air-fields; his opinions have had much to do with the design of snow-removal and other engineering equipment; and he is being called upon to interpret hydrologic data for the operational planner in foreign theaters of war, which more often than not, are meager and inconclusive.

Experience has taught the value of continuity of record in the modern use of hydrologic data. The broken record is branded as a "statistical outcast", never wholly regaining its reputation. Those who are engaged in gathering hydrologic data are making it their business to keep observational stations in operation in spite of the difficulties imposed by war. The Corps of Engineers, Geological Survey, Soil Conservation Service, Tennessee Valley Authority, Weather Bureau, and other organizations and individuals are active in safeguarding our sources of data. The Section of Hydrology of the American Geophysical Union has reacted to the stimulus of war, and rather than "hole-in for the duration", has undertaken an active campaign for new members.

Yes, the hydrologist is in war, as in peace, proving worthy of the important element assigned him--water.

U. S. Weather Bureau,
Washington, D. C.

DISCUSSION

GEORGE H. CANFIELD (District Engineer, United States Geological Survey, Portland, Oregon)--Although there may be no discussion at this time, I do not want this moment to pass without expressing appreciation for the very fine presentation by J. C. STEVENS and MERRILL BERNARD on the functions performed by hydrology in the war effort. When first I saw this subject on the program I appreciated the fact that careful thought and study would be required to show this relationship adequately, which we all realize, and in a forceful way which would be understood by the public. I believe the others present will agree with me that both speakers have handled this assignment in a very creditable manner.

Mr. BERNARD'S statement mentioned the importance of no break in continuity of basic hydrologic data during this war. I am particularly interested in this thought as the United States Geological Survey is obtaining basic data as regards river-flow. We have been hit rather hard by induction of our men into the armed services or by the calling to active duty of our employees who were Reserve Officers, but it has been my thought, and also that of State Engineer STRICKLIN, with whom we cooperate, that we endeavor to maintain existing stream-flow measuring stations throughout the war even though there might be a delay in the computations of the records thereat. That is a somewhat different policy than occurred during the first World War, when several gaging-stations were temporarily discontinued and continuity of record interrupted. We plan and hope to obtain continuous records without interruption during the present war.

ELMER FISHER (Unit Supervisor, United States Weather Bureau, Portland, Oregon)--At the present time there are 280 stations in Region No. 7 equipped with recording precipitation-gages. Our losses in this type of station due to observers quitting or moving out of the community for high-paying positions has been less than five per cent. In many cases we have been able to secure new observers. Three new stations have been established. Considerable effort has been put forth by Hydrologic Inspectors, Unit Personnel, and other interested Weather Bureau officials to encourage observers to improve chart-records and it is believed that we can report some progress.

IMPROVING STREAM-FLOW PREDICTIONS BY THE USE OF PAST RECORDS

C. H. Niederhof

Since 1926 the management of the International Power and Paper Company, Ltd., has been forecasting stream-flow for the Grand Lake Basin in western Newfoundland. (Appreciation is extended to ERIC HINTON of Bowater's, Newfoundland Pulp and Paper Mills, Ltd., for furnishing the data upon which this paper is based.) As the company operates its paper-mill at Corner Brook exclusively by hydroelectric power, it is interested in the magnitude of the spring-flood which produces the major portion of the annual stream-flow. Accordingly, predictions of flood-magnitudes have been obtained in the early spring of each year since 1928 by means of snow-surveys and precipitation-records. The predicted runoff each year consisted simply of the water-content of snow calculated from a snow-survey made about the middle of March, plus precipitation measured until the end of March, plus a constant average figure--based on past records--expressing the

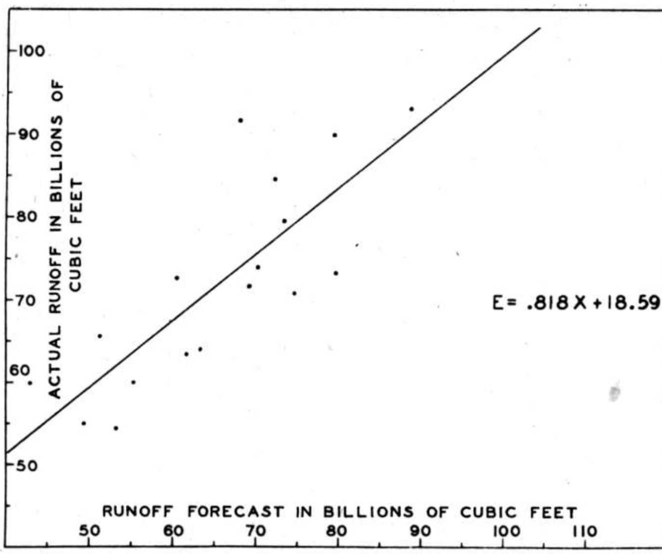

Fig. 1--Regression-line expressing relationship between actual and forecast runoff, in billions of cubic feet, based on snow-survey and precipitation records for the period 1928 to 1935

