GROUNDWATER SUPPLY IN CASCABEL

A report reviewing data collected by The Nature Conservancy since 1993.

Chris Eastoe, June 2024

Scientific papers cited in this report are available as pdfs on request – please email Chris at
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A. EXECUTIVE SUMMARY

Static water level measurements in four wells and the lengths of perennial reaches in stream beds indicate long-term, decade-scale decreases in the amount of groundwater in the two main aquifers that supply water in Cascabel. Large recharge events in Hot Springs Canyon have been insufficient to reverse the declines in static water level, except during a 7-year period, 2015-2021, when three such events occurred. The progressive decline in groundwater probably results from natural climate change, but will be exacerbated by over-exploitation.

B. INTRODUCTION: WHAT ARE WE LOOKING FOR?

Most of the groundwater used in Cascabel comes from two separate aquifers (see Eastoe and Clark, 2018, for a detailed explanation of why the two aquifers are distinguished):

1. An aquifer along the course of the San Pedro River between the Benson Narrows and the confluence with Hot Springs Wash (which I'll call the Confluence, below). Most wells draw water from beneath a set of clay-rich layers, deposited in wetlands a few hundred to a few thousand years old, that fill a trench excavated by the river towards the end of the last Ice Age. This aquifer is replenished by groundwater flowing from the flanks of the valley.

2. An aquifer including the sandy or gravelly sediments in Hot Springs Wash and along the east side of the San Pedro River between the Confluence and Gamez Road. This aquifer is replenished mainly by water from Hot Springs Canyon, and used to discharge year-round into the river bed near Gamez Road.

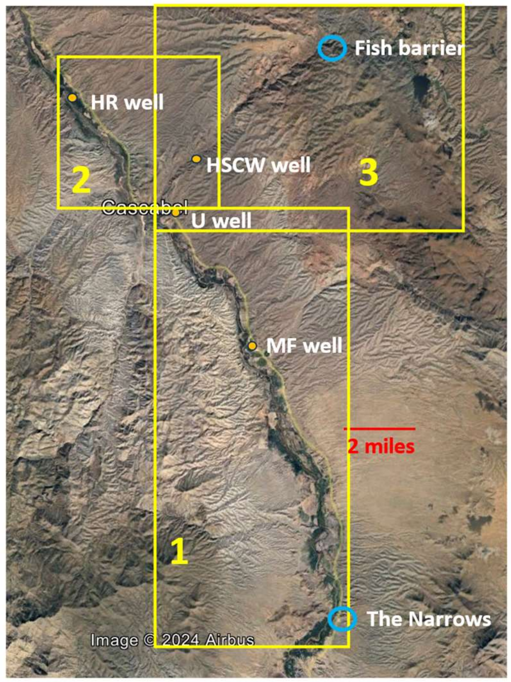
The two aquifers are separated by only a few feet near the Confluence. The water in each aquifer is distinctive in composition (hardness, total dissolved solids, isotopes – matters that are explained Eastoe and Clark, 2018). Water in aquifer 1 is at a higher level than that in aquifer 2 where they meet, but there is no evidence that water is flowing from 1 into 2. It's possible that the aquifers are in parallel, buried, ancient river channels where they pass close together.

A few wells tap groundwater of other sources, e.g. the sandy/gravelly sediments in the bottom of Paige Canyon, and the coarse gravels and conglomerate along the eastern flanks of the river basin.

We are looking for indications of changes in the amount of groundwater in aquifers 1 and 2. This can be observed in two ways.

First, in wells where measurements of groundwater level have been taken over a long period, how have water levels changed?

Second, where water is present in perennial reaches of the river, how much water is there? How have the lengths of the perennial reaches changed over time?



Sample location map.

Yellow rectangles are wet-dry mapping areas as shown in the report.

1 Three Links Farm

2 San Pedro River near Gamez Road

3 Hot Springs Canyon

The following observation points have been chosen.

Aquifer 1:

- the perennial reach at the Three Links pastures, length measured during wet/dry mapping at the summer solstice
- the Mason Fields (MF) irrigation well, in which static water level (SWL) has been measured at least twice per year since 2006

The well was chosen because it lies between two regularly irrigated bottom-land properties. Uncompacted alluvium in the valley bottom is broad in this area, 500-800 yards wide, providing a large storage volume for groundwater. Water levels at this observation point reflect the effect of irrigation on the groundwater supply.

Aquifer 2:

- Hot Springs Canyon just below the fish barrier, where flow volume has been measured
- the perennial reach of HSC upstream of the fish barrier, length measured during wet/dry mapping at the summer solstice
- the Hot Springs Canyon Windmill (HSCW) well, SWL measured at least twice a year since 1993
- the perennial reach upstream of an impermeable rock barrier in the bed of the San Pedro River near Gamez Road, length measured during wet/dry mapping at the summer solstice.
- the Urias (U) well, SWL measured at least twice a year since 1993

- the "Hughes River" (HR) well near the irrigated fields at the River Ranch, SWL measured at least twice a year since 1993

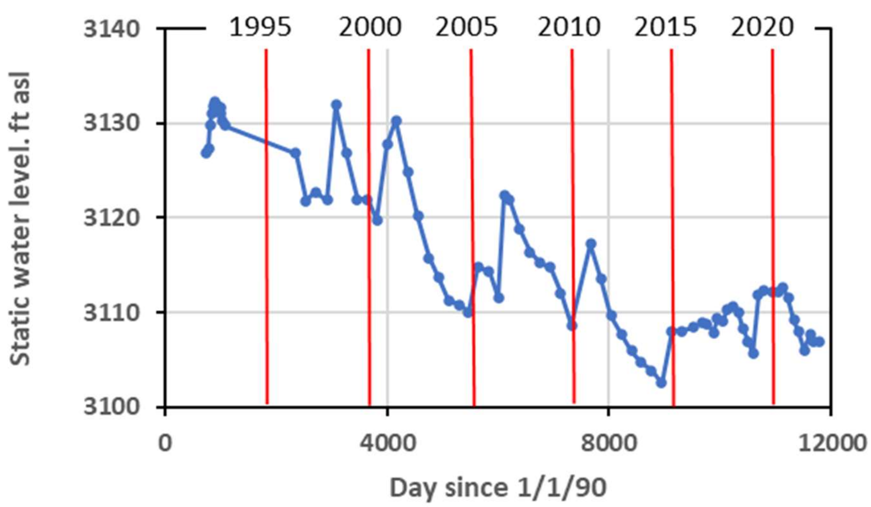
The HSCW and U wells provide information on groundwater input into aquifer 2, in an area where changes mainly result from climate fluctuation, because there is little pumping in these parts of HSC. The HSCW well has periodically gone dry in recent years and has begun to collapse at the base of the hole. The U well will continue to provide such information. It is located in a part of HSC where the deposit of uncompacted alluvium in the canyon bottomlands is much wider than at HSCW well. Therefore, the size of the fluctuations in groundwater level is smaller at the U well, but the pattern of variation over time is similar to that at the HSCW well.

