A STABLE ISOTOPE STUDY OF GROUNDWATER AND SURFACE WATER NEAR THE ST. DAVID CIENEGA, SAN PEDRO VALLEY, ARIZONA

Chris Eastoe

Retired, Department of Geosciences, University of Arizona

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Executive Summary

Warm groundwater discharging into wetlands at the St. David Cienega and the Dunlevy wells has stable O and H isotopes consistent with those of water originating from a confined aquifer beneath a unit of clay present under much of the Middle San Pedro Basin. Groundwater from the confined aquifer beneath the St. David area has a variety of isotope compositions, suggesting compartmentalization of the aquifer. Large increases in groundwater withdrawal from adjacent areas of the confined aquifer would bring a risk of drying the wetlands, removing riparian water, and diminishing the water supply for other users.

Introduction

Stable isotopes of hydrogen and oxygen in combination with tritium as a dating tool have proven to be useful tracers of groundwater origin in the alluvial and mountain aquifers of southern Arizona. In the San Pedro Valley, several recent studies using isotope data have contributed to an understanding of water sources in the perennial reaches of the San Pedro River, and in groundwater of the confined and unconfined aquifers of the basin fill sediments over which the river flows (Gungle et al., 2016; Cordova et al., 2015; Hopkins et al., 2014; Wahi et al., 2008; Baillie et al., 2007). In addition, geophysical surveys have greatly improved knowledge of the lithology and stratigraphy of basin–fill deep below the river (Dickinson et al., 2010). Together, these studies provide a context for understanding the isotope hydrology of smaller hydrological features of the valley.

One such feature is the St. David Cienega (Fig. 1a), located in the Middle San Pedro Basin, to the west of the San Pedro River about 7 km south of St. David. Warm water discharges at the surface, possibly through old, uncapped wells (which, if they exist, could not be located among the dense reeds during the present study). The discharging water supports a wetland. Closer to the Escalante Crossing, the uncapped Dunlevy wells discharge into a second wetland area.

In order to constrain the sources of discharging groundwater, a small isotope study was undertaken in January, 2017. Three samples (GR1, GR2, 2C) were taken from the bottom of the St. David Cienega, where warm water was detected. A fourth sample (LJ) of discharging warm water was obtained from the nearby Little Joe pond, and two samples were taken from the small stream draining the Cienega (CV near the Cienega outlet, and CF near the confluence of the stream with the San Pedro River). In addition, a single sample was taken from one of the Dunlevy artesian wells.

Hydrogeology

An important hydrogeological feature of the Benson sub-basin is the thick layer of impermeable clay separating sandy and gravelly clastic basin-fill units above and below. Near St. David, the clay is about 100 m thick (Fig. 1b), and it crops out in the bed of the San Pedro River immediately south of Escalante Crossing. The overlying clastic sediments are thin is this area, but form a shallow, unconfined riparian aquifer beneath the river channel. The clastic sediment layer beneath the clay forms a confined aquifer. Infiltration of groundwater from the upgradient (south or west) side of the study area generates artesian pressure beneath the study area, as suggested by the slope of the clay layer in Fig. 1b. Therefore water from the confined aquifer can flow to the surface where channels are present, either through fractures penetrating the clay, or by way of uncapped wells.

Methods

Samples were stored in sturdy plastic bottles, tightly capped. The samples from the Cienega and Little Joe pond were taken within bodies of surface water in locations where a temperature probe indicated maximum local temperature. In each case, an uncapped, inverted empty bottle was lowered into the warm water and filled and capped within the warm water. Such samples may be mixed to some extent with surface water affected by runoff or precipitation.

Isotope measurements were made at the Environmental Isotope Laboratory, University of Arizona. Stable O, and H isotope ratios were measured on a Finnigan Delta S® dual-inlet mass spectrometer equipped with an automated CO_2 equilibrator (for O) and an automated Cr-reduction furnace (for H). Results are expressed in delta-notation, e.g.

$$\delta^{18}\text{O or } \delta\text{D} \;=\; 1000\left\{ \frac{R(sample)}{R(standard)} - 1\right\} \text{ ‰, where } R = {}^{18}\text{O}/{}^{16}\text{O or } {}^{2}\text{H}/{}^{1}\text{H}.$$

Analytical precisions (1σ) are 0.08‰ (O), and 0.9‰ (H). Tritium was measured in a Quantulus 1220 ® Spectrometer by liquid scintillation counting on a 0.19 L water sample following electrolytic enrichment. Results are expressed in tritium units (TU), where 1 TU corresponds to 1 tritium atom per 10^{18} hydrogen atoms. The detection limit is 0.4 TU.

