AVERAGE ANNUAL RUNOFF AND PRECIPITATION IN THE NEW ENGLAND-NEW YORK AREA

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Prepared in cooperation with the United States Weather Bureau

DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

HYDROLOGIC INVESTIGATIONS ATLAS HA 7

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INTRODUCTION

This Hydrologic Atlas contains maps showing the average annual runoff, precipitation, water loss, and loss by evaporation from lakes in the New England-New York area. It is presented for general hydrologic use, for use in estimating average annual runoff and possibly yearly runoff, and for use in determining the difference between water loss from all surfaces and loss by evaporation from lake surfaces only.

The boundaries of the area included are essentially those designated by the New England-New York Inter-Agency Committee: the New England States and New York State except for parts of it lying in the drainage basins of the Delaware, Susquehanna, and Allegheny Rivers and for Long Island.

The Committee, which was established in 1950 by Presidential proclamation to devise a coordinated plan for the development of the natural resources of the area, appointed a subcommittee on hydrology to coordinate the work of several groups who were to make a study of the water resources. The subcommittee selected the 20 years of 1930-49 as being a representative period and, in accordance with the principle that in making hydrologic comparisons all data must relate to the same years, as being a period for which reasonably complete data were available. The subcommittee then asked the United States Geological Survey and the United States Weather Bureau to prepare the maps that constitute this atlas.

The maps and text concerning runoff and water loss were prepared by C. E. Knox, hydraulic engineer, United States Geological Survey, under the supervision of H. B. Kinnison, district engineer, and under the general direction of J. V. B. Wells, chief, Surface Water Branch, and C. G. Paulsen, chief hydraulic engineer, Water Resources Division. The maps and text dealing with precipitation and evaporation from lakes were prepared by T. J. Nordenson, chief, Hydrologic Investigations Section, United States Weather Bureau, under the general supervision of W. E. Hiatt, chief Hydrologic Services Division.

RUNOFF

The map showing average annual runoff is based on streamflow data collected during the 20-year period of 1930-49 at 260 gaging stations well distributed throughout the area. Of these, 135 were in operation throughout the whole period, and 125 others were in operation for at least 10 years of the same period. Data collected at these latter stations were adjusted to the 20-year period by standard methods of correlation with records of stations operating for the full period.

Development of Isopleths

The boundaries of drainage basins were first outlined on a base map of the area, and then the average annual runoff determined for each of the 260 gaging stations was recorded near the center of the basin gaged. Runoff for an intervening, or ungaged, basin was computed and shown on the map if the intervening basin was a relatively large part of the total basin. If the intervening basin was a relatively small part, its runoff was not computed because all errors in the basic data would be concentrated in the values of runoff for the small intervening basin and would thus produce an undependable result.

To show isopleths of average annual runoff, lines were plotted in each basin on the pattern of the isohyetal lines shown on the map of average annual precipitation. The isopleths deviate from this pattern to the extent necessary to provide a smooth transition from basin to basin and to a degree with the total amount of the runoff determined at each gaging station. Thus, if some isopleth values in one part of a gaged basin are too high, others in another part of the same basin are too low. However, the isopleths of one basin must connect with those in adjacent areas, and thus the probable error decreases as the size of the basin increases. The isopleths have an interval of 2 inches where the runoff is less than 30 inches, and an interval of 5 inches where runoff is 30 inches or more. The average of the values of the isopleths within a basin equals the average annual runoff of the basin as determined from stream-gaging records for the period of 1930-49.

Reliability

In small areas the isopleths of average annual runoff do not always represent the flow that would be measured at a stream-gaging station. Instead, they may represent the contribution of that small area to streamflow at a downstream gaging station. Thus, they may actually represent water yield rather than runoff. However, in areas as large as those of most stream-gaging stations, the difference between water yield and runoff is generally small, and runoff as determined from the isopleths represents the average flow that would be observed in a stream channel.

The outlines of the drainage basins gaged, as shown on the accompanying map, together with the topography of the region, should be considered in estimating the accuracy of the runoff values shown on the map. If there are many gaging stations in the area under consideration, the results should be within 5 percent of accuracy. If the basin under consideration is much smaller than those of the gaging stations in the vicinity, or if the basin is in a region of considerable relief or in a rain shadow, the results may be subject to large errors and should not be used except for very general purposes.

