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Radar Estimates + Gauge Data
A Perfect Union

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The most significant input into a surface water model is total rainfall volume. For years, hydrologists and engineers have tried to infer total rainfall volume over a watershed by spatially interpolating point rainfall data from sparsely placed rain gauges. In essence, hydrologists have only been able to guess at total rainfall volumes because of incomplete information.

Gauge Data Pitfalls

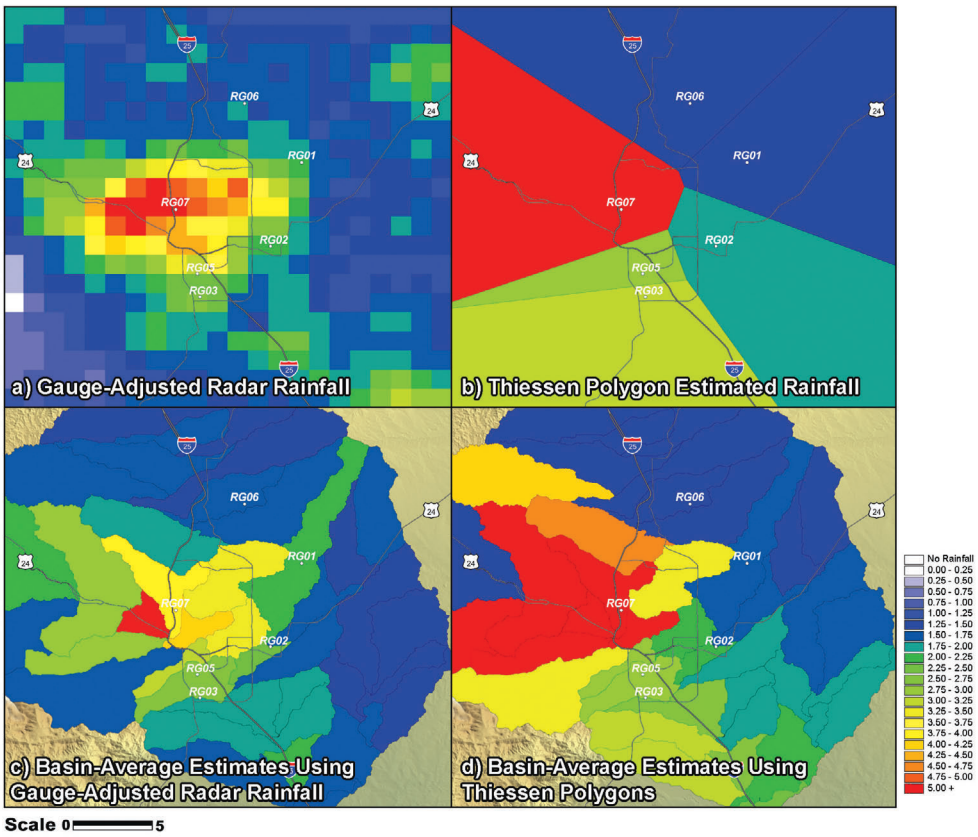
These guesses include the use of Thiessen polygons, which assign equal rainfall to the area closest to a given gauge, and inverse distance squared weighting, which assigns a rainfall value at a given location based on a weighted-average rainfall from nearby gauges. Both rainfall estimation techniques have major flaws. Thiessen polygons, originally proposed in 1911, create irregular polygon shapes of rainfall. When you watch the local news at night, how often have you seen an irregular polygon of constant rainfall moving toward your neighborhood?

Inverse-distance squared weighting interpolates rainfall between gauges, thus the maximum and minimum rainfall values have to occur at a rain gauge location for the estimate to be accurate. But what are the chances that the highest and lowest rainfall amounts occur over an area comprising 12.5 billionths of a square mile (the size of the opening of an eight-inch diameter rain gauge), where there just happens to be a rain gauge?

