SNOW PACK EVAPORATION [1]

By George W. Peak [2]

During the period that snow surveys have been made on the North Platte Basin there have been interesting and notable variations in the amount of streamflow obtained from a given snowpack. The addition of a soil moisture index and late spring precipitation during the snowmelt runoff did not disclose the reason for the wide variations. There were other influencing factors measured, or unmeasured, that were still not recognized.

In order to obtain comparable results from year to year, a snow course is placed in an area that will provide quiet, even depths of snow. Proper location will eliminate snow survey errors due to windslabbing and scouring, excessive exposure to the sun, forest canopy interception, or foreign ponded water.[3] Most snow courses are located on north slopes with sufficient soil drainage and with adequate forest protection from wind action.

The snow melt-stream flow analyst has generally assumed that the rate of evaporation from snow on the watershed was identical with that on the snow course and, therefore, need not be considered. In this area, temperatures, solar radiation, vapor pressure, and wind movement are the major facts determining the rate of evaporation from the snow. With one exception, these evaporational factors are probably applied equally to the snow course and the basin snowpack. The exception is wind movement.

If the weather is stormy the snow surveyor avoids the wind-swept parks and open ridges; for travel and for the bivouac, he seeks the quiet serenity of the winter woods. He is fully aware that the exposed areas of the watershed are subjected to wide variations in wind velocities. His snow course, therefore, is located deep in the forest where wind movement, at the snow level, may be considered consistently gentle.

Wind movement does not cause evaporation, but it is an important agent in determining the rate at which evaporation may occur. It is believed, the effects of wind on an exposed mountain snow pack are much the same as on a large body of water. When conditions are conducive to rapid evaporation, a saturated blanket of air quickly occurs, unless turbulent wind movement replaces the layer of moist air adjacent to the water, --or the surface of the snow.

Wind action over a large body of water creates waves which, in turn, increase the area exposed to evaporation. If the wind is strong enough, particles of free water are picked up--increasing still further the exposed area of water.[4]

High on the watershed, the snow surveyor often encounters the ground blizzard and tedious finger-drifts crossing the trail. He avoids the lee side of the ridge with its plumed cornice and deadly slab, and on clear days he sees tremendous snow banners trailing from wintry peaks. This vast movement of free snow particles and the formations, or "waves", left in the snow surface increases the exposed area of snow and indicates that the opportunity for evaporation from the snowpack increases with the velocity of the winter winds.

Since the snow course has deliberately been placed so that it is shielded from the wind, there is a strong probability that the measured storage on the snow course is not always accurately indicative of snow pack storage over the watershed. The difference between true watershed storage and the snow survey index may, in some years, substantially alter the water supply outlook. For example, the May 1, 1959, snow survey data and soil moisture indicated 110 percent of normal runoff at Northgate, Colorado. Through use of a wind correction parameter, this was reduced to 78 percent. Similarly, the Encampment River snow courses indicated runoff at 80 percent of normal. The wind parameter indicated a reduction to 59 percent of average. Subsequently, these large corrections proved to be correct. It is notable that winter wind for this watershed, in total miles, was second highest of any in the preceeding 23 years.

The following illustrations are of a graphical correlation showing the development of a forecast procedure to include an evaporation index.

Plate 1 shows the relationship between total precipitation and the ASROM (April-September runoff in thousands acre feet) for the North Platte River at Saratoga, Wyoming. The precipitation index includes the snow course water content as of April 1, plus the precipitation for April, or the April increase to the snow course, whichever is maximum. To the resultant May 1, water content index, was added the number of inches of soil moisture under the snow, and the number of inches of precipitation through June. These factors cover the major precipitation values indicative

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[1] Presented at the American Geophysical Union, Washington, D. C., April 27, 1960, and Western Snow Conference, Cheyenne, Wyoming, April 16, 1962.

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[3] Codd, A. R., and Work, R. A., "Establishing Snow Survey Network and Snow Courses for Water Supply Forecasting". Proceedings, 23rd Annual meeting, Western Snow Conference, 1955.

[4] Foster, H. Alden, "Rainfall and Runoff", pp. 266-278.

