CALCULATION OF PUMPING-INDUCED BASEFLOW AND EVAPOTRANSPIRATION CAPTURE ATTRIBUTABLE TO FORT HUACHUCA

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EXECUTIVE SUMMARY

This project uses the 2007 numerical groundwater model of the Upper San Pedro Basin (USPB) published by the U.S. Geological Survey (USGS) (Pool and Dickinson, 2007) to simulate pumping-induced stream baseflow and evapotranspiration (ET) depletions attributable to Fort Huachuca. The first part of the study examines the impacts of pumping within the boundaries of Fort Huachuca's reservation ("on post"). The second part of the study examines pumping-related stream baseflow and ET depletions attributable to all of Fort Huachuca's direct, indirect, and induced population within the USPB.

Simulated pumping rates for the period 1902-2003 provided in the USGS model were adjusted only to correct obvious errors. Population projections from the Arizona Department of Commerce were used to estimate future municipal, industrial, and domestic pumping in the Arizona portion of the USPB. Simulated agricultural and mine-related pumping in the U.S. portion of the basin, and all pumping in Mexico, remained fixed at 2002-2003 rates for the simulation period 2003-2105.

Combined data from the 2006 Programmatic Biological Assessment (BA) for Fort Huachuca (ENRD, 2006) and from 2008 and 2009 distributions of off-post Fort personnel by zip code, as well as spatially distributed population projections from the Arizona Department of Commerce, were used to estimate the off-post Fort-attributable population as a function of total projected population in the Arizona portion of the USPB (also referred to as the Sierra Vista subwatershed). This estimated Fort-attributable off-post population was, in turn, used to estimate Fort-attributable off-post pumping. This method for estimating the Fort's direct, indirect, and induced population within the USPB ties Fort-attributable off-post population growth (and pumping) to the projected growth of the total Sierra Vista subwatershed population. While no basis for this fixed relationship has been documented, this approach is considered conservative in lieu of detailed population figures for the Fort for the entire simulation period (1902-2105).

Stream baseflow capture, evapotranspiration (ET) capture, and aquifer storage depletion were calculated by comparing simulation results from a suite of four scenarios modeled over a 203-year simulation period: 1) no groundwater development (no wells/no artificial recharge in the entire basin), 2) full development (all historic and projected pumping/all artificial recharge in the USPB) 3) no on-post pumping (all other wells and all artificial recharge included) , 4) no Fort-attributable pumping on or off post (all non-Fort-attributable pumping and all artificial recharge remains in place; incidental recharge from septic tanks reduced). Results reveal that simulated cumulative (1902-2105) on-post pumping comprises only 5% of basin-wide pumping, but it is responsible for 31% of baseflow capture, 3% of ET capture, and 4% of total storage depletion in the basin. All simulated Fort-attributable pumping (on and off post) comprises 19% of basin-wide pumping, and accounts for 65% of total baseflow

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capture, 7% of ET capture, and 21% of all cumulative storage depletion in the basin by 2105.

Future water needs for the USPB to offset pumping-induced capture were determined from simulated capture results for the period 2005 to 2105. Total Fort-attributable pumping demand from 2005 to 2105 is projected at 823,777 AF (19% of total basin pumping demand). Of this future Fort-attributable demand, simulations indicate that 37,629 AF will be required to offset ET capture and 147,230 AF will be needed to mitigate baseflow capture over the 100-year period.

Simulated stream depletions related to Fort-attributable pumping are concentrated at the confluence of the Babocomari and San Pedro rivers, as well as several miles upstream on each river. Simulated stream depletions from on-post pumping only peak in the mid-21st Century, and include two 250-meter (820-foot) stream reaches that were "pumped dry" on the Babocomari in 2050. Total simulated Fort-related pumping (on- and off-post) dried out of a maximum of five stream reaches (1025 meters, 3363 feet) in 2050, and three reaches by the end of the simulation period in 2105.

Simulated pumping in on-post wells reveals a relatively strong hydrologic connection to the neighboring Babocomari and San Pedro rivers, as represented in the USGS model. For this reason, reducing or eliminating production from these wells may prove to be one of the most effective means for mitigating the Fort's pumping-induced depletions of stream baseflow and ET. Likewise, strategic artificial recharge in the area southwest of the confluence of these two rivers may offset pumping-induced stream baseflow and ET capture from on-post wells. Detailed simulations and in-situ field investigations will be required to determine the viability of near-stream or other artificial recharge in this area.

USF200010704

TABLE OF CONTENTS

EXECUTIVE SUMMARY i
TABLE OF CONTENTS iii
LIST OF TABLES iv
LIST OF FIGURES v
LIST OF APPENDICES vii
ACRONYMS AND ABBREVIATIONS viii
1.0 INTRODUCTION 1-1
1.1 MODEL STRUCTURE 1-1
1.2 PURPOSE OF STUDY 1-4
1.3 SCENARIOS SIMULATED IN STUDY 1-4
2.0 CAPTURE FROM ON-POST WELLS AT FORT HUACHUCA 2-1
2.1 CAPTURE CALCULATIONS 2-1
2.2 BASIN-WIDE PUMPING PROJECTIONS 2-3
2.3 RESULTS 2-3
3.0 CAPTURE FROM ALL PUMPING ATTRIBUTABLE TO FORT HUACHUCA 3-1
3.1 CAPTURE CALCULATIONS 3-1
3.2 ESTIMATES OF FORT-ATTRIBUTABLE PUMPING IN USPB 3-1
3.3 RESULTS 3-2
3.3.1 Quantification of Capture 3-2
3.3.2 Sources of Capture 3-7
3.3.3 Changes in Stream Baseflow 3-10
4.0 SUMMARY AND CONCLUSIONS 4-1
4.1 SUMMARY OF RESULTS 4-1
4.2 CONCLUSIONS 4-2
5.0 REFERENCES CITED 5-1

USF200010705

LIST OF TABLES

Table 1. Table of Scenarios Simulated in Study. 1-6
Table 2. Comparison of Capture Analyses (1902-2105) 4-1
Table 3. Simulated Future Water Needs (2005-2105) 4-2
Table A. 1. Seasonal Contributions of Individual Wells to Total Fort Huachuca On-post Pumping, 2003-2007. ..... A-2
Table A.2. Projected Pumping Rates for On-post Wells Based on Distribution in Table A.1, 2009-2105. ..... A-3
Table A.3. Projected Pumping Rates for On-post Wells Based on Distribution in Table A.1, 2009-2105. ..... A-3
Table A.4. Projected On-post Pumping and Effluent Recharge at Fort Huachuca, 2005-2015. ..... A-4
Table A.5. Reported Basin Influent (After Re-Use), Reported Pumping, and Estimated Recharge for Fort Huachuca, 2002-2009. ..... A-5
Table A.6. Projected Effluent Recharge Rates and Pumping Rates at Fort Huachuca, 2010-2015. ..... A-6
Table B.1. Arizona Department of Commerce Population Estimates for Select Portions of Cochise County. B-2
Table B.2. Arizona Department of Commerce Population Projections for Census County Divisions within the Sierra Vista Subwatershed Area of Cochise County. B-5
Table B.4. TischlerBise (2009) Population Projections for the City of Sierra Vista Including Fort Huachuca. B-8
Table C.1. Fort Huachuca Civilian Population Distribution. C-3
Table C.2. Actuary Zip Code Data on Fort Huachuca Military Retirees. C-4
Table C.3. Table 7 from 2006 BA (ENRD, 2006) with Off-post Direct, Indirect, and Induced Off-post Population Attributable to Fort Huachuca Shown on Right (Column 3). C-5
Table C.4. Estimated Fort-related Off-post Population and Associated Groundwater Demand Within the Sierra Vista Subwatershed as of 2005. ..... C-7
Table C.5. Total Off-post Simulated Pumping in USGS Model (Pool And Dickinson, 2007) for Winter of 2002-2003, and Estimated Off-post Pumping Attributable to Fort Huachuca, by Census County Division (CCD), and as a Percent of Total Simulated Pumping within Each CCD (cubic-meters). C-8

USF200010706

LIST OF FIGURES

Figure 1. Conceptualized Cross Section of USPB Showing Model Layers (after Figure 3 in Pool and Dickinson (2007)). 1-2
Figure 2. USPB Model Layers in Plan View. 1-3
Figure 3. Simulated On-post Pumping at Fort Huachuca 1902-2105 (af/yr). 2-1
Figure 4. Simulated On-post Pumping as a Percentage of Total Pumping in USPB, 1902-2105. 2-4
Figure 5. Simulated Cumulative Net Pumping in On-Post Wells, 1902-2105. 2-4
Figure 6. Simulated Storage Depletion from On-Post Wells as a Percentage of Total in USPB, 1902-2105. 2-5
Figure 7. Simulated ET Capture from On-post Wells as a Percentage of Total in USPB, 1902-2105. 2-5
Figure 8. Simulated Cumulative ET Capture from On-post Wells in USPB, 1902-2105. 2-6
Figure 9. Simulated Stream Baseflow Capture from On-post Wells as a Percentage of Total in USPB, 1902-2105. 2-7
Figure 10. Simulated Cumulative Baseflow Capture from On-post Wells in USPB, 1902-2105. 2-7
Figure 11. Simulated Total Fort-Related and Total USPB Pumping, 1940-2105. 3-2
Figure 12. Simulated Fort-attributable Pumping as a Percentage of Total in USPB, 1902-2105. 3-3
Figure 13. Simulated Cumulative Fort-attributable Pumping in USPB, 1902-2105. 3-4
Figure 14. Simulated Fort-attributable Storage Depletion as a Percentage of Total in USPB, 1902-2105. 3-4
Figure 15. Simulated Fort-attributable ET Capture as a Percentage of Total in USPB, 1902-2105. 3-5
Figure 16. Simulated Cumulative Fort-attributable ET Capture in USPB, 1902-2105. 3-5
Figure 17. Simulated Fort-attributable Stream Baseflow Capture as a Percentage of Total in USPB, 1902-2105. 3-6
Figure 18. Simulated Fort-related Cumulative Baseflow Capture in USPB, 1902-2105. 3-7
Figure 19. Simulated Sources of Capture for On-post Wells, 1902-2105. 3-8
Figure 20. Simulated Sources of Capture for All Fort-Attributable Pumping in USPB, 1902-2105. 3-9
Figure 21. Simulated Sources of Capture for All USPB Wells, 1902-2105. 3-9
Figure 22. Simulated Cumulative Recharge in the USPB, 1902-2105. 3-10
Figure 23. Simulated Changes in Stream Discharge Due to Pumping in On-post Wells Only, 1940-2105. 3-12

