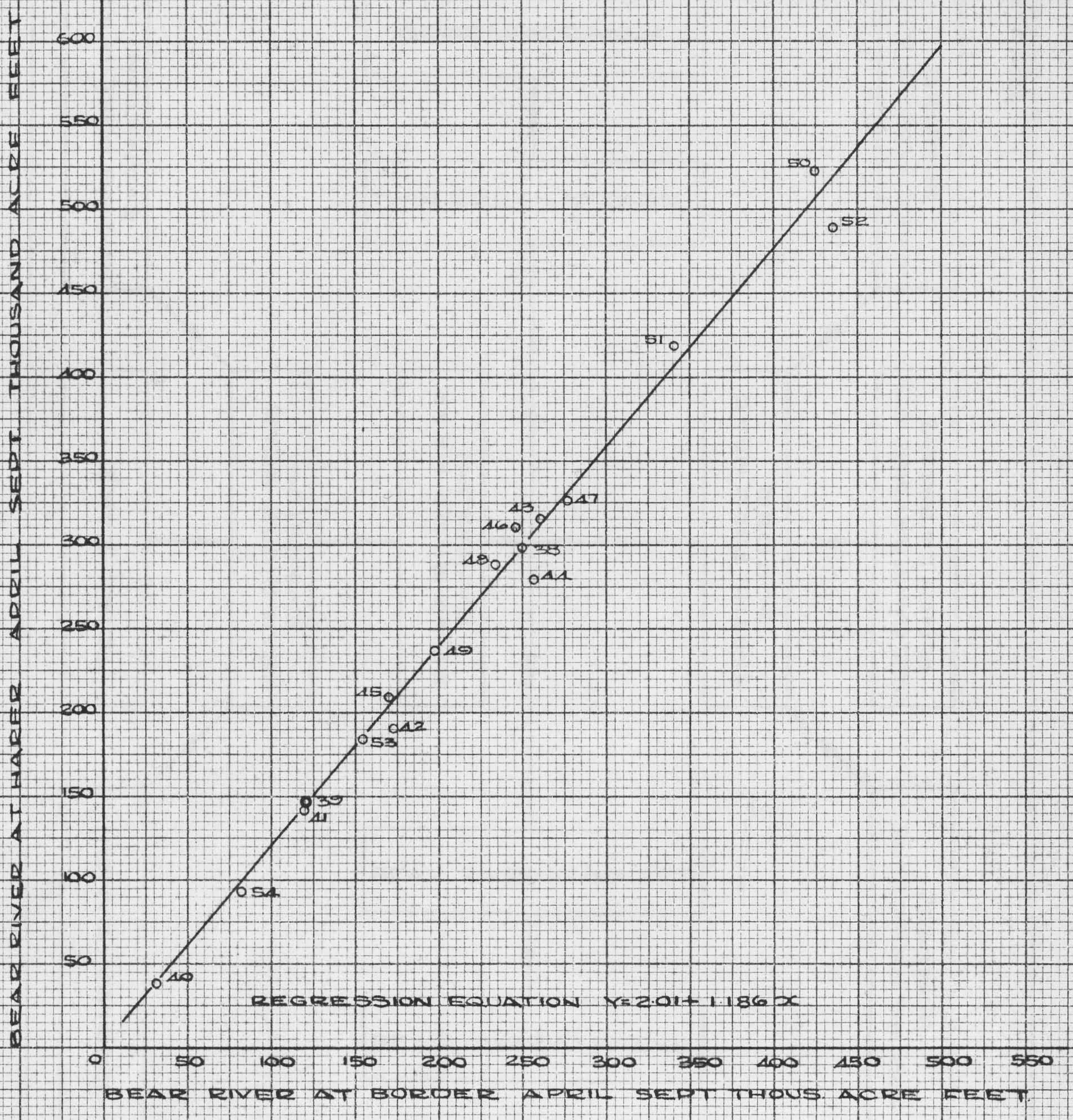
BEAR RIVER AT HARPER APRIL SEPT THOUSAND ACRE FEET
600
550
500
450
400
350
300
250
200
150
100
50
0
50
100
150
200
250
300
350
400
450
500
550
BEAR RIVER AT BORDER APRIL SEPT THOUS ACRE FEET
REGRESSION EQUATION Y=2.01+1.186X
50
52
51
47
43
46
33
48
44
49
45
42
53
39
41
54
40

