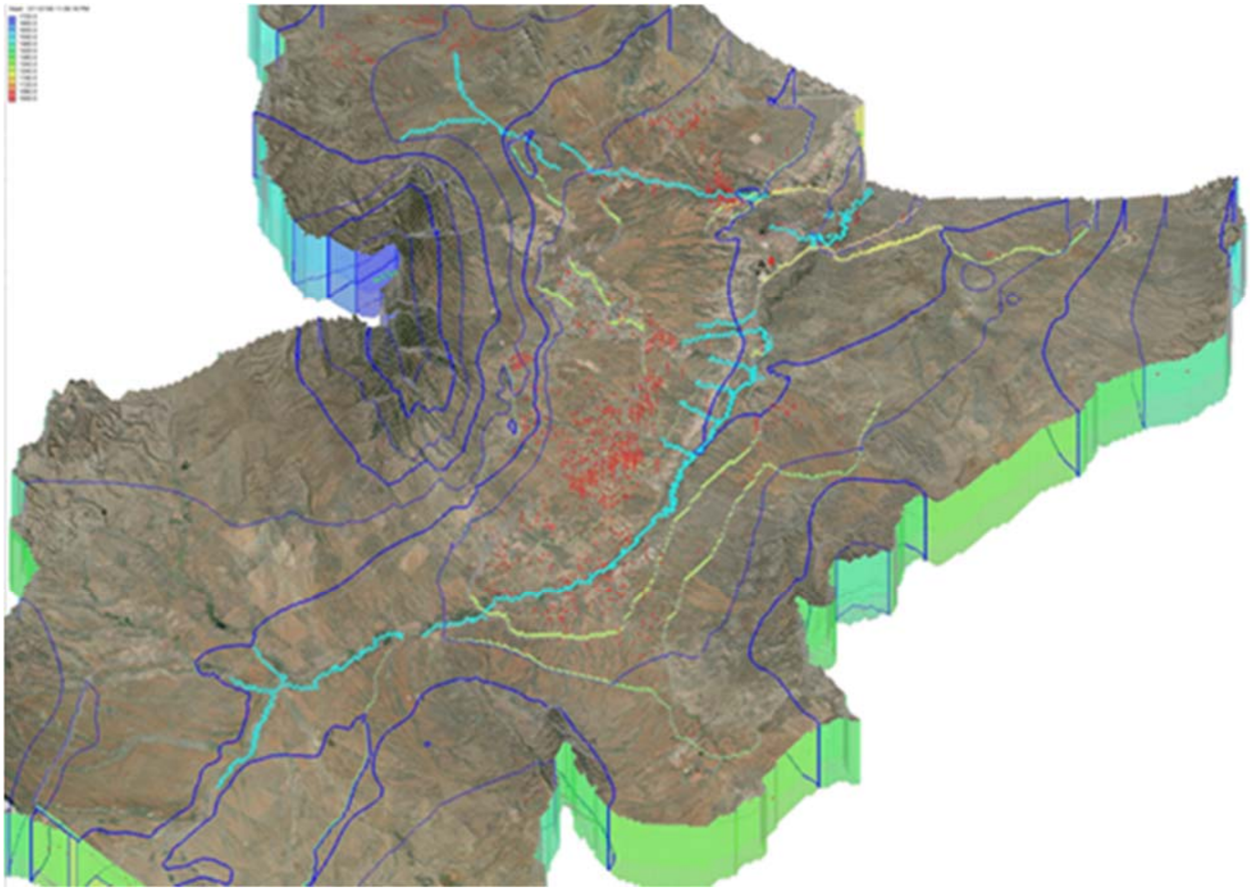
Evaluation of Impacts of Fort Huachuca Long-term Well Pumping and Recharge on San Pedro River Stream Flow (from 2011 to 2100)



Thursday, November 21, 2019

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1 Introduction

The Center for Biological Diversity (CBD) requested Integrated Hydro Systems, LLC (IHS) to evaluate impacts on San Pedro River flows due to Fort Huachuca attributable groundwater pumping and recharge from year 2011 to 2100, and to also discuss the effects of potential climate change impacts.

2 Review available reports

The following reports were reviewed:

1) March 31, 2014. Programmatic Biological Assessment for Ongoing and Future Military Operations and Activities at Fort Huachuca, Arizona (PBA), Appendix G – Groundwater Modeling Report.

2) Lacher, Laurel. 2011. Simulated Groundwater and Surface Water Conditions in the Upper San Pedro Basin 1902-2105. June 2011.

3) Lacher, Laurel. February 2018. Interim Update to Sierra Vista Sub-watershed Pumping and Artificial Recharge Rates in the Upper San Pedro Basin Groundwater Model. Prepared for The Nature Conservancy.

4) USGS Reports:

    a. Barlow, P.M., and Leake, S.A., 2012, Streamflow depletion by wells—Understanding and managing the effects of groundwater pumping on streamflow: U.S. Geological Survey Circular 1376, 84 p.Dickinson et al, 2010

    b. Pool, D.R., and Dickinson, J.E., 2007, Ground-water flow model of the Sierra Vista Subwatershed and Sonoran portions of the Upper San Pedro Basin, southeastern Arizona, United States, and northern Sonora, Mexico: U.S. Geological Survey Scientific Investigations Report 2006-5228 48 p.

5) Pueblo Del Sol Reports:

    a. January 25, 2012 Arizona Department of Water Resources "Designation or Modification of Designation of Adequate Water Supply Application" by Pueblo Del Sol Water Company.

    b. June, 2011. Fluid Solutions. Attachment D, Adequate Water Supply Hydrologic Study for Pueblo Del Sol Water Company.

    c. May 31, 2011. Brown and Caldwell. Groundwater Modeling Approach and Results from Predictive Simulations. Memo from Mark Nichols at Brown and Caldwell to Mike Lacey at Fluid Solutions.

3 Approach/Methodologies

Several steps were taken in this evaluation, including:

1) Review several reports,

2) Obtain and review available Upper San Pedro River Basin Model (USPRBM) files and long-term pumping projections (spreadsheet) from Laurel Lacher's recent February 2018 Modeling Study,

3) Revise long-term well pumping and recharge rates in the San Pedro River model to mimic changes described in the March 31, 2014 PBA, Appendix G study (see Figure 1 and Figure 2),

4) Simulate future Fort Huachuca well pumping and recharge rates (2011 to 2100), and

5) Assess changes in groundwater flow.

Details of each step are described below.

4 Upper San Pedro River Basin Model Review

Upper San Pedro River Basin Model (USPRBM) input files from recent modeling conducted by Laurel Lacher (February 2018) for The Nature Conservancy were obtained through the Upper San Pedro Partnership website (http://uppersanpedropartnership.org/groundwater-model-dss/). Due to file size limitations, Lacher model separated the 2003 to 2100 model simulation into 4 different models with simulation periods as follows:

- 2003 to 2030
- 2030 to 2057
- 2057 to 2084
- 2084 to 2100

Model inputs and outputs were opened and reviewed within the latest Groundwater Modeling System (GMS) Version 10.4.0 (64-bit) software.

5 Projected Fort Huachuca Changes to Groundwater Pumping and Artificial Recharge

Changes in the projected groundwater pumping and artificial recharge in the 2018 Laurel Lacher Modflow model inputs mimicked specifications given in Tables 3 and 4 in the PBA, 2014 Groundwater modeling report (App G), with the exception that changes were made from 2011 to 2100, instead of from 2011 to 2030 (Table 3).

Table 3. Key Model Simulations Assumptions

Parameter	*With Fort Attributable (WFA) Simulation 2003-2030*	*No Fort Attributable (NFA) Simulation 2003-2030*
Future Growth	The same growth projections and pumping assumptions that were used as in 2011 version of the model (Lacher). These are based on Arizona Department of Commerce projections (pre-2010 Census).	The same growth and pumping assumptions that were used as in 2011 version of the model (Lacher). These are based on AZ Dept of Commerce projections (pre-2010 Census).
Fort Huachuca On-Post Pumping	1300 acre-feet per year	0 acre-feet per year from 2011 to 2030
Fort Huachuca Off-Post Attributable Pumping	Included in overall pumping and not broken out.	Remove off-post attributable pumping from 2011 onward. Off-post pumping was estimated as constant not as a percentage of the total pumping. 4,700 acre-feet of off-Post pumping was removed from 2011 to 2030.
Agricultural Pumping	Clinton and Drivjers (C6) retired in early 2000s. Palominas Area agricultural pumping (C10) retired in 2005.	Clinton and Drivjers (C6) retired in early 2000s. Palominas Area agricultural pumping (C10) retired in 2005.
Artificial Recharge	All historic and projected artificial recharge. Includes the Fort's stormwater detention, East Range Facility, Huachuca City Effluent, and Palominas Pilot Stormwater Project.	Reduced off-post artificial recharge at the EOP by 40 percent of the Fort-attributable population within the City of Sierra Vista. Sets all Fort-attributable recharge equal to zero starting in 2012.

Figure 1. Table 3, March 31, 2014 PBA, App. G Key Model Simulation Assumptions

Table 4. Adjustments to Groundwater Modeling Packages

Groundwater Package	*With Fort Attributable (WFA) Simulation*	*No Fort Attributable (NFA) Simulation*
Well	Includes all Fort-attributable groundwater pumping. No change in groundwater pumping patterns.	All Fort-attributable pumping removed from the well package.
Recharge	Includes • East Range recharge • Huachuca City Effluent Recharge • Stormwater Detention Basin recharge	Does not include: • East Range recharge • Huachuca City Effluent recharge • Stormwater Detention Recharge

Figure 2. Table 4, March 31, 2014 PBA, App. G Adjustments to Groundwater Modeling Packages

All changes to time-varying, projected pumping and recharge made to model input in this evaluation were calculated using the 2018 excel spreadsheet provided by Laurel Lacher (personal communication). In effect, Lacher's recent adjustments (see Lacher, February 2018) reduced net pumping by nearly 10,000 ac-ft/yr (by year 2100) as referenced by the 2017 Net Pumping solid red line on Figure 3 below. This increases both aquifer

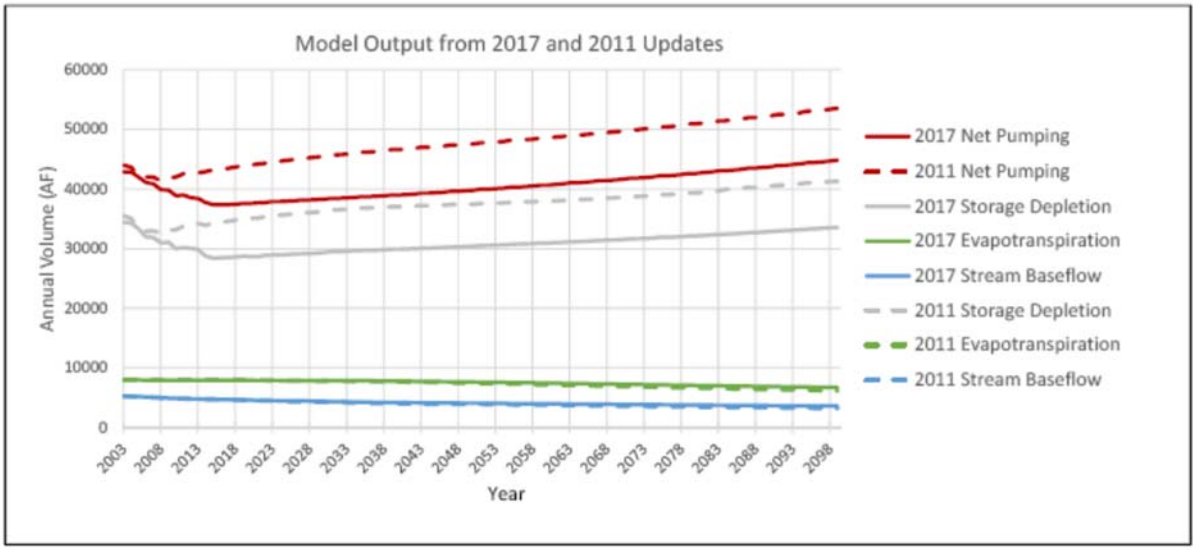

Figure 16. Comparison of water budget components from 2017 and 2011 groundwater model updates by Lacher.

