IMPROVING WATER SUPPLY FORECASTS BY LIMITING TECHNIQUES

By Donald W. Kuehl [1]

INTRODUCTION

To state the obvious, "Water Supply Forecasts are subject to errors." These errors are due to various causes among which are: (1) subsequent events of precipitation, melt conditions, and evapo-transpiration losses, (2) error inherent in the forecasting procedure due to inadequate sampling, (3) errors inherent in the measurement of the basic data and the dependent variable, and (4) errors due to the bias in the forecast relation caused by the basic inadequacy of the form and variables of the forecasting procedure. The methods proposed in this paper are intended to reduce the errors due to the last three of the causes listed above and then only in cases of the larger of these errors.

The methods discussed are intended to use basic data which are available at the time of forecast release but which are not used in the objective procedure to compute the basic forecast. The application of the methods is comparatively crude in that the probability of an event violating the limits of past occurrences are not analytically determined. Up to the present the application of the methods depends a great deal on the hydrologic judgment of the technician applying them. This paper will be limited to presenting the concepts for the information of other forecasters for their critical review. Further refinement of the methods will, of course, follow.

STREAMS WITH CARRYOVER

This first type of relationship is chosen because of its simplicity rather than because it is the most commonly used. Here, the flow of a stream prior to the forecast date is related to the flow during the forecast period. In Figure 1, Klamath Lake inflow was used as an example. October-March runoff is plotted as the abscissa and the April-September runoff as the ordinate. Of course, the latter is the desired forecast value.

At first glance, this relationship is only one step removed from a "shotgun" pattern. For example, for a given October-March runoff of 900,000 acre-feet the April-September flow has varied from about 400,000 to 1, 150,000 acre-feet.

In a base-flow stream the amount of runoff which will flow in any given period is dependent to some degree on the ground water condition existing at the beginning of the forecast period. That portion of the flow which originates from base flow is quite dependable and will occur almost without regard to subsequent conditions. A large part of the variance of the October-March runoff is related to the baseflow conditions. The remaining variance is due to winter runoff which is produced by winter precipitation at lower elevations. In turn, winter precipitation at higher elevations, as snow, explains much of the variance of the variance of the April-September runoff.

Therefore, we have reason to conclude that for a given October-March runoff there is a value of April-September runoff below which the probability of occurrence is very small. In the case of this particular basin we have drawn a line through the minimum points. With a period of record of 55 years, this line is relatively firm if we can assume the sample is homogenous.

This is a sample of a check relation. This effect can, of course, be built into an objective procedure with precipitation or snow explaining the variance above the minimum line.

To illustrate its use as a check relationship let us look at the published forecasts for two comparatively recent years, 1951 and 1958. On April 1, 1958, the October-March flow was 1,320,000 acre-feet and the published forecast (which was probably objectively derived) was 725,000 acre-feet. Plotting this point on our relationship, it fell, 100,000 acre-feet below our limit line.

Assuming no error in the measurement of the runoff in either of the two periods, the probability of this forecast materializing is extremely remote. At this point the forecaster is cautioned to examine the basic data used in the forecast procedure and to check the forecast procedure for any apparent bias which could cause a low forecast.

The subsequent runoff of course fell well above the limit line and 235,000 acre-feet above the objectively derived forecast. A modification of the forecast upward from 725,000 acre-feet to 820,000 acre-feet would have decreased the forecast error by 100,000 acre-feet, a reduction of one-third.

The modification of the forecast to the limit line, of course, is very likely to verify; the probability increases as we go somewhat above the limit line. However, when we consider the nature of this plot as a check relationship we feel we are not justified in modifying the forecast beyond the limit line without additional analysis.

