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Linking Science and Policy Through an Adaptive Management Approach: The San Pedro River

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LOW FLOWS IN THE UPPER SAN PEDRO RIVER, ARIZONA: RECENT TRENDS AND POSSIBLE CAUSES

Summary of the Issue by the Upper San Pedro Partnership Technical Committee

June, 2008

Introduction:

A Technical Committee was established by the Upper San Pedro Partnership (USPP) in 2000 to provide technical reviews and advice to the USPP, and to assist in getting technically correct information to the public. Many of the presentations, reports and modeling efforts produced by this Committee over the past decade are available online at: usppartnership.com.

The first ever observation of zero flow in the San Pedro River at the U.S. Geological Survey's Charleston streamflow-gaging station on July 6, 2005 inspired much public and scientific interest in understanding the causes of this event. The persistence of baseflows at this stream gage within the San Pedro Riparian National Conservation Area, managed by the U.S. Bureau of Land Management, had long been considered a "key indicator" of the river's health. This paper provides a summary of the issues and contributing factors associated with this hydrologic event. It was developed by the broad membership of the USPP Technical Committee, including hydrologists, engineers, ecologists and other scientists who worked together to reach a common understanding of this complex issue.

Background:

It was impossible to conclude that something has fundamentally changed in the aquifer-supported stream system with one event, but since that time the yearly low flows (typically in late June or early July, just before the monsoon onset) have continued to be very low (less than 0.5 cfs) when historical averages have been around 2.5 cfs. The short-term loss of measurable flow is not synonymous with the river bed becoming dry, but it does highlight the continuing reduction in base flow that has been ongoing at that location for decades.

In 2006, after one of the driest winter and springs on record, it was no surprise to see very low flows (0.01 cfs) return again in June. Of increasing concern was the return of very low flows (0.06 cfs) in June 2007 following winter and early spring flows, which were elevated by around 5 cfs from the previous years. Very low flows occurred occasionally during the 1900s (Table 1), but the recent string of very low flows in 2005-2007 is unprecedented in the nearly 100 year record of the Charleston gage (Figure 1). It is important to note, however, that while flows at the Charleston gaging station are the most closely watched along the entire river length, the variability in the Charleston record is likely related to changes that primarily affect the river reach immediately upstream.

1911-20	0
1921-30	1
1931-40	0
1941-50	0
1951-60	0
1961-70	6
1971-80	2
1981-90	25
1991-2000	101
2001-07	142

Table 1. Number of days with mean daily flow below 1 cfs at the USGS Charleston gage.

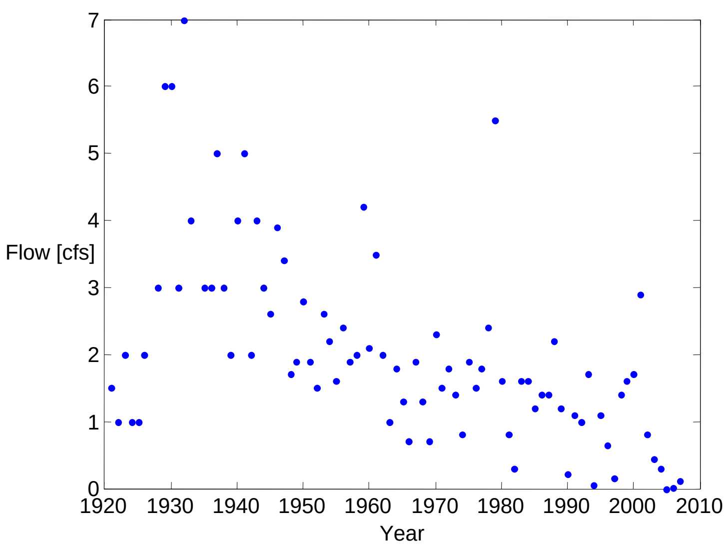

Figure 1. 1920-2007 May-July minimum daily average flow at the Charleston gage.

