USE OF SNOW SURVEYS IN VOLUMETRIC PREDICTION OF RUN-OFF

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At the 1952 Eastern Snow Conference, Vice President Finlayson read a very interesting and carefully prepared paper in which he concluded that the characteristics of spring freshets appeared to be associated with many unpredictable and widely varying phenomena, that the water content of snow cover which is the one factor which can be accurately determined appears to have an influence which is far from dominant, and that "the prospects of making accurate forecasts of spring freshet volume on the basis of snow surveys does not appear to be encouraging". These conclusions are fully concurred with. The purpose of this paper is to consider the uses of all available statistical information to determine whether or not it appears probable that methods may eventually be devised which will result in predictions of desired accuracy and which can be accepted with assurance. The distinguished Vice President of the Conference was stating a fact which is just as true in Maine as in Quebec when he said "it is much more important that evaluation be consistent within definite limits for all the time, than completely accurate most of the time and grossly in error occasionally". The question is how closely can the limits of the volume of spring run-off on any stream be determined with assurance that under the basic assumptions the estimates will always be equalled or slightly exceeded.

A snow survey is simply a determination of the water content of snow cover, this cover being a part of precipitation which has already been measured by observations when it fell. This snow cover may be very nearly equivalent to all the precipitation which has occurred from the time the snow began to accumulate to the time the snow survey was made, or it may be only a small percent of it. The natural phenomena which determine the percent of snow precipitation remaining on the ground at any time are numerous, almost all of them are extremely variable, and generally the influence of each of them is highly indeterminate. There seems to be little hope that procedures will be developed which will make possible an accurate prediction of volumetric run-off through the evaluation of the influence of each of these phenomena.

ACCURACY OF PRECIPITATION AND SNOW OBSERVATIONS

Precipitation records and snow surveys are the most important information readily available in attempting to predict volumetric run-off, and they constitute about the only information which has been collected over a long enough period in the past to be of value in this work. To focus attention on the problem it is therefore perhaps desirable to briefly consider the accuracy of this information. Precipitation records which are quite generally available over most drainage areas are known to be subject to considerable inaccuracy. This matter has been discussed by many people and much has been written about it. Most of us here have, at one time or another, compared records made by different observers using the same kind of equipment at locations very close together, and we know that these observations may vary quite widely over short periods at least. Similarly, snow surveys are subject to quite wide inconsistencies because of lack of uniformity of snow cover, the large amount of water in snow and ice which is often on the ground and cannot be picked up by the equipment, the difficulty under some conditions of getting all the snow and nothing else in the tube, and also because of the quite common difficulty of getting the instruments down through one or more layers of ice or crust in such a manner as to get a truly representative sample. It can be said, however, tnat tnere is a much closer agreement between precipitation records taken by different observers in about the same locality than would be expected, and also that the average result of snow surveys made by different observers using the same equipment or different equipment is much closer than one would expect. The comparison of precipitation records made at adjacent locations for short periods of time, or of snow surveys made at the same locations by different observers, would lead one to think that all precipitation records and snow surveys are subject to considerable inaccuracies, but these records taken over long periods of time and over widely scattered areas have a way of averaging out in a manner which gives confidence that they are reasonably accurate. On the areas where snow surveys are made by our office, surveys are also made by the United States Geological Survey and also by the forestry department of a paper company. Different snow sources are used, but usually all the records are in fairly good agreement.

VARIATION OF PRECIPITATION AND SNOW COVER

On practically all areas drained by the streams and rivers of northeastern United States and eastern Canada, there is considerable variation in precipitation, and even a wider variation in snow cover at any particular time, due to differences in elevation and other causes and to a great extent to the shielding of certain areas by the mountains. The areas above the principal storage lakes on the Kennebec River are valleys at elevations usually varying about a thousand to twelve hundred feet above mean sea level, these valleys being shielded extensively by mountains running up to elevations as high as four thousand feet. As an example of the effect of this shielding by mountains, the rainfall above Moosehead Lake varies from about thirty-six and a half inches at Jackman to forty-one and a half inches at Greenville, or about twelve percent. The snow observations at different points on the same area at the time of year when snow surveys are made, vary as much as thirty-five percent. There is about the same variation in precipitation and snow cover at the different points where observations are made above Flagstaff Dam on Dead River. As many points on these areas are not readily enough accessible to permit regular precipitation and snow observations, there can be little doubt that even wider variations in precipitation and snow cover would be shown if observations were posible over the entire area. The information gathered at the points where observations are made cannot be assumed to represent a true average for the entire area either by arithmetical or weighted means, though they were of course selected to give what was believed to be representative conditions. The averages of precipitation records and also snow observations on the areas are only indices which may give results which are quite consistently too high or too low, and which may be quite badly in error for a short period of time. For this reason, these records must be supplemented with as much other influencing information as can be gathered, they must be compared with all other information available, and they must be used consistently and adjusted in the light of good judgment, if they are to be used as a basis for prediction of volumetric run-off.

