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.

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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.

The object of this particular experiment is to determine the influence of the cutting treatments on losses of moisture from the soil, including both transpiration and evaporation. The total loss per season on any plot may be expressed by the equation

$$L = (M_1 - M_2) + (P_N - P_p)$$

in which L is the loss, in inches of water, M_1 is the soil-moisture at field-capacity or, as measured in this study, the moisture in the soil just after disappearance of snow in the spring, M_2 is the moisture-content of the soil at the end of the growing season, P_N is the total net rainfall reaching the ground during the subsequent growing season, and P_p is the amount of precipitation which percolates into the soil beyond the greatest sampled depth, at any time between the spring and fall samplings.

For the purposes of this study the total loss, expressed by the above equation, is of less importance than the "net" loss in the autumn--the actual deficiency in soil-moisture below field-capacity, which must be replenished by melting snow before stream-flow can be produced.

Sampling procedures--The following factors must be measured for the soil on each of the 20 plots, within reasonable limits of accuracy: (1) Soil-moisture in spring and autumn; (2) volume-weight; (3) wilting-coefficient; (4) net precipitation reaching the soil during each growing season. Because of the rocky nature of the soil, moisture-contents and volume-weights cannot practically be sampled in a single operation; especially since the volume-weights need be obtained only once and approximately for each plot, while soil-moisture must be sampled with greater precision and twice a year for several years. Thus volume-weights and wilting-coefficients have not yet been obtained, while soil-moisture data by weight are already available for one complete season (1941). Precise data have also been obtained on net precipitation (2).

In sampling for soil-moisture, cores were taken to an 18-inch depth with a two-inch post-hole auger, at ten randomized locations on each of the 20 plots. In these shallow, rocky soils, 18 inches represents the average depth to parent material, and the lower limit of the bulk of lodgepole-pine roots. One set of 200 samples was taken in late September, 1941, and another at the same locations about June 1, 1942. A new set of samples has been taken at newly randomized locations in September, 1942, and will be followed by its own set of spring data and by at least one additional year's observations. All samples were boxed and weighed in the field. In the laboratory, they were oven-dried at 110°C and reweighed. Then each sample was sieved into portions containing material below and above two mm in size, and each portion weighed. In addition, the moisture-equivalent of the fine portion of each sample was obtained by the standard centrifuge-method and, by allowing for the amount of coarse material, was finally expressed on a whole-sample basis.

Analysis--The first year's data for this experiment were analyzed for several purposes: (1) To ascertain preliminary trends in soil-moisture and moisture-losses as affected by timber-cutting; (2) to determine the effectiveness of adjusting the moisture-content of each sample, expressed on a whole-sample basis, to the value which would be expected if all samples contained the same amount of fine material; and (3) to calculate the relation between spring moisture-content, as an estimate of field-capacity, and the moisture-equivalent of each sample. The data on autumn moisture-contents and deficiencies, expressed in grams per 100 grams of oven-dry soil, were analyzed by the covariance method (3), using the "fines" contents of the samples as a concomitant in linear regression. For the relation of field-capacity to moisture-equivalent, a straight line was fitted to the field-data by least squares.

Results--Soil-moisture deficiencies in the season of 1941 were strongly affected by the cutting treatments, with the greatest deficiencies on the uncut plots and the smallest on the clear-cut areas. Autumn soil-moisture contents naturally showed a corresponding trend; this effect, however, became significantly greater than experimental error only after adjustment of all data to the average content of fine material. This adjustment considerably increased the precision of the soil-moisture comparisons; without greatly altering the treatment-variance, it reduced experimental error to one-third of its unadjusted magnitude. The average results by treatments are shown in Table 1, with all data expressed in inches of water in an 18-inch soil-column, on the preliminary assumption of a uniform volume-weight of 1.50 for all plots.

An interesting point is that, while the average "fines" content per plot was highly correlated with autumn soil-moisture (r = +0.847), it was not significantly related to moisture-deficiencies (r = +0.241). For these soils apparently the autumn deficiency is affected largely by evapo-transpirational draft and is relatively independent of variations in soil-texture.

Table 1--Effect of timber-cutting on soil-moisture

Factor	Reserve stand, board-feet per acre				
	(Uncut) 11,890	6,000	4,000	2,000	0
	inch	inch	inch	inch	inch
Autumn soil-moisture[a]	2.67	3.07	3.29	3.12	4.21
Deficiency	1.76	1.53	1.39	1.20	0.32
Net precipitation summer 1941	3.92	4.87	5.19	5.01	5.47
Total loss	5.68	6.40	6.58	6.21	5.79

[a]Adjusted to the average content of fine material.

A high correlation (r = +0.839) was found between spring moisture-contents and moisture-equivalents, both expressed on a whole-sample basis. The relation was expressed by the equation

$$FC = 1.9733(ME) + 0.4408$$

According to this equation, the field-capacities of these soils are approximately two times the moisture-equivalents. This result confirms BROWNING'S data for soils with low moisture-equivalents [1]. Thus the common assumption of equality for field-capacity and moisture-equivalent is apparently false in these soils, and it is believed to be unsound for other coarse-textured soils. At least the assumption should be tested quantitatively in any new study.

On the last line of Table 1 are shown the total moisture-losses under the five treatments, calculated on an approximate basis by adding the total net rainfall for the summer of 1941 to the observed deficiencies. While there seems to be a weak trend among the treatments, it was not significantly greater than chance variations. It may be that most of the autumn deficiency under any one treatment is associated with rainfall-interception rather than with variations in the sum of evaporation and transpiration; high transpiration on uncut plots may be compensated by high evaporation on the cut-over areas.

It should be commented that ordinarily the autumn deficiency rather than total loss must determine the net effect of each treatment on water-yields from snow-melt in the following spring. Since summer rainfall contributes negligible amounts to stream-flow in this zone, its only effect may be to alter the relative autumn deficiency under each treatment. In a very dry or wet season, moisture in the soil under all treatments might be uniformly dry or wet, approaching either the wilting-coefficient or field-capacity.

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STREAM-FLOW FORECASTING BY PATTERN-BEHAVIOR

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Purpose and scope--The principle of pattern-repetition as a means for forecasting the annual runoff- and flood-peaks of major rivers was first presented in a brief paper by the author under date of April 9, 1942. Therein was submitted a preliminary application of the pattern-principle to the problem of forecasting the summer peak and total annual runoff of the Columbia River at Cascade Locks, Oregon, for the year 1941-42. Pattern-analysis as presented in our paper of April 1942 introduced an entirely new departure so far as we know in forecasting river-flow. The present paper has been prepared in an effort to amplify the initial preliminary procedure and to extend