

SNOW SURVEY RECORD

Need of Long Term Records for Flood Regulation*

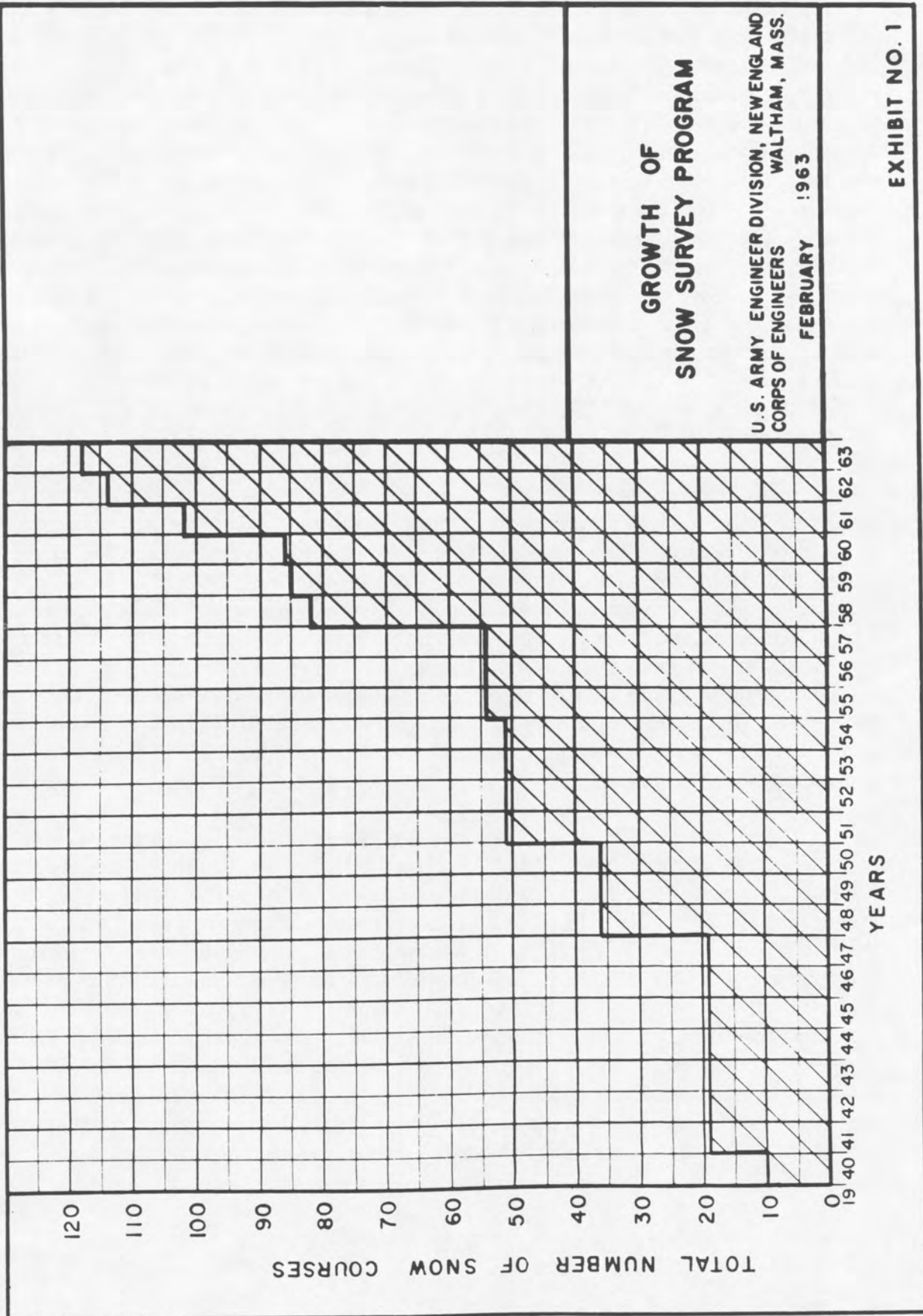
The Corps of Engineers in New England are relative newcomers to the field of snow measurements. For that reason the value of short term samples may be of greater concern to us than to those of you who have been collecting data for many years.

Historical records indicate that floods in New England can occur during any month of the year. However, on most of the larger streams the flood of record has been the result of snowmelt combined with warm rain such as experienced in March 1936. With the construction of flood control dams it became readily apparent that knowledge of the snow pack is necessary for the most efficient use of the reservoir storage during the spring runoff.

