Simulated Cochise Conservation and Recharge Network Maximum Recharge with Updated Sierra Vista Subwatershed Pumping

Prepared for The Nature Conservancy

Contract No. AZFO 160705

By

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June 2017

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EXECUTIVE SUMMARY

This study simulates groundwater recharge in the Sierra Vista subwatershed (SVS) via a network of five recharge sites known as the Cochise Conservation and Recharge Network (CCRN). As of the writing of this document, only the Palominas Recharge Project, the Horseshoe Draw Flood and Erosion Control Project, and the City of Sierra Vista's Environmental Operations Park (EOP) recharge facility are operational. While stormwater is presently the only identified source of recharge for the Horseshoe Draw site, future recharge of additional water that could conceivably increase the project's recharge capacity by ten fold is simulated in this study. For the remaining two CCRN sites, Riverstone and Bella Vista, the water simulated as recharge in this study has not been secured, final project design capacities have not been established, and no structures have been built. The simulated recharge scenarios in this study were informed by CCRN members to explore the maximum likely impact of simultaneous operation of all five recharge sites at their anticipated maximum potential recharge rates. An additional scenario with maximum CCRN recharge entailed a 2000-acre-foot per year (AFA) reduction in pumping in Mexico to test the impact of that change on simulated baseflows. The simulations were conducted using the most recent update (Lacher, 2017) to the U.S. Geological Survey's MODFLOW groundwater model of the Upper San Pedro Basin (USPB) (Pool & Dickinson, 2007).

The "Max CCRN" recharge scenario in this study applies 4,083 AFA of managed aquifer recharge from 2015 to 2039, then 4,483 AFA from 2040 to 2075. The "No CCRN" scenario applies 2,823 AFA of recharge from 2015 to 2023, then drops to 80 AFA from 2023 to 2075, representing the cessation of EOP recharge (2,743 AFA) and continued stormwater-only recharge at the Palominas and Horseshoe Draw sites. The Max CCRN scenario increases simulated baseflow and extends the time to peak simulated baseflow at the Charleston, Lewis Spring, and Palominas stream-flow gaging station sites on the USPR. Because of its location downstream of the EOP and Bella Vista recharge sites, the Charleston site experiences the largest simulated increase in baseflow from the Max CCRN scenario. By 2075, the Max CCRN scenario increases simulated baseflow at the three gaging station sites by 82% (Charleston), 16% (Lewis Spring), and 23% (Palominas).

The EOP is the largest single CCRN recharge site, making up more than 60% of the total Max CCRN recharge simulated in this study. These results suggest that maintaining current levels of recharge at the EOP will be extremely important for long-term maintenance of baseflows in the Charleston reach of the USPR and below the Babocomari confluence. An expanded Horseshoe Draw project has the potential to significantly increase simulated baseflows near Palominas. The Max CCRN recharge at Riverstone significantly increases simulated baseflow in up to three miles of stream near the center of the SVS and produces measurable gains at the Lewis Spring area.

Although pumping in Mexico makes up more than 50% of all simulated pumping in this study, reducing that pumping by 2,000 AFA (about 9% of the pumping centered on the Upper San Pedro River) has no discernable impact on simulated baseflows in the Max CCRN recharge scenarios. This result indicates that, because much of the simulated Mexico pumping occurs in a deep aquifer that is poorly connected to the USPR, for the simulation period in this study (2003-2075), most of this 2,000 AFA of reduced pumping derives from aquifer storage rather than stream or evapotranspiration capture.

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Acronyms Used

AFA – acre-feet per annum

cfs – cubic-feet per second (approximately 724 AFA)

EOP – Environmental Operations Park

ET - evapotranspiration

MAR – managed aquifer recharge

SPRNCA – San Pedro National Riparian Conservation Area

SVS – Sierra Vista subwatershed

USGS – United States Geological Survey

USPB – Upper San Pedro Basin

TECHNICAL MEMORANDUM

SIMULATED CCRN RECHARGE WITH UPDATED SIERRA VISTA SUBWATERSHED PUMPING

June 2017

Introduction

This study utilizes the most recent update (Lacher, 2017) to the Upper San Pedro Basin MODFLOW groundwater model developed by the U.S. Geological Survey (USGS) (Pool & Dickinson, 2007) to simulate the response of groundwater and surface water to managed aquifer recharge (MAR) in the Sierra Vista subwatershed (SVS). This simulated MAR occurs via the sequential development of five recharge projects managed by members of the Cochise Conservation and Recharge Network (CCRN) along approximately 25 miles of the Upper San Pedro River. The CCRN recharge projects are intended to help meet the water needs of this flowing river and the streamside riparian forest within the U.S. Bureau of Land Management's San Pedro Riparian National Conservation Area (SPRNCA) given the nearby regional cone of depression. In order to test the potential effectiveness of the CCRN recharge projects, this study compared the simulation results to a "no action" alternative simulation.

The five CCRN recharge sites include, from north to south: 1) Bella Vista, 2) the Sierra Vista Environmental Operations Park (EOP), 3) Riverstone, 4) Palominas, and 5) Horseshoe Draw (Figure 1). Each site's potential recharge capacity and mechanism is unique and, as of the writing of this document, only the Palominas Recharge Project, the Horseshoe Draw Flood and Erosion Control Project, and the EOP are operational. The Horseshoe Draw project construction was completed during the finalization of this memo, but stormwater runoff is presently the only source of recharge for that site. Future recharge of additional water (treated effluent) that could conceivably increase the Horseshoe Draw project's recharge capacity by 10 fold is simulated in this study. For the remaining two CCRN sites, Riverstone and Bella Vista, the water simulated as

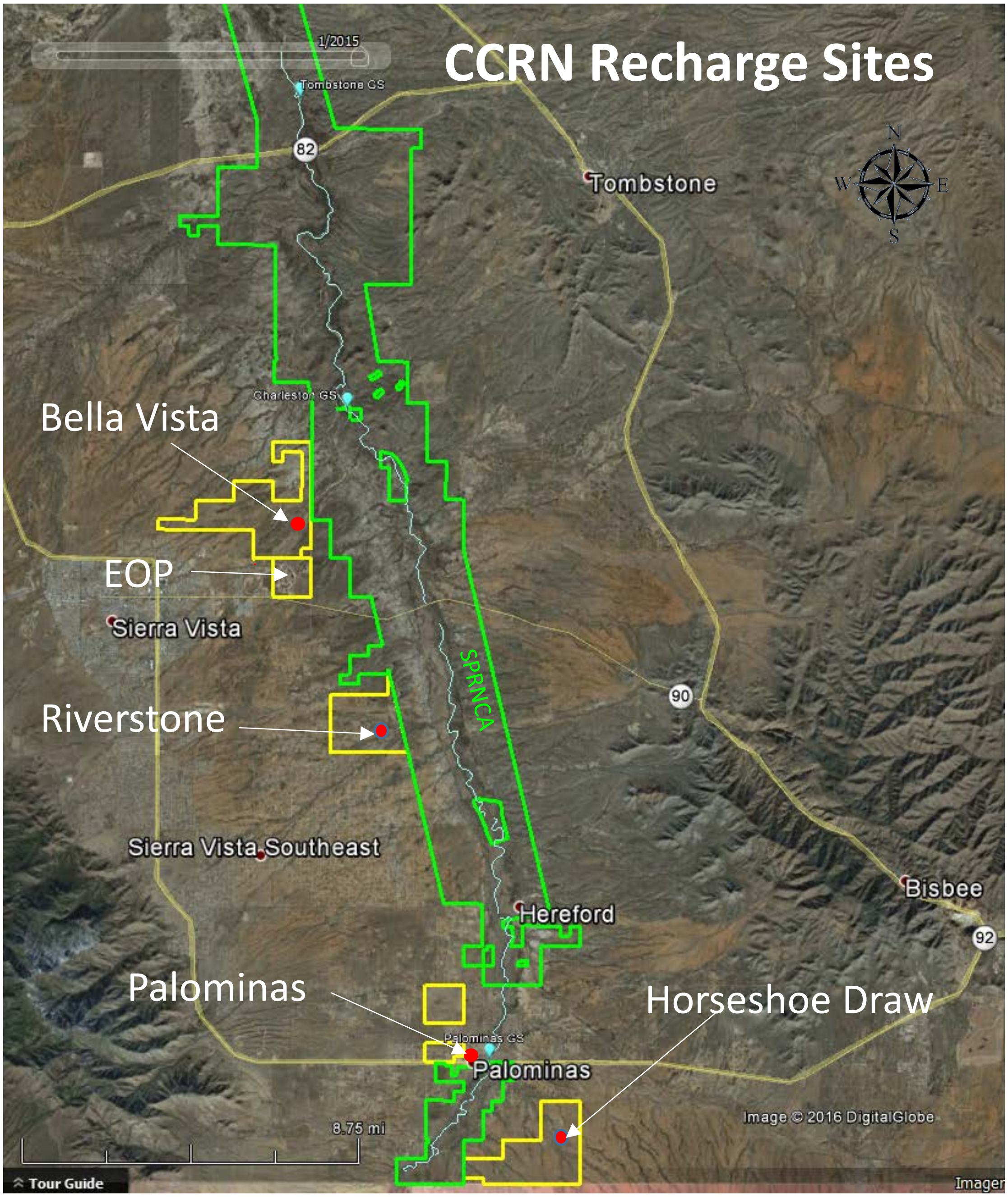

Figure 1. CCRN Sites in Sierra Vista subwatershed. San Pedro Riparian National Conservation Area (SPRNCA) outlined in green.

recharge in this study has not been secured, final project design capacities have not been established, and no structures have been built. The simulated recharge scenarios were informed by CCRN members and reflect either observed recharge volumes, or the best estimates of potential available recharge volumes. The scenarios were designed to explore the maximum likely impact of simultaneous operation of all five recharge sites at their maximum potential recharge rates. These simulations may be updated in the future with as-built project design recharge capacities if, and when, the proposed recharge projects are constructed.

Methods

Two recharge scenarios were simulated in this study. The first involves all five CCRN recharge sites shown in Figure 1 and is referred to as "Max CCRN." The simulation period extends from 2003 to 2075, with simulated recharge starting at specific times and continuing throughout the simulation period. In order to evaluate the potential cumulative impact of the five CCRN recharge projects, a second simulation, referred to as "No CCRN," was run with only the Palominas and Horseshoe Draw sites under their current designs and capacities. In this scenario, the EOP recharge ceases in 2023, reflecting the end of the City's obligation to recharge under its funding agreement with the U.S. Bureau of Reclamation (US Bureau of Reclamation, 2000). A variant of the Max CCRN simulation includes a 2,000 acre-feet per year (AFA) (9%) reduction in pumping in the Mexican portion of the Upper San Pedro Basin to represent potential conservation in agriculture and mining uses in order to test the sensitivity of simulated San Pedro River baseflows and CCRN recharge to pumping in Mexico.

