EFFECTS OF TEMPERATURE ON WINTER RUNOFF [1]

By

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During recent years the Bonneville Power Administration and the Geological Survey have collaborated on investigations of the techniques of evaluating the runoff potential during the wintertime period. The earlier studies were based primarily on the analysis of runoff records for selected tributaries of the Columbia River. The results of some of these have been reported by McDonald, 1953; Riggs, 1953; Sachs, 1957; and Simons, 1953. Recent studies (Rorabaugh, 1963) have examined the use of ground-water data and techniques as a further parameter in low-flow forecasting. This current paper utilizes the techniques of some of these previous studies and examines in a preliminary way the effect of temperatures on runoff during the October through March period.

Operating rule curves for a hydroelectric powerplant or system are based primarily upon critical and median flow conditions as determined from long-term runoff records. For any particular power year the short-term operating decisions are largely determined by the following factors (1) loads to be met, (2) installed generating capacity of the plants, and (3) water available for use. Items Nos. 1 and 2 above, can be estimated quite closely at the beginning of any power year. The water available for use during the reservoir drawdown period is the least known item and it has the greatest inherent variability from year to year. In many parts of the Columbia River basin these variations in low-water runoff commonly have a range in magnitude of five or tenfold. Under extreme conditions the range might be even larger. Thus, from an operating standpoint, it is important that the runoff potential during each low-flow season be evaluated as accurately as possible.

The water available for use during the October through March period has the following components: (1) the flow due to antecedent conditions, (2) the flow resulting from concurrent weather conditions during the forecast period, and (3) the amount of controlled storage. The controlled storage is known within reasonable limits with perhaps the exception of the amount of bank storage. This factor is not included in the following analysis. Rather, the effect of low temperatures upon stream runoff is briefly examined.

The runoff during the October through March period of the 1936-37 water year is the minimum at a very large number of tributary streams and is the minimum for all stations on the main-stem Columbia River. One of the basic questions of the current study is "Can a critical water season like that of 1936-37 be forecasted?" The records for Clark Fork at St. Regis, Montana, are used in the following analysis. A typical hydrograph of the observed flow for the October-March period with its base-flow recession curve superimposed from the first of October is shown on figure 1. The area below the base-flow recession curve represents runoff that already is in the hydraulic system of the river and is called the "assured flow". Its magnitude for any time period can be determined by integrating the area under the recession curve. The incremental flows are those caused by weather conditions occurring during the forecast period and are numerically equal to the difference between the observed flows and the assured flows. This may include direct runoff from concurrent precipitation and/or snowmelt; additional increments of ground-water discharge resulting from recharge; changes in bank storage and channel or lake storage associated with changes in river stage; and changes in storage related to ice formation and melting.

The magnitude of the three components of flow for each winter period was determined from the historical records of the water years 1930 through 1963. Frequency diagrams of these components of flow are shown in figure 2. The position of the flows for the winter season of 1936-37 is indicated on each frequency curve. It can be noted that forecasts of assured flow for the October through March period are greater than the 1936-37 observed flows in more than 50 percent of the years included in this study. Further examination of figure 2 shows that 1936-37 is not the minimum of the October through March assured flows,

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rather it occupies the 27th position in an array of the 34 years used in this study. Thus as of the first of October the occurrence of the minimum flow was not anticipated by this procedure.

The hydrograph of the October through March observed flows for the 1936-37 water year with the appropriate recession curves extended from the first of each month is shown on figure 3. The occurrence of "ice" periods were such that the recession curve extended from November 1, was used until the first of March. From this, forecasts of assured flow were derived for each of the six following periods: October-March, November-March, December-March, January-March, February-March, and March. The records for each wintertime period of the water years 1930 through 1963 were analyzed in the same manner. Frequency diagrams of assured flows for these six time periods are shown on figure 4. The position of the 1936-37 year is indicated on each frequency diagram. In tracing the position of the 1936-37 forecasts it is evident that a forecast of minimum conditions would not have been made until January 1. By this time it is almost too late to be of significant value in planning reservoir operations for the balance of the drawdown period. Minimum forecasts would have also been made on February 1 and March 1.

The observed flow dips below the recession curve for an extended period from late December to early February. (See figure 3.) This coincided, in time, with the occurrence of extremely cold temperatures which caused the formation of ice in the stream channel. Hoyt (1913) and Moore (1957) have described the various ways in which ice may form in stream channels and how to identify and evaluate these from the streamflow hydrograph. The formation of surface or shore ice is the most common form in western Montana. It also produces the largest effect on stream discharge as it causes temporary storage of water in the stream channel.