USF200010707

Figure 24. Simulated Pumping-induced Changes in Stream Discharge from All Fort-attributable Pumping, 1940-2105. 3-13
Figure 25. Simulated Changes in Stream Discharge Due to All USPB Pumping, 1902-2105. 3-14
Figure 26. Stream Reaches Simulated as Being Pumped Dry by On-post Wells. 3-16
Figure 27. Stream Reaches Simulated as Being Pumped Dry by Fort-attributable Pumping On and Off post. 3-17
Figure 28. Stream Reaches Simulated as Being Pumped Dry by All USPB Wells. 3-18
Figure B.1. Modified Census County Divisions Overlaid on Groundwater Model Area in Upper San Pedro Basin. B-3
Figure B.2. Estimated and Projected Population Growth Rates for the City of Sierra Vista (SV) for the Period 2002 to 2055. ....B-8
Figure B.3. Estimated and Projected Population for the City of Sierra Vista (SV) for the Period 2002 to 2055. ....B-9
Figure B.4. Estimated and Projected Population Growth Rates for Census County Divisions Within the Sierra Vista Subwatershed of Cochise County (sources: AzDC, 2009; AzDC, 2010; AzDC, 2006). B-9
Figure C.1 Sierra Vista Subwatershed Census County Divisions Overlaid on Cochise County Zip Code Map. C-6
Figure C.2 Mapping of Zip Code Population Data to Census County Divisions. C-6

USF200010708

LIST OF APPENDICES

Appendix A - SIMULATED PUMPING RATES AND ARTIFICIAL RECHARGE AT FORT HUACHUCA 2003-2105

Appendix B - ESTIMATION OF BASIN-WIDE PUMPING RATES FOR THE SIMULATION PERIOD 2003-2105

Appendix C - DEVELOPMENT OF PROJECTED FORT-ATTRIBUTABLE OFF-POST PUMPING RATES FOR THE SIMULATION PERIOD 2003-2105

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ACRONYMS AND ABBREVIATIONS

AF	acre-foot (325,851 gallons)
af/yr	acre-feet per year
BA	2006 Programmatic Biological Assessment
cfs	cubic feet per second
ET	evapotranspiration
MAF	million acre-feet
SV	Sierra Vista
USPB	Upper San Pedro Basin

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1.0 INTRODUCTION

The most recently published groundwater model of the Upper San Pedro Basin (USPB) (Pool and Dickinson, 2007) provides a tool for attributing hydrologic sources to water pumped from a given well or group of wells over time. "Sources," in this case, refers to components of the hydrologic system in the basin from which water may be directly extracted (such as aquifer storage) or captured (such as streams or evapotranspiration). Evapotranspiration (ET) represents a natural discharge from the basin as plants consume groundwater and release it to the atmosphere. If a well pumps groundwater that would otherwise have been evapotranspired by plants, the well is said to have "captured" ET from the hydrologic basin. Stream flow that is purely a surface expression of local groundwater levels and does not include any short-term bank storage or surface runoff is defined, in this context, as "baseflow." Like ET, baseflow represents a natural discharge from the aquifer to the atmosphere as water flows downstream and/or evaporates and is no longer held within the confines of the aquifer. A well pumping groundwater that would have otherwise (i.e. in the absence of pumping) been destined to discharge to a stream is said to have captured baseflow.

1.1 MODEL STRUCTURE

The numerical USPB groundwater model by Pool and Dickinson (2007) represents a conceptualization of the physical USPB by way of discreet "cells," each of which may gain or lose water during the course of a simulation. In this case, each model cell has a top area of 250 square meters. Model cells vary in thickness according to the conceptual model of the geologic layers comprising the aquifer units. When the model simulates a pumping stress, that stress propagates laterally from the pumping cell to neighboring model cells within the same layer, or vertically to cells within the same layer or in an adjacent layer, until the entire designated pumping volume is satisfied for that period of time. The maximum amount of water any given model cell can yield in response to the pumping stress is controlled by the hydrologic properties assigned to it (eg, storativity, hydraulic conductivity). For example, if a well pumps in a model unit representing a very productive aquifer, the resulting impact to neighboring cells may be minimal. The well may be able to extract all of its water from aquifer storage in its immediate vicinity, or groundwater may be easily conducted from a nearby cell to the pumping cell. In contrast, if a well pumps from a very "tight" aquifer unit in the model, then storage and/or hydraulic conductivity of cells in the vicinity of the well may be insufficient to produce all of the well's demand in the designated period of time (stress period). In that case, water may be recruited from more distant sources as the simulated cone of depression expands over time. Eventually, a pumping stress may propagate to a stream, thereby inducing leakance from the stream into the aquifer. This water is said to have been "captured" from the stream by the pumping well.

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The structure of the numerical groundwater model is defined by its authors and represents their conceptualization of the hydrogeologic features that make up the USPB. In this case, the model has 5 layers, with layer 5 forming a kind of "bowl" comprising the edges and bottom of the basin, and the other four layers stacked sequentially in the center of the basin from lowest (layer 4) to highest (layer 1) (see Figure 2). Importantly, the five layers cover different areas, with layer 5 having the largest aerial extent (the entire model area), and all other layers nested within the limits of that layer (see Figure 2). Specifically, the layer 4 – representing the regional aquifer – is recessed into layer 5, and layers 2 and 3 are recessed into the central part of layer 4.[1] Layer 1 consists of three separate segments representing the alluvial aquifer of the San Pedro River system, and it is recessed into layer 2. As Figure 2 illustrates, this "stacked bowl" type of model structure puts different model layers adjacent to one another. For example, in a surface transect from the Huachuca Mountains to the San Pedro River, layer 5 is west of layer 4 which is west of layer 2 which is west of layer 1. However, the numerical model (MODFLOW) has no capacity to compute lateral flow between cells in different layers. Each layer's external boundary (see Figures 1 and 2) is a "no-flow" boundary. Inter-layer flow may only occur through the top or bottom surfaces of layer. Thus, any groundwater moving from the Huachuca Mountains (layer 5), for example, into the regional aquifer in layer 4, can only flow upward and not laterally between the layers. Similarly, water discharging from the regional aquifer in layer 4 to the San Pedro River in layer 1 (Figure 2) must flow upward through layers 3 and 2 before reaching the river. While the model structure is based on interpreted hydrogeological conditions, the resultant simulated path of groundwater does not reflect a conventional "basinward" flow pattern from the mountains to the river.

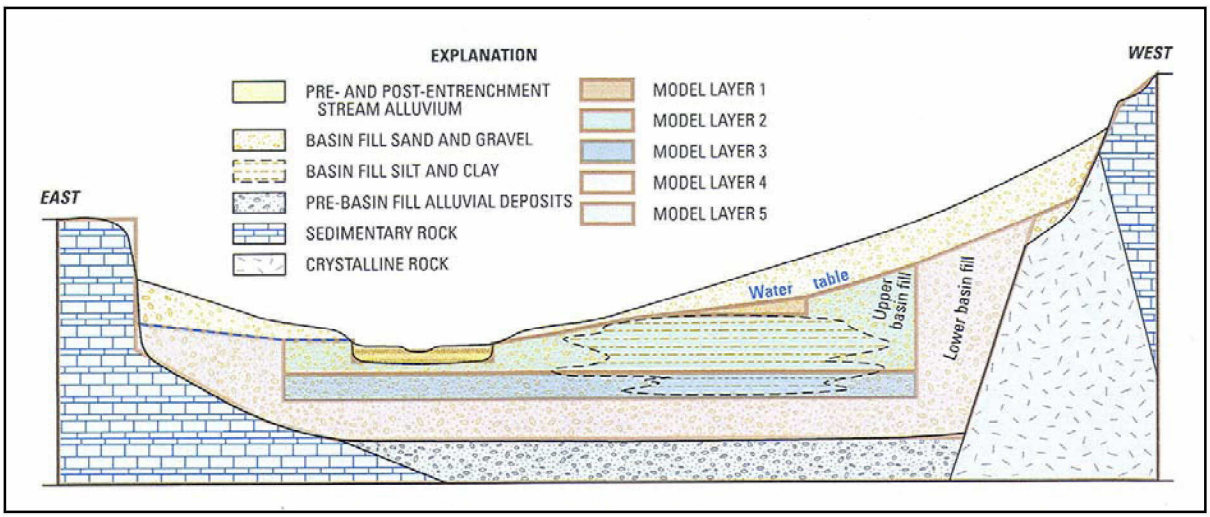

Figure 1. Conceptualized Cross Section of USPB Showing Model Layers (after Figure 3 in Pool and Dickinson (2007)).

[1] Layer 3 has no surface expression but directly underlies layer 2.

