Multiple Approaches to Estimate Ephemeral Channel Recharge

D.C. Goodrich, D.G. Williams, C.L. Unkrich, R.L. Scott, K.R. Hultine, D. Pool, A. Coes, J. Hogan

Abstract

Ephemeral channel transmission losses play an important role in ground water/surface water dynamics in arid and semi-arid basins in the Southwest. However, identification of the processes driving these dynamics is difficult. Specifically, data on the proportion of runoff transmission losses that escape from near-channel evapotranspiration (ET) and wetted channel evaporation to become deep ground water recharge are difficult to obtain. Quantifying recharge with greater certainty is a critical need required to manage basins whose primary source of water supply is derived from groundwater. This issue was addressed via coordinated field research within the USDA-ARS Walnut Gulch Experimental Watershed (WGEW) located in southeastern Arizona. Groundwater, surface water, chemical, isotopic, tree sap flux, micrometeorological techniques, and changes in microgravity were used to independently estimate ephemeral channel recharge. Wet 1999 and 2000 monsoon seasons caused substantial changes in near-channel groundwater levels. Crudely scaled to the basin level, this recharge would constitute between 20 and 50% of basin recharge as estimated from a calibrated groundwater model.

Goodrich is a Research Hydraulic Engineer, USDA-ARS, Southwest Watershed Research Center, Tucson, AZ 85719. E-mail: dgoodrich@tucson.ars.ag.gov. Williams is an Associate Professor, Department of Renewable Resources, University of Wyoming, Laramie, WY 82071. Unkrich is a Hydrologic Support Scientist and Scott is a Hydrologist, both at USDA-ARS-SWRC, Tucson, AZ 85719. Hultine is a graduate student, Department of Hydrology and Water Resources, University of Arizona, Tucson, AZ, 85721. Pool is a Hydrologist, U.S. Geological Survey, Tucson, AZ 85721. Coes is a Hydrologist, U.S. Geological Survey, Charlotte, NC 28217. Hogan is an Adjunct Assistant Professor, Department of Hydrology and Water Resources, University of Arizona, Tucson, AZ 85721.

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Introduction

Groundwater recharge is arguably the component of a basin's water balance that is known with the least certainty. In arid and semi-arid regions there is mounting evidence that recharge is likely to occur in only small portions of a basin, where flow is concentrated, such as depressions and ephemeral stream channels (Walvoord et al. 2003). Recharge along ephemeral channels can be large and play an important role in groundwater/surface water dynamics in arid and semi-arid basins (Goodrich et al. 1997). However, it is very difficult to quantify the proportion of transmission losses that escape from near-channel evapotranspiration (ET) and wetted channel evaporation to become groundwater recharge. This project has two principal objectives:

1. Assess the magnitude of ephemeral channel recharge to the regional aquifer.
2. Estimate channel evaporation and near-channel ET.

Study Site

The highly instrumented USDA-ARS Walnut Gulch Experimental Watershed (WGEW) is located in southeastern Arizona. (Figure 1). The watershed has the following attributes (Renard et al. 1993):

- Area: 149 km^2
- Elevation: 1250 to 1585 m MSL.
- Climate: mean annual temperature: 17.6°C
- Precipitation: 324 mm annually (~65% summer convective, ~35% winter frontal).