The amount of water so detained is a function of the temperature departure below freezing and the duration of the below freezing period; the length of time it is detained is dependent upon the duration of the period of below-freezing temperature and the subsequent melting rate. As soon as the temperature rises above freezing the ice will begin to melt and this releases water for use at downstream points. Thus the effect of ice formation is to temporarily delay the utility of water already in the stream system.

Cold temperatures also affect the amount of water reaching the stream system. In periods of cold temperatures precipitation occurs in solid form and is not available as runoff until melted by warmer temperatures. The cold temperatures may also, under some conditions, retard the flow of water from subsurface sources into the stream channels. Thus there may be a runoff potential, as evaluated by precipitation accumulation, ground-water index or base flow, that is not immediately realized because of extremely low temperatures.

The magnitude of flow can be affected by extremely low temperatures and by extended periods of below freezing temperatures. Both of these factors are briefly examined by utilizing two simple indices. These are: the minimum monthly mean temperature and the number of consecutive days the maximum daily temperature was 32°F or lower. The records for the October through March period of the water years of 1931 through 1960 for East Anaconda, Montana, were used as an example.

The minimum monthly mean temperature for each winter was determined regardless of which month it was. A frequency diagram of the lowest monthly mean temperature for each winter is shown in figure 5. The monthly mean temperature for January, 1937 is the minimum during this period. A quick review of other available temperature records at and near this station, indicates that January, 1937 may have been the coldest month in the last 50 to 60 years.

The daily maximum and minimum temperature at East Anaconda, Montana, for 3 winter seasons, 1935-36, 1936-37, and 1948-49, are shown in figure 6. In judging the length or duration of the cold period, the number of consecutive days the maximum daily temperature was 32°F or less was selected because it gives a larger range in year to year variability. The minimum daily temperature frequently remains below freezing almost continuously for several months at a time whereas the daily maximum temperature fluctuates above and below the freezing level. The maximum number of consecutive days that daily maximum temperature was 32°F or less was compiled for each winter during the 1931-60 period. A frequency diagram of these values are shown in figure 7. The longest period of below-freezing

