# STABLE ISOTOPE STUDY OF ST. DAVID CIENEGA AND SURROUNDINGS – 2018 SAMPLING

Report prepared for EarthJustice by Christopher J. Eastoe, Retired, Department of Geosciences, University of Arizona

March 13, 2018

**Executive Summary**

Resampling of groundwater discharging at the St. David Cienega and neighboring springs, and of surface water leaving the Cienega, confirms that the Cienega is hydrologically connected to the underlying confined aquifer. Outflow from the Cienega consists of confined-aquifer groundwater mixed with some local, cold groundwater of shallow derivation. Large increases in groundwater withdrawal from the confined aquifer in and near the study area are likely to affect present groundwater discharge from that aquifer, thereby depleting surface flows along the San Pedro River.

Results also suggest that the confined aquifer has a complex structure and comprises multiple compartments with distinctive isotope compositions. Localized removal of large volumes of groundwater may bring about rapid depletion of available water in a portion (compartment) of the confined aquifer, including its downgradient extent.

Finally, results indicate that discharges at St. David Cienega are likely very sensitive to small changes (a few feet) in artesian pressure (or head) of the confined aquifer. Sampling of seeps near Escalante Crossing in 2015, and downstream of the Crossing by Apache Nitrogen Inc., showed clear isotope evidence of the discharge of confined-aquifer groundwater into the river bed, indicating hydrological connections between the river bed and the confined aquifer. Furthermore, artesian pressure in 2015 was adequate to sustain the discharge of confined-aquifer groundwater in 2015. Such discharge could not be confirmed in February 2018 when discharge near Escalante Crossing had the isotope composition of bank storage, not confined-aquifer groundwater. This observation was likely due to two factors: (1) build-up of bank storage due to high river flow during the previous monsoon, and (2) the lack of sufficient pressure in the confined aquifer to overcome the pressure of the overlying bank storage. Groundwater pumping could have a similar effect by reducing pressure in the confined aquifer, which could, in turn, reduce or even reverse flows at the Cienega. Groundwater modeling would identify this tipping point.

**Introduction**

This report supplements a report written for the Community Watershed Alliance (Benson, AZ) and the Bureau of Land Management (Tucson) following sampling of groundwater and surface water at the St. David Cienega (referred to as the Cienega, below), in January 2017. Following consultations with EarthJustice and its partner organizations, it was decided to undertake a second sampling at the Cienega and in the surrounding area in February 2018. Sampling was undertaken on February 14, 2018, in the presence of David Murray (BLM) and three volunteers from the Community Watershed Alliance. The purposes of the second sampling campaign were:

1. Substantiation of the isotope signatures of water at the Cienega and the Dunlevy well, as observed in 2017. In the form of a question: Are groundwater sources in the Cienega stable over the period of a year?

2. Substantiation of the isotope signature in water in the confined aquifer east of the San Pedro River, at the latitude of the Cienega. In the form of a question: Is the suggested compartmentalization of the confined aquifer (Eastoe, 2017) stable over the period of a year?

3. Further investigation of the author's observations (from sampling prior to 2017) that groundwater from the confined aquifer also enters the San Pedro River bed at Escalante Crossing. In the form of a question: Can the small amount of prior evidence for such discharge be bolstered by further observation?

**Previous Work**

The report prepared in 2017 (Eastoe, 2017) is attached and provides the following description of the hydrogeology of the area, including the existence of an unconfined riparian aquifer beneath the river channel and a confined deeper aquifer.

> *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 of Eastoe, 2017), 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. 1bof Eastoe (2017). 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.*

Recently recharged water in the unconfined aquifer adjacent to the river is often referred to as bank storage.The present report is an addendum to the 2017 report, and incorporates background material from that report (e.g. a geological section of the San Pedro Basin near the Cienega, and analytical methods), which will not be reproduced here. Data from that report are included in Table 1 and in the discussions here. In addition, this report cites data from other sources:

1. The slope of the O and H isotope evaporation trend of surface water in the San Pedro River near Tombstone, AZ (Gungle et al., 2016).

2. O and H isotope data for groundwater in the confined aquifer at St. David, on the east side of the San Pedro River (Hopkins et al., 2014).

3. O and H isotope data for the shallow riparian aquifer at the Apache Nitrogen superfund site (supplied as a personal communication by, and used by permission of, Ms. Pamela Beilke of Apache Nitrogen Inc.). The isotope signature of these groundwaters appears to be consistent throughout the region; similar isotope signatures in shallow riparian groundwater can be found in the San Pedro Valley at Benson (Hopkins et al., 2014) and near Sierra Vista (Baillie et al., 2007).