Yearly Runoff

In certain hydrologic investigations the distribution of runoff from year to year and within a year is usually of greater importance than the average annual runoff. The pattern of yearly runoff for the New England-New York area can be determined from a study of streamflow records published in the Water-Supply Paper series of the Geological Survey. Although the names of all the individual stream-gaging stations have not been shown on the accompanying map, each station can be identified by one's finding the name of the stream in the index of the water-supply papers and then determining the proper station on that stream from the description of its location. Records for streams draining into the St. Lawrence River are published annually as part 4 of the series, Surface Water Supply of the United States, and records for streams in all other parts of the New England-New York area are published in part 1 of the same series of water-supply papers.

Deviation of runoff for any given year from average annual runoff can be due to either or both of two causes: deviation of precipitation from the average annual or deviation of water loss from the average annual. Because of variations in the distribution of precipitation within any given year and in carryover in ground-water storage, two years having the same amount of precipitation can have widely different amounts of water loss.

In the absence of complete data, the yearly runoff for an ungaged area for individual years can be estimated by use of the following formula:

$$R_u = (R_g + 20)\,\frac{(R_u\text{avg} + 20)}{(R_g\text{avg} + 20)} - 20$$

in which R_u is the runoff for any year of an ungaged area, R_g the runoff for that same year as measured at a stream-gaging station, and $R_u$avg and $R_g$avg the average annual runoff for the respective areas as determined from the accompanying map, all expressed in inches per year.

The above empirical formula takes into account the fact that if in any year the runoff from a gaged area is greater than average, the runoff from un ungaged area would also be greater than average but that the amount of change is not strictly proportional to the ratio of the average runoff figure.

PRECIPITATION

In flat and gently rolling country an adequate precipitation map can generally be developed from observed precipitation data. However, in mountainous terrain, the effect of topography on the precipitation must be considered in order to derive an accurate picture of the areal distribution of precipitation. A graphic method of correlation between precipitation and topographic factors was developed by Spreen (1947) for western Colorado. Although the topography of New England and New York is not so rugged as that of western Colorado, Spreen's method has been applied successfully in the preparation of the average annual isohyetal map for New England and New York.

The data used in the development of the isohyetal map consist of all precipitation records obtainable from files and publications of the Weather Bureau and those of State agencies. The publication Rainfall in New England, issued by the New England Water Works Association, was another valuable source of data (Goodnough, 1930; White, 1943a, 1943b). The average annual precipitation is based on the 20-year period of 1930-49.

Stations with at least 10 years of record were utilized by adjusting the observed data to an average for the 1930-49 period. This adjustment was accomplished by comparison of concurrent observations at the short-record station with those of two or three long-record stations nearby and by using the ratio to estimate the 1930-49 average annual value for the short-record station.

Relation of Annual Precipitation to Topographic Factors

The stations for which the 20-year average annual precipitation (observed or adjusted) had been computed were plotted on the United States Coast and Geodetic Survey sectional aeronautical charts. From topographic maps such physiographic features as elevation, rise, orientation, aspect, distance from coast, and distance to mountain barrier were obtained for each station. By means of graphic correlation, the best possible relation between average annual precipitation and selected topographic parameters was determined. The areas for which these relations were determined, the topographic parameters used, and the final results of the correlations are summarized below, r being the coefficient of correlation:

A. Maine area:
   (1) Parameters: index elevation, orientation, and shortest distance to the coast.
   (2) r = 0.94. Average error = 1.54 inches. Standard error = 1.98 inches. Average precipitation: 40.2 inches. Number of stations: 52.

B. Merrimack River drainage basin:
   (1) Parameters: index elevation, exposure, and latitude.
   (2) r = 0.91. Average error = 1.52 inches. Standard error = 1.91 inches. Average precipitation: 42.4 inches. Number of stations: 70.

C. Connecticut River drainage basin:
   (1) Parameters: index elevation, latitude, and distance from eastern barrier.
   (2) r = 0.89. Average error = 1.57 inches. Standard error = 2.11 inches. Average precipitation: 42.2 inches. Number of stations: 132.

D. Lower part of the Hudson River drainage basin, including Schoharie Creek:
   (1) Parameters: elevation, rise, and drainage zones.
   (2) See E below.

E. Adirondack and Lake Ontario areas:
   (1) Parameters: elevation and drainage zones.
   (2) Overall correlation for drainage areas D and E is 0.94. Number of stations: 161

It should be noted that in the development of these graphic relations many other parameters were tried and discarded because they did not significantly improve the correlation. In the above appraisals the index of correlation (r) shows the correlations to be highly significant.