Figure 3. Modeled output comparing water budget differences between 2011 and 2018 updates by Laurel Lacher (2018).

groundwater elevations (or the water height above mean sea level, also referred to as '***hydraulic head***', or typically just '***head'***) and groundwater discharge to streams ('**baseflow**') throughout the model relative to the PBA, 2014 App-G Groundwater modeling study, which relied on the Lacher 2011 model setup.

For this evaluation, to mimic the Fort-Attributable pumping as per the 2014 PBA App-G study, 40% was removed from pumping in all Census Designated Places within the SVS as per Lacher, 2018 (see Figure 4), with the exception of pumping within Census areas including AG, Fort Huachuca (FH), Mexico and Mining (as per CBD instruction). No change was made to pumping specified in these areas, and projections remain the same as those in Lacher 2018 modeling. App-G in the PBA, 2014 study shows projected 6000 ac-ft/yr Fort-Attributable Flows (4700 ac-ft/yr Off-post, and 1300 ac-ft/yr On-post, see Figure 5). These Fort-Attributable flows were reproduced in this modeling evaluation starting 2011.

It should be noted that this evaluation does not evaluate effects of the long-term, non-negligible Fort-Attributable pumping prior to 2011. This is an important consideration described further in a study referenced in the 2014 PBA, App-G study (i.e., *GeoSystems Analysis, Inc (GSA). 2010a. Calculation of Pumping-Induced Baseflow and evapotranspiration Capture Attributable to Fort Huachuca. Prepared for Environmental and Natural Resources Division, Fort Huachuca. Collaborated with Vernadero Group Inc. November 2010*). Figure 13 in the GSA, 2010a study suggests more than 300,000 ac-ft of groundwater was removed by Fort-attributable pumping (both on- and off-post). If this pumping were considered in this study, the total Fort-Attributable pumping impacts on the San Pedro River baseflow discharge would be much greater than just considering projected impacts from 2011 to 2100.

Recharge was also changed within the Fort Huachuca Basins (East Range recharge) and EOP areas as indicated on Lacher's 2018 Figure 11 (shown here as Figure 6). Despite the PBA, 2014 App-G Groundwater modeling report (Figure 2) appearing to exclude Huachuca City Effluent recharge for their No Fort-Attributable (NFA) simulation, the 2018 Lacher model did not appear to include this recharge. As a result, no changes were made to recharge in this area, only those associated with the EOP and East Range Basins.

It should also be noted that the PBA, 2014 App-G study did not appear to adjust recharge associated with things like septic return flows, which would have partially offset Fort-Attributable pumping impacts. However, even if such recharge had been included in their analysis, impacts of the substantial historic Fort-Attributable pumping (i.e., 1940 to 2010) would make this negligible by comparison.

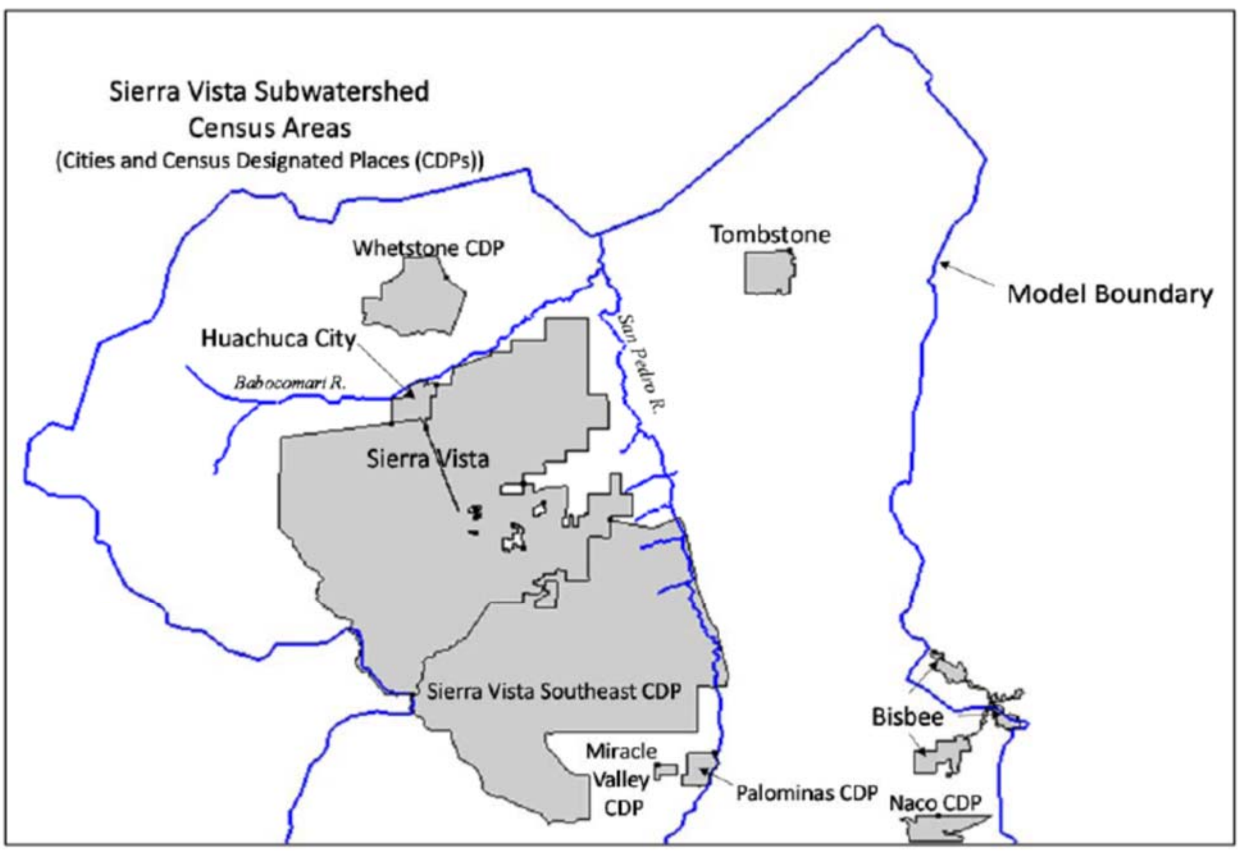

Figure 3. Incorporated areas and unincorporated Census Designated Places in the SVS.

Figure 4. Census Areas - from Lacher, 2018

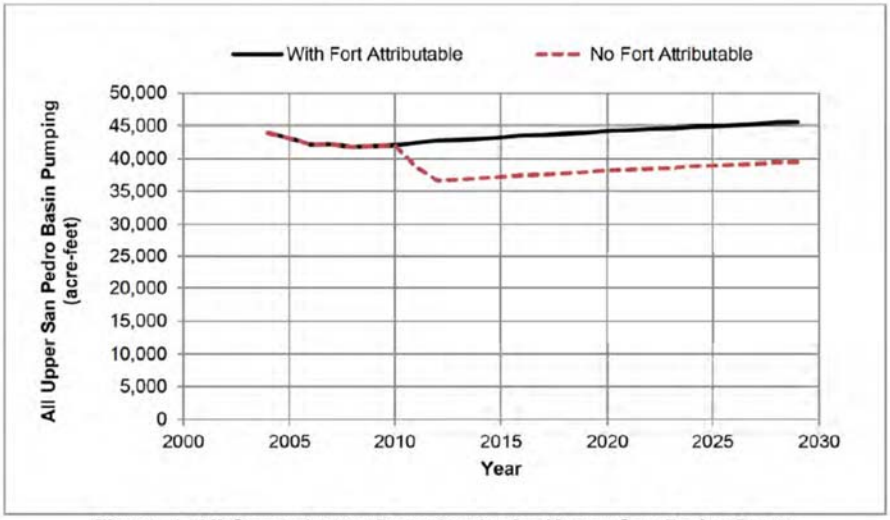

Figure 4. All Groundwater Pumping in the Upper San Pedro Basin

Figure 5. Estimated Fort-Attributable Pumping, From PBA 2014, App. G.

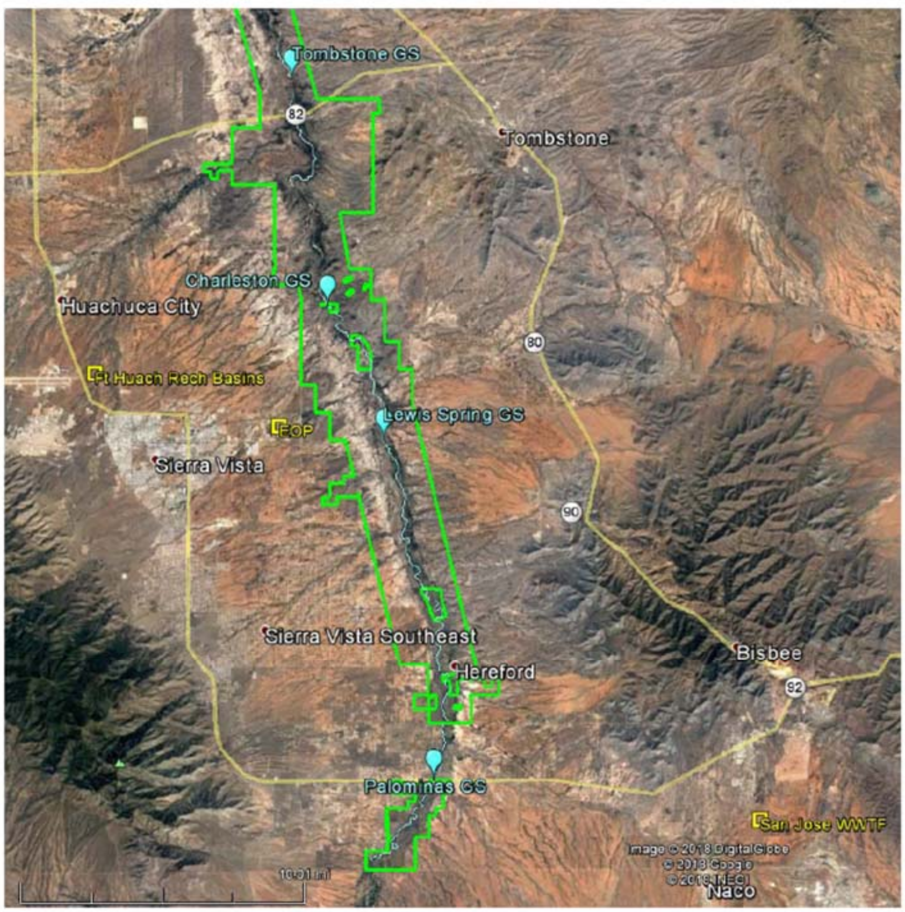

Figure 11. Map showing the Palominas, Lewis Spring, and Charleston stream-flow gaging stations (blue markers) on the Upper San Pedro River within the model area. The SPRNCA is outlined in green. Effluent recharge sites indicated with white boxes.

Figure 6. Recharge Areas - From Lacher, 2018 study

6 Projected Changes to Pueblo Del Sol Well Pumping

To account for all effects of future Fort-Attributable pumping, projected pumping at Pueblo Del Sol (PDS) wells were also accounted for in this evaluation from 2011 to 2100. The Pueblo del Sol Water Company (PDS) 2012 Arizona Adequate Water Supply Application (AAWS) specifies a Total Annual Demand of 4,870 ac-ft/yr starting in year 2032 (Part B of application).