Table 1 summarizes the Max CCRN and No CCRN recharge scenarios. While the recharge rates in the table start in 2015, past EOP recharge (Dooley, 2014) is incorporated in both simulations. As indicated in the yellow portion of Table 1, simulated recharge at Riverstone initiates in 2025 at 400 AFA then increases by 400 AFA (for 800 AFA total) in 2040. This increase reflects the possibility of additional treated effluent becoming available for recharge if development in Sierra Vista increases over time. The 400 AFA of simulated recharge at Horseshoe Draw reflects the likely maximum volume of treated effluent that potentially may be acquired from the Bisbee-Naco area for recharge in the future, including the estimated 40 AFY of stormwater recharge expected for the project as currently constructed (effective 2017).[1] Total CCRN recharge for the Max CCRN scenario is 4,123 AFA from 2015 to 2039, then 4,523 from 2040 to 2075.

[1] The 40 AFA of stormwater recharge at Horseshoe Draw was not included in the Max CCRN simulation for the 2017-2020 period as the simulations were completed prior to completion of the facility construction. However, the No CCRN simulations indicate no measurable baseflow effects from those three years of storm-water only recharge.

Table 1. Recharge Simulations

Simulated Recharge (2015-2075)				
Recharge Senario	**Site**	**Recharge Rate (AF/yr)**	**Year ON**	**Year Off**
Max CCRN Recharge	EOP Basins	1938	2015	
	EOP Wetlands	805	2015	
	Palominas RP	40	2016	
	Bella Vista	500	2020	
	Horseshoe Draw	400	2020	
	Riverstone (part 1)	400	2025	
	Riverstone (part 2)	400	2040	
Total Max CCRN Recharge 2015-2039		4483		
Total Max CCRN Recharge 2040-2075		4883		
No CCRN Recharge	EOP Basins	1938	2015	2023
	EOP Wetlands	805	2015	2023
	Palominas RP	40	2016	
	Horseshoe Draw	40	2017	
Total No CCRN Recharge 2015-2022		2823		
Total No CCRN Recharge 2023-2075		80		

The No CCRN recharge scenario (green portion of Table 1) includes a cessation of EOP recharge in 2023, as discussed in the Introduction above. The Horseshoe Draw and Palominas facilities recharge only stormwater in this scenario. Total CCRN recharge for the No CCRN scenario is 2,823 AFA from 2015 to 2022, then 80 AFA from 2023 to 2075.

All of the simulations in this study were run with the most recent update to SVS pumping and artificial recharge (Lacher, 2017). No change to the constant natural recharge rate applied in the original USGS MODFLOW model (Pool & Dickinson, 2007) was applied in this study.

Figure 2 illustrates the distribution and magnitude of simulated MAR for each of the five CCRN sites in the Max CCRN recharge scenario. As the figure indicates, EOP recharge constitutes the greatest single source of simulated MAR, totaling 61 to 67% of the total MAR volume in this scenario.

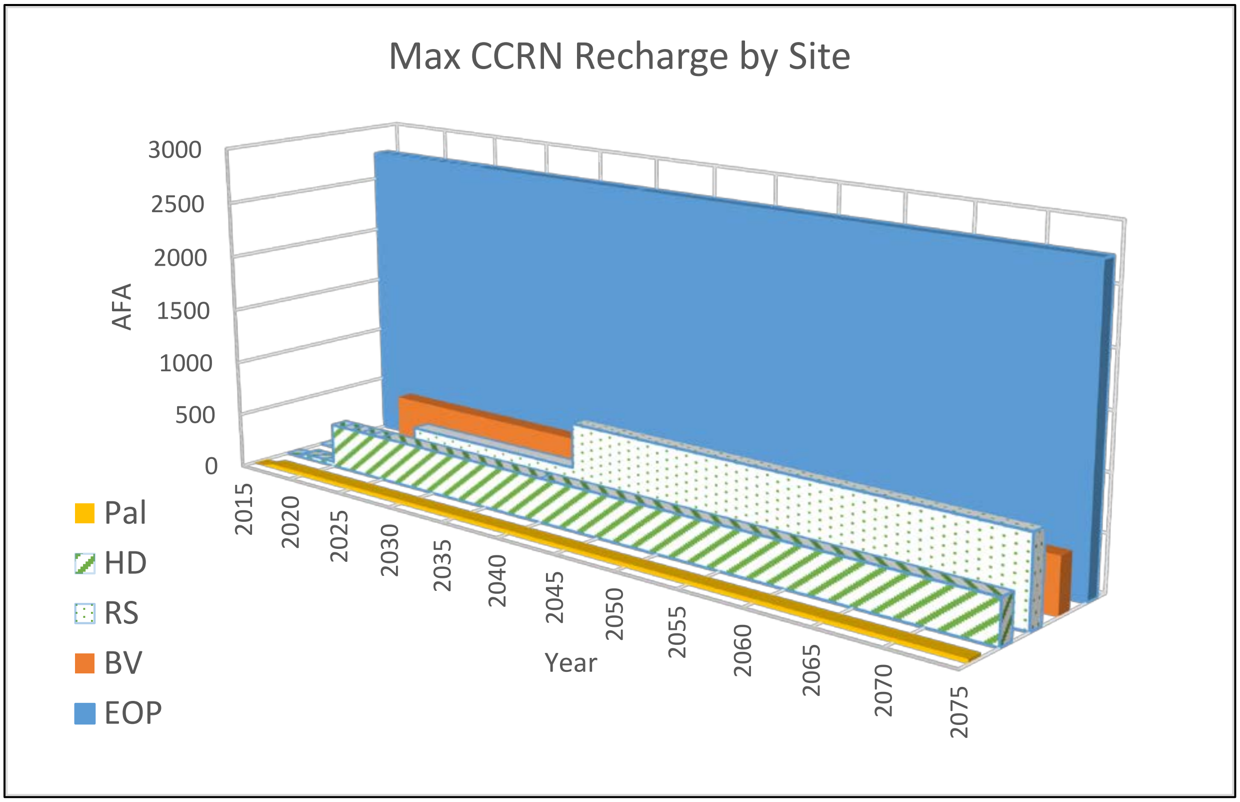

Figure 2. Simulated recharge rates by site for the Max CCRN recharge scenario.

Figure 3 presents the simulated MAR for the No CCRN recharge scenario. In this case, EOP recharge comprises more than 97% of total MAR until 2023, when simulated EOP ceases. From 2023 to 2075, only the Palominas and Horseshoe Draw sites contribute MAR in the No CCRN recharge scenario.

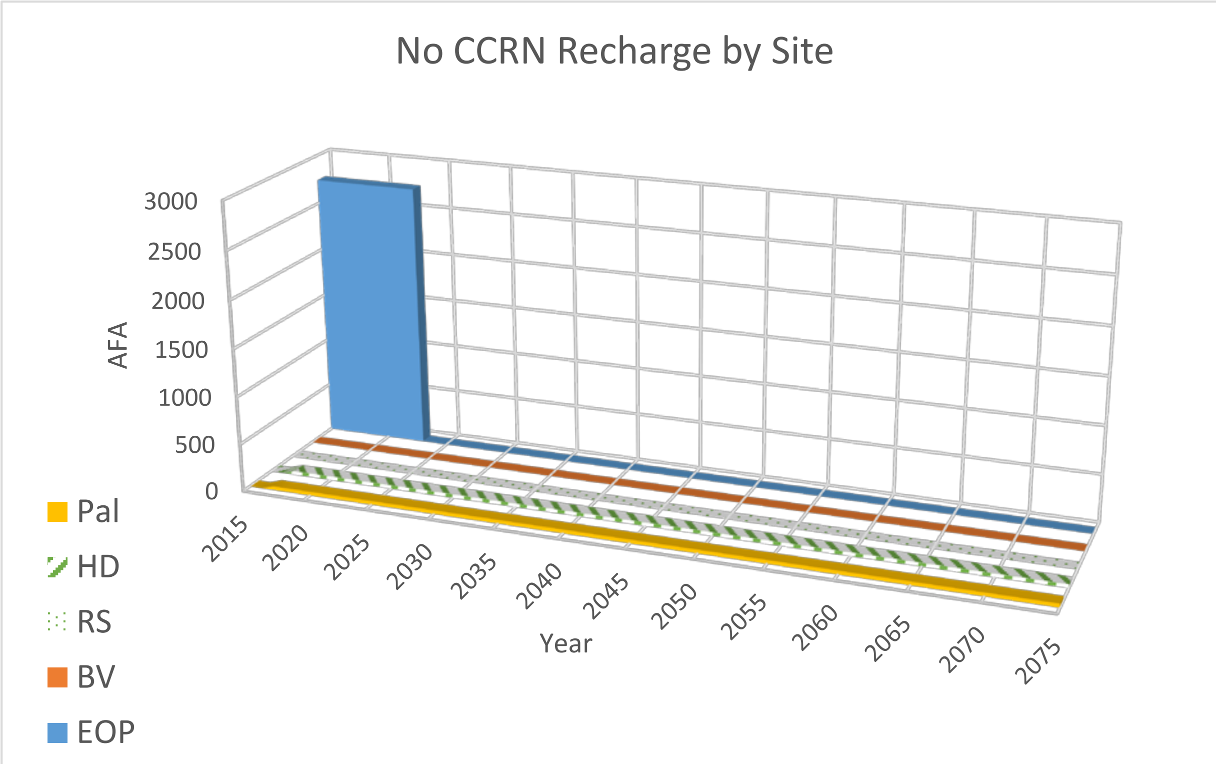

Figure 3. Simulated recharge rates by site for the No CCRN recharge scenario.

Results

Water Budget Analysis

Max CCRN vs No CCRN Recharge

Figure 4 plots simulated net pumping (extraction minus injection) and storage depletion for the Max CCRN and No CCRN scenarios. Net pumping in both scenarios is identical to that presented in the model update by Lacher (2017). The increased MAR in the Max CCRN scenario reduces storage depletion and this water budget component changes the most between the Max CCRN and No CCRN simulations, as discussed below. The minimum storage depletion (27,695 AFA) occurs in 2021 after the onset of Bella Vista and Horseshoe Draw (treated effluent) recharge. By contrast, minimum net pumping (37,364 AFA) occurs earlier (in 2016), indicating that the CCRN recharge offsets storage depletion by pumping.

