WATER SUPPLY FORECASTS
IN
NORTHERN NEW ENGLAND

By

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ABSTRACT-- The Hartford River Forecast Center has developed procedures for the preparation of Water Supply Forecasts for selected basins in Northern New England. A suggested program of Water Supply Forecasts is presented and discussed. A sample set of forecasts is shown, and the comments and suggestions of all interested parties are requested.

Introduction-- One of the problems of river forecasting is to determine by some form of basin accounting procedure the budget of basin precipitation and runoff. In northern areas where snow accumulates during the winter months, it is helpful for the river forecaster to have some estimate of the amount of runoff which he may expect from this snow when it eventually melts. One of the by-products of this investigation is a forecast of runoff volumes which can be expected from winter precipitation. It is a relatively simple matter therefore for the Hartford River Forecast Center to supply estimates of expected seasonal runoff for selected points in New England and New York to users of such estimates of runoff volume.

Discussions of the techniques used in developing such forecasts are numerous, but the most pertinent are papers by BERNARD (1949) and KOHLER and LINSLEY (1949). KOHLER and LINSLEY discuss the details of the techniques that have been developed by the U. S. Weather Bureau for forecasting seasonal runoff from precipitation measurements. BERNARD shows that these same techniques are applicable to New England basins.

Initial Forecast Program-- For the past several years a seasonal runoff forecast has been made and published for the Kennebec River at The Forks, Me., from the procedure for this basin as discussed by BERNARD. It seems likely that there could be other basins in New England and New York for which similar forecasts would be useful.

In our preparation of river forecasting procedures a group of basins in Northern New England has been studied to develop snowmelt volume runoff forecasting procedures. These basins are as follows:

River	Station	
West Branch Penobscot River	Millinocket, Me.	(1)
West Branch Penobscot River	Grindstone, Me.	(2)
Kennebec River	The Forks, Me.	(3)
Dead River	The Forks, Me.	(4)
Androscoggin River	Errol, N.H.	(5)
Connecticut River	Dalton (nr), N.H.	(6)

(1) Adjusted for change in storage in Chesuncook, Ripogenus, Caribou, Amajejus, Pemadumcook, North Twin, South Twin and Elbow Lakes and Moose Pond.

(2) Including 240 sq.mi. drained by Chamberlain Lake through Telos Canal and adjusted for change in storage in Telos and Grand Lakes.

(3) Adjusted for change in storage in Brassua and Moosehead Lakes and Second Roach, First Roach and Moxie Ponds.

(4) Adjusted for change in contents in Flagstaff and Spencer Lakes and Dead River Pond.

(5) Adjusted for change in storage in Kennebago, Mooselookmeguntic, Rangeley, Upper Richardson, Lower Richardson, Azischos and Umagog Lake.

(6) Adjusted for change in contents in First Connecticut, Second Connecticut and Francis Lakes.

These basins are shown on the map in Fig. 1. The precipitation stations available for developing runoff forecasting procedures are also shown.

Certain variations from the procedures discussed by the previously mentioned authors were necessary due to the fact that the New England climate is different from the climate in the Western United States, where most of the previous work has been done, and further study has suggested some variations in the techniques discussed by BERNARD.

The runoff quantity forecast in these studies is the runoff from November through May. Experimentation revealed that the correlation between this runoff quantity and winter precipitation seemed best. Furthermore, the period November through May includes the period during which snow accumulates and melts in these basins. It is known that on November 1st snow would not have accumulated to any extent, except possibly in the extreme alpine areas that comprise a very small portion of these basins. On December 1st, however, snow would have accumulated in appreciable quantities in some years. By June 1st in almost every year snow would have disappeared completely except in the alpine regions.

Discussion of Procedures-- BERNARD shows in some detail the steps involved in developing procedures for forecasting seasonal runoff from precipitation. It would be well to recapitulate these steps with comments on the variations used by the Hartford River Forecast Center. Following are the steps involved:

1. Assembly of precipitation and stream-flow data by months. Practically all the basic data are to be found in the publications of the Weather Bureau and the Geological Survey.