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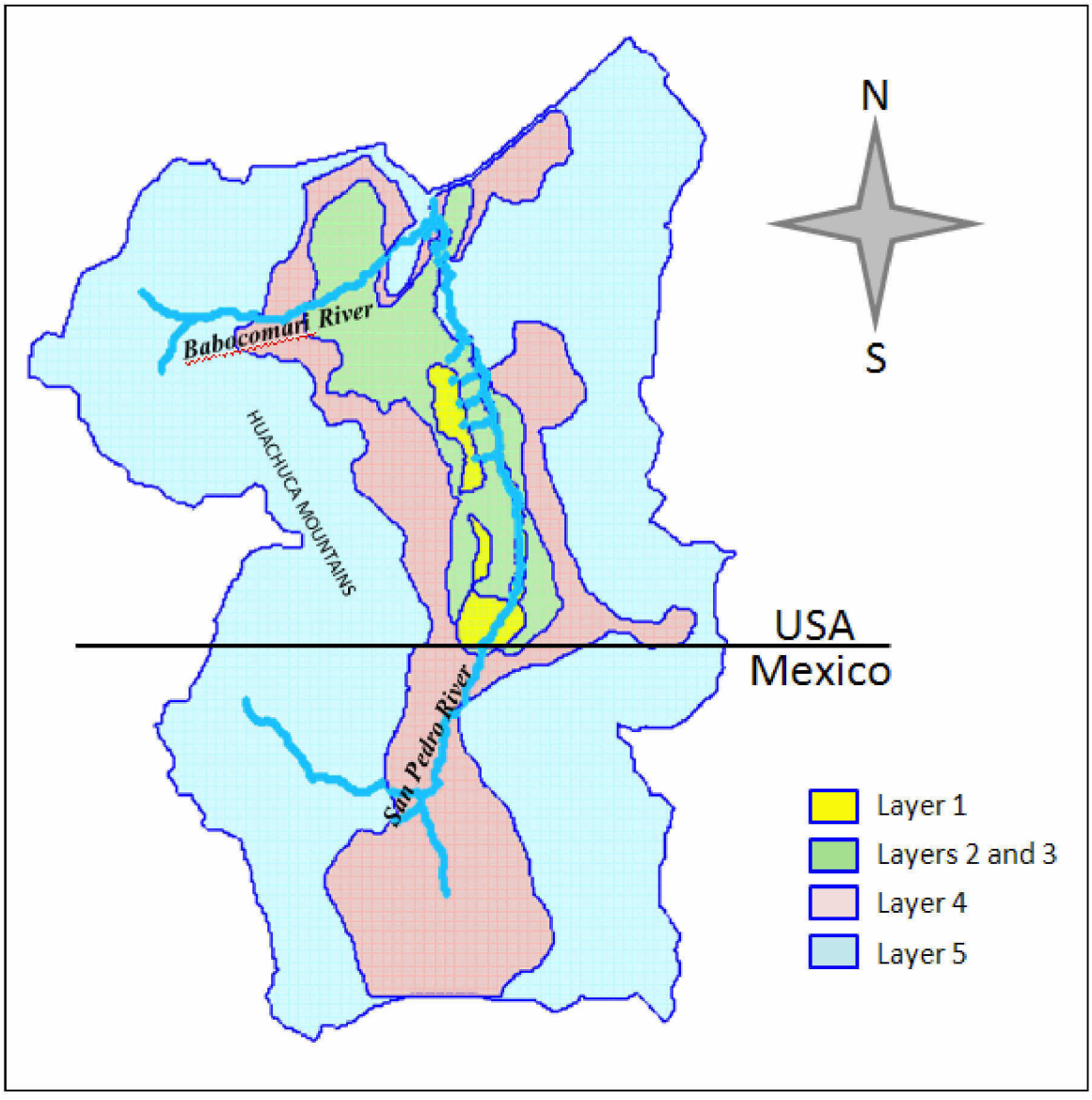

Figure 2. USPB Model Layers in Plan View.

Because the numerical groundwater model tracks the water "budget" for each individual model cell for every stress period, the model user can tally the amount of water derived from various types of model cells when a pump or group of pumps exerts a stress on the aquifer. Model cells may be assigned to one or more hydrologic boundaries designed to represent how that cell gains or loses groundwater under natural ("pre-development") conditions. Such boundaries in the USPB model include streams, ET, springs (represented by "drains"), surface recharge, and specified-head cells at the downstream end of the model area. Except for springs, which are isolated from the simulated aquifer system, each of these boundaries represents a potential source of pumping-induced capture.

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1.2 PURPOSE OF STUDY

The purpose of this study is to estimate the cumulative historic and projected impacts of groundwater pumping and artificial recharge on stream baseflow, aquifer storage, and ET depletions in the USPB attributable to Fort Huachuca for the period 1902 through 2105. It is, therefore, an analysis of impacts that have occurred in the past and a projection of impacts that may occur in the future under various scenarios and population projections. This analysis was done through use of a numerical groundwater model of the USPB developed by the U.S. Geological Survey (USGS) (Pool and Dickinson, 2007).

Groundwater pumping attributable to Fort Huachuca presently occurs within the external boundaries of the Fort's Reservation (on-post pumping) through operation of eight water production wells that supply potable water for all water needs at Fort Huachuca, including those of its resident population (i.e., military members and their dependents living in military family housing or in barracks). Pumping attributable to Fort Huachuca also occurs off post since many post employees (military, civilian, and contractors) live in the surrounding communities and receive their water through private water utilities or domestic wells. Additionally, the presence of the Fort induces jobs in the community involving the supply of goods and/or services to Fort Huachuca and/or its workforce, and these jobs have an associated water use (refer to the 2006 Programmatic Biological Assessment (BA) Section 3.7.5 and Appendix G in ENRD, 2006).

To partially offset on-post pumping effects, Fort Huachuca artificially recharges the regional aquifer through operation of its own treated effluent recharge facility. The Fort is also indirectly responsible for off-post artificial recharge since a portion of the Fort-attributable population lives within the City of Sierra Vista and this municipality operates a treated effluent recharge facility. Some passive, or "incidental," recharge also occurs through seepage from septic systems associated with Fort-attributable population living off post.

1.3 SCENARIOS SIMULATED IN STUDY

The impacts of pumping attributable to Fort Huachuca on stream baseflow, ET, and aquifer storage were evaluated for two different Fort-related scenarios. Quantifying the Fort's pumping-related impacts to the groundwater system in the USPB required the simulation of four different 203-year scenarios. The first scenario represents a baseline condition in which no groundwater withdrawal or artificial recharge occurs in the USPB over the entire simulation period 1902-2105 (referred to as the "no groundwater development" scenario). The second scenario represents the status-quo, in which all historic and projected groundwater withdrawal and artificial recharge in the USPB is included over the 203-year simulation period (referred to as the "full development" scenario). The third scenario (first Fort-related scenario) omits all historic and projected on-post pumping, but maintains all other groundwater development in the USPB, including artificial recharge on post (referred to as the "no on-post pumping" scenario). This simulation isolates the cumulative pumping-related impacts of on-post wells over the 203-year simulation period. It is not a cessation-of-

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pumping scenario, but rather, it quantifies the spatial impacts of all historic and projected on-post pumping in the presence of all other groundwater development in the USPB. This simulation provides insight as to how a replacement water supply for on-post water use would impact groundwater storage, stream baseflow, and ET.

The fourth simulation (second Fort-related scenario) omits all Fort-attributable pumping, both on and off post, for the entire 203-year simulation period (referred to as "no Fort-attributable pumping" scenario) while maintaining all other groundwater pumping and recharge in the basin. This scenario evaluates the cumulative impacts of all Fort-attributable historic and projected groundwater use in the USPB in the absence of any major future changes in water supply (i.e., importation) to the basin over the 203-year simulation period. Table 1 summarizes the four scenarios simulated in this study. Section 2.1 provides further details on the methods used to calculate pumping-related impacts in the basin.

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Table 1. Table of Scenarios Simulated in Study.

Simulation Number	Name/ Abbreviation	Description	Notes
1	No groundwater development (ND)	No groundwater pumping or artificial recharge from 1902 through 2105	Simulates basin's natural condition in the absence of any groundwater development over the 203-year simulation period.
2	Full development (FD)	All historic and projected future groundwater pumping and artificial recharge in the USPB	Simulates actual development history and projected development in the basin under status-quo conditions and in the absence of any major water importation to the basin.
3	No on-post pumping (NOP)	All historic and projected pumping and artificial recharge EXCEPT pumping within the external boundaries of Fort Huachuca's reservation. Artificial recharge on post is included.	Simulates all historic and projected groundwater development in basin in the ABSENCE OF any on-post pumping over the 203-year simulation period. Calculates spatially distributed stream and ET depletions related to on-post wells only. All off-post pumping, incidental recharge (eg, septic tanks and agricultural return flows), and artificial recharge continues.
4	No Fort-attributable pumping (NFA)	Omits all Fort-attributable pumping on and off post while maintaining all other historic and projected pumping and artificial recharge. On-post artificial recharge is included but off-post artificial recharge is reduced.	Simulates the basin's groundwater development in the ABSENCE OF any pumping related to Fort Huachuca. Calculates all spatially distributed storage, stream, and ET depletions from all Fort-attributable pumping in the basin. Artificial recharge remains the same as in the "All wells" scenario, but incidental recharge (eg, septic tank seepage) associated with all Fort-related pumping is excluded.

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2.0 CAPTURE FROM ON-POST WELLS AT FORT HUACHUCA

The published USPB model by Pool and Dickinson (2007) includes on-post pumping from 1902-2003. Fort Huachuca's Environmental and Natural Resources Division (ENRD) provided pumping rates for on-post wells and artificial recharge rates for the Fort's recharge facility for the period 2003 through 2008 (T. Runyon, email comm., 2007 and 2010). After 2009, simulated on-post pumping rates were held constant at 1300 acre-feet per year (af/yr), per Mr. Runyon's direction and based on Appendix H in the 2006 BA (ENRD, 2006). Projected on-post pumping for 2009-2105 was distributed across the same eight active wells operating on the Fort in 2008 according to the same distribution as actual pumping in 2008 (refer to Appendix A). Estimated artificial recharge rates for the Fort's effluent recharge basins for the period 2010 to 2105 are also provided in Appendix A. Figure 3 illustrates the simulated historic and projected total on-post pumping during the simulation period 1902-2105.