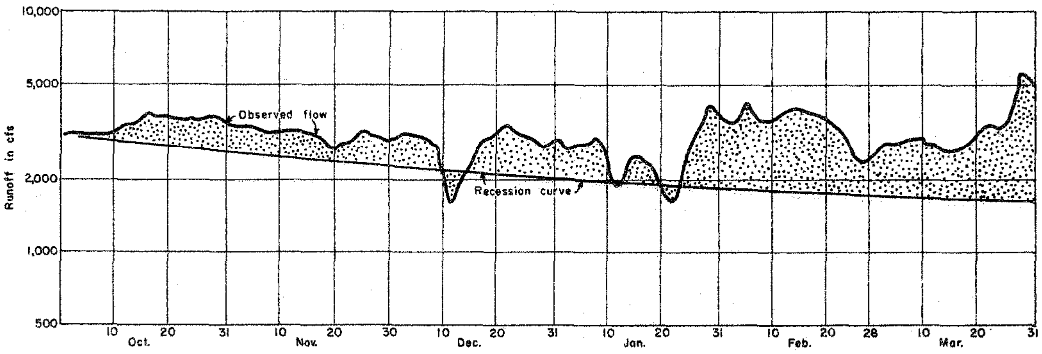

Fig. I— Typical hydrograph, Clark Fork at St. Regis, Montana

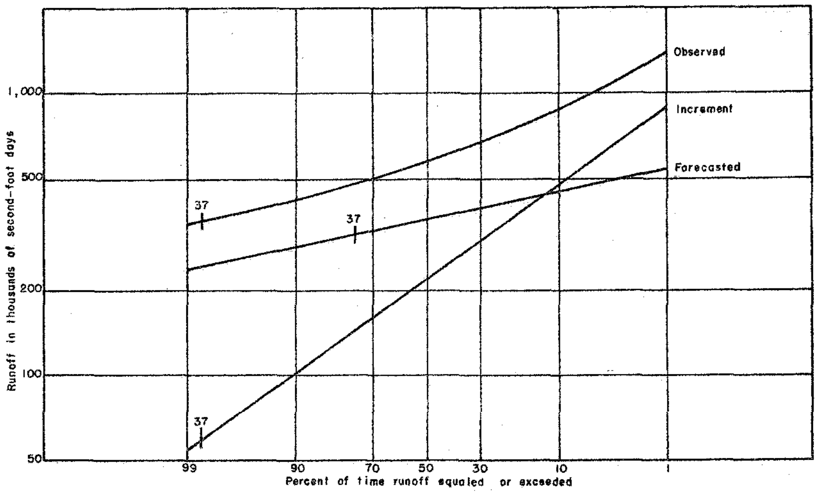

Fig 2.--Frequency diagram of components of October through March runoff of Clark Fork at St. Regis, Montana, for period 1930-63.

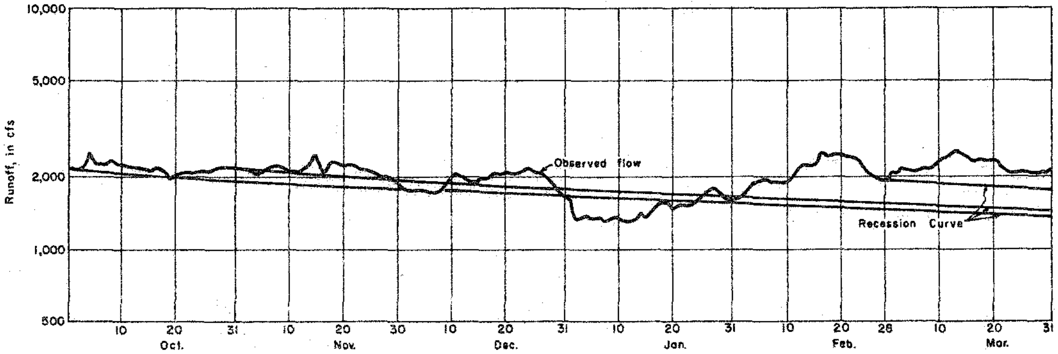

Fig 3--Hydrograph, Clark Fork at St. Regis, Mont., 1936-37

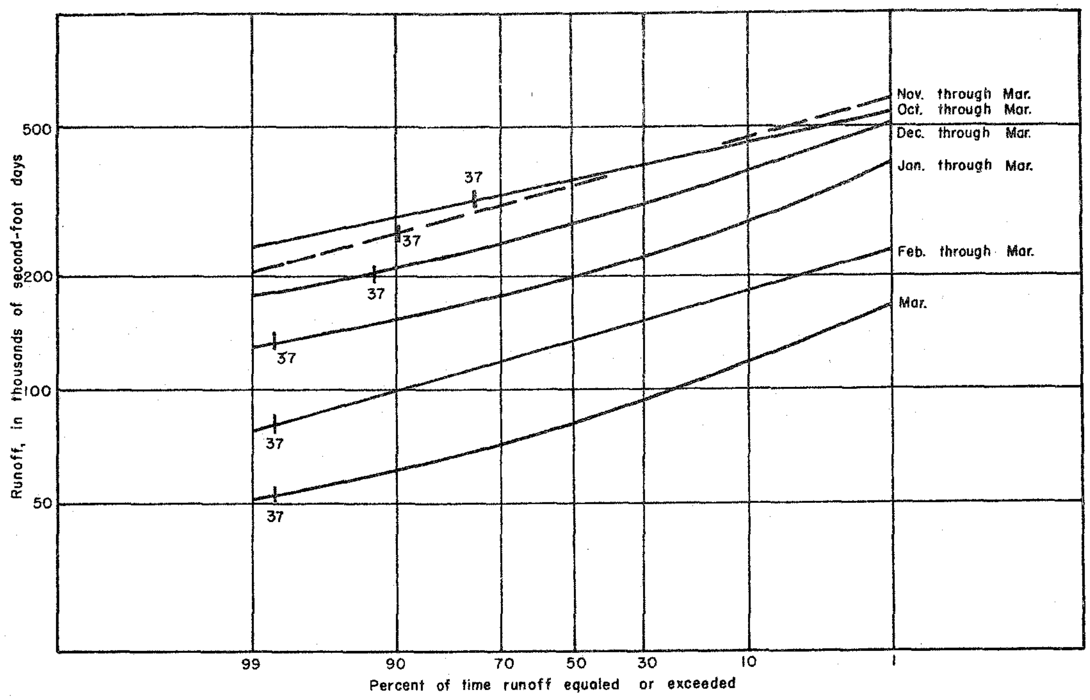

Fig.4--Frequency diagram of assured flow forecasts for Clark Fork at St. Regis, Montana, for various time periods during 1930-63