Results

Fig. 2 shows the relationship of the stable isotope data for the field samples. The three samples from St. David Cienega have closely similar compositions, ($\delta^{18}O$, δD) near (-8.3, -60)‰, indicating that contamination is unlikely, despite the difficulty of sampling. (If contamination were an issue, it would be unlikely to lead to such similar results in three separate samplings.) The temperatures ranged from 23.8 to 26.3 ^{o}C. The remaining samples form a linear trend of slope 6.9, with δ-values becoming more positive in the order Cienega, Little Joe Spring, Culvert, Confluence. Water might be progressively evaporated from the Cienega to the confluence, but the slope is too high for an evaporation trend in this area (cf. slope of shallow riparian groundwater in Fig. 3, and of an evaporation trend from Gungle et al. (2016), both with values near 4). Rather, it seems likely that the trend represents progressive mixing with shallow groundwater, consistent with the observation that the flow volume increased downstream on the outlet stream on the day of sampling. The isotope composition of the confluence sample is the same as the composition of much of the water seeping into the river bed at Escalante Crossing (cf. Fig. 3), indicating a typical isotope composition for local shallow groundwater near (-7.4, -54) ‰.

The Dunlevy well produces water of isotope composition (-7.7, -54)‰ different from that in the Cienega, but close to that of local shallow groundwater. The tritium content of the Dunlevy water, 0.4 TU, shows that the water originated as pre-1950s precipitation. The high temperature (24.6^{o}C) and the artesian pressure indicate that this water is not local shallow groundwater.

Discussion

Origin of Cienega and Dunlevy waters. Fig. 3 shows several local sets of isotope data for comparison with the Cienega and Dunlevy samples, which appear to belong to the group of groundwaters from the confined aquifer rather than to shallow riparian groundwater (sampled near the Apache Nitrogen Plant) or to surface water and associated seeps near the Escalante Crossing. Near St. David, the confined groundwater has a variety of isotope compositions, which make up a field extending beyond the Cienega and Dunlevy samples in both directions if the two river-bed seeps with more extreme isotope compositions (labeled E on the Figure) are included. The temperatures of emergent water (Table 1) are consistent with those reported for confined groundwater in this area by Hopkins et al. (2014).

Possible relationship to shallow riparian groundwater. The Dunlevy water appears to plot at the origin of the evaporation trend defined by shallow riparian groundwater from the valley downstream of Escalate Crossing, but this may be a coincidence. The seep and surface waters in the river at Escalante crossing show no relationship with the Dunlevy water, which would have to flow past Escalante Crossing if it were the source of the shallow riparian groundwater. Water discharging into St. David Cienega is not local shallow groundwater, as indicated by isotopes and temperature.

Nature of the confined aquifer. The isotope data for the Cienega and Dunlevy waters, along with the river-bed seeps E and data reported by Hopkins et al. (2014) for the St. David area show that the confined aquifer is not well mixed over a relatively small area, despite containing water of long residence time, thousands of years in the study area (Hopkins et al., 2014). This suggests that the confined aquifer is compartmentalized at small scale, the compartments containing water of different isotope compositions. The compartments might be permeable layers separated by impermeable sediment, or stringers of high-permeability sediment, perhaps old stream channels deriving water from different areas of the basin margin. The latter alternative seems more likely as an explanation of differing isotopes among relatively closely-spaced wells and springs. Paleochannels influence groundwater flow in basin-fill elsewhere, e.g. Tucson Basin (Eastoe et al., 2004).