INDETERMINATE INFLUENCING PHENOMENA

Other than the above mentioned variables which can be measured by instrument with considerable accuracy, there are natural phenomena which affect the volume of run-off during snow melt, and which to date cannot be evaluated within satisfactory limits. First, there are those natural phenomena which affect direct losses such as wind, percent of sunshine, temperature, relative humidity, and so forth. These are the factors which cause wide variations in snow sublimation and direct water evaporation from the surface of wet snow. They also greatly affect the amount of water taken by the vegetation during the melt period. If one attempts to predict volume of run-off from the time of the last snow surveys, the largest single indeterminate is the amount of water required to saturate the ground to a point where practically all water from further precipitation or from melt of snow still remaining on the ground, other than that required to supply the direct losses above mentioned, will run off.

PROCEDURES

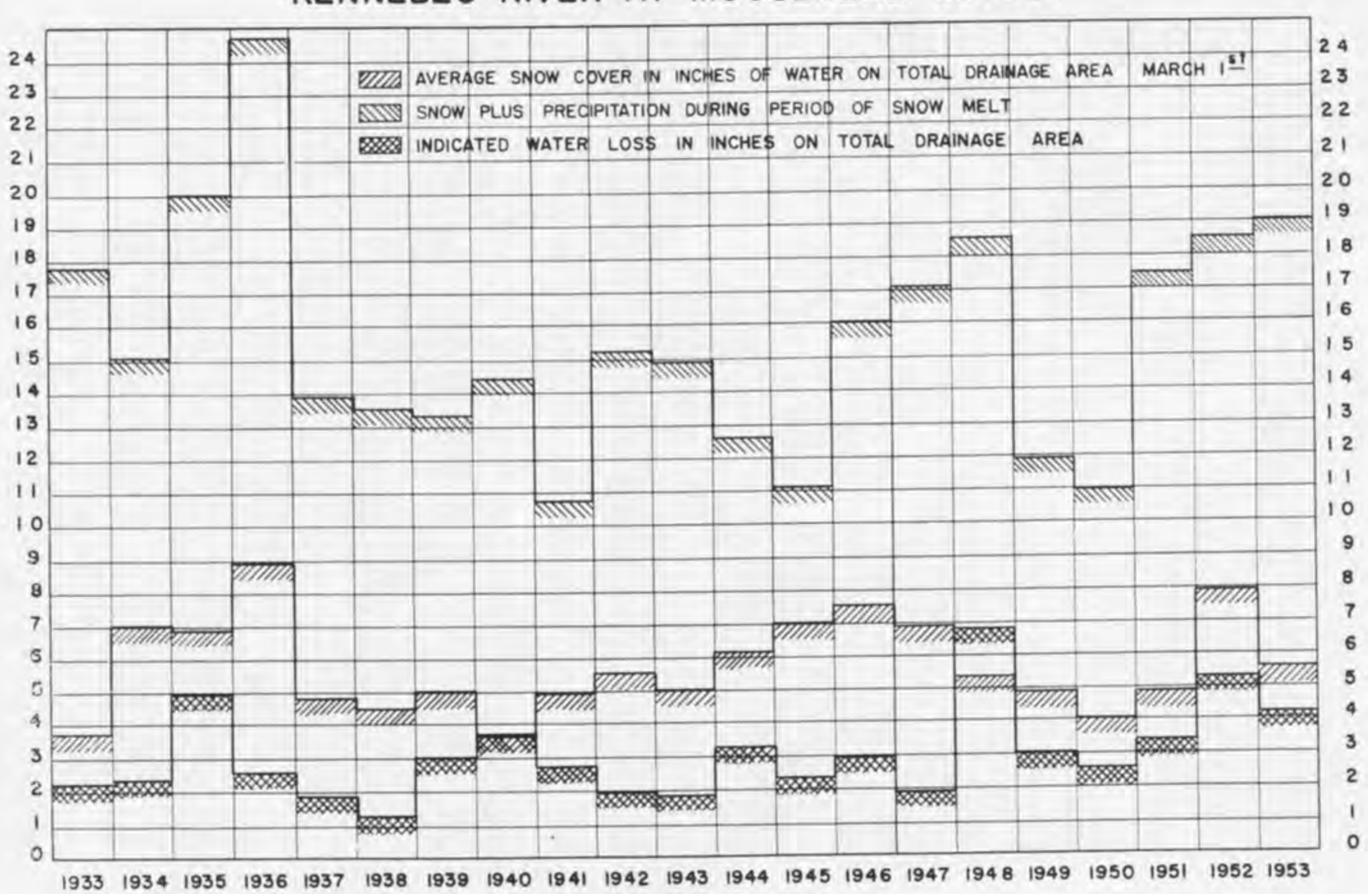
There are two general methods of approach in the solution of the problem where some of the influencing factors are known within limits of acceptable accuracy, and others are known as to the nature but not as to the amount of the influence. One procedure is the modification of the known elements of the problem through the use of empirical factors, which are arbitrarily selected to adjust for all or part of the unknowns. The other method is to make computations which are of such a nature as to throw the influence of all the unknowns into one element of the computation, and then to attempt to modify this element by judgment based on careful study extending over a considerable period of time. Both these procedures are of value and both should be used in attempting to predict the volumetric run-off during the snow melt. The first method, when the formula has been accepted, becomes purely mathematical, while the second requires constant investigation of the unknowns and the study of fulfillment in terms of prediction. The United States Weather Bureau has used the first procedure in predicting the volume of run-off at locations on some of the rivers of the country during recent years. One of the points selected for such predictions is the Kennebec River at The Forks. While it was not the privilege of the speaker to be present when the method used by the Weather Bureau was discussed, he has on several occasions, checked the Weather Bureau computations using their method and believes these predictions to be of considerable value. The second method is primarily of value in that it offers an opportunity to observe the magnitude of the departure from the normal which occurs when most of the unknown elements appear to be normal and one or more of the others depart quite radically from the normal.

