# Simple, Practical Method for Determining Station Weights Using Thiessen Polygons and Isohyetal Maps

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**Abstract:** A simple, practical method for computing station weights, which are commonly used in operational (i.e., real-time) hydrologic modeling, is presented. The weights are derived using Thiessen polygons and widely available isohyetal information. The method is shown to eliminate long-term bias associated with the difference between the spatial distribution of precipitation implied by Thiessen polygons and the more accurate spatial distribution depicted by an isohyetal map.

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## Introduction

Station weights are scalar factors used to transform point precipitation observed at rainfall gauging stations into an associated mean precipitation over an area that the station data are assumed to represent. A linear combination of these transforms is used to compute mean areal precipitation (MAP) over basins. Station weights are used primarily for operational (i.e., real-time) hydrologic modeling to determine MAP over short time intervals (typically 1–6 h). While much current research is aimed at improving the use of radar and satellite data to determine MAP, and the future of MAP estimation likely lies with remote sensing techniques, data collected at rain gauges is currently and will continue to be used extensively to compute MAP.

Station weights are used in an operational setting where it is not practical to perform more detailed analysis of precipitation fields. For example, the National Weather Service River Forecast System (NWSRFS), which is the tool employed to generate hydrologic forecasts in real time throughout the United States by the National Weather Service (NWS), uses station weights to generate MAP time series for model calibration and to compute MAP for operational forecasting on large rivers at (typically) 6 h intervals (NWS 2002). Several proprietary forecasting systems used by emergency managers and hydroelectric power companies also rely on station weights. Examples of these systems include RiverTrak, developed by Riverside Technology, inc.; CFS, developed by David Ford Consulting Engineers; and Inflow Vista, developed by Synexus Global Inc. While some of these systems are capable of using radar data, if available, all use station weights (annual or seasonal) as the sole means of translating gauge data into MAP. It is important to note that station weights are not used to estimate precipitation spatial variability in lieu of isohyetal maps; rather, they are used to estimate MAP over short time intervals (typically 1–6 h, but sometimes as small as 10 min) for input to real-time hydrologic forecasting systems.

There are two primary ways currently available to compute station weights: (1) the classical Thiessen methodology; and (2) inverse distance squared weighting (NWS 2002). However, station data are often sparse and do not represent areal processes well, particularly in mountainous regions. Gauges are commonly located at lower elevations in mountainous regions, causing consistent underestimation of MAP (NWS 2002). In these cases, users either subjectively modify (increase) computed station weights, or develop ‘‘synthetic stations’’ at high elevations; precipitation at these synthetic stations is also estimated with the inverse distance squared technique (NWS 2002). The goal is to make sure that the MAP computed in real time agrees with long-term climatology. This technical note describes a new, objective method to compute station weights by combining Thiessen polygons with isohyetal information so that the individual station weights better represent the areas surrounding them, thus ensuring that the time-averaged MAP is consistent with ‘‘true’’ time-averaged MAP (‘‘true’’ being represented by an isohyetal map). In doing so, hydrologic model bias due to consistent MAP estimation error is minimized.

## Method

Traditionally, the $MAP_i$ associated with a Thiessen polygon $i$ is taken to be equivalent to the point precipitation $P_i$ of the station located at the centroid of the polygon $i$, or

$$MAP_i = P_i \tag{1}$$

A hypothetical subbasin is shown in Fig. 1, with one gauging station and the associated Thiessen polygon defined. For a subbasin encompassing numerous Thiessen polygons, the subbasin MAP, here designated $MAP_T$, is computed by summing up the contributions of each area $i$