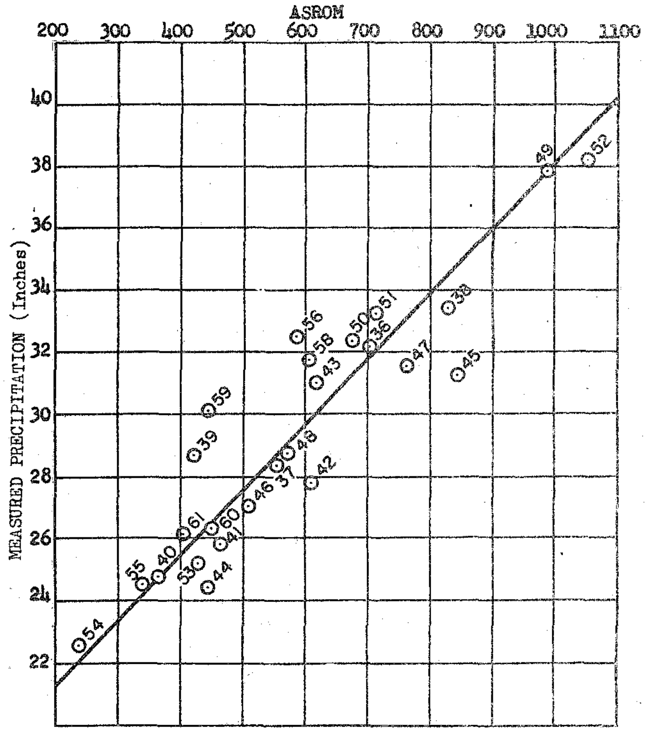

PLATE 1 "MEASURED PRECIPITATION", in inches, includes the May 1, water content of the basin snow courses plus the mountain soil moisture in inches plus May and June precipitation. The "ASROM" indicates the April to September runoff in thousands of acre-feet for the North Platte River at Saratoga, Wyoming.

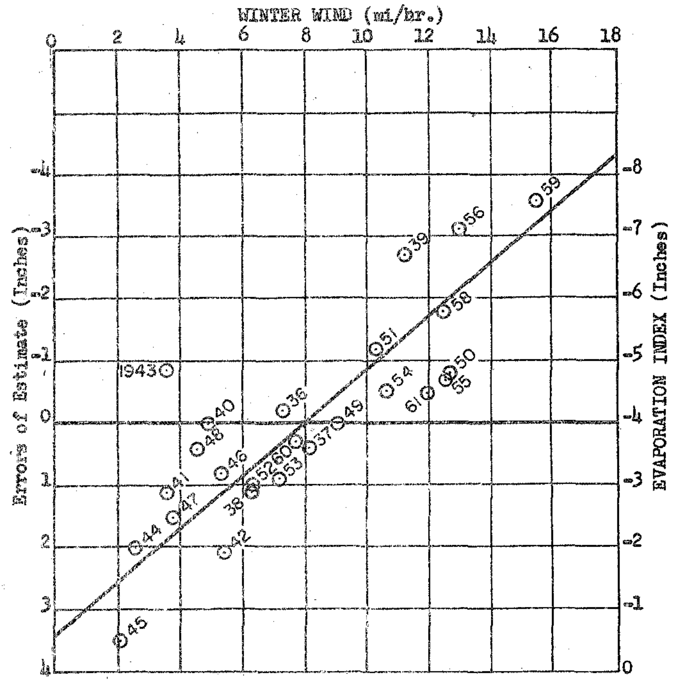

PLATE 2 The "Measured Precipitation" errors, plus and minus, are taken from Plate 1 and plotted against "Winter Wind". Cheyenne anemometer data includes monthly averages weighted as follows: November minus 11.0 plus (December minus 11.0) /2 + (March minus 11.0) /4 plus April minus 11.0.