The HR well lies just downgradient from irrigated pastures, and next to the reach where the groundwater in aquifer 2 discharges into the bed of the San Pedro River. Water levels in this well reflect the combined effects of irrigation withdrawals and climate variations.

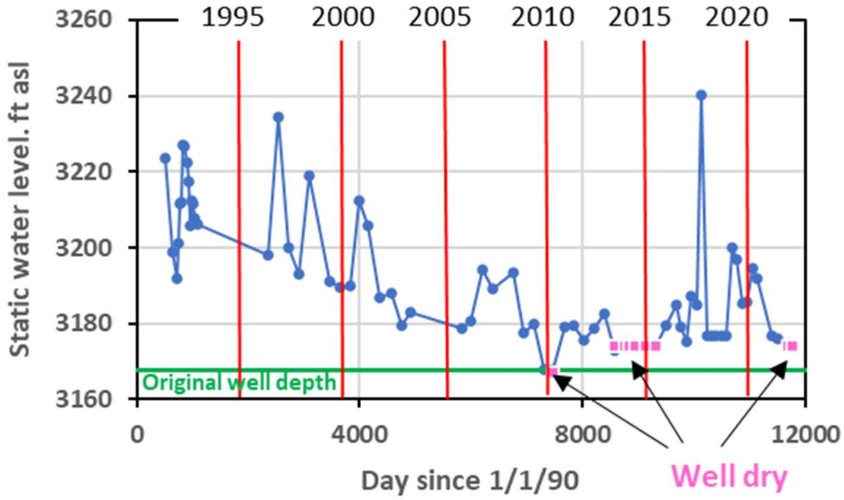
C. STATIC WATER LEVELS IN WELLS

The following diagrams show static water level (SWL, water level unaffected by recent pumping) as blue symbols + lines. Water levels are given as altitude above sea level (asl). Vertical red lines correspond to January 1 of the given year. Note that the depth scale differs from graph to graph.

URIAS WELL, HOT SPRINGS CANYON

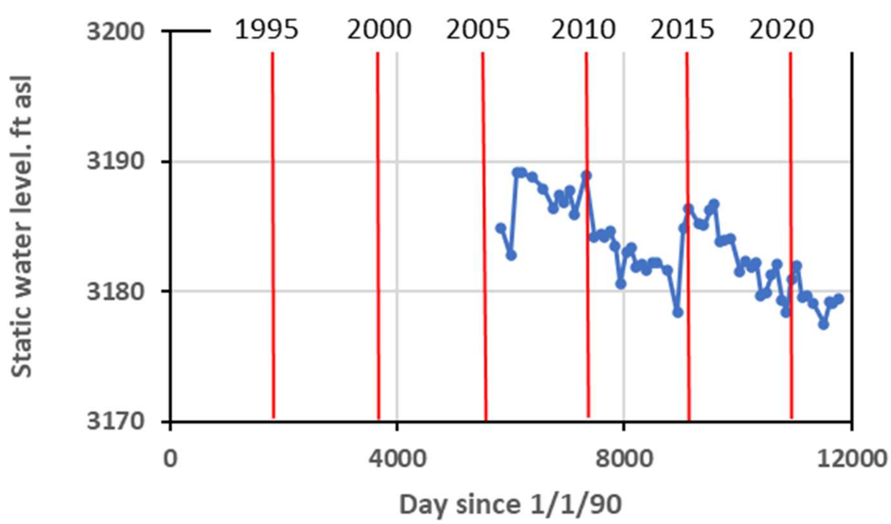


HOT SPRINGS CANYON WINDMILL (CORBETT CENTER)

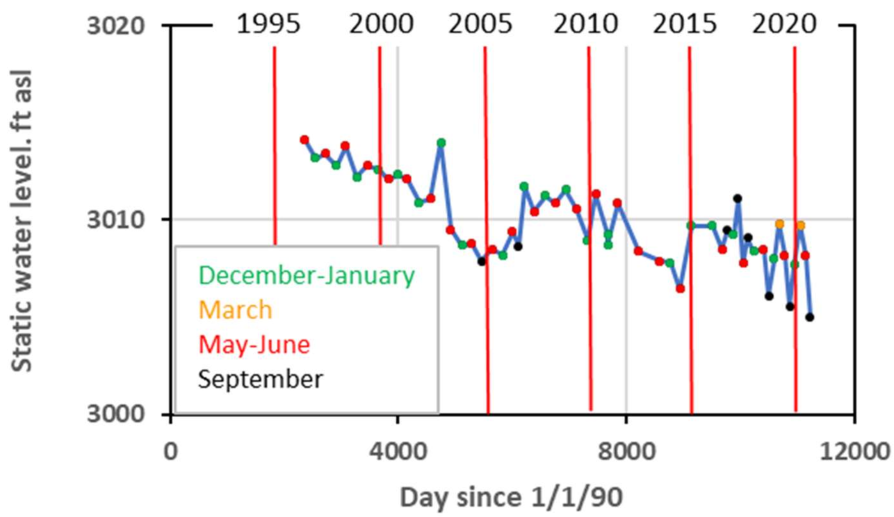


Notes: The well was originally 77 feet deep, but the bottom of the hole has collapsed inwards as water levels fell to the bottom of the well in late 2009. The depth of open hole was 71-72 ft. in 2013-2015. The well was dry on several occasions. The high SWL in 2014 is suspect, and is discussed in the text.

MASON FIELDS IRRIGATION WELL



HUGHES RIVER WELL (DOWNGRADIENT FROM RIVER RANCH)



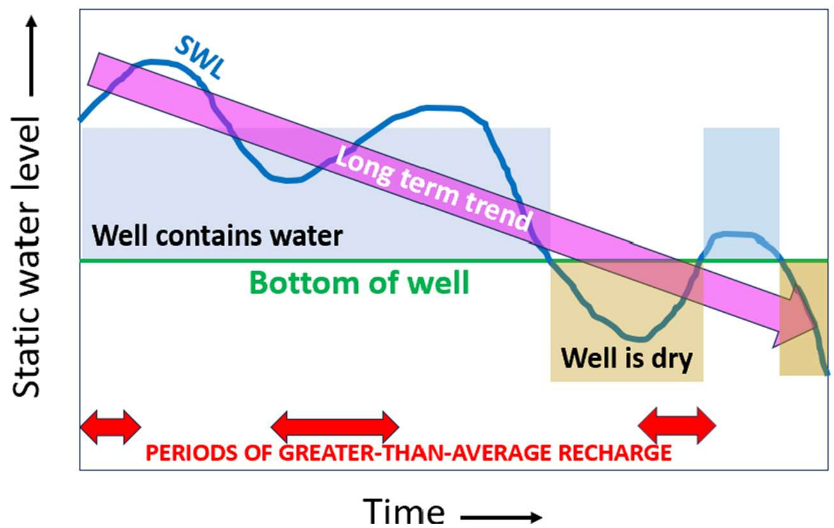
Note: In this case, data points are distinguished according to months of sampling in an attempt to understand the apparent seasonal cycling of water depth.