Implications for groundwater development. A small number of large-yield wells drawing from the confined aquifer may in the future be constructed in a limited area for a large real estate development. Benson already exploits this resource. The apparent compartmentalization of the aquifer notwithstanding, the effects of large extractions of groundwater in one area will propagate outwards through the confined aquifer. Eventually, static water levels will fall to a extent that causes drying of existing springs and seeps, and the disappearance of artesian water. Pre-development artesian pressure no longer exists in parts of Roswell Basin, New Mexico, because of excessive pumping of groundwater (Havenor, 1996). In the St. David area, the environmental consequences of a large increase in groundwater extraction are likely, eventually, to include:

(1) The drying of the St. David Cienega and Dunlevy wetlands.

(2) The replacement of upward water flow in river-bed seeps by downward flow, removing water from the riparian area. Two such seeps have been identified in the St. David area, and others exist downstream (Hopkins et al., 2014).

(3) The capturing of groundwater that would have replenished the part of the confined aquifer beneath Benson.

Figure Captions

Fig. 1 a. Map of part of the Middle San Pedro Basin.

Fig. 1b. (Modified from Fig. 3 of Hopkins et al., 2014). Longitudinal (approximately north-south) section of the Middle San Pedro Basin, with the area near the St. David Cienega indicated by the red rectangle. The section location is given in Fig. 1a. The dashed line indicates the downward limit of adequate geological control based on well logs.

Fig. 2. Plot of O and H isotopes, showing the relationships between samples collected for this study.

Fig. 3. Plot of O and H isotopes, showing the relationships between the Dunlevy and St. David Cienega samples and other groundwater (GW) and surface water samples in the Middle San Pedro Basin. Data for the confined aquifer (Conf. aq.) are from Hopkins et al. (2014), for the entire Middle San Pedro Basin, with data from sites near St. David (i.e. near the study area) distinguished. Data for seeps and surface water at Escalante Crossing (Esc. Cross.) are unpublished data of the author. Data for shallow riparian groundwater are used with permission of Apache Nitrogen Inc.

References

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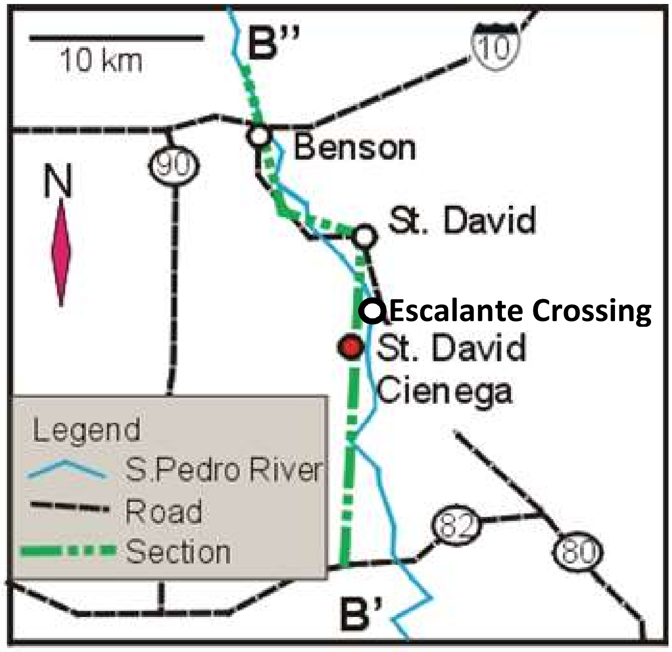
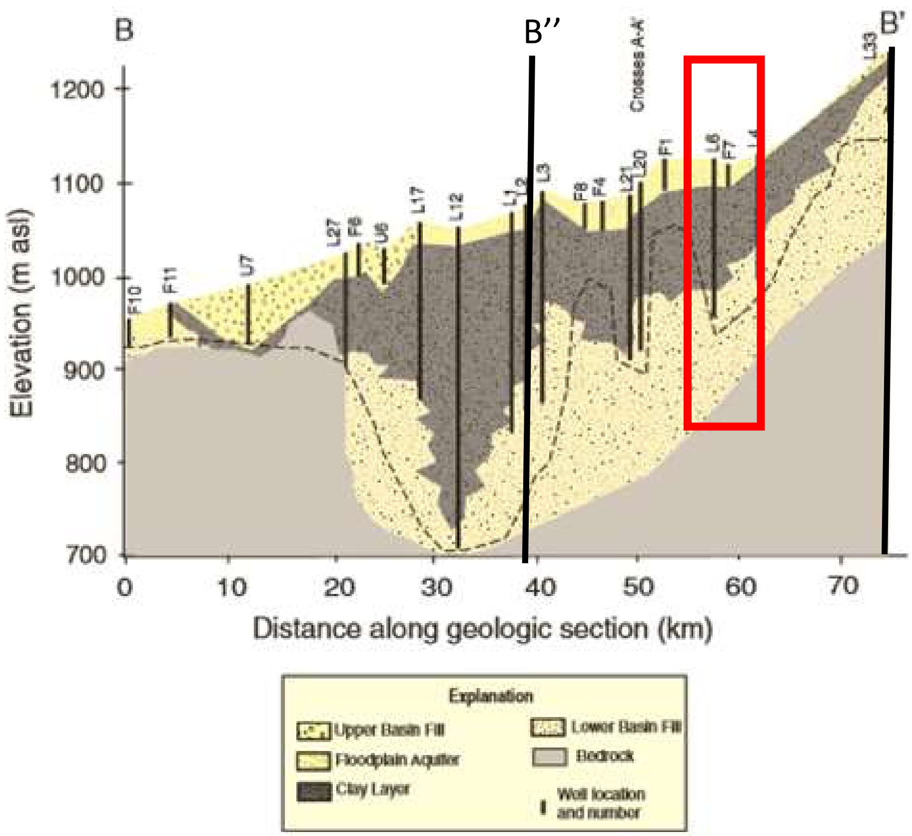


