Potential impacts of the Groundwater Pumping related to the Villages at Vigneto on Surface Water resources along the San Pedro River.

Analysis by Thomas Meixner, Professor Hydrology and Atmospheric Sciences

The Villages at Vigneto proposed development in Benson, Arizona will result in significant pumping of groundwater in the Middle San Pedro River basin. This groundwater pumping will result in hydrologic changes within the basin due to the following cause-and-effect relationships. Groundwater pumping will cause water to be withdrawn from the deep aquifer resulting in a decrease in groundwater elevation. This decrease in groundwater elevation will result in the eventual capture of surface water resources. This capture will occur through three potential pathways: (1) a decrease in discharge of groundwater to either the river or riparian vegetation, (2) an increase in the recharge of groundwater to the aquifer, and/or (3) a decrease in losses of groundwater from the Middle San Pedro groundwater basin into adjoining groundwater basins – predominately the lower San Pedro Basin. These cause-and-effect relationships are clear, and it is possible to specify the timing, location, and quantity of capture from surface flows along the San Pedro River through the development and implementation of a groundwater model for the aquifer systems that will be impacted by the Vigneto development.

I. The Middle San Pedro Groundwater Basin

The San Pedro River starts in Mexico and flows north into the United States near Naco, Arizona. The river is generally considered to have three groundwater basins (upper, middle, and lower). The upper encompasses the region in Mexico and the portion of the basin that drains to the Tombstone gauge near Arizona Highway 82. The middle encompasses the basin from this gauge location to a location known as the narrows (Figure 1). Finally the lower encompasses the portion of the river basin north of the narrows.

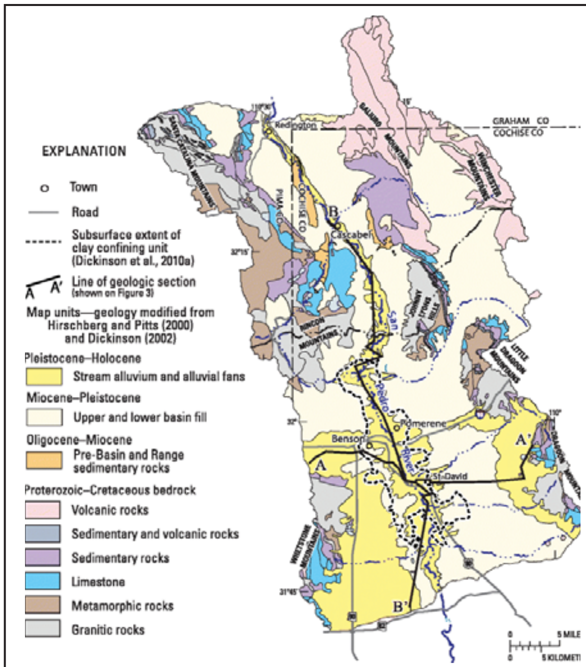

Figure 1 - Map of Middle San Pedro Basin from Hopkins et al 2014. Dotted area on map shows the extent of the subsurface confining layer present in the basin.

In the Middle San Pedro basin and similar Basin and Range watersheds that have both a deeper regional aquifer and a shallower alluvial aquifer, water runs off the mountains flanking the basin and percolates into the regional aquifer. This results in regional aquifer groundwater flow towards the basin's rivers, whose streamflow and riparian areas represent the main discharge point of these aquifers. Pressure in the regional aquifer causes groundwater to move from that aquifer upwards into the shallow aquifer and then into the rivers as "baseflow."

Increased groundwater pumping reduces the upgradient groundwater elevation, creating a cone of depression. This groundwater elevation decline reduces groundwater flow towards the river and, in turn, pressure near the river. The reduced pressure causes declines in baseflows. The expanding cone of depression caused by groundwater pumping eventually "captures" water from the aquifer that would have reached the surface near the river (either through evapotranspiration or as baseflow) or induces recharge from the river itself.

Capture is the hydrologic process that occurs when groundwater extraction from an aquifer is increased. This increase is typically imposed by increases in groundwater pumping due to municipal or agricultural developments in a groundwater basin. Prior to groundwater development, groundwater basins are generally assumed to exist in an oscillatory steady state where on annual to decadal time scales, recharge to aquifer systems is approximately equal to discharge from these aquifer systems.