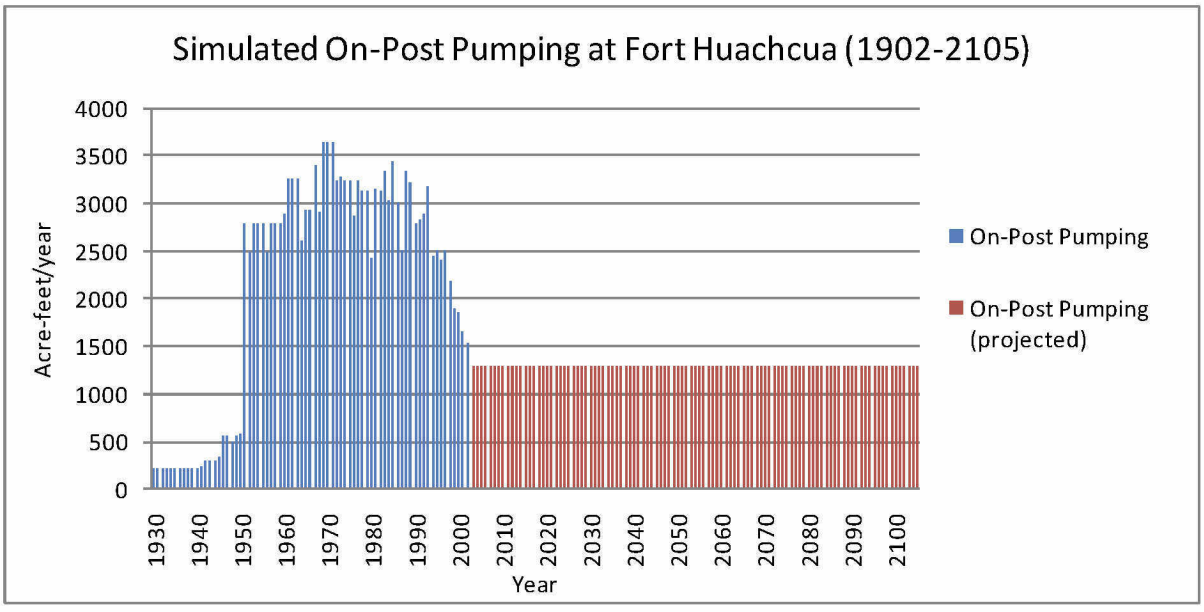

Figure 3. Simulated On-post Pumping at Fort Huachuca 1902-2105 (af/yr).

2.1 CAPTURE CALCULATIONS

Three 203-year simulations are required for each type of capture calculation related to on-post pumping. First, the "no groundwater development" (ND) scenario simulates the USPB under pre-development conditions, with no pumping and no artificial recharge (see Table 1). Any adjustments made to ET during the steady-state calibration of the model by the original authors still apply, and natural recharge is constant throughout the simulation period, as in the published model (Pool and Dickinson, 2007). Second, the "full development" (FD) scenario simulates actual historic and projected development in the basin by imposing realistic pumping and artificial recharge at the appropriate times and places in the model

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domain. Finally, a third scenario replicates the "full development" simulation except that all of the Fort's historic and projected on-post pumping is omitted[2]. This is the "no on-post pumping" (NOP) simulation.

Stream baseflow capture, ET capture, and storage depletion attributable to on-post wells is then calculated from the cumulative, basin-wide water budgets of the three simulations. Equations (1) through (3) describe the stream capture calculations. Similar equations can be written for ET capture due to on-post pumping by substituting "ET" for "Stream" in the second and third terms of equations (1) and (2). Likewise, net storage depletion from on-post well pumping can be calculated by substituting "Net Storage" for "Discharge to Stream" in equations (1) and (2).

Equation (1) describes the calculation of stream capture for the "full development" scenario:

$$\boldsymbol{FD\ Stream\ Capture} = (\boldsymbol{Discharge\ to\ Stream})_{\mathrm{ND}} - (\boldsymbol{Discharge\ to\ Stream})_{\mathrm{FD}} \quad (1)$$

Equation (2) calculates stream capture for the "no on-post pumping" scenario:

$$NOP\ Stream\ Capture = (Discharge\ to\ Stream)_{\mathrm{ND}} - (Discharge\ to\ Stream)_{\mathrm{NOP}} \quad (2)$$

The difference between these two capture values (equations (1) and (2)) equals stream capture attributable to on-post pumping, as shown in Equation (3):

$$On\text{-}post\ Pumping\ Stream\ Capture = FD\ Stream\ Capture - NOP\ Stream\ Capture \quad (3)$$

This three-step process captures the cumulative impact of the wells of interest (i.e., the Fort's on-post wells) in the presence of all other pumping and recharge in the basin. Substituting "$(Discharge\ to\ Stream)_{NOP}$" for "$(Discharge\ to\ Stream)_{FD}$" in the third term of Equation (1) would calculate capture due to on-post pumping in the <u>*absence*</u> of all other pumping, and would not account for additional cumulative impacts of off-post wells. This process differentiates this study from the approach used by Leake, et al. (2008) to develop the so-called "capture" maps of the USPB. That study applied a unit pumping stress, in

[2] Simulated artificial recharge on Fort Huachuca was maintained during the "no Fort" simulation.

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isolation from any other pumping stresses, to each model cell to examine the aquifer's capture response at that cell. That approach simulates the native hydrologic characteristics of each model cell in the basin rather than simulating capture attributable to a specific pumping well or group of wells in a developed basin.

2.2 BASIN-WIDE PUMPING PROJECTIONS

The USGS model (Pool and Dickinson, 2007) provides pumping rates for all simulated wells in the basin from 1902 to early 2003. In order to simulated capture related to on-post pumping from 2003 to 2105, pumping for all wells in the USPB had to be estimated for this time period. For the period 2003 to 2105, population projections provided by the Arizona Department of Commerce formed the basis for projecting domestic, municipal and industrial pumping across the USPB (outside of Fort Huachuca)[3]. Appendix B describes the methodology for applying population estimates to the Sierra Vista (SV) subwatershed of the USPB to estimate future pumping demand across the area.

2.3 RESULTS

Figure 4 shows that, over the entire 203-year simulation period (1902-2105), on-post pumping accounted for just 5% (289,456 AF) of all simulated net pumping in the USPB, including Mexico (5.7 million acre-feet (MAF) total). Figure 5 plots cumulative net pumping (extraction minus recharge[4]) for three subsets of wells in the USPB. These three subsets can be described in terms of scenarios 2 and 3 in Table 1 as follows:

1. all wells in the basin (FD scenario),
2. all off-post wells (NOP scenario), and
3. all on-post wells (FD scenario – NOP scenario).

Cumulative simulated storage depletion in the USPB as of 2105 is 4.1 MAF. Of that total, 4% (183,699 AF) is a result of simulated pumping by on-post wells (Figure 6). Figure 7 shows that simulated on-post pumping accounts for 3% (14,734 AF) of total ET capture in the USPB (551,682 AF). Cumulative ET capture over time for: a) the entire USPB, b) all off-post wells, and c) on-post wells only, is plotted in Figure 8.

[3] All 2004-2105 mining and agricultural pumping rates were held at 2003 levels in the simulations.

[4] Recharge occurs on a per-well basis to represent agricultural return flows and septic system seepage.

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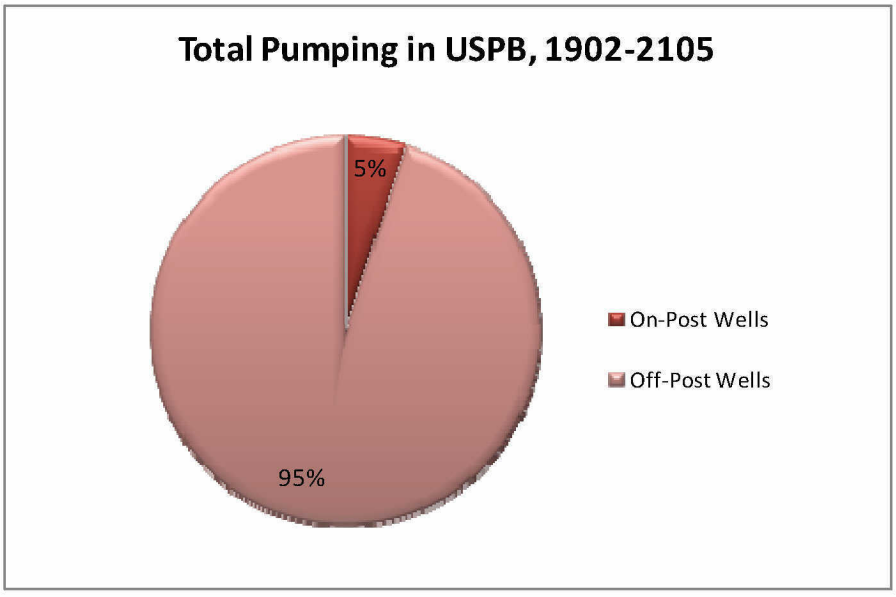

Figure 4. Simulated On-post Pumping as a Percentage of Total Pumping in USPB, 1902-2105.

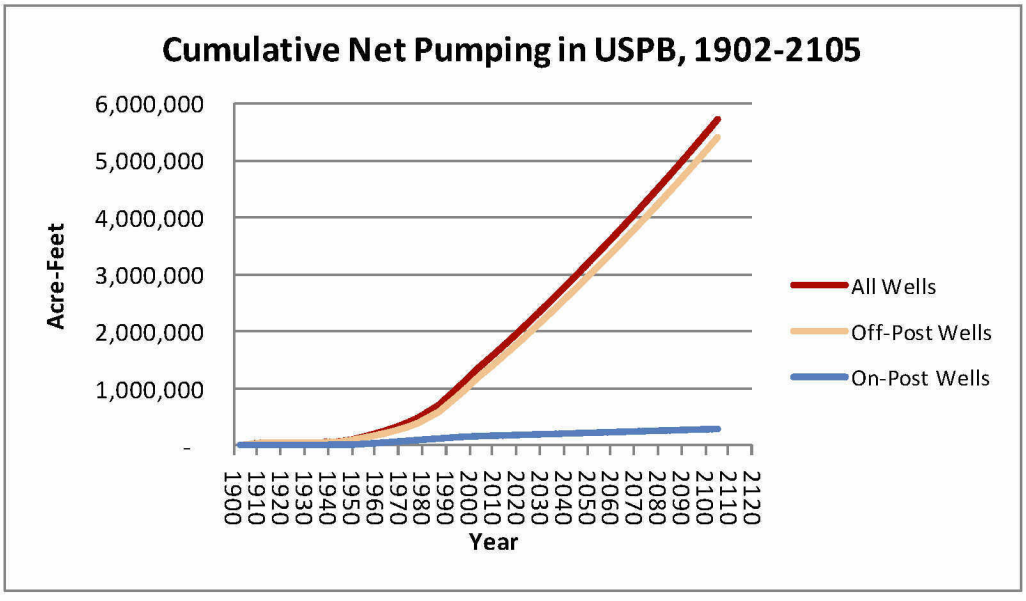

Figure 5. Simulated Cumulative Net Pumping in On-Post Wells, 1902-2105.