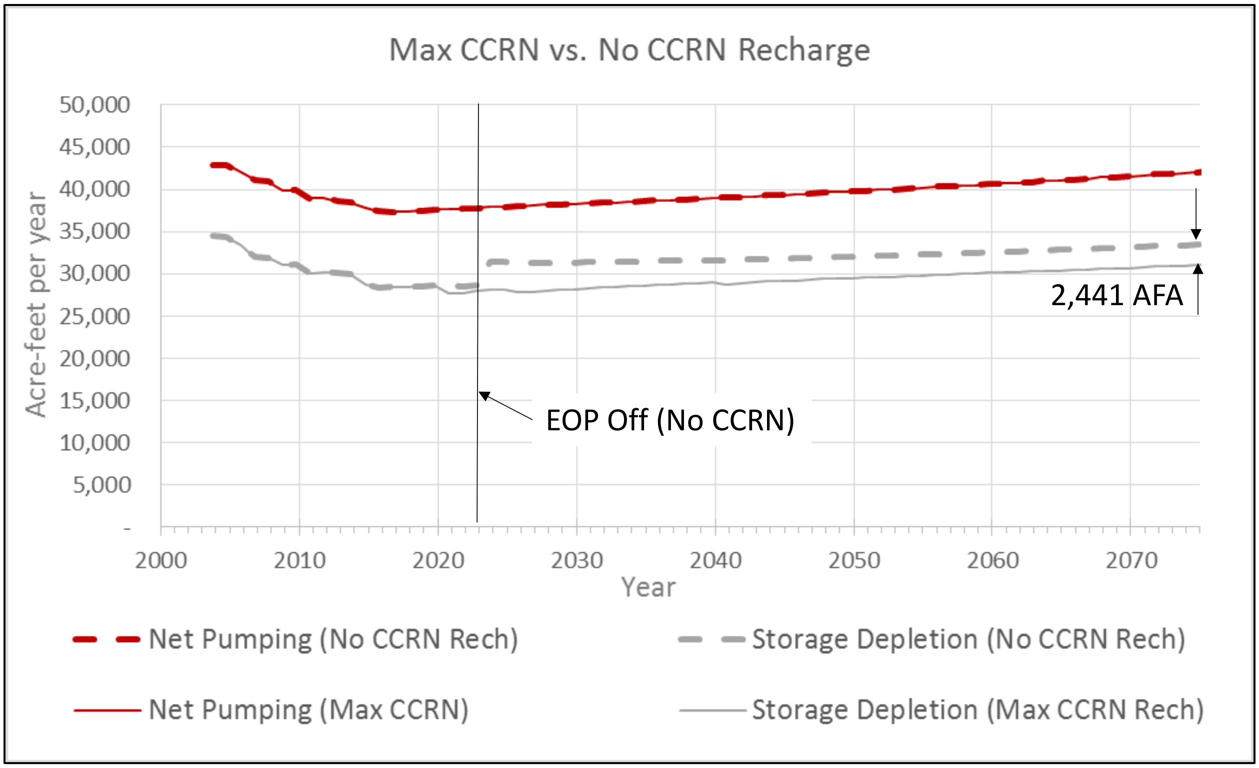

Figure 4. Simulated net pumping and storage depletion for the No CCRN and Max CCRN recharge scenarios.

Comparison with the No CCRN recharge scenario illustrates the cumulative impacts of the Max CCRN recharge. As shown in Figure 4, net pumping remains the same as in the Max CCRN scenario. However, compared with the Max CCRN scenario, simulated aquifer storage depletion in the No CCRN scenario (grey dashed line) increases slightly in 2020 and then sharply in 2023 in the absence of the large recharge rates at Bella Vista, Horseshoe Draw and the EOP that are present in the Max CCRN recharge scenario (solid grey line in Figure 4). By 2075, the simulated difference between storage depletion in the Max CCRN and No CCRN scenarios is 2,441 AFA.

Simulated evapotranspiration (ET) and stream baseflow, which together comprise the riparian water in the model, are also supported by MAR in the Max CCRN scenario, as indicated in Figure 5. In this scenario, simulated stream baseflow peaks in 2031 at 3,776 AFA, and by 2075, total simulated baseflow is 3,286 AFA, which is 116 AFA higher than the minimum simulated value of 3,170 in 2003. Simulated ET in this scenario peaks in 2044 at 8,264 AFA compared with 7,980 AFA in 2003 and 7,994 AFA in 2075.

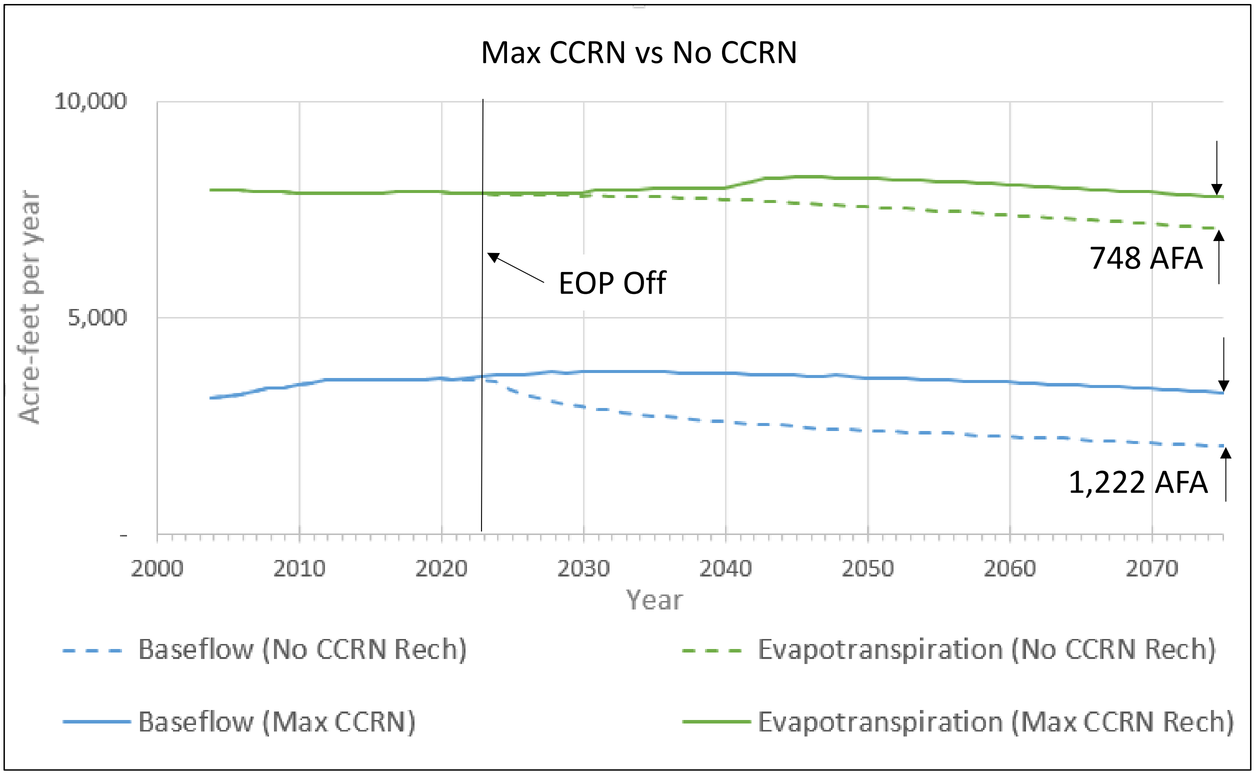

Figure 5. Simulated ET and baseflow for the No CCRN and Max CCRN recharge scenarios.

The dashed-line curves of the No CCRN scenario in Figure 5 depart from, and fall below, the solid lines of the Max CCRN scenario starting in 2023 when the simulated EOP recharge ceases in the No CCRN scenario. Both curves remain below the Max CCRN curves for the remainder of the simulation period. By 2075, the simulated Max CCRN values for ET and baseflow are 748 and 1,222 AFA higher than the No CCRN curves, respectively.

Error! Not a valid bookmark self-reference. lists the 2075 values for simulated storage depletion, ET, and baseflow for the Max CCRN and No CCRN recharge scenario simulations. The "Difference" column (column 4) in **Error! Not a valid bookmark self-reference.** shows that the Max CCRN scenario produces less simulated storage depletion (2,441 AFA), more ET (748 AFA) and more baseflow (1,222 AFA) than the No CCRN scenario. The sum of the absolute values of these differences (last column in **Error! Not a valid bookmark self-reference.**) shows that the total volumetric difference between the two simulations in 2075 for these three major water budget components is 4,411 AFA. Storage depletion makes up 55% of the total difference, with

ET (17%) and baseflow (28%) comprising the other 45%. Comparing this 4,411 AFA value to the difference in MAR between

Table 2. 2075 Simulated Storage Depletion, ET, and Baseflow (AFA) for the Max CCRN and No CCRN Recharge Scenarios

2075 Simulated Values (AFA)				
Water Budget Item	**Max CCRN**	**No CCRN**	**Difference**	**Absolute Value**
Storage Depletion	31,638	34,079	(2,441)	2,441
ET	7,631	6,883	748	748
Baseflow	3,138	1,916	1,222	1,222
Total			(471)	4,411

the two scenarios from Table 1 (4,423 AFA) suggests that by 2075, the system is in a new equilibrium where MAR is nearly completely distributed between riparian water (ET and baseflow) capture (45%) and storage depletion (55%). Figure 6 plots the simulated difference between the Max CCRN and No CCRN recharge scenarios for net pumping, storage depletion, baseflow and ET. This plot shows that the differences between these two scenarios stabilize after about 2060 even though the last major change in MAR occurs in 2040 (Riverstone in the Max CCRN case) and the absolute values of simulated storage depletion, ET, and baseflow continue to change (see Figure 4).

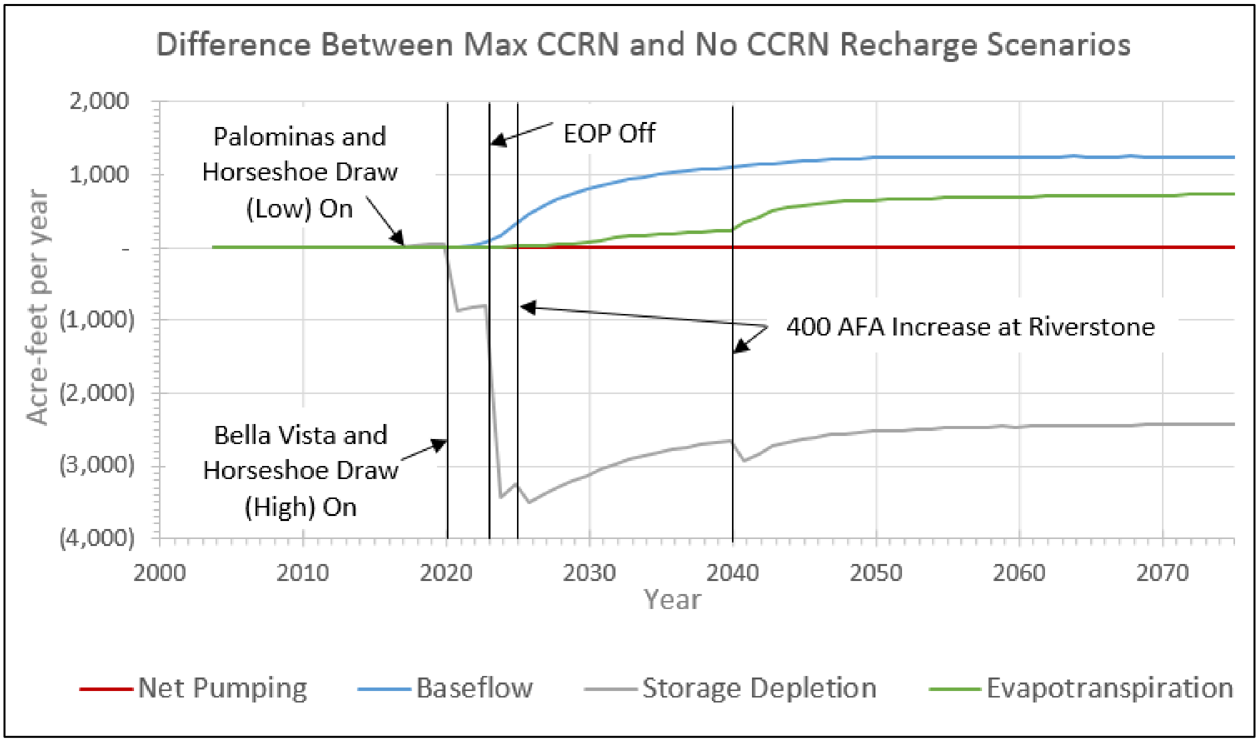

Figure 6. Simulated difference in major water budget components between Max CCRN and No CCRN recharge scenarios.