SNOW COVER, PRECIPITATION, AND RUN-OFF ABOVE MOOSEHEAD

A very simple diagram is presented showing for the last 21 years in inches of water on the total drainage area of 1240 square miles above Moosehead Outlet the following data: (1) The snow cover on March 1st; (2) Precipitation from March 1st to the date of balancing against run-off when the snow was entirely melted and the flow was, for the first time, at a level of about one cubic foot per second per square mile on a falling stage; (3) The volume of run-off which actually took place during the balancing period, and (4) The indicated amount of available water which did not run off. For convenience, the water which did not run off will be called the water loss.

The average snow cover on March 1st (shown by the red line), for the twenty-one year period was equivalent to 5.71 inches of water and varied from 3.59 inches to 7.89 inches. The precipitation from March 1st to the balancing date (the ordinate between the red and blue lines) averaged 9.82 inches and varied from 4.01 inches to 15.75 inches. The total indicated water available (shown by the blue line) averaged 15.53 inches and varied from 10.68 inches to 24.65 inches. The actual run-off (the ordinate

KENNEBEC RIVER AT MOOSEHEAD OUTLET



between the blue and green lines) averaged 12.50 inches and varied from 8.03 inches to 22.04 inches. Thus, the indicated water loss (shown by the green line) averaged 3.03 inches and varied from 1.24 inches to 6.75 inches.

Attention is invited to the relatively small variation in water loss as shown on the diagram. If one had assumed each year that the loss was to be equal to the average of 3.03 inches, there would have been only four years out of the twenty-one period when the assumption would have been in error by more than one and a half inches, but on the worst year (1948) when the loss was 6.75 inches, this assumption would have been in error by 3.72 inches. On sixteen of the twenty-one years shown on the diagram, the balancing date was between June 1st and 15th, on three of the years it was on July 1st, and on one (1945), the run-off was complete and the flow was down to a rate of about a cubic foot per second per square mile on April 21st. The diagram shows remarkable consistency for most years and an equally remarkable radical departure on several of the years.