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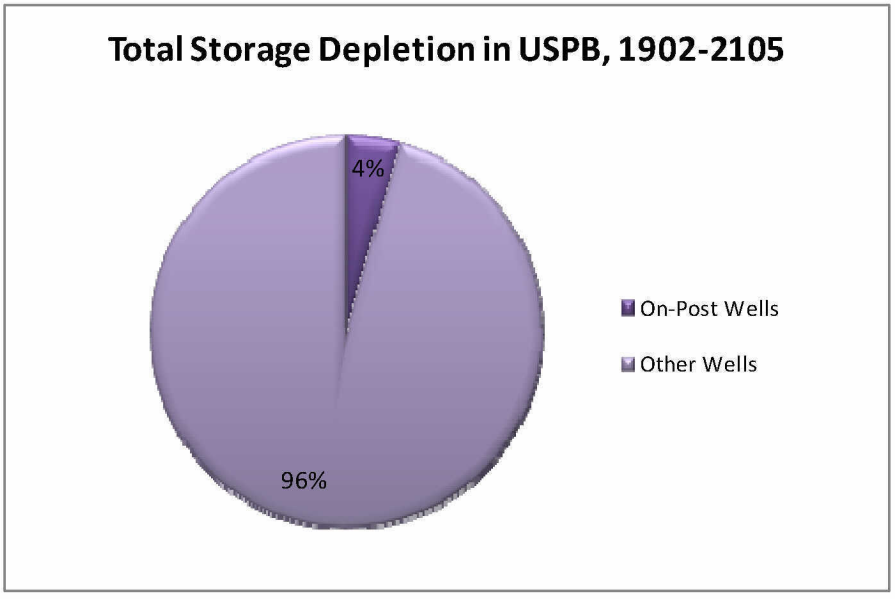

Figure 6. Simulated Storage Depletion from On-Post Wells as a Percentage of Total in USPB, 1902-2105.

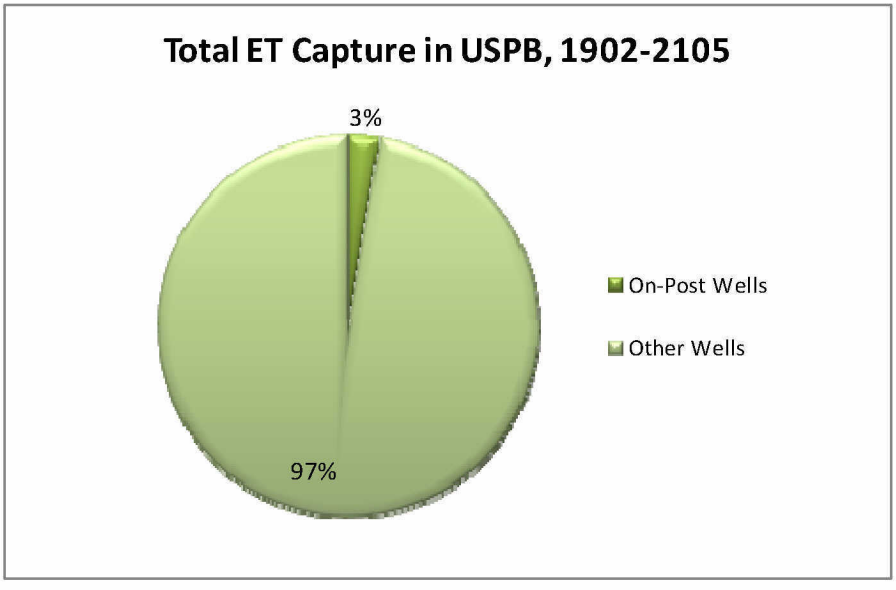

Figure 7. Simulated ET Capture from On-post Wells as a Percentage of Total in USPB, 1902-2105.

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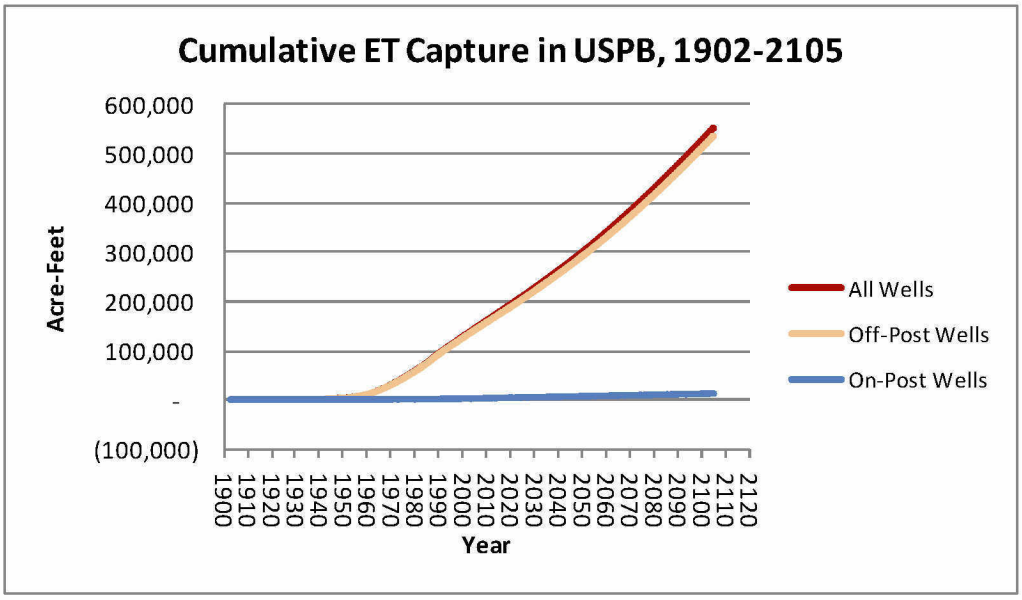

Figure 8. Simulated Cumulative ET Capture from On-post Wells in USPB, 1902-2105.

Figure 9 shows the percentage of simulated baseflow capture attributable to simulated pumping by on-post wells. Simulated on-post pumping, at 5% of the total pumping, accounted for 91,583 (31%) of the 293,383 AF of simulated baseflow captured by 2105 in the entire USPB, and shows that the Fort's on-post pumping has a disproportionately large impact on baseflow capture relative to wells in other areas of the basin.

Figure 10 illustrates the progression of simulated baseflow capture over time for the three subsets of simulated pumping wells (all wells, all off-post wells, and all on-post wells). Simulated capture attributable to on-post pumping begins to level out after 2009 as simulated pumping by the Fort's on-post wells remains steady while pumping in the remainder of the basin continues to grow.

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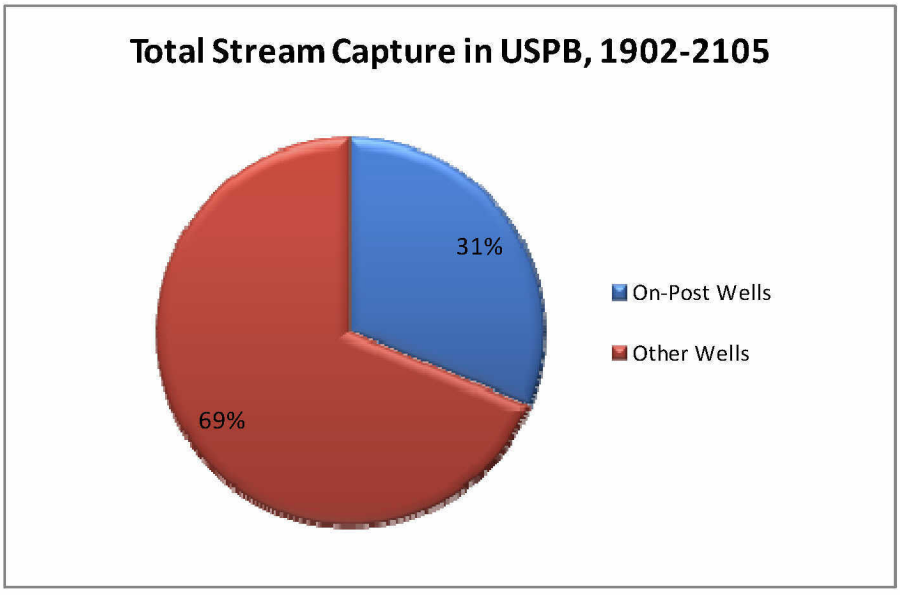

Figure 9. Simulated Stream Baseflow Capture from On-post Wells as a Percentage of Total in USPB, 1902-2105.

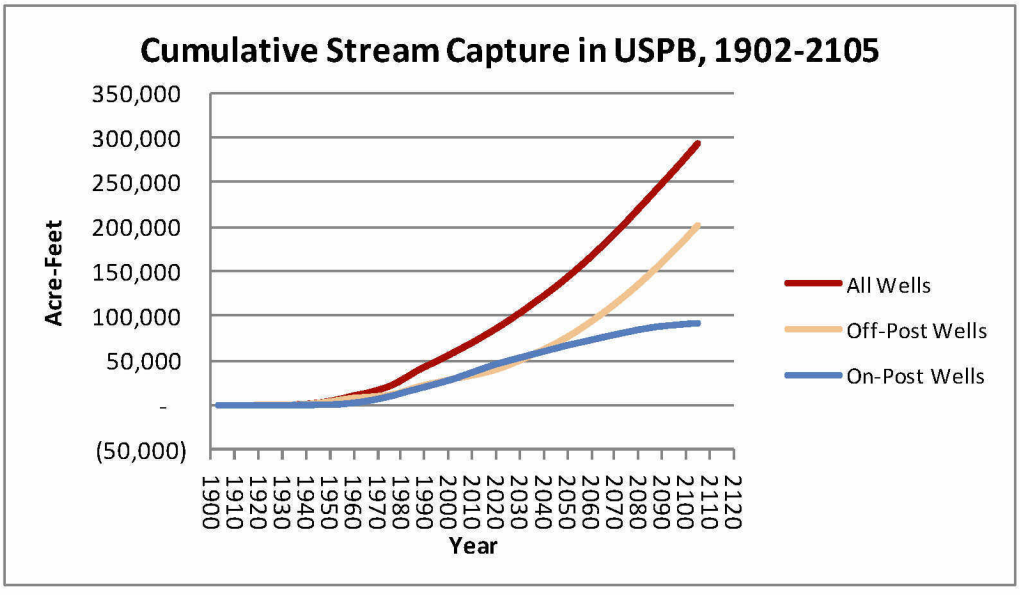

Figure 10. Simulated Cumulative Baseflow Capture from On-post Wells in USPB, 1902-2105.