Reduced Mexico Pumping with Max CCRN Recharge

The simulated USPB pumping south of the US-Mexico border is 26,035 AFA for the 2003-2100 simulation period, with about 22,000 AFA centered along the headwaters area of the San Pedro River, and about 4,000 AFA located near Naco, Mexico. Because SVS pumping varies over time in the simulation, the Mexico pumping ranges from 59% (2003) to 68% (2015) of total pumping in the model area. In order to evaluate the impact of pumping in Mexico on the Max CCRN recharge scenario's effect on simulated ET and baseflow, the Max CCRN recharge scenario was simulated with a 2,000-AFA reduction in Mexico pumping. This reduction was applied by equal proportion across the Mexican pumping wells circled in red[2] in Figure 7 in 2020, and it constitutes a roughly 9% decrease in simulated pumping compared to the values used for those wells in the original USGS MODFLOW model (Pool & Dickinson, 2007) and maintained by Lacher (2017).

Figure 8 plots the simulated net pumping (extraction minus incidental recharge) and aquifer storage depletion for the Max CCRN recharge scenario under original pumping (Lacher, 2017)

[2] The four irrigation wells near Naco, Mexico were not included in the pumping reduction in order to focus the pumping change in the headwaters area of the San Pedro River.

and with a 2,000-AFA reduction in Mexico pumping starting in 2020. The two pumping curves diverge by 2,000 AFA starting in 2020, and virtually the same pattern is reflected in the simulated storage depletion curves, indicating a direct correspondence between pumping and storage depletion.

Figure 9 plots the original Max CCRN simulated ET and baseflow curves with the same curves for the reduced-Mexico pumping scenario. In this case, the simulated ET and baseflow curves in the reduced-Mexico pumping case remain nearly identical to the original pumping results. The fact that a 9% change in Mexico pumping has no effect on the simulated ET and baseflow under the Max CCRN recharge conditions over the 2020 to 2075 simulation period indicates that all of the 2,000 AFA of simulated reduced pumping is produced from aquifer storage rather than capture of ET and baseflow. This result is explained by the fact that all of the adjusted simulated wells are located in the lowest model layer (5) (Figure 7[b]), whereas the headwaters of the San Pedro River lies in the next higher (surface) model layer (4) (Figure 7[a]).

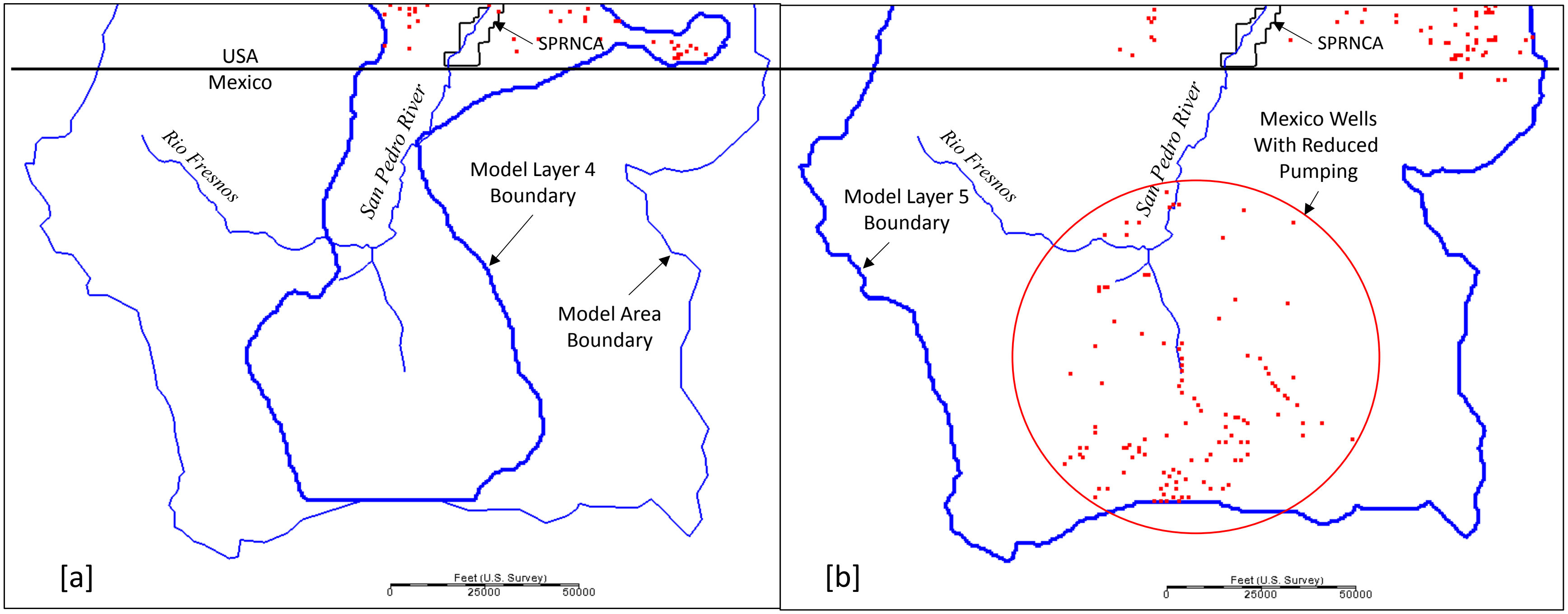

Figure 7. Simulated well locations shown in red dots, with Layer 4 wells shown in [a] and Layer 5 wells shown in [b]. Wells within red circle in [b] shared a proportional percentage of the 2000-AFA pumping reduction applied in 2020.

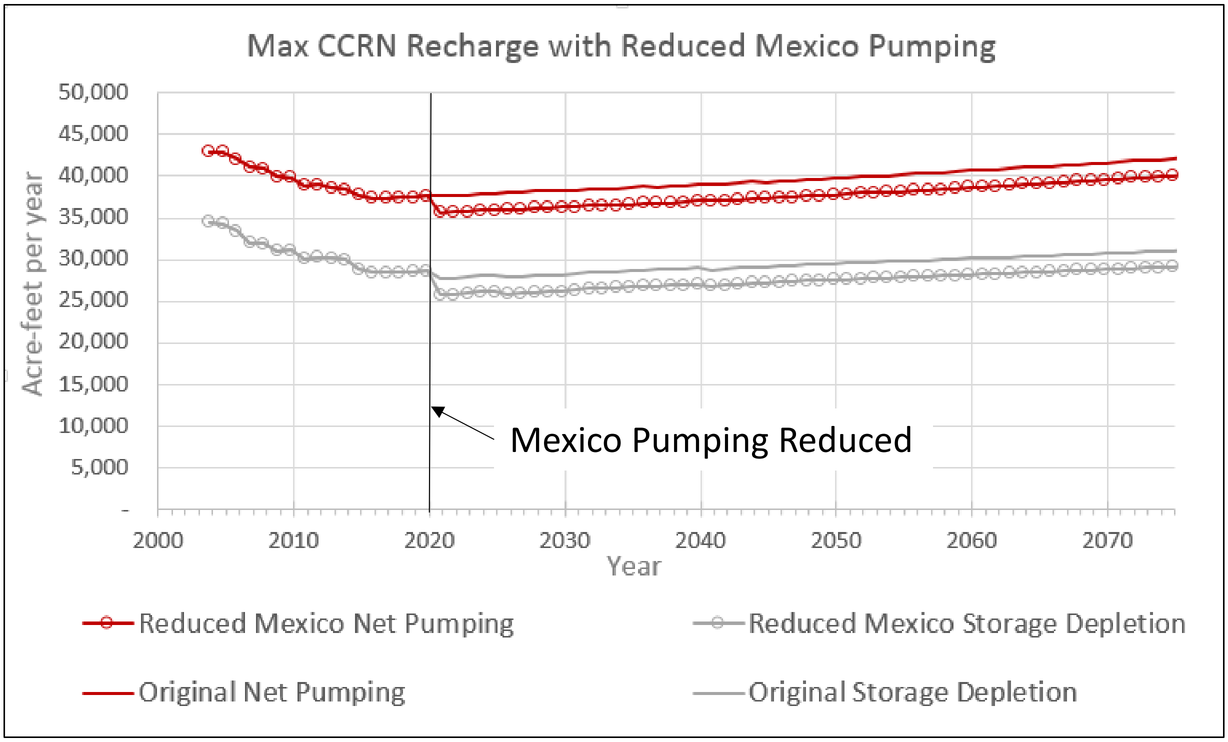

Figure 8. Simulated net pumping and storage depletion for the Max CCRN recharge scenario with original pumping and a 2,000-AFA reduction in Mexico pumping starting in 2020.