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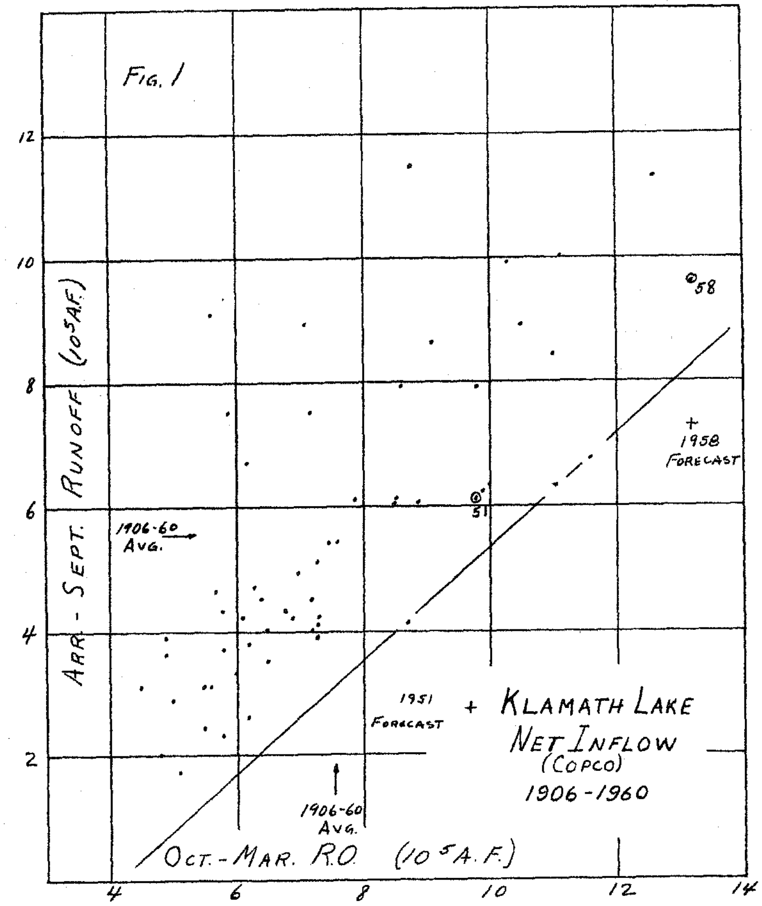
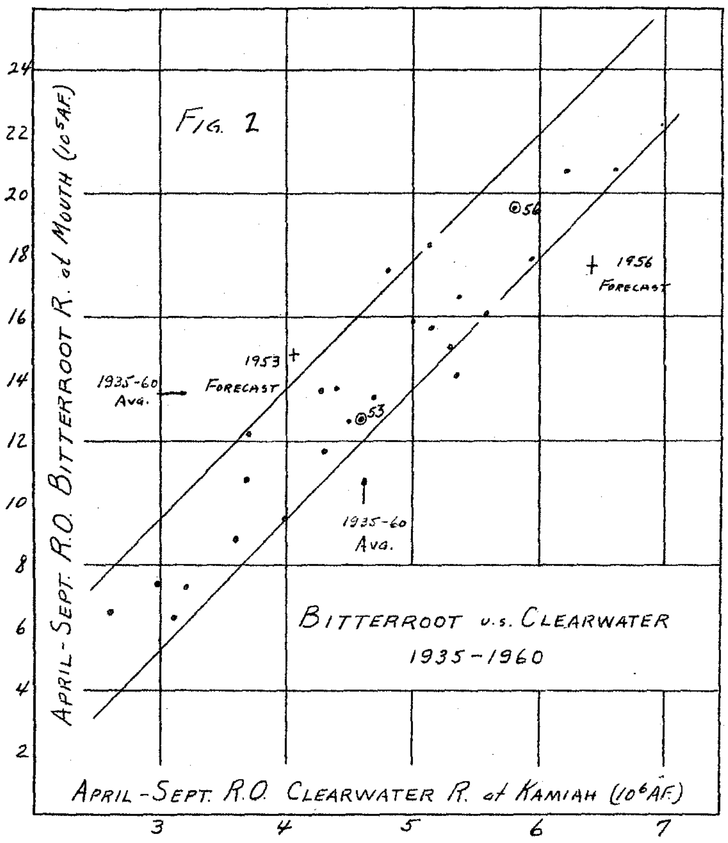
Fig. 1