Observations

1. All four wells show static water level (SWL) changes at different time scales, ranging from general trends over decades to peaks and troughs lasting a few years, to seasonal variations.
2. *Decadal time scale.* All four wells show general decline in static water level (SWL) from the 1990s to 2014 (2006-2014 at MF).
3. *Annual time scale*. A. In 2015, SWL increased in all four wells, remaining high until 2021 at the HSCW, U and HR wells. SWL may be declining at all four sites since 2021. Measurements in coming years will show whether this is indeed the case. B. The HSCW, U and MF wells all show some similar variations over the period of observation. All three show peaks in SWL at 2001-2002 and 2007-2008. C. A SWL peak at 2011 was seen at the U and MF wells, but not at the HSC well.
4. *Seasonal time scale.* Sampling near the summer and winter solstices, undertaken at all four wells, shows little seasonal variation in SWL, except at the HR well where spring and fall data are also available in recent years. At HR, there are periods of several years when the relationship of winter and summer SWL appears consistent, but the seasonal SWL relationship is reversed at different times (compare 2003-2007, 2007-2009, 2009-2012).

Discussion

1. The figure below is an explanation of the observed SWL variations at the HSC well. An annual-scale variation is superimposed on a long-term downward trend in SWL.



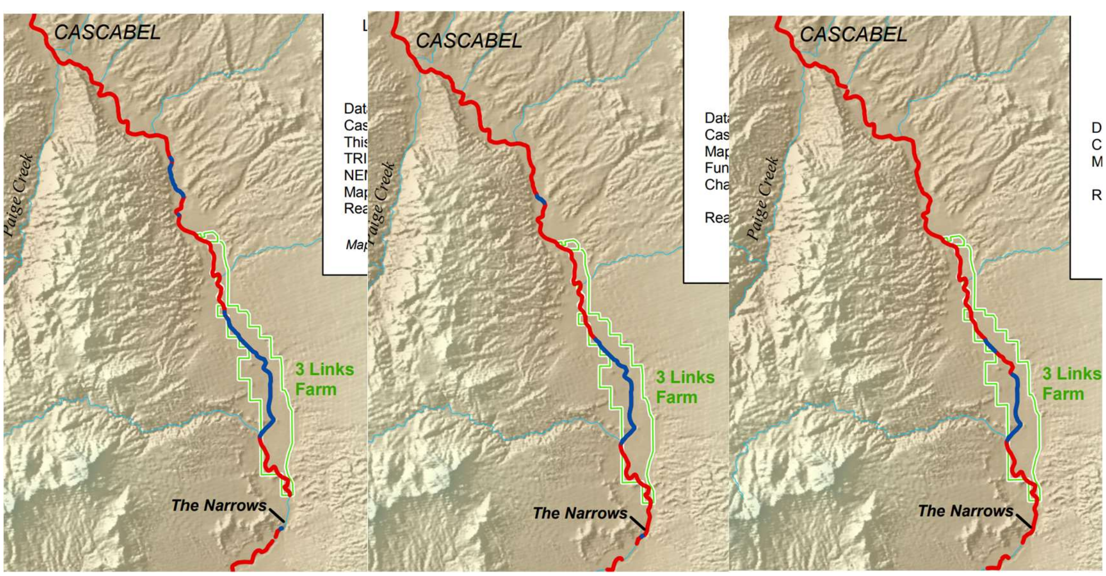
2. The well first goes dry when the annual-scale variation causes water in the aquifer to fall below the bottom of the well. A subsequent period of higher recharge causes water to reappear in the well for several years, but the long-term decline in water level eventually outweighs the short-term recharge variations and the well returns to being dry.
3. The short term (annual-scale) variations in SWL move through the aquifers like waves. It may take years for a particular wave to move through an aquifer, e.g. from the Yellow Cliffs to the Urias well in HSC. It takes decades for water to move from upper HSC to Gamez Road (see Eastoe and Clark, 2018, for justification).
4. Similar combinations of shorter- and longer term trends are observed in the U, MF and HR wells. The amplitudes of change are smaller, because these three wells are in broad parts of the valleys, where groundwater can spread out over a large area. These broad areas of the valley act as groundwater storages.
5. The recovery of SWL in 2015 followed two major rainfall events: Hurricane Odile in September 2014 (which caused a large flood in the San Pedro River, lasting for over two weeks, with peak floodwater depths estimated at 12-14 feet at 5500 N Cascabel Rd.), followed by an unusually wet January, 2015 (5.5" in Tucson). Isotope data were used to show that the flood caused recharge in two places along the river (at the Clayworks and near the HR well; see Eastoe, 2020). It is very likely that these two events caused the increases in SWL observed in 2015.
6. At the U and HSCW wells, it appears that the persistence of high SWLs to 2021 was due to a third major recharge event that occurred in winter 2018-2019 (4" winter rain in Tucson, extended base flow in HSC upstream of the Fish Barrier).

7. The very high SWL at the HSCW well in 2017 is probably spurious. It is unlikely that the HSC aquifer could fill to such an extent and empty again in so short a time. There may have been a data transcription error, or possibly leakage of surface water into the well from the surface.
8. The SWL trends at the U and HSCW wells in 2015-2021 suggest that SWL would rise in HSC if more frequent major recharge events were to occur. Between 1993 and 2015, 5 or 6 such events are recorded in the SWL data, or about one every four years. Between 2015 and 2021, three are recorded, an average of about one every 2 years.
9. The SWL peaks in 2007-2009 follow two wet winters in southern Arizona (in Tucson, 7.7" in winter 2004-2005, and 6" in 2006-2007). It is more difficult to look for relationships with summer monsoon intensity because rain amounts commonly vary greatly from place to place, and we don't have rainfall data for HSC catchment itself. Isotope data for Cascabel indicate that about-equal amounts of summer and winter rain contribute to recharge on average (see Eastoe and Towne, 2018, for an explanation).

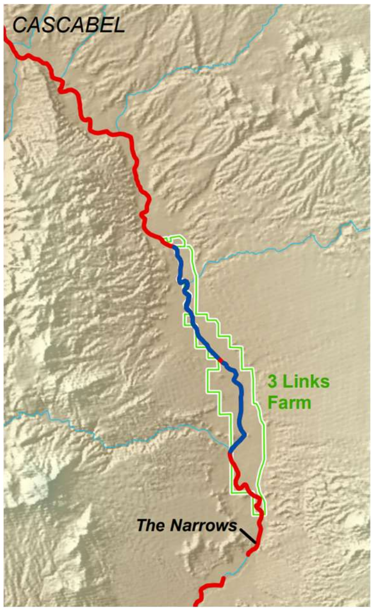
D. WET/DRY MAPPING OF PERENNIAL SURFACE WATER

Observations were made at the summer solstice, which is the time of year when flow in the river is most likely to be base flow, i.e. groundwater discharging into the river, rather than runoff from rain events or a combination of runoff and groundwater. Reaches with flowing water were mapped if they exceeded 30 feet in length.

