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Mean Annual Precipitation and Evapotranspiration -Plate 2

MEAN ANNUAL RUNOFF, PRECIPITATION, AND EVAPOTRANSPIRATION IN THE GLACIATED NORTHEASTERN UNITED STATES, 1951-80

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INTRODUCTION

Maps of mean annual runoff, precipitation, and evapotranspiration in the glaciated Northeast, averaged over the 30-year period 1951-80, were drawn as part of the U.S. Geological Survey's Northeast Glacial Aquifers Regional Aquifer-System Analysis project (Lyford and others, 1984; Lyford, 1986). These maps can be used to estimate amounts of water available for recharge to aquifers, as described by Lyford and Cohen (1988), and for other general purposes. The paragraphs that follow explain how the maps were prepared and checked for accuracy.

MAP PREPARATION AND VERIFICATION

The map of mean annual runoff in the glaciated Northeast (pl. 1) is based primarily on records of streamflow from 503 gaged watersheds. Nearly all of these watersheds include less than 500 square miles, and 60 percent include less than 100 square miles. Recorded streamflows were corrected for any significant diversions. Values of mean annual runoff from 486 of these watersheds for 1951 through 1980 were compiled as part of a study by Krug and others (1990), in which any streamflow record that did not include all 30 years was extended by regression with the record from a nearby station according to a method explained by Matalas and Jacobs (1964). Mean annual runoff values were compiled as part of the present study for eight watersheds in northeastern Ohio and nine watersheds in Canada near the United States border, all of which were gaged continuously from 1951 through 1980. The boundary of each watershed was drawn on a base map of 1:1,000,000 scale, and the mean annual runoff was assigned to that watershed area. The watershed-runoff values were supplemented by point estimates of runoff at 419 precipitation stations in the United States and 64 in Canada, which were obtained as follows: Precipitation at each station was partitioned into estimates of evapotranspiration and runoff, which were constrained such that evapotranspiration estimates would vary smoothly across the region and decrease with increasing altitude and latitude, while the runoff estimates would be consistent with measured runoff from any nearby watersheds. A point estimate of runoff was considered consistent if it equaled average runoff from a nearby watershed, or if it were somewhat higher (or lower) and a compensating departure from average watershed runoff could reasonably be inferred in more distant parts of the watershed on the basis of altitude or regional trends. Bishop and Church (1992, 1995) also computed point estimates of runoff at precipitation stations to supplement runoff data from gaged watersheds for use in contouring average annual runoff, although their partitioning procedures differed somewhat from those described above.

Plate 1 differs appreciably in detail from a map of mean annual runoff drawn by Krug and others (1990) from nearly the same runoff data, but the two maps are broadly similar and of comparable accuracy. Krug and others (1990, table 4) excluded 5 percent of the watersheds in their data set, selected at random, before drawing their runoff map; then, as a test of map accuracy, they estimated runoff from their map for each of the excluded watersheds and compared the results with runoff compiled from gaging-station records. A total of 38 watersheds within the glaciated Northeast were excluded. The same 38 watersheds were excluded in this study during preparation of the first draft of plate 1, and runoff for each excluded watershed was estimated from that map by the weighted-average method described by Krug and others (1990). That draft of plate 1 depicted mean annual runoff from 21 of the 38 watersheds more accurately than the map by Krug and others (1990), 3 equally well, and 14 less accurately. The mean absolute deviation from observed runoff for the 38 watersheds was 1.42 inches on plate 1, and was 1.72 inches on the map by Krug and others (1990). Both maps slightly underestimate runoff; mean signed deviation was about -0.5 inches for both maps. Subsequently, the accuracy of plate 1 was improved by incorporating the data from Canada and from the 38 watersheds initially excluded.

After revision of the runoff map, a map of mean annual precipitation (pl. 2) was drawn such that precipitation contours parallel runoff contours and are consistent with the point precipitation data. Differences between runoff and precipitation on the two maps correspond to evapotranspiration as estimated earlier by partitioning of precipitation at each station into regionally consistent point runoff and evapotranspiration values. Evapotranspiration is shown on plate 2 as 1-inch zones of uniform evapotranspiration rather than as contours because evapotranspiration at each precipitation station was estimated only to the nearest inch during the partitioning process. Finally, as a means of quality control, Geographic Information Systems software was used to create a three-dimensional surface from the runoff contours, and a similar surface from the precipitation contours, by the Delaunay method of triangulation (ESRI, 1991, p. 2-11). These surfaces were resampled to generate lattices having a spacing of 4 miles between lattice points, and runoff was subtracted from precipitation in each lattice block. Discrepancies between the array of evapotranspiration values thus computed and the original evapotranspiration zones led to correction of several mislabeled contours and minor misinterpretations in placement of contours.