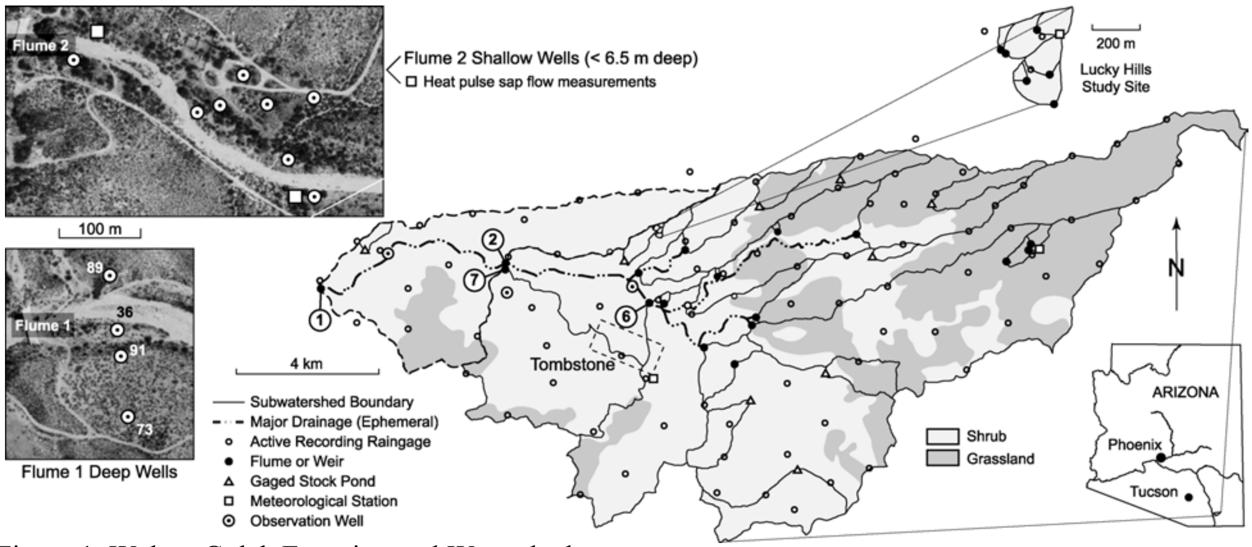

Figure 1. Walnut Gulch Experimental Watershed.

- Soils: well drained, calcareous, gravelly loams with large percentages of rock and gravel at the surface.
- Runoff: almost exclusively from summer monsoon storms via infiltration excess.
- Groundwater: depths to the regional aquifer ranges from 50 to 145 meters.
- Vegetation: dominated by desert shrub steppe species and desert grasslands.

Methods

The primary methods employed to estimate ephemeral channel recharge (R) include:

1. Channel reach water balance:

R = $P + Q_i + Q_l - Q_o - T - E$ where,
P = precipitation from multiple rain gages
Q_i = measured inflow into study reach (flumes 2 and 7 in Figure 1),
Q_l = runoff modeling using KINEROS2 (Smith et al. 1995) to estimate lateral inflow (from the area delineated by a dashed line in Figure 1),
Q_o = measured outflow (flume 1 in Figure 1),
T = scaled sapflow (Barrett et al. 1995) or energy flux (Scott et al. 2003) estimates of near-channel transpiration,
E = estimates of channel evaporation (Sorey and Matlock 1969),

The water balance approach assumes that recharge equals channel transmission losses ($P + Q_i + Q_l - Q_o$) less additional near-channel E and T.

2. Observations and modeling of groundwater mounding (Hantush 1967).
3. Chloride concentration change (Allison et al. 1994).
4. Natural tracers (Allison et al. 1994).
5. Microgravity measurements of water mass change (Pool and Eychaner, 1995).

Instrumentation and Measurements

Figure 1 illustrates the location of rain gages, runoff flumes, and gaged subwatersheds within the WGEW. The Walnut Gulch supercritical runoff flume was specifically designed to provide accurate runoff measurements in mobile bed alluvial channels. In addition to the runoff flumes, the following instrumentation was installed and the following observations were made over 1999 and 2000 (Figure 1):

1. Water levels in deep wells above flume 1 and along the main channel.
2. Water levels in a shallow occluded aquifer above flume 2.
3. Runoff samplers at flumes 6 and 2 for chloride and isotopes.
4. Water samples from precipitation gages and wells for chloride and isotopes.
5. Sapflux measurements above flume 2.
6. Meteorological measurements.

In addition, USGS studies at flume 1 included unsaturated zone sampling, monitoring, simulation of streamflow infiltration, and gravity monitoring.

Observations

Groundwater responses recorded by the shallow wells above flume 2 for 1999, and for the deep wells upstream of flume 1 for 1999-2001, are illustrated in Figure 2.

An example of discharges from flume 2 and chloride concentrations from runoff samples is illustrated in Figure 3.

Oxygen and hydrogen isotope composition of rainfall and runoff for various events in 1999 is illustrated in Figure 4.

Isotope compositions from selected deep wells for 1999-2000 and runoff for 1999 are plotted in Figure 5. The relationship between hydrogen and oxygen isotope composition of precipitation, runoff and deep groundwater for 1999 is plotted in Figure 6.

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Water from runoff and deep wells at Walnut Gulch apparently is not significantly evaporated from meteoric waters, whereas waters from the slow moving San Pedro River are.