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3.0 CAPTURE FROM ALL PUMPING ATTRIBUTABLE TO FORT HUACHUCA

In 2005, approximately 43% of the population in the Arizona portion of the USPB was directly or indirectly attributable to the presence of Fort Huachuca (ENRD, 2006). The 2006 BA (ENRD, 2006) provides an in-depth discussion of how the total Fort Huachuca-attributable population in the basin was determined. The Fort's off-post population includes active military living off post, government civilian employees and their family members, contractors and their families, military retirees, and others. In addition to these "direct" and "indirect" members of the Fort's population, the Fort's presence creates an "induced" population of business owners and other service providers who serve the needs of Fort's population. According to Section 3.7.6 of the 2006 BA (ENRD, 2006), 26.7% of the Fort's total 2005 "direct" and "indirect" population within the SV subwatershed of the USPB comprised the Fort's "induced" population in 2005. Any estimate of groundwater capture attributable to the Fort's total population in the USPB must account for the groundwater used by the Fort's off-post population in addition to its on-post pumping.

3.1 CAPTURE CALCULATIONS

Equations (2) and (3) in Section 2.1 can be modified to calculate capture for all Fort-attributable pumping, both on and off post, as shown below:

Equation (2) becomes Equation (4) which calculates stream capture for the "no Fort-attributable pumping" (NFA) scenario (see Table 1):

$$Non\text{-}Fort\text{-}attributable\ \ Stream\ Capture = (Discharge\ to\ Stream)_{\mathrm{ND}} - (Discharge\ to\ Stream)_{\mathrm{NFA}} \qquad (4)$$

Subtracting Equation (4) from Equation (1) gives stream capture from *all* Fort-attributable pumping, as shown in Equation (5):

$$All\ Fort\text{-}attributable\ Pumping\ Stream\ Capture = FD\ Stream\ Capture - NFA\ Stream\ Capture \qquad (5)$$

3.2 ESTIMATES OF FORT-ATTRIBUTABLE PUMPING

Simulated off-post pumping attributable to the Fort began in 1940 in the USGS model (Pool and Dickinson, 2007). The capture simulations for this study required estimates of Fort-

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attributable off-post pumping from that time through early 2105. Appendix C describes the methodology used for estimating off-post Fort-attributable pumping from 1940 to 2105, and provides suggestions for how these estimates could be further refined with additional data. Figure 11 shows total simulated historic and projected pumping for the entire USPB and for the Fort's direct, indirect, and induced population in the USPB, both on and off post (i.e., Fort-attributable pumping).

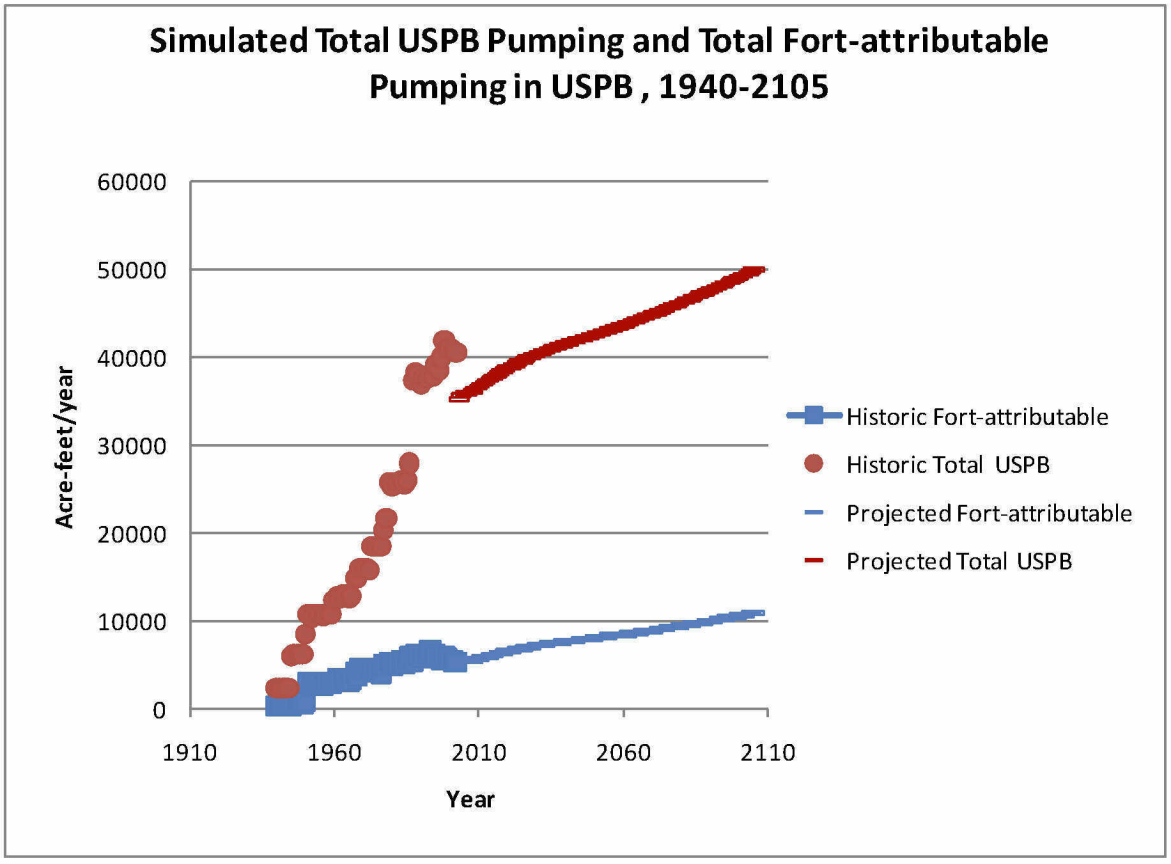

Figure 11. Simulated Total Fort-Related and Total USPB Pumping, 1940-2105.

3.3 RESULTS

3.3.1 Quantification of Capture

Of the 5.7 million acre-feet (MAF) of groundwater pumped in the USPB during the simulation period 1902-2105, the method described in Appendix C yields an estimate of 19% (1,082,045 AF) attributable to Fort Huachuca (Figure 12).. Figure 13 plots cumulative simulated pumping over time for the entire 203-year simulation period for the three types of

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USPB pumping.[5] These three types can be described in terms of scenarios 2 and 4 in Table 1 as follows:

1. all pumping in the basin (FD scenario),
2. all non-Fort-attributable pumping (NFA scenario), and
3. all Fort-attributable pumping (FD scenario – NFA scenario).

Figure 14 shows that Fort-attributable pumping is responsible for 21% (850,791 AF) of total simulated basin storage depletion (4,129,324 AF) during the 203-year simulation period. As shown in Figure 15, total simulated Fort-attributable pumping results in 7% (41,024 AF) of all simulated ET capture in the USPB from 1902-2105 (551,682 AF). Figure 16 plots cumulative ET capture versus time for the three types of pumping simulated. Note that the Fort's total simulated capture from on- and off-post pumping increases after about 1990.

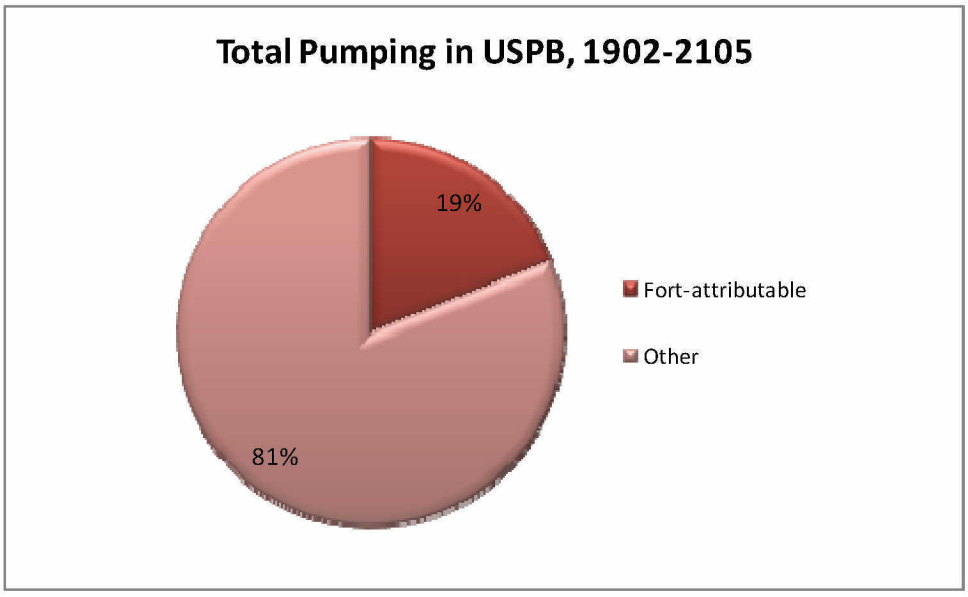

Figure 12. Simulated Fort-attributable Pumping as a Percentage of Total in USPB, 1902-2105.

[5] Here, "types of USPB pumping" replaces the term "subgroups of wells" found in Section 2.3 because the fraction of total simulated off-post pumping attributable to the Fort occurs in wells shared with the non-Fort-attributable population.

