THE EXPERIENCE OF ONTARIO HYDRO IN FORECASTING RUNOFF IN ONTARIO

BY

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GENERAL INTRODUCTION

The Province of Ontario covers a total area of 412,600 miles of which 88.1 per cent is land area and the remainder lakes and rivers. The province extends 1,000 miles from east to west and 1,050 miles north to south. As a comparison Ontario is one and one-half times as large as Texas. (See plate 1.)

The mean annual precipitation varies from 25 inches in the western portion of the province to 30 to 35 inches in the eastern and southern portions. The recovery from this in the form of runoff varies from 35 per cent in the west to 50 per cent in the east and south. The mean annual snowfall in the west end of the province is 70 inches increasing easterly to 120 inches on the north shore of Lake Huron and decreasing to 40 inches in the extreme southern portion of the province.

The topography of the province is quite varied. An extensive area of land bordering on James Bay and Hudson Bay is low and swampy. A height of land runs generally east and west just north of Lake Superior; elevations in this region are in the neighbourhood of 1,000 feet and over. The land slopes very gently from this height of land to Hudson Bay and James Bay. The eastern portion of Ontario is relatively low level land draining into the Ottawa and St. Lawrence rivers. Most of this area is between 200 to 300 feet above sea level, rising 400 to 500 feet north of Lake Ontario. The highest areas in the southern portion of the province lie immediately south of Georgian Bay. Elevations range from 1400 to 1700 feet. A remarkable feature is the Niagara escarpment with a height of 250 to 300 feet and extending from the Niagara peninsula northeast to the Bruce Peninsula.

To give some idea of the magnitude of the hydro power produced, the following approximate figures are given: In the northwestern portion of the province, the total average power production is 444 megawatts, of which the Nipigon watershed produces 190 mw, and the English and Winnipeg watersheds 210 mw in Ontario (the same water producing an additional 464 mw in Manitoba), the remainder of 44 mw being produced by other developments. In the northeastern portion of the province 198 mw is produced, of which the large plant at Abitibi Canyon produces 129 mw. In southern Ontario, 2,078 mw can be produced; this figure does not include the output from the new St. Lawrence Power Project. The Madawaska River watershed produces 52 mw. In addition to the power produced in Ontario, an additional 800 mw is purchased from sources outside the province.

FORECASTING METHODS AND TECHNIQUE

The computations for our investigations were done by an electronic computer, which effected a great saving in time and computing effort, and also a much more thorough investigation of the inter-relation between the numerous variables, was made possible.

Forecasts are generally made at the beginning of each month (more often if required), starting on January 1st and running through to the end of the spring freshet. Various runoff periods are given, such as January to June, February to June, March to June, and April to June. At each forecast date, five values are computed: Maximum, median, minimum, and the two quartiles. In this way, five forecasts giving the likely range of possible runoff are obtained. Generally, as the months progress, the range between forecasted maximum and minimum runoff contracts. At the end of the freshet period one value is obtained and this should be close to the runoff observed. Using these forecasts, a plan of operation of the storage reservoirs can be worked out, which as the winter season progresses, can be modified as required.

METHOD OF ANALYSIS

The procedure for analyzing the data may be described in board terms as finding, by procedures based on mathematical techniques, the relation between past precipitation and snow survey data and runoff. To give the analysis stability and significance, a minimum of thirty years of record is usually required.

The steps in the procedure are as follows:

1. Preparation and preliminary analysis of the data from a large number of precipitation measuring stations in and around the watershed in question.

2. Computation of precipitation station weights and "effective" precipitation. This is computed by multiple linear correlations between various seasonal totals of a number of precipitation stations and runoff. After this analysis is completed, the seasonal precipitation period is set and the precipitation stations are selected. A set of weights for the selected stations is also computed. The monthly precipitation from each station for each month is then multiplied by its weight and the monthly weighted precipitation is then summed for all stations to arrive at the "effective" precipitation.

3. Computation of monthly weights and precipitation "index". This is computed by multiple linear correlation between the "effective" monthly precipitation and runoff. The monthly weights thus determined are multiplied by their respective "effective" monthly precipitation, thus producing a monthly "index". The sum of the monthly indices forms the seasonal precipitation index.

4. Further analysis will indicate whether there is a carry-over effect of the previous year's precipitation to contribute to the current year's runoff. In general, it has been found that this is not the case except in the more southerly portions of the province.