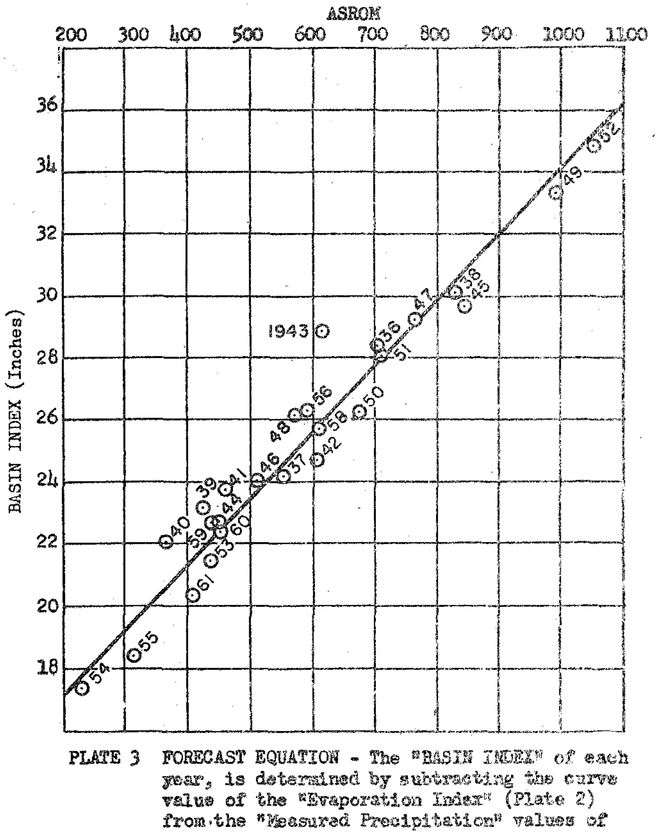

PLATE 3 FORECAST EQUATION - The "BASIN INDEX" of each year, is determined by subtracting the curve value of the "Evaporation Index" (Plate 2) from the "Measured Precipitation" values of Plate 1.

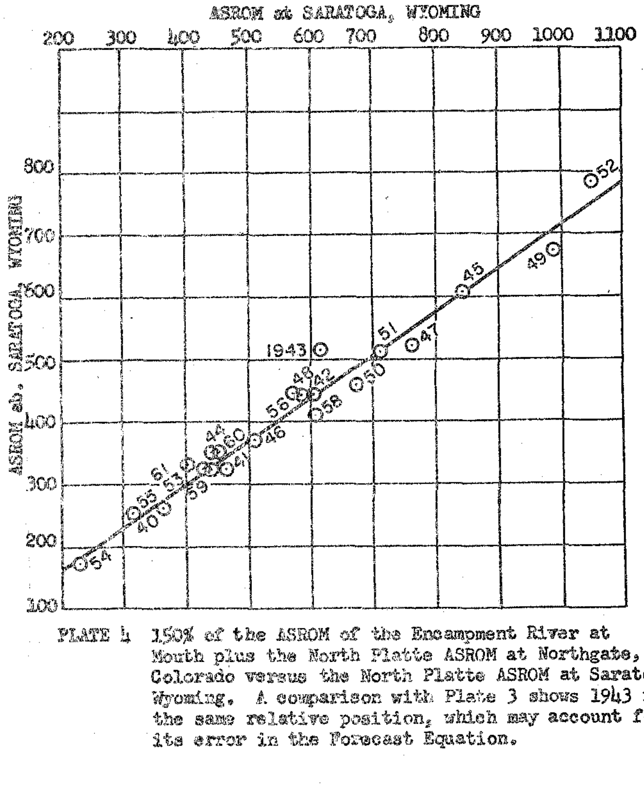

PLATE 4 150% of the ASROM of the Encampment River at Mouth plus the North Platte ASROM at Northgate, Colorado versus the North Platte ASROM at Saratog Wyoming. A comparison with Plate 3 shows 1943 i the same relative position, which may account fo its error in the Forecast Equation.

of snow melt runoff. Weights were assigned to the data by an analysis involving the relative location of snow courses on the watershed.

This is the most accurate precipitation versus runoff relationship that could be obtained. The poor correlation, about 0.7 indicates the need for greater forecast dependability required by municipalities, irrigation and power interests on this stream.

Plate 2. Graphical analyses indicated that wind velocities carried the greatest influence during November and April; were of 50 percent value during December; 25 percent in March, and were of least importance during January and February. These weights also parallel the air temperature—evaporation loops of Rocky Mountain, lake and reservoir evaporation pans.

From inspection the minimum limiting velocity for the Cheyenne Data appeared to be eleven miles per hour, therefore, average monthly wind velocities of eleven and under are considered to be zero.

This weighing system was applied to winter wind data of the Cheyenne anemometer, and each index of wind movement was plotted against the errors of estimate from Plate 1. A definite relationship was established and the mean curve plotted in order to convert winter wind velocities to the Evaporation Index shown on the right. 1957 is not shown as precipitation throughout the summer was so heavy, the snow-melt--runoff relationship was obscured. A possible explanation for the error in 1943, is presented in Plate 4.

To indicate that the North Platte Basin is not an isolated example, we have included graphical analyses of other watersheds in Wyoming that are also subjected to heavy evaporation losses. Each series will consist of three plates. The first will consist of a measured precipitation index versus ASROM. The second will consist of (1) the errors of estimate from the first plate versus the winter wind, and (2) the mean curve and the evaporation index. The third plate, in each series, is derived by subtracting the evaporation indices shown on the second plate, from the measured precipitation values shown on the first plate.