4. The author's unpublished O and H data and observations on surface water and groundwater discharging into the bed of the San Pedro River near the Escalante Crossing (Fig. 1).

**Study Area**

A map of the study area, and sample sites for the current round of sampling, is provided as Fig. 1.

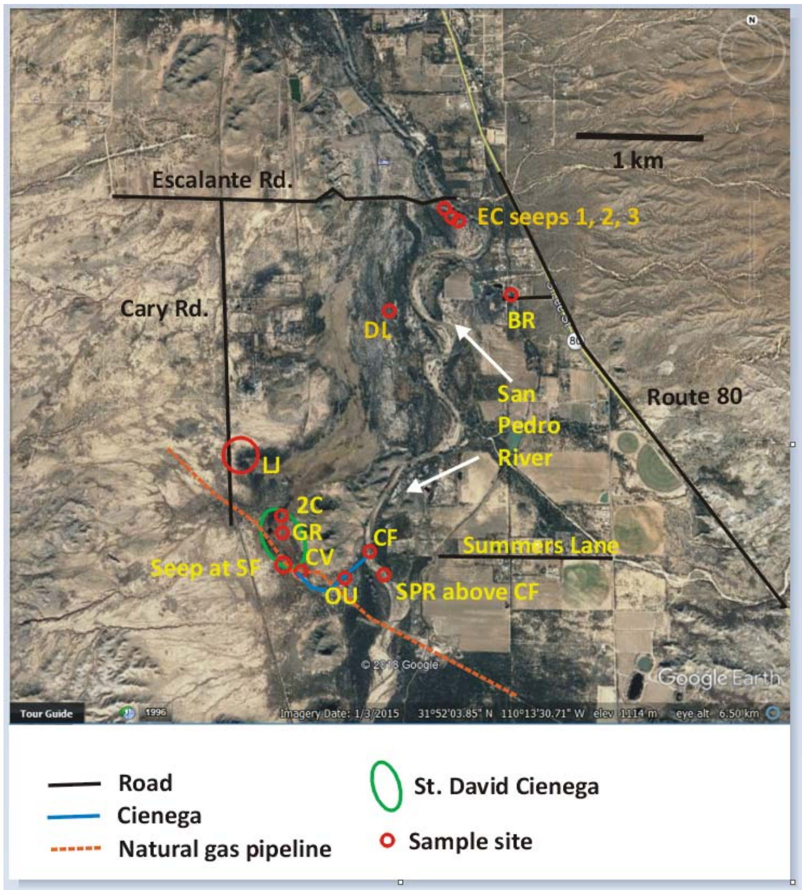


Fig. 1: Google Earth Image of the study area, showing sample locations for the 2018 investigation. Refer to Table 1 for explanation of the sample names.

At the time of the 2018 sampling, the study area had experienced unusually severe drought since the middle of August, 2017, when a month of unusually heavy monsoon precipitation ended. Samples taken in and near the Cienega are therefore considered to be essentially free of any additions from recent runoff. The San Pedro River bed, on the other hand, had been strongly affected by continuous and large-volume flow from July to September 2017 (Fig. 2, taken from U.S. Geological Survey, 2018).

**Discharge, cubic feet per second**

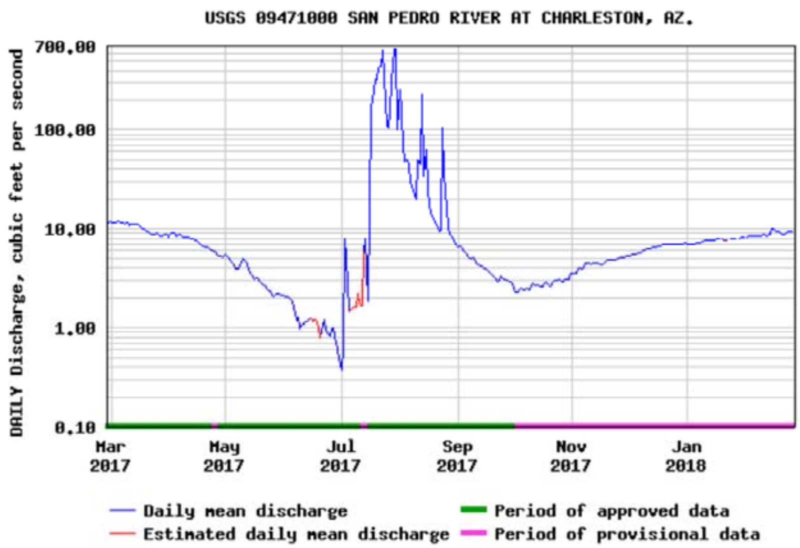


Fig. 2: Flow record at the Charleston Gage, upstream of the study area (U.S. Geological Survey, 2018).