5. The final forecast equation is obtained by fitting the runoff data and seasonal precipitation index to a curve of the general form $aX^3 + bX^2 + cX + d = Y$, where X is the seasonal precipitation "index" and Y the runoff.

6. Computation of partial precipitation indices. This involves the partial summation of a season's monthly indices from the end of the precipitation period to its beginning. The monthly partial indices for all years thus formed are arranged in order of magnitude and the maximum, upper quartile, median, lower quartile, and minimum values are selected.

7. Making the forecast. Suppose a forecast relation has been computed for the April plus May runoff, using the November to June precipitation, and it is desired to

make a forecast as of February 1st. The precipitation index for the current year is computed for the period November 1st to February 1st and added to the five values of the February partial index to arrive at seasonal indices. Using the forecast equation, the five forecast values (median, quartiles and extremes) are determined.

USE OF SNOW DATA

Thus far, no mention has been made of the use of snow survey data. It is felt that the precipitation-runoff relation is required as a base with which relations, using other parameters may be compared.

The following method is adopted to include or interchange parameters. A weighted mean of the snow survey data from a number of stations in and around the watershed, is calculated, and this is combined with the "effective" precipitation mentioned above. This is usually done by replacing one of the months of "effective" precipitation by the weighted mean water content of the first of the month following; as an example, the February "effective" precipitation would be replaced by the March 1st snow survey. A number of combinations are tried until the best relation is obtained. Unfortunately, in many areas of the province the snow survey records are of relatively short length and consequently the relations, statistically speaking, are not too reliable.

DISCUSSION OF RESULTS

As a basis for discussion, the Madawaska River watershed is being given as an example, and indicates in general, our experience throughout the province. Referring to plate 2, it is seen that the Madawaska River lies in a generally east-west direction. The drainage basin area from source to mouth is 3140 square miles. The forecast relations are based on the upper two-thirds of the watershed, which covers an area of 2231 square miles. This portion contains the major controlled storages. The total controlled storage amounts to 349,000 acre-feet, of which Bark Lake dam controls 302,000 acre-feet. At present, there are three power sites with a combined capacity of approximately 150,000 horsepower. There are a number of proposed sites that may be developed in the future and also an additional control structure or dam may be built to increase the storage capacity of the system.

Plate 3 shows the final forecast equation, using precipitation only. In this study, 30 years of record were used and the runoff forecast period was April and May. It was found that six precipitation stations indicated the best relationship with runoff and the precipitation period was November to May. Other runoff periods were also worked out but no mention of these will be made here.

As can be seen from the drawing, a reasonably good fit to the points was obtained: the average April plus May runoff for the 30 years is 716,000 acre-feet, and the Standard Error of Estimate for the relation is 94,700 acre-feet with a Co-efficient of Regression of 0.93.

Since we are primarily interested in snow, a detailed discussion of the results of the investigation will here be given. In the Madawaska River watershed, there are six snow courses, the records of which extend back to 1943. This is a very short period and will only give an indication of the relation linking snow pack with resulting runoff. Preliminary investigation suggested that the results of the March 1st snow survey were the best indication of April plus May runoff. Plate 4 is a plot of the March 1st snow-water equivalent against the April plus May runoff. The scatter of these points is quite large although a definite trend is indicated. When the snow is combined with the "effective" precipitation (February precipitation was eliminated) in the technique described before and a precipitation-snow "index" computed, the resulting plot of the index versus April plus May runoff (see plate 5) shows a close fit indeed.

In order to show, more forcibly, the value of including snow data with precipitation data, plate 6 is given to show the difference between the two relations. The drawing shows a plot of the observed April plus May runoff against the amount estimated from the respective forecast equations. The lines shown are drawn at 45 degrees and indicate the perfect forecast. Only the 13 years from 1943 to 1955 are shown for the precipitation relation. It is evident from the two plots and the statistical parameters that a marked improvement was achieved by including snow survey data in the relationship.

