AN ANALYSIS OF LONG TERM SNOW COVER RECORD AS RELATED TO HYDRO-ELECTRIC OPERATION

by

Louis D. Pierce
Civil Engineering Department, New England Power Company
Boston, Massachusetts

In June 1907, a small group held a meeting on an island in the Connecticut River close by Bellows Falls, Vt. At this meeting the organization of a corporation to be known as the Connecticut River Power Company was perfected. Following the election of officers and a board of directors, authorization was voted for the construction of a hydro-electric plant on the Connecticut River, between Vernon, Vt., and Hinsdale, N. H., which was later named Vernon Station.

Here at Vernon was the genesis of the present New England Electric System, New England's largest integrated power system, combining both steam and hydro power sources. Following the construction of the Vernon Plant additional hydro capacity was added on the Deerfield, and thence on the Connecticut, until the completion of the Moore Station on the Connecticut near Littleton, N. H., completed a fairly comprehensive utilization of the economically feasible head available on these two river systems. During this period and since, steam generation was also being acquired with plants in Providence, R. I., and new steam generating facilities added at tidewater in Salem, Mass., and inland at Worcester, Mass. Today the system, which serves some 820,000 customers over an area of 4,750 square miles, has available generating capacity of some 550,000 Kilowatts of hydro and 930,000 Kilowatts of steam. In testing stage is the Yankee Atomic Plant, a heterogeneous pressurized light water reactor type with ultimate capacity of 134,000 Kilowatts, in which the system has some 30% ownership interest, and a new steam generating station on which construction is about to begin, with two units totaling 450,000 Kilowatts, due for completion in 1963 and 1964.

Early in the system history, when hydro capacity provided the bulk of the generating facilities available, the proper operation of these facilities to economically utilize all available water became a primary concern of the dispatching and operating forces. Now more than ever the hydro generation and operation is of importance in that it carries the peak loads and provides the regulation necessary for meeting the daily load demand as expeditiously and economically as possible. Regulation of the daily load or the absorption of the hourly fringe is carried most of the time during the day by the Moore Hydro Station. At night and during periods of heavy river flow when all hydro is running wide open, Salem Harbor steam will provide the regulation. During these times the hydro is essentially carrying the base load.

Seasonal operation of the storage available in First and Second Lakes, Moore and Comerford on the Connecticut (see figure 1), and Harriman and Somerset on the Deerfield (see figure 2), involve a low draw in the spring to accommodate the runoff from melting snow and the spring rains. This results in full or nearly full reservoirs by the end of May or early June. The drawdown period generally extends from July through the following March, with the timing and rate of drawdown depending upon various influences including load conditions, hydrological conditions, and the availability of power from other sources. Some refill of the storage is frequently obtained in November. Although this procedure is generally followed year after year, the timing and amount of this low draw limit and the timing and rate of the refill cycle is influenced by the snow measurements taken semi-monthly throughout the snow season, the anticipated precipitation during the spring months of March, April, and May, and the expected rate and form of the precipitation and snow melt runoff.