Analyses of published anemometer data in Colorado, Utah, Idaho, Montana, South Dakota and Wyoming indicated that the Cheyenne anemometer produced the only data applicable to high elevation evaporation. It was necessary to substitute Winds Aloft data. The accuracy of the Cheyenne anemometer appears to be due to its close relationship to Cheyenne Winds Aloft data, up to and including the 700 millibar. This anemometer also bears a close relationship to the laminar flow of the Rapid City 800, 750 and 700 millibar data, but there is no correlation with the comparatively turbulent data registered by the Rapid City anemometer. The anemometers of surrounding states have average velocities of less than eleven miles per hour per month, they are poorly related to winds aloft of the same station, and are, therefore, not indicative of mountain wind velocities.

Beginning with Plate 8, winter wind is obtained from the 750 millibar wind velocities at Boise, Idaho, and the 700 millibar data at Lander, Wyoming.

In each example, the daily data for each month were revised from meters per second and knots per hour, to miles per hour per month, and weighed as follows: 100 percent of November plus 50 percent of December plus 50 percent of March plus 100 percent of April. The total is divided by three in order to provide an average velocity for the winter comparable to the separate months. This method and terminology were adapted, principally, for use at water supply outlook meetings throughout the state.

The Little Popo Agie watershed near Lander, Wyoming, with a southern, high elevation exposure, was provided an excellent evaporation index by the 700 millibar wind at Lander. Moving up the Wind River Basin to the north, the Lander 700 millibar data provides a fair evaporation index for the snowmelt runoff of the North Popo Agie near Milford, Wyoming. Still further north, Bull Lake Creek indicated a poor relationship with monthly, winter wind values and the Wind River Basin correlation about DuBois reflected no snow pack evaporation. Coupled with this, the reader may find some interest in the information that the Wind River Range extends North 45° West, and the average direction of the Lander 700 millibar wind is 270 degrees.

Although winds aloft records were obtained for Billings, Montana and Sheridan, Wyoming, they have been, surprisingly, of no value to the Big Horn Mountains. Lander wind, apparently, zeros straight into the Big Horn watersheds that open to the southwest. So far, nothing has been found to correlate with the flows on the east and northeast flanks. Casper wind may eventually prove to be indicative of losses on Big Horn Watersheds opening to the southeast.

Each year the forecaster is plagued with the same old problems of the division between fall precipitation and snow pack accumulation. With reference to the North Platte, it was assumed, in the spring of 1960, that a substantial, high elevation snow pack existed throught November and December of 1959. Winter wind during these late fall months had been exceptionally high and indicated a considerable amount of evaporation. Accordingly, about four inches of water was subtracted from the total precipitation index. March and April wind also proved to be considerably above normal, so an additional four inches was removed from the precipitation index, and the North Platte forecast published.

Later, inspection of the high elevation precipitation station at Foxpark revealed that there had been little, or no precipitation during November and December. Apparently, four inches of evaporation had been subtracted from a non-existent snow pack. The resulting, large, forecast error was reflected quite accurately.

SUMMARY

The primary object of this analysis is to indicate that the relationship of snow course to snow pack varies with the total wind movement over the watershed, particularly during the relatively warmer winter months.

However, there are other important water producing areas in Wyoming, that at this time, defy accurate analyses, possibly because they are subject to unrecorded wind movement. Small snow "labs", located high in each major watershed, may eventually prove essential to accurate, snowmelt, stream flow forecasts.