CONCLUSION

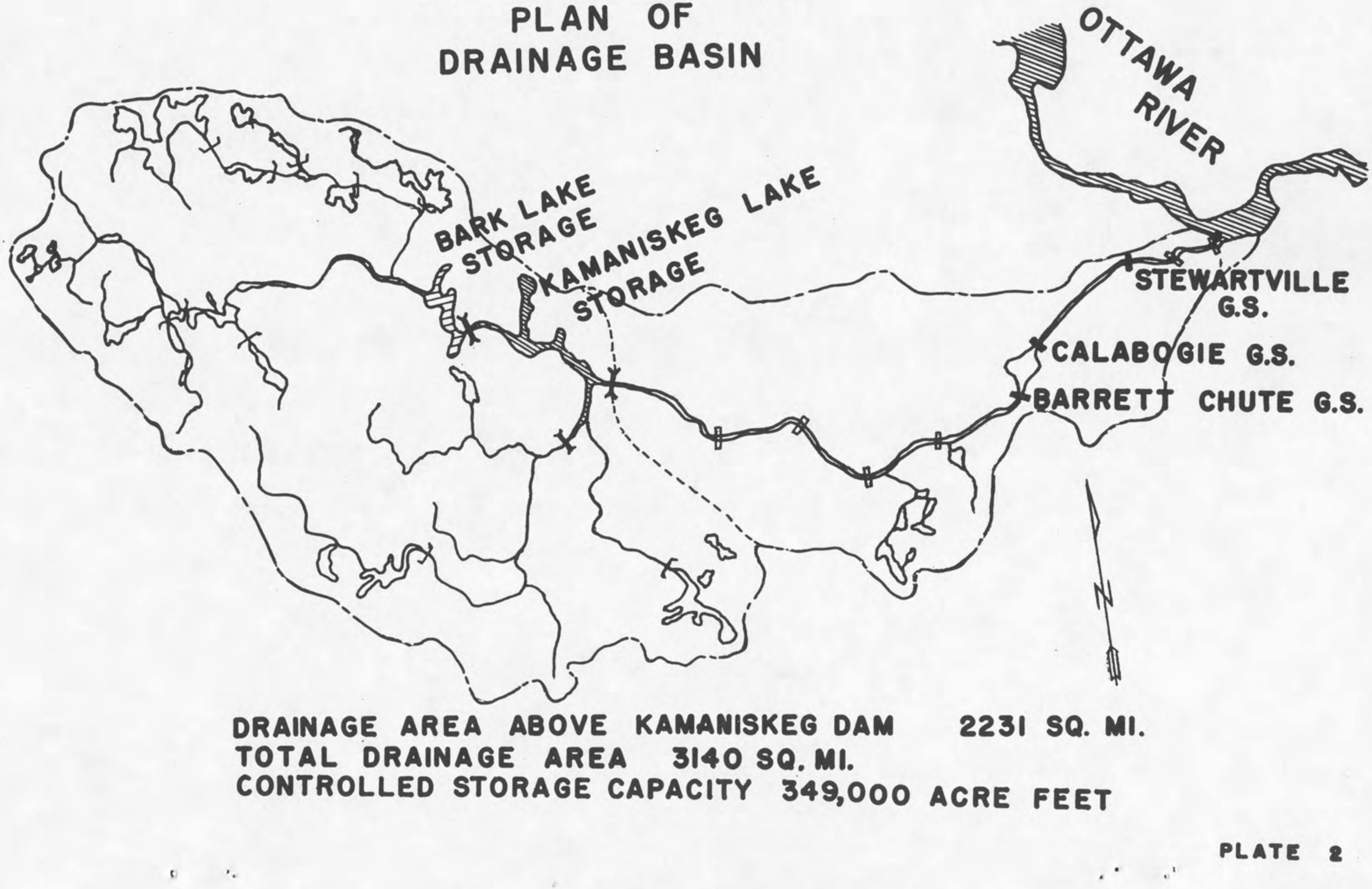
This exposition gives very briefly an insight into the experience of Ontario Hydro in forecasting water supply. It should be mentioned that a tremendous amount of calculating time is required in order to reduce the many parameters to a forecast equation, and without the use of an electronic computer much of the detailed analyses would have been impossible. To say that we are pleased with the results obtained would be an overstatement, since although the forecast equations show good precision when based on total seasonal precipitation and snow surveys, yet when making a forecast some months in advance, say February or March, the results leave much to be desired.

To the hydrologist, most of his water problems arise from a lack of knowledge of future precipitation. In such a climate as ours, where the bulk of the runoff is from a snow pack that has been accumulating all winter, the effect of rainfall at the time of snow melt is also a major factor in producing excessive runoff conditions, even bordering on flood conditions. Ontario Hydro does not operate its storage basins primarily as flood control projects; however, we do attempt, by judicious regulation of our storage basins, to reduce excessive flooding on any of our river systems. The role of the meteorologist in this regard is of the utmost importance. Long-term forecasting of precipitation of reasonable accuracy must be made available to the hydrologist in order to arrive at a more positive and efficient forecast. It has now become a relatively simple and mechanical operation to integrate a forecast of precipitation with runoff on a statistical basis. Herein lies the challenge: the hydrologists are ready; are the meteorologists?

