EVAPOTRANSPIRATION-DRIVEN DIURNAL FLUCTUATIONS IN GROUNDWATER LEVELS AT SAN MARCIAL, NM

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ABSTRACT: Between March 1997 and May 2001, water levels were measured hourly in well 68.72-1 near the San Marcial railroad bridge. The well is 2" PVC with a 4" steel casing, approximately 300 feet from the near river bank (350 feet from the center of the river channel), and 12.5 feet deep, drilled into unconsolidated river deposits. Water level measurements within the well show diurnal fluctuations in water level of up to 0.35 feet during the summer season. Diurnal fluctuations during the winter are closer to 0.05 feet.

This paper explores the relationship between diurnal and multi-day well level fluctuations, evapotranspiration and river flow. We find the diurnal well fluctuations are strongly correlated with evapotranspiration and suggest that the specific yield near the well is 0.07 to 0.18. Longer-term water level trends appear to be driven primarily by flow in the main channel of the Rio Grande.
KEY TERMS: groundwater, evapotranspiration, conjunctive use, Rio Grande, New Mexico

INTRODUCTION

The Rio Grande basin in New Mexico between Cochiti Reservoir and Elephant Butte Reservoir (hereafter referred to as the Middle Rio Grande) is a region in which water is scarce and fully subscribed. Consequently, there is a need to understand the current water availability and use within the region. This requires understanding not only the surface water system but also the groundwater system, since the region is underlain by unconsolidated river deposits and the shallow groundwater system in the basin is well connected with the river.

Most of the groundwater usage in the region is localized at wells and can be quantified, with the exception of riparian evapotranspiration. Riparian ET is one of the primary water consumption terms in the Middle Rio Grande region, accounting for about a third of the regional water use. Riparian water use is particularly high in the San Marcial region, which is infested with salt cedar, a non-native plant known to be a high water user. Since salt cedar draws water directly from the water table, it is reasonable to assume that the plants' high evapotranspiration rate may be visible in groundwater levels.

Well monitoring at well no. 68-72-1, located near the San Marcial railroad bridge, began March 1997. This monitoring was unusual because sampling was done at hourly intervals for several years, providing a far more complete record of well water elevations than is typical. One of the most noticeable features of the data is large diurnal fluctuations in water elevation that do not appear correlated with river stage. We hypothesize that these fluctuations are driven by riparian evapotranspiration.

DATA

Groundwater level data from well no. 68.72-1 near San Marcial, New Mexico were collected by the US Bureau of Reclamation (Chris Gorbach personal communication). The well is 2" PVC with a 4" steel casing, approximately 300 feet from the near river bank (350 feet from the center of the river channel), and 12.5 feet deep, drilled into unconsolidated river deposits. Data measured in the well include water elevation and temperature measured at hourly intervals from March 18, 1997 to May 5, 2001; only data from March 18, 1997 to December 31, 1999 are used in this paper. The data were used as delivered to calculate maximum and minimum well elevations and total diurnal well level fluctuation for each 24-hour period starting at midnight.

Groundwater level data are compared to streamflow data measured in the main channel of the Rio Grande (the Rio Grande Floodway) at the USGS San Marcial gage. Hourly streamflow data were obtained directly from the USGS for October 1996 through December 1999.

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Daily ET data from March 1997 to December 1999 were obtained from the ET Toolbox (http://yampa.earthsci.do.usbr.gov:8080/awards/ettoolbox.html) for Reach 6 of the Middle Rio Grande, the region from San Acacia to San Marcial. ET data are available for agriculture, riparian, and urban consumption. Values for riparian consumption were used, and converted to cubic feet per day per square foot. This unit can then be directly compared with changes in well elevation in feet per day.

FINDINGS

The measured well data and Rio Grande Floodway flow are shown in Figure 1. As can be seen, the well water elevations generally track the river flow, peaking at the points when river flow peaks and dropping when the river flow is low or zero. However, the correlation between the two data sets for the full period of record shown is only 0.55, indicating that the groundwater elevation is not entirely driven by the river flow. In particular, small-scale variations and slow trends in the river flow can be absent in the well data. For example, from November 1997 through March 1998 the well data is a relatively smooth, rising curve while the river flow is slowly dropping, and occasionally fluctuates sharply. Clearly, flows above 1000 cfs will serve to refill the shallow groundwater system at this location.