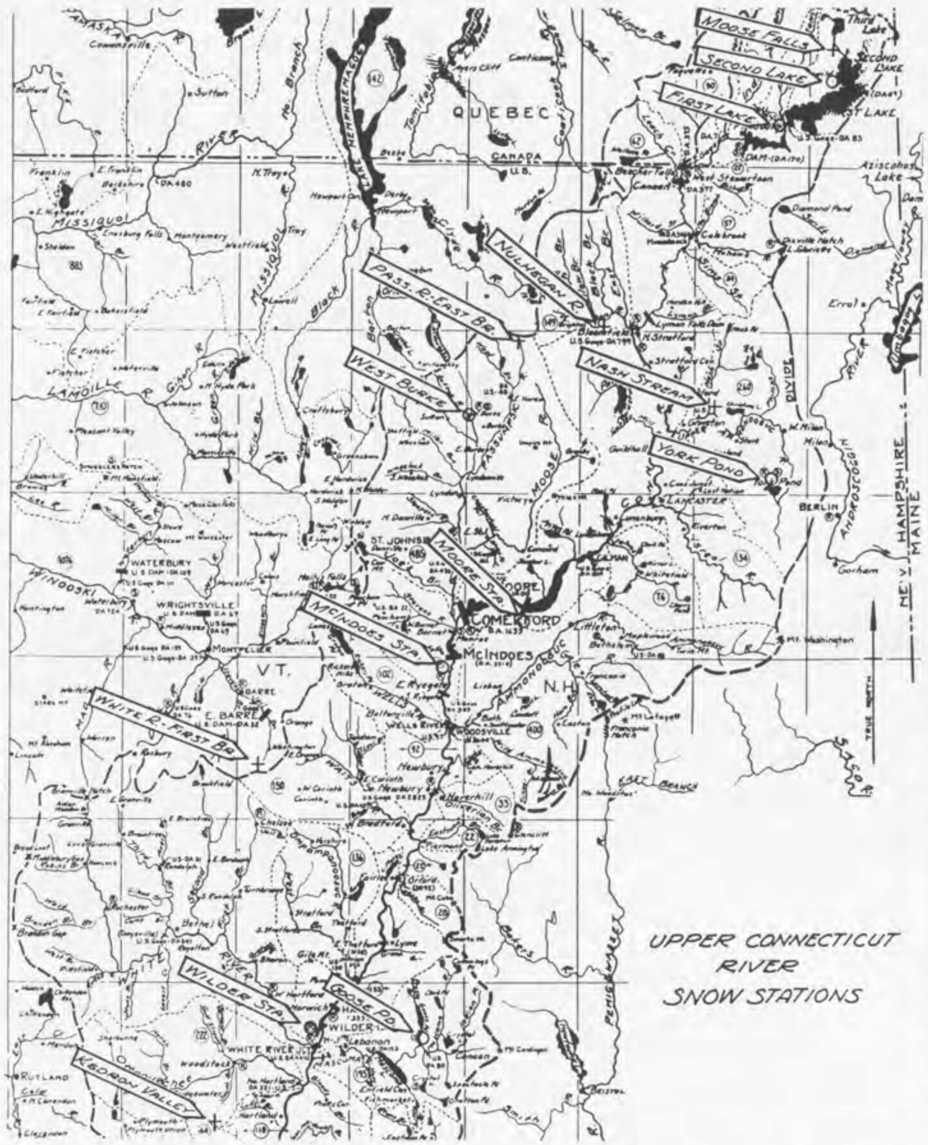

Figure 1. Map showing Upper Connecticut River Snow Stations

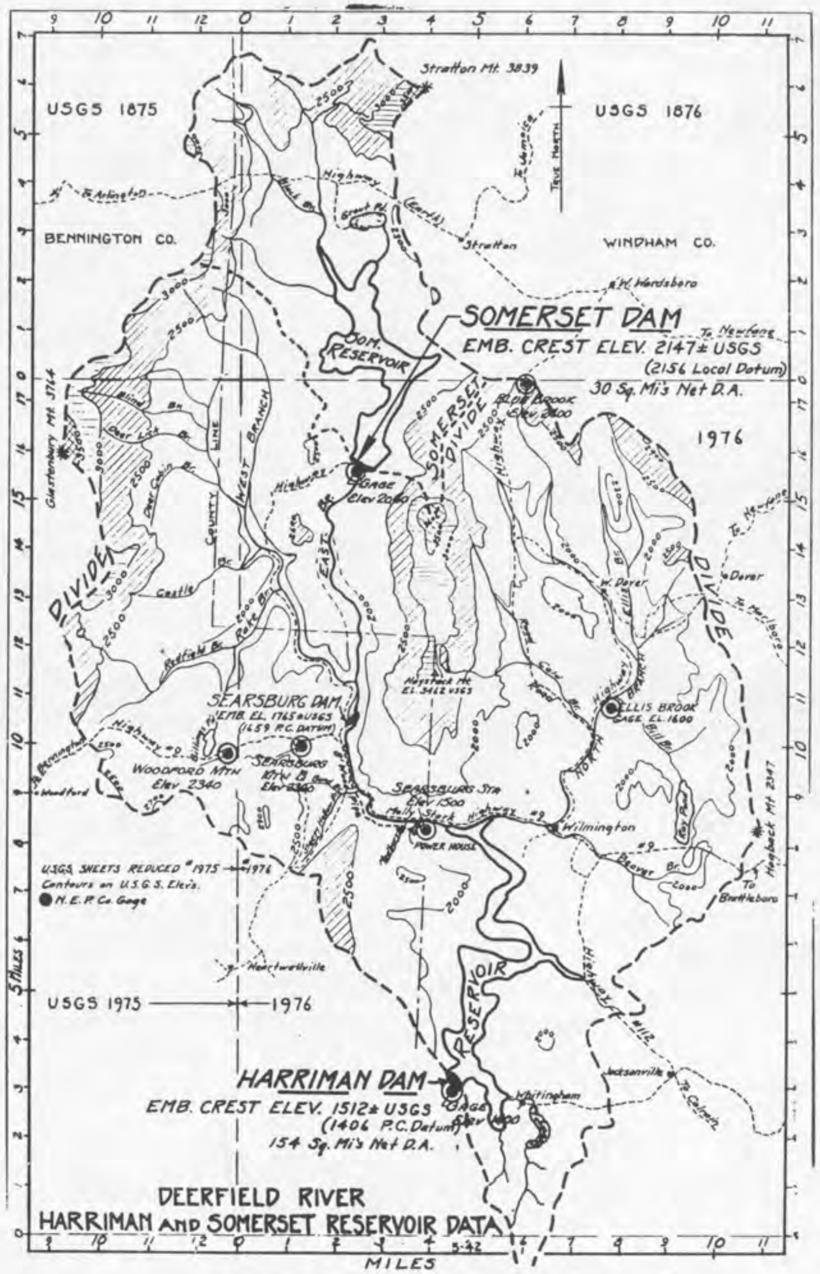

Figure 2. Map of Deerfield River Basin showing Harriman and Somerset Reservoir Data

Following the completion of the first storage reservoir on the Deerfield at Somerset, and during these early years when hydro capacity formed the bulk of the generating facilities, the value of a knowledge of potential runoff in the form of snow on the watershed was fully recognized. As a result, measurement of snow depth was begun at a few station locations in the Somerset area in the winter of 1914. The early attempts at snow measurement were more or less experimental as to station location and equipment used, and the data obtained was limited in scope and of questionable accuracy. During this first phase, which extended over a period of 10 years until about 1925, two methods of measurement were utilized. The first several years of measurements were made merely by using the precipitation can as a collector of each snow fall. The snow catch was then melted and the melt volume obtained by measurement in the gage glass. Depth of snow on the ground was taken with a rule at various times during the season. Following this a second method was introduced by which measurements were made with a snow board, obtaining depth from the accumulated snow on the board. Water content was determined by melting down a sample coring obtained off the snow board with a sheet metal cylinder 8" in diameter. Each storm was measured separately, the board being reset on the surface of the snow after each storm. The total of the individual storm records was corrected by making assumptions as to loss by melt and evaporation. In the light of the present development of the science, we can see that these early methods left much to be desired.

With the completion of the remaining Deerfield sites at Searsburg, Harriman, and Sherman in the early 1920's, a more comprehensive program was felt necessary, using better methods for obtaining measurements than heretofore. Consequently in 1925 equipment somewhat similar to that used today was introduced. This consisted of a 4" diameter iron pipe to obtain the snow sample, a pail into which the sample was deposited, and a platform type scales for weighing the sample. The weight was converted to inches of water by use of a constant. The extent of the survey was expanded by the establishment of five regular stations; two in the Somerset drainage area, and three in the Harriman area. A schedule of bi-monthly readings was also established. In addition to the readings at the regular stations, supplemental readings were introduced as the runoff season approached in typical areas throughout the watershed. These readings, besides supplementing the bi-monthly observations, also served as a check as to the area representation of the five regular stations.