The 2018 Lacher spreadsheet database already included pumping specified at PDS wells 2, 3, 4 and 5, but she also included pumping at a PDS Golf Course well, and a well near well PDS2 (2 cells to the north and east), with rates duplicating those at well PDS2. She indicated this neighboring well probably accounted for either dry cell issues, or to supplement PDS pumping in this area and should be left in the simulation. Leaving this well in the simulation does not affect this simulation, which focuses on the **change** in PDS well pumping. In other words, this neighboring duplicate PDS2 well pumping was included in both the Laurel Lacher simulation (which I refer to herein as the 'Baseline' simulation) and the new ADWR AAWS Application with increased PDS pumping.

7 PDS Pumping Dataset (Brown & Caldwell, 2011 report)

An evaluation of PDS pumping data used in the Brown and Caldwell (BC) May 2011 modeling simulations was used along with Lacher's spreadsheet database to specify PDS well locations (Section 7.1), model layers pumped (Section 7.2) and pumping rates in time (Section 7.3), described below.

7.1 PDS well locations

Only 5 wells (PDS 2 through 6) appear to have been simulated in the BC modeling evaluation for the AAWS application evaluation. It is unclear why well PDS#1 was not included (deactivated?). Locations for the 5 PDS wells simulated in the BC were spatially located from Figure 1 in the Brown and Caldwell May 2011 report. Since Laurel Lacher (LL) already located PDS 2, 3, 4 and 5 wells in her model, only PDS6 needed to be added. Locations for PDS wells 2 to 5 appear consistent with the locations indicated in the ADWR AZ Well Registry (55) database (see Figure 7).

7.2 PDS well pumping model layer

Pumping layers for PDS wells 2, 3, 4 and 5 were specified the same as in Laurel Lacher's 2018 model (LL model). These include:

- PDS 3, 4 and 5 (layer 4 only),
- PDS 2 (layer 5 only)

Specification of well screened depth, or model layer could not be found in the BC modeling report (May 2011) for well PDS6. Initially, all pumping was assumed equal to layer 5, but simulations showed considerable drawdown occurs (hundreds of feet) in this layer. As a result, all pumping was placed in layer 4, similar to nearby PDS wells 3, 4 and 5 (all layer 4), which has much specified higher permeability and storage coefficient values compared to underlying layer 5.

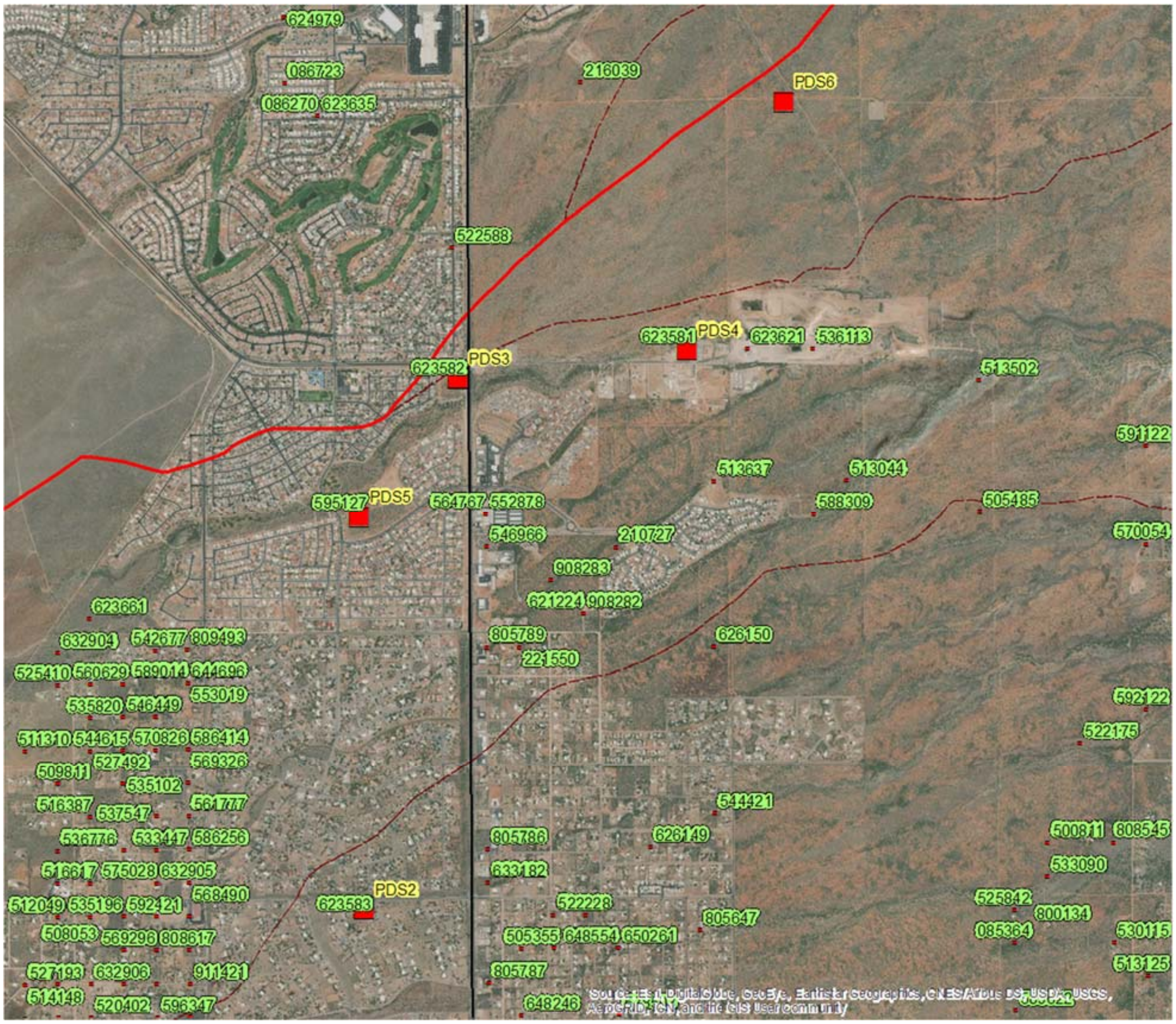

Figure 7. ADWR AZ Well 55 Registry locations (and ID) compared to PDS wells.

7.3 PDS Pumping Rates/Schedule in Model

Although the total future pumping rate is known from the AAWS application (i.e., 4,870 ac-ft/yr), no information was found on **future** pumping rates specified at each PDS well in either the Fluid Solutions (June 2011) or Brown and Caldwell (May 2011) reports. The BC modeling report did however provide historical annual pumping for wells PDS 2 through 5, from 1986 to 2010. These overlap pumping rates already specified in the LL model for years 2003 through 2010. A comparison between the two rates shown below on Figure 8 indicates similar pumping rates for these wells, though LL modeling includes estimates for two seasons (winter and non-winter), while BC modeling only specified a single annual rate.

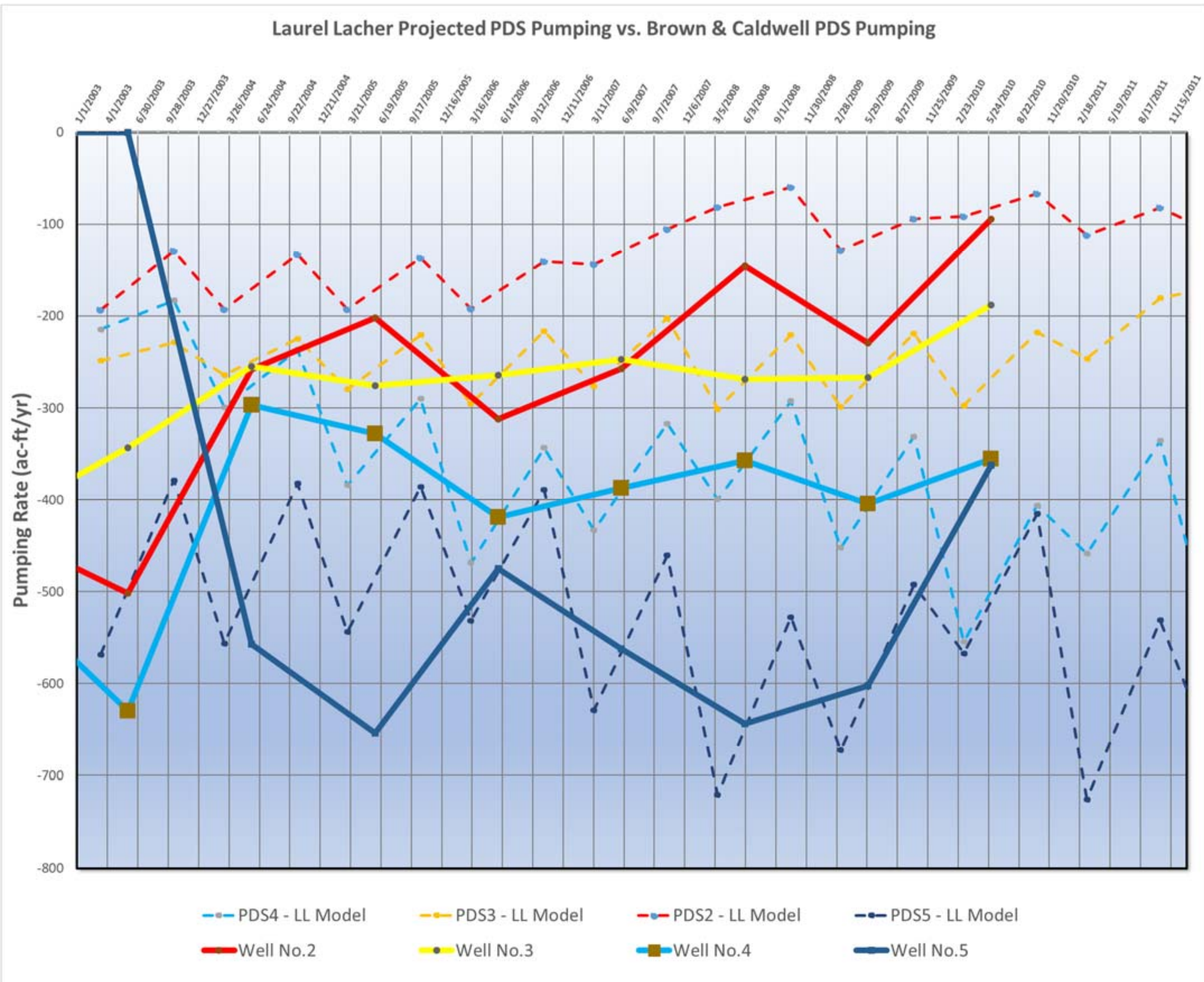

Figure 8. Comparison of historical pumping rates specified by Brown and Caldwell (Well No.) and LL modeling (PDS – LL Model) for PDS Wells 2, 3, 4 and 5.

In the LL model, PDS 2 through 5 well pumping was already projected from 2003 to 2100, generally increasing with community growth projections. For this simulation, LL model pumping projections for wells PDS 2 to 5, beyond year 2032 (full PDS buildout date), were replaced with constant flow rates calculated with three constraints:

- Total Annual Demand from wells PDS 2 to 6 total 4870 ac-ft/yr (ADWR AAWS application)
- Maximum pumping rates at PDS wells 2 to 5 is constrained to maximum well pumping capacity (see Figure 9) and
- Constant Well pumping from 2032 to 2100 for all PDS wells (i.e., 2 to 6) – this replaces LL projected 2-season pumping, which increases over time.
- Prior to 2032:
    - o no well PDS 6 exists.
    - o Pumping projections from 2010 to 2032 for PDS wells 2 to 5 were kept the same as in the LL model – i.e., 2-season pumping rates.
- PDS Golf well pumping was left unchanged from LL modeling and not included in the 4870 ac-ft/yr. Annual PDS Golf well pumping was relatively small compared to other PDS wells.
- PDS pumping rates and schedule are shown on Figure 10.