THREE LINKS FARM



2007 2008 2009



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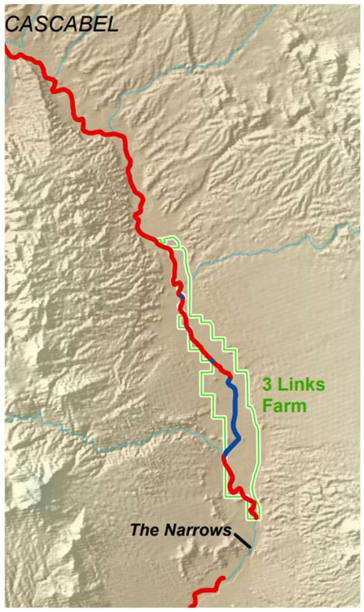

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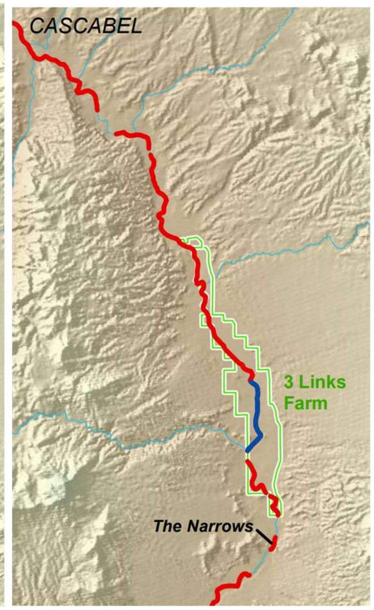

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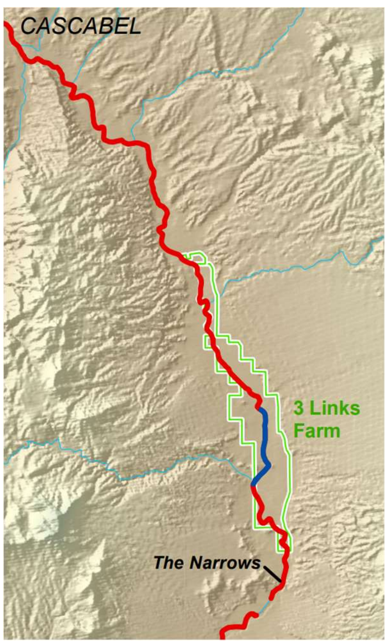

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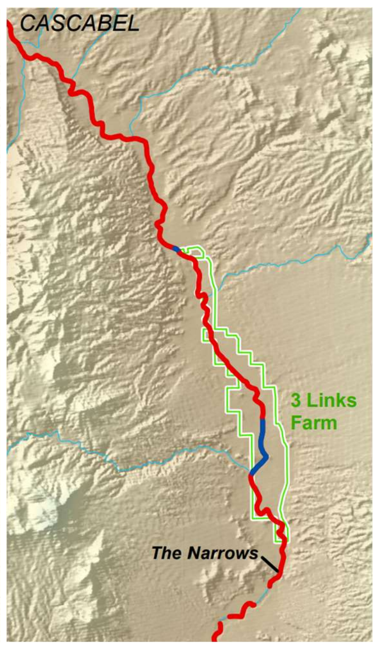

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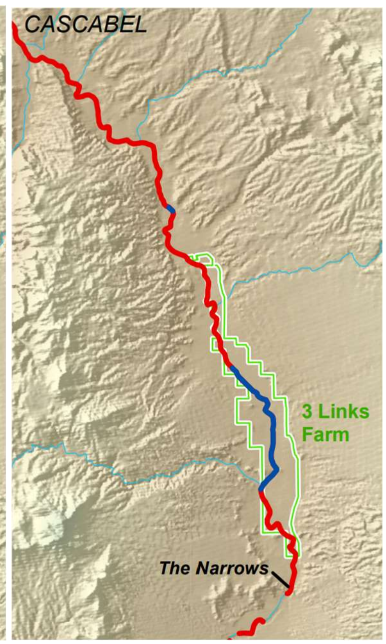
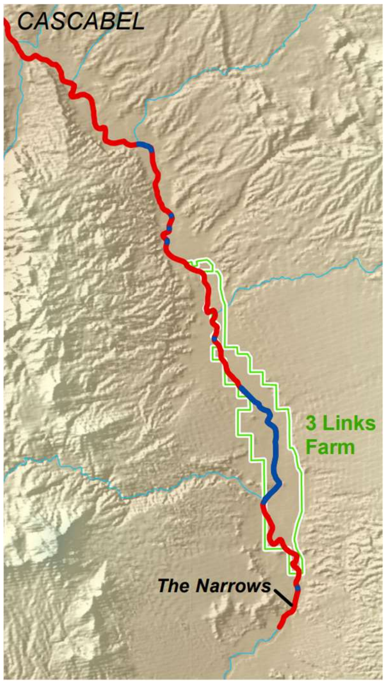


2015



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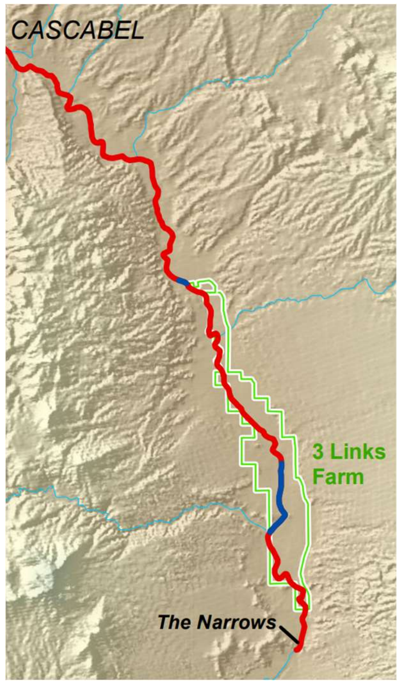

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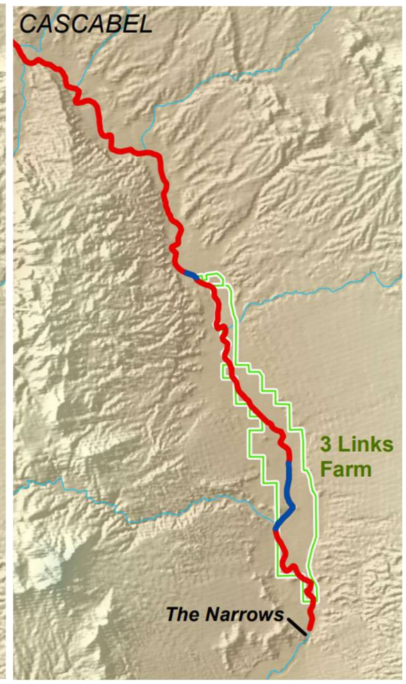

