San Pedro Wet/Dry Data Scoping and Prospectus

Jessie Pearl

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The importance of healthy desert rivers to the surrounding ecosystems and communities cannot be overstated. The San Pedro River, which flows northward from Sonora, Mexico through southern Arizona is the last major undammed river in the American southwest, and a critical water supply for the surrounding communities. In 1999, The Nature Conservancy began monitoring San Pedro River surface water presence through "wet/dry" mapping during the dry season each year: recording where along the has surface water in that particular year. The San Pedro wet/dry data set continues to evolve, with the incorporation of new tributaries, and different stretches of the river mapped each year. Despite the dynamic nature of the dataset, there remain important trends and patterns in presence of water along the river. There have been various efforts to determine the leading causes of wetness along the river, and these studies underscore the importance of geologic setting, precipitation, and drought to water presence. It remains, however, undetermined how this climate sensitivity changes in different reaches along the San Pedro and its tributaries. To address this, my goal is to harness the heterogeneous settings captured by wet/dry mapping (tributaries, reaches with recharge projects, reaches with heavy agriculture use, preserve areas, and high elevation streams) to determine which sections of the San Pedro are most tightly tied to climate, and how the importance of different climate drivers and seasonality changes within the river system.

Main-stem

My initial analyses compared the percentage wetness of the San Pedro with localized and gridded climate datasets found that prior fall (September-November before wet/dry mapping) temperature and hydroclimate conditions are extremely important for"priming" the main-stem of the Sand Pedro. Specifically, cooler than normal temperatures across the southwest, and higher than normal soil moisture and precipitation in southern Arizona have the strongest correlations (p less than 0.01) with river wetness the following June.

Although we did not see any significant change in the climate signals when analyzing SPRNCA only (meaning, SPRNCA wet percentage has the same climate relationships as the entire main-stem), there are additional ways to analyze the main-stem. We can further breakdown the sections of the main-stem by their geologic and ecologic properties to determine how various sectors respond to climate and weather. A detailed geologic map or analysis of local wells will enable this analysis in the future. The ecological classifications of riparian health along the San Pedro identified by *Stromberg et al.* (1996) are used annually for partner analysis of the wet/dry data set. A no regrets next step, then, is to analyze the Stromberg reaches for their different patterns and potential climate relationship.

Tributary signals

When averaged together, tributaries of the San Pedro do not show the same climate relationship as the main stem (prior fall local hydroclimate, March-May precipitation and soil moisture, and a low-pressure system in the Pacific Ocean offshore California have a positive correlation with tributary wetness). When we perform a Principal Component Analysis to determine if there is a significant common signal of all San Pedro tributaries, we find that there are no principal components (PCs) that rise above both our test for white (Gaussian) and red (autoregression-1) noise at the 95% confidence interval.

I then split up the tributaries based on their geography (Mexico, Upper Tributaries, Babocomari, Rincon/Catalina Mountain, Muleshoe, Aravaipa, and Lower Tributaries), and ran additional Principal Component Analyses to determine if each geography might have a common signal. Again, many geographies had no significant PCs that rose about the 95% confidence interval. This testifies to the noisiness of the data, which often is a function of record brevity rather than true signal strength. This is reflected in that some of the leading PCs have almost 80% of the variance of all the tributaries in that geography- yet do not pass the significance test.

We can use the highest loading PC(s) to determine what the common climate signal is (if one exists) to inform the main influences on water presence in the dry season. I also used the highest PC to determine the relationship of the tributaries to the patterns of the main-stem. All correlation values (Pearson's R) between the main-stem and the leading signals of tributaries were insignificant ($p \leq 0.05$). Of note, in all these analyses, only tributaries that have the longest, continuous datasets were included. Tributaries that were only measured for the most recent years or have discontinuous datasets were not suited for the analyses.

