UNITED STATES DEPARTMENT OF AGRICULTURE
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WATER SUPPLY FORECASTING AS IT APPLIES TO WINTER SNOW COVER AND SPRING RUNOFF 1/

In the Western states from 75% to 85% of the streamflow is produced by the snow that accumulates in the mountainous areas. The accuracy of water supply forecasts is dependent on the ability to relate, over a period of years, the water content of the snow cover and subsequent runoff. Water users in the Western states were the first to recognize that careful use of water resources was necessary, since there have always been shortages in the arid areas for irrigation and other purposes.

The overall program of snow surveys and water supply forecasts in the Western states is known as the Federal-State-Private Cooperative Snow Surveys coordinated by the Soil Conservation Service. In British Columbia, the Department of Lands and Forests and Water Resources, Water Investigations Branch, conducts the snow survey program. In California, the work is under the leadership of the State Department of Water Resources. Time and space will not permit mentioning the numerous agencies and individuals whose good will and participation have made this cooperative effort possible. The major cooperators are the U. S. Forest Service, U. S. Bureau of Reclamation, U. S. Army Corps of Engineers, Bonneville Power Administration, private power companies, irrigation districts, soil conservation districts, the State Engineers, and Agricultural Experiment Stations in the various states.

The Soil Conservation Service holds a West Wide Snow Survey and Water Supply Forecasting Conference at two-year intervals, supplemented by training in individual states. Special training is provided to snow surveyors and forecasters of other agencies and organizations as well as to Service personnel. Instructors include experts in the fields of winter survival, avalanche hazards, skiing, cross-country over-snow travel, first aid, data collection techniques and forecasting.

In 1965 there were about 1,550 snow courses, 310 aerial markers, 230 precipitation gages and 210 soil moisture sites in the Western United States and Canada. About 1,200 snow surveyors from all organizations participated in the data collection work. Snow surveys made each season amount to about 7,000.

The volume and kind of basic data that snow surveyors gather have increased greatly since the first surveys were made in 1904 by Dr. James E. Church in Nevada. At the present time, technicians use water content of the snow

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1/ Prepared by Morlan W. Nelson, Snow Survey Supervisor for Idaho, Soil Conservation Service, Boise, Idaho for the Eastern Snow Conference at Hartford, Connecticut - February 10-11, 1966.

as the most important variable which is supplemented by precipitation, soil moisture beneath the snow pack, soil temperature, base flow of individual rivers, wind speed and solar radiation. Some of these data are systematically taken near the first of each month from January through June. On a few key courses, measurements are taken every two weeks beginning December 1st.

The Soil Conservation Service during the last three years has been engaged in development work at its Mt. Hood, Oregon, test site on various sizes of "pressure pillows" and associated telemetry, encoding and decoding devices. Several prototype remote automatic or interrogation type systems have been installed by the Soil Conservation Service in six states.

The pressure pillow readings are recorded at the data collection site in addition to the base station record, during the snow accumulation season and on through the snow-melt period. The application of snow-melt rates to the operation of reservoirs is extremely important when rather fine adjustments are being made on large reservoirs or systems involving tremendous areas and volumes of water such as the Columbia, the Colorado, and the Missouri Basins. The pressure pillows produce continuous data which have many uses that are discusssd later in this paper.

Forecasts are made from these basic data using modern computer techniques combined with practical experience. The multiple-regression equation is a standard test for all the independent parameters as they relate to the dependent variable of streamflow. A forecast equation, using snow water content, soil moisture status, precipitation, and possibly other variables related to streamflow, indicates the importance of each parameter. For instance, soil moisture by itself may not relate significantly to streamflow, but may indicate some adjustment to supplement the major variable, the water content of the snow pack. The same thing applies to other independent variables. This statement does not hold unless snow melt makes up the major portion of the streamflow during the summer season. Here in the East, rainfall no doubt is more important on many rivers than the water content of the snow pack which accumulates in the winter.

All of the basic data are placed upon I.B.M. cards for the publication of summary data as well as record-keeping and individual analysis of each snow course. It is interesting to note that the last snow survey summaries published by the Soil Conservation Service were completely done by I.B.M. printout procedures from basic data cards. Statistical analysis of the data allows anyone using the forecasts to have a mathematical computation expressing the dependability of the forecast. These same analyses also show the extremes in error as well as the average.