Mean sap flow rates for four well-watered mesquite trees located above flume 2 in the perched aquifer were measured during August of 1999. These measurements were combined with a field survey to establish a relationship between mesquite sapwood area and canopy area. A field survey was also conducted to estimate the area adjacent to the main channel where it was assumed that deep-rooted trees could access water from channel

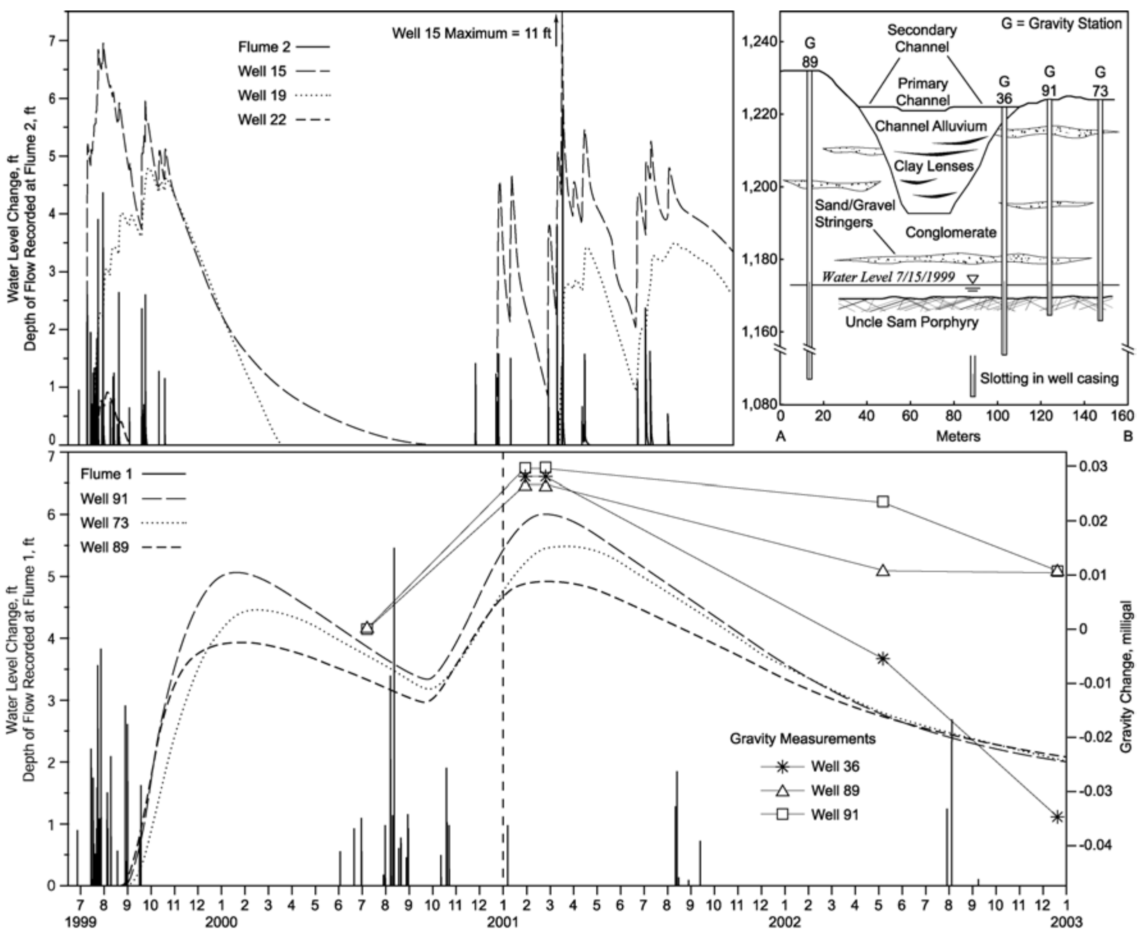

Figure 2. Well levels and flow depths at flume 2 (top) and flume 1 (bottom). Bottom figure also shows gravity measurements at flume 1. Diagram on upper right shows cross-section of well transect above flume 1