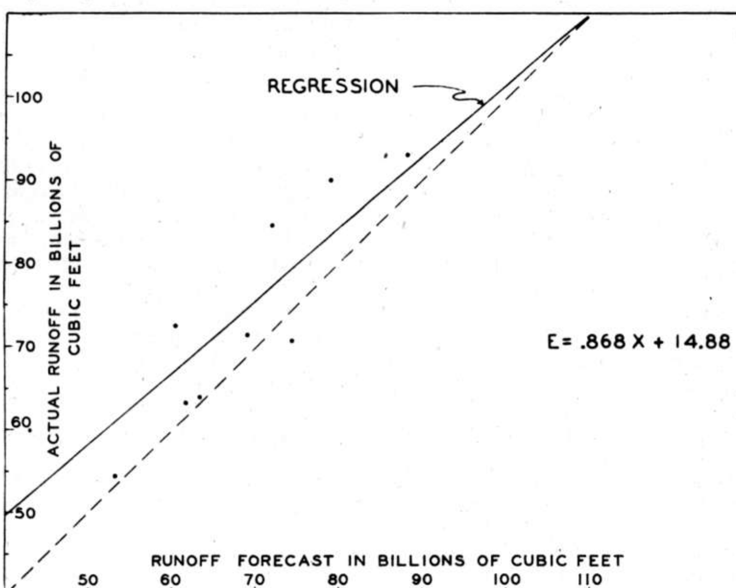

Fig. 2--Regression-line expressing relationship between actual and forecast runoff, in billions of cubic feet, based on snow-survey and precipitation records for the entire period 1926 to 1942

most probable precipitation after the end of March. All figures were expressed in billions of cubic feet (BCF). The results of the first ten years from 1926 to 1935 have been summarized and discussed by HINTON [see 1 of "References" at end of paper].

According to the data presented in HINTON'S paper, the predicted stream-flow has been less than the actual stream-flow in nine years out of ten. This fact led to the thought that subsequent forecasts (1936 to 1942) might have been improved if these ten years of records had been used as a modifying basis for future predictions. To test this hypothesis the following analysis was made.

The actual annual stream-flow for the first ten years, 1926 to 1935, was plotted against the

Table 1--Summary of actual and forecast runoff for period 1936 to 1942

Year	Actual annual runoff	Forecast runoff: Based on snow-survey and precipi-tation-record	Forecast runoff: Based on regression	Actual error: Based on snow-survey and precipi-tation-record	Actual error: Based on regression	Standard error of forecast
	BCF[a]	BCF	BCF	BCF	BCF	BCF
1936	91.8	67.8	73.7	-24.0	-18.1	±2.19
1937	59.9	55.2	62.8	- 4.7	2.9	±2.92
1938	54.9	49.3	57.7	- 5.6	2.8	±3.69
1939	73.2	79.5	83.9	6.3	10.7	±3.16
1940	65.7	51.3	59.4	-14.4	- 6.3	±3.42
1941	73.9	70.0	75.6	- 3.9	1.7	±2.26
1942	79.6	73.0	78.2	- 6.6	- 1.4	±2.46
Total error		.....	.....	65.5	43.9	....
Mean annual error		.....	.....	9.4	6.3	....
Improvement by use of regression-values: (9.4 - 6.3) = 3.1 BCF						

[a]BCF = billion cubic feet.

predicted stream-flow based on snow-survey and precipitation-records (Fig. 1). A regression-line was fitted to the plotted points by the method of least squares [2]. The regression-line fell to the left of the "dashed" line representing perfect correlation between predicted and actual stream-flow, indicating that on the average the predicted stream-flow has been less than the actual. This implies that subsequent predictions might have been improved if they had been increased by the amounts represented by the vertical distances between the "dashed" line and the regression-line. For example, if the runoff-forecast based on the snow-survey and precipitation-records for any year was 70 BCF, an improvement might have been attained by adding 5.6 BCF to the prediction, or, in other words, reading the value 75.6 BCF directly from the regression-line. The improved forecast "E" could also be obtained by solving the equation $E = (0.868\ X + 14.88)$, in which 70 BCF is substituted for X, in which case $E = 70(0.868\ X) + 14.88 = 75.6$.

To aid in demonstrating that the regression actually yields a better estimate of runoff than the forecast based solely on snow-survey and precipitation-records, Mr. HINTON kindly furnished the observed data from 1936 to 1942. These data are presented in Table 1, together with the "revised" estimates derived from the regression. The deviations for each year have been summarized and averaged regardless of sign to give the mean annual error for each method of forecasting.