2. Double-mass adjustment of precipitation records by comparison with a regional precipitation base as discussed by KOHLER (1949). These precipitation adjustments were performed in terms of water-year precipitation. The monthly distribution of precipitation in New England is quite even throughout the year in contrast to the Mediterranean type of distribution found in much of the Western United States. In the Western United States a great deal of the year's precipitation falls during the winter months, and, accordingly, precipitation adjustments are generally made in that area in terms of fall and winter precipitation.

3. Preliminary adjustment of runoff to the most recent period of record through comparison with a simple precipitation function. Testing for such a preliminary adjustment of runoff was made by comparing each basin's November through May runoff with the average November through May precipitation. No preliminary adjustments were found necessary.

4. Determination of precipitation station weights by means of a multiple correlation between November-May runoff and November-May precipitation at various stations.

5. Selection of station weights and computation of effective basin precipitation by months using those weights.

6. Determination of monthly weights by the use of multiple correlation between November-May runoff and the effective basin precipitation for each month from October through May. These computations were performed for two basins, Kennebec River at The Forks and Androscoggin at Errol. The resulting average weights were then used for all six basins.

7. Computation of the basin precipitation index for each year using monthly weights applied to the effective basin precipitation by months.

8. Determination of the relative effect of the previous year's precipitation by means of a three-variable correlation between November-May runoff, the precipitation index and the previous year's precipitation index. The effect of the previous year's precipitation was found to be negligible in all but one basin. In this basin, the Kennebec River at The Forks, Maine, a small carry-over effect was found and used, since it seemed to produce a significant improvement in the correlation.

9. The adjustments of runoff were checked by means of a double-mass plotting of computed versus observed runoff, the computed runoff being determined from the relationship between runoff and the precipitation index. No runoff adjustments were required for any of the Geological Survey data, but in one basin where the data were supplied from a private source an adjustment of the earlier years of record seemed indicated.

10. The final forecasting relationship consists of the linear regression between precipitation index (with or without carry-over) and runoff.

11. The correlation coefficient and average errors for the relationships were computed.

12. An analysis was made of the frequency distribution of partial precipitation indices for periods from a given forecast date through the end of the season. This technique, which is standard in the Weather Bureau, enables forecasts of runoffs associated with various probabilities of occurrence to be made very early in the season.

A tabulation of the various coefficients of determination at various stages of the analysis for each basin is shown in Table I. Table I shows the improvement in the correlations as various refinements are made to the procedures. It will be noted that no correlations are shown for the Dead River at The Forks, Maine, before the step using the precipitation index itself with smoothed station and monthly weights. The forecast for the Dead River at The Forks is made by using a weighted average of the precipitation indices for the Kennebec and Androscoggin Rivers. No precipitation stations are available in the Dead River Basin that were not already used for forecasting the two contiguous basins.

Figure 2 shows one of the final relations developed between precipitation index and November-May runoff.

Sample Forecasts--Sample forecasts for these basins are shown as appendices. Appendix A consists of the forecast as of January 1, 1959 and Appendix B consists of the forecast as of February 1, 1959, for the runoff period November 1948 through May 1959. These sample forecasts are furnished for inspection and comment.

Forecast Utility--There are certain questions as to the utility and form of such forecasts that can be answered only by the users of the forecast. Accordingly, a questionnaire has been added in the form of Appendix C. Any additional comments or suggestions are, of course welcome.

Future Expansion and Improvement of Water Supply Forecast in the Northeast--Water supply forecasts can be issued for many more basins in the Northeast than the six shown in this study. Certainly basins in upper New York State might be forecast and it is quite possible that more southerly basins, at least in the more mountainous regions, could be forecast. The problem in extending this type of forecasting consists of finding areas where there is a forecast advantage (or, in other words, where the time lag between precipitation as snow and subsequent snowmelt is long enough to be seasonal in character) and where there is a use for the forecast. Future studies certainly must be made to analyze in some objective way the problems of forecast time advantage.