At the present time there are 22 flood control reservoirs in operation in the New England Division. To assist in the regulation of these reservoirs snow measurements are made at approximately 120 snow courses. This data is supplemented by similar information from power companies and other federal and state agencies. Exhibit No. 1 is a graph depicting the growth of the snow survey program maintained by the Corps of Engineers. It is possible to draw a parallel diagram indicating the growth of the flood control reservoir system, since every time we complete a new dam we add three to five additional snow courses to our program. Despite the large number of courses, an examination of Figure No. 1 shows that more than half of the snow courses have less than five years of record, which statistically speaking means no record.

As the program expanded during the last five to ten years the New England Division found itself collecting more snow data than any other single agency or private company. As a result of this, they began to receive more and more requests from interested parties inquiring as to the current condition of the snow pack at various locations in New England. It must be noted that when the term "New England" is used, it does not include the State of Maine, since to date, the Corps has not been able to justify any flood control reservoirs in that state. The Corps must rely on the Weather Bureau, the Geological Survey and the power and paper companies in that state for data on snow or snowmelt runoff.

* By Nicholas Lalley, Chief, Flood Plain Information Section, Corps of Engineers Division, New England, Waltham, Massachusetts.



**GROWTH OF
SNOW SURVEY PROGRAM**

U.S. ARMY ENGINEER DIVISION, NEW ENGLAND
CORPS OF ENGINEERS WALTHAM, MASS.
FEBRUARY 1963

EXHIBIT NO. 1

As the requests for data increased it was decided that the Corps would attempt to publish their data to supplement the monthly water bulletins published by the U. S. Geological Survey. Therefore each year beginning about the 15th of January, a weekly bulletin is prepared indicating the estimated average water content of the snow pack for selected river basins in New England. Every other week, the bulletin includes a map with isograms of water content in inches. Exhibit No. 2 is a sample of such a map. It should be noted that where the data is determined from observations the lines are drawn solid and where interpolated the lines are broken. The weekly bulletin also includes what the normal is for that particular date for comparative purposes. This is one place where the length of record becomes a factor. As noted previously, less than half of the snow courses have more than five years of record. Therefore, no attempt is made to quote any normals or averages for stations with less than ten years of record. Although the Corps publishes a weekly bulletin, the observations of the complete system of snow courses are made only semimonthly. During the intervening weeks measurements are made at the dams and at one or two index courses in the upper portion of each watershed.

As indicated previously the snow survey program grew as the number of flood control reservoirs increased. That is, the data was needed for deriving regulation procedures and flood forecasting. With the exception of the dam at Franklin Falls, New Hampshire, the flood control reservoirs are located on streams and tributaries where the drainage areas controlled are about 200 square miles or less. With these smaller streams, the flood problem becomes primarily a function of peak discharges rather than the volume of runoff. Therefore, the regulation of these dams has been related to the rate of rise and magnitude of the downstream flood development rather than the actual development of the flood hydrographs of inflow to the reservoir. Past studies have indicated that this type of operation is the most effective in a nonsnowmelt flood.

During a spring runoff, the situation can develop where the upstream snow pack may have a water content of 10 inches or more; the density is considered ripe; Weather Bureau forecasts indicate two to four inches of rain in the next 24 to 48 hours; and the available storage in the reservoir is about six inches on the total drainage area. The regulator must now weigh upstream and downstream conditions so that the reservoir is operated to provide the maximum downstream benefit while using a minimum amount of storage. He cannot ignore upstream conditions and close the gates completely as soon as somebody downstream complains about getting his "toes wet". If operated that way there is a chance of filling the reservoir and having uncontrolled discharges over the spillway which can cause much more serious damage on the tributary or perhaps coincide with the peak on the main river and thus contribute to what may already be a serious situation.