$$MAP_T = \sum_i T_i \; MAP_i = \sum_i T_i \; P_i \tag{2}$$

where $T_i$ = Thiessen-based station weight, computed as

$$T_i = \frac{A_i}{A_T} \tag{3}$$

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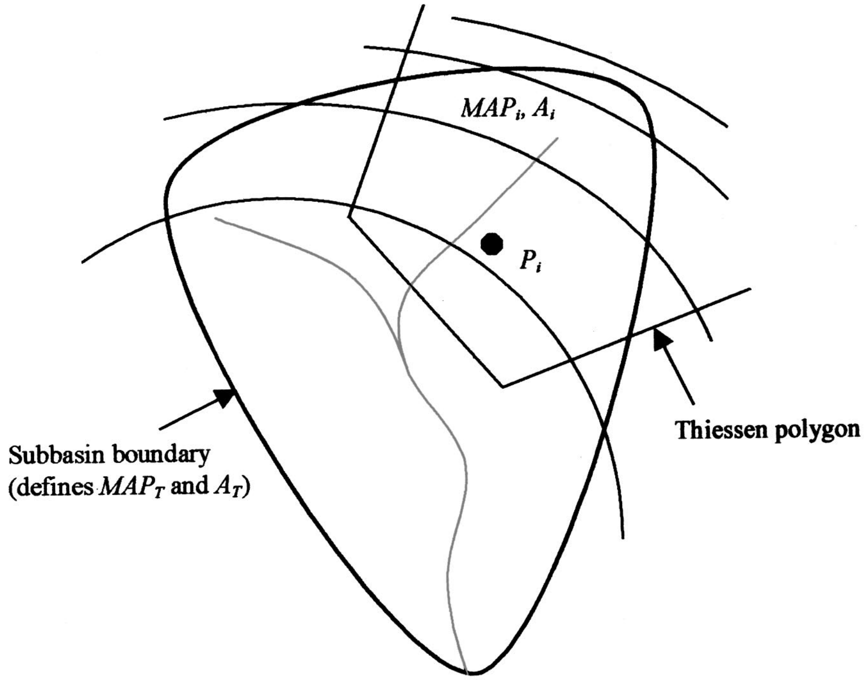


**Fig. 1.** Hypothetical subbasin with one gauging station and associated Thiessen polygon defined. Curved lines in upper right portion of figure represent isohyets. $P_i$ = mean precipitation measured at gauging station, and $MAP_i$ = mean areal precipitation in $A_i$ (area defined by intersection of Thiessen polygon and subbasin boundary) as defined by isohyets. $MAP_T$ and $A_T$ = mean areal precipitation computed over entire subbasin and total subbasin area, respectively.

where $A_T$ = total area of the subbasin; and $A_i$ = area defined by the Thiessen polygon alone (if the polygon lies completely within the subbasin), or by the intersection of the Thiessen polygon and the watershed boundary.

Depending on station locations and local climate patterns, the first equality is generally not true. Isohyetal maps typically define a more accurate spatial distribution of precipitation than do Thiessen polygons and can be used to compute time-averaged $MAP_T$ and $MAP_i$. Isohyetal maps can be developed using a variety of means and often account for nonlinear spatial variations (e.g., by using kriging) and orographic effects. Excellent mean annual and monthly isohyetal maps are available for the entire United States, developed using the PRISM methodology (Daly et al. 1994; see http://www.ocs.orst.edu/prism/state_products.html). Government agencies in numerous countries also disseminate isohyetal maps. However derived, they can be used to compute station scale factors that adjust the individual Thiessen weights to better represent the area surrounding them and ensure that the "true" (isohyetal) time-averaged $MAP_T$ is preserved. The station scale factor, designated $S_i$, is derived from the relationship between point precipitation $P_i$ observed at a station $i$ and the isohyetal-derived $MAP_i$ in the intersection of the subbasin boundary and the Thiessen polygon $i$ represented by station $i$. It is computed as

$$S_i = \frac{MAP_i}{P_i} \tag{4}$$

leading to an unbiased MAP for the subbasin of

$$MAP_T = \sum_i S_i \; T_i \; P_i \tag{5}$$

Or, if a new scaled weight is defined as $W_i = S_i \; T_i$

$$MAP_T = \sum_i W_i \; P_i \tag{6}$$

Note that the station weights can be derived using the mean annual precipitation observed at each station and an annual isohyetal map, or seasonal weights can be derived using location-specific appropriate time periods for both the mean station precipitation and the isohyetal map. NWSRFS and other systems only allow the use of either annual or seasonal station weights. While the weights (and station scale factor) could conceivably be varied at much smaller time scales to provide more accurate MAP estimates, it is not possible to do so given current system limitations.