Because of the weight involved in transporting the above described sampling equipment from location to location, the sampling tube was changed in 1928 to a 3" Shelby steel tube. In this same period additional development of the Connecticut River was in progress with the completion of plants at Bellows Falls, Comerford, McIndoes, and storage reservoirs at the Connecticut Lakes through the early 1930's. As this development progressed additional regular snow stations were established for bi-monthly checks in the upper Connecticut watershed. In addition, the one-shot general watershed sampling previously mentioned in the Deerfield area was also extended to the Connecticut area.

Sampling continued with the previously described equipment until 1945, when, after several studies of our whole procedure, we converted to our present equipment, making it universal throughout the system. Our present equipment is a variation of the Kadel type and consists of a standard rolled 3" aluminum tube with replaceable steel cutter of our design having a bore of 2.655" and a standard Chatillon spring scale with a special plastic dial calibrated directly to inches of water. Weight saving over the older type was one great advantage with the new equipment.

From 1945 to 1958 observations were made semimonthly at 13 regular stations located generally near the various plants so as to be readily accessible to

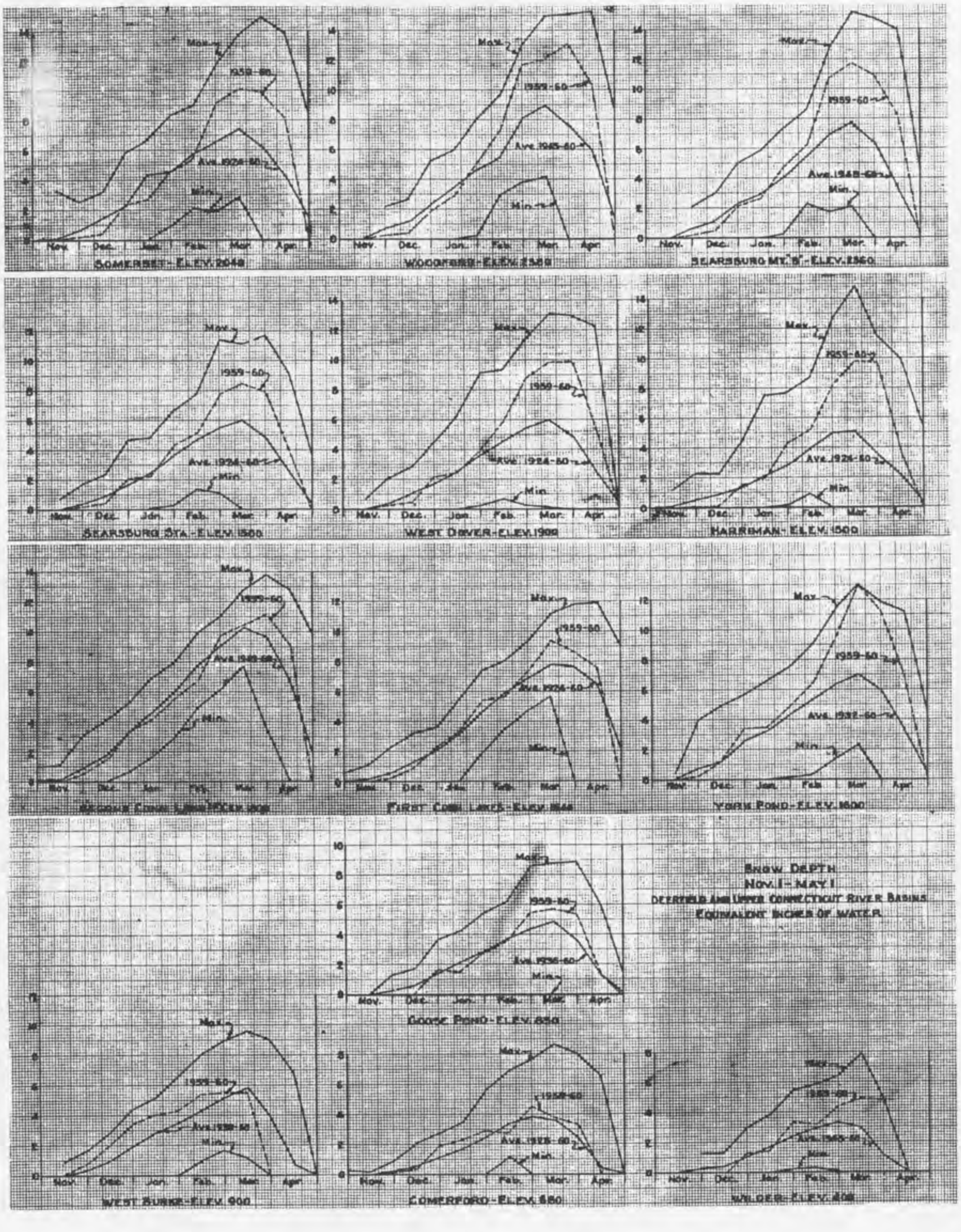

Figure 3. Snow depths, November 1 to May 1, Deerfield and Upper Connecticut River Basins

station operating personnel. In addition, some 120 sampling stations were being covered on the general watershed survey, which was made around the first of March. In 1958 studies showed that the March 1st general survey did not add enough additional knowledge of snow depth coverage to warrant the time and expense involved. On the basis of the studies made of these measurement results, some nine pilot stations were selected, one in each tributary watershed, which reflected average conditions of all those previously being taken on the March 1st survey in a particular watershed area. These pilot stations were scheduled for reading on a semimonthly basis, and the remaining stations formerly read were abandoned. Consequently, as of today, our program consists of thirteen regular and nine pilot stations read semimonthly, with the results plotted in chart form for use of all interested departments. The slide you are now viewing is a plotting of the regular stations only, showing the average, minimum, maximum, and previous year's records.