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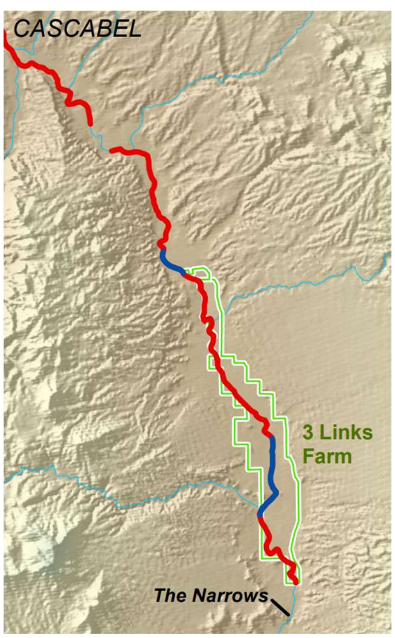
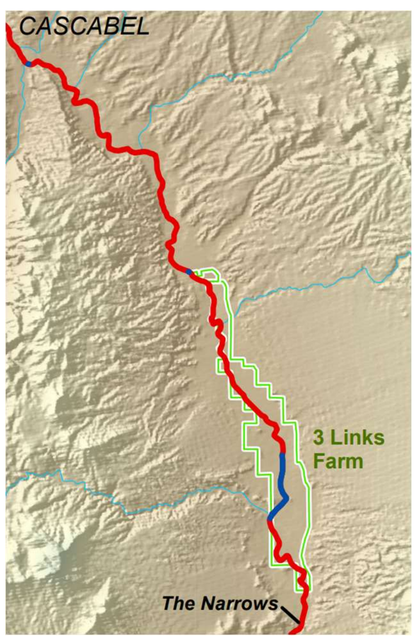
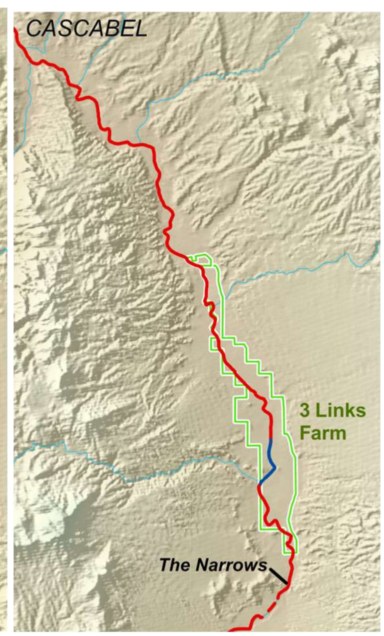


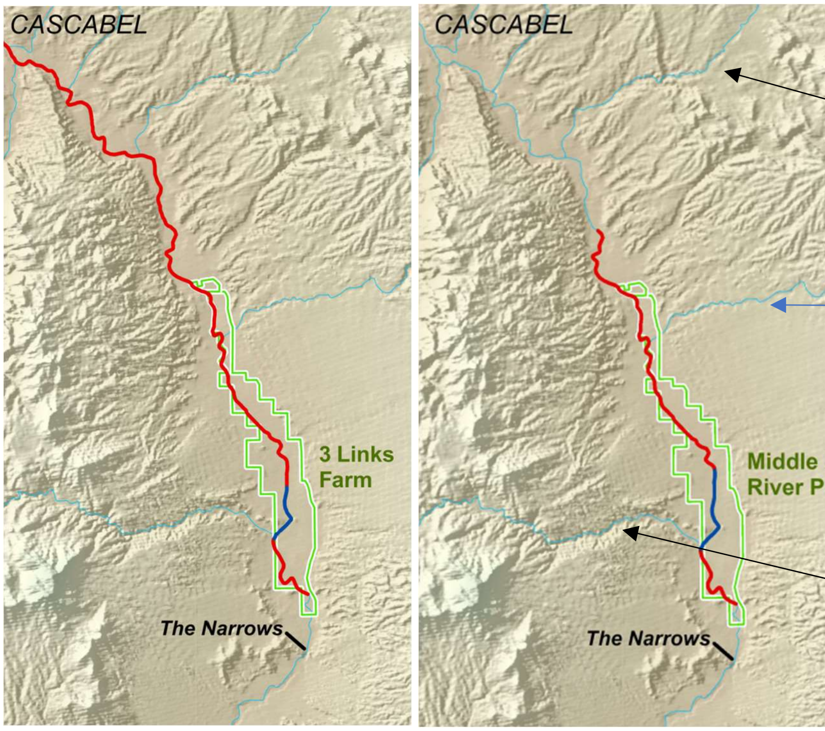
2019



2020



2021



Teran Wash

Palomas Wash

Red Rock Creek

>4” winter rain in Tucson

<2.5 “ winter rain in Tucson

2022 2023

Observations

1. The perennial reach of the river at Three Links Farm invariably begins at the confluence with Red Rock Creek.
2. The length of the perennial has decreased between 2007 and 2023. There are years when the length increased, but the overall trend is a decrease in length.
3. There is no simple, short-term relationship between wet winters and years when the perennial reach increases in length. The data for wet winters are for Tucson, and probably relate directly to wet winters on the Rincon Mountain block that is the source of water for the Red Rock watershed. The wet winter in 2015 was succeeded by two years in which the length increased, but no such effect was observed following wet winters in 2012 and 2019+2020. It is more difficult to relate base flow to preceding wet monsoon years, because of the irregular distribution of monsoon rain.
4. The increase in length of the perennial reach in 2015 also followed heavy rain and a major flood associated with Hurricane Odile in September 2014.
5. In the reaches downstream of Three Links Farm, base flow has been present at a variety of locations, but not every year.
6. At the Benson Narrows, mapping is incomplete. Surface water was last seen in 2016.