Improvement of the forecasts as presently made can be accomplished in two ways. With the accrual of additional years of record, an increased reliability of the relationships can be expected. Due to the larger degrees of freedom available with longer records, it should be possible not only to increase the reliability of the present relations, but to further refine the relationships by more elaborate analyses. On the other hand, additional types of data may be utilized, the most obvious being measurements of snow water equivalent. Future plans include the use of such snow-survey data as time permits the necessary studies.

REFERENCES

Bernard, Merrill. The Long Term Precipitation - Runoff Relation as the Basis for Forecasting Water Supply, Trans. Amer. Geophys. Union, pp. 386-395, 1949.

Kohler, M. A. and R. K. Linsley, Jr. Recent Developments in Water Supply Forecasting from Precipitation, Trans. Amer. Geophys. Union, pp. 427-435, 1949.

Kohler, M. A. Double-Mass Analysis for Testing Consistency of Records for Making Required Adjustments. Bull. Am. Met. Soc., Vol. 30, pp. 188-189, May 1949.

TABLE I

VARIATION IN COEFFICIENTS OF DETERMINATION NORTHERN NEW ENGLAND WATER SUPPLY FORECASTS

Nov.-May Runoff Versus	Grindstone	Millinocket	The Forks (Kennebec)	The Forks (Dead)	Errol	Dalton
Av. Seasonal Pcpn (Nov.-May)	0.859	0.781	0.808	-	0.846	0.738
Station Wts. (Nov.-May)	.882	.812	.812	-	.861	.771
Assumed Station Wts. (Nov.-May)	.880	.808	.805	-	.859	.762
Monthly Weights (Oct.-May)	Not Used	Not Used	.956	Not Used	.893	Not Used
Assumed Monthly Wts.	.929	.867	.918	.904	.887	.891
Previous Yr's Index	Not Used	Not Used	.927	Not Used	Not Used	Not Used
Final Relation	.929	.933	.927	.904	.887	.891