The pumping of groundwater upsets the oscillatory steady state by artificially increasing discharges from an aquifer. If a new steady state is to be achieved (i.e., the aquifer is not completely drained of all water), the increased pumping must be balanced by either increased recharge or decreased discharge from the aquifer. In the San Pedro basin, increased recharge is unlikely as most recharge processes occur through a thick unsaturated zone and changes in hydraulic gradients simply do not have a pathway to induce increased recharge in the basin. The result is thus likely to be little change in recharge in the basin. By contrast, decreased discharge from the aquifers tend to predominate as the aquifer is more directly impacted by changes in the groundwater system. Even small changes in groundwater levels could induce decreased surface flows since by their nature groundwater levels are at stream levels and surface flows in this systems are small to begin with. These decreases in discharge typically take the form of decreases discharge of groundwater to streams, decreased groundwater sourced evapotranspiration (ET) by vegetation and decreased discharge to downstream and adjoining aquifers. Such capture would only occur along the San Pedro and would result in decreased surface flows along the river.

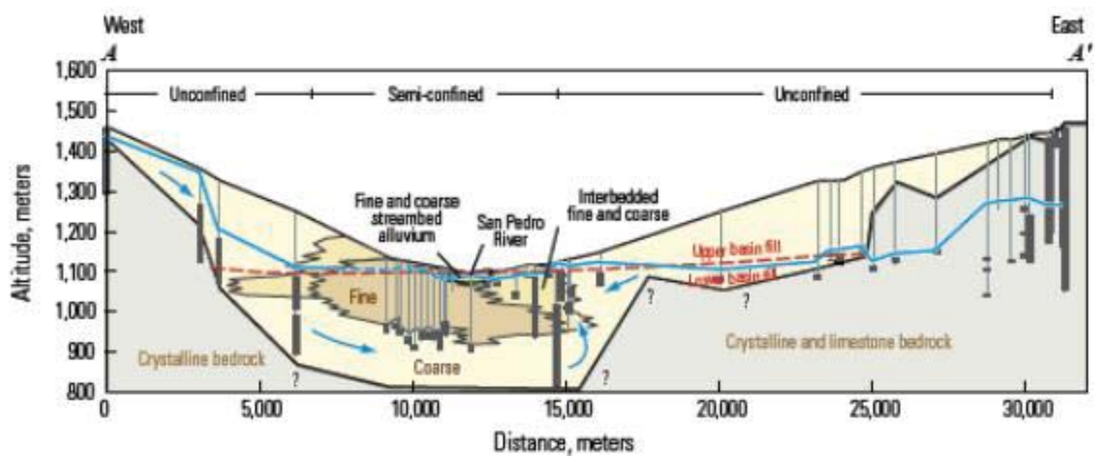

Figure 2 Cross Section of basin from Cordova et al. (2015). Arrows illustrate how confining layer can induce hydrologic discharges and effects distant form recharge and pumping locations.

II. Pumping at the Villages at Vigneto Will Likely Capture Surface Flows

The capture process in the Middle San Pedro was investigated by Prucha (2016). He utilized a modified version of the previously published Goode and Maddock (2000) model to investigate how pumping at the Villages at Vignetto would impact groundwater and surface conditions in the Benson reach of the

San Pedro River. He concluded that increased groundwater pumping would impact the river and would likely impact the flow of water at the springs along the river at the northern end of the San Pedro River National Conservation Area (SPRNCA). These springs feed what is known locally as the St. David Cienega. There would also be effects of capture at the northern end of the aquifer system affecting surface water discharge in the river near the Narrows. Prucha's results confirm that groundwater pumping will predominantly impact discharge to surface waters and likely near riparian areas along the San Pedro River.