Below we review what we know about the potential causes for this near-zero flow condition at the Charleston gage, which include near-river pumping, regional pumping, drought conditions, upland vegetation change and riparian vegetation change. The framework for this overview is to use only published sources of analysis or to clearly present the data if they have not been published. For more information on the management activities of the Upper San Pedro Partnership (USPP) member agencies that address some of these concerns, please see http://www.usppartnership.com/.

A. Near-river pumping

In this section we focus on the known effects of near-river pumping due mainly to agricultural use. Near-river pumping withdraws water from the alluvial aquifer or from the regional aquifer immediately below or next to the alluvial aquifer and can have relatively fast (hours to weeks) impact on water levels in the stream alluvium and consequently on streamflow.

Though in decline over the past several decades, near-river pumping for agricultural use has affected flow in the San Pedro River (Pool and Dickinson, 2007). The impacts of agricultural pumping in the area around Palominas and the US-Mexico border have been particularly evident in this reach of the river, which historically had perennial flow but now has intermittent flow. In this area, changes in the hydraulic gradient tell us that in recent decades only a portion of the water that used to flow from the aquifer to the river still does (Pool and Dickinson, 2007; Pool and Coes, 1999). Since the 1940s, winter flows at Palominas have decreased by more than 50 percent, which has likely translated into decreased downstream flows at the Charleston gage.

When considering the contribution of near-river pumping to the recent very low flows at the Charleston gage, one must consider how near-river pumping has changed with time. As previously mentioned, pumping for agricultural use has been in decline for the past several decades. ADWR (2005) reported a peak agricultural demand of 5900 ac-ft/yr in 1985 for the Sierra Vista Subwatershed that decreased by 62% to about 2500 ac-ft/yr by 2002. The retirement of agricultural pumping through the creation of the SPRNCA in 1988 and subsequent purchases of conservation easements in the 1990's resulted in the retirement of approximately 1300 acres of irrigated land. Fort Huachuca in partnership with the Bureau of Land Management and The Nature Conservancy has purchased conservation easements in the 2000's that have resulted in a 1140 ac-ft/year reduction in near-stream pumping in the area around Palominas. Additionally, cessation of some agricultural pumping has been observed unrelated to these measures. One such operation which ceased pumping around 2005 was estimated to have pumped approximately 1700 ac-ft/year to produce alfalfa (ADWR 2005).

The beneficial effects of this retired pumping are observable in wells in this area and there is some evidence that flow is occurring more often around Palominas (Figure 2). This indicates that some of the lost base flow has been and will be restored around Palominas which might ultimately translate to increased base flows further downstream.

This trend of decreased near-river pumping for agricultural uses is out of phase with the recent trend of near-zero flows at the Charleston gage. There has been, however, significant residential development in rural portions of the watershed, some of which has occurred relatively near (< ~ 1 mile) the river. This increased residential development, with its associated groundwater pumping that is not monitored or quantified, will continue to have unknown impacts on streamflow.