12
10
8
6
4
2
Apr. - Sept. Runoff (10⁵A.F.)
⊙58
+ 1958 Forecast
⊙ 51
1906-60 Avg.
1951 Forecast
+ Klamath Lake
Net Inflow
(Copco)
1906-1960
1906-60 Avg.
Oct.-Mar. R.O. (10⁵A.F.)
4
6
8
10
12
14

Fig. 2



24
22
20
18
16
14
12
10
8
6
4
2
April-Sept. R.O. Bitterroot R. at Mouth (10⁵A.F.)
⊙56
+ 1956 Forecast
1953 + Forecast
1935-60 Avg.
⊙53
1935-60 Avg.
Bitterroot v.s. Clearwater
1935-1960
April-Sept. R.O. Clearwater R. at Kamiah (10⁶A.F.)
3
4
5
6
7

In 1951, the objectively derived forecast on April 1 was 261,000 acre-feet after 977,000 acre-feet had been observed in the October-March period. In other words the forecast procedure was calling for an event which violated our limit line by over 200,000 acre-feet; obviously something was wrong. A modification of the forecast from 261,000 acre-feet to 510,000 acre-feet again would be a conservative adjustment and would decrease the error by 249,000 acre-feet.

ADJACENT BASIN PLOTS

The second type of limiting relationships which can assist in reducing the forecast errors by pointing the forecaster's attention to the occasional potentially "large error" forecast is an adjacent basin plot. In Figure 2 the April-September runoff of the ClearwaterRiver at Damiah, Idaho is related to the runoff for the same period for the Bitterroot River at Mou h, Montana. The relative position and size of these two basins can be seem in Figure 3.

As was the case with the baseflow relationship, this plot must have a hydrologically sound basis before we can hope to improve our forecasting. Spurious or fallacious relationships can produce good-looking plots and high correlation coefficients but result in poor forecasts.

We need not look far for the hydrologic reasons for the validity of the relationship between the Clearwater and Bitterroot runoff; the basins share a long common divide which is perpendicular to the normal winter storm path. During the snow accumulation season the storms which deposit precipitation on the Clearwater Basin generally continue to the east-northeast and deposit proportionate amounts of precipitation on the Bitterroot drainage.

Therefore, we can conclude that the causes of the runoff in each basin are not isolated random events. On this basis we can be sure that there exists limit lines beyond which the probability of occurrence is relatively small. However, in this case, the period of record is only 26 years and we cannot draw the limit lines with the same degree of assurance that we could in the case of the 55 years of record in the Klamath Lake Basin. You can see that the points on the plot form a reasonable distribution.

The limit lines have been drawn to envelope all but two points. This was done to illustrate that we feel that the limit lines should not be drawn or considered to be limits beyond which the probability of occurrence is zero. The main purpose of this type of plot is to call the attention of the hydrologist to the forecasts which must be analyzed more carefully for possible cause of extreme error prior to release.

Two recent forecasts issued on April 1, 1953, and 1956, are plotted on the relationship by a "+". Such forecasts very rarely verify. The observed runoff is shown by a circled dot.

A second example of adjacent basin plots shows the relationship of the April-September runoff for the Kootenai River at Leonia, Idaho and Flathead River at Columbia Falls, Montana in Figure 4. The drainage areas of these two basins are shown in Figure 3.

The two basins share a minimum of common divide and therefore our hydrologic justification is not as direct as in the case of the Clearwater-Bitterroot basins. In this case, the two basins have adjacent portions of the Continental Divide for their eastern boundary. The winter storms which deposit the majority of the winter precipitation are widespread and cover large areas of both basins. To partially compensate for the less direct cause and effect relationship we have a longer period of record, i.e., 33 years.

Again two examples of recent forecasts are indicated by a "+". In both of these cases the forecaster would have been warned to take a second look at the forecasts. The observed data later proved the warning to be valid.

One word of caution on the length of record. Large samples are desirable in order that the probabilities of violating the limits are small. However, the forecaster must be sure that he is dealing with a homogenous sample. Double-mass plotting techniques will determine readily whether there is any large time trend or inconsistencies in the record. Possible non-reversible causes of a non-homogenous record could be (1) man-made causes such as increased irrigation above the station, and (2) change in runoff measuring techniques or measuring point.