C A N A D A

NEW ENGLAND DIVISION
CORPS OF ENGINEERS

WATER EQUIVALENT
OF SNOW COVER

DATE 14 MARCH 1960

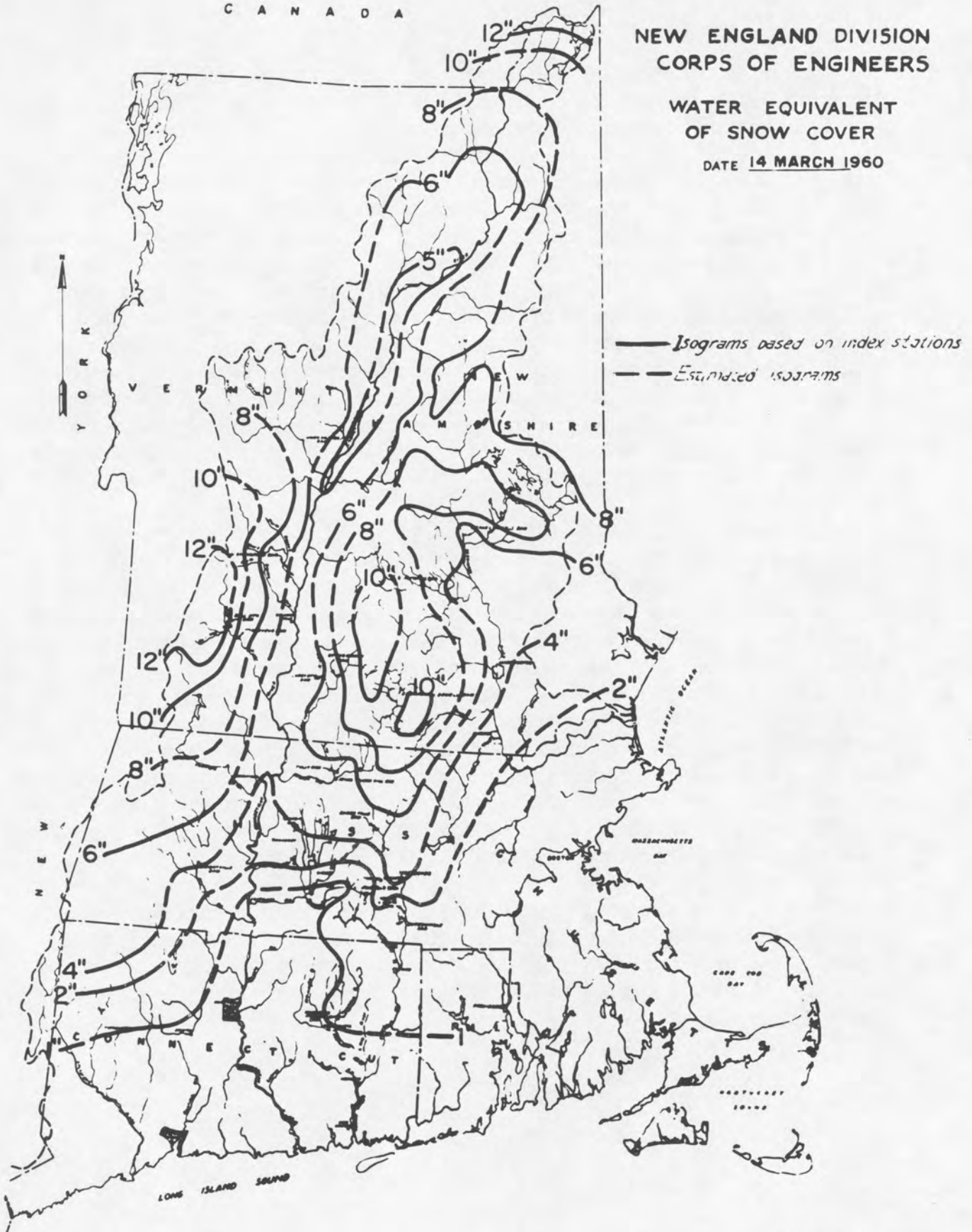


EXHIBIT NO. 2

A recent example of a flood operation with snowmelt was at the Surry Mountain Dam located on the Ashuelot River above Keene, New Hampshire. This reservoir has a storage capacity of six inches on the 100 square miles of drainage area. On 1 April 1960 the average water content of the upstream snow pack was more than eight inches. This was augmented by four inches of rain during an eight day period. This operation prevented about \$300,000 worth of damages in the City of Keene while the maximum storage utilized at the reservoir was about four inches. To accomplish this it was necessary to maintain a continuous outflow from the reservoir varying 300 to 1,300 cfs. In doing so about six homes experienced some basement flooding and temporary loss of heating systems due to seepage caused by the high river stages. If the upstream conditions had been ignored and outflows reduced to give complete protection to these six homes, it would have resulted in uncontrolled spillway discharges causing flooding above first floor levels in many more homes and commercial establishments. The knowledge acquired during the last 20 years of regulation at this reservoir was responsible for this successful operation.

The preceding was an isolated local problem on one tributary. The problem is compounded when there are 11 reservoirs in one river basin and all are in operation during the same flood. Every spring this situation develops to some degree in the Connecticut River Basin where the reservoirs are all located on tributaries. About half of them must be regulated for local problems on the tributaries, but the operation of all of them must be coordinated for conditions on the main river. Therefore, a forecast of peak flood conditions on the Connecticut River is a major requirement to the success of their operation. This forecasting is the responsibility of the U. S. Weather Bureau located at Windsor Locks, Connecticut. With the increased number of flood control reservoirs, this forecasting becomes more difficult since the natural regimen of the flood development in the basin no longer hold. The Weather Bureau hydrologists must now be aware of the proposed method of operation at each reservoir before they can make a fair estimate of what can be anticipated. This is generally resolved by a mutual exchange of data in the early development of a possible flood. All this points to the need for rules of regulation for snowmelt floods which can only be developed by analyzing many past floods and the causative factors related to the peak rates of runoff such as water content and density of the snow pack; type of cover and percentage of cover; additional precipitation; temperatures; hours of sunshine; etc.