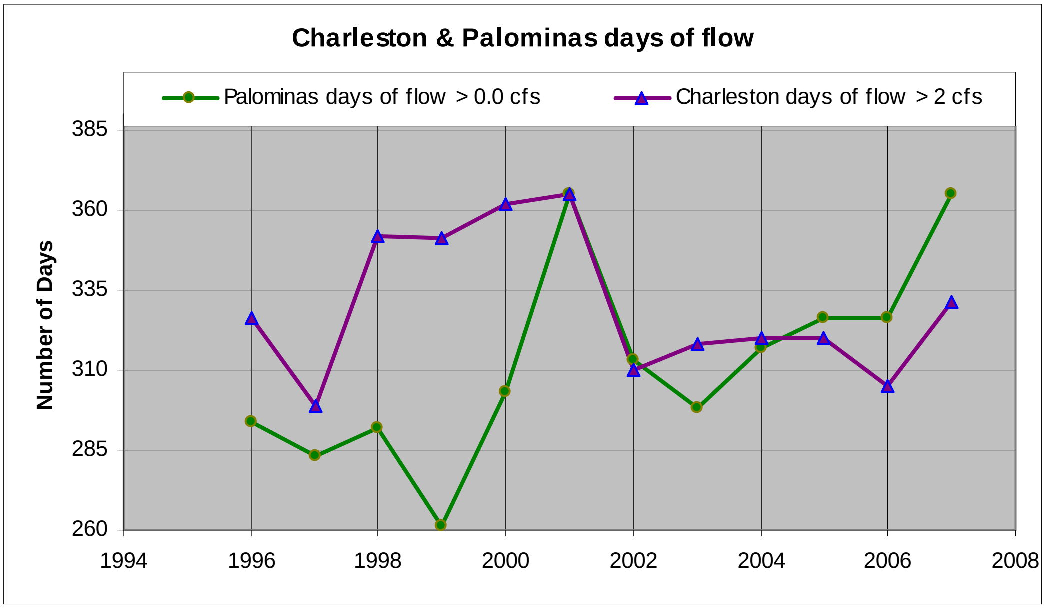

Figure 2. Number of days in a year with the flow at Palominas exceeding 0 cfs and at Charleston with flow exceeding 2 cfs.

B. Regional pumping

In order to directly assess the impact of pumping from the regional aquifer on flows in the San Pedro River at the Charleston gage, one must determine the change in hydraulic gradient between the pumping centers and the river upstream of the Charleston gage. To do this, one would need a series of wells installed along transects oriented parallel to the direction of regional groundwater flow between the river and regional aquifer pumping centers. By measuring groundwater levels along these transects, one can calculate the change in hydraulic gradient and combine it with information about the aquifer properties to compute the flux of groundwater between the pumping centers and the river. Unfortunately, there are very few long-term records of groundwater levels that would allow such a calculation. Fort Huachuca has been monitoring groundwater levels along a transect between its production wells and the river for the last 13 years. The hydraulic gradient between the closest monitoring well (about 1 mile to the southwest) and the river at Charleston has decreased by about 4 % from 1995-2007, suggesting that 96 % of the water that used to flow from the aquifer to the river in that area prior to the past decade still does.

As an alternative to groundwater data, the streamflow record at the Charleston gage has been used to estimate trends in groundwater contribution to the river's base flow. Under pre-development conditions, winter base flow at the Charleston gage was approximately equal to natural recharge. Assuming that natural recharge has not changed significantly, changes in winter (i.e., non-growing season) base flow would then primarily reflect withdrawals from the groundwater system by regional pumping. Observed declining trends in base flow indicate that significant reductions have occurred during the growing season (Apr-Oct), but such reductions in base flow have not occurred during the non-growing season (Thomas and Pool, 2006; see Figure 3 for example). Regional pumping is expected to have a year-round and non-seasonal influence on the river flows (Thomas and Pool, 2006). Because there is no long-term trend in winter base flows, regional pumping is not necessarily a cause of the recent near-zero flow events.

Winter base flows are not entirely a function of discharge from the regional groundwater system as is apparent from the streamflow record for 2000-2001 (Figure 3). During this period, base flow remained elevated for months after an unusually wet October of 2000. This phenomenon occurs when runoff enters alluvial material near the stream channel during high streamflow and, over a period of hours to months, drains back into the channel upon flow subsidence. Thomas and Pool (2006) evaluated the effects of bank storage on streamflow and found that there is a significant correlation between winter and spring total flows and the five previous months of flows. The authors noted that the decreasing trend in summer total flows could be contributing to the decreasing trends in fall and early winter flows since decreasing summer flows would lead to less bank storage.

