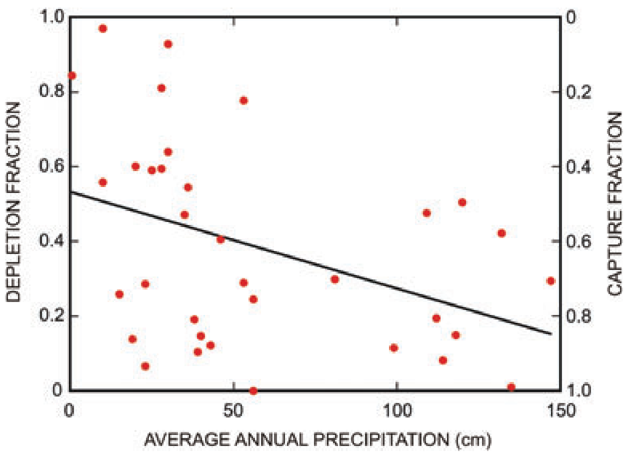

Figure 13. Relation between average annual precipitation and long-term cumulative depletion and capture fractions for 33 aquifer areas and subareas, showing a best-fit linear regression line (from data in Table S1).

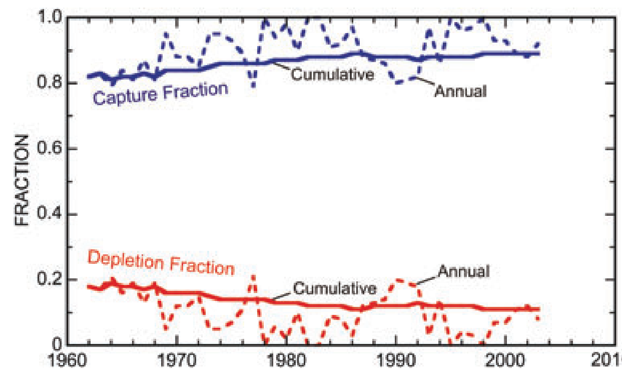

Figure 14. Results of water budget calculations of the Central Valley, California, calibrated groundwater-flow model (Faunt et al. 2009b), showing storage depletion (red) and capture (blue) fractions (solid lines for cumulative fractions; dashed lines for annual rates).

Well-calibrated and well-constructed simulation models of long-term responses in aquifer systems offer a means to analyze the sources of water derived from wells and how they vary with time. For this type of analysis, a well-constructed model would be free of artificial boundaries that would affect calculations of groundwater storage depletion and capture for a groundwater system. This will be illustrated briefly using two representative examples of such well documented model analyses.

The Central Valley of California is a major agricultural area in a large valley with an area of about 52,000 km^2 (Williamson et al. 1989; Bertoldi et al. 1991). The Central Valley has an arid to semiarid Mediterranean climate, where the average annual precipitation ranges from 13 to 66 cm (Bertoldi et al. 1991). Streamflow is an important factor in the water supply of the valley. Groundwater development began around 1880. By 1913, total well pumpage was about 0.44 km^3 annually (Bertoldi et al. 1991). During the 1940s and 1950s, the pumpage increased sharply, and by the 1960s and 1970s averaged about 14.2 km^3/yr. By the 1980s there were approximately 100,000 high-capacity wells in the Central Valley for either irrigation or municipal supply. During 1962 through 2003, withdrawals from irrigation wells averaged about 10.6 km^3/yr (Faunt et al. 2009a).

A transient groundwater-flow model of the Central Valley was developed for 1961 through 2003 (Faunt et al. 2009b). The model indicates that the decrease in groundwater storage from 1961 through 2003 was about 71.2 km^3. However, the total decrease in groundwater storage from predevelopment conditions until 1961 was about 58 km^3 (Williamson et al. 1989, 95), and this is not accounted for in the 1961 through 2003 model. As expected, the cumulative fractions are smoother than the annual fractions (Figure 14), and the year-to-year variability in annual fractions is largely controlled by variations in annual pumpage and precipitation. The depletion and capture fractions (both cumulative and rate based) for the first year of the simulation period are 0.18 and 0.82, respectively. But over the 42-year simulation period, the fractional rates did not change greatly, as reflected by the relatively small change in the cumulative storage depletion and capture fractions to 0.11 and 0.89, respectively, indicating that such long-term cumulative fractions (such as presented in Figure 4) are relatively stable and representative of conditions in the aquifer. Compared with the generic fractional curves (Figure 1), it is evident that this model of the Central Valley of California, which begins about 80 years after the start of pumpage, cannot and does not represent the expected early-time system responses of high depletion fractions and low capture fractions, so that the cumulative depletion fraction would be too small (and cumulative capture fractions too high) in the early years of these simulation results.

Antelope Valley, California, is a small (2400 km^2) topographically closed basin with an arid climate (average annual precipitation is less than 25 cm). The basin contains a thick (more than 1500 m in places) sequence of unconsolidated alluvial and lacustrine sediments. Surface water is limited, and the area includes several springs, playas, and intermittent streams that drain into the playas (Leighton and Phillips 2003). Delivery of some imported water began in 1986. Leighton and Phillips (2003) note that recharge to the groundwater system is primarily from the infiltration of precipitation runoff near the valley margins, and discharge from the aquifer system was primarily from evapotranspiration. Development of the groundwater system began around 1915 and increased rapidly into the 1950s. Pumpage peaked at more than 0.37 km^3/yr in the 1950s and 1960s, but by the mid-1980s had declined to about 0.12 km^3/yr (Galloway et al. 2003). Groundwater pumping has caused large water-level declines in the basin, resulting in a major decrease in evapotranspirative discharge (Leighton and Phillips 2003).

A 3D transient MODFLOW model was developed and calibrated to simulate groundwater-flow and aquifer-system compaction in the area (Leighton and Phillips 2003). The model was first calibrated to represent

Source: Konikow and Leake, 2014, Groundwater, v. 52, Issue S1, pgs. 100-111.