To complicate the problems of regulation further there is always the possibility of a communications failure, thereby isolating the operator at the dam. It should be noted that while the communications are intact, the regulator issuing instructions from the Division Office is always in a position to make adjustments that deviate from the rules as the flood progresses. With the loss of communications, the operator at the dam is handicapped and must base his decisions on conditions at the dam, perhaps supplemented with a downstream observation. In this situation, the best that can be done is to operate based on precipitation or rates of inflow or both. Present rules for emergency operation prescribe conditions which require closure of the gate only. Once the gates have been closed, the operator is not permitted to open them for emptying until communication has been restored by some means. These means may be by use of state police or civilian defense emergency radio network. These emergency rules of regulation for use during a loss of communications, in general will prove very satisfactory in a flood without snowmelt. However, a post-mortem analysis of a snowmelt flood may prove that releases during a flood would have resulted in a more beneficial operation. Under the present rules this cannot be done with one exception which will be discussed further.

The exception noted above is the Franklin Falls Dam located in the foothills of the White Mountains in New Hampshire on the Pemigewasset River which is the main stem of the upper Merrimack River basin. It is one of the oldest and controls the largest drainage area of the flood control dams in New England. The storage capacity of the reservoir is equivalent to 2.9 inches of runoff for the 1,000 square miles of drainage. Originally it was designed as the downstream dam of two dams to be in tandem on the Pemigewasset River. The upper dam was to control 408 square miles of drainage. The system of two dams would then result with the storage at Franklin Falls Dam equivalent to 4.9 inches on the net drainage area of 592 square miles. Due to high real estate costs and local opposition, the construction of the upper dam has been deferred to date. Meanwhile the Franklin Falls Dam, if operated judiciously, can still do an effective job of reducing flood damages and has already paid for itself since its completion in 1941.

It was recognized early in the design of this dam that the rules of operation would have to be related to the volume of flood runoff and rates of inflow rather than downstream conditions. That was when the Corps of Engineers first got involved with the establishment of snow courses in New England. The new courses established, combined with existing courses maintained by the Public Service Company of New Hampshire resulted in a network of about 20 stations by the time that the dam was ready for operation in 1941. There have been some minor changes in the network that today has 22 courses from which data is available. The location of these courses are shown on Exhibit No. 3. Exhibit No. 4 shows an area elevation curve of the watershed above the Franklin Falls Dam and also the distribution of the snow courses as related to elevation. Considering the accessibility of the areas, it is believed that these locations give a good representation of the snow pack.