In six out of the seven years the values derived from the regression are closer to the actual runoff than are those based solely on the snow-survey and precipitation-records. In the latter method the mean annual error is 9.4 BCF as compared with 6.3 BCF by the regression. This indicates that an improvement in runoff-forecasting of approximately 33 per cent was obtained by revising the predicted values by means of the regression. From the data available for the regression during 1926-35, the standard error of each regression-forecast can be calculated [2, Sec. 6.19]. These statistics indicate the error with which, in about two times out of three, the predicted runoff should estimate the actual runoff. As shown in Table 1, the actual error of the forecast is smaller than the standard error in four cases out of the seven.

To improve future estimates of runoff a regression-equation was calculated incorporating all the data from 1926 to 1942 (Fig. 2). Although this did not change the slope of the original regression-line appreciably, it is based on more data and should be more reliable in revising future forecasts of runoff. The standard error of each forecast in future years may be calculated from the equation

$$SE_F = \pm \sqrt{(V_{y.x}/17) + (X - \bar{x})^2\ (V_{y.x}/Sx^2)}$$

or, for the equation of 1926-42

$$SE_F = \pm \sqrt{3.4091 + (X - 65.3)^2\ (0.0242)}$$

Thus if, for example, the amount "X" predicted from a snow-survey and precipitation-data in some given year is 70 BCF, the expected amount of runoff should be about $E = 0.818(70) + 18.59 = 75.85$ BCF and the true runoff for the season (with 2:1 odds) should fall within a range of one standard error, or 1.98 BCF; with 19:1 odds it should fall within a range of "t" times the standard error, or $(2.13)(1.98) = \pm\ 4.22$ BCF on 15 degrees of freedom. Then, in 19 cases out of 20, the true runoff may be expected to lie between 71.63 and 80.07 BCF.

The correlation-coefficient for the new equation is 0.805 with a corresponding coefficient of determination of 0.649, which indicates that 64.9 per cent of the variation in actual runoff is associated with the variation in snow-survey and precipitation-records upon which the forecast of runoff is based. The 35.1 per cent of the variation in actual runoff unaccounted for may be associated with such factors as variation in ground-water levels from year to year, unpredictable spring rainfall, and insufficient snow-samples which inadequately represent conditions throughout the watershed.

In conclusion, it should be pointed out that the above regression would not be applicable to revise the forecast-runoff if the method of prediction, based on snow-survey and precipitation-records, should be changed radically in the future.

References

[1] ERIC HINTON, Forecasting runoff in Newfoundland by International Power and Paper Company, of Newfoundland, Ltd., Trans. Internat. Comm. Snow and Glaciers, Bull. 23, pp. 195-212, 1936.
[2] GEORGE W. SNEDECOR, Statistical methods, 3d edition (Chapters 6 and 7), Iowa State College Press, 1940.

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DISCUSSION

FRED PAGET (Department of Public Works, Sacramento, California)--It appears to me that, although Mr. NIEDERHOF'S suggestions are an improvement over Mr. HINTON'S 1935 methods, they may perhaps lag somewhat behind the present status of generally accepted snow-survey forecasting procedure. The latter's forecasts are based upon runoff of 100 per cent from the winter snow-pack plus runoff of 100 per cent from the precipitation that occurs during the melting period and in nine cases out of ten, as Mr. Niederhof points out, the forecasts have been too low. (The excess may be accounted for by a contribution to runoff from the precipitation during June to September greater than Mr. Hinton assumes.) Mr. Niederhof suggests that Mr. Hinton's forecasts be corrected by a certain amount based upon past performances--the amount to vary with the magnitude of the year.

My thought is that instead of going through these two steps of first forecasting on a premise, which apparently is not correct, and then correcting this inadequate forecast by a varying amount to bring it more in line with what might actually occur, why not do the whole thing in one operation, that is, plot the sum of the snow-pack water-content and the effective precipitation directly against the ensuing runoff according to past performances, and then use this curve directly for forecasting? This suggestion is in accordance with the forecasting methods used by the snow-survey department of the California State Division of Water Resources and has been described in previous Transactions; first in my paper at the Davis meeting in January, 1938, and discussed further in CARL ELGES' paper at the Los Angeles meeting in December, 1938.

SOIL-MOISTURE UNDER A CONIFEROUS FOREST

H. G. Wilm

On the Fraser Experimental Forest, Colorado, a detailed experiment is being conducted to find out the effects of cutting mature lodgepole-pine on various factors affecting water-yield [see 2 and 4 of "References" at end of paper]. Of these factors, soil-moisture deficiencies are particularly graphic in showing the relative consumption of water by uncut and cut-over stands. One year's data have been collected on soil-moisture deficiencies; although the study will require several more years for completion, the methods and results are of sufficient utility to be worth current discussion.

Experimental design--Twenty 5-acre plots in mature lodgepole-pine are being used for this and related experiments. The plots are arranged in four randomized blocks; in each block four plots were cut-over in 1940, leaving one plot uncut and one each with a commercial reserve stand of 0, 2,000, 4,000, or 6,000 board-feet per acre.