Too often, these estimation methods put the wrong amount of rain in the wrong place at the wrong time. And hydrologists too often try to solve this problem by tweaking calibration parameters in a hydrologic model that might not need tweaking. If too much flow is coming out of subbasin A105, let's adjust the loss rates in subbasin A105! During the next storm, you might end up with too little flow out of A105 because the loss rates were incorrectly changed during the last calibration attempt. Perhaps the original loss rates were accurate all along, but the rainfall input for basin A105 was incorrect. Again, total rainfall volume is the most important and significant input into a surface water model.

Gauge-adjusted radar rainfall data … maintain volume accuracy at the gauge locations while retaining the spatial information from the WSR-88D data.

So what is the best way to get an accurate view of the total volume of precipitation falling over a watershed? Theoretically, you could place enough gauges to completely eliminate errors in the spatial interpolation of rainfall, but that would be prohibitively expensive. A better solution is to use radar rainfall estimates from the national network of Weather Surveillance Radar-88 Doppler (WSR-88D), commonly know as NEXRAD, in conjunction with the existing rain gauge network.



In this example from Colorado Springs, rainfall estimates from gauge-adjusted radar rainfall estimates (a) nearly match estimates from rain gauges (b) at the gauge locations. However, because radar can fill in the gaps between gauges, basin-average estimates using radar (c) are quite different from basin-average estimates using only rain gauges (d). The rain gauges clearly put the wrong amount of rain the the wrong place at the wrong time.

Radar Estimate Plusses and Minuses

The network of WSR-88D radars across the United States was deployed between

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1992 and 1996. Today, the network consists of around 140 radars in the contiguous United States and another 20 or so in Alaska, Hawaii, and abroad. They estimate precipitation to a distance of about 140 miles and generally have been placed around the country to maximize coverage of the most populated areas.

WSR-88D radar works the same way as airport radar. Just as airport radar can determine the size and location of a plane based on the strength and timing of the reflected signal, WSR-88D radar does the same for smaller objects in the atmosphere, such as precipitation. Rayleigh scattering, a principle which states that the reflected signal from objects is proportional to the sum of the sixth power of the diameters of all of those objects, dictates the relationship between the reflected signal and rainfall intensity. This relationship does not hold perfectly because of signal attenuation and because the objects (raindrops) are not perfectly spherical. But since a mathematical relationship exists between backscatter and total drop size, empirical relationships have been developed to relate reflected signal strength with estimated rainfall rate.

Unfortunately, WSR-88D is not a perfect tool. It does not directly measure rainfall. Rather, it measures the reflected signal from objects in the atmosphere. Consequently, the radar measures dust, birds, planes, bats, golf balls, hail, mountains, tall buildings, superheroes, you name it. Anything that gets in the way of the radar will produce a reflected signal that is interpreted as rainfall, a phenomenon known as ground clutter. Additionally, because the radar beam cannot penetrate these objects, the radar won't "see" rainfall on the other side of the impeding object, an error known as radar shadow. In the mountainous West, this can be a significant problem and often precludes radar rainfall estimation as a viable solution.

But the main error associated with WSR-88D is its inability to consistently estimate rainfall totals at a given location. The empirical relationships mentioned

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PERSIANN: Another Source for Precipitation Data

