ET–The Key to Balancing the Water Budget in the Southwest

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Throughout the Southwest, state and federal water-resource managers are becoming increasingly concerned about the impacts of future groundwater development on the region's limited water resources, environmentally sensitive ecosystems, and rural lifestyle. To address their concerns, scientists and engineers are deploying physically based mathematical models to assess and predict the potential effects of increased groundwater pumping. The accuracy of these predictions is directly related to how well water budgets are quantified and balanced at basin and regional scales.

Groundwater Discharge Via ET

Of the three main components of a predevelopment groundwater budget—natural discharge, natural recharge, and subsurface flow—estimates of natural discharge are the most straightforward to obtain, and can be used to constrain the other, more difficult to quantify water budget components. In the Southwest, groundwater discharges naturally in low areas of intermontaine basins by 1) spring and seep flow; 2) transpiration by local phreatophytes, and 3) evaporation from soil and open water.

Evapotranspiration (ET) is the combined process that transfers evaporated and transpired water from the land surface to the atmosphere. ET measurements from discharge areas typical of the Southwest include spring and seep flow because most of the discharged water evaporates from pools or open drainages, or infiltrates downward to the shallow water table where ultimately it is transpired by local vegetation. Thus, hydrologists often use ET to estimate regional groundwater discharge in the Southwest.

One method commonly used to estimate regional groundwater discharge is to compute the difference between ET and local precipitation. First, ET is calculated as the product of ET rates and the acreages of vegetation, open water, and moist soil through which ET occurs. Next, the calculated volume of ET is partitioned into local precipitation and regional groundwater sources. This method, illustrated at right, was applied recently in Spring Valley, Nevada (part A on figure), where groundwater discharge was estimated as part of a congressionally mandated evaluation of the water resources of White Pine County, Nevada (Welch and others, 2007). Although Spring Valley is used to illustrate the method; it is only one of 12 basins for which ET and discharge were estimated using this regional approach.

Mapping ET Units

The ET rate in groundwater discharge areas varies with vegetation type and density, and soil characteristics. In general, the more dense and healthy the vegetation and the wetter the soil, the greater is the ET. Remote-sensing techniques using satellite imagery in combination with field mapping have been used in the Southwest to group areas of similar vegetation and soil conditions within groundwater discharge areas (Laczniak and others, 2001). These "ET units" represent areas of similar ET rates. Reliable estimates of groundwater discharge require accurate mapping and grouping of local ET units and a sound knowledge of local ET rates.

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ET units typical of the Southwest range from areas of no vegetation, such as open water, dry playa, and moist bare soil, to areas with vegetation often dominated by phreatophytic shrubs, grasses, rushes, and reeds. The use of remote sensing to delineate the units is an improvement over earlier studies, which relied only on time-consuming and costly field mapping that often resulted in fewer and less precise ET-unit groupings.

The Spring Valley discharge area, defined by the extent of the phreatophytic shrub greasewood (*Sarcobatus vermiculatus*), was mapped using satellite data, aerial photography, and elevation models along with established control points to a 1:24,000 scale. Ten ET units were identified within the Spring Valley discharge area and other such areas in White Pine County and delineated using Landsat Thematic Mapper (TM) imagery-based methods.

Shrubland, grassland, meadowland, and moist bare soil ET units were delineated using the Modified Soil Adjusted Vegetation Index and a Tasseled Cap transformation of a single TM image (Smith and others, 2007). Dry playa, marshland, and open water ET units were delineated using a published land cover map based on multiple-date TM imagery (Southwest Regional Gap Analysis Program). Recently irrigated acreage was delineated from multiple-date TM imagery. ET units delineated by these techniques were combined into a single ET-unit map of the groundwater discharge area (parts B and D on figure). The accuracy of the ET-unit map was assessed and ground-truthed through field observations.

Measuring ET Rates

Ideally, ET rates should be measured in each of the dominant ET units until a long-term average is established. Although it now is possible to measure ET continuously over long time periods with micrometeorological instrumentation, time and funding constraints often limit the acquisition of field data. Researchers therefore often must rely on ET rates measured over less-than-optimal time periods or on reported rates measured outside their study areas, adding uncertainty to estimates because of differences in measurement techniques, climate, soil, and vegetation.