Table 2. PDS Service Wells

Well Name	Location	ADWR No.	Pumping Capacity	Well Depth (*ft bls)	Static Water Level (*ft bls)	Screen (*ft bls)
PDS 2	D(22-20)36abb	55-623583	644 gpm	601	416	433-601
PDS 3	D(22-20)24aaa	55-623582	600 gpm	795	412	485-676, 680-795
PDS 4	D(22-21)18ddc	55-623581	1153 gpm	650	373	450-650
PDS 5	D(22-20)24dbb	55-595127	1350 gpm	800	434	450-776
PDS 6	D(22-20)7dcc	This is a proposed location				

*ft bls is feet below land surface

Figure 9. PDS Pumping Well Capacity obtained from the Fluid Solutions June 2011 Report "Attachment D Adequate Water Supply Hydrologic Study" page 12

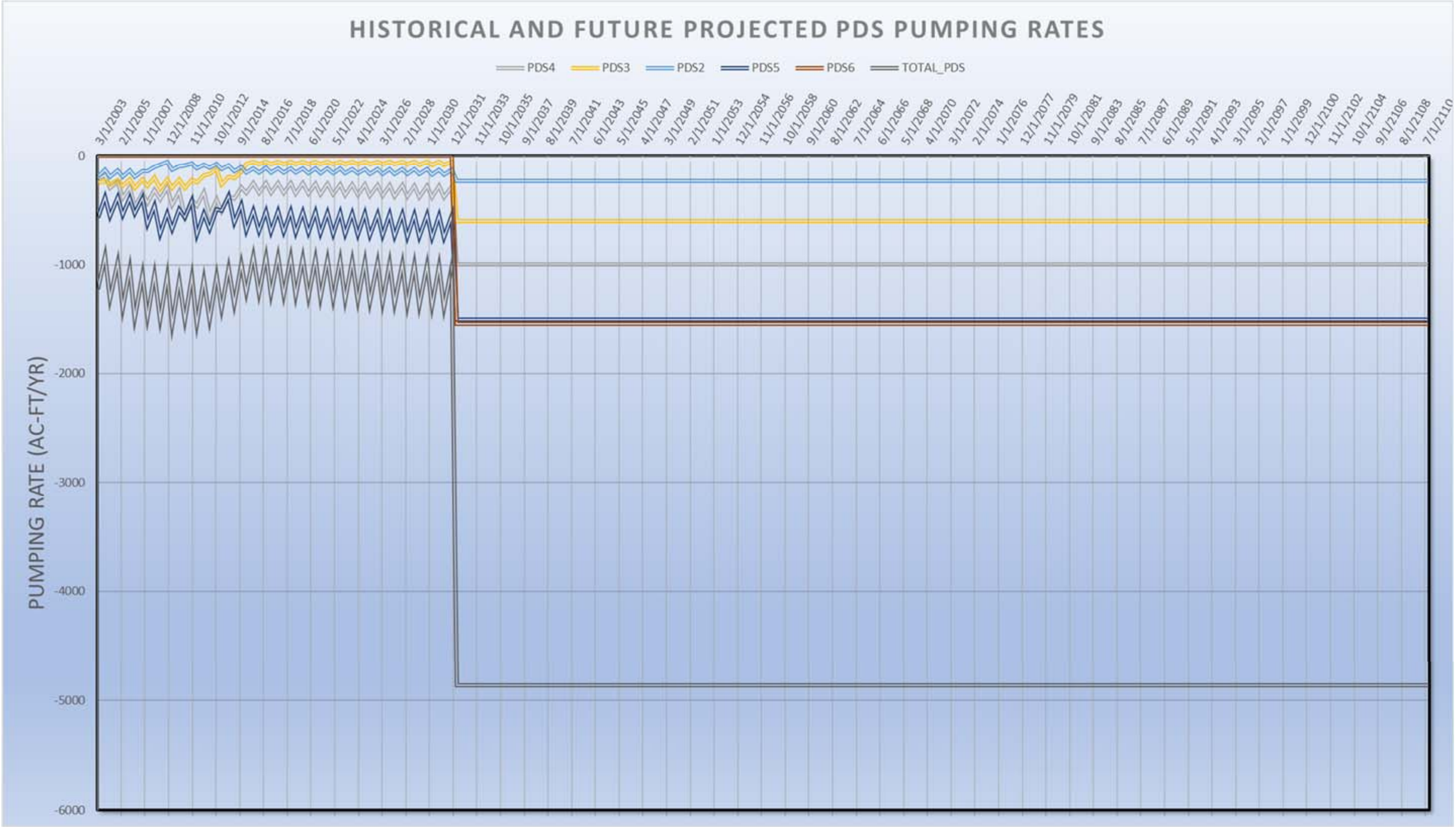

Figure 10. Historical and Future Specified Projected PDS Well Pumping

8 Simulated Scenarios

All four of the Lacher model setups needed to be run to obtain results from 2011 through 2100, and included the following periods:

- Model 1 – 2003 to 2030
- Model 2 - 2030 to 2057
- Model 3 - 2057 to 2084
- Model 4 - 2084 to 2100

Following simulation of Model 1 (from 2003 to 2030), simulated groundwater elevations (or heads) for all model layers at year 2030 were used to replace initial heads in all model layers for the next model (Model 2) simulation (replacing year 2030 starting heads). The same was done for the last 2 simulations for Model 3 and Model 4 (i.e., 2057 to 2084 and from 2084 to 2100, respectively).

As described in the 2014 PBA Groundwater modeling report (App G), two scenarios were setup and run from 2003 to 2100, using the 4 model setups above:

1) **Scenario 1 - Baseline Conditions** – **With Fort-Attributable (WFA)** pumping and recharge. It should be noted that the Baseline Conditions defined in this evaluation differ from the evaluation described in the PBA App G, in three ways:

    a. The Baseline scenario simulated in this evaluation is based on the 2018 LL model rather than the 2011 model used in the PBA, App-G evaluation, which reduced net pumping by about 10,000 ac-ft/yr (see Figure 3).

    b. A constant pumping rate in time of 1300 ac-ft/yr was specified from year 2011 to 2100 for Fort Huachuca On-Post pumping, instead of only projecting this to 2030.

    c. Pueblo Del Sol well pumping (at wells PDS 2 through 6) was increased from ~1502 ac-ft/yr (2009) to 4870 ac-ft/yr starting in 2032, based on their 2012 Arizona Adequate Water Supply Application (AAWS) Total Annual Demand (see Figure 12).

- **Scenario 2 – No Fort-Attributable (NFA).** Pumping and recharge inputs of both on- and off-post were changed as per PBA, 2014, App-G, Tables 3 and 4 (see Figure 1 and Figure 2). In addition, pumping at PDS wells (wells 2 to 6) was also reduced by 40%.

9 Simulation Results

Results from Model 4, or from 2084 to 2100 simulation were used to evaluate cumulative future impacts of the Fort Huachuca pumping and recharge at year 2100 on surrounding groundwater levels and stream baseflow. Simulated impacts to the following groundwater flow components are described below:

- Groundwater Levels
- Riparian Evapotranspiration
- Spring Flows
- Stream Baseflow Discharge

9.1 Fort-Attributable Impacts to Groundwater Levels

To assess impacts of Fort Huachuca pumping and recharge on groundwater levels (or groundwater head) from 2011 to 2100, simulated 'Baseline' heads (or With-Fort-Attributable, WFA) were subtracted from simulated No-Fort-Attributable (NFA) scenario levels at each model layer and cell, and for every winter and summer period (twice a year) model timestep. This approach is similar to how Fort-Attributable impacts to groundwater levels and streamflow were calculated in the PBA, 2014 App-G modeling study (see page G-8).

Simulated Fort-Attributable drawdown of groundwater levels (or drawdown) at year 2100, shown on Figure 11, extend throughout much of the lowest, but most spatially-extensive model layer (Layer 5). Several observations are worth noting:

1) Drawdowns exceed 18 meters in the central high density pumping well area, 2 meters beneath, and north of the central Babocomari River, and nearly 2 meters beneath portions of the southern extent of the SPRNCA, south of Lewis Springs.

2) Drawdowns vary by model layer, but in general show greater drawdown in shallower layers at the same location.

3) Fort-Attributable impacts to groundwater levels extend south of the Mexican border in the Naco/Bisbee area as shown on Figure 11.

4) Fort-Attributable pumping reduces groundwater levels most in high density well locations, as denoted by the red-triangles on Figure 11 (areas west of SPRNCA, and along lower Babocomari). At the blue triangle (478884), Fort-Attributable drawdowns exceed 25 meters, or ~82 feet (see Figure 12) by year 2100, and diminish outwards, with distance from this location.

5) The magnitude of Fort-Attributable drawdowns decrease towards zero along Babocomari and San Pedro River sections in direct hydraulic communication with different model layers (i.e., green symbols on Figure 11 denote active stream cells in model layer 5). The outward propagation of Fort-Attributable drawdowns over time north of Babocomari Wash and east of San Pedro River is moderated by increasing aquifer inflow from streams in these areas.

6) Near-linear Fort-Attributable declines in head in layers 4 and 5, from 2003 to 2100 (see Figure 12) will continue to increase beyond Year 2100 as illustrated by dashed lines/arrows projected out to about 2150.

Figure 13 shows groundwater level change (or drawdown) caused by Fort-Attributable pumping in layer 2. Again, drawdowns due to Fort pumping are greatest in western extent of layer 2. Beneath the western extent of Babocomari River in layer 2, drawdowns reach nearly 4 meters by 2100, while near the San Pedro River (near the Mexican border), heads decline nearly 1.0 m.

9.2 Fort-Attributable Impacts to Riparian Evapotranspiration

Because the Fort pumping causes drawdowns throughout the model, near Babocomari and San Pedro Rivers, this decline in water levels also reduces the loss of groundwater that sustain Riparian vegetation as transpiration from groundwater as shown on Figure 14. By 2100, the model calculates an increasing (near-linear response, like groundwater drawdowns over time) summer period transpiration loss to atmosphere, which is not insignificant (i.e., ~1.2 cfs during summer, or ~500 ac-ft cumulative loss since 2003). As a result, if model simulations were extended another 100 years (i.e., to year 2200), results would likely show continued, near-linear increasing summer-period loss of groundwater to transpiration by about 1.0 cfs. These effects should be added to net Fort-Attributable reductions in hydrologic Riparian streamflow declines. The PBA, 2014, App-G groundwater modeling study did not appear to consider these impacts caused by Fort pumping, but should have as they exceed reported streamflow reductions at year 2030.

9.3 Fort-Attributable Impacts to Spring Flows

The groundwater flow model simulates spring flow using the Modflow 'Drain' Package, which remove groundwater from the model when water levels at spring locations (foothills west of Fort Huachuca, or along Garden Canyon, Ramsey Canyon and Miller Canyon). Fort-Attributable pumping and recharge reduces drain (spring) discharge by about ~2% of the ~0.01 cfs NFA simulated flow. Though this is a relatively small impact compared to streamflow or transpiration losses, small change can be important and it is expected to increase beyond year 2100. The PBA, 2014, App-G study also failed to discuss impacts in these locations.