Mexico

The first PC of Mexico tributaries accounted for 74.5% of all the variance (did not pass significance test), and has a very clear negative correlation with southwestern winter temperature (i.e. if winters are colder, there is more water in Mexico tributaries). Interestingly, there is a highly localized positive correlation with summer temperature (e.g. warmer summers lead to more water), but summer here is defined as June-August, and our records are made in June. Thus, this is not a causal relationship. There is not a strong precipitation correlation, but we see a positive correlation ($r \leq 0.3$) with prior fall and spring precipitation directly over the Mexico tributaries geography.

Upper Tributaries

There is a common signal in the Upper Tributaries that explains 63.5% of the total variance of the wet dry data, and also passes both the red and white noise significance test.

Interestingly, the Babocomari river loads more on the 3rd and 4th eigenvector. By separating out the Babocomari (16 years of data), from the rest of the dataset (limited to 12 years), we see that there is no strong local climate signal that relates to how much surface water exists in June. Prior studies show that the river is primarily fed by groundwater and stormwater runoff, with peak flows occurring during the monsoon season. The river is noted for its unusual hydrology, with water moving in and out of the underground aquifer system. Water presence in June of this river could be more sensitive, therefore, to recharge rates of the underground aquifer–which can change on much longer time scales– than year of or year prior climate.

Catalina and Rincon Mountain Tributaries

PC1 explained almost 70% of the variance of these tributaries, although did not pass the significance tests. Despite this, we have some of the strongest climate signals of all the geographies. There is a very clear positive correlation (with $r \geq 0.6$ in parts of the southwest) of wet percentage with regional winter precipitation. Looking at a spatial correlation of temperature with PC1 we see a very clear jet-stream blocking pattern semi- indicative of a La Niña event, with cooler winter temperatures in the Pacific Northwest, and warmer prior fall, winter, and spring over the central US. A La Niña event would typically not bring about a wet-winter to the southwest, however we have seen in recent years of La Niña and substantial snowfall during the winter. Overall, I interpret these tributaries to be heavily dependent on winter precipitation (rather than spring temperatures) for their dry season wetness.

Muleshoe

Muleshoe showed two leading PCs, with PC1 explaining 48.7% of the variance, and PC2 (significant) explaining an additional 40.7%. These two PCs also had some of the highest correlations with the San Pedro main-stem. PC1 has a weak climate relationships, with positive correlation with prior fall temperatures and negative correlation with summer temperatures. PC2 has a clear regional relationship with spring time temperatures and winter precipitation. Redfield Canyon loads most heavily on the first PC, and Hot Springs Canyon loads most heavily on the second PC. As Hot Spring Canyon is ultimately fed by most other Muleshoe tributaries, it makes sense that this would have a significant shared signal. Redfield Canyon, however, has a separate flow path and potentially more isolated geohydrology that could give more insight into the climate vulnerabilities of Muleshoe water.

Aravaipa

The first PC of Aravaipa tributaries accounts for 76.5% of the shared variance, and has higher correlation (insignificant) with the main-stem percent wet than most other tributary systems. We see a very clear positive correlation with spring, winter, and prior fall precipitation, as well as a very clear regional negative correlation with spring time temperatures (e.g. when it is a cooler spring, there is more water in Aravaipa). Extent of dry season surface water presence, although relatively consistent in Aravaipa creek across the years (2010-2022 varying from 68-100%), appears to be dependent on cool and wet seasonal conditions (especially in the spring). Given the changing underlying groundwater regime with continued intensive groundwater withdrawals in the Wilcox basin, we may interpret our results that baseflow conditions in Aravaipa creek may be at most risk for future changes in groundwater flow paths, while Oak Grove Creek and Turkey Creek (which load much more on PC1 than Aravaipa Creek), are highly sensitive to winter and spring weather that may lead to high water content in the alluvial aquifers and bank storage. This is well demonstrated in 2014 when Oak Grove and Turkey Creek have some of their lowest values (31% and 0% wet, respectively), while Aravaipa Creek remained ≈ average at 72% wet. This was not the case in 2021, however, when all three tributaries saw low values- highlighting that winter and spring conditions do still impact surface water across the system.