ET rates reported in recent literature for vegetation and soil moisture conditions similar to those of White Pine County were normalized to local long-term precipitation averages to develop a reasonable range of the annual ET rate for each of the ET units in the county. The rates were then scaled based on vegetation density to develop an estimate of the ET rate for each of the ET units in Spring Valley.

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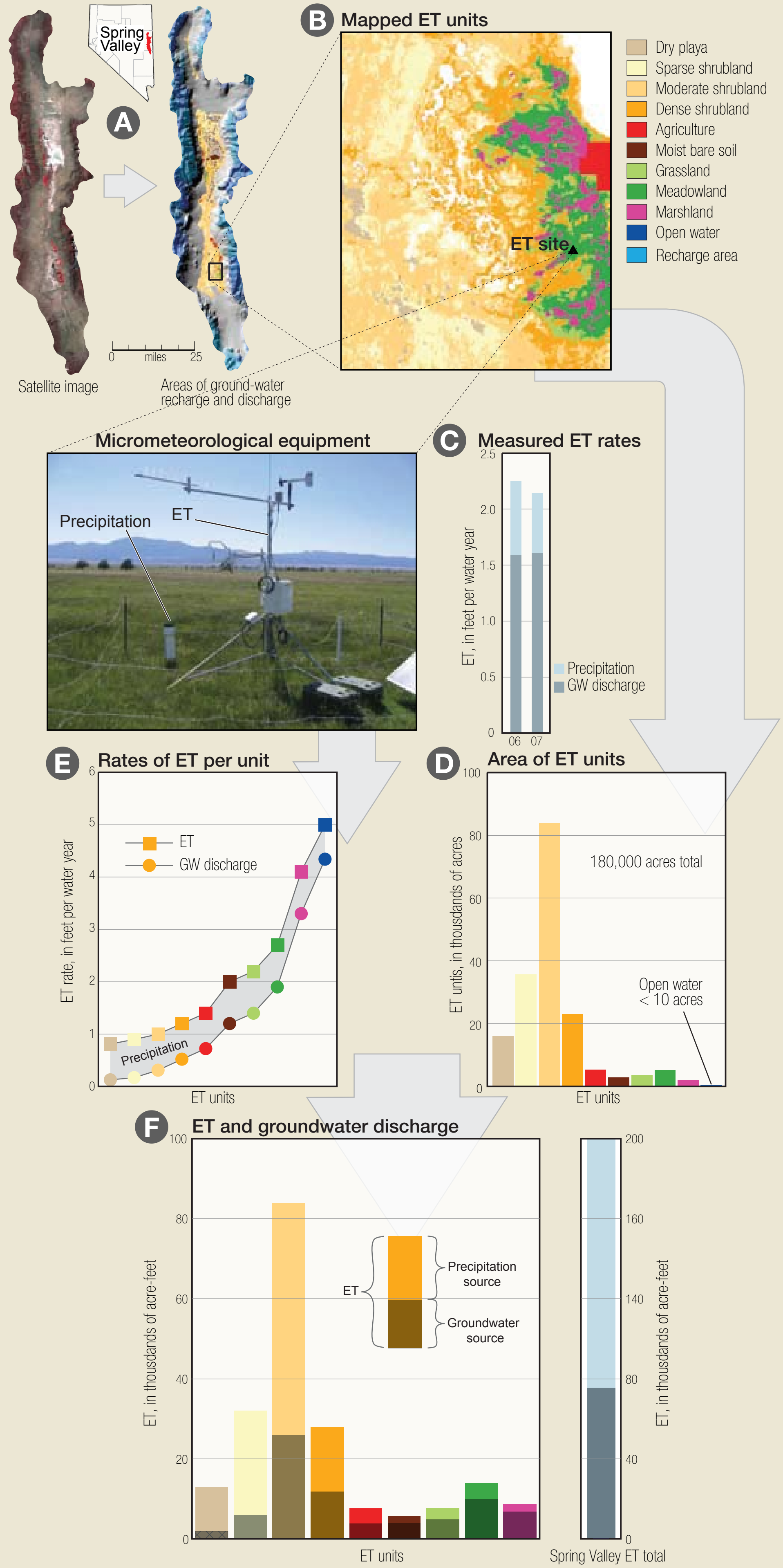
Photo: Howard Grahn



Conceptualization of the ET units and the groundwater discharge estimation process for Spring Valley.