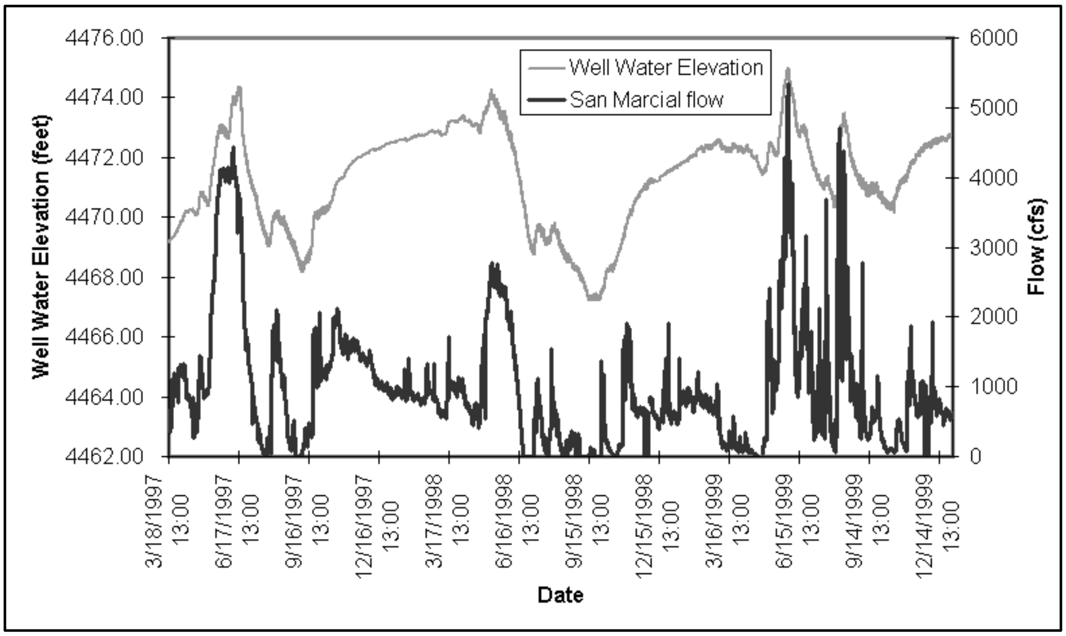

Figure 1: Water elevations in well 68.72-1 and flow in the Rio Grande Floodway at San Marcial for the period March 18, 1997 to December 31, 1999.

The well elevation and river flow data differ more dramatically on the smaller scale. Figure 2 provides a close-up view of an 11-day period from August 15 to August 25, 1997; at this scale, diurnal fluctuations in the well data stand out strongly. Similar fluctuations are absent in the stream data. Clearly, explaining these diurnal fluctuations requires diurnal addition to or consumption of water in the shallow groundwater system. The only mechanisms to add water to the groundwater system are river infiltration and precipitation, neither of which can account for the diurnal variation seen. Consequently, we must turn to consumption terms to explain the fluctuations.

The diurnal fluctuations in the groundwater, as shown in Figure 2, tend to be at a maximum around 7 or 8 am and at a minimum at about 6 pm. This corresponds well with meteorological signals; solar radiation, temperature, and evapotranspiration all cycle daily, rising to their maximum at around 2-4 pm and falling to a minimum between 4 and 6 am. Because riparian evapotranspiration draws water directly from the shallow groundwater, it seems likely that the source of the diurnal fluctuations seen in the well record is riparian vegetation water consumption, with a lag of a few hours between evapotranspirative forcing and groundwater elevation response.