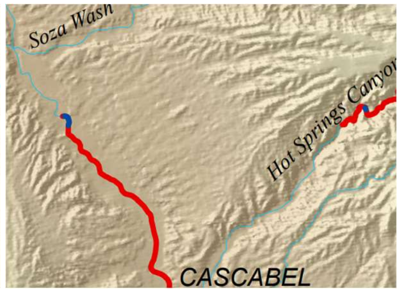
Discussion:

1. Isotope data confirm that the base flow (groundwater emerging at the surface) at Three Links Farm contains little recent rainwater. The isotope composition of the base flow is remarkably consistent over several years (see Eastoe and Clark, 2018).
2. The source for the base flow is most likely the Red Rock watershed, where surface water consistently appears in the San Pedro riverbed. Red Rock watershed appears to contain a groundwater storage capable of retaining groundwater for many decades, and possibly much longer. A little water has been added to the storage from rainfall since 1953 (see Eastoe and Clark, 2018), but discharge from the storage has decreased greatly since 2007. All of this suggests a groundwater reservoir that is gradually emptying. The reason for declining discharge might be the drought of the 1950s, or longer-term drying since the wetter centuries of the Little Ice Age, approximately AD 1400-1800 (see Eastoe, 2020). The perennial reach is in decline at decadal time scale, probably because of natural climate change, and despite the retirement of irrigation at Three Links Farm.
3. Between Three Links Farm and Paige Creek, the sporadic presence of water could be associated with damming of the river channel by sediments deposited from Paige Creek (2020) and Teran Wash (2016). In other areas, the surface water is close to irrigated fields and may have been irrigation reflux.
4. Little or no water discharges from the sub-basin upstream of the hard rock barrier at the Benson Narrows into the Cascabel sub-basin. In 2008 and 2016, the presence of surface water might be related to wet winters 1-2 years before. The general lack of surface water at the Narrows (in the parts that have been mapped) indicates no continuous discharge from the sub-basin upstream, and is consistent with the USGS determination that ground water withdrawals, natural and human, from the Benson sub-basin have exceeded recharge for many decades (Cordova et al., 2015). The inconsistency of data collection for this part of the river bed precludes firm conclusions based on observation rather than modeling.

SAN PEDRO RIVER NEAR GAMEZ ROAD

2007 2008 2009

2010



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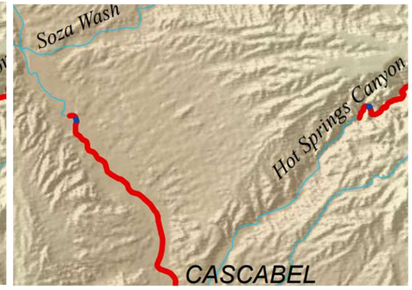

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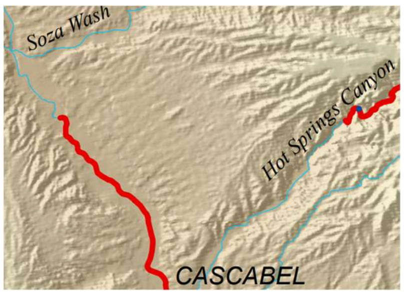

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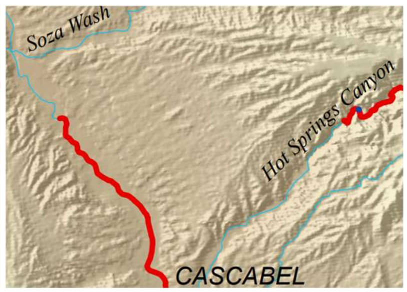

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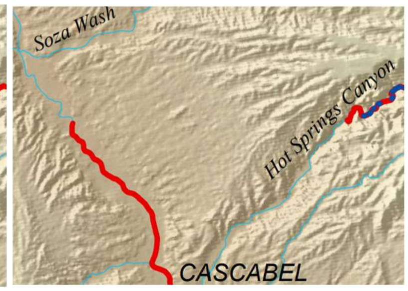
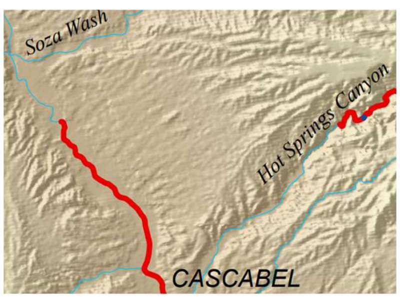
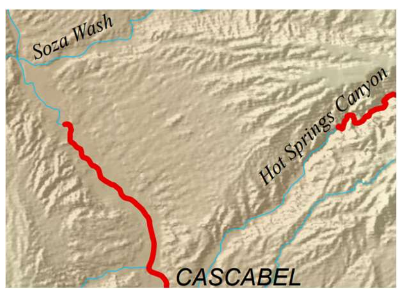