AUXILIARY PROCEDURES

The third technique for recognizing whether forecasts are reasonable in light of all the data available involves comparing the forecast from one objective procedure with the limits of error of another objective procedure for the same basin. Figure 5 shows two forecast procedures for forecasting the April-September runoff of the Boise River near Boise, Idaho; (5a) based entirely on precipitation and (5b) based on water equivalent measurements.

The envelope lines again are drawn, not as being absolute limits, but to include most of the points. Therefore, we must remember that there is a slight but distinct probability of a point falling outside the limits. This, however, should not alarm us because forecasting is a method of playing probabilities and if both of these procedures are basically sound procedures the probability of a point falling outside is so small that we do not want to issue a forecast which violates these limits.

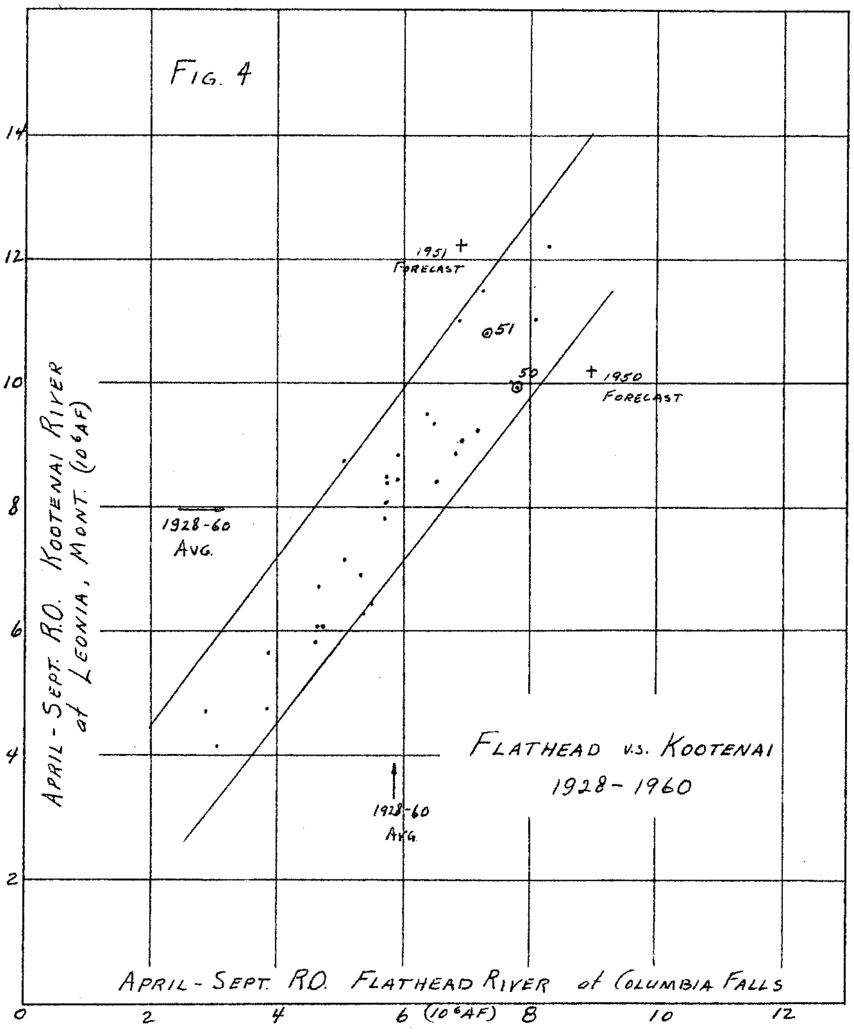


Fig. 4
Flathead v.s. Kootenai
1928 - 1960
April - Sept. R.O. Kootenai River at Leonia, Mont. (10⁶AF)
April - Sept. R.O. Flathead River at Columbia Falls
(10⁶AF)
0
2
4
6
8
10
12
14
1951 +
Forecast
⊙51
50
+ 1950
Forecast
1928-60
Avg.
1928-60
Avg.