SNOW COURSE
 ABOVE
 FRANKLIN FALLS
 PEMIGEWASSET RIVER,
 FEBRUARY 1963

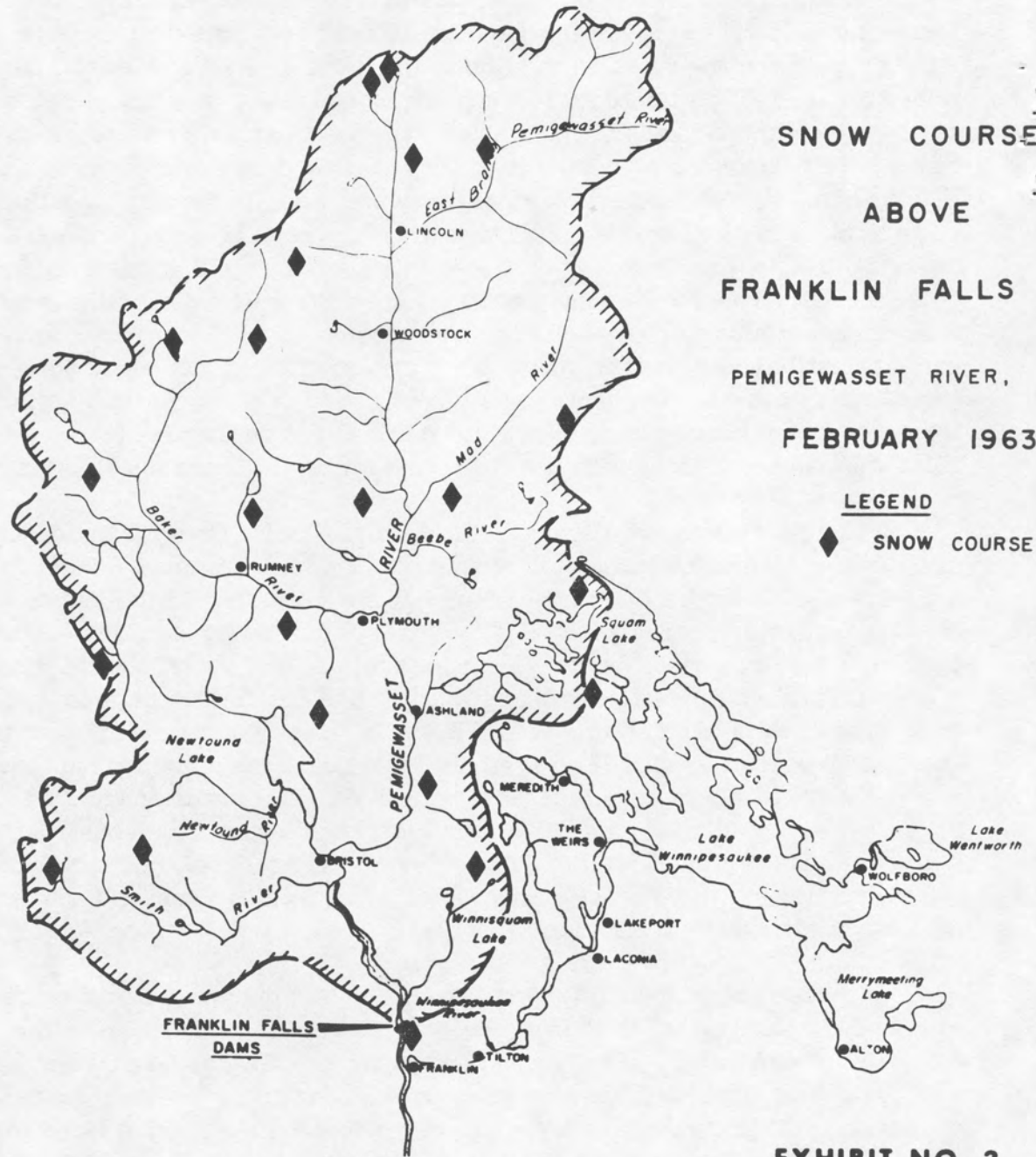


EXHIBIT NO. 3

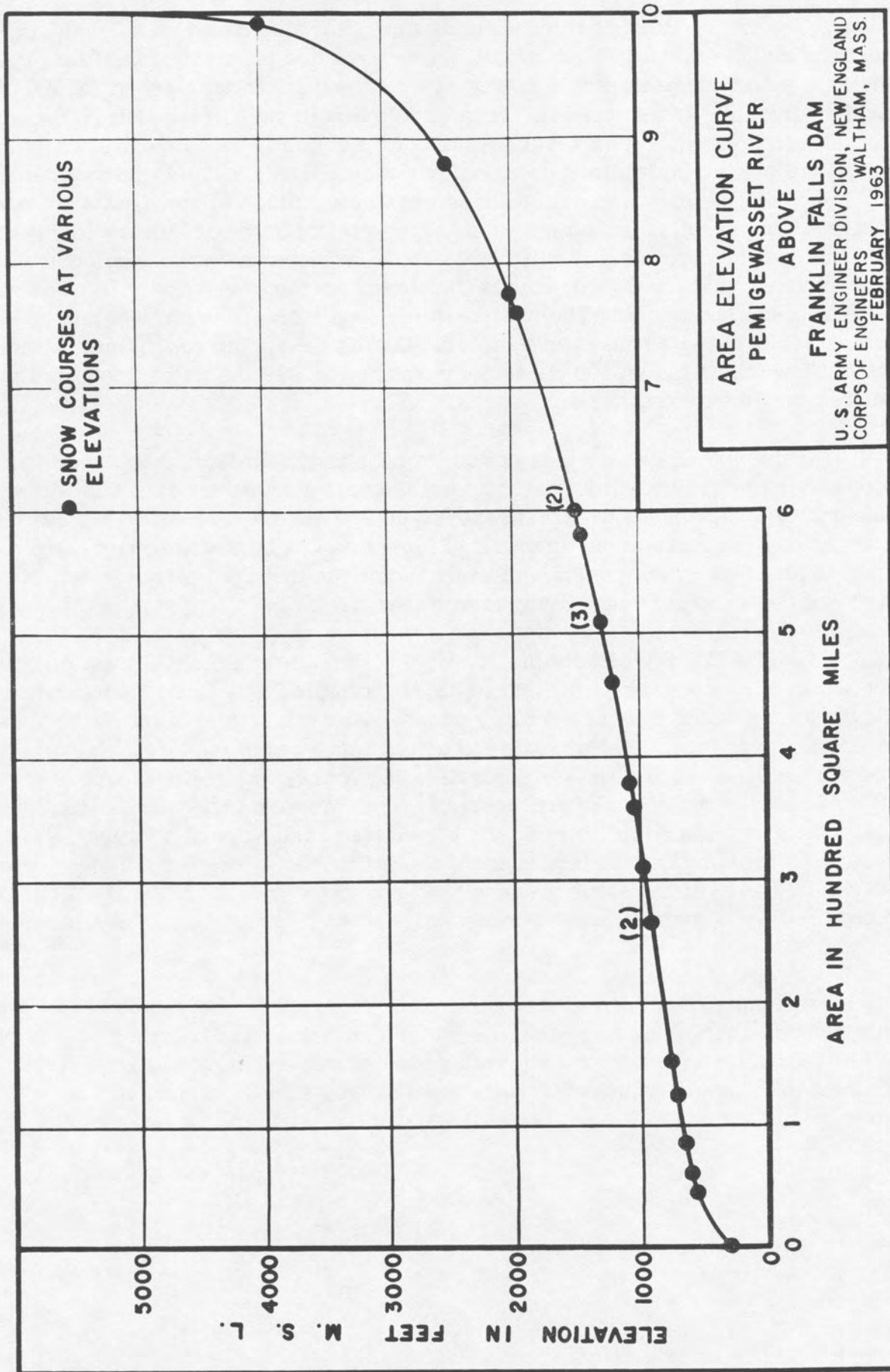


EXHIBIT NO. 4

The initial rules of regulation for this dam were based on an analysis of the record flood of March 1936. On that basis, the rules prescribed that the gates at the dam would not be throttled or closed until the outflow approached 18,000 cfs. At that time, the gates would be operated to maintain an outflow of 18,000 cfs throughout the entire flood. After several years of operation it became evident that this method of operation, while necessary for a major flood, was not the most efficient for minor floods or nonsnowmelt floods where the volume of runoff was not a serious factor. This resulted in further studies to correlate rates of inflow with downstream flood developments. As a result of this study, telemarks were installed at three upstream river gages and guide curves developed for various rates of inflow and water content of the snow pack. The present rules do permit the outflow to be reduced as low as 5,000 cfs in a nonsnowmelt flood. During the spring runoff, any reduction of the outflow below the 18,000 cfs is not permitted unless the water content of the snow pack is less than three inches.

This type of operation has often brought criticism from some uninformed people who complained about "all that water coming out of the dam while it is still half-empty and people downstream are having trouble from flooding." However, until more confidence in snowmelt flood forecasts can be developed or more can be learned about snowmelt analysis or until such time that the upstream dam is constructed the operation must continue in this manner.

Exhibit No. 5 indicates the seasonal distribution of the basin average water content in the snow pack as measured above Franklin Falls Dam. It indicates that the maximum water content normally occurs about the 15th of March each year. An inspection of Exhibit No. 6 reveals the actual range of the maximum values that did occur each year. The abscissa scale denoting years, was plotted from 1962 back to 1941 to indicate the effect of additional years of record on this one element of an analysis. The accumulated mean indicates the effect of adding each additional year of record. For some unexplained reason, the maximum values for the most recent five years yield an average about one inch higher than the true mean for the 22 years of record. This is just a simple demonstration of the unreliability of small samples of record.

Attempts have been made to correlate these maximum values of water content with peak discharges or 24 hour flows with no success. Including the observed rainfall during times of flood have not yielded any better results. Until coefficients can be developed for all of the other variables involved such as temperatures, hours of sunshine and cover, any correlations used can be considered to be of a very crude nature.