Isohyetal Map

The observed and adjusted average annual precipitation values were plotted on a map of the scale of 1:500,000. To supplement these data, a grid of points was established with an arbitrary spacing of 15 minutes of longitude and 15 minutes of latitude. The necessary topographic parameters were computed for each grid point. A determination of the average annual precipitation was made for each point by using the appropriate relation between annual precipitation and topographic factors. Additional point values were derived where required to define more adequately the precipitation pattern.

It will be noted that by the use of this technique, the data have been increased many fold, especially at the higher elevations. With the topographic contours as a guide, the isohyetal lines were then drawn by using observed and derived data.

Accuracy of Isohyetal Map

In order to assess the reliability of the average annual precipitation map, the average annual precipitation was computed for the drainage basins used in the runoff study and compared with the average annual runoff as measured at the stream gaging stations. In practically all instances, these comparisons were consistent throughout the region, generally varying only with latitude and elevation. In only a very few places was it necessary to reexamine the precipitation pattern over a basin. When apparent discrepancies were noted, the precipitation data were reanalyzed and the precipitation pattern modified only when justified by the margin of error in the precipitation data.

This average annual isohyetal map is more reliable than one based exclusively on observed precipitation data. If the map is used to determine the average annual precipitation for areas greater than 500 square miles, the values should generally be accurate within 5 percent. If used to obtain precipitation values at specific points, the reliability may be considerably less. This estimate of reliability is based on the assumption that the observed precipitation catch is the true precipitation.

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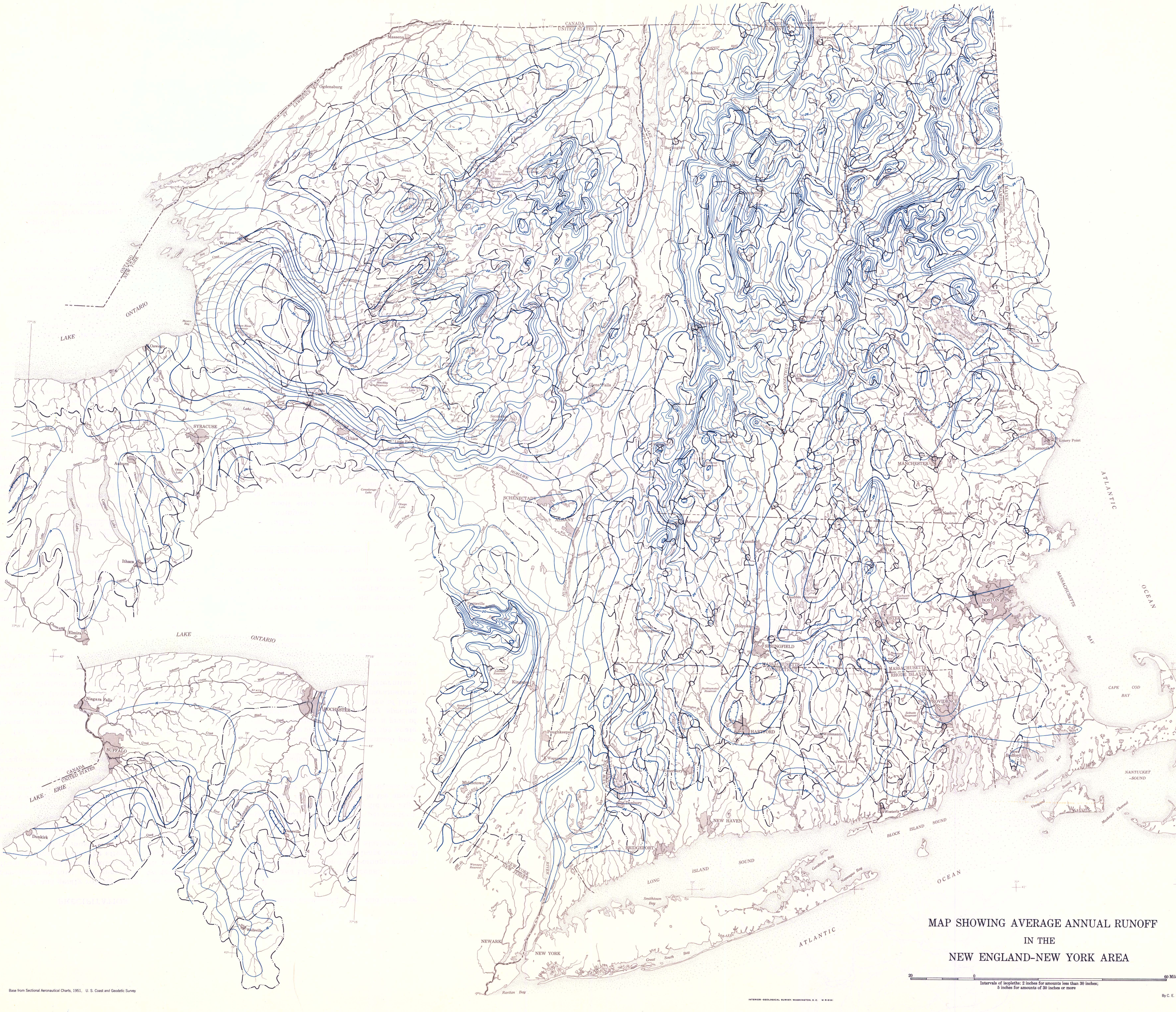