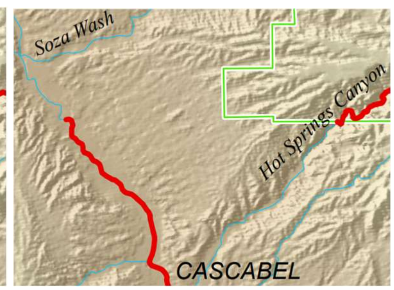
2015



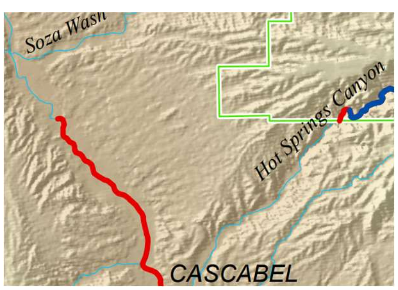
2016



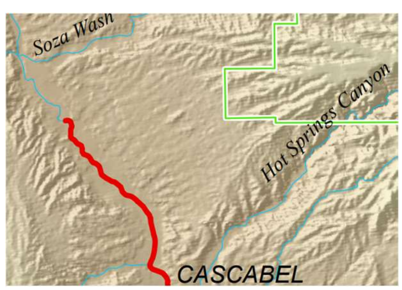
2017



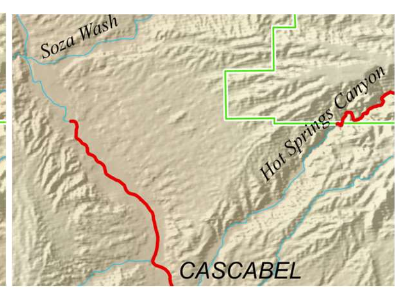
2018



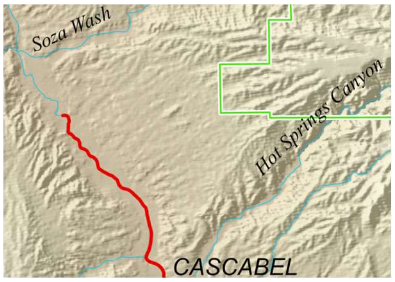
2019

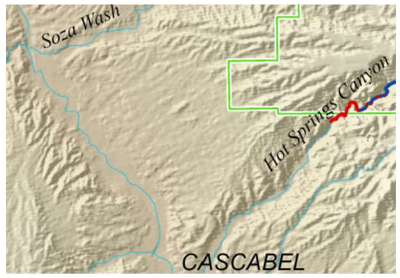


2020



2021





2022 2023 not mapped

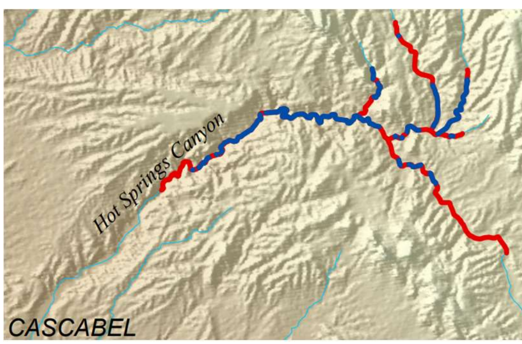
Observation

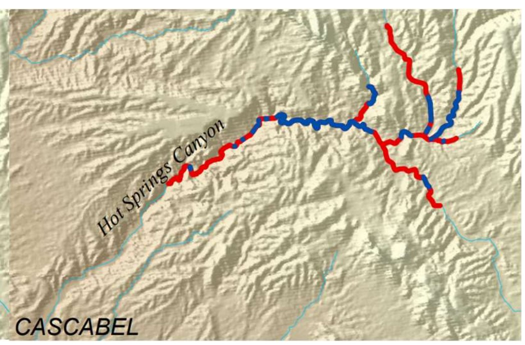
The perennial water feature shrank to less than 30 feet by 2012 and remained insignificant or absent thereafter. It continues to be present at other times of the year.

Discussion

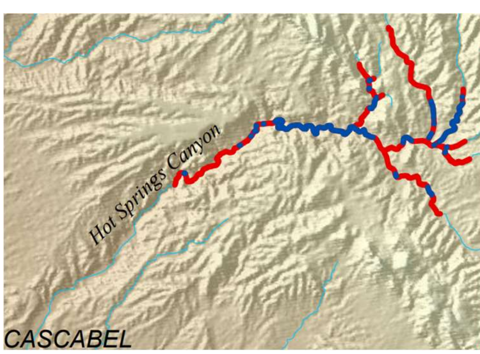
The observation is consistent with declining SWL at the HR well (see above).