In preparation for this paper, an analysis was made of the long term record existing on the upper Deerfield Watershed utilizing the measurements of the six stations located in this area (see figure 3). Four of these stations have been continuously maintained in their present locations since 1924. One begun in 1924 was moved a short distance from its original location in 1945, and the sixth was a new station established in 1945. The results of the summarization utilizing 36 years of record revealed the following interesting facts:

A. The average of the annual maximums of the water content of the snow cover, which occurs mainly in March, is 7.7 inches, varying from a low of 3.3 inches in 1957 to a maximum of 13.6 inches in 1958.

B. Considering the three months March, April, and May for relating snow water, precipitation, and runoff, the average of the water content of the snow cover as of March 1st is 6.3 inches; adding to this the three-month precipitation average of 13.5 inches, we have 19.8 inches' of water available. The average runoff for this period has been 18.95 inches and the resulting percentage of recovery is 96%.

C. Neglecting any loss in the three-month period precipitation on the basis of the above high percentage of delivery, the difference between runoff and precipitation equals 5.45 inches, or 86% of the average March 1st snow water figures of 6.3 inches.

The system dispatching and operating personnel have been forecasting runoff for the spring-fill months since about 1931, using the results of the semimonthly snow water data being obtained. The forecasting methods have been continuously improved as more years of record became available. Today the runoff forecast is made utilizing average spring precipitation figures, snow water on the ground as of February 15, and this total adjusted for a specific year as to departure from normal on the basis of precipitation totals for the previous summer and fall. Specifically the forecast is determined as follows: To the snow water on the ground, as of February 15, is added the average of record of the precipitation total for the spring period from February 15 through June 1, this being generally the period of melt, and June 1 the time of expected full reservoirs. The above figure of potential water available for runoff is adjusted in an attempt to allow for variation from the normal. This correction amount is based on the excess or deficiency from normal of the previous summer and fall precipitation total for the period June 1 to November 1. Should the previous summer-fall precipitation be less than the normal, a correction amount of 42% of the deficiency in inches is subtracted from the expected available water for runoff. If the previous summer-fall precipitation is more than the normal, a correction amount of 18% of the excess in inches is added to the expected runoff figure. The correction can be picked off a curve (see figure 4). The smaller percentage correction applied