MAP SHOWING AVERAGE ANNUAL RUNOFF IN THE NEW ENGLAND–NEW YORK AREA

20 0 60 Miles

Intervals of isopleths: 2 inches for amounts less than 30 inches; 5 inches for amounts of 30 inches or more

By C. E. Knox

Base from Sectional Aeronautical Charts, 1951, U. S. Coast and Geodetic Survey

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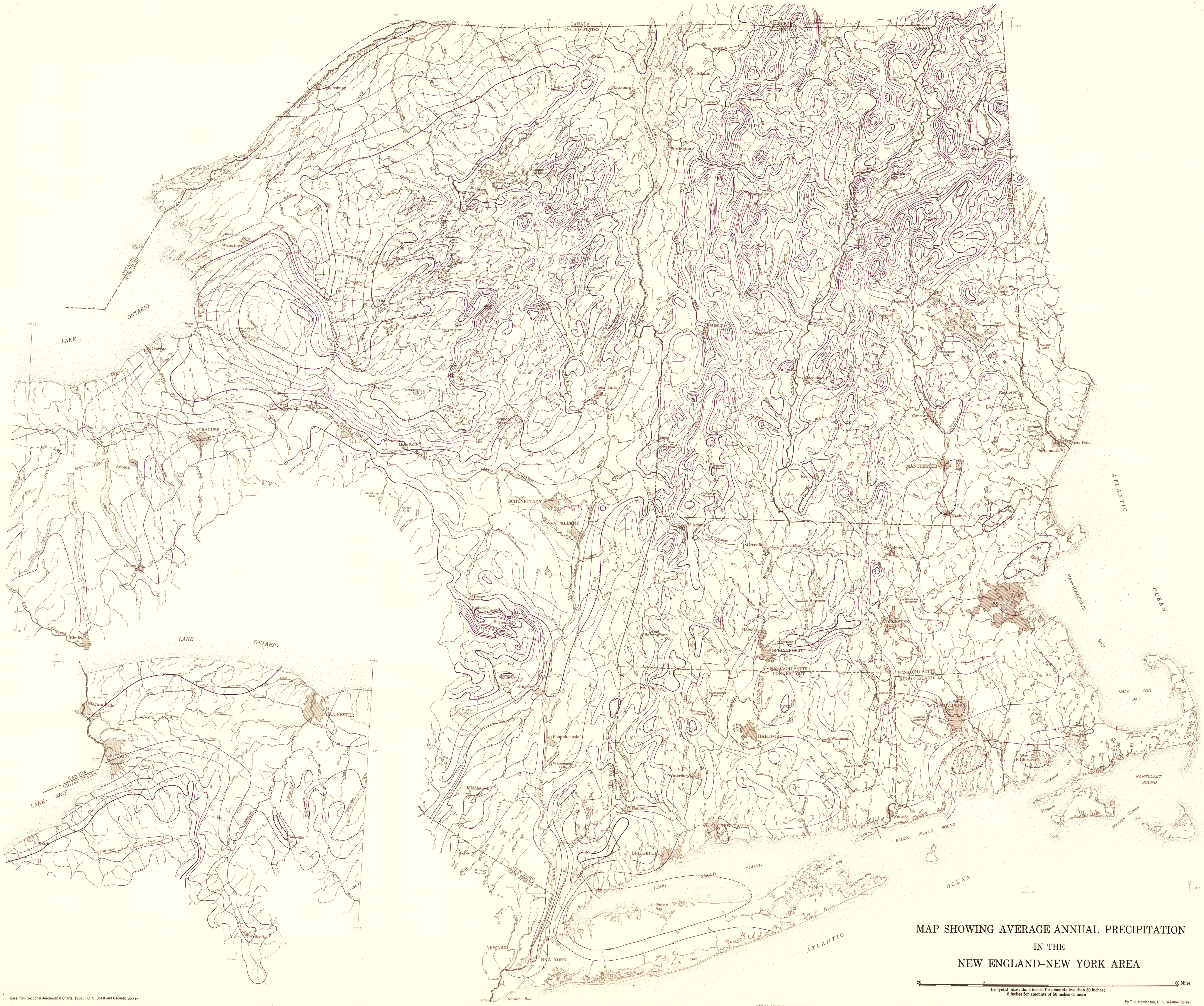