A good example of an excellent forecast relationship is the forecast for the Columbia River at the International Boundary for the April-through-September period. The equation is as follows:

$$X_1 = 1.50X_2 + .07X_3 + 1.58X_4 + 10.36$$

X_1 April through September runoff in millions of acre feet
X_2 Snow water index in inches
X_3 November 1 base flow index
X_4 Average precipitation, in inches, for April

This equation illustrates the relationship that exists between the factors of snow pack, soil moisture or base flow, spring rains, and the resultant 6 months' flow of a river. Use of this equation provides flow forecasts of the Columbia River having an average error of 4.4 percent on April First and a maximum error under 11 percent.

In general, the accuracy of forecast relationships and actual performance, using snow-water content as the major parameter, varies in average accuracy from 4% to 20%. Maximum errors may be considerably greater than this in the extreme year, but these extremes are considered in the average accuracy figures.

Dr. Harold G. Wilm, now Conservation Commissioner for New York, some time ago assisted water supply forecasters, Snow Survey Superivsors, and other hydrologists in the statistical analysis approach involving the multiple-regression equation. This work, previously done by hand, is now a simple matter when using an electronic computer.

The best basic relationship that can be developed at the time of the maximum snow pack, whether it be March 1, April 1, or May 1, is the most useful forecast equation for any period. The forecasts made on January 1 must use normal figures for the period between January 1 and the time of maximum snow pack. This is a practical procedure which allows the same equation to forecast for the entire season regardless of the date. The relationship merely gets more precise each month as more of each parameter becomes an actual measured amount. In some cases, these relationships may be derived using data as of June 1 with forecasts increasing in precision each month until that time.

The other technique, which is a practical corrective factor, is to subtract water which has already been measured at the time the forecast is made. For instance, a forecast of March through September, for the purposes of irrigation, can begin on January 1. The accuracy of the forecast as of April 1 is significantly increased by knowing the amount of water that flowed down the river during the interim period. Forecasts are made for given periods and are adjusted each month or at shorter intervals to correct for subsequent information.

The use of this technique also provides a better correlation, with time, between volume and peak flows on very small streams as well as great river systems such as the Columbia.

The relationship of peak and volume flows, as used by the Soil Conservation Service, is related to water rights or long range predictions of potential hazard from high flows. This type of forecast is also used in the multiple-purpose operation of reservoirs built under the watershed program administered by the Soil Conservation Service.

The following illustrates the increase in forecast accuracy as the long period forecast is adjusted using current information. Consider the three periods computed on the Columbia River, as measured near The Dalles, Oregon.

In figures 1, 2, and 3, it is possible to visually see the increase in precision of relationship as the period is shortened.

Many of the water rights throughout the West are cut off if the flow falls below a specified rate. Therefore, the forecaster is faced with the problem of forecasting the date on which a given river will fall below a stipulated flow, at which time a portion of the water users will no longer receive water. There are several methods of forecasting the date and cubic feet per second of flow on a river. Usually the period of the volume-peak relationship is shortened until the stipulated flow and date fall within a given series of days. Relationships between snow cover, flow volume, peak flows and dates are derived from past records. Once the peak flow is reached on most snow-melt rivers, the river falls at a known rate. Therefore, the date and stipulated flow can be forecast rather generally at the beginning of the season, and with reasonable accuracy on some streams after the peak of the year has been reached. These techniques are still being improved and are becoming more important each year as a greater need for water develops.

The pressure pillow, with its accurate measurement of the rate of snow melt as well as the rate of accumulation, provides a new parameter which has the potential for wide use by hydrologists. For instance, a pressure pillow, recording the rate of snow melt above a stream gaging station, will give hydrologists a measure of some factors involved in precipitation-runoff relations and the water holding characteristics of watersheds. The determination of lag time between snow melt and resultant stream flow will be useful. In larger river systems, it will give the reservoir operators better information for more precise control of water expected from melting snow as it varies with the rate of melt. The runoff characteristics of the watershed, as determined from snow melt when there was no rain involved, may also be a measure of what to expect in terms of volume and peak flows if it rains on saturated soils.

In view of the tremendous variation in total snowfall and precipitation that has occurred throughout the United States and the world since 1840, and the increase in population, the many users of water must be served with efficiency. The greatest factor in the efficiency of water use, with or without reservoirs, lies with the forecast of the amount and distribution of water from a watershed each year. Agriculture, industry, communities, hydro-power generation, water-dependent recreation of all kinds, navigation, watershed management, fish and game production--and a relatively new one, pollution abatement--are major users of water.

It is interesting to note that the pollution problem can be involved with forecasts in the West. In 1961, a very light snow pack developed. Some irrigation and power reservoir managers, guided by forecasts of extremely low streamflow, started storing practically all of the runoff in the month of January. Pollution became an acute problem because a greater portion of sewage made up the streamflow in many rivers. Pollution of municipal water supplies required some drilling of wells to improve the situation.