SPRING RUNOFF FORECAST - FEBRUARY 15-JUNE 1 - HARRIMAN

1960

1	2	3	4	5	6	7	8	9	10
	Actual Precip. 1960		36 Yr. Ave. Precip. to Date	Act. Ave. Precip. 2/15 to Date	Exp't R/O 2/15 to 6/1	Act. R/O to Date	Present Exp't R/O	Present Reservoir Contents	Exp't. Use or Spill before 6/1 Elev. 14.00"
	for the internal	Feb. 15 to date							
Feb. 15					22.20				
15-29	2.66	2.66	1.59	+1.07	23.27	.80	22.47	7.07	15.54
March 15	1.04	3.70	3.76	- .06	22.14	1.26	20.88	2.72	9.60
15-31	1.91	5.61	6.01	- .40	21.80	2.25	19.55	1.46	7.01
April 15	3.77	9.38	8.39	.99	23.19	11.79	11.40	8.29	5.69
15-30	2.61	11,99	10.55	1.44	23.64	18,93	4.71	11.61	2.32
May 15	2.46	14.45	12.69	1.76	23.96	20.85			
15-31	1.20	15.65	15.12	0.53	22.73	21.94			

Water 2/15	5.88
Ave. Precip. 2/15 - 6/1	15.12
	21.00
Correction	+1.20
	22.20

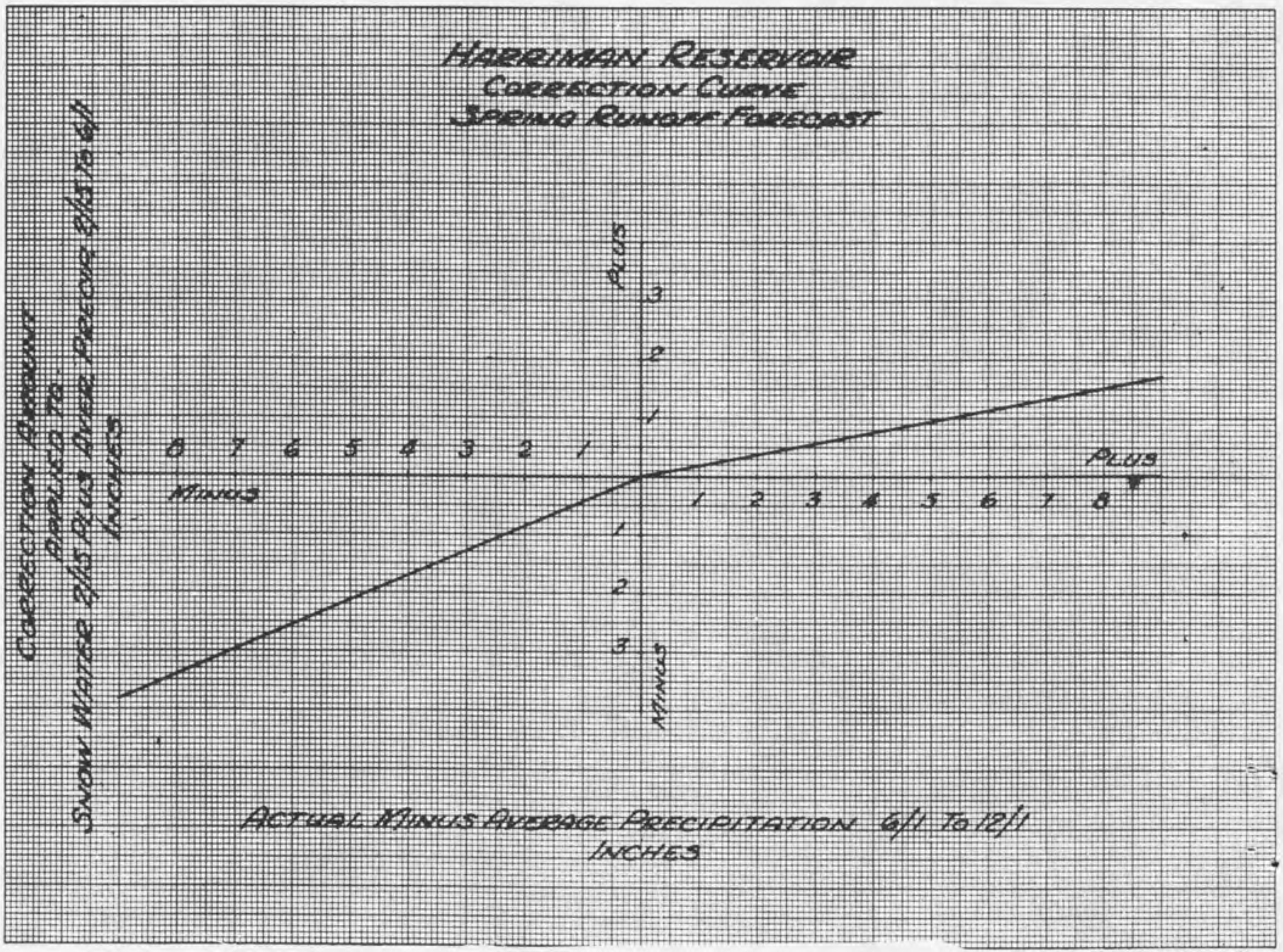

Figure 4. Harriman Reservoir, correction curve for Spring runoff forecast

to excess is based on the assumption that any unusually high precipitation runs off relatively soon and would not be available as ground water to affect the spring period. This prediction for expected runoff is made immediately upon receiving the February 15 snow measurements. As the season progresses, a semimonthly check is made and an adjustment is applied to the originally determined runoff total. The procedure of adjustment is demonstrated by figure 5. The first two columns following the date column tabulate the interval and accumulated total of precipitation for the spring period. The next column gives the normal precipitation of record for the equivalent period. The following column shows excess or deficiency of the actual precipitation for each period amount from the normal. In column 6 is the adjusted expected spring runoff figure corrected by the precipitation excess or deficiency from normal from column 5. The next two columns account the runoff, column 7 listing actual runoff for the period, and column 8 the remaining runoff expected by subtracting the actual runoff from the forecast of column 6. The last two column relate reservoir fill conditions to the expected runoff, column 9 showing current contents in inches, and the last column