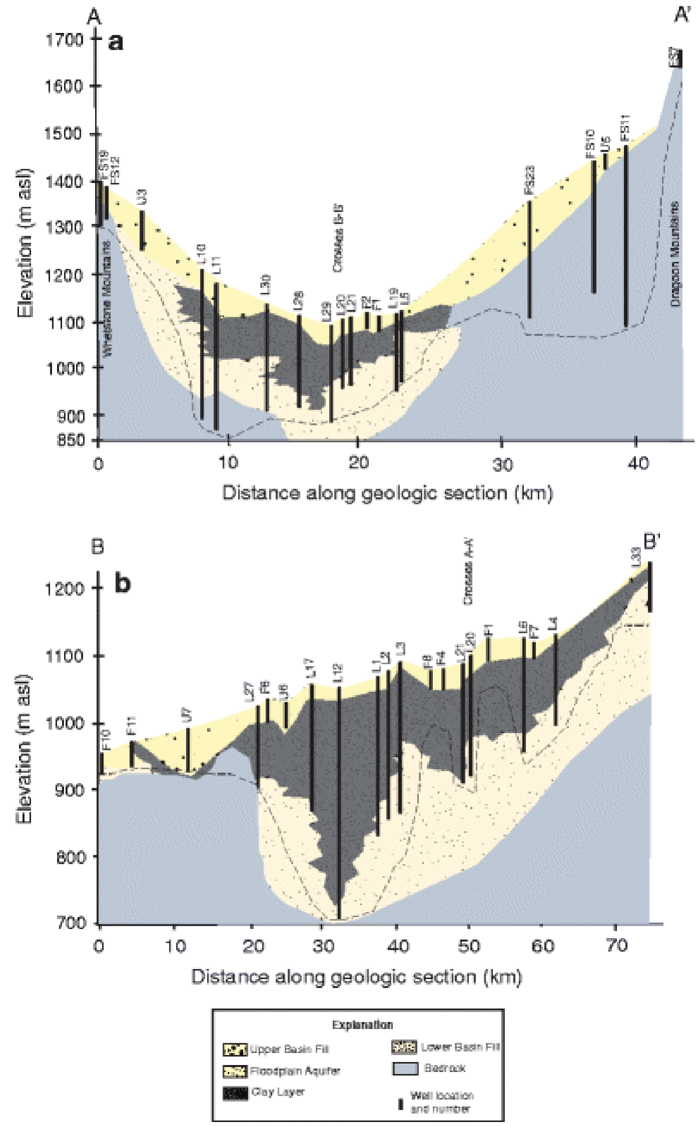

Figure 3 – From Hopkins et al. 2014. Figure shows the thickness of the confining layer in two different cross sections (referenced in Figure 1) across the Middle San Pedro basin. Notably the confining layer in general thins toward the upstream end (right hand side of bottom panel of figure).

Prucha's modelling illustrates how the capture process would likely work in the San Pedro basin. In particular, the modelling demonstrates how the confining fine layer present in the basin would affect the location and timing of capture. This confining layer is present in much of the center of the basin (Cordova et al. 2013) but is not present near the St. David Cienega nor near the downstream exit of the aquifer system near "the Narrows". This structure to the confining layer was later confirmed in hydrochemical investigations by Hopkins et al. (2014). The geochemical tracer work in this study generally showed that the confined aquifer beneath the fine-textured confining unit had little hydrogeologic connection to the unconfined aquifers nearer to the surface of the basin. The confined nature of the deeper aquifer has several important functional effects. Pumping in the unit may not affect aquifers directly above the pumping site. Rather, and perhaps most importantly, capture related connections between the aquifer and surface flows will be displaced horizontally in time and space (Figure 2).

Prucha refined the Goode and Maddock (2000) model with this updated geologic information on the confining unit in the Middle San Pedro Basin. His model predicted that the effects of pumping at the Villages at Vigneto would spread to distant quarters of the aquifer system due to the effects of the confining layer. Specifically, the Prucha results show that the springs that feed St. David Cienega would be impacted by the approximately 5700 acre-feet per year pumping by the proposed Villages at Vigneto development. The reason for the zone of capture extending to the St. David springs is likely due to the thickness of the confining layer across the basin. At the downstream end the clay layer connects to the bedrock (Figure 3) indicating difficulty for water to be easily discharge from the lower confined aquifer at the northern and downstream end of the basin. The thinning of the layer towards the upstream end and the fact that the confining layer appears to completely disappear in and around the St. David Cienega means that the geologic structure of the basin facilitate a connection between the confined aquifer and the river in and around the St. David Cienega.

Prucha's results makes sense given that St. David Cienega is a known discharge point for groundwater in the basin. While the location of the springs somewhat south of the development might lead one to believe that pumping impacts might be seen elsewhere first the confining layer and its effect on the structure of flow in the basin (Figures 2 and 3) determine the location and timing of the impacts predicted by Prucha's modelling.