10 km
B''
10
Benson
90
N
St. David
Escalante Crossing
St. David
Cienega
Legend
S.Pedro River
Road
Section
82
80
B'

Fig. 1a



B
B''
B'
Crosses A-A'
Elevation (m asl)
Distance along geologic section (km)
Explanation
Upper Basin Fill
Floodplain Aquifer
Clay Layer
Lower Basin Fill
Bedrock
Well location and number

Fig. 1b

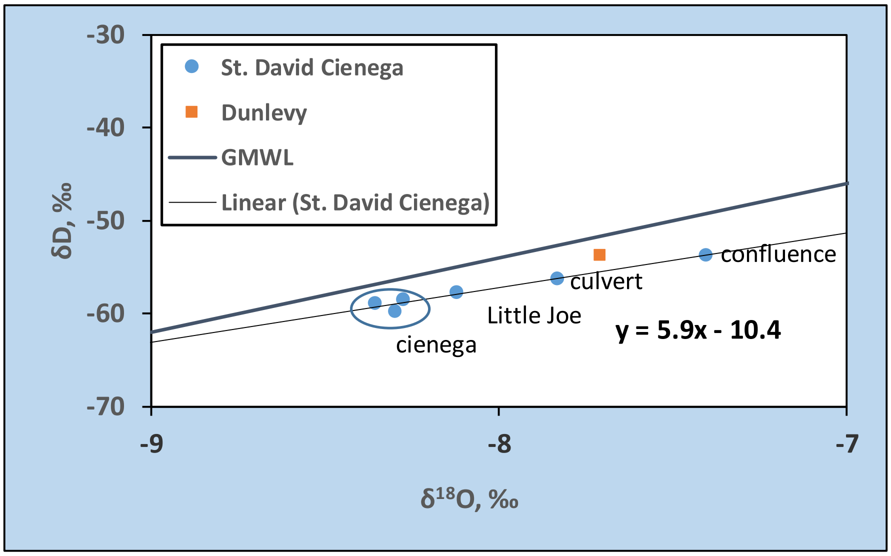

St. David Cienega
Dunlevy
GMWL
Linear (St. David Cienega)
δD, ‰
-30
-40
-50
-60
-70
-9
-8
-7
δ18O, ‰
confluence
culvert
Little Joe
cienega
y = 5.9x - 10.4