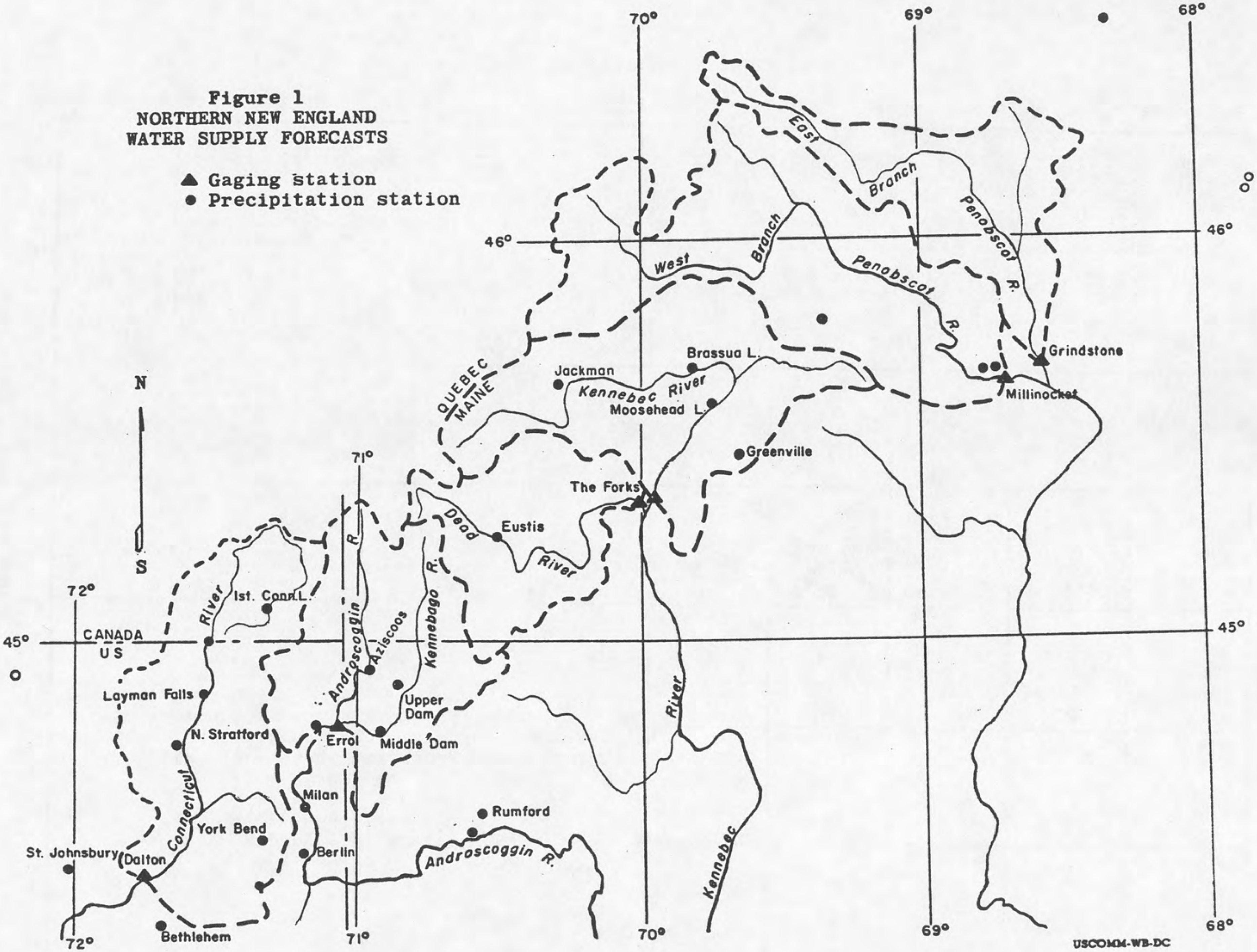

Figure 1
NORTHERN NEW ENGLAND
WATER SUPPLY FORECASTS

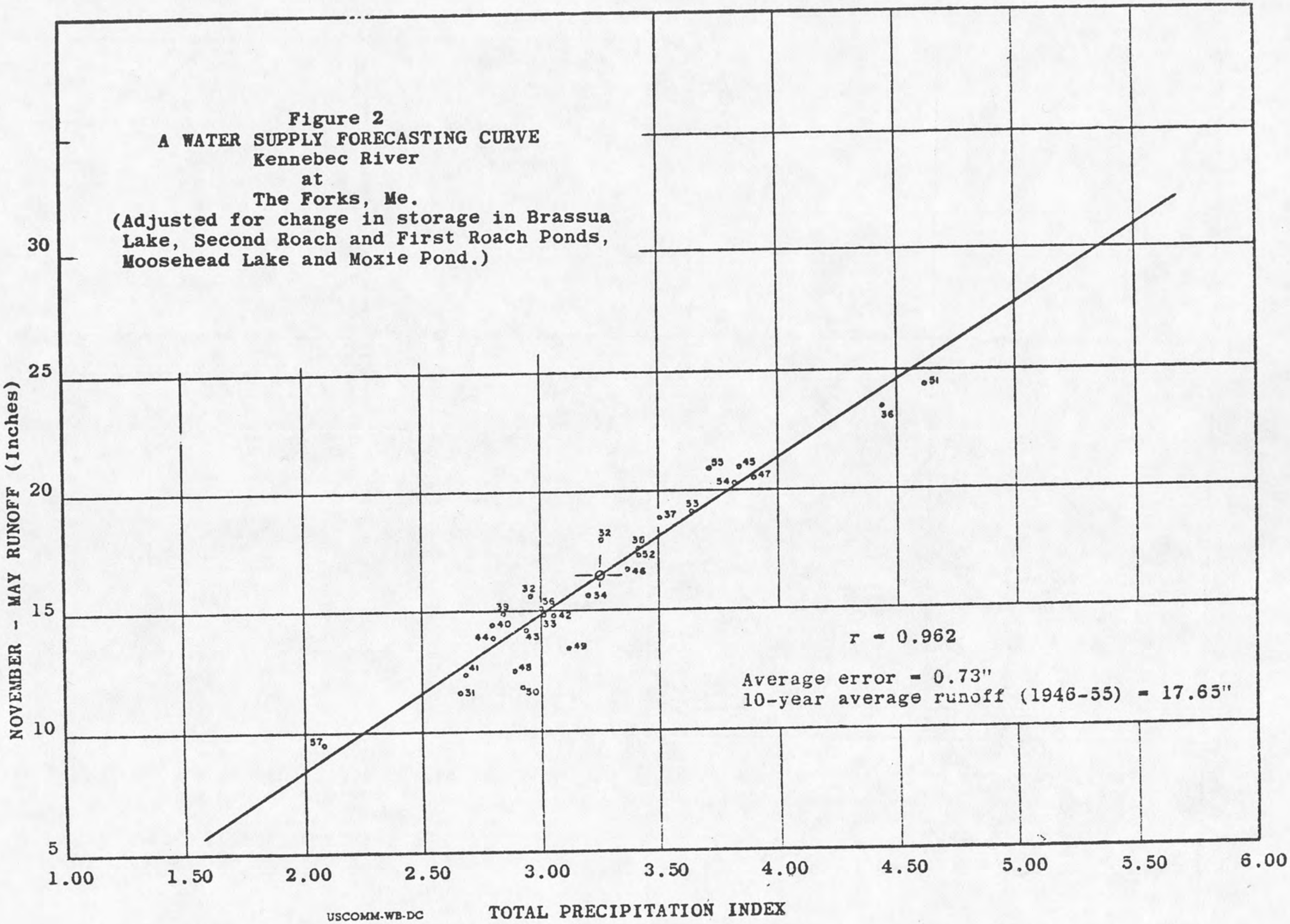

Figure 2
A WATER SUPPLY FORECASTING CURVE
Kennebec River
at
The Forks, Me.
(Adjusted for change in storage in Brassua Lake, Second Roach and First Roach Ponds, Moosehead Lake and Moxie Pond.)

APPENDIX "A"

WATER SUPPLY FORECASTS FOR NORTHERN NEW ENGLAND

Issued as of January 1, 1959

Summary of Forecasts

October through December precipitation in the headwater basins of Northern New England was 84% of normal. October precipitation amounts averaged 155% of normal, declining to 65% of normal in November and dipping further to 40% of normal in December.

The October precipitation ranged from 132% of normal in the East Branch of the Penobscot Basin to 187% of normal in the Androscoggin Basin. November precipitation ranged from 55% of normal in the West Branch of the Penobscot to 73% of normal in both the Androscoggin and the Connecticut Basins. December precipitation amounts were very low, ranging from 30% of normal in the East Branch of the Penobscot to 48% of normal in the Connecticut headwater areas.

If subsequent precipitation through May is near normal, the water supply outlook is for an average of 85% of the 1946-55 average water-year streamflow for Northern New England headwater basins.

Explanation

Weather Bureau forecasts of runoff presented in this bulletin are computed from procedures based on mathematical analyses of the relation between precipitation and runoff. The precipitation data used in the analyses are from publications of the U. S. Weather Bureau. The stream-flow data are from publications of the U. S. Geological Survey. These forecasts have been prepared by the River Forecast Center, U. S. Weather Bureau, Bradley Field, Windsor Locks, Conn, and any inquiries or correspondence concerning them should be addressed to that office.