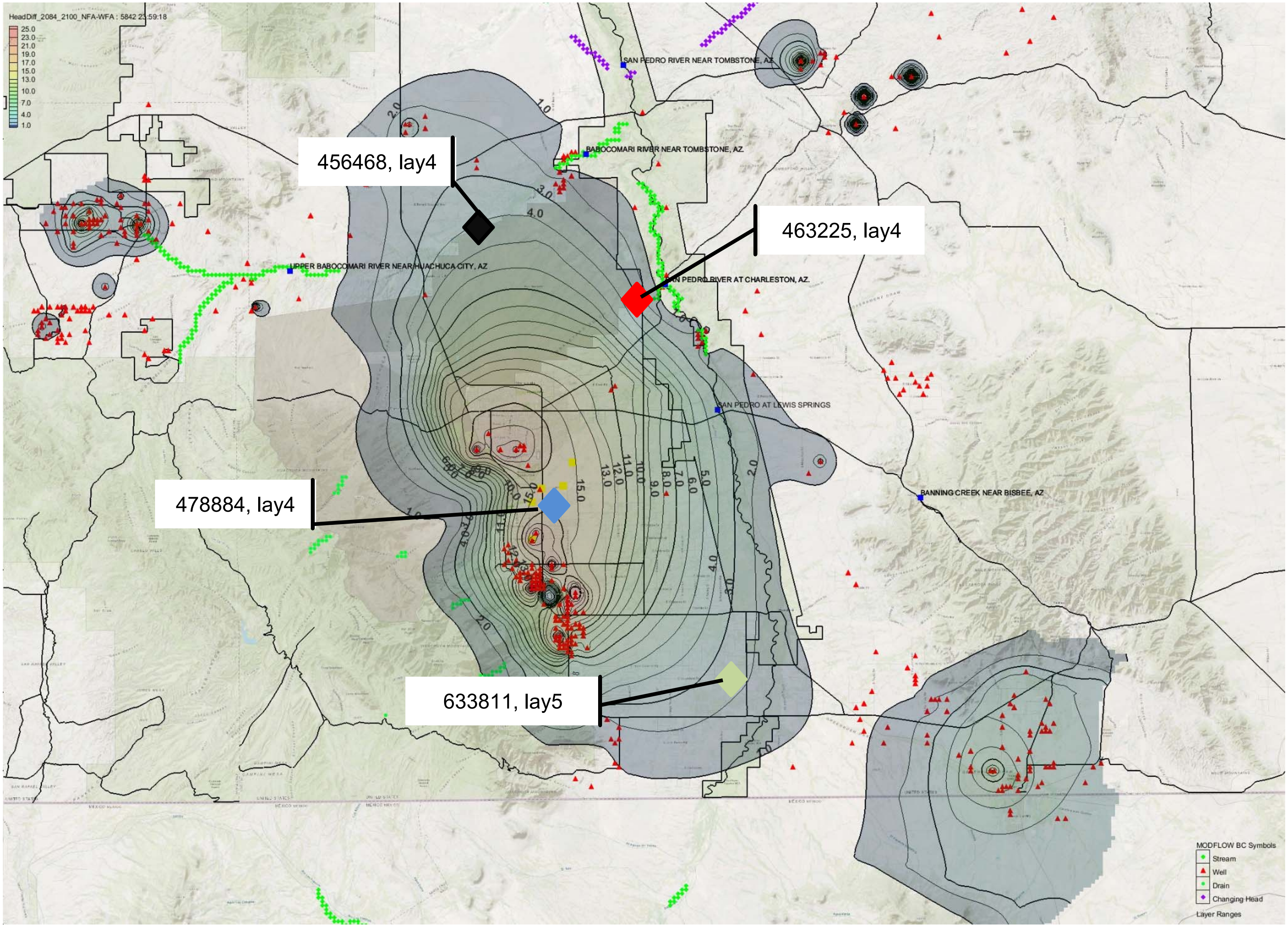

Figure 11. Simulated Fort-Attributable Groundwater Level Decline (m), or drawdown in Layer 5 at Year 2100 (winter). Contours are shown every meter and exceed 18 meters in higher density pumping areas (red triangles are pumping wells). Green diamonds are stream cells in this layer, and dark blue squares are surface water gage locations. Graphs showing Fort-Attributable head change over time are provided at the colored triangles (see Figure 12).

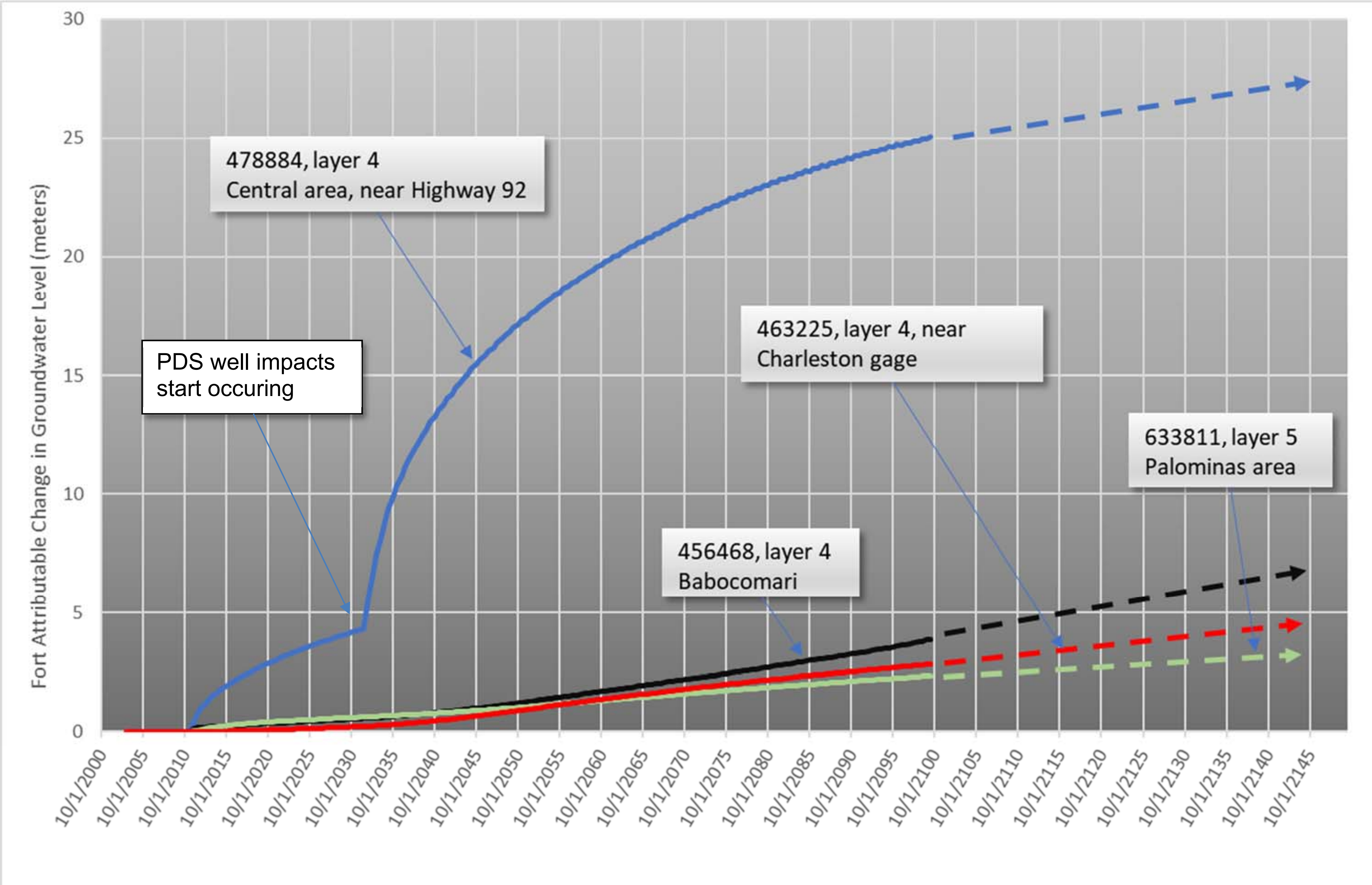

Figure 12. Simulated Fort-Attributable Drawdown (or Decrease in Groundwater Levels) at select locations on Figure 11.

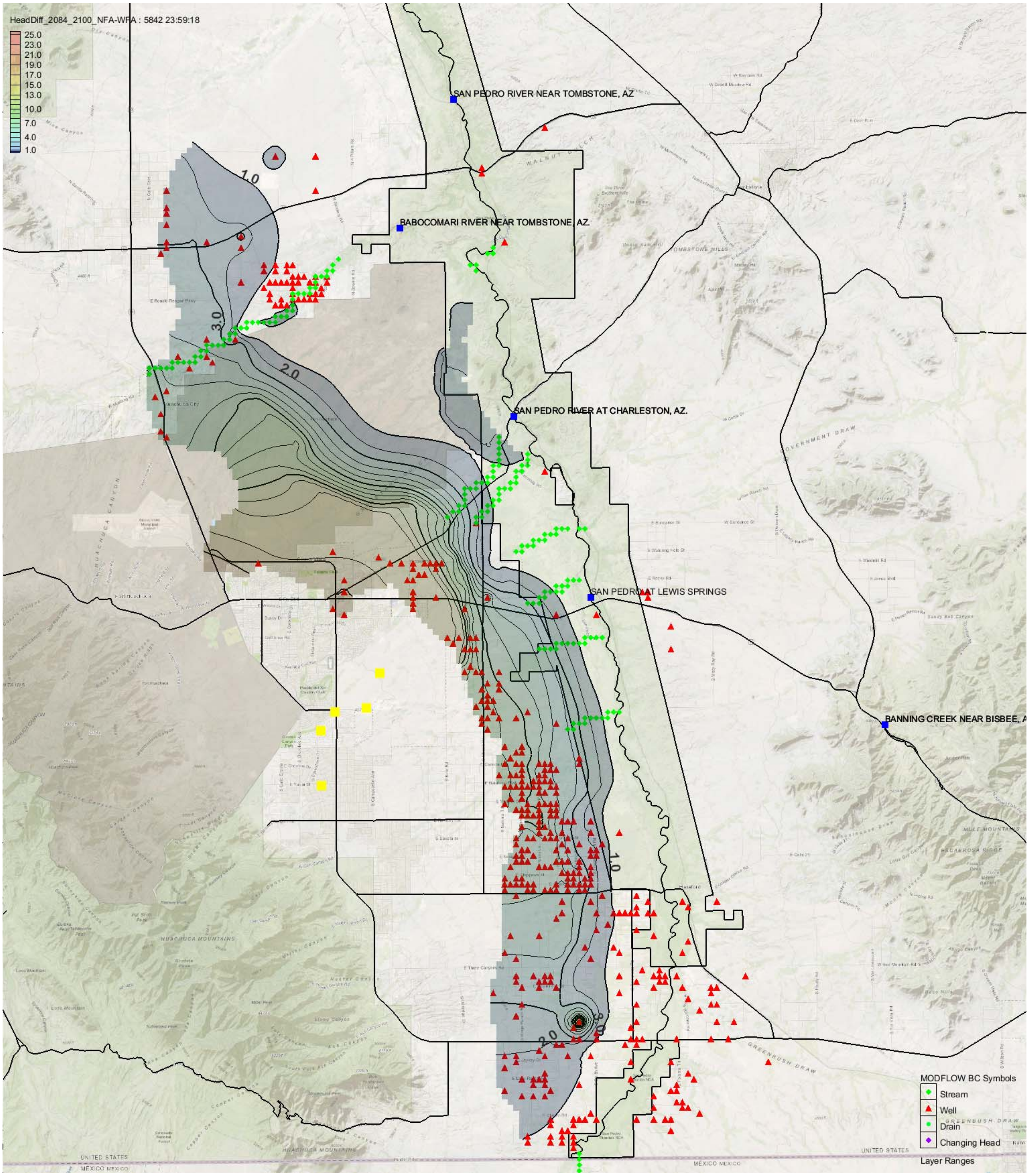

Figure 13. . Fort-Attributed Drawdown in Groundwater Levels (m) in Layer 2 at Year 2100 (winter). Drawdowns exceed 14 meters in the central-west area. Contours are shown every meter. Red triangles are wells pumping in this layer, while green symbols indicate streams in this layer. Yellow squares indicate PDS well locations. Blue squares indicate stream gage locations.