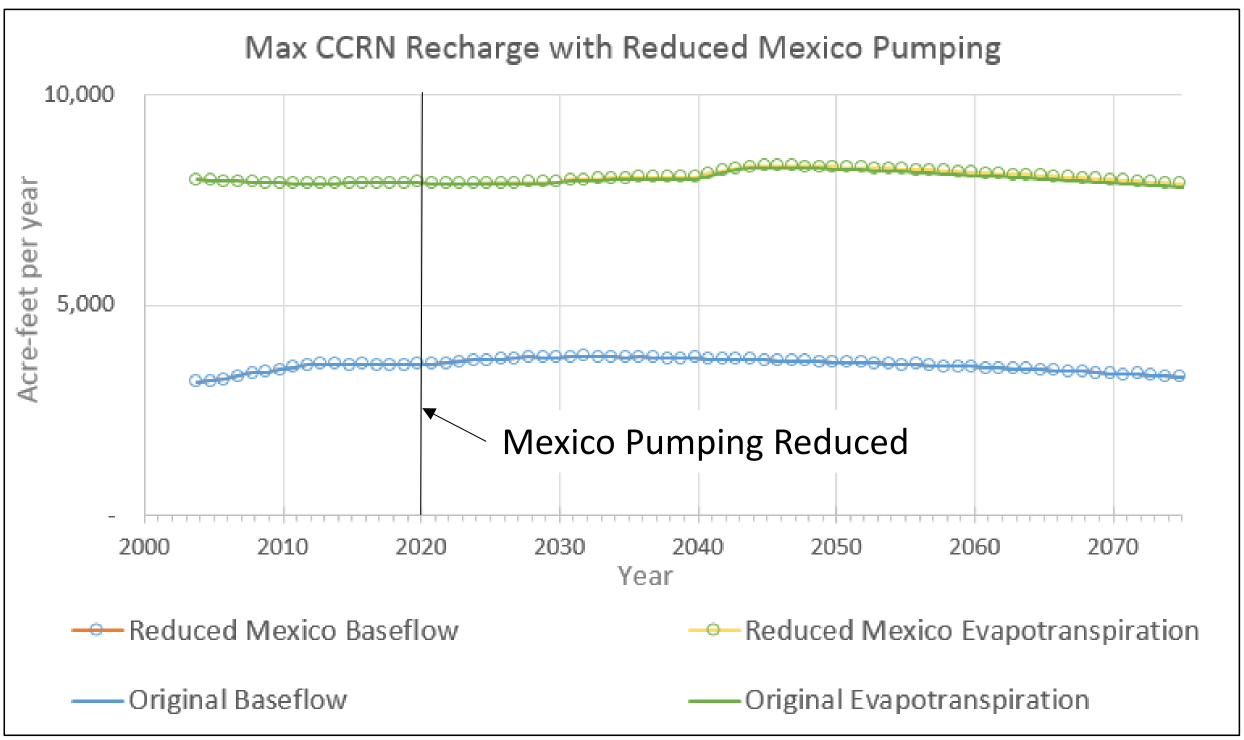

Figure 9. Simulated ET and baseflow for the Max CCRN recharge scenario with original pumping and a 2,000-AFA reduction in Mexico pumping starting in 2020.

Spatial Distribution of Recharge Effects

While the water budget analysis provides insight to the partitioning of pumping and MAR between aquifer storage depletion/replenishment and capture/replenishment of ET and baseflow, it does not demonstrate the spatial variations in recharge benefits to the groundwater and riparian systems in different areas of the San Pedro River. This section examines MAR-related changes in simulated baseflow at three locations on the mainstem of the San Pedro River. These three sites correspond to the locations of the USGS stream-flow gaging stations identified in Figure 10 by blue pins labeled Charleston, Lewis Spring, and Palominas.

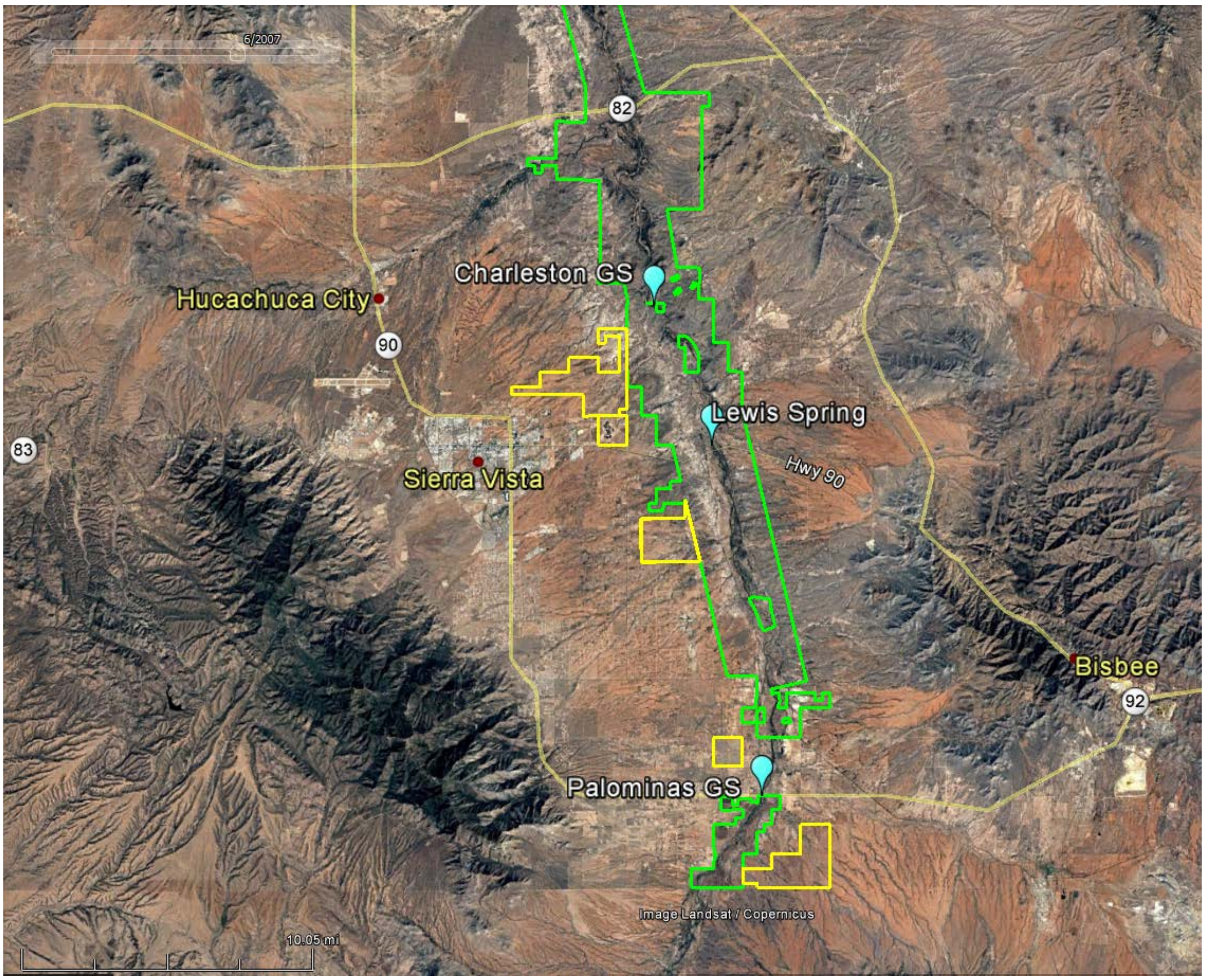

Figure 10. Blue pins indicate locations of Charleston, Lewis Spring, and Palominas stream-gaging stations on the Upper San Pedro River. CCRN recharge sites are outlined in yellow and the SPRNCA is outlined in green.

Charleston

Figure 11 plots the simulated stream baseflow at the Charleston gaging station site for the Max CCRN, No CCRN, and reduced Mexico pumping with Max CCRN scenarios. The vertical black line at year 2023 marks the simulated cessation of EOP recharge in the No CCRN scenario. The top two curves, Max CCRN and reduced Mexico pumping with Max CCRN recharge, are nearly identical and show that simulated baseflow peaks at 2,755 AFA in the year 2035. By 2075, simulated baseflow in these two scenarios (2,563 AFA) still exceeds the 2020 value of 2,503 AFA by 160 AFA. By contrast, simulated baseflow drops sharply in 2023 in the No CCRN recharge scenario after the cessation of EOP recharge. In this case, simulated baseflow drops from a peak of 2,507 AFA in 2022 to 1,506 AFA in 2050 followed by a slower decline to 1,410 AFA in 2075. The long-term difference in simulated baseflow attributable to the Max CCRN recharge scenario is about 1,150 AFA. This difference amounts to an 82% increase over the simulated baseflows at Charleston without the Max CCRN recharge. Notably, the source of this recharge (treated effluent) is continuous year-round, providing a particularly large boost to low flows in the dry early summer and late fall seasons.

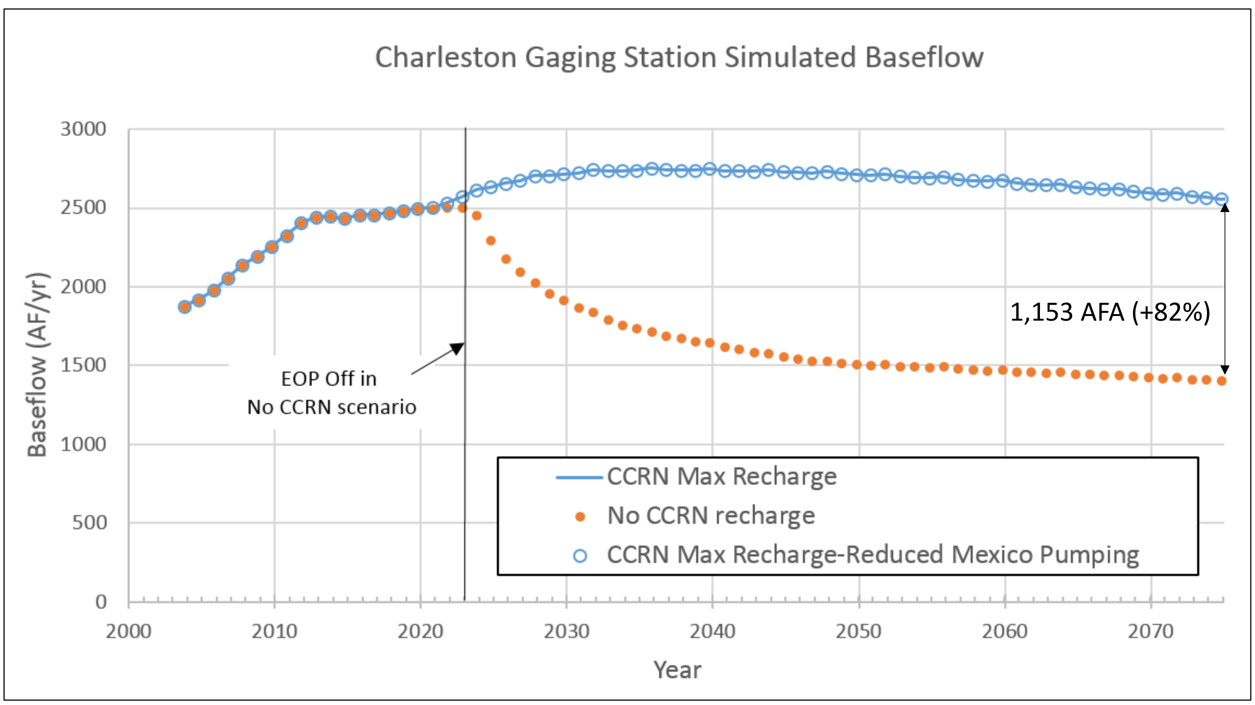

Figure 11. Simulated baseflow at the Charleston stream-gaging station for the Max CCRN and No CCRN recharge scenarios.

As explained earlier and shown in Figure 11, the reduced Mexico pumping has no impact on the resulting simulated baseflow at this location.