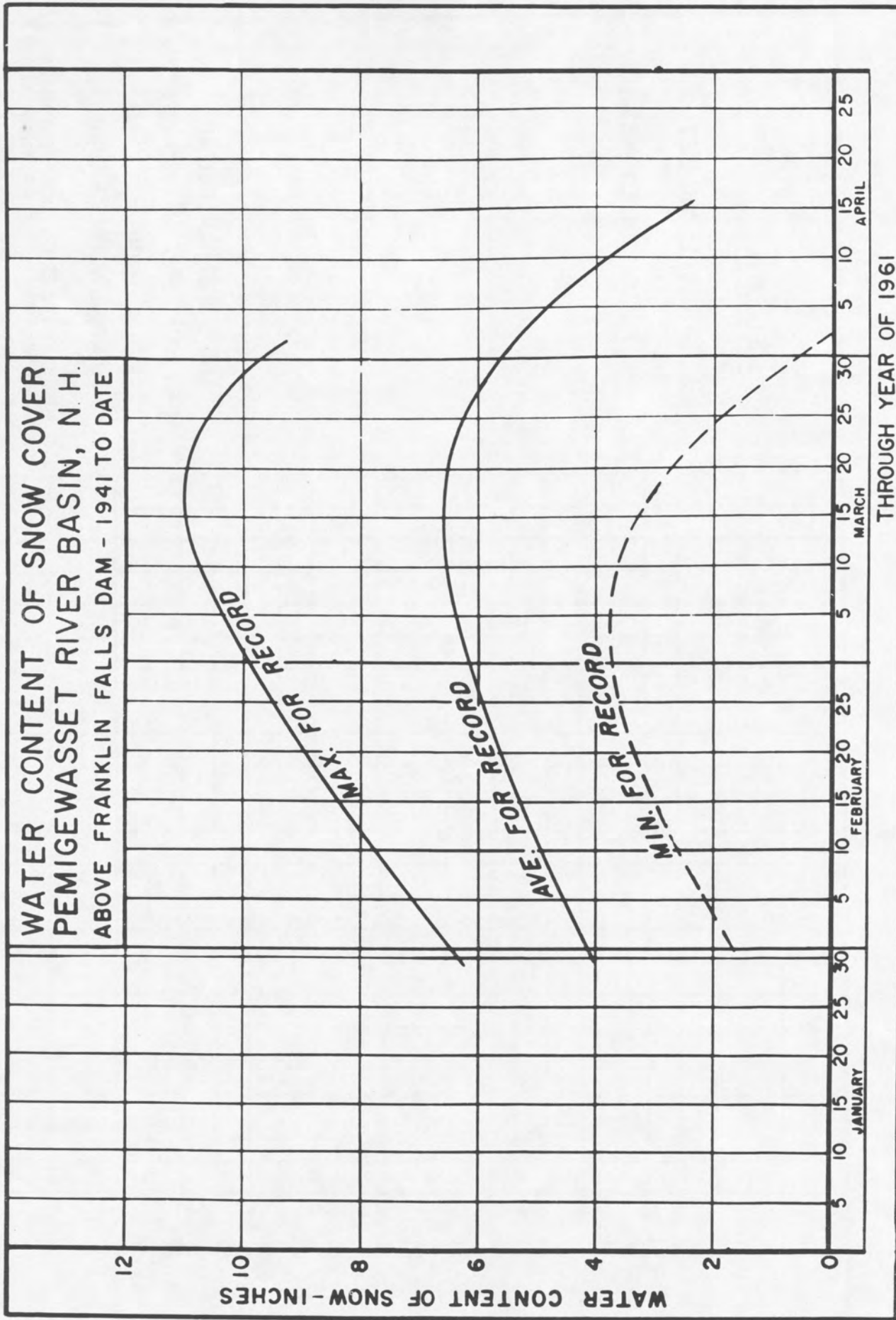




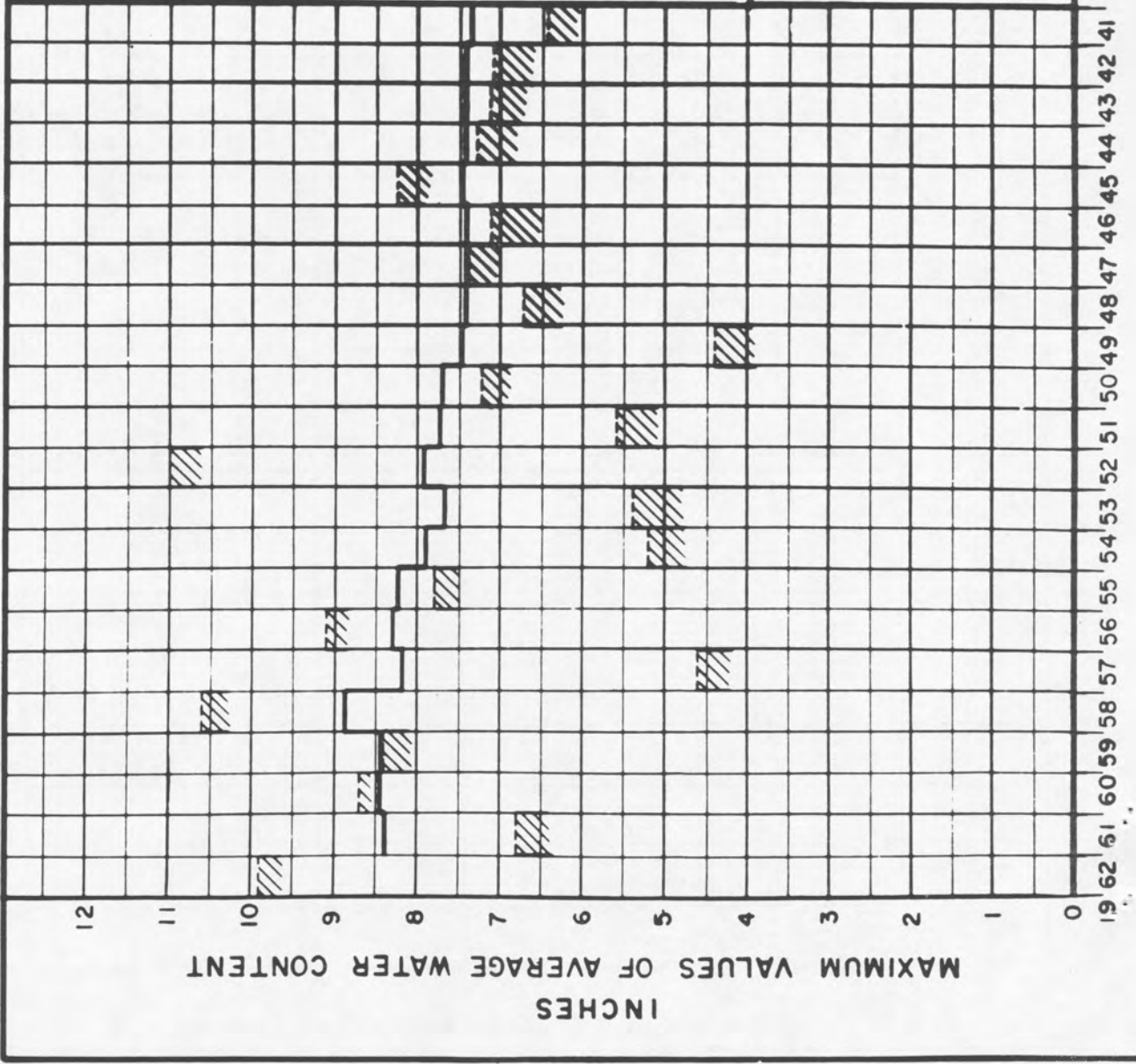
EXHIBIT NO 5

LEGEND:

-  ANNUAL VALUES
-  ACCUMULATED MEAN

**MAXIMUM ANNUAL
WATER CONTENT OF SNOW PACK
ABOVE
FRANKLIN FALLS DAM**

U. S. ARMY ENGINEER DIVISION, NEW ENGLAND
CORPS OF ENGINEERS WALTHAM, MASS.
FEBRUARY 1963 I



These comments so far have pertained to the current need for long records of natural phenomena. There will also be future needs for such data. Such a need is close at hand for the New England Division has recently been authorized to make a comprehensive water resources study of the Connecticut River basin. This authorization requires that the Corps with the cooperation of other federal agencies go beyond just flood control and consider all other water uses such as water supply, recreation, low-flow regulation for pollution control or to firm up hydro-generation and also consider possible locations for additional hydro-generation. This will be a four or five year program and will probably be the forerunner of future river basin studies in New England.

In any comprehensive basin study it becomes necessary to establish "yardsticks" for determining relative values of proposed projects. One of these yardsticks is always some type of synthetic basin flood called a Standard Project Flood. The Standard Project Flood, generally greater than a flood of record, is considered to be a major flood with a high degree of probability. It is normally used in the design of walls, dikes or channel improvements for local flood problems and also to demonstrate the effectiveness of proposed reservoirs. The present standard project flood for the Connecticut River basin is based on a hurricane-type storm so oriented that it yields the most critical flood from the selected rainfall as measured at the major communities in Massachusetts and Connecticut. Although the flood of record in these communities was the flood of March 1936, the lack of procedures for synthesizing a snowmelt flood precluded the use of such a flood for this purpose.

In retrospect, it is felt that the adopted standard project flood is adequate as far as the degree of protection provided is concerned. However there is always an element of doubt that perhaps a snowmelt type flood would prove that some critical areas have been overlooked or the need for additional reservoirs can be proven. It may well be, that in a basin as large as the Connecticut River, more than one standard project flood should be used. Perhaps a snowmelt flood should be adopted for the areas in Vermont and New Hampshire and a hurricane-type used for the lower portion of the basin. It is anticipated that with procedures developed from data obtained from the snow laboratories on the west coast, supplemented by more recent studies, an attempt will be made to synthesize a snowmelt standard project flood for the Connecticut River basin. However the value of such a flood can only be measured by some correlation with observed data.

In conclusion, long term records are very vital to the achievement of satisfactory procedures for regulating flood control reservoirs. In addition, the data will contribute to a better evaluation and design of flood control projects. For these reasons, the collection of snow data will continue and the program will be expanded as new projects are completed. It is felt that electronic computers will eventually prove the value of collecting all this data.