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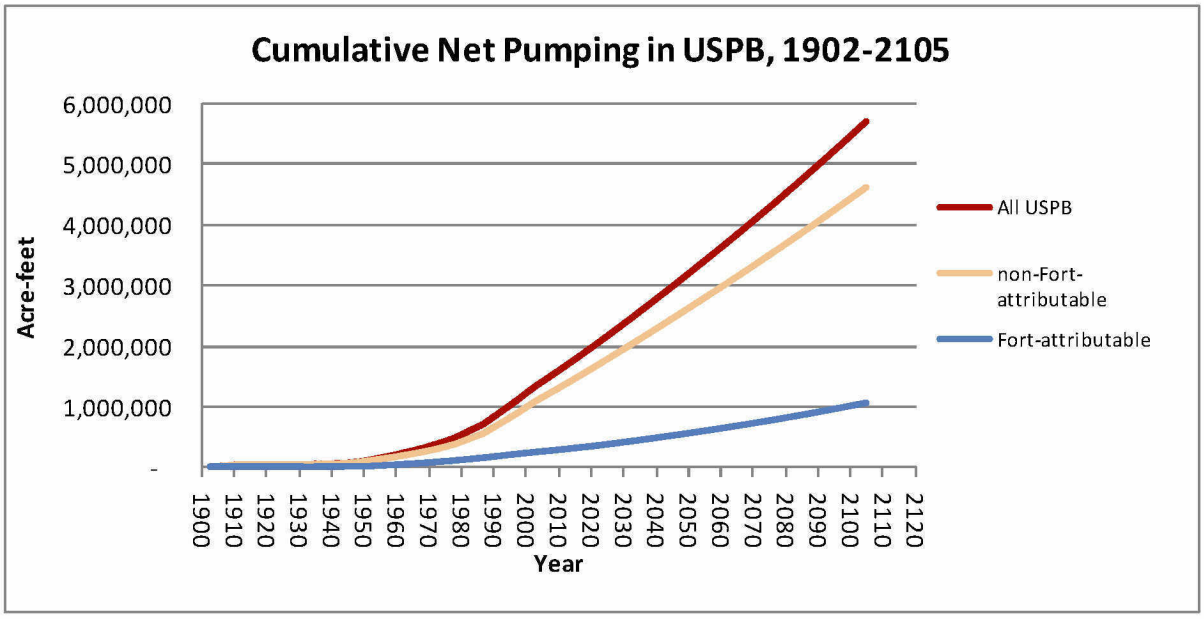

Figure 13. Simulated Cumulative Fort-attributable Pumping in USPB, 1902-2105.

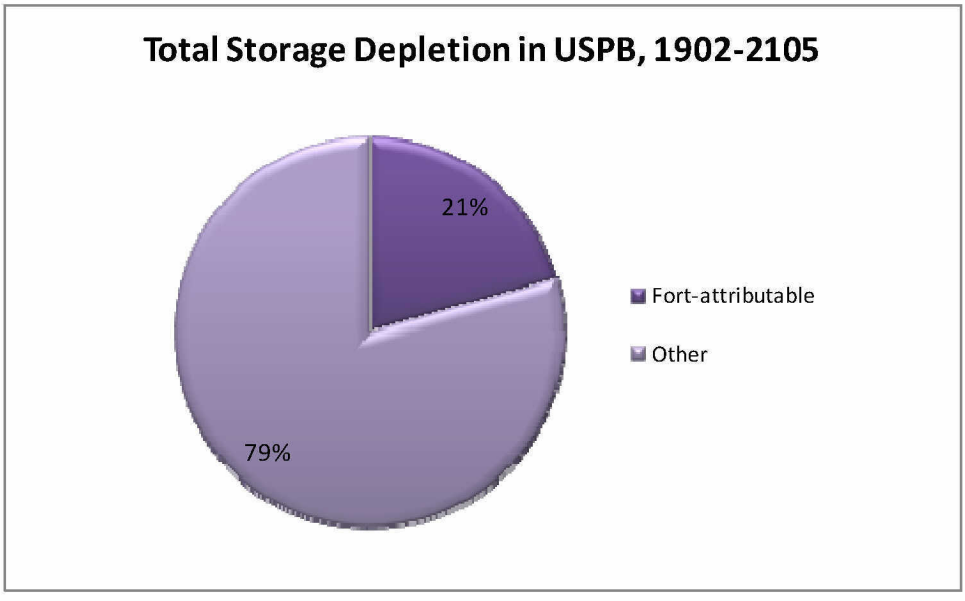

Figure 14. Simulated Fort-attributable Storage Depletion as a Percentage of Total in USPB, 1902-2105.

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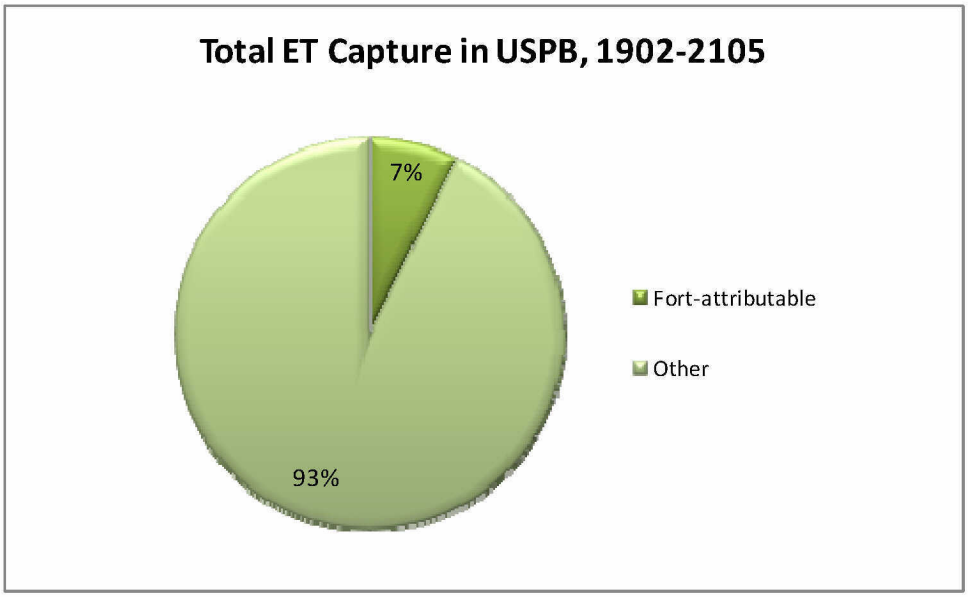

Figure 15. Simulated Fort-attributable ET Capture as a Percentage of Total in USPB, 1902-2105.

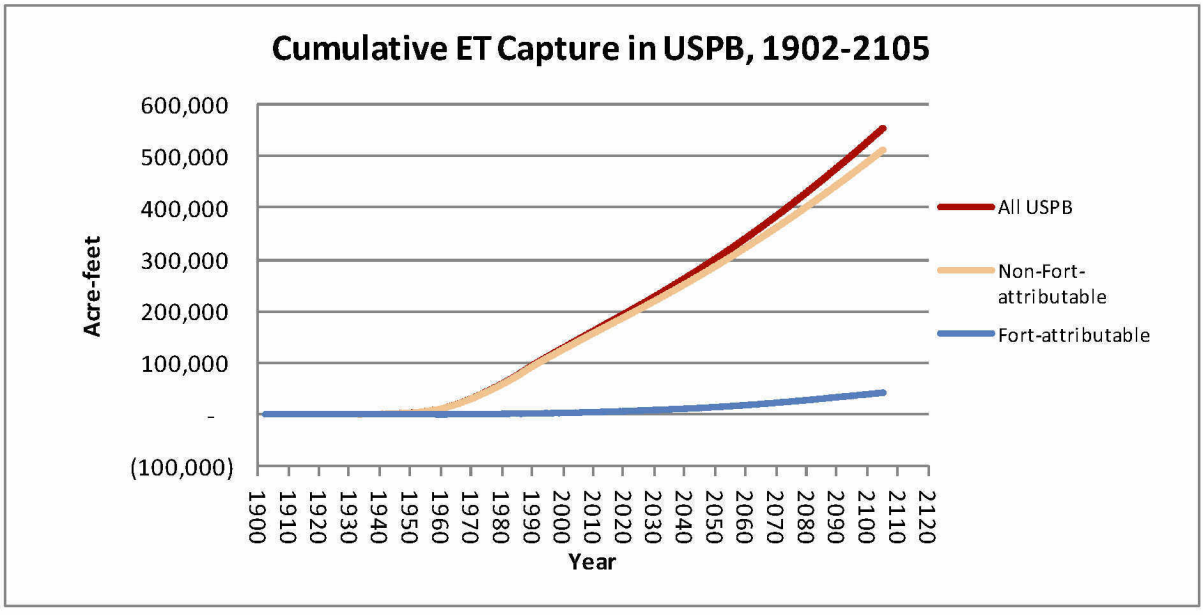

Figure 16. Simulated Cumulative Fort-attributable ET Capture in USPB, 1902-2105.

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 in Figure 17. The capture simulations estimate that 186,237 AF out of a total of 293,383 AF, or 63%, of captured baseflow in the USPB is caused by Fort-attributable pumping during the period 1902-2105. However, the inclusion of off-post

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wells in the simulations actually reduces the proportional impact of the Fort's pumping relative to that of the on-post wells alone. For on-post pumping, 31% of baseflow capture comes from 5% of basin pumping, for a percentage-of-capture-to-percentage-of-pumping ratio of 6.2. The same ratio calculated for the Fort's total impact, including off-post pumping, is 3.3. This reduction reflects the fact that much of the Fort's simulated off-post pumping liability occurs in areas of the basin represented in the model as having less direct hydrologic connection to stream sources in the model. Figure 18 plots simulated cumulative baseflow capture over the period 1902-2105 for all Fort-attributable pumping and for all other wells in the basin.

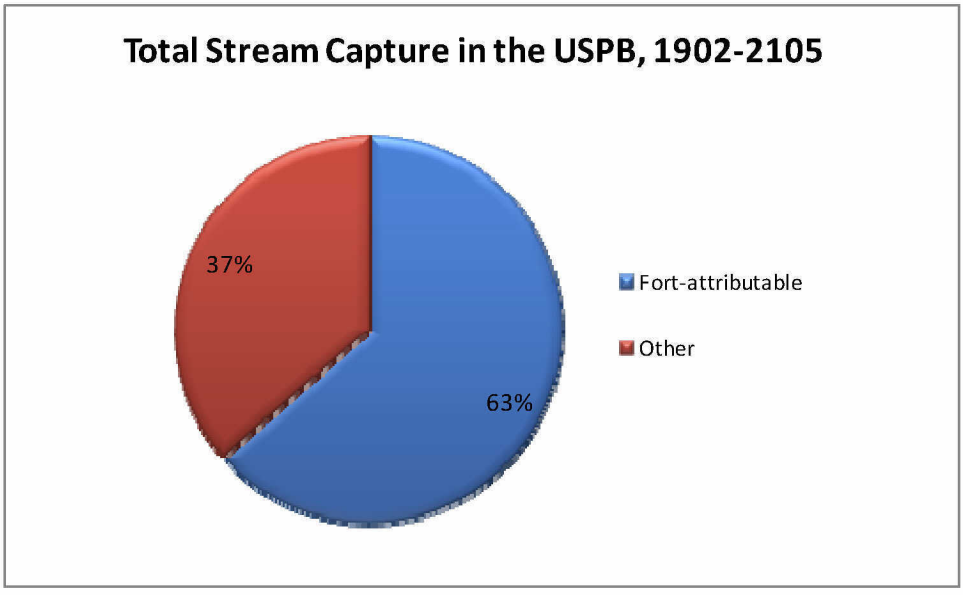

Figure 17. Simulated Fort-attributable Stream Baseflow Capture as a Percentage of Total in USPB, 1902-2105.