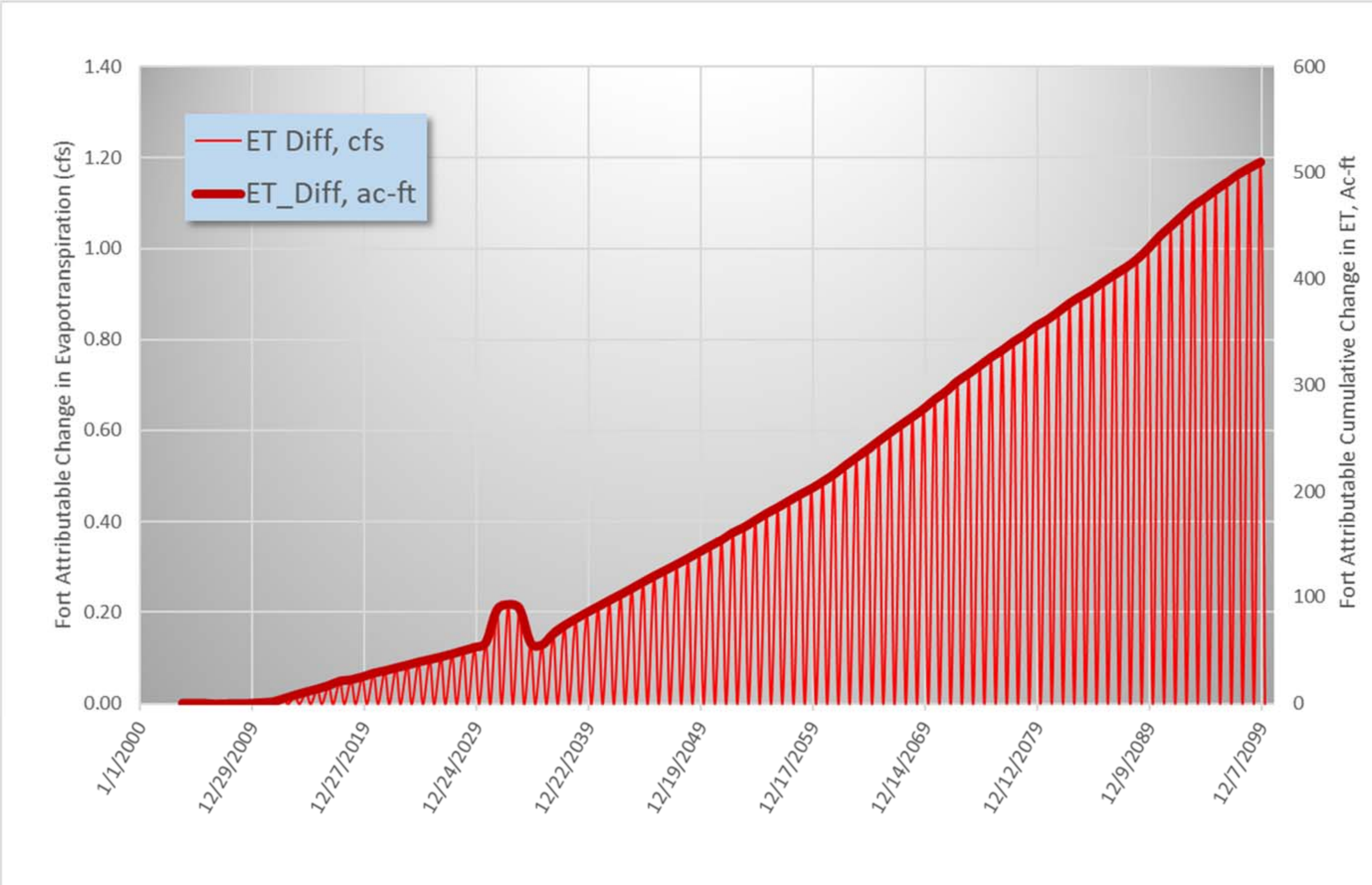

Figure 14. Fort-Attributable Change in ET (cfs and Acre-ft/yr). Positive value indicates Fort Pumping reduces (summer period from March to October) transpiration to Riparian vegetation.

9.4 Fort-Attributable Impacts to Winter Streamflow in Year 2100

Figure 16 and Figure 17 show projected impacts of Fort-Attributable Pumping (and recharge) on streamflow at year 2100 (winter). Results indicate:

- Stream discharge in Babocomari River is reduced by ~0.7 cfs (*~506 ac-ft/yr*) by year 2100 for much of the lower portion, east of State Route 90. Flows are reduced as much as ~0.23 cfs for several miles west of Huachuca Blvd.

- Flows are reduced ~1.32 cfs *(~956 ac-ft/yr*) at the northern model outlet along the San Pedro River, north of the confluence with Babocomari River (near the Tombstone surface water gage). These Fort-Attributable reductions are due to a combination of reductions in Babocomari Wash (~0.7 cfs) and San Pedro River flows upstream of the confluence (~0.63 cfs, or *~457 ac-ft/yr*).

- The tributary that feeds into the San Pedro River from the west, nearest the EOP recharge area, shows a Fort-Attributable decrease of ~0.04 cfs (*~29 ac-ft/yr*) in stream discharge by year 2100. The PBA, 2014, App-G study by contrast found a Fort-Attributable increase in flow in this area in 2030, due to the EOP recharge (and East Range recharge basins). Clearly, by 2100, Fort-Attributable pumping impacts overcome any positive impacts on the San Pedro River and tributaries near/downgradient of Fort-related recharge projects.

- Upstream of the EOP-affected tributary and south along San Pedro River to upstream of Lewis Springs (about 2.5 miles above tributary), San Pedro River discharge is reduced by Fort-Attributable pumping by about 0.11 cfs (*~77 ac-ft/yr*) by year 2100.

- Figure 16 shows San Pedro River discharge is also reduced by Fort-Attributable pumping near the Palominas census area, south of State route 92 (~3 miles) by up to ~0.72 cfs (*~521 ac-ft/yr*).

Figure 17 shows Fort-Attributable Pumping/Recharge impacts on modeled streamflow as a percent of simulated flow in each drainage (based on NFA scenario). This helps show for example, that the changes in streamflow (baseflow) in the lower San Pedro River are generally less than 10% of total baseflow at year 2100. The exception is along the lower Babocomari (~8 miles), which shows that by year 2100, Fort-Attributable Pumping reduces baseflows by 50% to 100% (darker red cells on figure). This is also the case for the southernmost San Pedro River area (near San Pedro River crossing at State Highway 92, or Palominas).

Comparison of simulated streamflow at four San Pedro River stream locations (from 2003 to 2100 on Figure 18) against those predicted for the PBA, 2014, App-G groundwater modeling study from 2005 to 2030 (see Figure 19) show:

- predicted streamflow at each location is greater than predicted in the PBA study from 2005 to 2030, because of the notable decrease in historical and projected pumping (~10,000 ac-ft/yr) estimated from Lacher's 2011 model to the 2018 model. The PBA evaluation relied upon Lacher's 2011 model.

- Though the PBA, 2014 App-G study shows Fort-Attributable recharge (i.e., EOP, east range basins) increases flows at Tombstone and Charleston gage locations (graphs on Figure 19 – dashed NFA line less than solid WFA line) at year 2030, simulated results in this study clearly show (see Figure 18) that continued Fort-Attributable pumping beyond 2030 reverses these short-term benefits by 2050 (Tombstone) and 2070 (Charleston), causing reductions in streamflow.

- Predicted streamflow at year 2100 continues to decline at a relatively steady rate, for both WFA and NFA scenarios, due to increasing pumping with time (much higher than artificial recharge in case of WFA).

- The NFA simulated flows are the same as the WFA through year 2011, but then start to deviate. NFA reductions in near-stream **recharge** at the EOP and East Range Basins cause NFA scenario streamflow at the Charleston and Tombstone locations to decline, relative to the WFA (i.e., where solid WFA lines are above dashed NFA lines on Figure 18). NFA flows remain less than the WFA flows until about 2054 (Tombstone) and 2080 (Charleston), when NFA streamflow exceeds WFA streamflow, which reflects when Fort-Attributable pumping effects reverse benefits of Fort-Attributable recharge projects. This is further supported by seeing the opposite effect along Babocomari wash, where the NFA flows increase (see green lines on Figure 18) very shortly after 2011, because streamflow in this wash is dominated by the nearby, high density of wells. This Babocomari wash area is too far away to be directly influenced by EOP and east range basin groundwater recharge.

Predicted change in streamflow at the four stream locations (on Figure 17) are illustrated on Figure 20. Results show the following:

- At all locations, except at Babocomari, Fort-Attributable pumping will continue to reduce streamflow (beyond year 2100), though the rate of decline will decrease over time. However, it is important to appreciate that these Fort-Attributable impacts **do not** consider the relatively long historical impacts of Fort pumping prior to 2011 (i.e., 1940 through 2010), which would significantly increase both the magnitude and duration of Fort-Attributable impacts groundwater levels and streamflows reported here. GeoSystems Analysis, Inc, 2010[1] describe earlier attempts at assessing the entire historical impacts 1902 to 2105. They state on page 3-5 "*While simulated Fort-attributable pumping accounts for only 19% of total basin pumping from 1902-2105, the Fort's simulated impact on baseflow capture is again large relative to its total pumping, as indicated on Figure 17. The capture simulations estimate that 186,237 AF out of a total of 293,383 AF, or 63%, of capture baseflow in the USPB is caused by Fort-attributable pumping during the period 1902-2105*"

- At the Babocomari location, the rate of change in Fort-Attributable streamflow reduction calculated in this study decreases beyond year ~2090, likely due to flows approaching zero (i.e., drying up), caused by intensive pumping along the lower reach.

- The rate of decline of change in Babocomari streamflow translates into a decreasing rate of decline at the model outlet (Tombstone gage), though by 2100, Fort-Attributable flow reduction here reaches ~1.32 cfs, which is much higher than the 0.1 cfs decline estimated by the PBA, 2014, App-G modeling effort through 2030.

- Though declines near the Tombstone gage appear to reach a steady value (~1.32 cfs) by 2100, these will likely increase beyond 2100 due to increasing reduction of Fort-Attributable streamflow (~0.47 cfs at year 2100) at the upstream Charleston gage location (see Figure 20), and even further upstream at the Lewis Spring location, though increases here are much less at 2100 (~0.1 cfs).

[1] GeoSystems Analysis, Inc. (GSA). 2010a. Calculation of Pumping-Induced Baseflow and evapotranspiration Capture Attributable to Fort Huachuca. Prepared for Environmental and Natural Resources Division, Fort Huachuca. Collaborated with Vernadero Group, Inc. November 2010.

9.5 Future Climate Change Effects

The MODFLOW groundwater flow model does not have the capability of translating climate changes (i.e., precipitation, air temperature, humidity, potential evapotranspiration, snowmelt etc) into changes in groundwater recharge and transpiration from the groundwater system. This process is complicated, and requires a more sophisticated code such as the fully-integrated, physically-based DHI MIKE SHE/MIKE Hydro code and the associated IPCC-based, Climate Change tool by DHI. This code has been used extensively, to assess climate change impacts on hydrologic systems worldwide, for example prucha et al, 2011[2], Wobus et al, 2015[3], and Thompson et al, 2017.

Estimated International Panel on Climate Change (IPCC) changes for climate factors used in integrated models at the Fort Huachuca latitude/longitude, were selected as a combination of 22 standard Global circulation models for the SRA1B CO2 emission scenario, year 2100. Figure 15 shows air temperature at year 2100 for all months increases from 3 to nearly 4.5 degrees C, which then increases the Potential Evapotranspiration (PET) for all months. Increased PET will reduce groundwater levels and recharge to the Upper San Pedro River aquifer system, which in turn will reduce streamflows. A simple conceptual MIKESHE hillslope model, using hourly (NLDAS) precipitation and PET climate data for the area, was developed here, and confirms that both streamflow and groundwater levels **throughout the year** will likely decrease, due to future changes in climate. This is important, because impacts of continued Fort Huachuca pumping will likely be further negatively impacted by changing climate. Detailed climate change analysis of the future projections should be accounted for in assessments of Fort Huachuca pumping impacts on future San Pedro River surface flows. Variations and characteristics of Fort-Attributable land-surface modifications, soil and vegetation types and distributions, and climate throughout the San Pedro River need to be considered in this type of analysis, which would also require more complex codes like MIKESHE (or GSFLOW and Hydrogeosphere, as noted on page 128 of the 2016 San Pedro River Aquifer Binational Report).