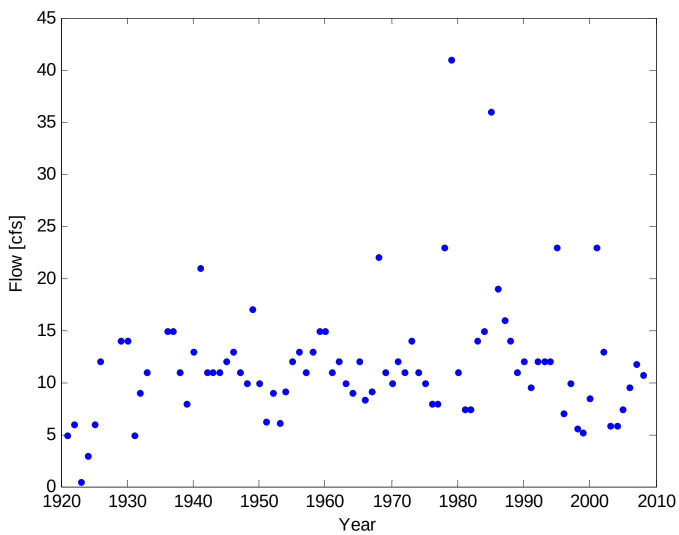

Figure 3. 1920-2008 January - March minimum daily average flow at the Charleston gage.

Nevertheless it is important to state that all pumping in the basin (historical and current) will eventually capture/reduce water to both riparian vegetation and base flow. Groundwater budgets from calibrated groundwater models (e.g., by the USGS) do indicate that net discharge from the basin groundwater system (i.e., the sum of net base flow plus riparian vegetation water use) was reduced by about 30% from 1930's to 2003 due to capture of base flow from pumping and increases in riparian vegetation water use (Pool and Dickinson, 2007), but the specific locations of this capture have not been determined. There are numerous examples of riparian systems that have been degraded or eliminated due to regional groundwater pumping in Arizona, Mexico and throughout the Southwest. Thus, it is important to reduce groundwater pumping in the basin where groundwater pumping will have the most direct and immediate effects on the riparian ecosystem.

C. Drought Conditions

Southeastern Arizona has been in a period of below average rainfall from about 1996 to present (Figure 4) with only 2000 being above average, and this has led to drought conditions over many parts of the basin for much of this period. Below-average rainfall leads to reduced storm runoff in the river which decreases alluvial aquifer recharge and storage (Leenhouts et al. 2006). Thus, a protracted drought is expected to lead to a depleted alluvial aquifer and decreased base flow, but this is contrary to the recent rising water level trends observed near the river in the Palominas and Hereford area. Drought conditions also affect mountain precipitation, which is the most important source of recharge for the regional aquifer, but it would likely take millennia to see a decrease in groundwater flow to the river due to decreased mountain front recharge (Wahi et al. 2008).

The most extensive review of the long-term effect of precipitation on base flows at Charleston comes from Thomas and Pool (2006). Analyzing the period of 1913 to 2002, annual precipitation in the valley decreased by about 13 percent at Tombstone. However, over this same period total annual streamflow at Charleston decreased by 66 percent. Winter precipitation and streamflow changed by a small amount, but summer precipitation decreased by 26 percent, and summer streamflow decreased by 85 percent. Removing this trend in precipitation from the trend in streamflow, they concluded that factors other than precipitation caused statistically significant trends in total and low flows for summer through early winter and did not cause significant trends for winter through spring. Thus, a seasonal pattern was determined with significant trends coinciding with the growing season, and no significant trends in late winter and early spring (non-growing season).

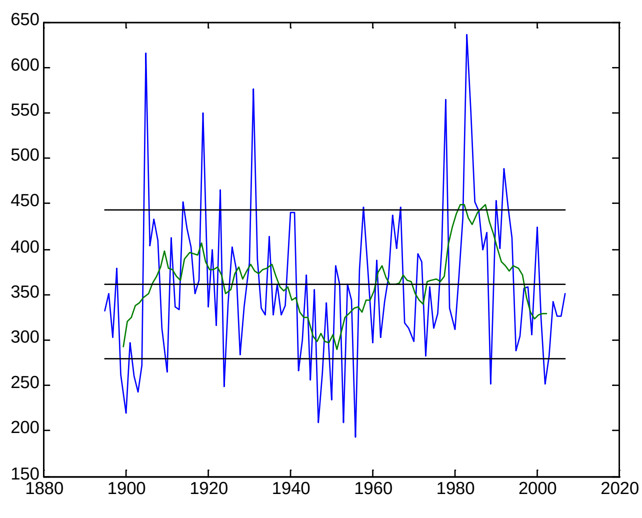

Figure 4. Average annual precipitation for southeastern Arizona (climate division 7). 10-yr running mean and +/- 1 standard error (sigma) for SE Arizona also shown. Western Region Climate Center (http://www.wrcc.dri.edu/)

Drought conditions even longer and more severe than the recent decade have occurred in the basin (e.g., 1950's, Figure 4). While these other dry periods did have pre-monsoon daily average flows as low as 0.9 cfs at Charleston (Figure 1), the summer flows in the river were not as low as the last three years. Likewise, it is unlikely that the below-average precipitation in the valley was entirely responsible for the string of near-zero flows in 2005-2007 as winter low flows (Figure 3) were recovering from the worst of the recent drought in 2003 and 2004.