## Computational Procedure

Given a digital isohyetal map, such as the PRISM maps, and the areas defined by the subbasin boundaries and Thiessen polygons, a geographic information system (GIS) is used to compute $A_T$ and $MAP_T$ (Fig. 1). Both areas and mean values over a given area are standard GIS computations. In addition, the area, $A_i$, and $MAP_i$ (Fig. 1) are determined for each Thiessen polygon/subbasin intersection area. Then, the desired $W_i$ values for each station and subbasin are determined using the aforementioned equations [$S_i$ computed using Eq. (4), $T_i$ computed using Eq. (3), then $W_i = S_i \; T_i$].

For Thiessen polygons that lie completely within the subbasin boundary, $A_i$ and $MAP_i$ are computed using the entire polygon area. However, the GIS analyst must make sure to use only the portion of the Thiessen polygon that lies within the subbasin for those Thiessen polygons that do not lie completely within the subbasin (along the subbasin boundaries).

## Example Results

Table 1 contains the results for the subbasin designated GRUV2 located in the NWS Big Sandy River basin, which is the respon-

**Table 1.** Results for Subbasin GRUV2, Located within Big Sandy Forecast Group of Ohio River Forecast Center

| Station | $A_i$ ($km^2$) | $T_i$ | $P_i$ (cm) | $MAP_i$ (cm) | $S_i$ | $W_i$ |
|---|---|---|---|---|---|---|
| WV4408 | 21.05 | 0.034 | 112.47 | 119.83 | 1.07 | 0.036 |
| WV3353 | 17.85 | 0.029 | 103.99 | 120.14 | 1.16 | 0.033 |
| VA7997 | 15.91 | 0.026 | 111.02 | 121.01 | 1.09 | 0.028 |
| VA4180 | 30.49 | 0.049 | 113.54 | 117.73 | 1.04 | 0.051 |
| VA4078 | 26.60 | 0.043 | 108.56 | 119.71 | 1.10 | 0.047 |
| VA3640 | 398.47 | 0.642 | 113.72 | 114.53 | 1.01 | 0.647 |
| VA2269 | 110.28 | 0.178 | 109.14 | 115.60 | 1.06 | 0.188 |

Note: $\Sigma T_i P_i = 112.29$; $\Sigma W_i P_i = 115.62$

sibility of the Ohio River Forecast Center. This river basin is located in the Cumberland Plateau, near the intersection of the state borders of Kentucky, West Virginia, and Virginia. Historical data from October 1, 1948, to September 30, 1998, were used to estimate mean annual point precipitation values. For the subbasin GRUV2, $A_T = 620.6\ \text{km}^2$, and the ''true'' (isohyetal) annual $MAP_T = 115.62$ cm. Using the unadjusted Thiessen weights, the annual MAP is computed to be 112.29 cm. Thus, using station weights adjusted with the station scale factor, a long-term bias in subbasin MAP of approximately $-3\%$ is avoided. In model calibration, bias is typically minimized by adjusting model parameters. Thus, some amount of hydrologic model parameter distortion is avoided when using this method. When using any model that maintains a water balance, which all valid models do, the bias in the time-averaged MAP must translate directly into bias in the (simulated) time-averaged streamflow. In the example provided, the MAP bias is $-3\%$. Thus, given identical model parameters, and assuming a water balance is maintained, the absolute difference in time-averaged streamflow for simulations performed with the developed method versus the unmodified Thiessen method must be 3%.

Note that, in this example, the station scale factors are all greater than one. This is a common result in mountainous areas, because precipitation gauges are usually located at relatively low elevations within a particular subbasin to facilitate access for gauge maintenance, and precipitation is often positively correlated with elevation (NWS 2002). Therefore, while this percent difference in the example provided may seem small, the cumulative effect over an entire watershed modeled as many subbasins can be significant.

## Conclusion

A simple, practical method of computing station weights is presented and shown to eliminate long-term bias associated with the difference between the spatial distribution of precipitation implied by Thiessen polygons and the ''true'' spatial distribution as depicted by an isohyetal map. The developed method represents an improvement over current methods and fits into the framework of existing forecasting systems.


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