Lewis Spring

Figure 12 shows simulated baseflow at the Lewis Spring site, upstream of the EOP. At this site, the Max CCRN and No CCRN curves show less divergence than at the Charleston site. The peak simulated baseflow of 278 AFA occurs at the end of 2023 in both recharge scenarios. However, in the Max CCRN recharge scenario (with and without reduced Mexico pumping), simulated baseflow remains essentially constant until nearly 2060, when it begins to decline slightly. By 2075, simulated baseflow in the Max CCRN recharge scenario at Lewis Spring is 267 AFA which is 5 AFA higher than the simulated 2003 value. Simulated baseflow in the No CCRN recharge scenario declines steadily from 2023 to 2075, ending at 231 AFA in 2075. The 36 AFA difference in 2100 simulated baseflow values represents a 16% increase in flow with the Max CCRN recharge scenario compared to the No CCRN scenario. These data suggest that the simulated Max CCRN recharge upstream of Lewis Spring, particularly at Riverstone, has a positive effect on this site.

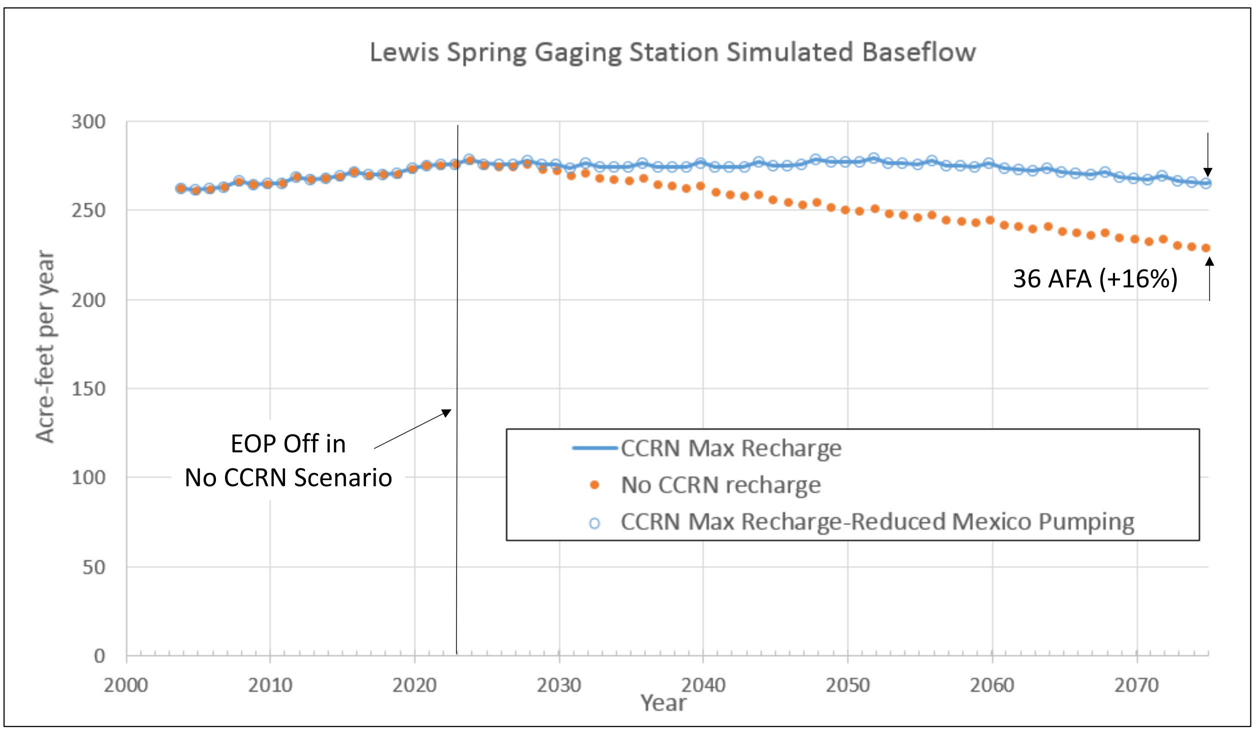

Figure 12. Simulated baseflow at the Lewis Spring stream-gaging station for the Max CCRN and No CCRN recharge scenarios.

Palominas

Figure 13 shows simulated baseflow at the Palominas stream-gaging station. At this southernmost of the three gaging stations shown in Figure 10, only the Palominas and Horseshoe Draw recharge sites would be expected to influence simulated baseflows. The shapes of the simulated baseflow curves reflect the lack of influence by the EOP's large recharge volume as well as the pumping-related stress on the San Pedro River system in this area. Although the Max CCRN and No CCRN recharge curves diverge in about 2023, after the simulated cessation of EOP baseflow, the cause of this divergence is most likely the onset of significant recharge at Horseshoe Draw in 2020 rather than any changes at the EOP. Since MAR at the Palominas Recharge Project is constant at 40 AFA in both scenarios, Horseshoe Draw recharge is the most important factor separating the two recharge scenarios. Simulated baseflow in the Max CCRN recharge case peaks in 2031 at 416 AFA, while peak simulated baseflow for the No CCRN recharge scenario peaks in 2007 at 402 AFA. This early peak in the No CCRN recharge case reflects the groundwater system's recovery to the cessation of pumping at several large agricultural wells on in the local area in the late 1980's through early 2000's (Lacher, 2011).

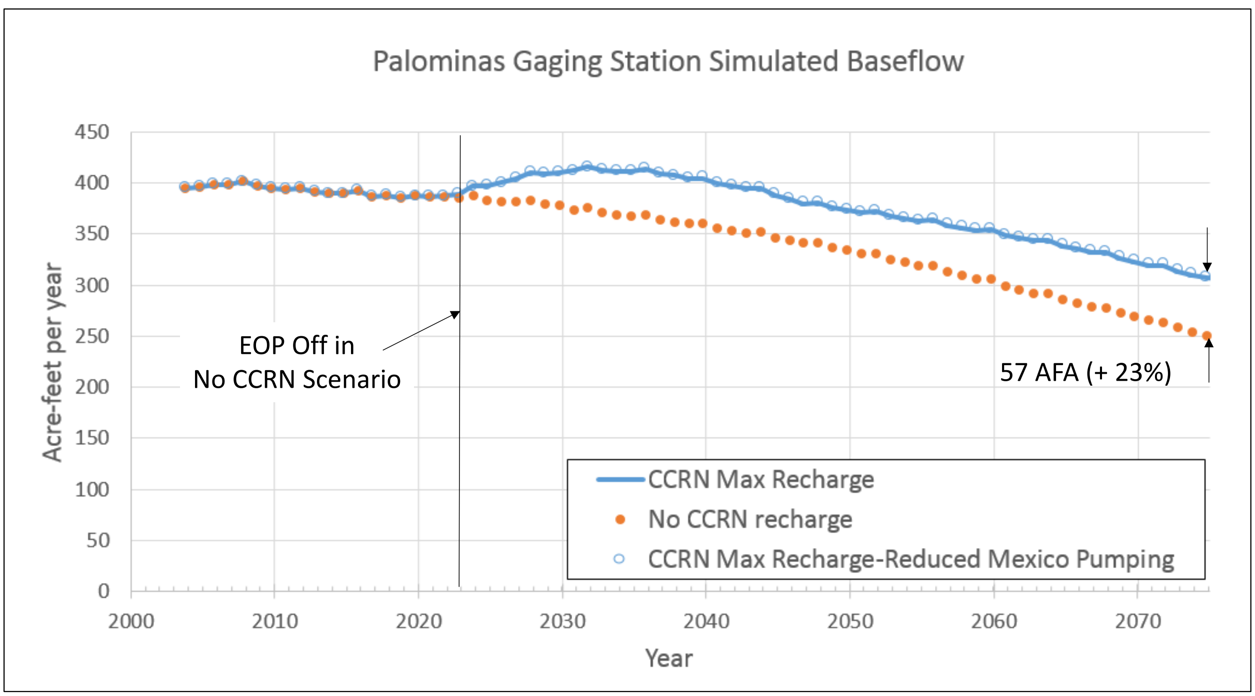

Figure 13. Simulated baseflow at the Palominas stream-gaging station for the Max CCRN and No CCRN recharge scenarios.

From 2032 to 2075, simulated baseflow curves for both recharge scenarios decline at roughly the same rate. By 2075, simulated baseflow values for the Max CCRN and No CCRN recharge scenarios are 306 AFA[3] and 248 AFA, respectively. This 57 AFA difference attributable to the Max CCRN recharge distribution constitutes a 23% increase over the No CCRN scenario.

Figure 14 compares maps of simulated stream baseflow change from 2003 to 2025 for: a) No CCRN recharge, and b) Max CCRN recharge. The graphics show colors corresponding to simulated baseflow change in cubic-feet per second (cfs), with green and blue indicating positive change and warm colors (yellow-orange-red-brown) indicating negative change. Figure 14(a) (No CCRN recharge) shows a smaller increase in simulated baseflow downstream of the EOP (0.58 cfs) than in the Max CCRN recharge conditions of Figure 14(b) and (c), where simulated baseflow change is about 1.1 cfs in this "Charleston" reach. Simulated baseflow change northeast of the EOP in the Curry Draw tributary (not labeled) is also lower in the No CCRN case (0.5 cfs) shown in Figure 14(a) than in the Max CCRN cases in Figure 14(b) and (c) (1.0 cfs). Flows in the Babocomari River on the north end of the study area are relatively constant (about -0.2 cfs) across all three cases in Figure 14, but the area below the Babocomari-San Pedro confluence is also lower in Figure 14(a) by about 0.5 cfs than in Figure 14(b) and (c). Simulated baseflow change downstream (north) of the Palominas Rechare Project covers a slightly longer reach in the Max CCRN recharge case (Figure 14(b)) than in the No CCRN recharge case (Figure 14(a)), but both cases show simulated baseflow change of -0.2 to -1.0 cfs south of the US-Mexico border.

The same graphics for the period 2003 to 2050 are provided in Figure 15. By 2050, simulated baseflows across the entire model area are lower than they were in 2003 in the No CCRN recharge case shown in Figure 15(a). While simulated baseflow change in the Charleston reach (1.2 cfs) in the Max CCRN recharge case (Figure 15(b)) is slightly larger than it was in 2025, simulated

[3] The reduced Mexico pumping with Max CCRN value is 308 AFA in 2075.