Sample sites for this sampling round were:

1. The Cienega, Little Joe Spring, Cienega outlet (Culvert) and Dunlevy artesian well sites, as close as possible to sites of the same names in the 2017 sampling.

2. Cienega outflow near the termination of surface flow, which was not reaching the San Pedro River because of the dry conditions.

3. A spring supplying water to a salt flat (visible at high magnification on Google Earth images, but obscured by symbols on Fig. 1) immediately south of the Cienega.

4. A private domestic artesian well (BR) east of the San Pedro River, near Escalante Crossing. This was the only private well in the area for which permission to sample was obtained in time.

5. Base flow in the San Pedro River, sampled upstream of the confluence with the stream draining the Cienega.

6. Three seeps of groundwater discharging into the San Pedro River upstream of Escalante Crossing, all within 100 m of the crossing.

Measurements of stable oxygen and hydrogen isotope composition were made by the Environmental Isotope Laboratory at the University of Arizona.

**Results**

The 2018 field and isotope data are listed in Table 1. Data for the Cienega, nearby springs and its outflow are plotted in Figure 3. In Fig. 4A, data from the 2018 sampling are compared with data for shallow riparian groundwater at the Apache Nitrogen superfund site (which extends 4 km downstream of Escalante Crossing), and with data for groundwater in the confined aquifer east of the San Pedro River at St. David, (from Hopkins et al, 2014). In Fig. 4B, data for the seeps at Escalante Crossing and the Apache Nitrogen Superfund site are shown separately.

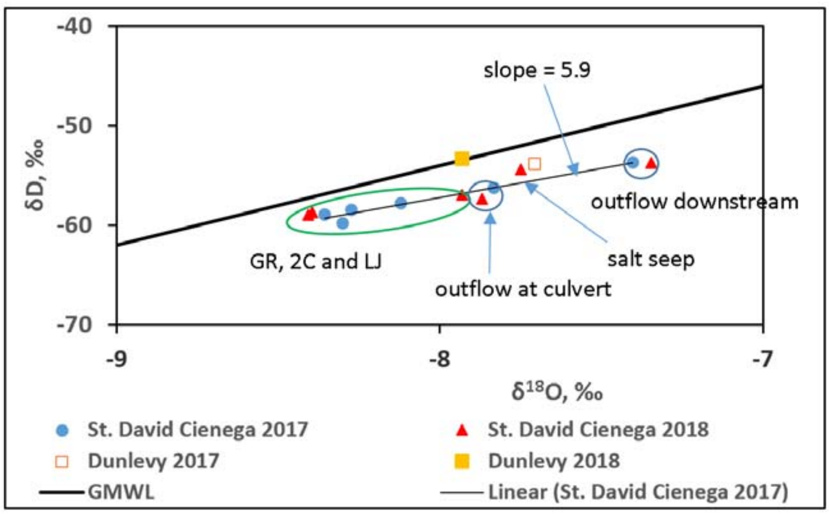


Fig. 3: Graph of δD vs. $\delta^{18}O$, showing data for St. David Cienega, surrounding springs, and the outflow of the Cienega. Both 2017 and 2018 data are shown.