MAP SHOWING AVERAGE ANNUAL PRECIPITATION
IN THE
NEW ENGLAND–NEW YORK AREA

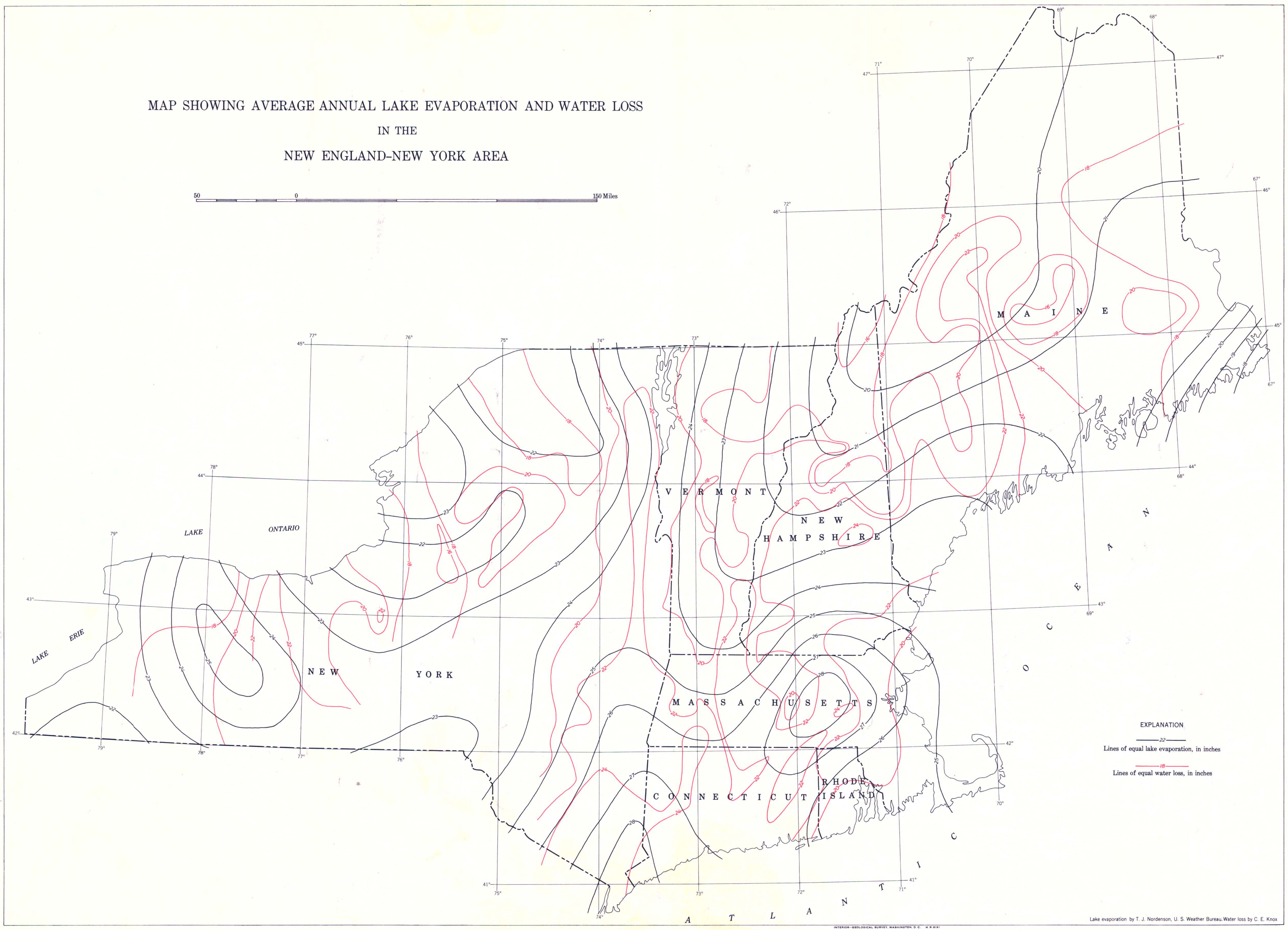
20 0 60 Miles

Isohyetal intervals: 2 inches for amounts less than 50 inches;
5 inches for amounts of 50 inches or more

By T. J. Nordenson, U. S. Weather Bureau

Base from Sectional Aeronautical Charts, 1951, U. S. Coast and Geodetic Survey

INTERIOR—GEOLOGICAL SURVEY, WASHINGTON, D. C. M R-8191



LAKE EVAPORATION

Introduction

There are three widely accepted methods for estimating annual lake evaporation: energy budget, mass transfer, and pan-coefficient. The energy-budget method requires accurate estimates of factors such as long-wave radiation, reflected solar radiation, surface-water temperature, and others, which are not normally observed and need special instrumentation. The mass-transfer method requires surface-water temperature, dewpoint, and wind-speed data. Considerable effort was made to collect surface-water temperature data so that this method could be applied. However, water temperature data were much too sparse for a reasonably accurate estimate of mean monthly water temperature and the method was discarded. The pan-coefficient method involves the application of a coefficient to the annual amount of pan evaporation to obtain lake evaporation.

The annual lake evaporation map in this atlas is based on the pan-coefficient method; however, computed pan evaporation was used rather than observed pan evaporation. There are very few class A pan records in the New England-New York area and these records are only for parts of years; observations are not made during winter. In the report Water-Loss Investigations: Lake Hefner Studies, Technical Report, a procedure is described for estimating class A pan evaporation from the meteorological factors of air temperature, dewpoint, wind speed, and solar radiation. The annual lake evaporation in the present report was then computed by multiplying the estimated pan evaporation by the coefficient of 0.69 as verified by the Lake Hefner study.

Basic Data