The success of water supply forecasting from precipitation is in large measure due to the time lag between winter precipitation and spring runoff and the greater effectiveness of winter precipitation in producing runoff as compared to that occurring during the spring. The basic procedures relate seasonal precipitation (October through May) to November through May runoff. These forecasts can be converted into residual forecasts by subtraction of the flow to date or a reasonable estimate thereof. In order to prepare a forecast as of any date, the precipitation from that date through May 31st must be added to the precipitation already observed. Although little success has been achieved in forecasting precipitation several months in advance, it is possible to utilize expressions of future precipitation which have known probabilities of occurrence as determined by analyses of past records.

A brief description of the method of determining probabilities follows:

It is assumed that the January 1 forecast is being prepared for a particular basin. As the January through May precipitation is not known, it must be assigned a value. To this end, the effective precipitation for January through May for the years of record (27 in all) is tabulated in order of magnitude. From this tabulation it is possible to determine the percent of the years which have had precipitation greater or less than that which occurred in any particular year. Thus, it is seen that the middle value of the tabulation has been exceeded in 50% of the years, and it may therefore be assumed that the probability of its being exceeded during the coming year is 50%. This middle value, called the median, has, therefore, the odds of one-to-one of being exceeded. Likewise, the analysis of the 27 years of record shows odds of approximately 1 to 27 that the maximum year's value will be equalled or exceeded. Odds of 27 to 1 apply to the value of the minimum year of record. In order that the user of the forecasts may have some idea of the intermediate chances, or odds, favoring his operation, two other values are presented which are usually referred to as the quartiles or quarter points. Thus the precipitation may be expected to exceed the lower quartile value on an average of 3 years out of 4, that is, with odds of 3 to 1. The upper quartile will be reached or exceeded, on the average, in 1 year out of every 4. In other words, the odds are 1 to 3 that precipitation equal to or greater than the upper quartile will occur in any one year.

The basic Weather Bureau forecasts are given in columns 2 and 3 of the table. These are computed on the assumption that subsequent precipitation will be equal to the median of record. The forecasts are given in inches of runoff and in percent of the 10-year average flow.

The flow given in column 4 is the average November through May runoff for the water years 1945-46 through 1954-55 in inches of runoff. These are the last 10 years now published.

Observed flows for the next two years after the end of present publication are summarized in columns 5 and 6 in inches of runoff.

Columns 7 through 10 show the flow volumes corresponding to various assumed precipitation values (through May) of known probability, namely, extremes and quartiles. While it is known that the odds for the runoff values are not necessarily the same as those for precipitation, it has been found that they are sufficiently close to serve all practical purposes.

1959 WATER SUPPLY FORECASTS

Issued as of: January 1, 1959

Stream and Station	Seasonal Flow Nov. 1958 thru May 1959			Nov. thru May flow of previous years		Nov. thru May flow to be expected if precipitation for remainder of season is equal to:							
	Forecast		10-year Average	1955-56 (a)	1956-57 (a)	Minimum of record		Lower Quartile		Upper Quartile		Maximum of record	
(1)	Inches (2)	% 10-yr Avg (3)	Inches (4)	Inches (5)	Inches (6)	Inches (7)	% 10-yr Avg (8)	Inches (9)	% 10-yr Avg (10)	Inches (11)	% 10-yr Avg (12)	Inches (13)	% 10-yr Avg (14)
WEST BRANCH PENOBSCOT RIVER Millinocket, Me. (1)	14.6	79%	18.66	13.39	9.74	9.9	53%	13.4	72%	17.2	93%	23.1	124%
EAST BRANCH PENOBSCOT RIVER Grindstone, Me. (2)	15.5	77%	20.13	12.49	10.91	10.4	52%	14.3	71%	17.6	87%	24.6	122%
KENNEBEC RIVER The Forks, Me. (3)	15.2	86%	17.65	15.05	9.48	10.0	57%	13.2	75%	17.5	99%	24.4	138%
DEAD RIVER The Forks, Me. (4)	14.9	83%	17.99	16.04	10.30	9.5	53%	13.4	75%	17.5	97%	24.4	136%
ANDROSCOGGIN RIVER Errol, N.H. (5)	18.3	89%	20.63	17.95	12.77	11.1	54%	16.4	80%	20.8	101%	27.2	132%
CONNECTICUT RIVER Dalton (nr) N.H. (6)	18.5	94%	19.72	17.64	14.59	13.6	69%	17.0	86%	20.0	101%	24.6	125%