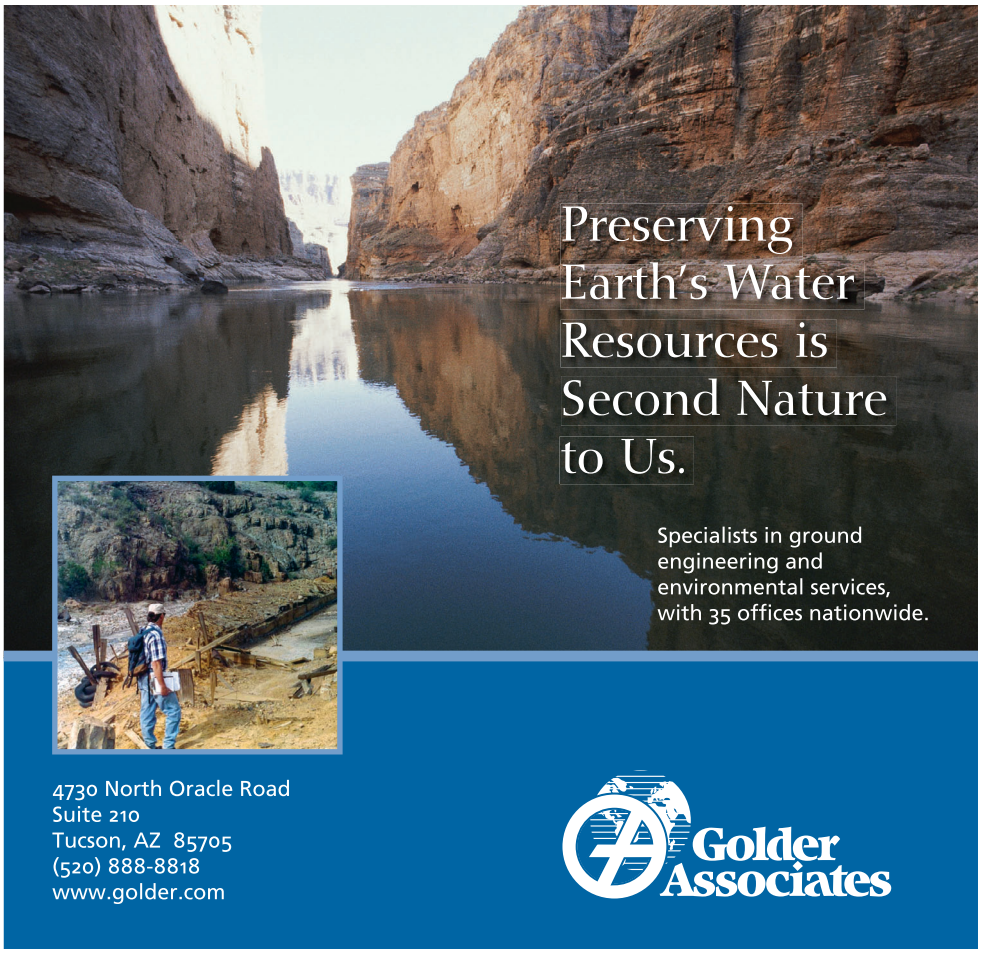
The PERSIANN (Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks) system uses neural network procedures to compute estimates of rainfall rates around the globe between latitudes 50°N and 50°S. An artificial neural network (ANN) is a type of software that can learn to recognize patterns in data (see page 12). Once it has been trained on existing data relations, the ANN can make predictions by detecting similar patterns in future data. PERSIANN measures rainfall rates at each 0.25-degree latitude (about 15 miles) by 0.25-degree longitude pixel of the infrared brightness temperature image provided by geostationary satellites.

An adaptive training feature allows the network parameters to be updated whenever independent estimates of rainfall are available. Current PERSIANN model parameters are adjusted from rainfall estimates from several NASA, NOAA, and DMSP low-orbital satellites. The PERSIANN system uses geostationary environmental satellite longwave infrared imagery to estimate surface rain rates. Precipitation estimates are generated every 30 minutes and are accumulated to longer time periods, such as 6-hour or daily rainfall.

While the resolution of PERSIANN data is low relative to radar-derived data, it can provide data from areas inaccessible by radar, such as mountainous terrain and under certain cloud conditions. It is particularly useful for remote, rugged areas of the Southwest not covered by gauges or radar. PERSIANN appears to perform better in convective storms due to their cloud features, and is less effective in measuring snowfall.

PERSIANN precipitation data can be downloaded free from the HyDIS Web site (hydis8.eng.uci.edu/persiann/). Files containing precipitation data for every six-hour period from March 2000 to the present are compressed into a single file for each month. The data for one six-hour period are contained in a single, global grid (400 rows by 1,440 columns) at 0.25-degree resolution in units of millimeters per six hours (see "Instructions" in the HyDIS PERSIANN Web page for detail).

PERSIANN-CCS is being developed with about 2.5-mile square resolution. Real-time hourly rainfall data are available back to 2002 (see hydis8.eng.uci.edu/CCS/) and soon will be available for download.