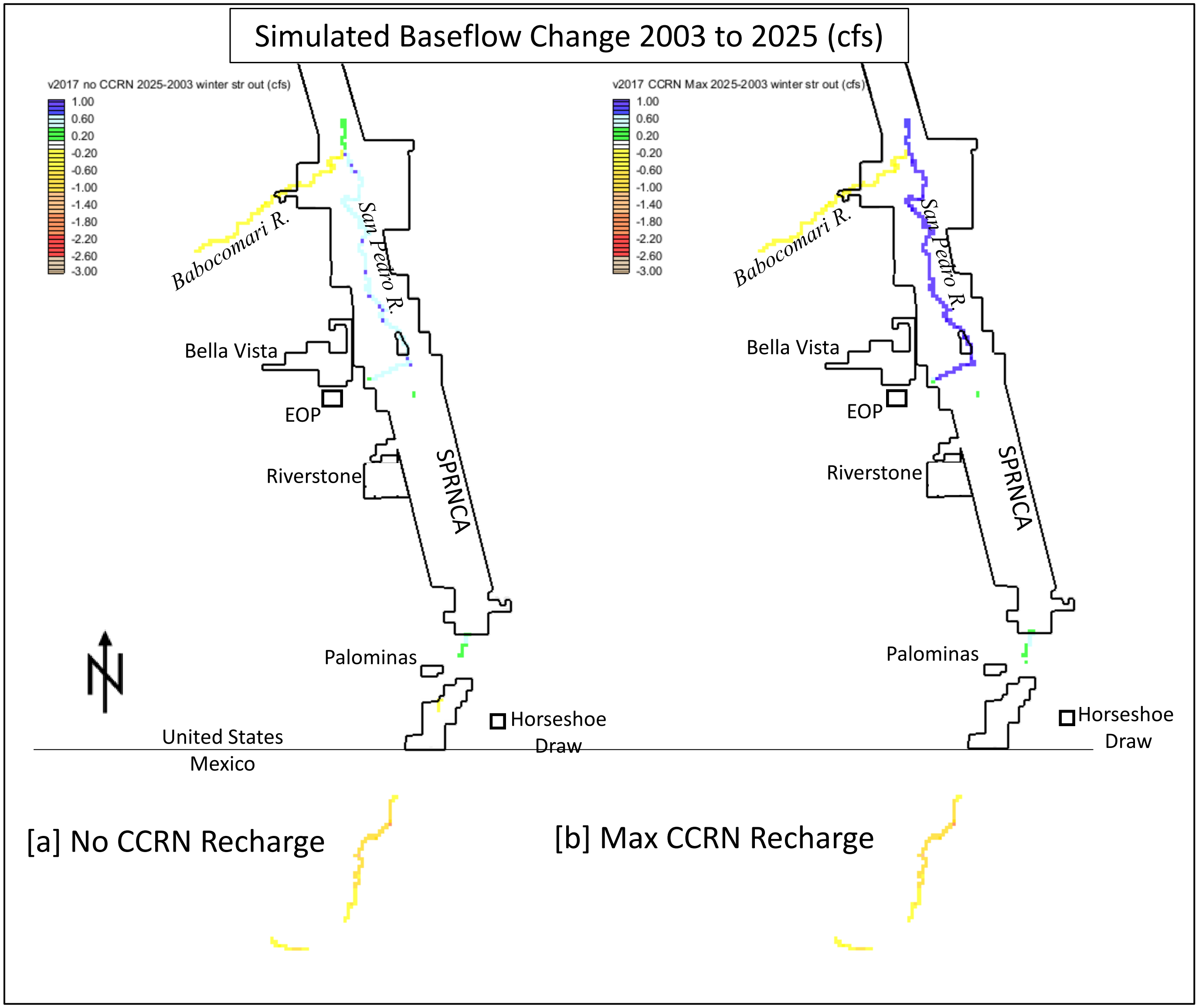

Figure 14. Simulated baseflow change from 2003 to 2025 (2025 minus 2003) for: a) No CCRN recharge, and b) Max CCRN recharge.

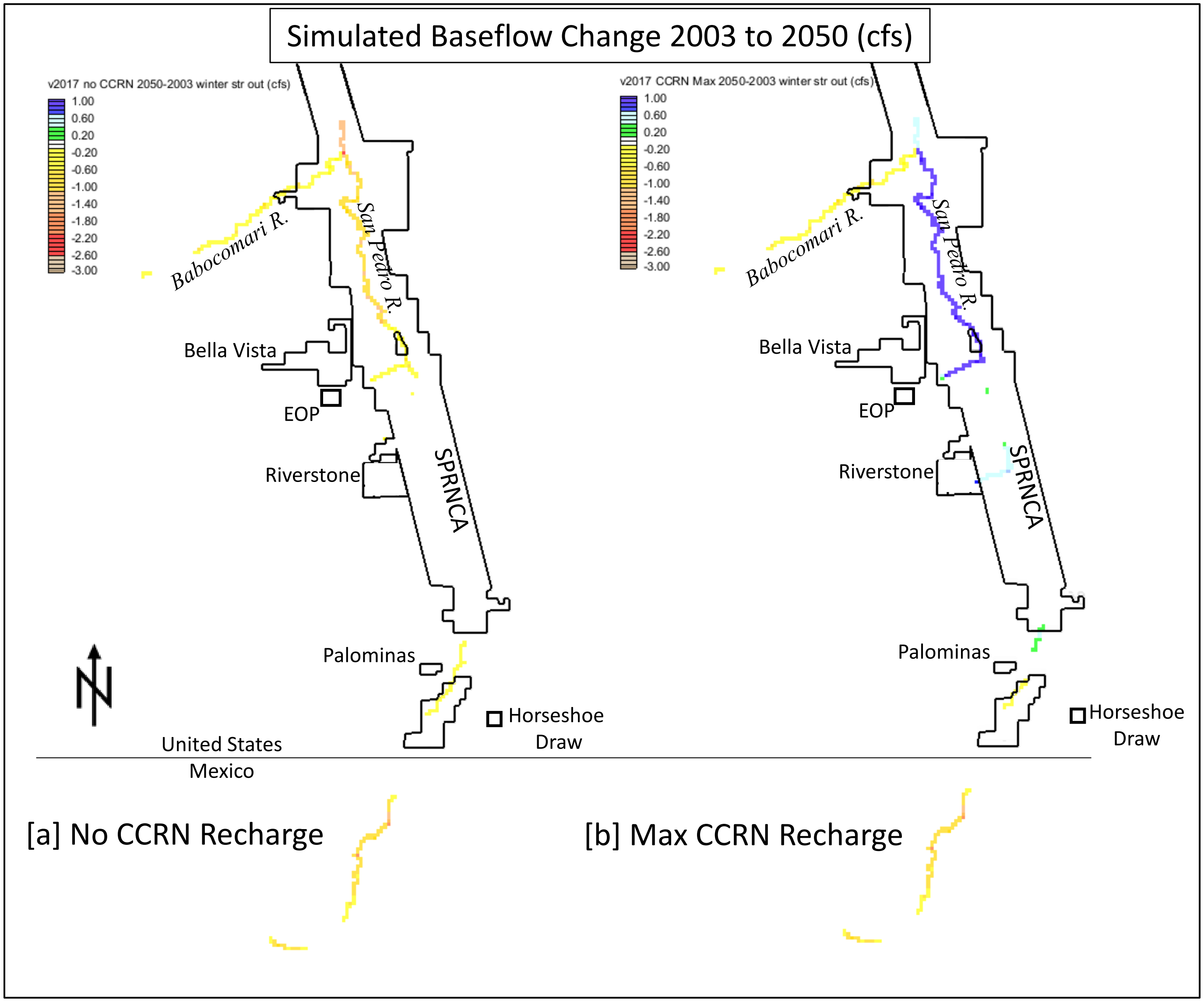

Figure 15. Simulated baseflow change from 2003 to 2050 (2050 minus 2003) for: a) No CCRN recharge and b) Max CCRN recharge.

baseflow change below the Babocomari confluence is lower than in 2025. Positive simulated baseflow change of 0.60 cfs is visible for 3 miles downstream of the CCRN Riverstone site. The simulated increase in baseflow at the Lewis Spring gaging station site, which is about 1.3 miles farther downstream, is less than the 0.1-cfs minimum contour level for these plots so is not visible in Figure 15(b).

Simulated baseflow change near Palominas is essentially unchanged from 2025 values in the Max CCRN recharge cases (Figure 15(b) and (c)), but is slightly negative in the No CCRN recharge case (Figure 15(a)). In both cases shown in Figure 15, simulated baseflow declines south of the US-Mexico border have intensified slightly from 2025.

Figure 16 repeats the simulated baseflow change graphics for the period 2003 to 2075. In the No CCRN recharge case (Figure 16(a)), simulated baseflow changes on the lower Babocomari and the Charleston reach of the San Pedro are -0.7 to -0.8 cfs and -0.9 to -1.0 cfs, respectively. Negative baseflow changes in this figure also extend through Curry Draw (downgradient of the EOP) and south in the San Pedro River for more than a mile. The Charleston reach of the San Pedro still shows positive simulated baseflow change on the order of 0.9 to 1.0 cfs in the Max CCRN case shown in Figure 16(b). Positive simulated baseflow change downstream of Riverstone remains fairly constant from 2050 at about 0.55 cfs, although the extent of that change is slightly shorter (2.5 miles). In both cases, 2075 simulated baseflow change near, and south of, Palominas is negative, ranging from -0.5 to -1.0 cfs in the No CCRN case (Figure 16(a)), and from -0.3 to -0.5 cfs in the Max CCRN case (Figure 16(b)). South of the US-Mexico border, simulated baseflow change ranges from -0.2 to -1.1 cfs in both cases.

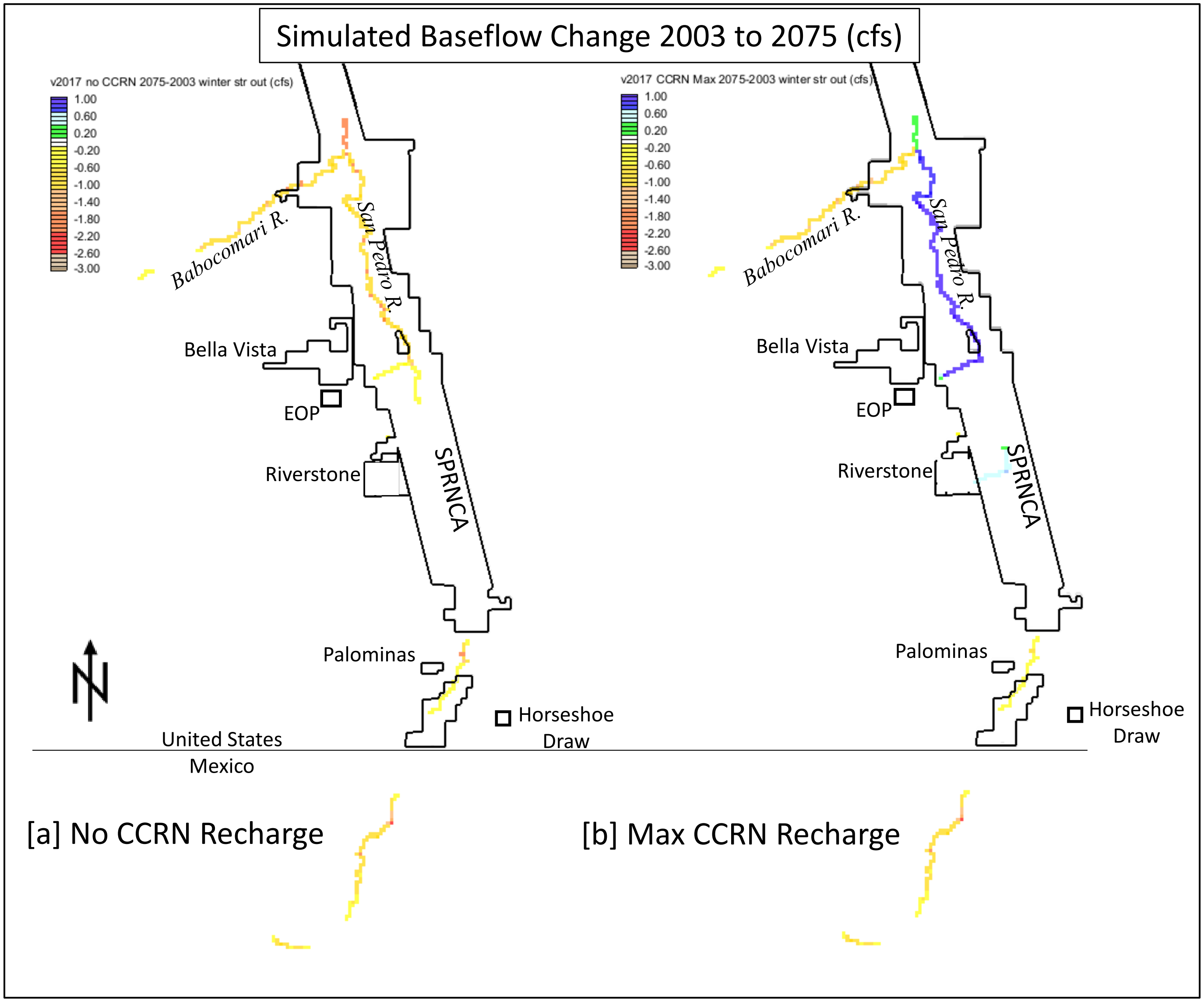

Figure 16. Simulated baseflow change from 2003 to 2075 (2075 minus 2003) for: a) No CCRN recharge and b) Max CCRN recharge.