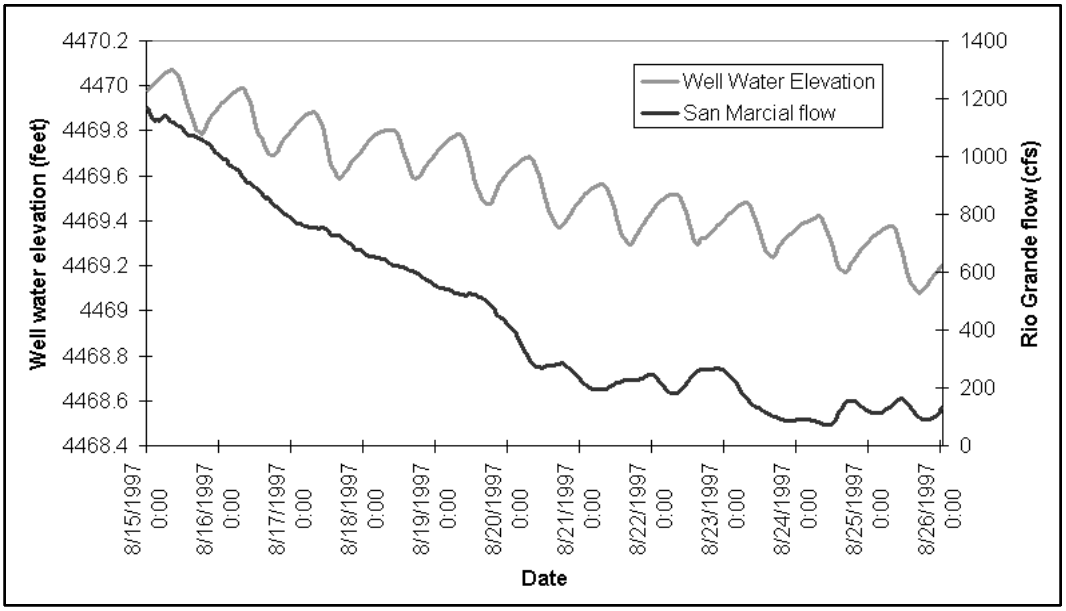

Figure 2: Water elevations in well 68.72-1 and flow in the Rio Grande Floodway at San Marcial for the 11-day period from August 15 to August 25, 1997.

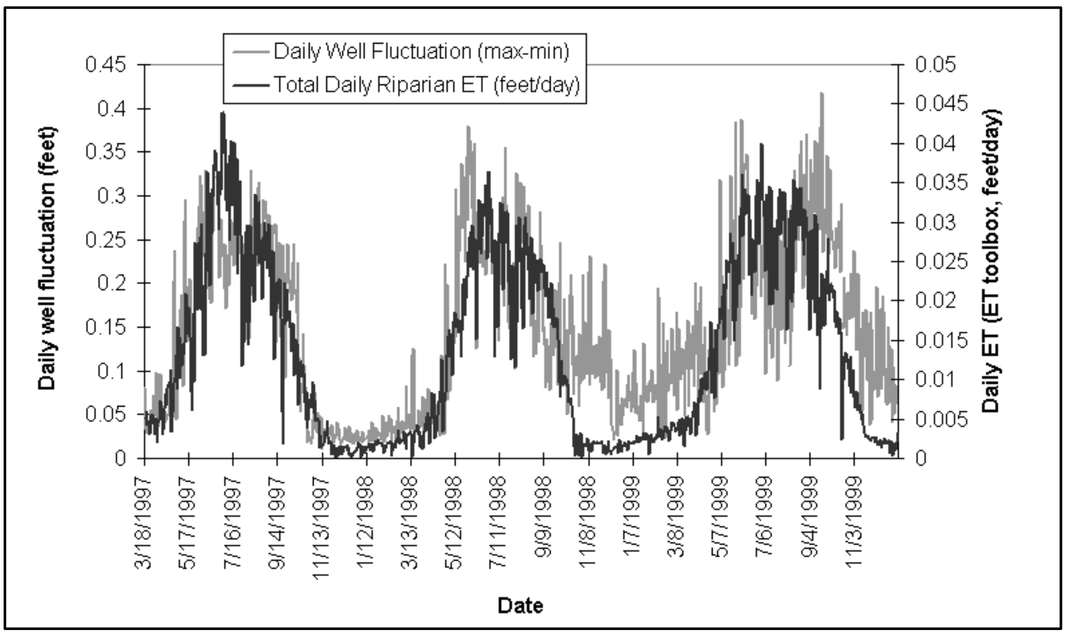

Figure 3: Amplitude of the diurnal well level fluctuations and ET toolbox daily reach 6 riparian evapotranspiration, March 1997 to December 1999.

Figure 3 shows the amplitude of the diurnal well level fluctuation for the entire period of record, plotted vs. the ET toolbox daily riparian evapotranspiration calculated for reach 6. For the most part, well level fluctuations closely track the calculated evapotranspiration; the correlation between the two data sets for the entire period shown in Figure 3 is 0.78, a stronger correlation than that between well water elevation and river flow.

From October 1998 to mid-December 1998 the diurnal well fluctuations appear high, nearly half the magnitude of the summer fluctuations. In mid-December they change sharply to a lower value, though still not as low as during the 1997-98 winter. This may be indicative of instrumentation problems from October 1998 on. Considering only the early part of the dataset, the correlation between the two datasets from March 18, 1997 to September 30, 1998 is 0.86.

These correlations between the amplitude of the diurnal well fluctuations and the calculated ET from the ET toolbox are very high, particularly given that the ET toolbox values are for a large region and are calculated using data from relatively few meteorological stations within that area. It is possible that ET measurements taken at the well location would correlate even more strongly.

Table 1: Well statistics for River, Salt Cedar and No. 68.72-1 wells.