Lower Tributaries

There are two tributaries in the Lower San Pedro not encompassed by geographic categories described above: Camp Grant Wash and Putnam Wash B. The first PC explains 82% (insignificant) of the variance of these tributaries, and we see very weak correlations with climate; negative relationship with prior fall, winter, and spring temperature ($\leq$ 0.25), and a weak positive correlation with spring precipitation. Given the extreme variability of Putnam Wash B wet percentage (0.03% to 95% wet from one year to the next), and that Camp Grant wash loads on to PC1 almost at 99%, this analysis primarily reflects the climate influences of Camp Grant Wash.

Potential to Quantify Mountain Front Recharge

A critical data gap in San Pedro hydrology knowledge is the quantification of mountain front recharge and mountain block recharge. Mountain system recharge (both mountain front and mountain block) rates were estimated between 2 × 106 m^3/yr and 9 × 106 m^3/yr, with 40-90% contribution from winter precipitation and a 10-60% contribution from summer precipitation (*Wahi*, 2005). This data is heavily parameterized in the groundwater models (including MIKSHE) used by the Upper San Pedro Partnership and affiliates, and it is not well understood how we might expect mountain system recharge to change year to year. I looked into our Ramsey data (where we have both wet/dry and a USGS streamflow gauge above where water recharges the mountain block aquifer) to determine if we could identify a proxy for mountain front (groundwater recharging at adjacent basin fill to the mountain) or mountain block (groundwater inflow to a lowland aquifer from an adjacent mountain block) recharge with our data, or better understand the tributary's relationship to climate (*Markovich et al.*, 2019).

Our wet/dry data in Ramsey has the highest percentage wet in years with high flows in the spring season (May-June), and when average spring flow is paired with high prior winter flow. Is is possible, therefore, to posit that an appropriate proxy for changes to mountain block recharge as reflected by baseflow conditions in the driest time of year (from wet/dry data) is antecedent spring and winter conditions. There is a clear anti-correlation between dry season (May-June) flows and temperature and monsoon season (July-September) flows and summer temperatures. The relationship between winter temperature and winter flows is not quite as clear, likely due to the influence of melt timing.

There is ultimately more analysis to be done here, including looking at the influence of precipitation and digging into other influences on winter streamflow (when the majority of mountain front recharge occurs). But there is potential to utilize our understanding of these relationships to best describe anticipated changes to mountain system recharge.

Next steps and opportunities

The scoping described above demonstrates how heterogeneous the climate sensitives and forcings are for baseflow in both the main-stem and tributaries of the San Pedro River. Importantly, the tributaries' wet/dry percentage often sees a much stronger antecedent winter and spring hydroclimate signal than the main stem, which appears to be more temperature sensitive. Tributaries originating in high mountain ranges (like the Rincons and Catalina's) have a very clear winter-time precipitation correlation. Some tributaries do not appear to have much relationship to temperature or precipitation, which could indicate their reliance on groundwater (either ancient or recently recharged), changes in geohydrology, or alternative forcings (groundwater pumping, etc).

Although these wet/dry data are very noisy, and there might not be skillful large scale analyses at this time, there remains potential for wet/dry to inform on specific actions and vulnerabilities. There are a few small scale analyses mentioned in the proceeding sections to be accomplished in FY24, including grouping tributaries by stream order, querying the main stem patterns as divided by riparian health classification (*Stromberg et al.*, 1996) and geohydrology (*Baillie et al.*, 2007). As these datasets remain short (especially for the tributaries), each year of additional data may bring stronger climate relationships or disintegrate these initial findings. It will be important to continue updating these analyses with the most recent data wet/dry data.

One avenue of research that would benefit from partnering with external groups and researchers would be to spatially analyze the relationship between presence of surface water with well depth (through empirical orthogonal function analyses if appropriate) to determine if presence of surface water is related to, or can be a proxy for, groundwater elevations in the floodplain (and what the extent of that relationship is spatiotemporally). Coordination with partners to develop the well data set would help facilitate this study. Conservation science could advance with this understanding to more accurately determine how the groundwater system is changing through point measurements of wet/dry. This, in turn, would greatly improve our monitoring and metrics of our actions along the river.

References

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