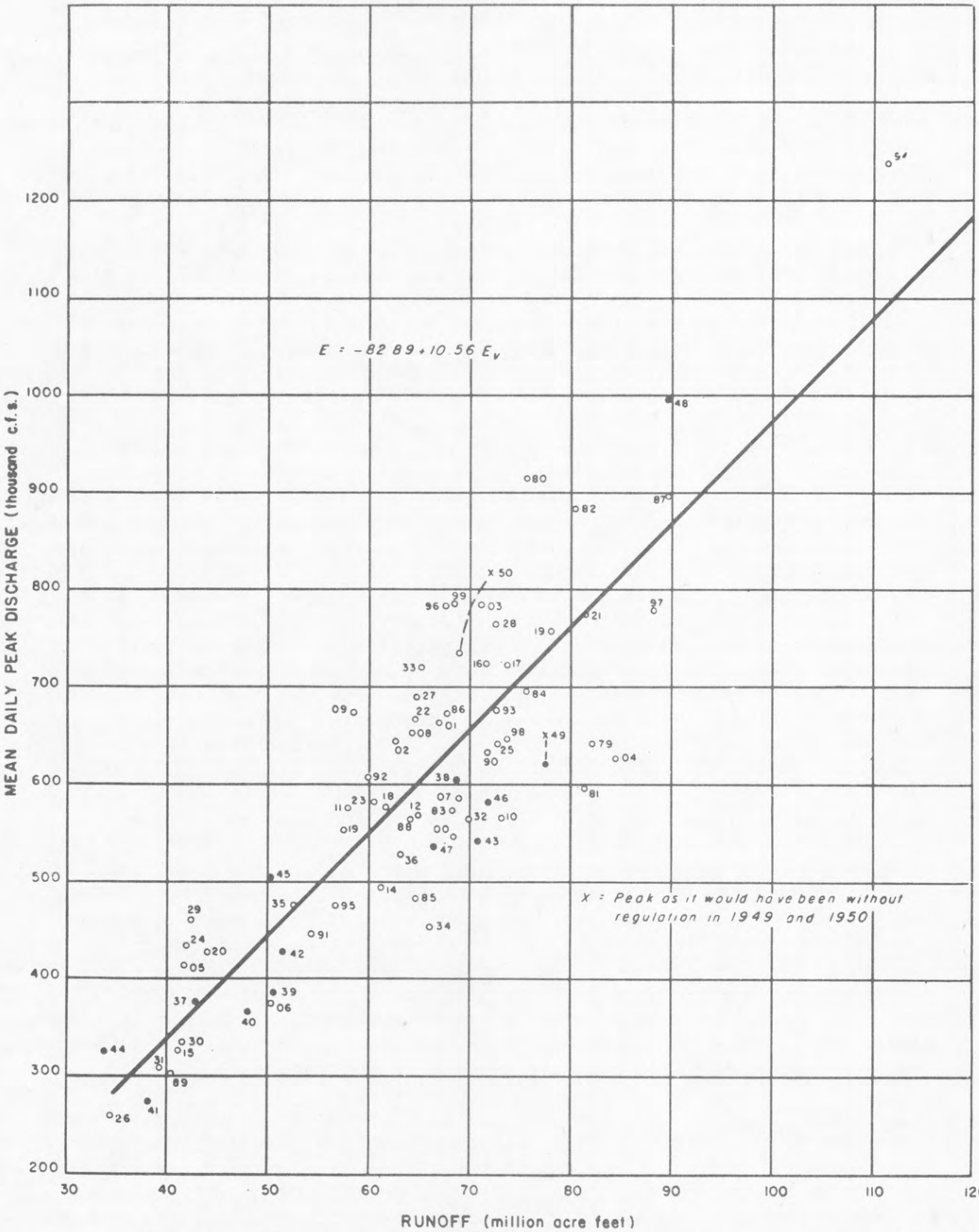

FIGURE 1 —Relation of peak discharge to April-June runoff volume for Columbia River at The Dalles, Oreg.