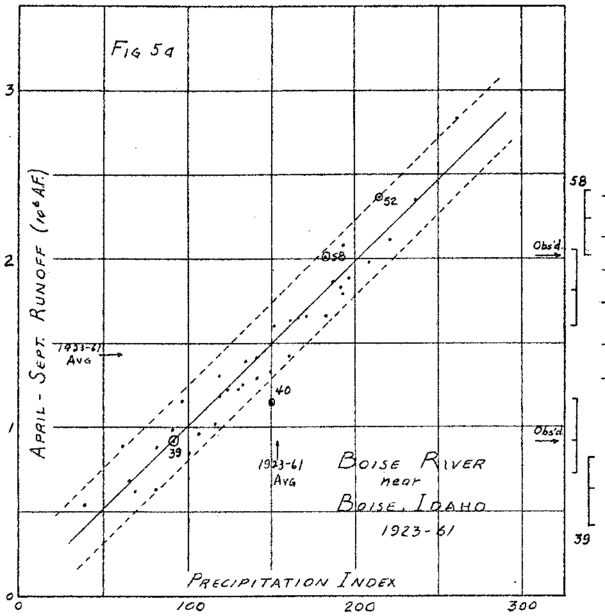


Fig 5a
April - Sept. Runoff (10⁶A.F.)
Precipitation Index
0
100
200
300
1
2
3
⊙52
⊙58
40
39
1923-61
Avg
1923-61
Avg
Boise River
near
Boise, Idaho
1923-61
Obs'd.
Obs'd.
58
39

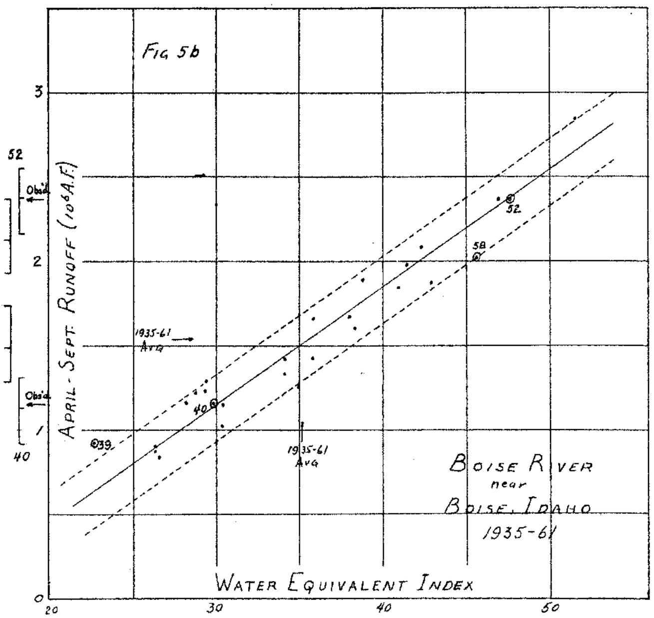


Fig 5b
April - Sept. Runoff (10⁶A.F.)
Water Equivalent Index
20
30
40
50
0
1
2
3
52
Obs'd.
Obs'd.
40
1935-61
Avg
1935-61
Avg
52
58
40
⊙39
Boise River
near
Boise, Idaho
1935-61

The suggested method of analysis of prepared objective forecasts is illustrated for four years -- 1939, 1940, 1952 and 1958. The forecasts and the upper and lower "limit" values are given below:

Year		Precipitation (10^5AF)	Water Equivalent (10^5AF)
1952	Forecast	2120	2380
	Lower/Upper	1930/2360	2150/2550
1958	Forecast	1830	2230
	Lower/Upper	1600/2060	2020/2420
1940	Forecast	1500	1130
	Lower/Upper	1390/1740	920/1320
1939	Forecast	920	640
	Lower/Upper	730/1170	420/820

The above table is presented visually on Figure 5 between the two plots. The forecast for 1952 can be analyzed in a manner such as this: The water equivalent forecast falls just outside the upper limit of the precipitation forecast range, while the precipitation forecast falls below the lower limit of the water equivalent forecast by an equal amount. We might conclude that both forecasts are within reason but that there is a greater probability of the precipitation forecast being low and the water equivalent forecast being high rather than the reverse.