PLATE I

PLAN OF ONTARIO SHOWING MAJOR WATERSHEDS

MADAWASKA RIVER
PLAN OF
DRAINAGE BASIN



DRAINAGE AREA ABOVE KAMANISKEG DAM 2231 SQ. MI.
TOTAL DRAINAGE AREA 3140 SQ. MI.
CONTROLLED STORAGE CAPACITY 349,000 ACRE FEET

PLATE 2

PLATE 3

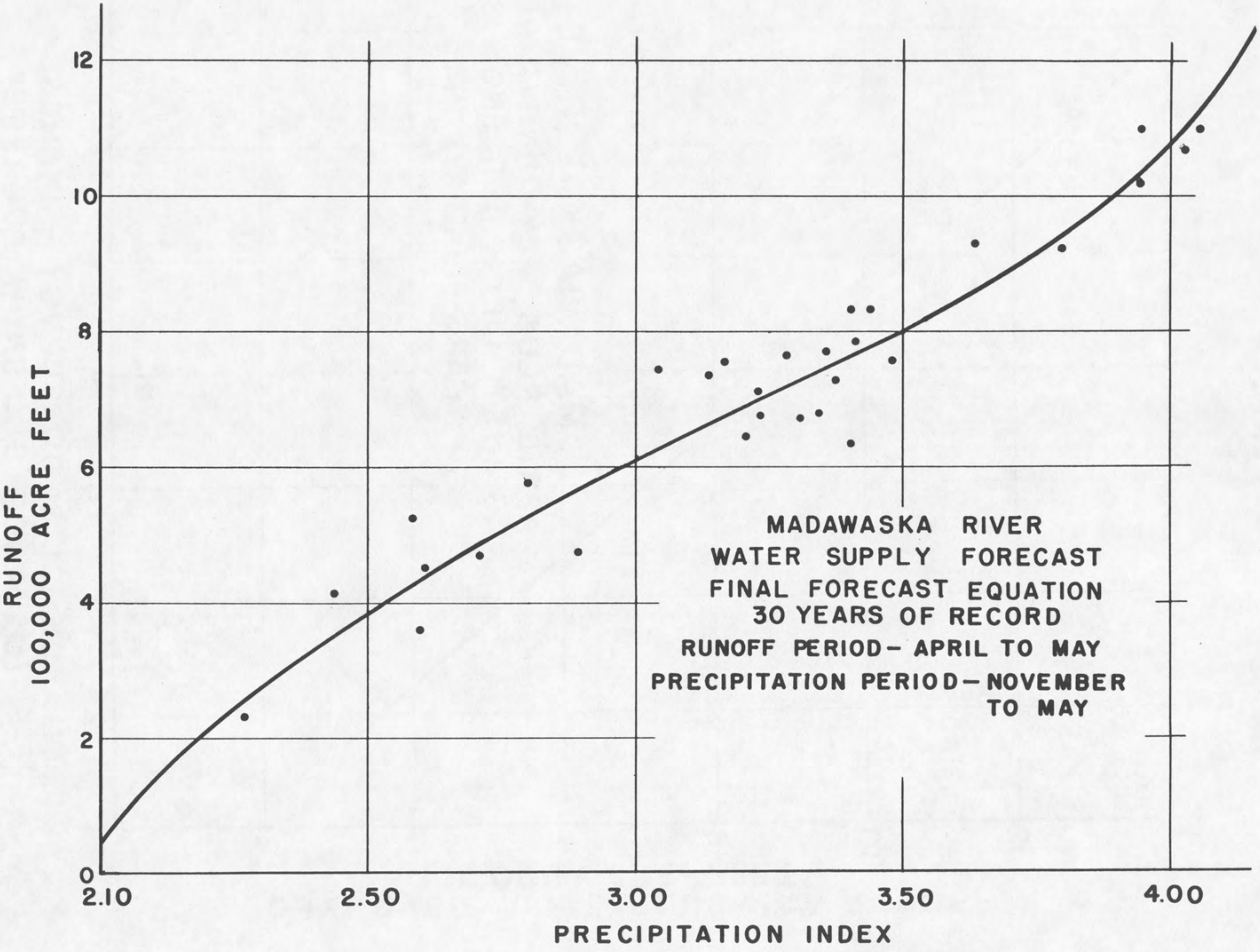