(a) Preliminary data furnished by U.S. Geological Survey (Subject to Revision)
(1) Adjusted for change in storage in Chesuncook, Ripogenus, Caribou, Amajejus, Pemadumcook, North Twin, South Twin and Elbow Lakes and Moose Pond.
(2) Including 240 sq.mi. drained by Chamberlain Lake through Telos Canal and adjusted for change in storage in Telos & Grand Lakes.
(3) Adjusted for change in storage in Brassua and Moosehead Lakes and Second Roach, First Roach and Moxie Ponds.
(4) Adjusted for change in contents in Flagstaff and Spencer Lakes and Dead River Pond.
(5) Adjusted for change in storage in Kennebago, Mooselookmeguntic, Rangeley, Upper Richardson, Lower Richardson, Aziscohos and Umbagog Lake.
(6) Adjusted for change in contents in First Connecticut, Second Connecticut and Francis Lakes.

APPENDIX "B"

WATER SUPPLY FORECASTS FOR NORTHERN NEW ENGLAND

Issued as of February 1, 1959

Summary of Forecasts

January precipitation was considerably above normal in the Connecticut Basin, but, by and large, fell off to near normal or even below to the east. Consequently, as compared to the January forecasts, those for the Connecticut Basin are increased considerably. For the Androscoggin, Dead, and Kennebec Basins they are slightly higher, and for the Penobscot are the same or lower.

If subsequent precipitation through May is near normal, the water supply outlook is for an average of 87% of the 1946-55 average water year streamflow for Northern New England headwater basins.

1959 WATER SUPPLY FORECASTS

Issued as of: February 1, 1959

Stream and Station	Seasonal Flow Nov. 1958 thru May 1959			Nov. thru May flow of previous years		Nov. thru May flow to be expected if precipitation for remainder of season is equal to:							
	Forecast		10-year Average	1955-56 (a)	1956-57 (a)	Minimum of Record		Lower Quartile		Upper Quartile		Maximum of Record	
(1)	Inches (2)	% 10-yr Avg (3)	Inches (4)	Inches (5)	Inches (6)	Inches (7)	% 10-yr Avg (8)	Inches (9)	% 10-yr Avg (10)	Inches (11)	% 10-yr Avg (12)	Inches (13)	% 10-yr Avg (14)
WEST BRANCH PENOBSCOT RIVER Millinocket, Me. (1)	14.7	79%	18.66	13.39	9.74	11.0	59%	13.5	72%	16.5	89%	21.1	113%
EAST BRANCH PENOBSCOT RIVER Grindstone, Me. (2)	15.2	75%	20.13	12.49	10.91	11.2	56%	14.2	71%	17.2	85%	22.7	113%
KENNEBEC RIVER The Forks, Me. (3)	15.5	88%	17.65	15.05	9.48	11.5	65%	13.9	79%	17.2	98%	22.1	125%
DEAD RIVER The Forks, Me. (4)	15.4	86%	17.99	16.04	10.30	10.5	58%	13.5	75%	18.0	100%	23.0	128%
ANDROSCOGGIN RIVER Errol, N. H. (5)	19.0	92%	20.63	17.95	12.77	13.2	64%	16.9	82%	20.9	101%	27.0	131%
CONNECTICUT RIVER Dalton (nr), N.H. (6)	19.9	101%	19.72	17.64	14.59	15.8	80%	18.2	92%	21.1	107%	25.1	127%

(a) Preliminary data furnished by U.S. Geological Survey (Subject to Revision)
(1) Adjusted for change in storage in Chesuncook, Ripogenus, Caribou, Amajejus, Pemadumcook, North Twin, South Twin and Elbow Lakes and Moose Pond.
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