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earlier that convert a reflected signal to rainfall rate use an assumed distribution of raindrop sizes. If this assumption is incorrect – and it almost always is – then the rainfall estimate at that given location will be incorrect. But there is good news: because the factors that affect drop size distribution (temperature, humidity, uplift, etc.) are relatively consistent at a given time over a small area, the radar is able to capture relative rainfall amounts between two nearby locations. In other words, while the radar cannot determine exactly how much rainfall fell at point A or point B, it can provide a very accurate reading on the relative amounts at each location.

Thus, the strength of WSR-88D data, the ability to capture spatial rainfall information, is the weakness of rain gauge data. And the weakness of WSR-88D data, the inability to accurately capture rainfall amounts at a single location, is the strength of rain gauge data. By merging the two datasets, the result is gauge-adjusted radar rainfall data, a dataset that maintains volume accuracy at the gauge locations while retaining spatial information from the WSR-88D data.

A More Perfect Union

Merging the two datasets is an extremely important step. Keep in mind that a 2-km by 2-km radar pixel is around 100 million times the size of the opening of a rain gauge, roughly the ratio of the state of California to a football field. Consequently, a rain gauge and radar pixel at the same location might have significantly different estimates and both estimates could be correct.

While the length of record is relatively short, there are some promising applications for gauge-adjusted radar rainfall applications. A good example is the development of depth-area reduction factors. In the past, these have been estimated from the spatial interpolation of point rainfall data and the results from these studies are dependent upon the method of interpolation. The spatial information inherent in the WSR-88D dataset provides a much better understanding on the true size and shape of storms and this will significantly impact design storms.

Raw, unadjusted rainfall data are available for free from the National Weather Service, although some significant holes exist in the data record, and the data will require substantial time to decode for your hydrologic model. Alternately, commercial providers can offer gauge-adjusted radar rainfall data for any region in the country back to 1993, and these data can be formatted for direct input into hydrologic models such as HEC-HMS, HEC-1, HYDRA, InfoWorks, and SWMM. The service and these data are not free – a month's worth of rainfall data for a small watershed will cost a couple thousand dollars, more with increasing size and complexity. But if you are creating a hydrologic model that can significantly impact future development, don't you want to have the best data available for the most important input into your model?

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to other feature types. The infrared band is used to identify and map vegetation that is directly related to pervious features. The blue, green, and red bands are used to determine urban features and soil characteristics.

Thus, QB orthorectified multispectral imagery is accurately classified into impervious and pervious surfaces using computer image processing and other editing techniques. Common impervious surface classification is about 80 percent accurate from this initial computer analysis, and increases to greater than 90 percent accuracy with semiautomatic and manual editing techniques. The price for the impervious surface maps is about $450 per square mile, and includes the orthorectified QB imagery, the impervious surface map as binary raster files, and an ESRI shapefile, together with an attribute table that quantifies the amount of impervious surfaces for each parcel (in square feet) and the percentage of impervious surfaces per parcel.

The Denver Wastewater Management District now uses these data to update their user fee billing system according to each customer's impervious surface area. When parcel information is overlaid on the maps, the amount and percentage of impervious surfaces per parcel can be quantified and used to determine a fair stormwater "user fee," assessed according to what a parcel contributes to stormwater runoff.

The same impervious surface data can provide input to hydrologic modeling packages to help determine runoff coefficients and other physical characteristics. Because the data used in developing impervious surface maps represent what is actually on the ground, these products are superior in driving hydrological models to those based on planning, zoning and other data which merely estimate the amount of impervious surfaces. Many public domain and commercial hydrologic modeling packages can ingest impervious surface information, including HEC 1&2, HEC RAS, SWMM, XP, and WISE.

The impervious surface map also helps quantify water pollution characteristics and identify appropriate treatments based on local geographic factors. For example, runoff from large parking lots can be isolated and treated for pollutants such as lubricants, antifreeze, or asbestos.

What's in the future? GIS-based surface-water modeling is still in its infancy; it has many potential applications and capabilities. Geographic information such as impervious surfaces, topography, and land use and cover, used in conjunction with physical hydrologic information and proper planning, will enable timely and well-informed surface-water management decisions.

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