the inches of runoff available for use over and above that needed to fill, which in the case of Harriman is 14 inches. The dispatcher, by maintaining a semimonthly accounting of all water available on the watershed during this critical period, is able to determine fairly closely the rate at which he must put water into the reservoir in order to fill by the end of the period, and yet know the excess of water he has available for release to generating plants below during the period. The tabular notation under the table is the calculation figures for the runoff forecast, which for this particular year was 22.2 inches. The actual runoff for the period was 21.9 inches, the last figure of column 7. So the dispatcher didn't do too badly for this particular year.

It is felt that this paper would not be complete without, in conclusion, making reference to the record of the Deerfield snow cover in its effect on maximum flows. Many times, with a heavy runoff potential lying on the ground in the form of snow water, we are prone to anticipate, as a consequence, heavy runoff of major flood proportions. As we all know the snow pack requires special meteorological conditions of temperature and additional heavy precipitation for it to contribute very heavily to flood flow buildup. An analysis of annual peak flow conditions on the Deerfield, as registered at the United States Geological Survey gauge at Charlemont, Mass., for the period 1926 to date, shows the following:

> There were some 21 occurrences in which the peak discharge has exceeded 10,000 cfs or 27 cfs/sq. mile on the drainage area.
>
> Of these 21 occurrences, 8 of them occurred during the snow melt season.
>
> In the case of 3 of these 8, precipitation in the form of rain was a major contributing factor governing the size of the peak flows, March 1936 being a notable example of one of these.
>
> Of the remaining 5, in which snow melt was a major contributing factor, the highest of these was 8th in order of size.

So it can be seen that although snow on the ground forms a potential flood threat, the records show that in very few instances has snow runoff in itself contributed to the major flood peaks.