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heat transfer, which can be substantial. Finally, recall that the goal is to measure fluctuations in humidity and wind speed at the same point; in a closed-path system it is possible to pull the sample air from the same volume being measured by the anemometer. In an open-path system there is a gap of at least 10 centimeters between sensors that causes an underestimation of the covariance. Corrections can be applied, but inevitably introduce additional uncertainty. Both types of IRGAs require periodic calibration, usually with a dew-point generator, adding several thousand dollars to the $25,000 to $30,000 cost of the basic eddy-covariance instrumentation.

Data analysis can be the most intimidating aspect of eddy covariance. Data collected at 10 Hertz accumulate quickly and require numerous steps to process. Software is available to perform these processes, but it requires a knowledgeable user. Detailed mathematical descriptions can be found in the listed references, but the first step, data screening, deserves a few words.

Not all data collected with an eddy-covariance system are usable. Instrument failures and environmental factors—particularly precipitation, winds from an unfavorable direction, or extremely calm conditions—can cause erratic, nonsensical results. Algorithms must be used to flag these gaps and suspicious values and replace them with informed estimates.

Site Requirements for BREB and EC

To accurately measure the ET of a given surface type, the entire "flux footprint," or area over which surface exchange is being measured, should be uniform. The surface should extend upwind for a distance approximately 100 times as great as the height of measurement. Thus, a two-meter tower requires placement at a site with 400-meter study area on each side, or around 40 acres, so that ET can be measured from any wind direction. Tower height can be lowered over shorter crops to reduce the flux footprint, but eddy size decreases and eddy frequency increases near the surface, factors which can cause systematic underestimation of the flux. Thus sensors should be at least one meter above a relatively smooth surface like grass or a row crop, and higher over rough surfaces. Additional complications arise if the measured surface is not level.

Eddy covariance and BREB are powerful methods for measuring ET, but neither is a routine, turnkey technique with universal application. Potential users should evaluate the characteristics of their site, their ability to periodically calibrate gas analyzers, and their willingness to learn and apply the necessary data processing procedures before investing the money and effort required to install either system.

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Resources

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The initial rate ranges were assessed and refined using ET rates measured for one near-average precipitation year at six eddy-covariance ET sites established specifically for this study (Moreo and others, 2007). Five of these sites were located in shrubland to evaluate the effect of vegetation density on ET rates, and to better understand the relation between ET and groundwater discharge in the dominant (greater than 80 percent) vegetation type of the study area. One site, established near a boundary between the grassland and meadowland ET units, was located in a mixed-grass riparian area to represent an environment indicative of greater ET (part C on figure). Annual ET rates based on a combination of reported and measured ET data vary slightly between basins, and range from 0.8 feet to 5.0 feet for the ET units in Spring Valley (part E on figure).

Estimating Groundwater Discharge

Average annual ET from a discharge area is estimated as the sum of the ET (the product of the ET rate and its acreage) of all the component ET units. In Spring Valley, total annual ET was estimated to be 200,000 acre-feet.Regional groundwater discharge is estimated from total ET by subtracting the volume of local precipitation falling directly on the discharge area (part F on figure). In Spring Valley, about 0.69 feet or 124,000 acre-feet of local precipitation annually falls on the 180,000-acre discharge area, thus annual regional groundwater discharge from the valley is estimated to be 76,000 acre-feet.

As the population of the Southwest increases, so will the competition and need for additional water supplies. Agencies responsible for water-resources management must be prepared to tap the limited water supply in the most efficient manner and will require more thorough quantification of the water budget beyond our current reconnaissance-level understanding. The accuracy of these estimates will rely, to a large degree, on a representative basin- or region-wide coverage of spatial and temporal ET measurements. And just as importantly, accurate estimates of ET and groundwater discharge will improve confidence in the results of modeling efforts, particularly those directed at predicting the effects of increased groundwater pumping.

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