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[2] Prucha, R.H., Leppi, J., McAfee, S., Loya, W., 2011. Integrated Hydrologic Effects of Climate Change in the Chuitna Watershed, Alaska for the U.S. Fish and Wildlife, Anchorage, AK.

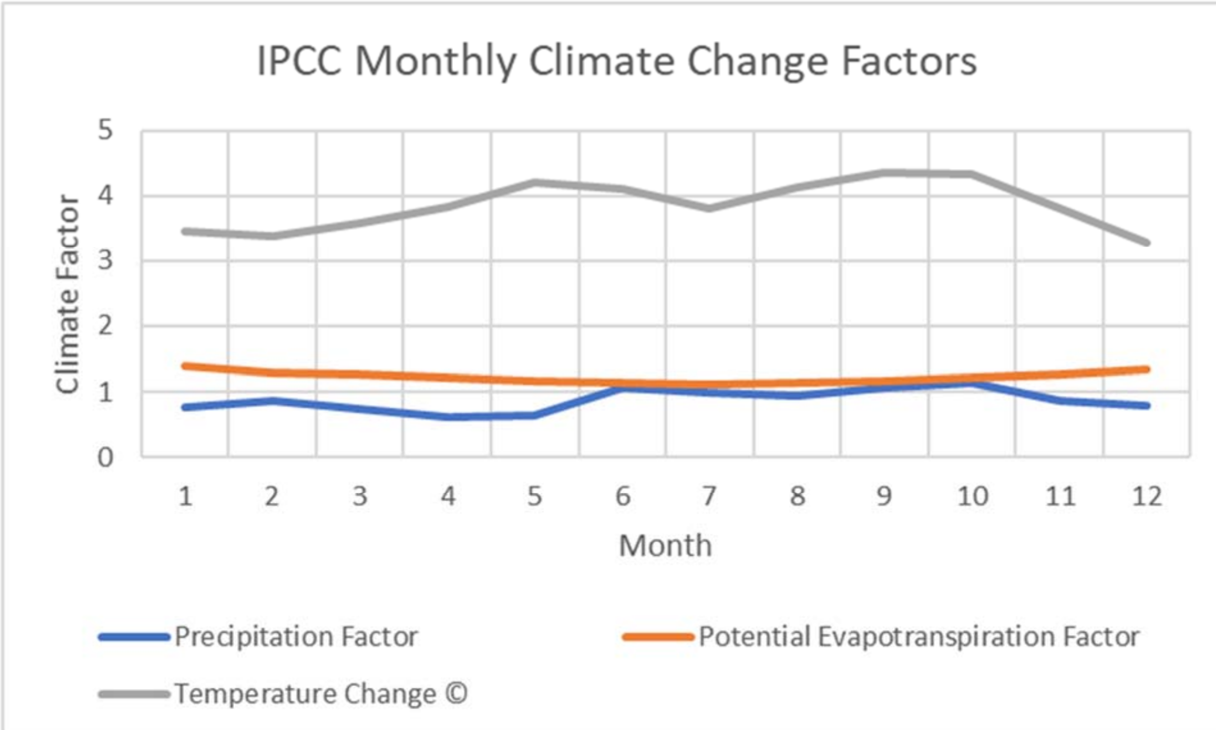

Figure 15. Estimated Monthly IPCC-based Changes in Climate factors at Ft. Huachuca.

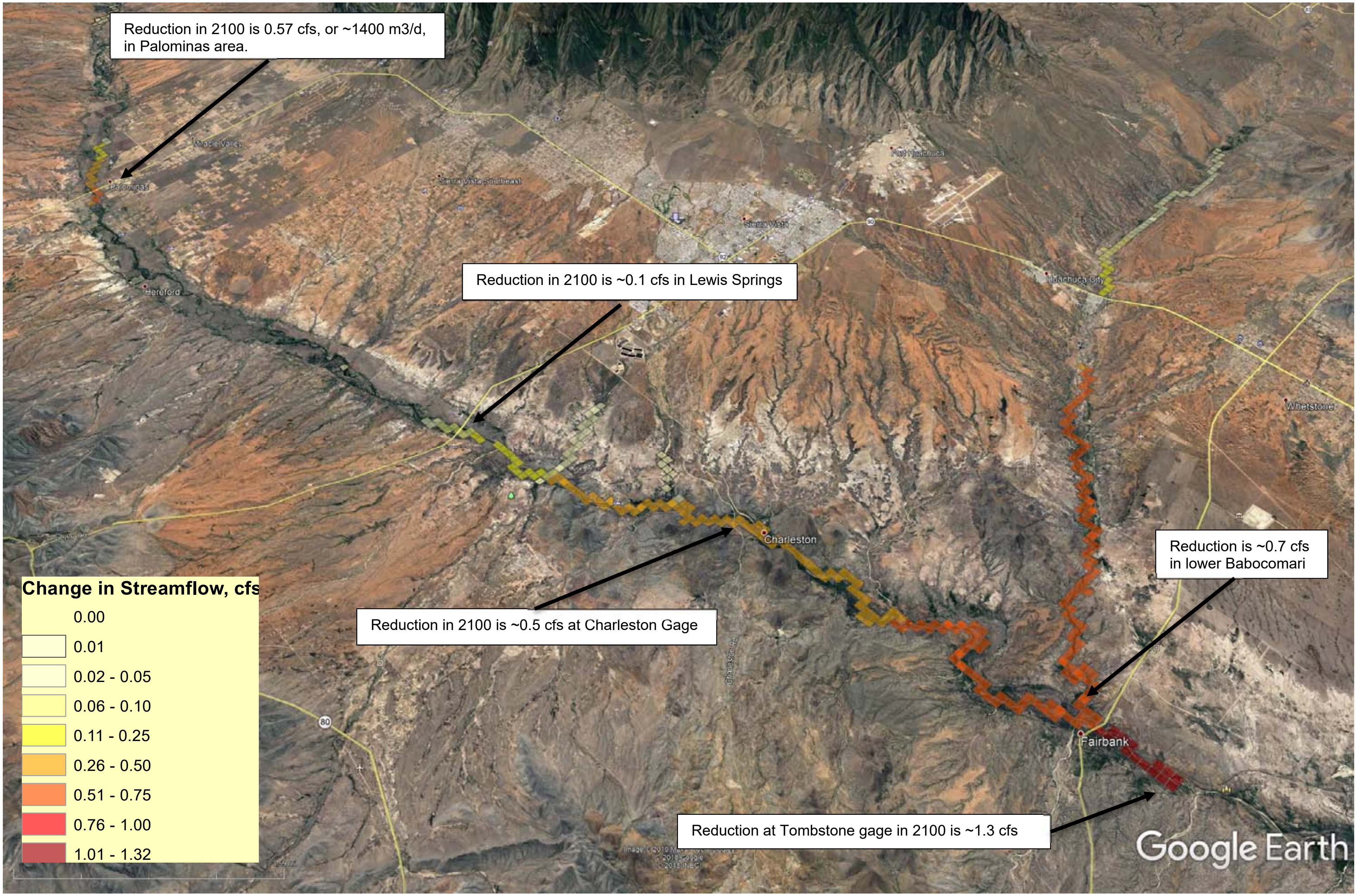

Figure 16. Change in Winter Streamflow (cfs) at Year 2100 due to Fort-Attributable Groundwater Pumping and Recharge (Southern SPRNCA Area). Positive values indicate streamflow decreases, and Negative values indicate streamflow increases.

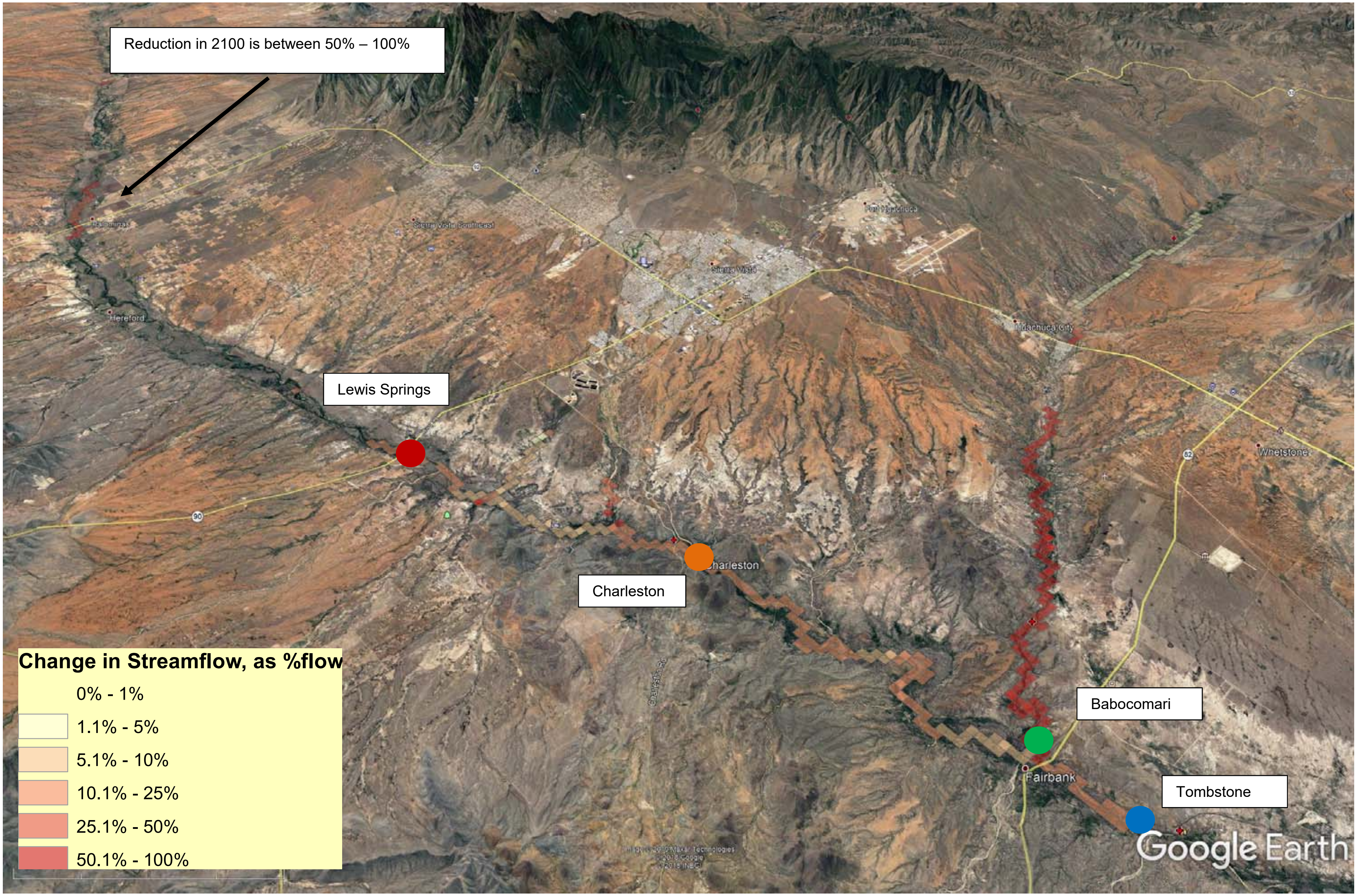

Figure 17. Change in Streamflow at Year 2100 as a Percent of NFA Simulated Flows. Surface flow gages shown with green-balloon symbols, black symbols are wells. Colored Circles are locations of time series (see Figure 18).