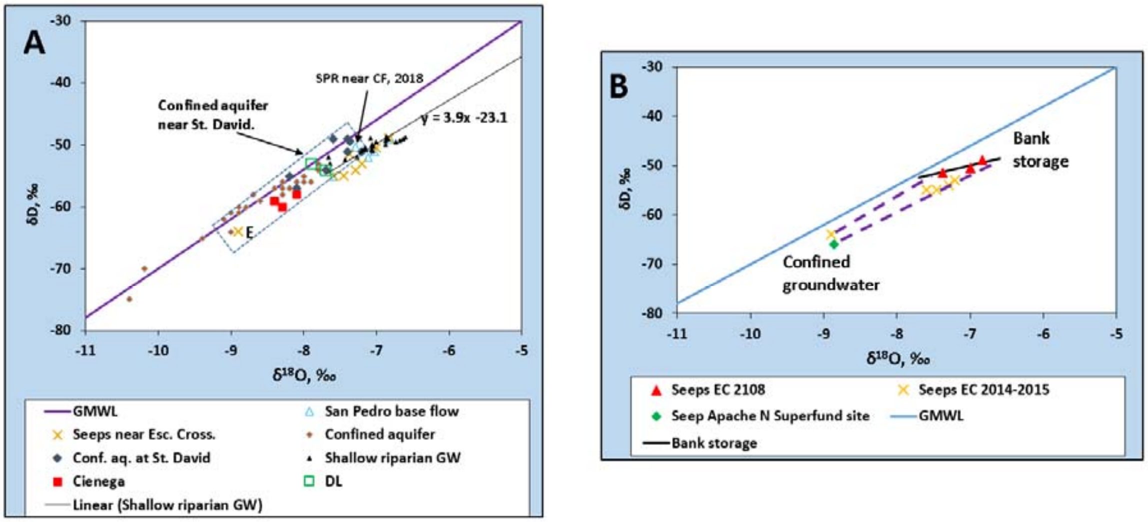


Fig. 4. Graphs of δD vs. $\delta^{18}O$, showing: A. data for the Cienega, the Dunlevy artesian well, seeps in the bed of the san Pedro River and base flow in the River in relation to data from other groundwater from the confined aquifer in the St. David area (Hopkins et al., 2014), shallow riparian groundwater from the Apache Nitrogen Superfund Site; B. Groundwater from seeps in bed of the San Pedro River in the study area.

**Discussion**

1. *The Cienega groundwater system.* Groundwater from the 2018 sampling plots on precisely the same linear trend as the 2017 data for the Cienega area. As observed by Eastoe (2017), the linear data trend has a slope of 5.9 and is too steep to be an evaporation trend. Local evaporation trends have slopes near 4 (Gungle et al., 2016; also see the slope of the data trend for shallow riparian groundwater in Fig. 4A). The slope of the linear data trend at the Cienega indicates mixing of local groundwater (represented by a point at or beyond the right-hand end of the trend) with groundwater discharging from the confined aquifer (represented by the left-hand end of the trend). Discharge from the confined aquifer in this area is consistent with the broad range of isotope composition in the confined aquifer (Hopkins et al. 2014) but not with local groundwater such as bank storage along the San Pedro River. Discharge from the confined aquifer is also indicated by its high temperature (Table 1); contrast temperatures of >18$^{o}$C at sites LJ, GR and 2C with 4$^{o}$C, representing the overnight surface temperature, at site CV. The Cienega groundwater system therefore has the same isotope sources as observed in the 2017 sampling, with some changes in mixing ratio. The water source in the center of the Cienega is discharge from the confined aquifer, with little or no admixture of local groundwater. Local groundwater is added to confined-aquifer groundwater at the sites CV, OU and Seep at SF.

2. *The Dunlevy artesian well*. The isotope composition and the electrical conductivity remain distinct from those of the Cienega discharge. The 0.2‰ difference in $\delta^{18}O$ since 2017 is equal to the $2\sigma$ analytical precision, and is therefore not an indication of any change in composition since 2017. Discharge from the confined aquifer is therefore consistent over time in composition at this sample point, but differs between sample sites only a few kilometers apart.

3. *Seeps at Escalante Crossing*. In past sampling campaigns (2015, and Apache Nitrogen Superfund data) seeps with O and H isotope compositions consistent with confined-aquifer discharge were identified (Fig. 4B), and an association of one such seep at Escalante Crossing with growths of orange algae, suggesting availability of dissolved iron, was noted. The precise location of the seep in the Apache Nitrogen Superfund zone was not recorded by the consulting personnel who took the sample, but that seep was not in the same area as the one upstream of Escalante Crossing. In 2018, seeps at Escalante Crossing, including two with orange algae (Fig. 5), had isotope compositions consistent with bank storage. The samples with orange algae were discharging at slightly higher temperatures than the sample without such algae, but all three samples appear to be dominated by bank storage, probably resulting from flooding during the previous monsoon. Up to 10% of confined-aquifer water could be present, but undetectable in the isotope data (because of the analytical uncertainty of the isotope measurements). Other seep samples, taken in 2014 and 2015, may be mixtures of bank storage with a small amount of confined-aquifer groundwater (Fig. 4B).

Fig. 5. Orange and green algae growing at a groundwater discharge point in the bed of the San Pedro River, near Escalante Crossing.

The zone in which confined-aquifer water has been observed discharging at the surface can be considered as a permeable zone containing a column of water, as depicted in Fig. 6.