D. Upland vegetation change

Upland vegetation cover across much of the valley has changed significantly over the last 100 years. Urbanization (roads, buildings, landscaping) has impacted some of the basin, while much of the desert grassland that once dominated the valley floor has been encroached upon by woody vegetation (mesquite, creosote, and other shrubs) (Kepner et al. 2000). Urbanization on the valley floor is expected to increase storm runoff by increasing the amount of impervious surfaces, while impacts of woody plant encroachment on runoff are uncertain. For the period of record, total flows in the river, of which storm runoff is a large part, have decreased (Thomas and Pool, 2006). Recent work by Goodrich et al. (2008) shows that storm runoff from a major ephemeral San Pedro tributary, Walnut Gulch, decreased in almost the same percentage as storm runoff at Charleston for 1966 through 1998 period. From this they state, "the similarity in these percentages suggests that the decrease in summer flows in the San Pedro might be the result of the decreasing ephemeral tributary inflow." While storm flow reduction is different from base flow reduction, the large decrease in total flow at the Charleston gage (74% from 1966 to 1998), the majority of which is storm flow, would result in significantly less near-stream aquifer recharge, which has been shown to be a significant component of subsequent base flow (Baillie et al. 2007).

E. Riparian vegetation change

Earliest accounts of the river from the late 1800's indicate that the water tables were shallow and vegetation along the river was much more marshy with fewer cottonwood and mesquite trees. During the late 1890's there was a period of very large floods and the river began to down cut its banks with almost the entire reach of the Upper San Pedro River entrenched by 1920 (Huckleberry, 1996). Much of the type of riparian forest of the post-entrenchment channel seen today did not develop until after the late 1930's (Hereford, 1993). From entrenchment (late 1800's) until at least the late 1930's, the entrenched channel lacked a significant density of riparian trees. Conditions for the forest improved after the 1930's when the entrenchment had stabilized in width and provided space on relatively stable surfaces for the expansion of the riparian forest.

Since the SPRNCA was established in 1988 the traditional ranching and farming (and its associated irrigation) that used to occur along the river banks has nearly ceased. Since then the riparian vegetation has flourished, which has greatly improved the habitat for many organisms. It should be noted that the 1980s into the early 1990s was one of the wettest periods on record (Figure 4), which likely enhanced some types of riparian vegetation growth. Some of these changes in riparian vegetation condition and cover may have led to changes in riparian vegetation water use, but determining the direction and magnitude of this change is difficult. This is because: 1) we do not have accurate records yet to assess the changes that have occurred in riparian cover (a joint SAHRA/ASU study is currently taking place), and 2) it is often hard to predict the change in water use when you replace one type of cover (e.g. an open sandbar along the river with grazed grasses and shrubs) with another (e.g. a cottonwood forest). For example, the evaporation from the partially-shaded river exceeds, and the water use of a common tree-shaded shrub nearly equals, cottonwood use along a perennial portion of the San Pedro (Scott et al. 2006). The understory evaporation from the shrubs or river would be even higher without the tree shading.