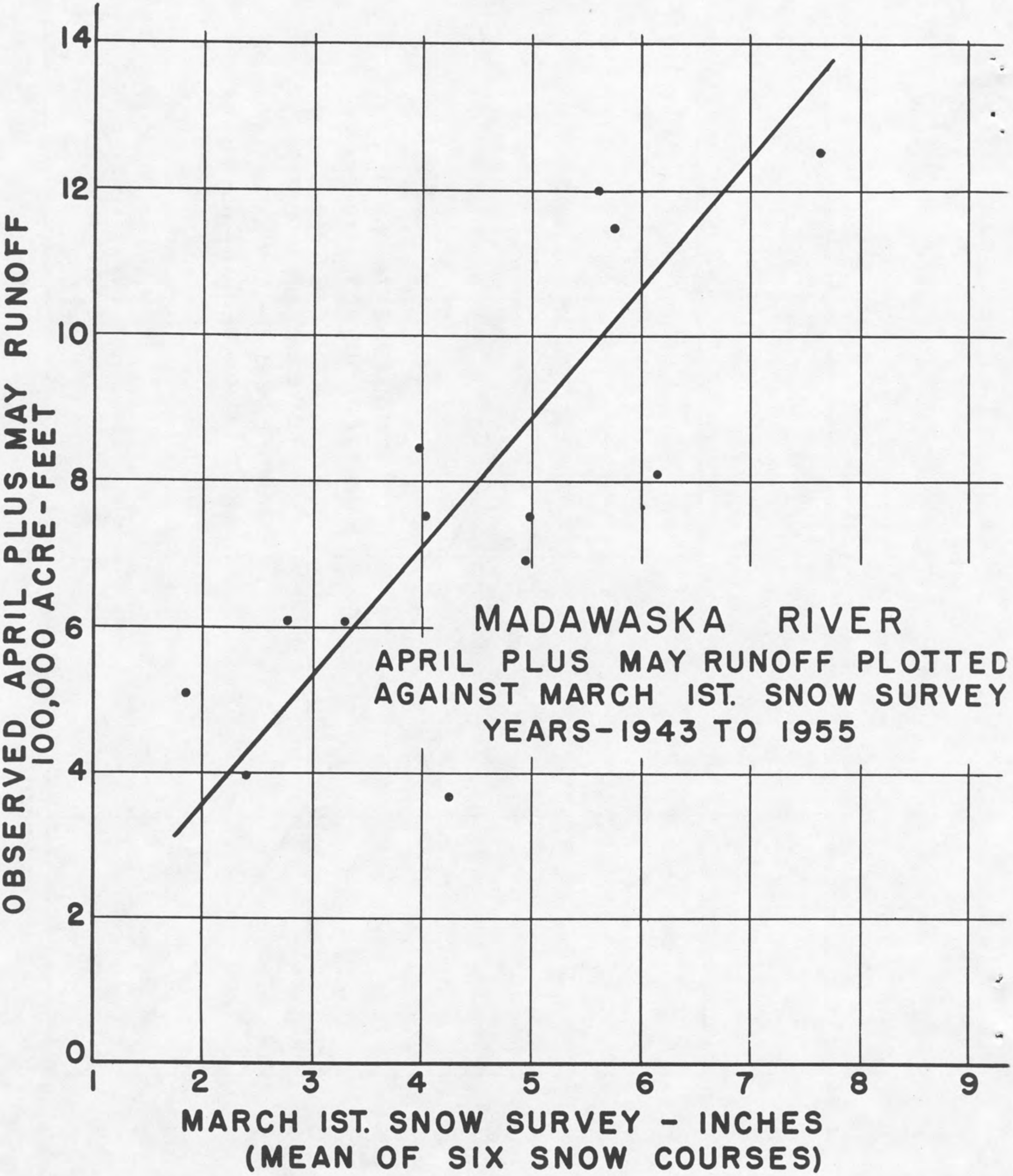

MADAWASKA RIVER
WATER SUPPLY FORECAST
FINAL FORECAST EQUATION
30 YEARS OF RECORD
RUNOFF PERIOD – APRIL TO MAY
PRECIPITATION PERIOD – NOVEMBER TO MAY
RUNOFF 100,000 ACRE FEET
0
2
4
6
8
10
12
2.10
2.50
3.00
3.50
4.00
PRECIPITATION INDEX