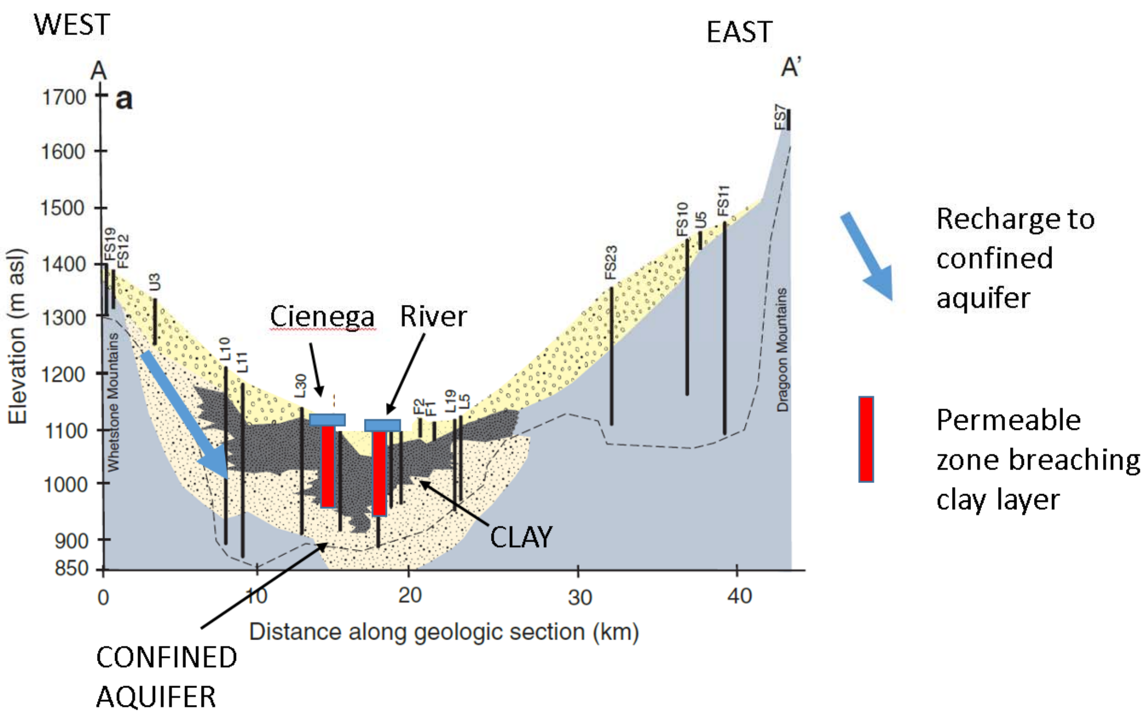


Fig. 6. Vertical section across the San Pedro Basin near the study area (adapted from Hopkins et al., 2014), showing schematically the permeable zones connecting the Cienega and the San Pedro River bed with the confined aquifer.

There is a water supply at the base (the confined aquifer) and at the top (the river system, consisting of surface water in the river bed, and a more permanent supply of water in the shallow riparian aquifer beneath the river and above the Benson clay). Which source prevails in generating flow through the permeable zone depends on the pressure, or head, that each exerts.

In 2015, upward flow was occurring, indicating that the artesian head of the confined aquifer exceeded the head of the river system. In 2017, there appears to have been sufficient head in the flooded river system to reverse the flow temporarily, resulting in the replacement of confined-aquifer discharge by discharge of bank storage from the river. This indicates that the head of the confined aquifer is not very much larger than the usual head in the river system, because the depth of floodwater (a few feet) in 2017 was sufficient to reverse the pressure gradient. In the future, if pumping causes a decline in the head of the confined aquifer, the river system head will begin to control the flow direction under most conditions, and river water will be captured by the confined aquifer. How much river water might be captured is not indicated by the present study; that is a matter for modeling. Fig. 7 is a sketch diagram illustrating these three states of the Escalante Crossing area.