In spite of these difficulties, there is significant circumstantial evidence that does implicate vegetation change (i.e., riparian vegetation thickening) as a factor for seasonal base flow declines. Thomas and Pool (2006) suggested that changes in vegetation were likely major factors in the decreasing trends in total stream flows and low flows. The significant trends in base flow coincide with periods that have high rates of transpiration from vegetation in the summer, and the non-significant trends coincide with the periods of low rates of transpiration in the winter. Yet, it is important to keep in mind that correlation with trends (e.g., vegetation growth with streamflow declines) does not necessarily imply causation. A number of other studies indicate that the amount of green riparian vegetation has increased over the last 30 years (Krueper et al. 2003, Jones et al. 2008) but we do not know how the relative proportions of the different riparian ecosystems have changed. Initially, the increase in riparian greenness beginning in the 1980's was probably due to the restoration of the riparian forest gallery. Over the last 10-15 years the total vegetative mass of this forest has probably stabilized or even decreased due to wildfire loss and the introduction of beavers (Stromberg et al. 2006) On the other hand, several photographic records have shown that mesquite populations along the alluvial terraces have increased dramatically (Turner et al. 2003). The mesquite vegetation type represents the single biggest vegetation use of groundwater along the San Pedro (Scott et al. 2006). The expansion of mesquite along the old alluvial terraces effectively expands the lateral extent of groundwater-using vegetation near the river and increases total groundwater use.

Changes in the amount and composition of riparian vegetation through time could cause changes in base flow. Low flows in June have declined by about 2 cfs over the last 80 years (Figure 1) whereas estimates indicate that current riparian groundwater use along the San Pedro from the border to the Tombstone gage represents about 8200 ac-ft/yr (Scott et al. 2006). In 2003, there were about 2100 acres of mesquite on the alluvial terraces that used around 2.3 ft/yr of groundwater, resulting in 4700 ac-ft/yr of consumptive use. The 920 acres of cottonwood/willow forest along this portion of river uses around 1.3 – 3.2 ft/yr of groundwater, resulting in about 2400 ac-ft/yr (Scott et al. 2006), or approximately half the total consumptive water use of mesquite. Mesquite shrub lands are now a target for vegetation management programs using prescribed fire and other techniques. The total groundwater evaporated from sacaton grasslands and the river was considerably less due to the much smaller area that they occupied.

Concluding remarks:

The recent string of very low flows in early summer in the San Pedro River at the Charleston gage are likely related to changes that have occurred in the immediate upstream river reach. Recent increases in flow at the Palominas gaging station indicate more water is entering the upstream reaches, while relatively constant groundwater depths and streamflows near Lewis Springs indicate that the gaining reach has not been depleted there. Less flow, however, is reaching Charleston in early summer, as evidenced by the decreasing trends in summer flows (Figure 1) for the entire period of record as well as the lack of trends in the winter low flows (Figure 3). Historical and current groundwater pumping in the Upper San Pedro Basin may have already and will ultimately capture base flow and impact the river and its habitat. However, it does not seem that pumping in the basin was the main reason for the recent string of very low flows at Charleston. Groundwater pumping near the river (at least in the form of large production wells for agriculture) has decreased in recent decades, and statistically significant decreasing trends in low flows only occur during the growing season months, not year round, implying that regional pumping has yet to appreciably impact the flows at Charleston.

Over the last decade or so, below average rainfall has occurred in the basin. These drought conditions have improved somewhat in the last two years. Total streamflow in the San Pedro, which is dominated by storm runoff, has decreased through time and the below-average rainfall, especially in winter and spring, in the last ten years has further decreased storm runoff. Storm runoff is an important contributor to alluvial aquifer recharge and helps to elevate and sustain alluvial aquifer water levels and base flow. Thus, the cumulative reduction in storm runoff associated with the recent drought has probably helped to contribute to the very low base flows conditions observed at Charleston in the pre-monsoon period of 2005, 2006, and 2007.

In addition to the recent drought, it is likely that vegetation change has played a role in the decreasing trend and recent near-zero flows. Total runoff, again the bulk of which is comprised of storm flow, was decreasing in the basin even before the severe drought years of 2002-2005, but only a part of this reduced runoff was due to decreases in rainfall (Thomas and Pool, 2006). A number of recent studies have indicated that there has been an increase over the last 30 to 60 years in the amount of riparian forest, replacing what in many areas were streamside marshlands. Therefore, the synergistic effects of drought, groundwater pumping, riparian vegetation change, urbanization, and changes in upland vegetation types have all likely played a role in current low flow conditions.

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