Fig. 2

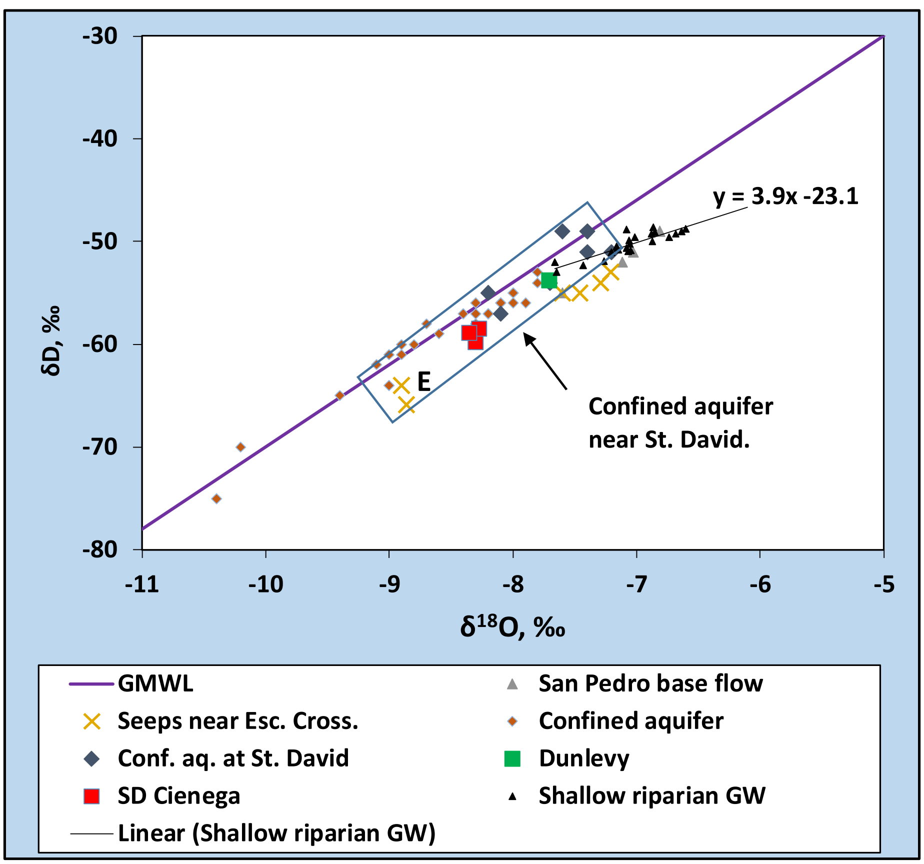

δD, ‰
-30
-40
-50
-60
-70
-80
-11
-10
-9
-8
-7
-6
-5
δ18O, ‰
y = 3.9x -23.1
E
Confined aquifer
near St. David.
GMWL
Seeps near Esc. Cross.
Conf. aq. at St. David
SD Cienega
Linear (Shallow riparian GW)
San Pedro base flow
Confined aquifer
Dunlevy
Shallow riparian GW

Fig. 3

TABLE 1: FIELD AND ISOTOPE DATA

Sample	Location	Notes	T	EC	pH	DO2
			ºC	µS/cm		mg/L
2C	Two cienega -- warm water at north edge of cienega	Sample from 2' deep	24.4	917	7.60	1.65
GR1	Geiser ride 1 -- center of cienega	Sample from near bottom	23.8	919	7.61	1.99
GR2	Geiser ride 2 -- center of cienega	Sample from near bottom	26.3			
LJ	Little Joe spring/pond	Sample from as near as possible to warm area in pond bank	>15.5	932	7.65	
CV	Culvert -- drainiage from cienega close to cienega					
CO	Confluence of creek draining cienega and SP River	Flow rate greater than at culvert.				
DL	Dunlevy wells -- aresian well near SPR	Sample from well	24.6	203	8.50	5.2

Sample	δ18O	δD	Lab No.	Tritium	Lab No.
	‰	‰		TU	
2C	-8.3	-60	W66248		
GR1	-8.3	-58	W66244		
GR2	-8.4	-59	W66245		
LJ	-8.1	-58	W66243		
CV	-7.8	-56	W66247		
CO	-7.4	-54	W66249		
DL	-7.7	-54	W66246	<0.4	AT5609