COMPARISON TO ALTERNATIVE INTERPRETATIONS

Maps of precipitation and runoff that were drawn independent of each other appear together in some publications (for example, Lyford and others, 1984; Olcott, 1995; Moody and others, 1986) and have been used together in some hydrologic analyses. Such independent maps are commonly inconsistent. For example, precipitation and runoff are interpreted as increasing in different directions, as much as 90 degrees apart, in some places, which is inherently implausible and which results in large, anomalous differences between adjacent areas in evapotranspiration as computed by subtracting runoff contours from precipitation contours. Although extreme differences in evapotranspiration might be expected between adjacent local terranes as different as a bare bedrock slope and a swamp, spatial variability should be small and gradual when evapotranspiration is estimated from runoff averaged over watersheds of several square miles or more, as suggested by maps of evapotranspiration by Knox and Nordenson (1955) and Hely and Nordenson (1961). Plates 1 and 2 are interdependent and mutually consistent in that precipitation minus evapotranspiration equals runoff at all locations and precipitation and runoff increase together.

Plate 2 may slightly underrepresent average precipitation and evapotranspiration in mountainous regions. A small-scale map of evapotranspiration in New York and New England by Knox and Nordenson (1955) indicates smaller decreases in evapotranspiration with increased altitude than does plate 2. A few records, some discontinuous (Iorio, 1972; Bishop and Church, 1992) suggest that precipitation on mountain peaks may generally exceed values indicated on plate 2, and at high altitudes fog drip and rime augment the moisture recorded by rain gages (Dingman, 1981). Research in Switzerland suggests that precipitation in mountainous areas is typically underrecorded (Diaz, 1995). Furthermore, although differences between runoff from small upland watersheds, runoff from large watersheds, and point runoff partitioned from precipitation required depiction of greater runoff (and precipitation) at higher altitudes in many localities on plates 1 and 2, most precipitation stations in areas of high relief are near population centers in valleys, so the contours are not precisely controlled by point data at high altitudes.

Plates 1 and 2 are based on data from 1951-80 because runoff and precipitation data sets that had already been adjusted to represent that period were available. Trends toward increased runoff and decreased evapotranspiration from 1940 or 1950 through 1988 have been reported (Lins and Michaels, 1994) but were not considered in this study.

Church and others (1995) computed point values of 1951-80 evapotranspiration in northeastern United States by subtracting runoff (plotted at watershed centroids) from precipitation (projected to watershed centroids by linear interpolation between precipitation stations), and by subtracting runoff as interpolated from the map by Krug and others (1990) from precipitation at precipitation stations. This approach is objective and readily automated but does not allow spatial variation in precipitation data to affect interpretation of runoff data, nor the reverse, and its treatment of runoff from large watersheds as point data can be misleading. The point values were contoured, following topographic contours and constraining evapotranspiration to decrease with increasing altitude. The evapotranspiration zones thus generated (Church and others, 1995, fig. 5a) are broadly similar to those on plate 2 but differ in some details and incorporate a slightly greater range in evapotranspiration from north to south than shown on plate 2.

Maps of precipitation, runoff, and evapotranspiration more detailed and accurate than plates 1 and 2 or other cited maps of this region could be prepared by a more comprehensive approach that first quantified the relation of precipitation to altitude and other orographic factors, then calibrated those results against concurrent watershed runoff to ensure that contours of precipitation, runoff, and evapotranspiration are mutually consistent. Knox and Nordenson (1955) adopted such a comprehensive approach, but mapped only part of the glaciated Northeast, used data from 1921-50, and did not document their computations. Hely and Nordenson (1961) comprehensively mapped the Delaware River basin and presented graphical relations of precipitation to orographic factors. Bishop and Church (1995) reported preparing a runoff map similar to that of Krug and others (1990), based in part on a numerical model under development that computes precipitation distribution from altitude and slope orientation.

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Base map from various sources

Plate 2. Mean Annual Precipitation and Evapotranspiration