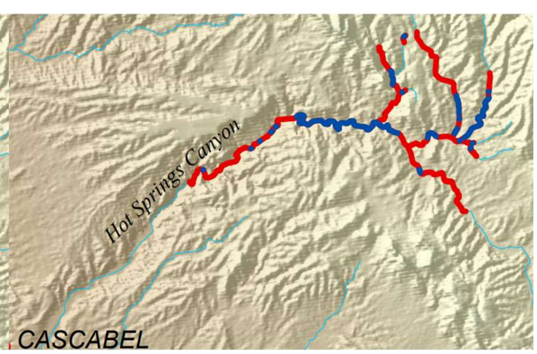
HOT SPRINGS CANYON ABOVE THE FISH BARRIER



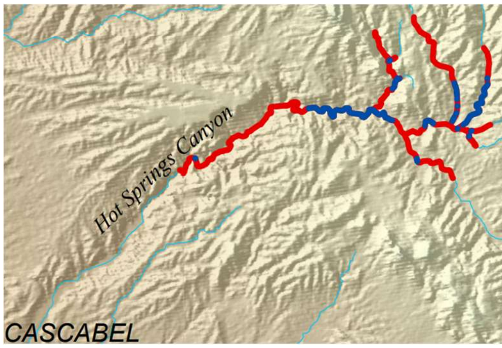


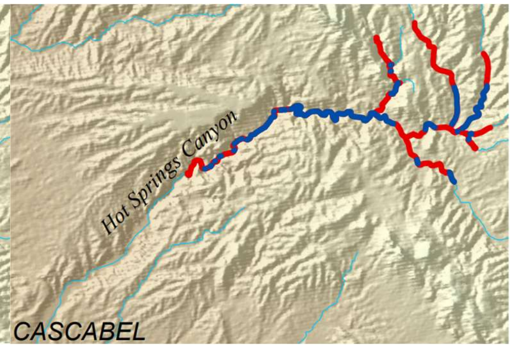
2010 2011





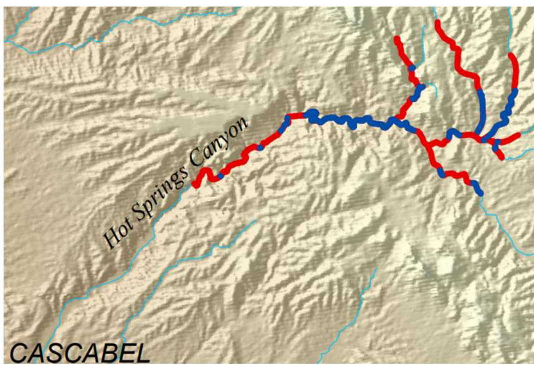
2012 2013

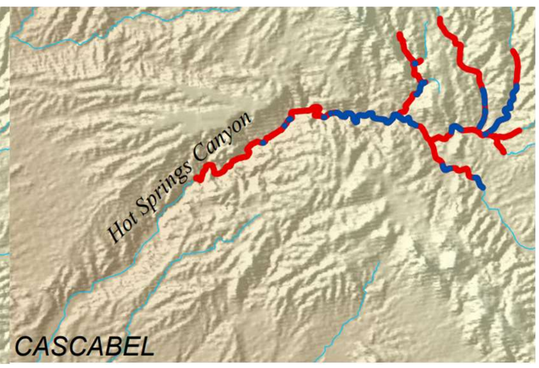




2014

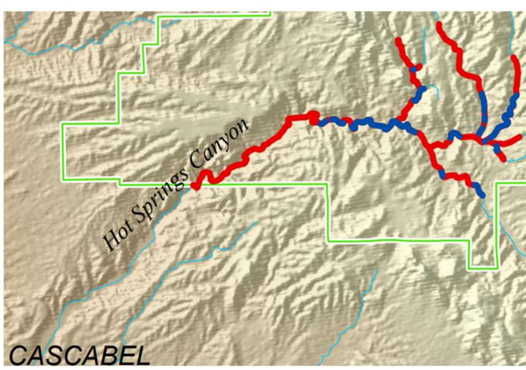
2015

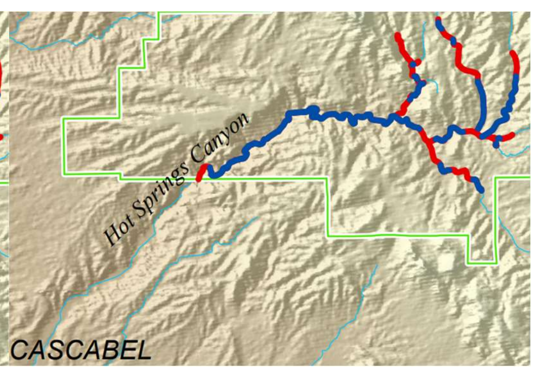




2016

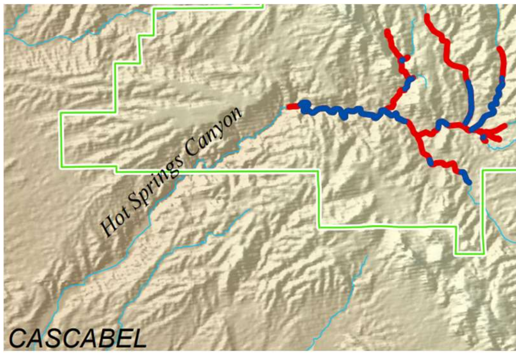
2017

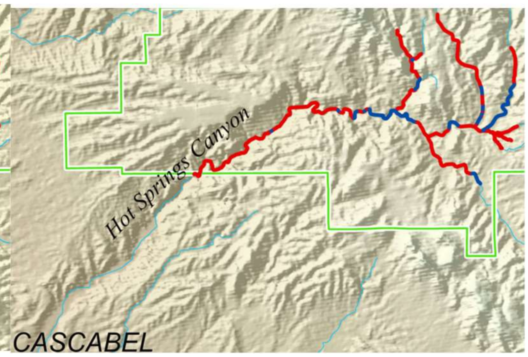




2018

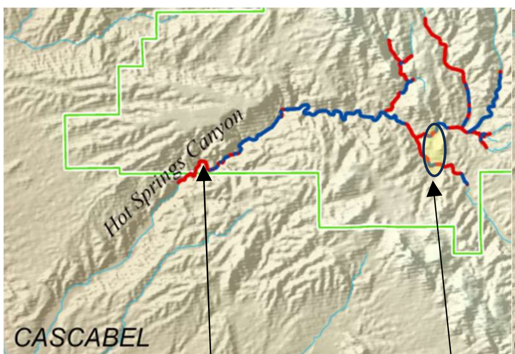
2019

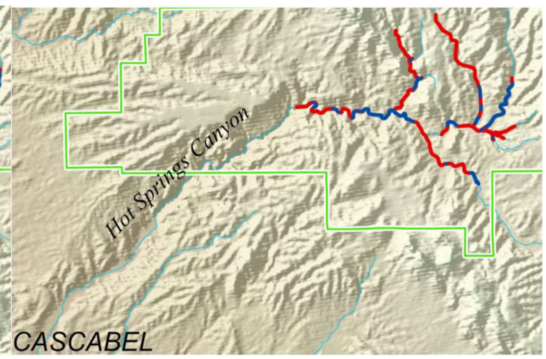




2020

2021





2022

2023

>4" winter rain in Tucson

<2.5 " winter rain in Tucson

Fish barrier

Hot springs

Observations

1. Base flow at the solstice occurs over varying lengths of the hard-rock channel upstream of the fish barrier. The lengths appear to increase in summers succeeding wet winters in Tucson.
2. Base flow was present at the fish barrier in several years prior to 2015, but has been absent at the fish barrier from 2015 onwards (no observation was made in 2020).

Discussion

The fish barrier is a concrete structure sitting on solid rock. Any water flowing in stream-bed sediments should therefore be forced to the surface at the fish barrier. The paucity of June solstice base flow at the fish barrier since summer 2015 therefore suggests that the watershed upstream of the fish barrier is drying out, and groundwater supply in that area is declining.

E. SURFACE WATER FLOW AT THE FISH BARRIER IN HOT SPRINGS CANYON

The following table lists all available measurements.

Date	Observer	Cfs	Gal/sec	2se relative error*		Gal/yr	
5/15/2017	CJE		0.15	5.6%		4733640	
2/12/2018	ABW	2.09	15.67			494356557	
5/15/2018	ABW	0.08	0.57			17942262.8	
7/7/2018	ABW	0.00	0.00			0	
3/25/2019	ABW	6.71	50.22			1584821189	
6/29/2019	ABW	0.00	0.00			0	
Notes:	* This is twice the standard error of the mean of 6 separate measurements,						
		expressed as a percentage of the mean.					
	Standard error = standard deviation of the mean divided by the square root						
		of the number of measurements.					
	ABW = Alex Binford Walsh			CJE = Chris Eastoe			

Observations

1. No base flow is present at times close to the solstice in 2018 and 2019.
2. At other times, the amount of surface water varies by a factor of 330. The highest measurement, in March 2019, followed a wet winter.

Discussion

1. The high measurement probably reflects runoff in addition to base flow. At this time, water was reaching the HSC aquifer, as indicated by static water levels in the HSCW and U wells (see above).
2. At other times, it is uncertain how much water reaches the HSC aquifer. Surface flow is present at cooler times of the year (e.g. November 2022, when flow extended about half way to the Yellow Cliffs). Much of the water is lost to transpiration, because riparian trees line the channel for half a mile below the fish barrier.

F. CAUSES OF GROUNDWATER DECLINE – HUMAN OR NATURAL?

Declines in the static water level and amount of groundwater discharge at Three Links Farm and in Hot Springs Canyon appear to be the result of natural climate change, because they are taking place in areas with little pumping of groundwater. The Nature Conservancy retired most irrigation wells at the Three Links Farm in 2002, yet the length of the perennial reach of the river at the farm has diminished over subsequent years. In Hot Springs Canyon, there is no pumping upstream of the HSCW well, and little pumping upstream of the U well.

The inland southwestern part of North America from Chihuahua to southern California has dried since the Little Ice Age, a period of wetter climate between about AD 1400 and 1800. Evidence in the scientific literature for the wet climate and subsequent drying is discussed in Eastoe (2020, p. 475-476). In the area of Cascabel, the Native American village thought to be Baicatcán was built near Hot Springs Wash, presumably near a source of fresh water in the wash. The village was occupied until the late 1700s. Did the surface water supply vanish at the time that the village was abandoned?   Drying since the Little Ice Age would constitute climate change at multi-century scale. In addition, there are shorter cycles of climate change. In southern Arizona the transitions from drought (1950s) to wetter climate (1980s) to drought again (since about 1998) constitute a climate cycle at multi-decade scale. It is possible that both cycles are interacting at present to cause the decline in groundwater supply for which evidence has been presented here. The shorter-term cycle is important, as indicated by SWL observations in HSC, where it appears that SWL would increase again if the frequency of large recharge events were to double. Large recharge events did become more frequent between 2015 and 2021, but may be less frequent since 2021.

Pumping of groundwater is exacerbating the decline of groundwater where irrigation is practiced. In both wells where SWLs have been documented near irrigated land, the declines are relatively small, 10 feet or less. Nonetheless, there is reason for concern. Groundwater may take decades to flow from source areas to irrigated areas. Eastoe and Clark (2018) estimated that water from HSC upstream of Cascabel Road takes at least 70 years to reach Gamez Road. The complete effects of present-day drought may not become apparent in irrigated areas for decades to come, but they will eventually appear.

G. REFERENCES CITED

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Wet/dry mapping maps are available at:
https://azconservation.org/publication/san_pedro_wet_dry_mapping/