Figure 17 illustrates simulated head change in model layer 1 from 2003 to: a) 2050 and b) 2075. Model layer 1 represents "pre- and post-entrenchment stream alluvium" (Pool & Dickinson, 2007), and therefore is closely associated with the modern (post-entrenchment) floodplain where it occurs in contact with the San Pedro River. In their riparian water-needs study of the San Pedro River, Leenhouts, Stromberg, and Scott (2006) found that:

> *The forests were dense and multi-aged where maximum ground-water depths averaged less than about 3 meters [9.8 ft], streamflow permanence was greater than about 60 percent, and intra-annual ground-water fluctuation was less than about 1 meter [3.3 ft] (Lite and Stromberg, 2005), but declined in abundance and age-class diversity where water availability was less … Cottonwood-willow forests gave way to tamarisk stands as site-average ground-water depths across the flood plain exceeded 3 meters. Conditions were too dry at intermittent-dry streamflow regime sites to allow for establishment of cottonwood and willow seedlings.*
>
> -- USGS, 2006

These findings demonstrate that even a small change in head within the active floodplain has the potential to substantially increase riparian health. Figure 17[a] shows that 1,478 acres in model layer 1 *and* within the SPRNCA have a simulated head increase of 0.5 feet (ft) or more from 2003 to 2050 in the Max CCRN scenario, while Figure 17[b] shows that the number of affected acres increases to 3,680 for the period 2003 to 2075. These head increases directly affect riparian water availability along the mainstem of the San Pedro River.[4]

[4] Tributaries downstream of the Bella Vista, EOP, and Riverstone CCRN recharge sites also exhibit simulated baseflow increases with CCRN Max recharge (see Figure 15[b] and Figure 16[b]), but these increases are mostly associated with shallow recharge seeping out to the ground surface ("daylighting") downstream, rather than reflecting a large-scale change in head in the floodplain.

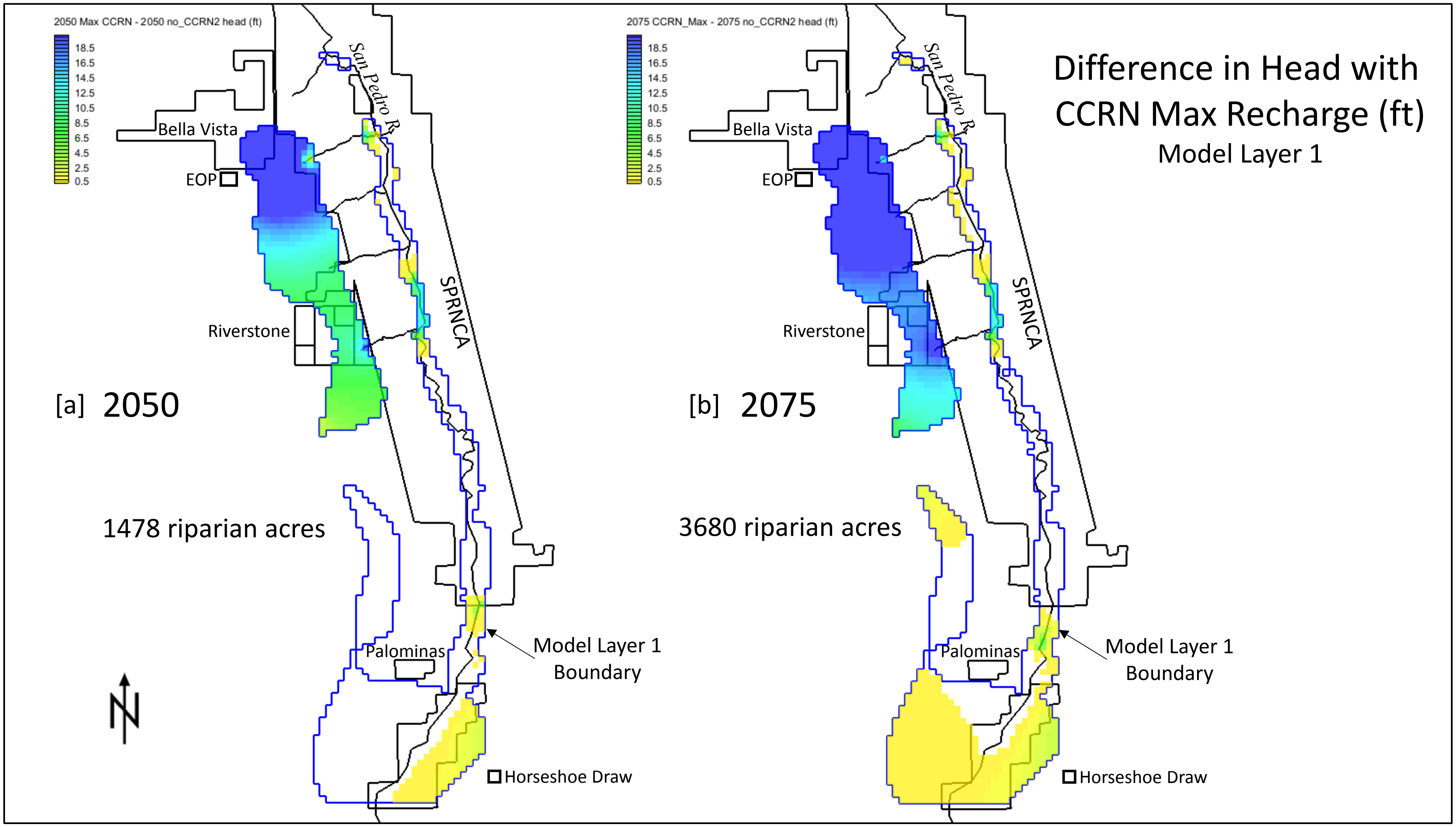

Figure 17. Simulated head change of 0.5 feet (ft) or more in model layer 1 from 2003 to: [a] 2050, and [b] 2075. Total acreage within SPRNCA with layer 1 head change of 0.5 ft or more is 1478 in 2050 and 3680 in 2075.

Summary and Conclusions

The simulations in this study were designed to evaluate the impact of concurrent recharge operations at five CCRN sites along the Upper San Pedro River in the SVS: 1) Bella Vista, 2) EOP, 3) Riverstone, 4) Palominas, and 5) Horseshoe Draw. Each recharge site was simulated according to current assumptions about its most likely period of operation and maximum capacity. Of the five CCRN sites, three are currently operational: the EOP, the Palominas Recharge Project, and the Horseshoe Draw Flood and Erosion Control Project. The Horseshoe Draw project was recently completed and is expected to recharge stormwater under its current design. Efforts to bring treated effluent to Horseshoe Draw aim to significantly increase recharge at that site in the future. Riverstone and Bella Vista have not yet been designed, nor do they have secured recharge water sources. The Max CCRN recharge scenario in this study applies 4,483 AFA by the year 2075 whereas the No CCRN recharge applies only 80 AFA after 2023 when the simulated EOP recharge (2,743 AFA) ceases.

Because of its hydrogeology and its location downstream of the large simulated recharge rates at the EOP, Riverstone, and Bella Vista in the Max CCRN scenario, the Charleston reach of the San Pedro River benefits the most from the Max CCRN MAR. The Max CCRN scenario produces 1,153 AFA (82%) more simulated baseflow than the No CCRN recharge scenario. Without the Max CCRN recharge, baseflows at the Charleston gaging station drop below 2003 levels as early as 2030 and continue to decline throughout the simulation period.

The Lewis Spring site is downstream of the Riverstone site and is the only one of the three stream-gaging sites to show direct simulated baseflow benefits from the Riverstone MAR. By 2075, simulated baseflows at the Lewis Spring site increase 36 AFA (16%) with Max CCRN compared to the No CCRN scenario.

The Palominas stream-gaging site near the southern end of the SVS responds to simulated Max CCRN recharge primarily from the (expanded) Horseshoe Draw project. Peak simulated baseflow in the No CCRN recharge scenario occurs in 2007, while in the Max CCRN recharge case, it occurs in 2031. After 2035, simulated baseflow in both recharge scenarios declines steadily. By 2075, simulated baseflow in the Max CCRN case is 306 AFA, and for the No CCRN case is 248 AFA. This 57 AFA difference attributable to the Max CCRN recharge constitutes a 23% increase over the simulated value in the No CCRN scenario.

In conclusion, the locations and magnitudes of the Max CCRN recharge sites simulated in this study, combined with local hydrogeology, result in a wide range of spatially varying simulated baseflow responses in the San Pedro River over the simulation period 2003 to 2075. The EOP is the largest single MAR site in the CCRN network, making up more than 60% of the total Max CCRN recharge simulated in this study. These results suggest that maintaining current levels of recharge at the EOP will be extremely important for long-term maintenance of baseflows in the Charleston reach of the San Pedro River and below the Babocomari confluence. Expanding Horseshoe Draw recharge to include treated effluent has the potential to significantly increase otherwise declining simulated baseflows near Palominas. The Max CCRN recharge at Riverstone significantly increases simulated baseflow in up to three miles of stream near the center of the SVS and produces a 16% increase in simulated baseflow at the Lewis Spring site.

Although pumping in Mexico makes up more than 50% of all simulated pumping in this study, reducing that pumping by 2,000 AF (about 9% of the pumping centered on the San Pedro River headwaters) has no discernable impact on simulated baseflows in the Max CCRN recharge scenarios. This result indicates that, for the simulation period in this study (2003-2075), most of this 2,000 AFA of pumping in Mexico derives from aquifer storage rather than stream or ET capture.

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