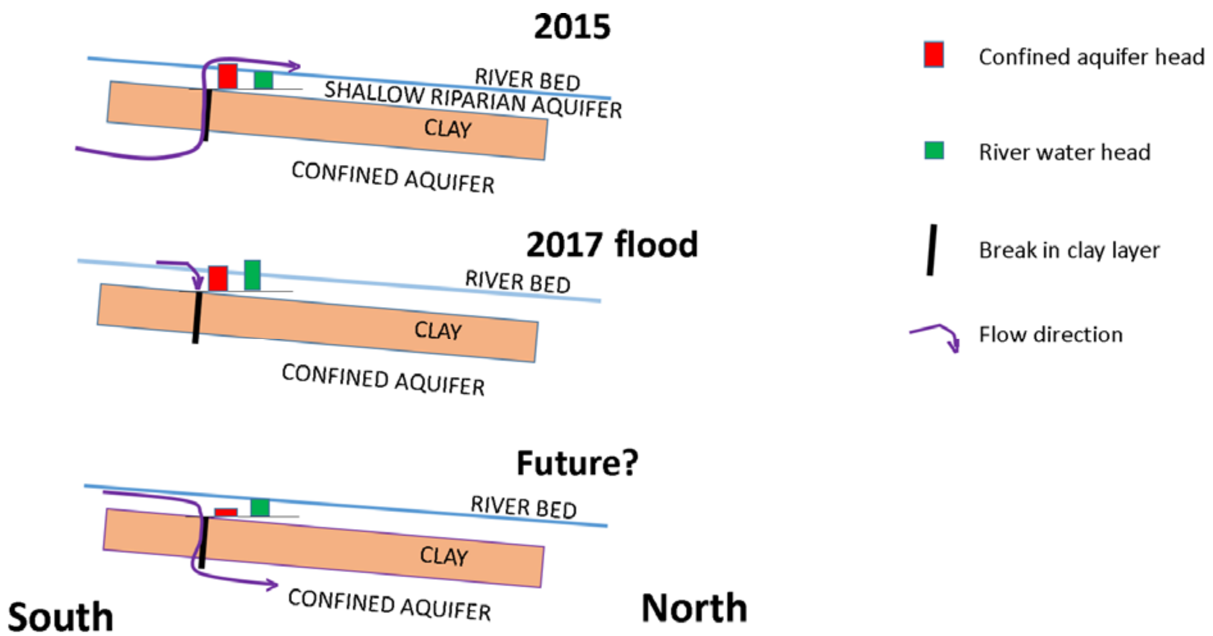


Fig. 7: Sketch vertical cross section of the river bed at Escalante Crossing, showing three hydrologic states, as outlined in the text.

One structure in which the confined aquifer is usually discharging has been identified by the author near Escalante Crossing. Another was found by the consultants working on the Apache Nitrogen Superfund site, but its location was not well recorded. Isotope data clearly indicated discharge of confined-aquifer water in that case. Locations of confined-aquifer discharge into the river bed are not easy to identify under all conditions; the hydrologic conditions in the river bed must be suitable. The sampling in 2018 could not confirm a hydrologic connection between the confined aquifer and the river bed by isotope measurements because hydrologic conditions in the river bed concealed any confined-aquifer discharge. Nonetheless, it can be concluded that two such hydrologic connections are known near St. David, and therefore others may exist. The flow reversal in 2017 suggests that the direction of flow through the hydrologic connection near Escalante Crossing is sensitive to small changes (a few feet) in the artesian head of the confined aquifer.

4. *The Borman domestic artesian well*. This well draws water from the confined aquifer, as indicated by the artesian head and by the drill log (Fig. 8). The O and H isotopes, ($\delta^{18}O$, $\delta D$) = (-7.4, -59‰) are consistent with those of other samples taken at St. David and east of the San Pedro River by Hopkins et al. (2014), including a sample from Summers Lane (-7.7, -54‰), at the same latitude as the Cienega. The owner of the well has noted that artesian head no longer exists at this well during summer when pumping for irrigation on nearby agricultural land is at maximum levels. The data collected from this well confirm that the isotope composition of the part of the aquifer to the east of the San Pedro River has been consistent over several years (values of $\delta^{18}O$ near -7‰, as also measured nearby at Summers Lane by Hopkins et al. (2014)). The data from Summers Lane and site BR indicate a third distinctive zone in the confined aquifer.

**Well Driller Report and Well Log**

WELL REGISTRATION NUMBER **55-** 214906

| SECTION 5. GEOLOGIC LOG OF WELL | | | |
|---|---|---|---|
| DEPTH FROM SURFACE | | DESCRIPTION<br>Describe material, grain size, color, etc. | Check (**X**) every interval where water was encountered |
| FROM (feet) | TO (feet) | | |
| 0 | 25 | WEATHERED GRANITE | |
| 25 | 70 | VOLCANIC CONGLOMERATE | |
| 70 | 380 | SANDY RED CLAY | FIRST WATER 380 |
| 380 | 460 | SANDY RED CLAY W/STREAKS OF GRAVEL | |
| 460 | 515 | VOLCANIC CONGLOMERATE | |
| | | | |

Fig. 8. The driller's log for site BR well.