Considering the dependability of the location of the limit lines, there is little reason to change either forecast. In other words, if we have no information from adjacent basin plots or carryover relationships, or any reason to question either the water equivalent or precipitation observations, we should let the basic forecast be issued as computed. The observed runoff showed the wisdom of this conclusion as it violated neither set of limit lines.

Our other sample forecasts are for the years 1958, 1940 and 1939. Here none of the forecasts are near the limit of the other; in fact, in 1958 and 1940 the upper limit of one and the lower limit of the other are practically the same. There is still a slight possibility of the observed points falling within the limit lines of each plot (as it did in 1958 but failed in 1940 and 1939). These three forecast situations illustrate the dilemma of the forecaster; he must decide, (1) which forecast is most likely to be correct, or (2) if both are approximately equal in error.

The analysis would include critical examination of the precipitation data to determine whether any station had extreme quantities as compared to the rest so as to be questionable or not representative. Similar analysis of the water equivalent data might reveal an unusual depth-elevation distribution or questionable or unrepresentative observations. Adjacent basin plots and carryover relationships may supply a hint as to which course to follow. As I warned early in the paper, no objective method is suggested; the forecaster must depend on hydrologic judgment to a great degree.

In a way, the Boise Basin is a poor example because the two procedures are of comparable accuracy. In other basins where either water equivalent or precipitation data is limited or nonrepresentative, one forecast procedure will be considerable more dependable than the other. In this case, the limiting techniques are much more useful. Even then the limits of the poorer relation should not be violated unless there are unusual occurrences which are not indexed in the procedures. Such unusual occurrences might be:

Dry soil mantle under snowpack;

Unusual depth-elevation distribution of snow;

Unusually late beginning of snow accumulation;

Very localized storms covering only a portion of the basin;

Extreme observed values of one element of basic data;

Unusually early melt prior to forecast data.

Figure 6 shows the case of adjacent plots for three basins. The clearwater Basin against the Bitterroot Basin, and the Bitterroot against the Clark Fork Basin. As an example of the use of these plots, the year 1946 (plotted with a "+") is chosen as a very extreme example. The Kamiah objective forecast plotted high and the Bitterroot forecast plotted low.

From the right plot we can conclude that the forecast for the Clark Fork and the Bitterroot basins are not in violation of our plot. However, the left plot forces us to look critically at the relative forecasts for the Clearwater and Bitterroot basins.