FIGURE 6

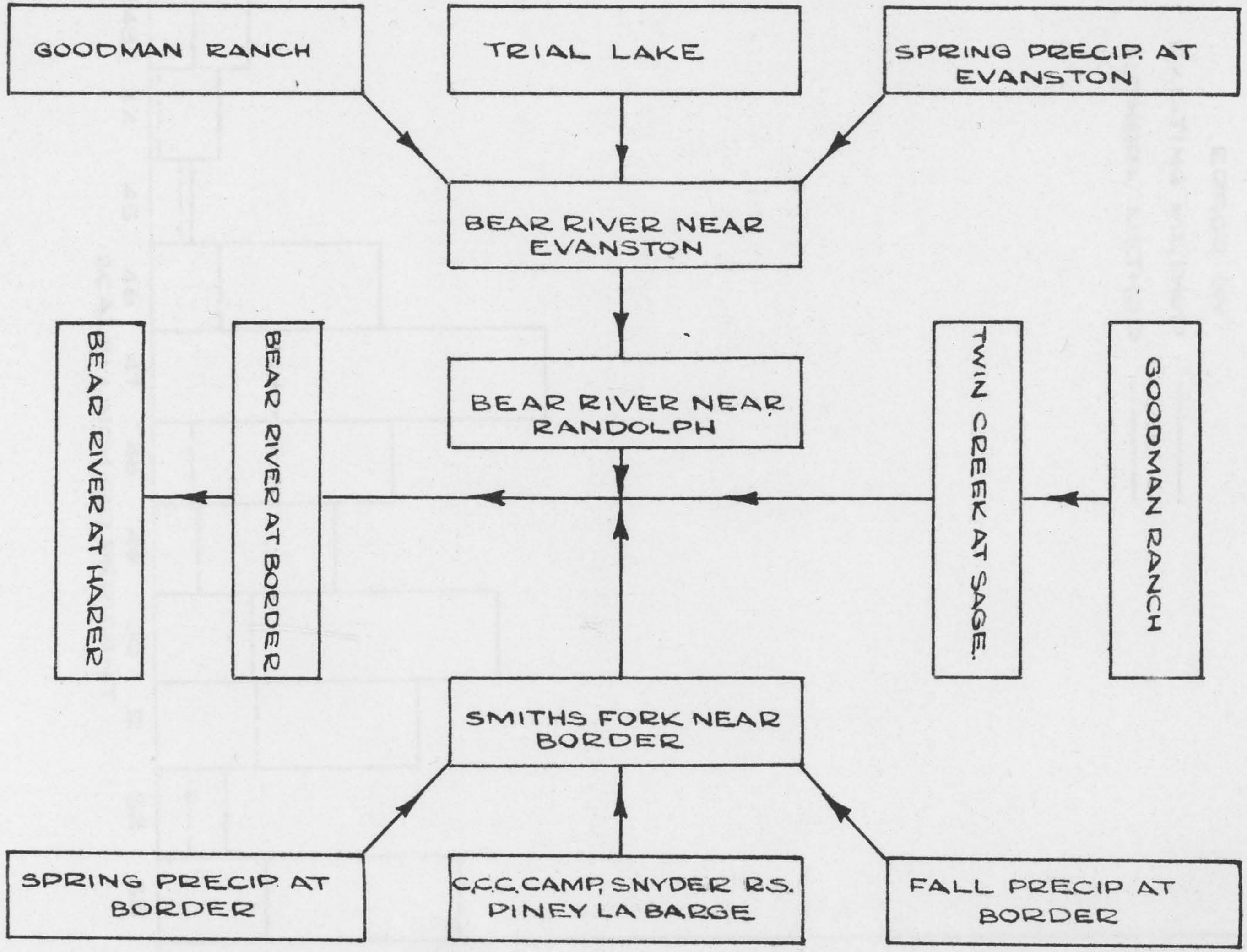
GOODMAN RANCH
TRIAL LAKE
SPRING PRECIP. AT EVANSTON
BEAR RIVER NEAR EVANSTON
BEAR RIVER NEAR RANDOLPH
BEAR RIVER AT HARER
BEAR RIVER AT BORDER
TWIN CREEK AT SAGE.
GOODMAN RANCH
SMITHS FORK NEAR BORDER
SPRING PRECIP. AT BORDER
C.C.C. CAMP, SNYDER R.S. PINEY LA BARGE
FALL PRECIP. AT BORDER