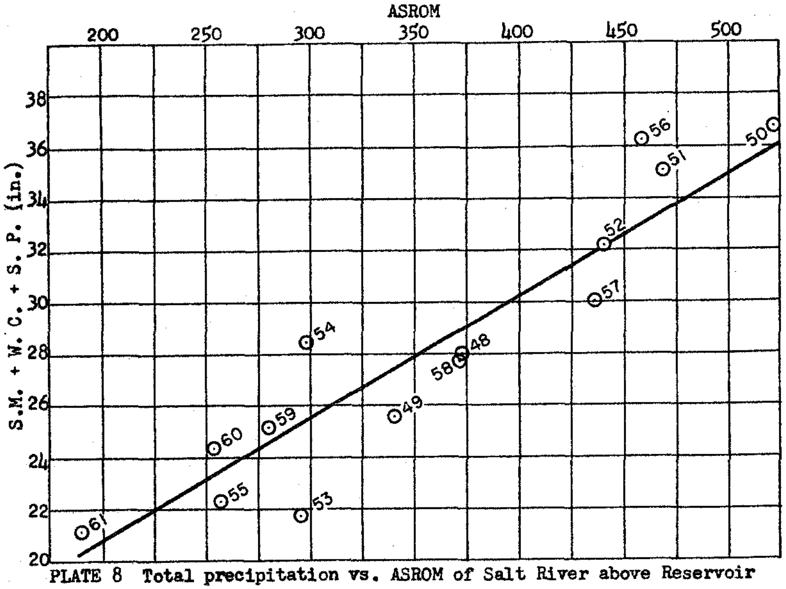

PLATE 8 **Total precipitation vs. ASROM of Salt River above Reservoir near Etna, Wyoming.**

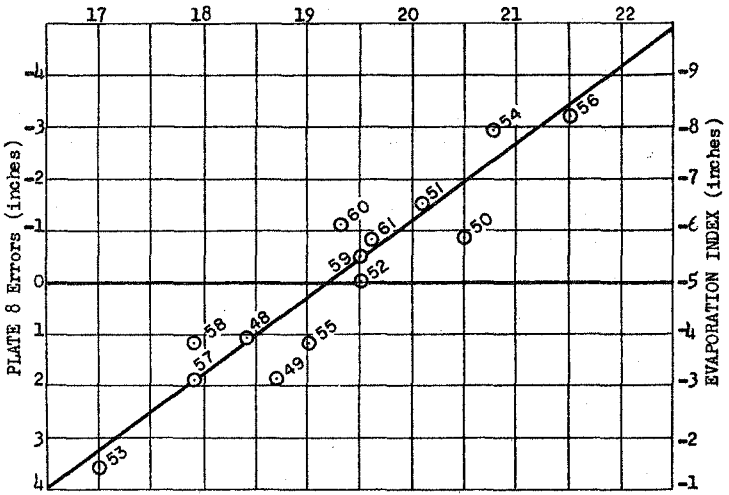

PLATE 9 **Winter Wind Velocity derived from average of 750 millibar at Boise, Idaho and 700 millibar at Lander, Wyoming.**

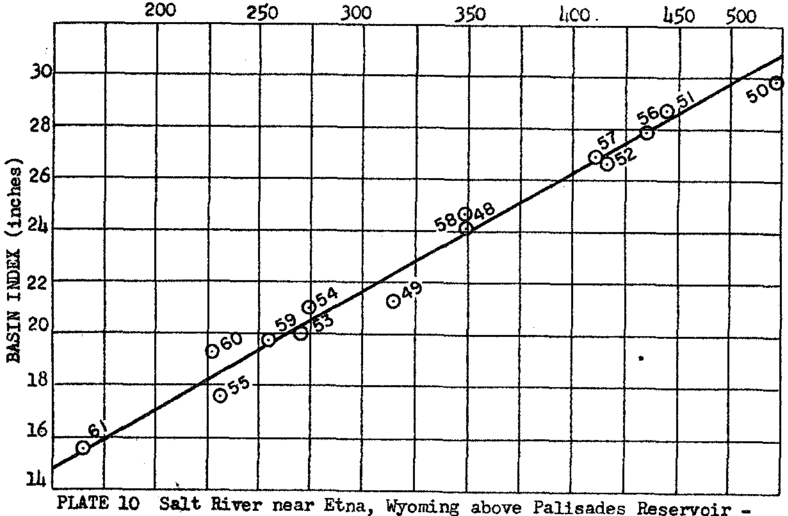

PLATE 10 **Salt River near Etna, Wyoming above Palisades Reservoir - Forecast Equation.**

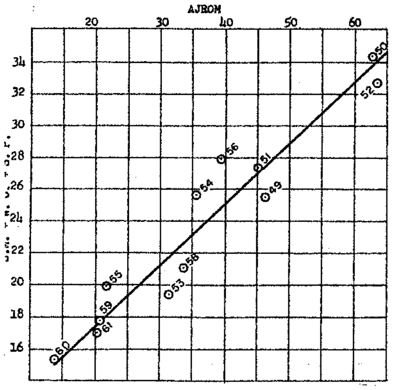

PLATE 11 Total precipitation vs. April-July runoff of the Little Popo Agie near Lander, Wyoming.