5. *Structure of the confined aquifer*. The 2018 dataset confirms the wide range of O and H isotope compositions in the confined aquifer near St. David and the St. David Cienega. The dataset also shows that isotope compositions of groundwater have remained close to constant over one year at each of the sample sites that were repeated for this study. The suggestion of Eastoe (2017) that the confined aquifer is compartmentalized with regard to isotope composition therefore appears valid. Water in the

confined aquifer south of Benson has been resident for thousands of years on the basis of carbon-14 content and geochemical modeling (Hopkins et al., 2014). Groundwater of such long residence time should be well-mixed in stable isotope composition unless it is distributed among volumes (compartments) with isotopically-distinctive water sources and restricted communication.

Compartmentalization might reflect the presence of sub-aquifers in discrete layers, or in discrete paleochannels (ancient stream channels) in the aquifer beneath the Benson Clay, or both. The well log for the Borman domestic well (Fig. 8), its poor geological terminology notwithstanding, suggests layering in that case. Well logs are not available for the Dunlevy artesian well and neighboring wells.

6. *Implications for water supply.* Large increases in groundwater withdrawal from the confined aquifer in and near the study area are likely to affect groundwater discharge from that aquifer (or set of aquifers). Elimination of artesian and surface discharge is possible, and has already been noted during summers by the owner of the BR well located adjacent to the San Pedro River. Decreases in static water level could reduce or eliminate discharge to the bed of the San Pedro River and to the St. David Cienega, and in the extreme might capture surface flows, changing the present gaining reach of the river (where there are increasing surface flows) into a losing reach (where there are decreasing surface flows).

The implications of a compartmentalized confined aquifer should be carefully considered in the context of increasing groundwater demand. Localized removal of large volumes of groundwater may bring about rapid depletion of available water in a portion (compartment) of the confined aquifer, including its downgradient extent. The effects of pumping would eventually spread, but more slowly, into neighboring compartments.

**Acknowledgements**

Permission for sampling and the assistance of David Murray of the Bureau of Land Management, and assistance with sampling from members of the Community Watershed Alliance of Benson are gratefully acknowledged.

**References**

Baillie, M. N., Hogan, J. F., Ekwurzel, B., Wahi, A K., Eastoe, C. J., 2007, Quantifying water sources to a semiarid riparian ecosystem, San Pedro River, Arizona, J. Geophys. Res., 112, G03S02, doi:10.1029/2006JG000263.

Eastoe, C.J., 2017, A stable isotope study of groundwater and surface water near the St. David Cienega, San Pedro Valley, Arizona. Report prepared for Community Watershed Alliance (Benson) and Bureau of Land Management, Tucson, 7 p.

Gungle, B.G., Callegary, J.B., Paretti,, N.V., Kennedy, J.R., Eastoe, C.J., Turner, D.S., Dickinson, J.E., Levick, L.R., Sugg, Z.P., 2016, Hydrological conditions and progress toward sustainable use of groundwater in the Sierra Vista Subwatershed, Upper San Pedro Basin, southeastern Arizona: U.S. Geological Survey Scientific Investigation Report 2016–5114., http://dx.doi.org/10.3133/sir20165114

Hopkins, C., McIntosh, J., Dickinson, J., Eastoe, C, Meixner, T., 2014, Evaluation of the importance of clay confining units on groundwater flow in alluvial basins using solute and isotope tracers. Hydrogeology Journal, DOI 10.1007/s10040-013-1090-0.

U.S. Geological Survey, 2018. USGS 09471000 San Pedro River at Charleston, AZ. https://waterdata.usgs.gov/az/nwis/dv/?site_no=09471000&PARAmeter_cd=00060, consulted Feb. 2018.

## TABLE 1: ISOTOPE AND FIELD DATA

Sampling 2/14/18
Also present: Dave Murray BLM
Howard + Mike + Tom, Community Water Group