The analyses for deriving pan data were made on a monthly basis. The basic data consisted of average monthly values of air temperature, vapor pressure (or dewpoint) at the 6-foot level above ground (standard shelter), wind speed at pan anemometer height (about 2 feet above ground), and solar radiation.

The average monthly air temperature data were obtained from the Weather Bureau's Climatological Data for the United States.

Average monthly vapor pressure was computed for all first-order Weather Bureau stations, Civil Aeronautics Administration stations, and Air Force stations. Vapor pressure observations were adjusted to a 6-foot level above ground by using the correction graph of A. F. Meyer in his report Evaporation from Lakes and Reservoirs (1942). The adjusted vapor pressure data were plotted against station elevation, and a correction graph for the effect of elevation was derived. The vapor pressure data were reduced to a common elevation of 100 feet above sea level. The adjusted values were plotted on a map, and isopleths of vapor pressure drawn. A series of 12 monthly maps indicating the vapor pressure at 6 feet above ground at an elevation of 100 feet above sea level was prepared.

Average monthly values of wind speed were computed for all first-order Weather Bureau stations, Civil Aeronautics Administration stations, and Air Force Stations. These wind-speed data had to be adjusted to a 2-foot level above the ground. The formula used to reduce the wind speed from anemometer height to the 2-foot level is that of Rossby and Montgomery (1935):

$$\frac{U_2}{U_1} = \frac{\text{Log}\,(Z_2 + Z_0) - \text{Log}\,Z_0}{\text{Log}\,(Z_1 + Z_0) - \text{Log}\,Z_0}$$

where U_2 = observed wind speed at anemometer height
U_1 = estimated wind speed at 2-foot level above ground
Z_2 = height of anemometer above ground
Z_1 = 2-foot level above ground (pan anemometer height)
Z_0 = coefficient of roughness

The coefficient of roughness was assumed to be 100 centimeters based on studies by Panofsky and Singer (1951). The monthly wind-speed data reduced to pan anemometer level were plotted, and isopleths of wind speed drawn.