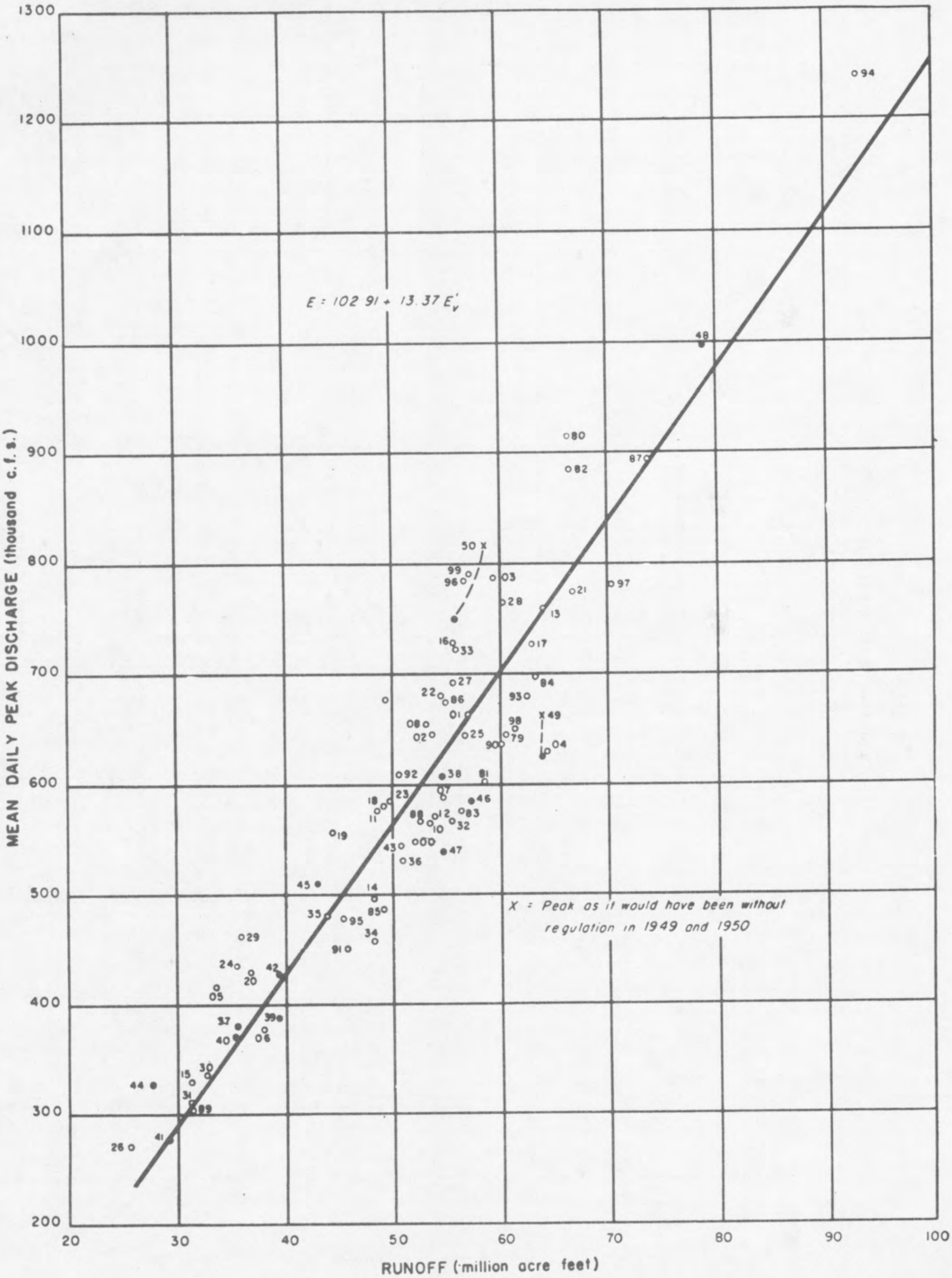

FIGURE 2.—Relation of peak discharge to May-June runoff volume for Columbia River at The Dalles, Oreg.