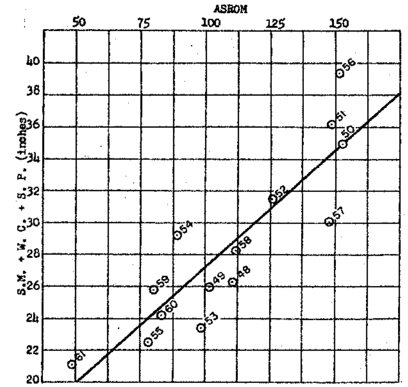

PLATE 11 Total precipitation vs. the ASROM of the Smith's Fork near Border, Wyoming.

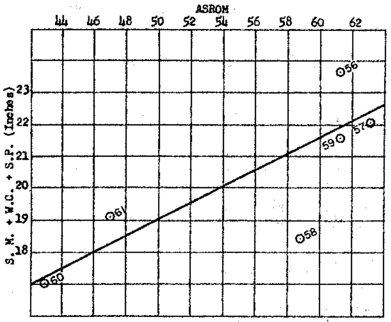

PLATE 14 Precipitation Index vs. the ASROM of Shell Creek near Shell, Wyoming.

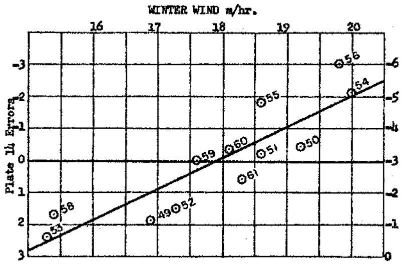

PLATE 12 The Winter Wind is determined by the average monthly velocities of the Lander, Wyoming 700 millibar winds aloft data. Combined as follows (November + December /2 + March /2 + April)/3.

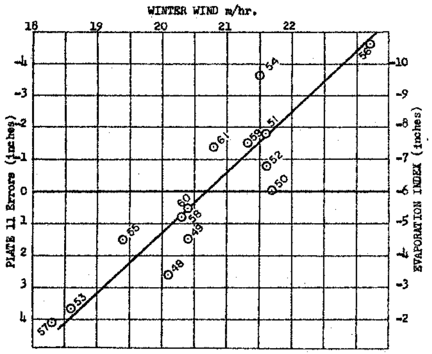

PLATE 12 Winter wind velocity derived from 750 millibar wind data at Boise, Idaho.

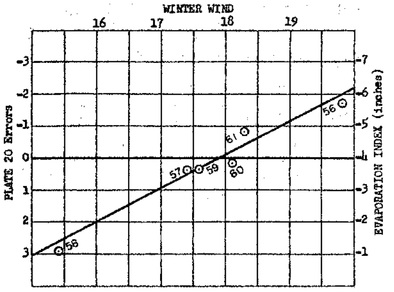

PLATE 15 The 700 millibar data of Lander, Wyoming proved applicable to the west flank of the Big Horns.

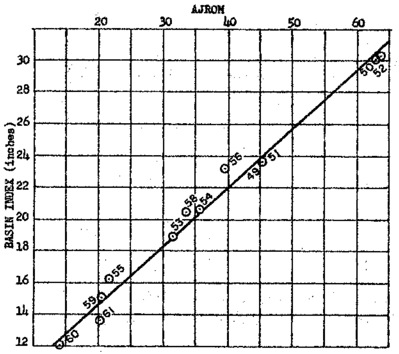

PLATE 13 The Forecast Equation of the Little Popo Agie near Lander, Wyoming.

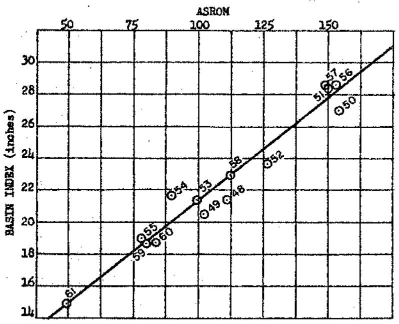

PLATE 13 Smith's Fork near Border - Forecast Equation.

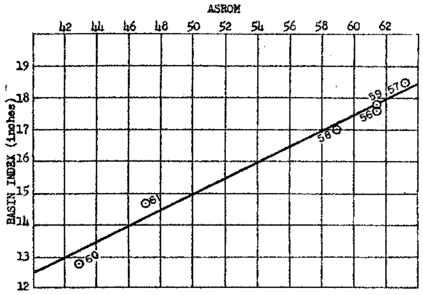

PLATE 16 Shell Creek forecast equation. The AJROM of Tensleep Creek near Tensleep, Wyoming proved to be almost identical to the Shell Creek analysis.