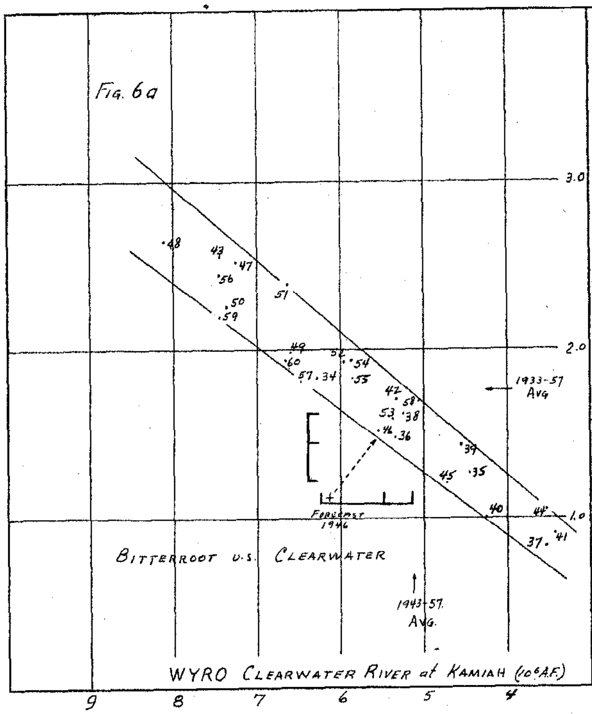


Fig. 6a

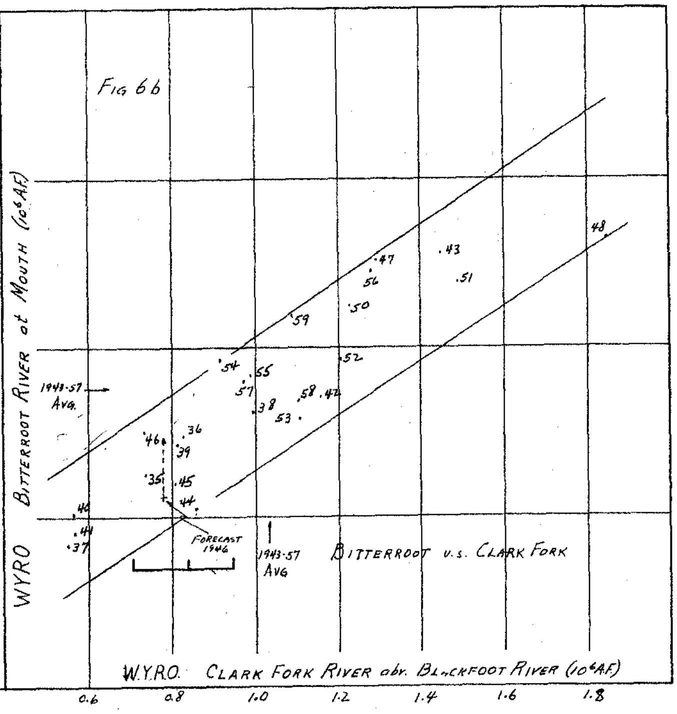


Fig 6b

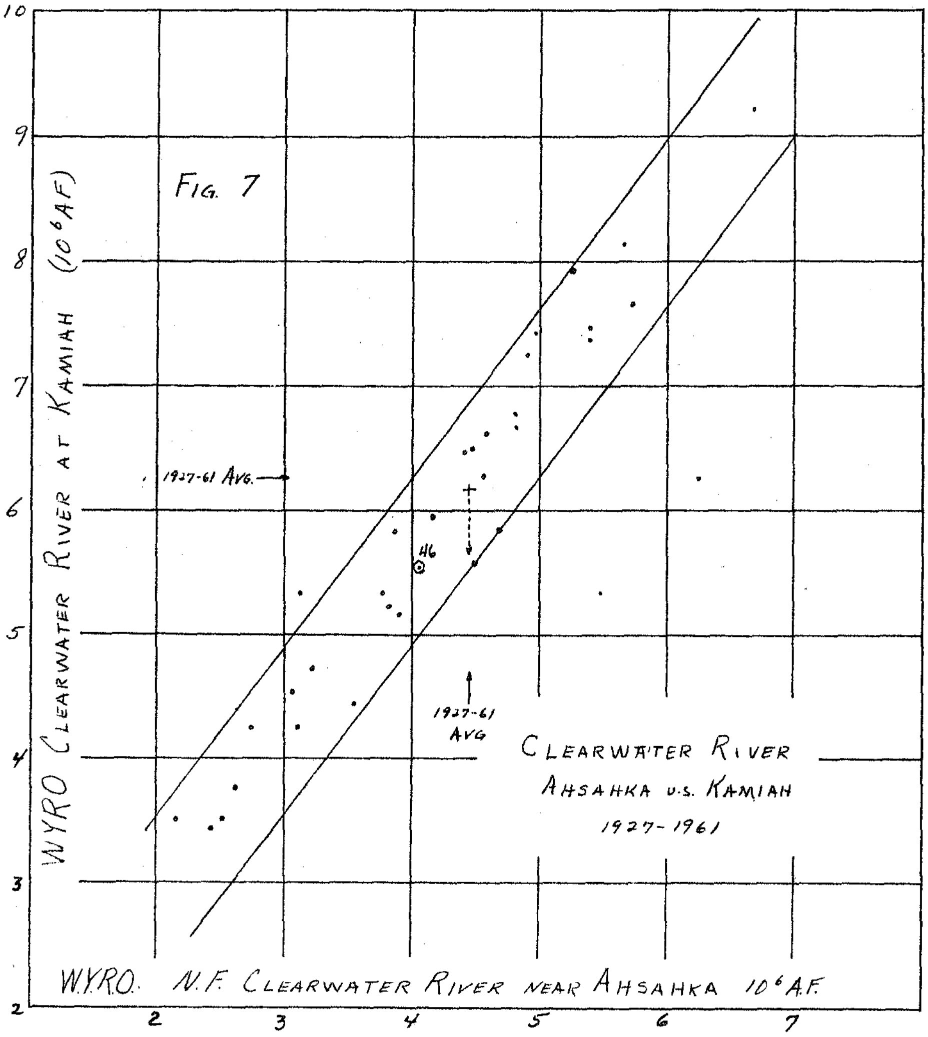


Fig. 7

A modification of these two forecasts as indicated by the dashed lines would bring all forecasts within the limit lines. However, can we justify such modifications?

As we discussed in Figure 5, we have a choice of making the entire adjustment (1) in the Clearwater forecast, (2) the Bitterroot forecast, or, (3) adjusting both forecasts. Comparison of the basic objective forecast relations showed that both relations are of comparable accuracy, therefore we are not justified on this basis in questioning one forecast more than the other and ought to modify each forecast in general proportion to their variance or range.

Auxiliary procedure forecasts for the Clearwater and Blackfoot are shown by the horizontal brackets and for the Bitterroot by the vertical bracket. These forecast limits indicate the advisability of modifying the basic forecast as shown by the dashed line.

Now -- how about the Clark Fork-Bitterroot plot? Is the modification within reason? The dashed line on the right hand plot indicates that it is acceptable. An auxiliary forecast procedure for the Clark Fork and an adjacent basin plot with the Blackfoot Basin forecast indicates that no modification is indicated. If we check Kamiah with its next adjacent basin plot (Kamiah-Ahsahka, not shown), our adjustment is within the limits.

When starting the discussion of the year 1946, it was stated that it is an extreme year, however, quite within the realm of possibility. Most forecast procedures have adjusted standard errors at the mean in the order of 10 percent of the average flow. This means that in isolated cases errors of 15 to 20 percent will occur with all data available. On April 1, forecast errors of this magnitude occur more frequently. The 1946 forecast was 9.6 percent in error.