| Sample nar | Loc. | Time | T °C | pH | EC µS/cm | DO2 | δ18O | δD | Lab No. | Notes |
|---|---|---|---|---|---|---|---|---|---|---|
| LJ | Little Joe Spring | 930 | 18.9 | 6.8 | 850 | 6.6 | -7.9 | -57 | W68868 | |
| CV | Culvert | 950 | 4 | 6.7 | 597 | 12.2 | -7.9 | -57 | W68869 | Outflow from Cienega, adjacent to Cienega |
| OU | Outlet 50 m dowstream from gas pipe | 1025 | 8.3 | 7.2 | 738 | 8 | -7.3 | -54 | W68867 | Last point with any flow -- outlet creek dreis below this poit. |
| Seep @ SF | Seep feeding salt flat west of Cienega | 1045 | 7.1 | 7.3 | 1330 | 11 | -7.7 | -54 | W68872 | Salt contains some NaCl |
| GR | Geiser Ride | 1100 | 25.1 | 7.3 | 1115 | 2.6 | -8.4 | -59 | W68866 | Standing water a few cm deep in center of Cienega |
| 2C | Two Cienega | 1110 | 23.6 | 7.4 | 961 | 1.1 | -8.4 | -59 | W68874 | Standing water 1 m deep, N edge of Cienega |
| DL | Dunlevy well 1 | 1200 | 24.4 | 8.0 | 298 | 7.9 | -7.9 | -53 | W68870 | Artesian well, uncapped |
| EC seep 1 | Seep, W side of SPR, 100 m S of Escalante Cro: | 1230 | 10.8 | 7.5 | 693 | 1.6 | -6.8 | -49 | W68863 | Beginning of surface flow, no orange algae |
| EC seep 2 | Seep, W side of SPR, 50 m S of Escalante Cros | 1240 | 12.1 | 7.4 | 1193 | 1.4 | -7.0 | -51 | W68864 | Seep with orange algae Turbid (high EC?) |
| EC seep 3 | Seep, W side of SPR, 10 m S of Escalante Cros: | 1245 | 14.1 | 7.3 | 570 | 0.4 | -7.4 | -51 | W68865 | Seep with orange algae |
| BR | Heather Borman domestic well | 820 | | | | | -7.4 | -49 | W68871 | Sometimes artesian. |
| SPR above C | San Pedro River | 1010 | 12 | 7.1 | 514 | 14 | -7.3 | -50 | W68873 | SP River 100 m above confluence wiith Cienega outlet |

## OTHER SAMPLES CITED IN THIS REPORT

January 2017 sampling
Also present: Dave Murray BLM
Howard Community Water Group

| Site | Description | T °C | EC µS/cm | pH | DO2 mg/L | δ18O ‰ | δD ‰ | Lab No. | Tritium TU | Lab No. | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 2C | Two cienega -- warm water at north edge of cienega | 24.4 | 917 | 7.60 | 1.65 | -8.3 | -60 | W66248 | | | Sample from 2' deep |
| GR1 | Geiser ride 1 -- center of cienega | 23.8 | 919 | 7.61 | 1.99 | -8.3 | -58 | W66244 | | | Sample from near bottom |
| GR2 | Geiser ride 2 -- center of cienega | 26.3 | | | | -8.4 | -59 | W66245 | | | Sample from near bottom |
| LJ | Little Joe spring/pond | >15.5 | 932 | 7.65 | | -8.1 | -58 | W66243 | | | Sample from as near as possible to warm area in pond bank |
| CV | Culvert -- drainiage from cienega close to cienega | | | | | -7.8 | -56 | W66247 | | | |
| CO | Confluence of creek draining cienega and SP River | | | | | -7.4 | -54 | W66249 | | | Flow rate greater than at culvert. |
| DL | Dunlevy wells -- aresian well near SPR | 24.6 | 203 | 8.50 | 5.2 | -7.7 | -54 | W66246 | <0.4 | AT5609 | |

Sampled 4/8/2014
Also present: Greg Hall, Apache Nitrogen

| Site | Description | δ18O ‰ | δD ‰ | Lab No. | |
|---|---|---|---|---|---|
| SD-1 | SPR base flow near Flynn St. | -7.0 | -51 | W59055 | |
| SD-2 | SPR base flow near Curtis station | -7.1 | -52 | W59056 | |
| SD-3 | Escalante crossing; seep at beginning of surface flow | -7.2 | -53 | W59057 | Water flowing on top of Benson Caly |
| SD-4 | Escalante crossing; seep at beginning of surface flow | -7.3 | -54 | W59058 | Seep in river bed |
| SD-5 | Escalante crossing; SPR base flow at crossing | -6.8 | -49 | W59059 | |
| SD-6 | Escalante crossing; seep? 50-100m upstream. | -7.5 | -55 | W59060 | Seep in river bed |

Sampled 2/19/2015
Also present: James Callegary

| Site | Description | δ18O ‰ | δD ‰ | Lab No. | |
|---|---|---|---|---|---|
| | Escalante Crossing: seep 100-150 m upstream | -7.6 | -55 | | Water flowing on top of Benson Caly |
| | Escalante Crossing : seep at crossing | -8.9 | -64 | | Seep below west bank, with orange algae. |