It is not difficult to explain the extremely high indicated water loss of 6.75 inches in the year 1948. The year 1947 was the driest ever experienced since good water records have been available on the Kennebec River. The summer of 1947 was extremely hot. Natural run-off for the area under study was negative in both September and October of that year, and it averaged only about 0.15 cfs. per square mile for the seven months period August 1st, 1947, to March 1st, 1948. No effective rainfall occurred during the fall months to replenish the ground water and consequently the ground had to be filled from melting snow and precipitation which occurred after the snow observations of March 1st, 1948. The computation shows that the water loss during the fill period that spring was 6.75 inches compared with the water equivalent of the snow on March 1st of 5.29 inches or was more than twice the normal water loss for the 21 year period shown on the diagram.

NEED FOR FURTHER ANALYSIS

The diagram which has been considered is based entirely on "hind-sight", or the examination of statistics after run-off was complete. The indication is that while the assumption that the water loss will average 3.03 inches might be accurate within the limits of 1½ inches for the 17 of the 21 years or about 80% of the time, the loss on any year can exceed this average by more than 100% and for satisfactory run-off prediction, methods must be devised to anticipate and accurately predict the time and the amount of such radical departures. It seems probable that on most streams and rivers where predictions of volumetric run-off are of great importance, no method will be satisfactory unless it results in predictions which are consistently accurate within a limit of about one inch of run-off on the area under study. During the last two or three years, a procedure has been used on the Kennebec River in conjunction with the analyses on the basis shown on the diagram, and in comparison with predictions of the United States Weather Bureau, which we hope will eventually make volumetric predictions consistently accurate within the limits stated.

On most of the Maine rivers, and doubtlessly on most of the rivers in the northeastern United States and in eastern Canada, there is usually (but not always) a time in the fall of the year when the ground becomes fairly well saturated with water and natural run-off increases to a level of more than one cubic foot per second per square mile. When this condition does develop, it is often possible to select the date when the flow is at about this level on the last falling stage before the freeze-up and when the water content of the snow cover is quite accurately known. On years when this can be done, cumulative computations of indicated water held back can be made periodically, say every two weeks, from this date until the time when snow run-off is complete the following spring and the run-off is again about a second foot per square mile on a falling stage. The computation is a simple one and consists of simply adding the precipitation and deducting the run-off for each computation period to the summations of the indicated accumulation from the previous period. This computation carried on in conjunction with snow accumulation and knowledge of conditions which have affected run-off, gives helpful information. While these procedures have not been carried on long enough or carefully enough to conclusively establish their value in predicting volume of run-off, thus far, it has been surprising, in normal years, to observe how closely the indicated water loss during and immediately following the snow run-off period equals the sub-surface ground water run-off during the period of snow accumulation.

No-one familiar with stream run-off would contend that a stream flowing at the rate of a second foot per square mile on a falling stage would always discharge the same volume of water from that time until the time it ceased to flow, if no precipitation fell on the drainage area during the period. There is, however, probably considerable similarity in the volume which would run off below this arbitrarily selected level of flow after fairly complete ground saturation, if the draining out of the sub-surface ground water takes place when evaporation and water required to supply the vegetation is relatively small, as is the case between the late fall and early spring.

CONCLUSIONS

1. — It seems hopeful that after a number of years of careful study of the problem on different streams by competent analysts, methods can be devised which will make possible the prediction of volumetric run-off during and immediately following the period of snow melt within the limits of about an inch of run-off, after assumptions have been made as to the amount of precipitation which will fall on the area during the period covered by the prediction.

2. — If consistent predictions within this limit are possible, they can be made only with very careful and extensive observations of precipitation and snow cover as well as the accumulation of statistics on all natural phenomena which affect volume of run-off. These predictions will probably require the full time study of a competent and experienced analyst from the date of the first snow accumulation until the run-off is complete.

3. — Many of the factors which influence volume of run-off are not now capable of even approximate determination, and are not likely to be accurately evaluated in the future, but information on the departure of these phenomena from normal, when used in conjunction with the analysis of the other influencing factors, will probably give results which are satisfactory in most instances.

4. — It is believed that there are relatively few situations where accurate volumetric prediction of run-off during snow melt is needed, but that in some of these situations, the matter is of very great importance, and that the solution, if accomplished, justifies any effort which may be required. The problems on each stream are different from those on any other, but there may be enough similarity in many instances to justify an attempt to standardize procedures so that the work done on one stream will be available to those who are attempting to solve the problems on other streams.

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