	River Well	Salt Cedar Well	Well No. 68.72-1
Average diurnal fluctuation amplitude (feet)	0.04	0.05	0.147
Correlation with ET	0.17	0.47	0.78 to 0.86
Correlation with river flow	0.87	0.86	0.55

The strong diurnal fluctuations in well water elevation are not seen in all shallow wells located near the river. Two shallow wells about 9.5 miles north of San Marcial (Bosque del Apache area) were investigated; river well is about 10 ft from the edge of the river and salt cedar well is about 800 ft from the river. Data from the river and salt cedar wells (Table 1) show only small-amplitude diurnal fluctuations (average fluctuation = 0.04 and 0.05 ft respectively) that have low correlations with evapotranspiration rates (r=0.17 and 0.47 respectively). This appears to be due to the more immediate connection these wells have to the river system. Correlation between river flow and well data is 0.87 and 0.86 respectively. This is a significantly stronger correlation than was found between river flow and well no. 68.72-1, in spite of the fact that well 68.72-1 is much closer to the San Marcial gage than the river and salt cedar wells. If the river and salt cedar wells are more immediately connected to the river, we would expect the riparian vegetation to have a smaller impact on groundwater levels, which is what we see in the low correlations with ET and low-amplitude diurnal fluctuations. Additionally, the correlation with ET and average diurnal fluctuation amplitude is weaker for the river well than for the salt cedar well, as expected given that the river well is significantly closer to the river than the salt cedar well.

SPECIFIC YIELD CALCULATIONS

Daily fluctuations in well no. 68.72-1 range in amplitude from 0.05 to 0.35 feet. Corresponding daily evapotranspiration rates range from 0.0025 to 0.040 feet. If the diurnal fluctuations in well elevation are attributed to evapotranspiration, we can then use the relative magnitudes of the ET and elevation changes to determine specific yield.

We assume that evapotranspiration is negligible from midnight to 4 a.m. and that the hourly recharge from midnight to 4 a.m. is approximately the average rate for the day (Todd, 1980). We can then use the hourly rate of water table rise from midnight to 4 a.m. (h), multiplied by 24 hours, to represent the total daily recharge. Total daily displaced volume is the total daily recharge (24h) plus or minus the net rise or fall of the water table (s) during the 24-hour period. Finally, specific yield can be calculated as the total daily evapotranspiration divided by the total daily displaced volume:

$$SpecificYield = \frac{TotalDailyEvapotranspiration}{24h \pm s}$$

This calculation was made for each 24 hour period from March 18 1997 to Dec 31 1999. The resulting specific yield values were variable, particularly during periods of low evapotranspiration and during periods when the magnitude of the rise was large. It appears that during these periods, groundwater level is only weakly influenced by evapotranspiration, and more strongly affected by other mechanisms such as river flow.

During periods of high evapotranspiration and small rise, specific yield ranges from 0.07 to 0.18 with an average of about 0.12. These values are in line with both measured and estimated storage coefficients for this type of substrate.

CONCLUSIONS

Well no. 68.72-1, located near the San Marcial railroad bridge, is clearly well connected with the river system. The correlation between river flow and well elevation from March 1997 to December 1999 is 0.55. However, strong diurnal fluctuations are seen in the well water elevation but are absent in the river flow. These diurnal fluctuations appear to be driven by riparian evapotranspiration; correlation between the diurnal fluctuation amplitude and total daily ET is 0.78 to 0.86. Similar fluctuations are not found in all wells located near the river in this region, however. It appears that the presence of fluctuations of this type and magnitude indicates that the well is connected to the river, but with some lag. Wells that are strongly connected to the river, such as the river and salt cedar wells in the Bosque del Apache, show much smaller diurnal fluctuations, and the fluctuation amplitude is poorly correlated with daily evapotranspiration.

The strong correlation between diurnal fluctuation amplitude and evapotranspiration in well no. 68.72-1 was used to estimate the storage coefficient for the shallow groundwater system in this region. The storage coefficient is estimated at about 0.12.

The potential for future work in this vein is significant. The response of riparian vegetation evapotranspiration to drought is currently poorly quantified. Wells such as the San Marcial well could potentially provide information on year-to-year variability in evapotranspiration, helping quantify the reduction in riparian evapotranspiration during droughts. This could provide a valuable and inexpensive independent assessment of riparian evapotranspiration for the San Marcial region. It is likely that well sites with similar responses to evapotranspiration could be found in other regions if this ET calculation approach proved valuable.

REFERENCES

Todd, David Keith, 1980. Groundwater Hydrology. John Wiley & Sons, New York.