Average monthly values of solar radiation were obtained from the report Average Solar Radiation in the United States by Fritz and MacDonald (1949).

Evaporation Map

The points for which annual pan evaporation was estimated consisted of a well-distributed network of climatological stations. Climatological stations were selected because the average monthly air temperature, elevation of the station above sea level, and latitude and longitude were readily available in Climatological Data for the United States. The average monthly values of vapor pressure (100 feet elevation) were determined for each station and corrected to the station elevation. Average monthly values of wind speed and solar radiation were estimated for each location. The average monthly pan evaporation was computed for each station by use of the relation in the Lake Hefner report for estimating pan evaporation from air temperature, vapor pressure (dewpoint), wind speed, and solar radiation. The monthly values were added to obtain an average annual total of pan evaporation for each station in the network. These average annual pan evaporation values were multiplied by 0.69 (Lake Hefner pan-to-lake coefficient) to obtain the average annual lake evaporation. These values were plotted, and isopleths of average annual lake evaporation drawn.

Reliability

Studies subsequent to the Lake Hefner report indicate that annual class A pan evaporation can be estimated from meteorological factors within an average of 5 percent of accuracy. Such accuracy is based on the meteorological observations at the proper levels. Admittedly the weakest part of the analysis for the New England-New York area is the reduction of wind velocity to the pan anemometer level. However, errors in wind velocity are not invalidating, for it can be shown that an error of 100 percent in wind velocity results in an error of only 10 to 15 percent in the estimate of pan evaporation. Computed evaporation values based on meteorological factors were within 5 percent of the observed evaporation values at the five evaporation stations in the area.

The studies, which are the basis of the generally accepted class A pan coefficient of 0.7 and the Lake Hefner experiment, were conducted in areas of a more arid type than the New England-New York area. The more recent evaporation studies have disclosed that it is quite likely that the pan coefficient is slightly dependent on the climatic regime of an area. (Probable range, 0.60 to 0.80.) Preliminary results indicate that a coefficient of 0.75 might be more applicable to the New England-New York area. The theory of a geographical variation in the pan coefficient is being examined in additional studies in progress.

The effect of altitude has not been considered except as it affects the vapor pressure for the network of stations selected. A more detailed analysis would be required to differentiate between the evaporation in the valleys and evaporation near the mountain peaks.

WATER LOSS

The term "water loss" as used in this atlas is the difference between precipitation and runoff. The average annual precipitation for each of the 260 stream-gaging stations was computed from the isohyetal map prepared by the Weather Bureau. Water loss for each basin was obtained by subtracting the measured runoff from precipitation. Because the precipitation and runoff data used were average annual values for the 20-year period of 1930-49, the resultant water loss values are also average annual values for the same period.

Development of Isopleths

In the development of isopleths of water loss, the average annual water loss for each drainage basin was plotted on a map. The isopleths of water loss were drawn at 2-inch intervals and distributed in such a way that the water loss for any gaging station area, as shown by the map, equaled the value as computed from precipitation and runoff within 1± inch. Water loss for adjacent gaged areas was used as a guide in drawing the isopleths of water loss through relatively large ungaged areas.

Because the map of water loss was prepared independently of the maps of runoff and precipitation, it is to be expected that values of L computed by subtracting the value of R from the value of P at any point may depart more than 1 inch from the value as determined from the map of water loss. The water-loss map does not indicate water loss at points but only as an average over an area equal in size to that of the drainage area above the stream gaging stations.

The water loss for adjacent basins was found to be remarkably uniform, the maximum difference between any two basins being about 4 inches. The differences in average annual water loss in basins throughout the New England-New York area are due to differences in precipitation, temperature, vegetation, and geologic and topographic characteristics. The average annual precipitation so greatly exceeds the loss by evapotranspiration in this area that variations in the amount of average annual precipitation have little or no effect on average annual water loss.

Conclusion

In the New England-New York area the rate of evaporation from lake surfaces is slightly larger than the rate of water loss from drainage basins. In most of the area average annual evaporation from a future reservoir would be only a few inches more than the average annual water loss that occurs over the reservoir area under present conditions.

Because of variation in the amount of water loss from year to year resulting from variation in the distribution of precipitation during the year, values of water loss as shown on this map should not be used in estimating the runoff for any given year. Rather, the method suggested in the section on Runoff should be used if runoff by years is desired.

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