The above process is quite involved to go through for every forecast point, but the number of cases where a set of forecasts fail the quick test of an adjacent basin plot are few and the need for adjustment occurs in only a very small number of cases. As stated in the introduction, these techniques are intended to be used to modify only the large forecast errors. I do not believe small modifications can be justified. Probably one cardinal rule to follow should be "Keep the modification of forecast down to a *minimum*".

Now, the question that probably occurs to all of you is, Can these techniques, in the hands of experienced hydrologists, actually reduce forecast errors?". From our experience over the last ten years of forecasting in the River Forecast Center, we believe they have. A study of 14 basins in which the adjustments were applied most frequently shows that the modifications improved the forecast in 71 percent of the cases and hurt the forecasts in 29 percent. In 26 percent of the cases the improvement exceeded 10 percent and in only 5 percent of the cases were forecasts hurt more than 10 percent.

Because of the influence of the hydrologic event after any given forecast date, it is not always possible to determine objectively whether any single modification was the correct one at the time or not. Remember all forecasts have built into them a real or implied assumption of median or average conditions subsequent to the forecast date. Should the subsequent precipitation deviate from median in a direction opposite to the direction of a modification a conclusion that the modification was wrong is not justified. Therefore, we must base our conclusions as to the success of these methods on the average results of a large number of adjustments over a long period of years.

SUMMARY

The use of carry-over relationships, adjacent basin plots, and auxiliary forecast procedures will enable to the forecaster to recognize forecasts which have a potentially large error. In the hands of experienced hydrologists, these techniques make it possible to make subjective modification of forecasts prior to release. The techniques spot potentially large errors only and should not be used to make small minor adjustments within the limit lines.