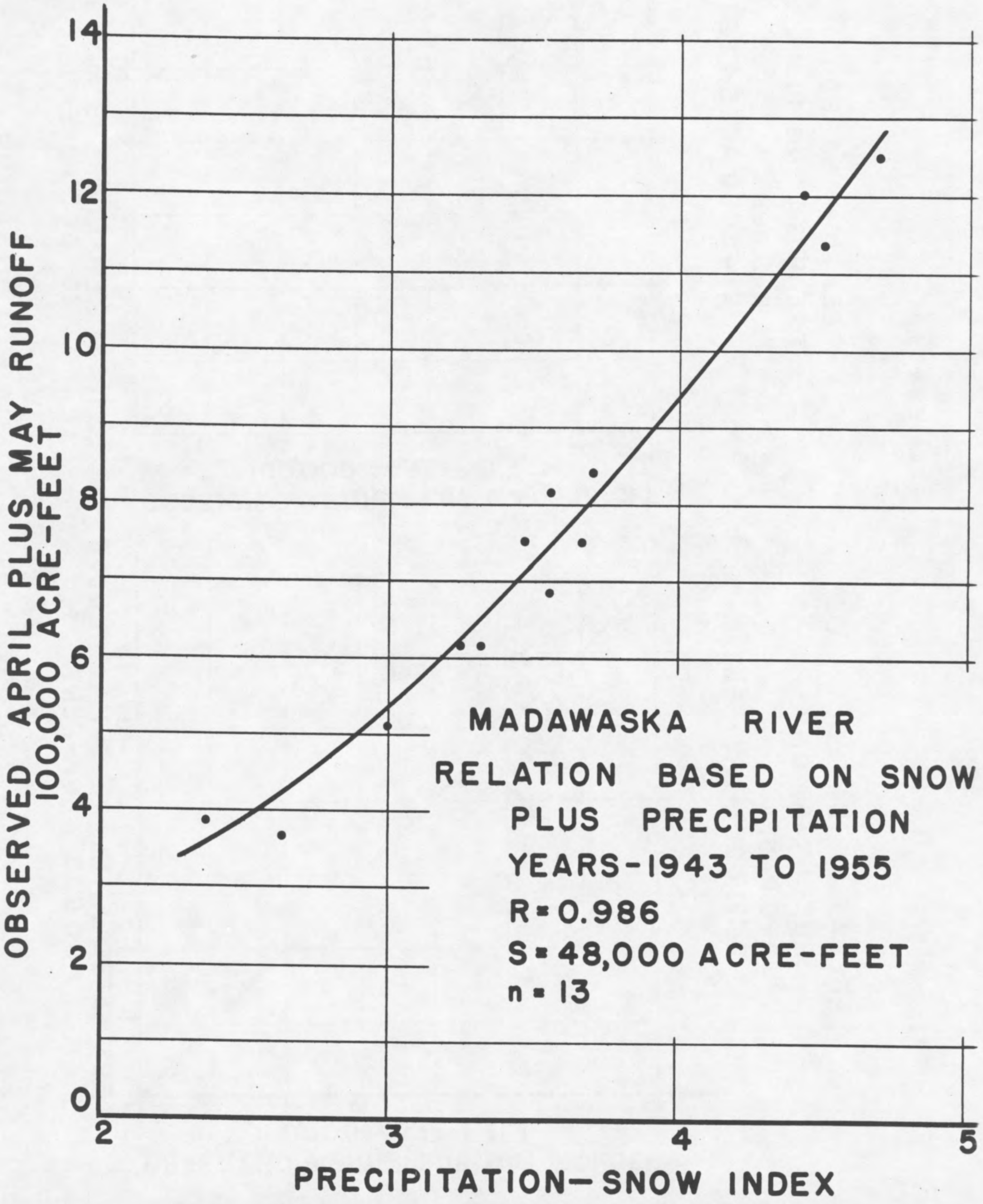
PLATE 4



MADAWASKA RIVER

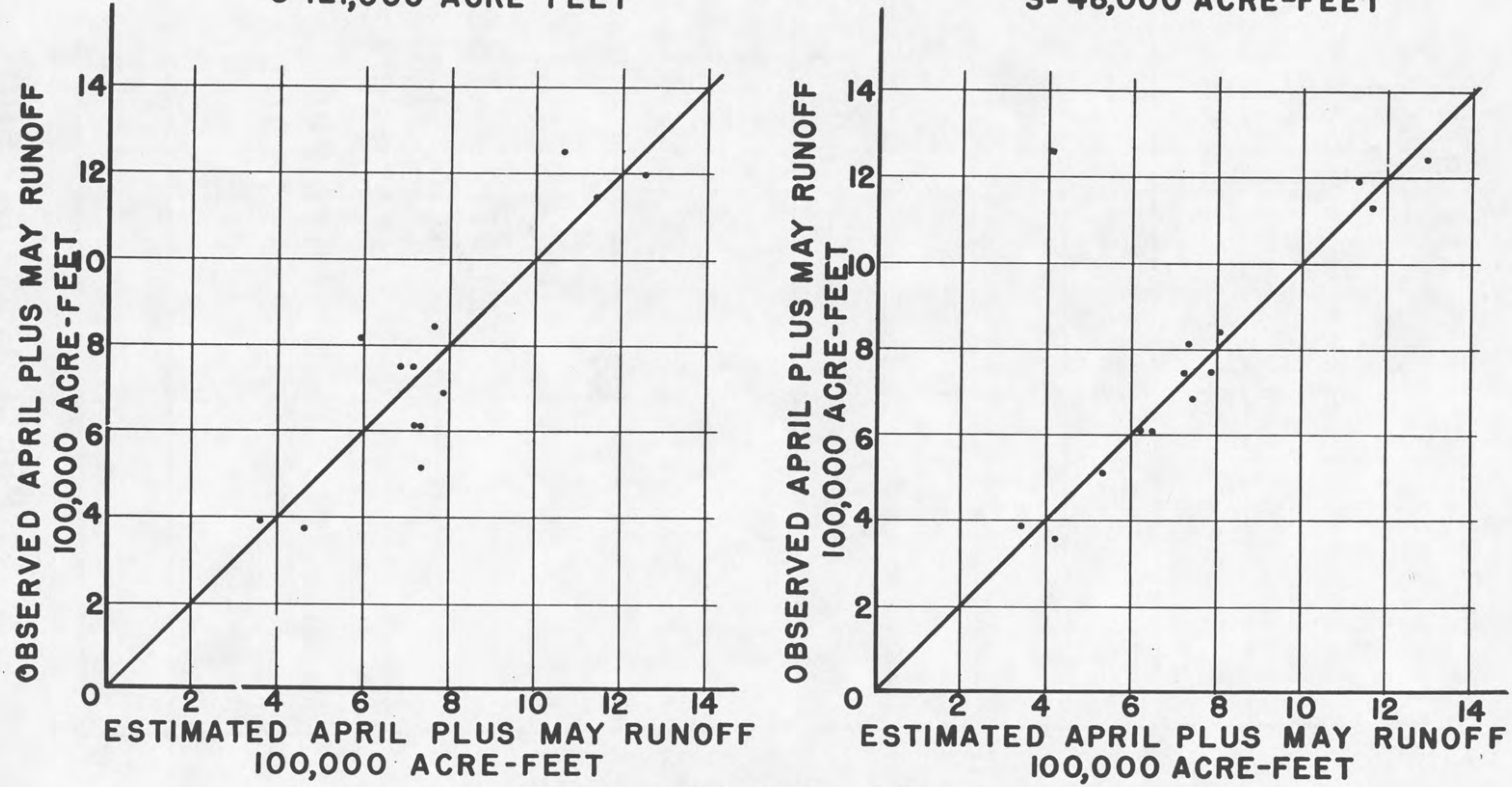
APRIL PLUS MAY RUNOFF PLOTTED
AGAINST MARCH IST. SNOW SURVEY
YEARS–1943 TO 1955

PLATE 5



MADAWASKA RIVER
RELATION BASED ON SNOW
PLUS PRECIPITATION
YEARS-1943 TO 1955
R=0.986
S=48,000 ACRE-FEET
n=13

PLATE 6



RELATION BASED ON PRECIPITATION
R= 0.905
S=121,000 ACRE-FEET

RELATION BASED ON PRECIPITATION PLUS SNOW
R=0.986
S= 48,000 ACRE-FEET

MADAWASKA RIVER
ACCURACY OF FORECAST EQUATIONS
YEARS-1943 TO 1955