The previous Environmental Assessment prepared by the U.S. Army Corps of Engineers concluded that the confining layer as modeled by Golder and Associates would prevent any impact to the San Pedro River from pumping at the Vigneto site. This conclusion was based on the assumption that the groundwater aquifer was not connected to the unconfined aquifer that feeds the San Pedro River. This conclusion now appears to be false based on two independent pieces of data. The first piece of evidence is the Prucha modeling results, which indicate pumping would impact discharges from the confining layer to the surface near St. David. The second piece of evidence is the isotopic results from Eastoe (2017), which indicate that the water discharged at the St. David Cienega is isotopically similar and thermally similar to the confined aquifer in the area of St. David, as tested by Hopkins et al. (2014) (Figure 4). These isotopic results confirm that the there is a hydrologic connection between the confined aquifer and the surface flow system of the San Pedro at St. David. These results also offer further confirmation of the Prucha modelling results. Finally, these isotopic results would support the conclusion that changes in hydrologic conditions in the confined aquifer (from Pumping at the Villages) would impact surface flows at St. David.

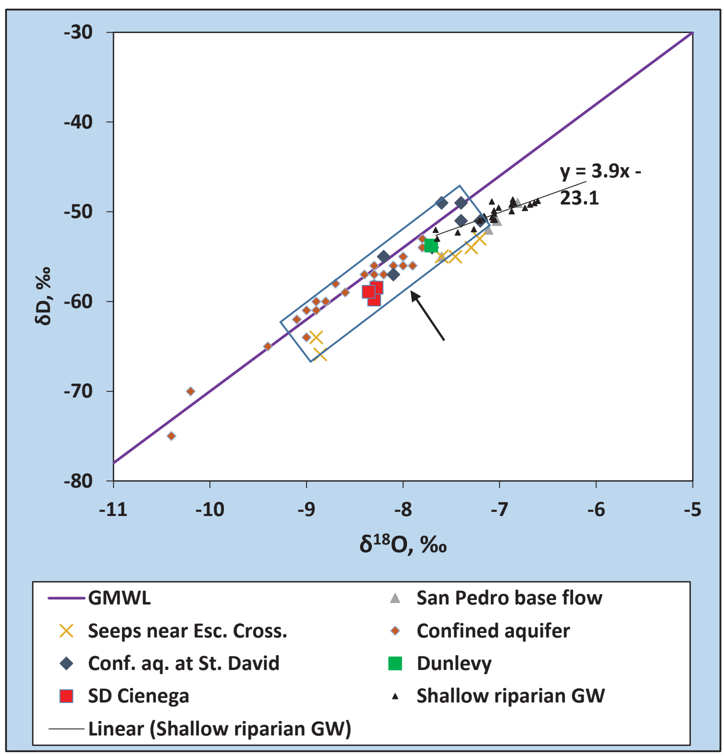

Figure 4 – (From Eatsoe 2017) Isotopic results comparing the St. David Cienega (red squares) to the confined, unconfined and San Pedro River waters. The results clearly show that the water discharged to the surface at St. David comes from the confined aquifer system.

III. **Developing a Groundwater Model is Feasible and Would Directly Identify the Impacts of Groundwater Pumping**.

There are tools and data available to construct a detailed model of the system that quantifies the impacts of groundwater pumping on surface flows along the San Pedro River. In 2010, the U.S. Geological Survey (USGS) embarked on a three-phase project to generate just such a groundwater model for the Middle San Pedro Basin. In Phase I (completed in 2010), the USGS described the hydrogeologic framework of the middle San Pedro basin. In Phase II (completed in 2015), the USGS developed a detailed groundwater budget for the San Pedro Basin (Cordova et al. 2015). Though the USGS never completed Phase III, USGS' research provides valuable information on the basin's hydrology that can be used to create a detailed model of the system and fully understand the nature of groundwater recharge in the basin, including the relative connectedness between the confined unit and the surface water system.

Such modelling work would be relatively straightforward with the robust work by the USGS in the basin being available. It would take one hydrologist roughly two years to complete a model at a cost of approximately $200,000. This process could be accelerated by employing more hydrologists, thus reducing the time needed to construct a complete model.

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