FIGURE 7

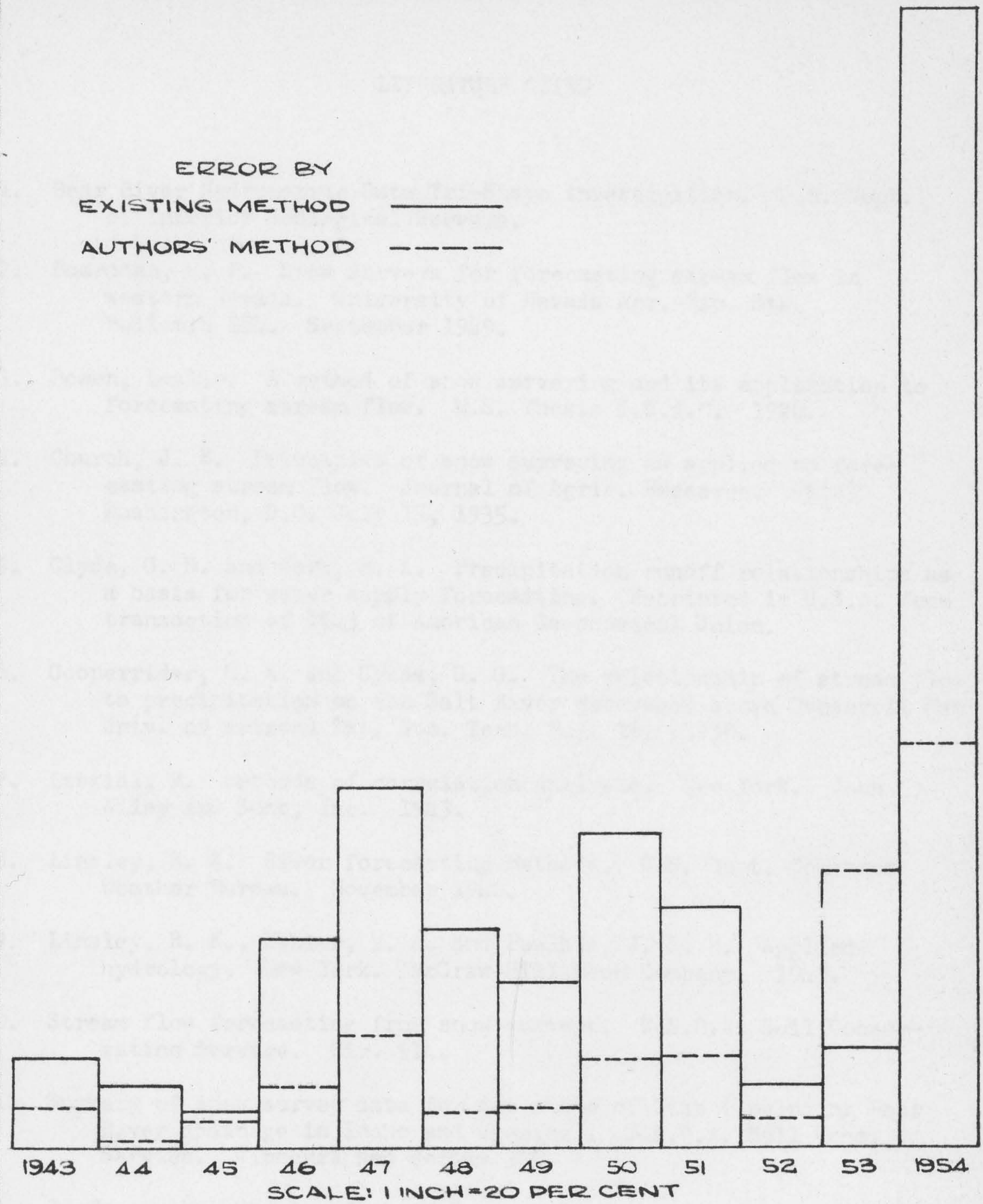

FIGURE 8

COMPARISON OF FORECAST ERROR

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