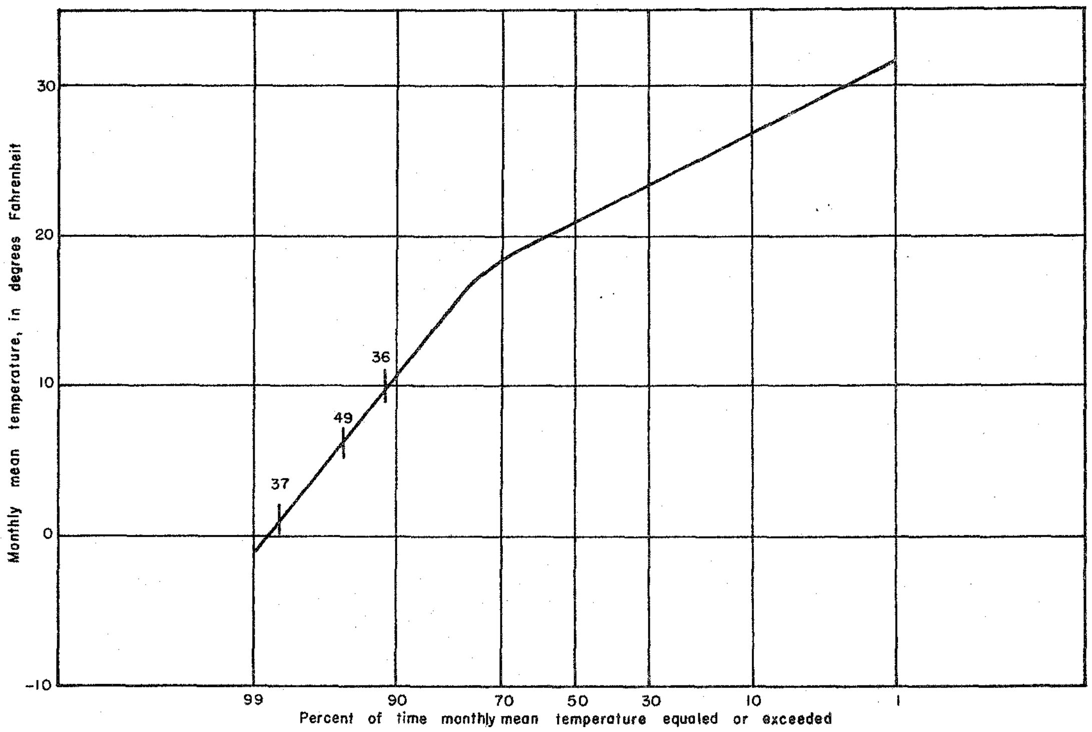

Fig 5.--Frequency diagram of coldest monthly mean temperature during each water year 1931-60, East Anaconda, Montana.