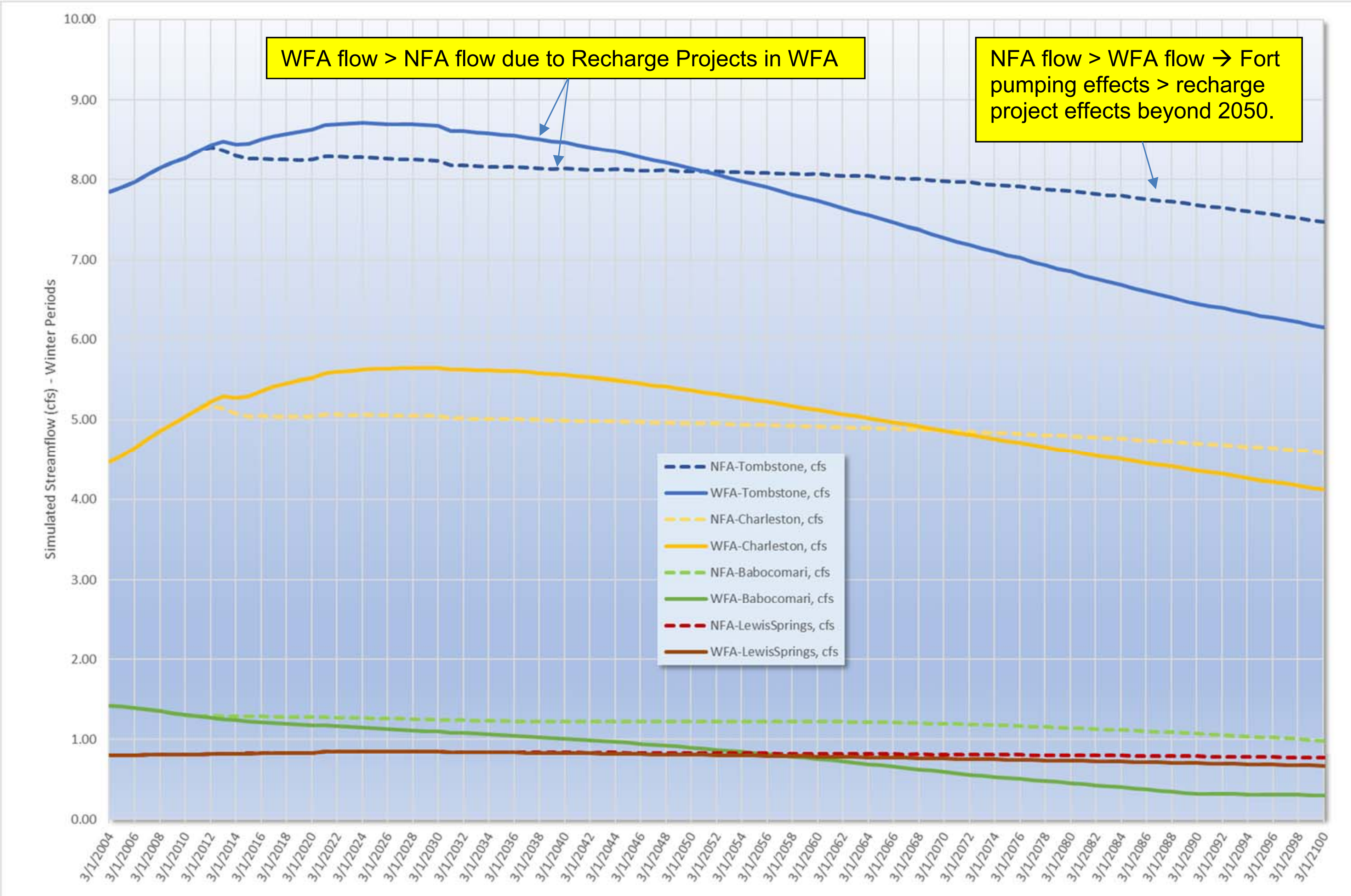

Figure 18. Simulated Streamflow and Change in Streamflow at Key Surface Flow Gages (see Figure 16 for locations).

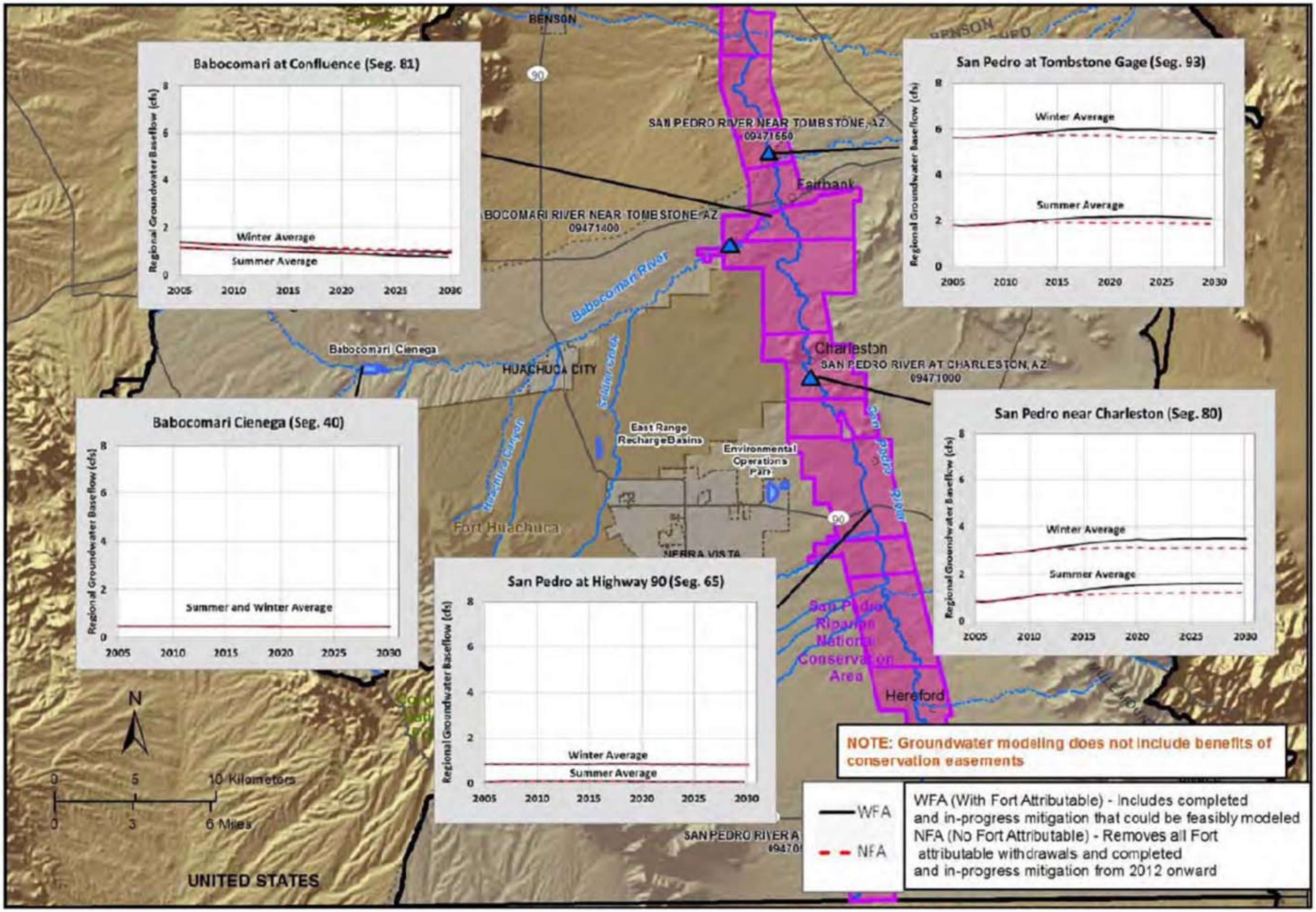

Figure 19. From PBA Appendix G Groundwater Modeling Report (Figure 10). Though the 2014 PBA, App-G study shows positive Fort-Attributable impacts (i.e., at Charleston and Tombstone) due to recharge projects at 2030, the previous figure (Figure 18) clearly shows Fort-Attributable pumping impacts reverse recharge benefits in these areas by 2050 (Tombstone) and 2070 (Charleston).

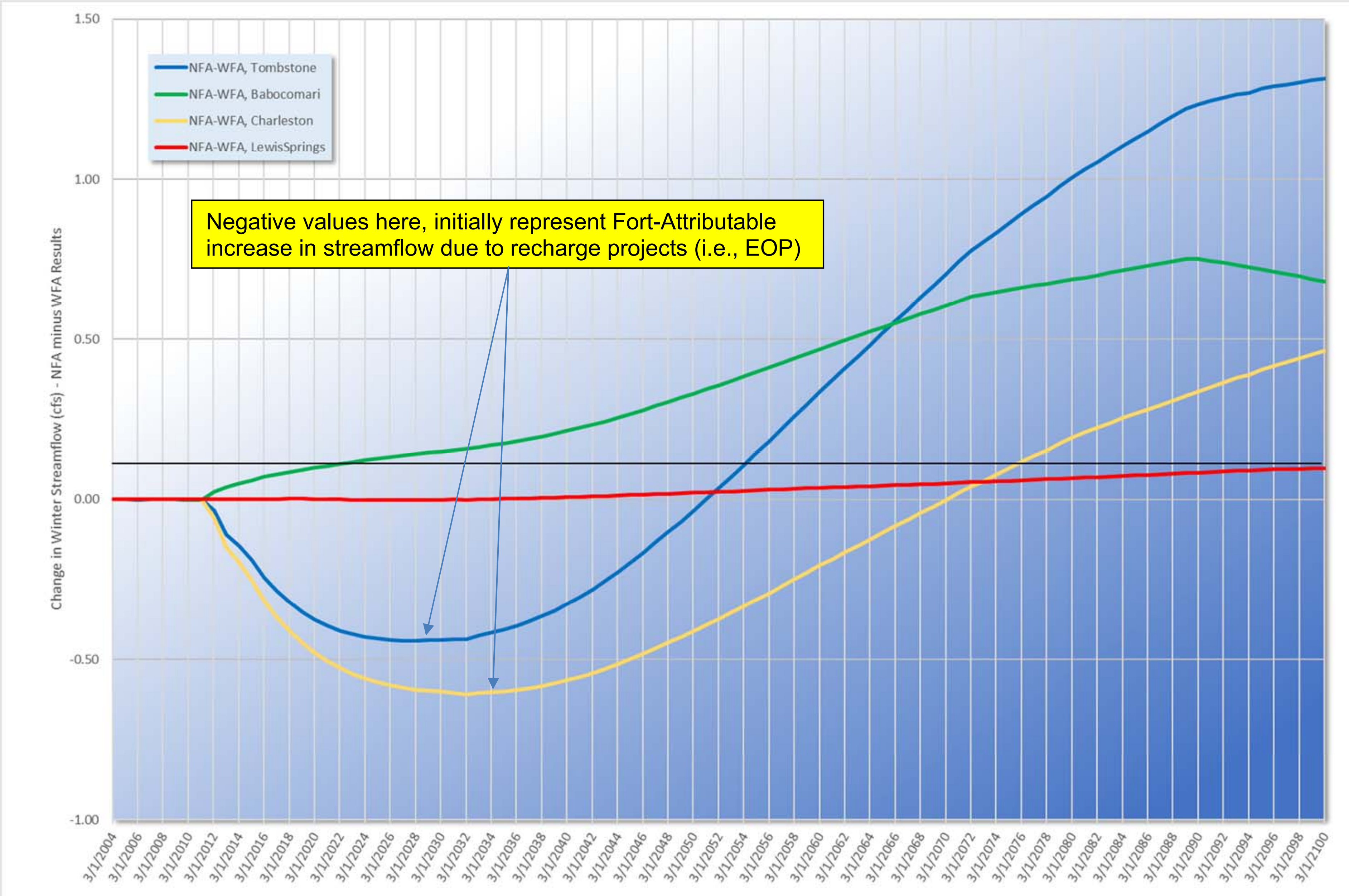

Figure 20. Simulated Fort-Attributable Change in Winter-period Streamflow (see Figure 16 for locations). Positive values – reflect Fort-Attributable reduction in streamflow. Negative values – reflect Fort-Attributable increase in streamflow (i.e., recharge projects).