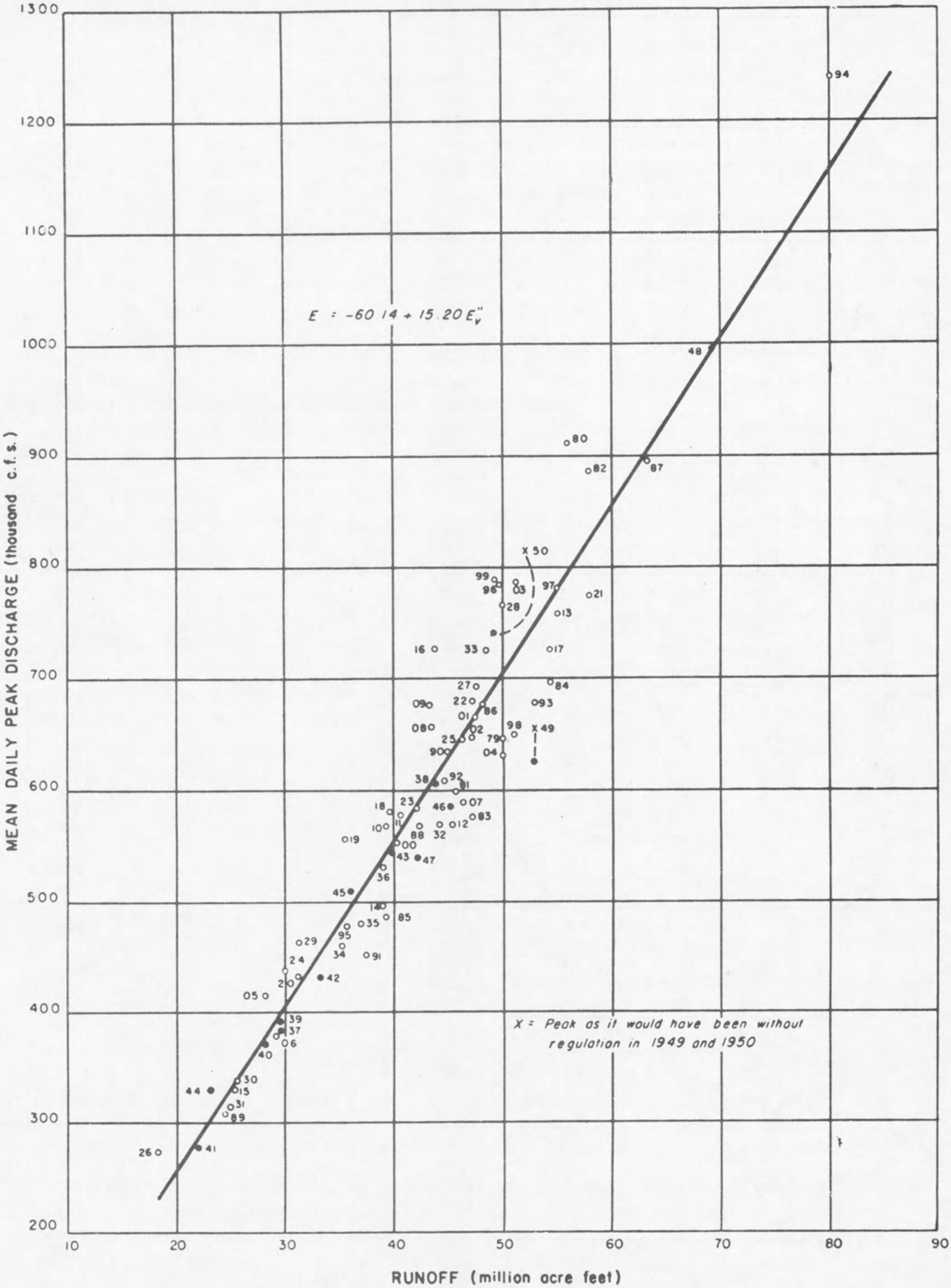

FIGURE 3—Relation of peak discharge to May 16-June 30 runoff volume for Columbia River at The Dalles, Oreg.

The annual snow pack provides a natural reservoir of water which is necessary for the economy of the West. The snow pack also has some undesirable features, such as clogging road and transportation systems and producing destructive floods. Snow avalanches are always a threat to people traveling or working in the high mountain areas. As more winter sports areas are developed, more people become exposed to the hazards. There is still a great need for knowledge and scientific measurements of the snow pack to fully realize the potential of this resource and to lessen the detrimental effects.

In general, temperatures throughout the world between 40° and 70° north latitude climbed steadily between 1860 and about 1940. 2/ The trends changed in the early 40's and have been leveling out or dropping since then. Precipitation during the same period has fallen significantly when considered on a five-year running mean. Here in the East, it seems that during these last few years precipitation has reached the bottom. In the West, at least, this trend changed in 1961, with snowfall and precipitation in 1965--in some instances--being the highest of record since 1896 or before.

Members of the Western Snow Conference have enjoyed contacts with the members of the Eastern Conference for many years. I bring you the very warmest regards from the Western Snow Conference and hope that, in the future, the same cordial relations will be mutually beneficial. The many problems in the future use of water require that technicians use the best approaches that can be developed anywhere in the nation.

2/ J. Murray Mitchell, Jr. "Recent Secular Changes of Global Temperature" From Annals of the New York Academy of Sciences. Vol. 95, Article 1, Pages 235-250, October 5, 1961.