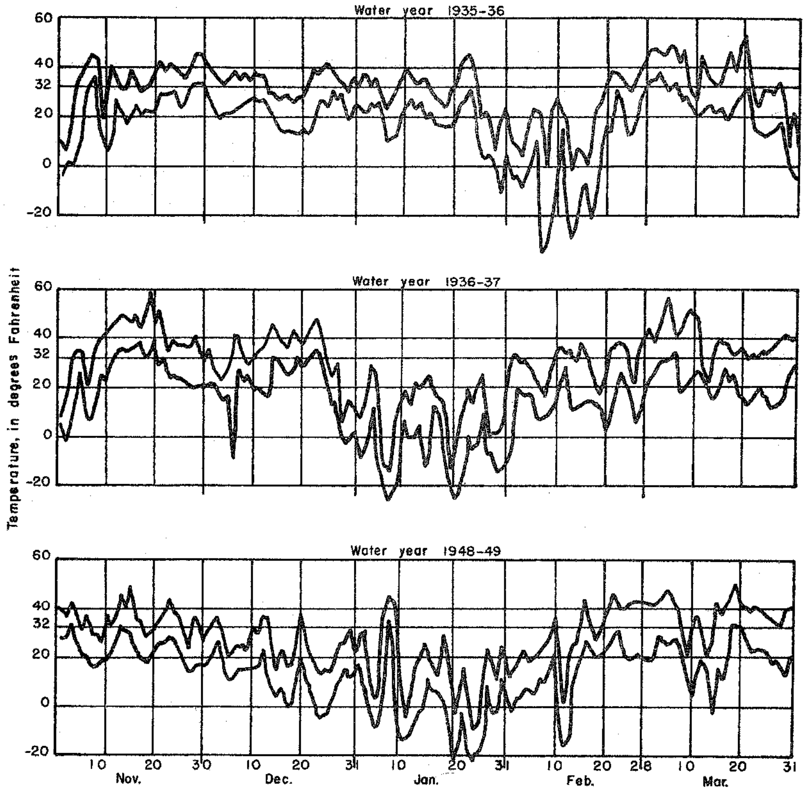

Fig 6.-- Daily maximum and minimum temperature at East Anaconda, Montana.

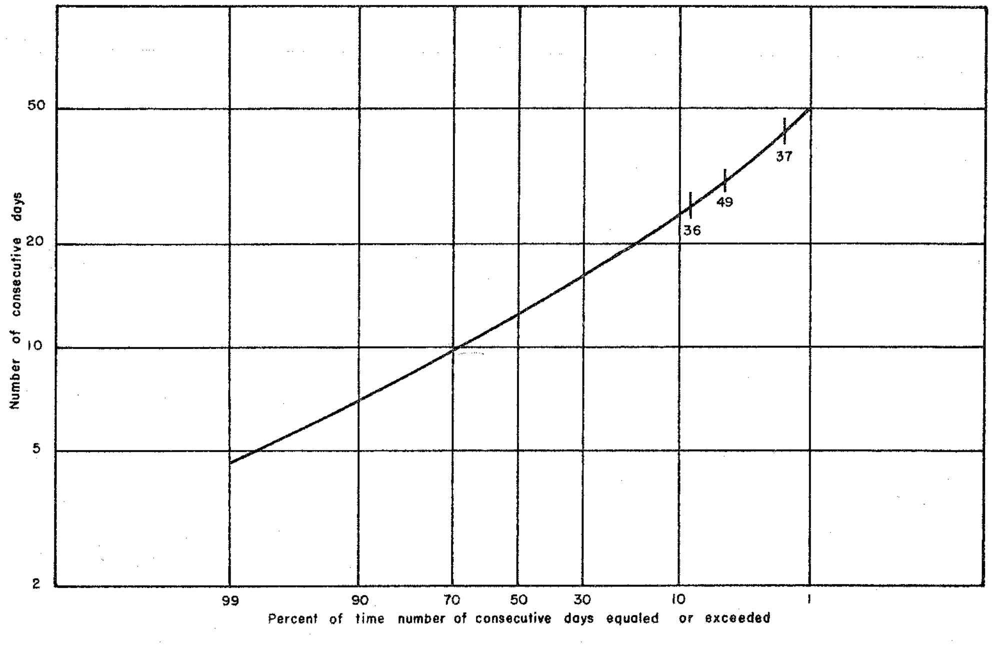

Fig.7 --Frequency diagram of the number of consecutive days daily maximum temperature was 32°F or colder 1931-60, East Anaconda, Mont.

temperatures also occurred during the 1936-37 period. Based on the indices used in this study, the 1936-37 winter was extremely cold and probably one of the most severe ones in the past 50 to 60 years.

A review of the flow sequence for the winter of 1936-37 reveals that the runoff potential was not at a minimum level until the occurrence of extremely low temperatures and that it was not recognized as the minimum until the first of January. Thus the critical flow sequence for the 1936-37 period was the result of a runoff potential in the lower quartile combined with the occurrence of record-breaking cold temperatures. The net result of the cold temperatures was the temporary storage of water already in the stream channel, which in turn reduces the stream discharge. Additional studies of the temperature sequences during 1936-37 for other parts of the Pacific Northwest should be made and the relation between temperatures and runoff during the wintertime evaluated in more detail.

The occurrence of low temperatures creates an ancillary problem because it increases the demand for additional amounts of power. This compounds the effects as far as the hydroelectric systems of the Pacific Northwest are concerned because the larger load demands calls for an increase in water use at a time when natural flows are being reduced because of temporary ice storage. This makes it doubly desirable to undertake a more detailed study of the probable occurrence of low temperature sequences for various parts of the Pacific Northwest and their effects on stream discharges.

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