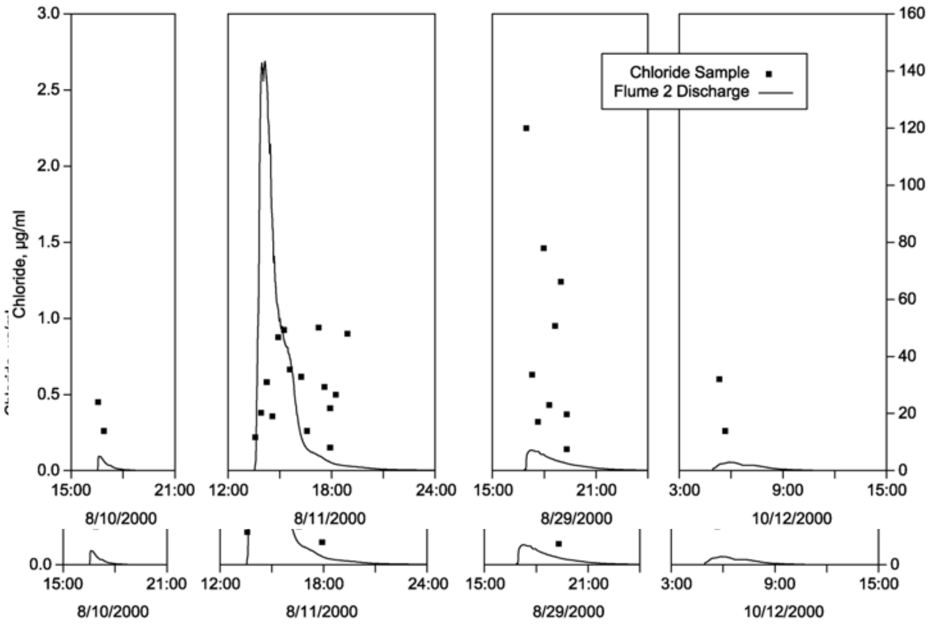

Figure 3. Discharge rate and Cl concentration at flume 2 in 2000.

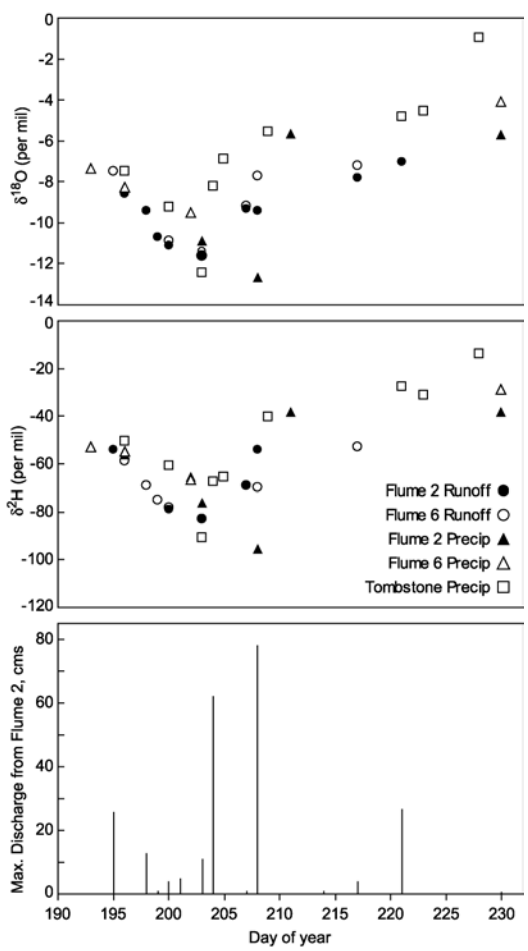

Figure 4. Oxygen and hydrogen isotope composition of rainfall and runoff during 1999, and maximum discharge rates at flume 2.

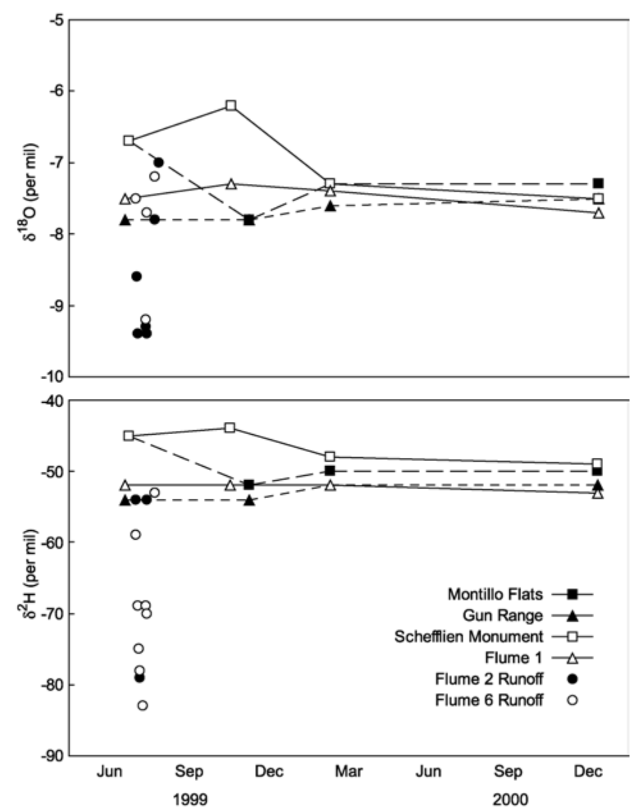

Figure 5. Oxygen and hydrogen composition of deep wells and runoff.

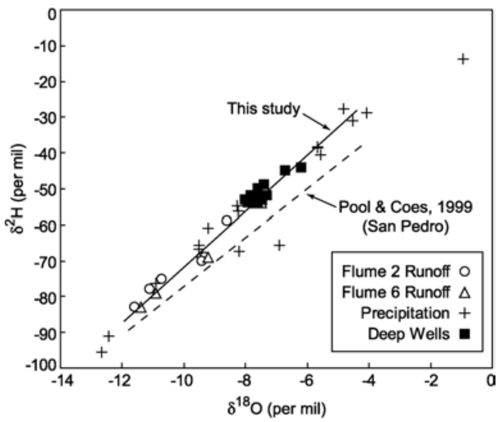

Figure 6. Relation between hydrogen and oxygen isotope composition of rainfall, runoff, and deep groundwater collected in 1999.

transmission losses. Total canopy area in the near channel zone was estimated by image processing techniques to be 10.4% (~ 103,000 m^2).

In addition to sapflow-derived rates of near channel transpiration, transpiration volumes were also computed from a nearby energy flux station positioned over a well- watered mesquite bosque (Scott et al. 2003), as sapflux techniques in mesquite are not well-tested.

Results

Space does not allow a complete presentation of results with error and uncertainty analyses. Average or mid-range values are presented in the following tables.

Table 1. Summary of recharge estimates from modeled transmission losses less abstractions (m^3).

Inputs	*1999*	*2000*
Midpoint Modeled Transmission Losses	514400	399700
Precipitation on Wetted Channel	6500	4000
Precipitation on Canopy less Interception	25800	25500
Total Inputs	546700	429200
Abstractions		
Channel Evaporation	300	800
Near Channel ET (Energy/Flux Estimate)	37500	59100
Total Abstractions	37800	59900
Total Potential Recharge	**508900**	**369300**

Table 2. Recharge estimates from groundwater mounding model recharge volume (m^3).

	1999		
Well	Low	High	Average
89	127200	250400	188800
91	107200	211000	159100
73	214000	421300	317600
	2000		
Well	Low	High	Average
89	85600	168500	127100
91	68500	134900	101700
73	138800	273300	206100

Table 3. Recharge estimates from Cl concentration change from runoff to groundwater (m^3).

Year	Midpoint Trans. Loss Runoff	Well 89 Cl Conc.& Avg. Cl Ratio	Well 73 Cl Conc. & Avg. Cl ratio
1999	514400	312600	88300
2000	399700	242900	68600

Table 4. Comparison of recharge estimates (m^3) *

Year	Trans. Loss less Abstract.	Chloride Well 89 Ratio=0.61	GW Model Average Well 89	Microgravity Change
1999	508000	313000	189000	
2000	369000	243000	127000	
Total	**877000**	**556000**	**316000**	**455000**

* Rounded to nearest 1000 m^3.

Changes in water storage were measured using microgravity methods at a single cross section between at flume 1. Measurements were done during July 2000 through December 2001, a period with few streamflow events and drainage of water that infiltrated during 1999 and 2000. Nearly all of the gravity change and storage loss occurred near the stream channel indicating vertical transport to the water table and little lateral migration through the unsaturated zone. This distribution of gravity change allowed scaling to the flume 1-2 stream reach on the basis of the ratio of average channel width and to flume 1 channel width. A preliminary estimate of total recharge over the 1999 and 2000 runoff season is 455,000 m^3. Results must be assumed to represent a portion of the previously infiltrated water because water levels (Figure 2) indicate that complete drainage of the ground-water system to pre-existing conditions had not occurred by December 2001, however, drainage of water in from the unsaturated zone beneath the channel was likely nearly complete.

Conclusions

Results indicate relatively good agreement between the average estimates from each of the methods, in that they differ by less than a factor of three. This range is not surprising given the limitations of the various methods, and the differences in time scales over which they are applicable.

Another primary purpose of this study was to assess whether recharge from ephemeral channels was a significant component of the overall San Pedro Basin water budget (Walnut Gulch is a tributary to this basin). If one crudely scales the above estimates by the overall length of channel in the basin with a support area equal to that of the drainage area at flume 2, the minimum recharge estimates for 1999 in Table 4 scale to approximately 18% of the total basin recharge estimated from a regional groundwater model (Corell et al. 1996). The maximum value in Table 4 for 1999 scales to roughly 48% of the groundwater model estimate. If the values in Table 4 are even approximately correct it is fair to conclude that ephemeral channel recharge from monsoon runoff can constitute a substantial percentage of overall basin recharge, especially during periods lacking winter runoff.

Acknowledgments

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