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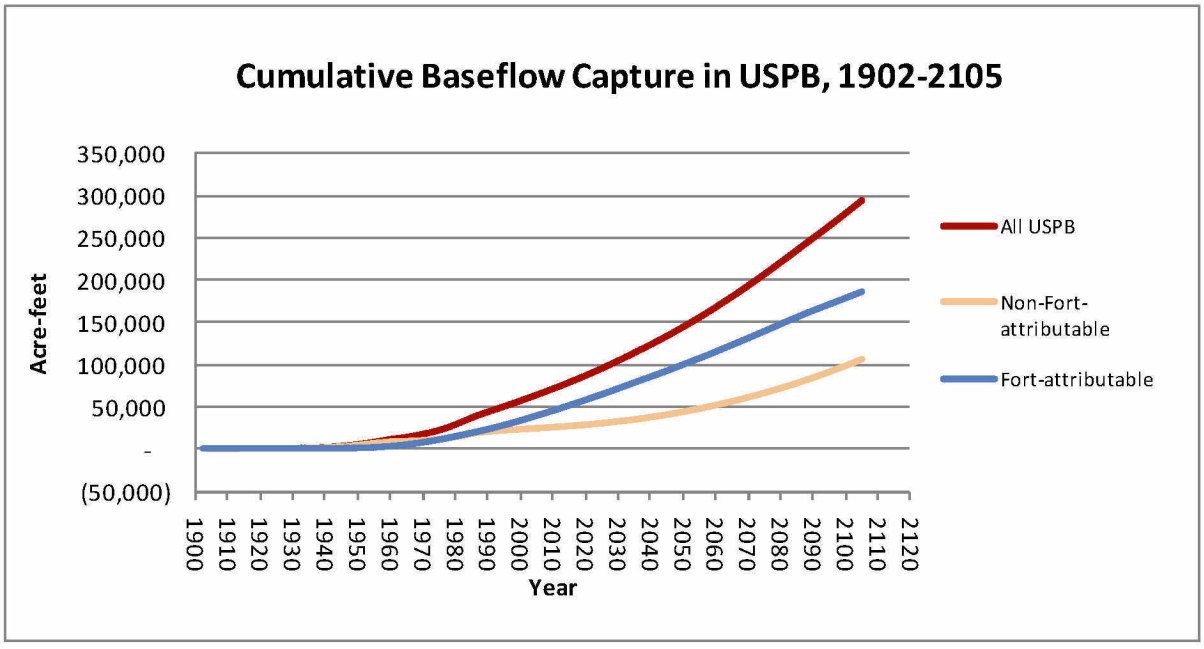

Figure 18. Simulated Fort-related Cumulative Baseflow Capture in USPB, 1902-2105.

3.3.2 Sources of Capture

Figures 19, 20, and 21 partition simulated pumping by sources of capture. The three primary sources of capture for Fort-attributable pumping are: 1) storage, 2) stream baseflow, and 3) ET. Other potential capture sources, including groundwater through-flow at the downstream model area boundary, artificial recharge, and springs, constitute less than one percent of all computed Fort-attributable capture. Aquifer storage is by far the most important source of water for all simulated Fort-attributable pumping, both on and off post. Simulated on-post wells derive approximately 63% of all their pumped water from aquifer storage, 32% from stream baseflow capture, and 5% from ET capture (Figure 19). Roughly 79% of all simulated Fort-attributable pumping derives from aquifer storage, while 17% comes from stream baseflow capture, and 4% from ET capture (Figure 20).

Comparison of Figure 19 and Figure 20 shows the pronounced difference in the relative impact on simulated baseflow capture from on-post wells alone versus all Fort-attributable pumping. For the on-post wells, 32% of all simulated pumping derives from the capture of stream baseflow, whereas only 17% of all Fort-attributable pumping (on and off post) derives from stream baseflow capture. This result indicates that the group of on-post wells has a better hydrologic connection to stream sources in the conceptual model (Pool and Dickinson, 2007) than does the larger group of wells representing all Fort-attributable pumping.

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Figure 21 presents sources of capture for all simulated wells in the USPB. Aquifer storage is still, by far, the largest source (72%; 4.13 MAF) of all pumped groundwater in the model simulations. In contrast to the two groups of Fort-related wells in figures 19 and 20, however, the basin-wide USPB wells also capture artificial recharge, which accounts for 13% (727,600 AF) of all groundwater pumped in the model area. Simulated ET capture comprises 10% (551,700 AF) of total pumping in the model, and simulated stream baseflow capture contributes just 5% (293,000 AF) of all water pumped by wells in the USPB model. A significant portion of artificial recharge in the groundwater model stems from mine dewatering near Tombstone, Bisbee, and Cananea, much of which occurred in the early half of the twentieth century. More recent additions to this category of the model water budget include recharge basins at Sierra Vista's Environmental Operations Plant, Fort Huachuca's effluent recharge basins, and excess irrigation at golf courses and other large turf areas (Pool and Dickinson, 2007). Figure 22 plots cumulative simulated recharge from 1902 to 2105 for the "full development" and "no groundwater development" model scenarios (refer to Table 1). The difference between the two curves represents simulated artificial recharge. By 2105, cumulative simulated artificial recharge exceeds 720,000 AF, all of which the simulations indicate is captured by pumping wells in the basin.

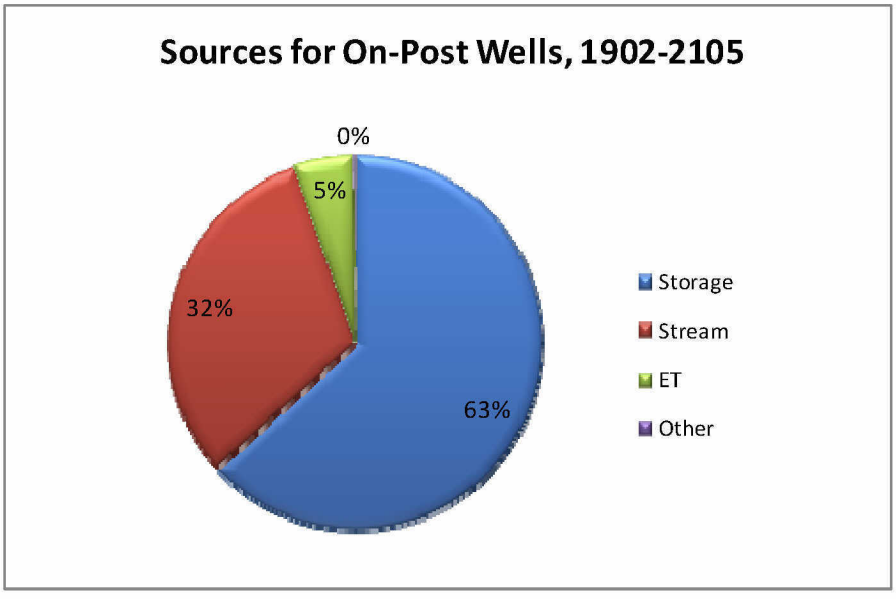

Figure 19. Simulated Sources of Capture for On-post Wells, 1902-2105.

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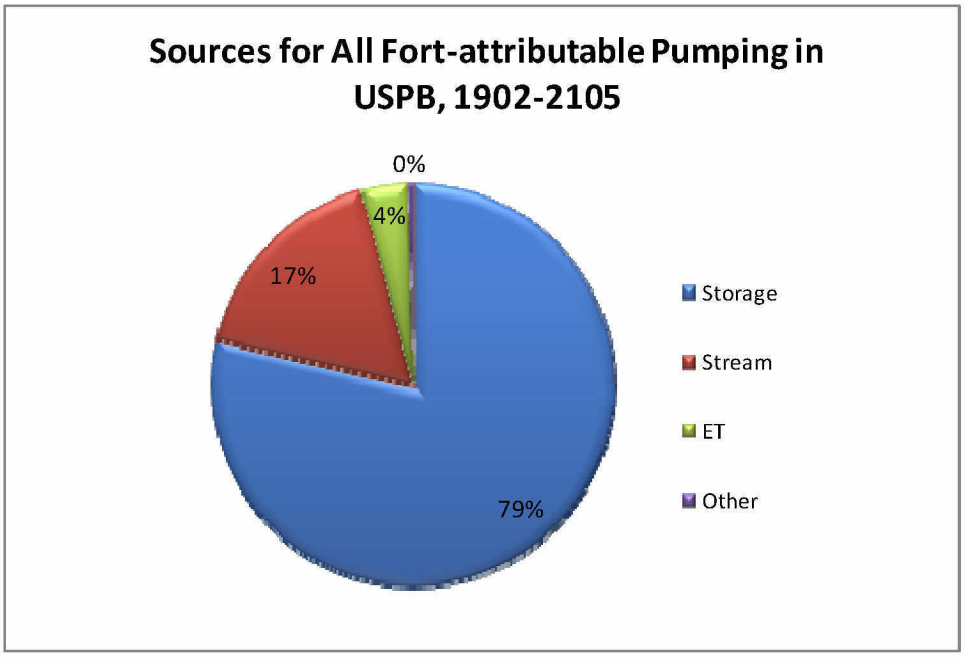

Figure 20. Simulated Sources of Capture for All Fort-Attributable Pumping in USPB, 1902-2105.

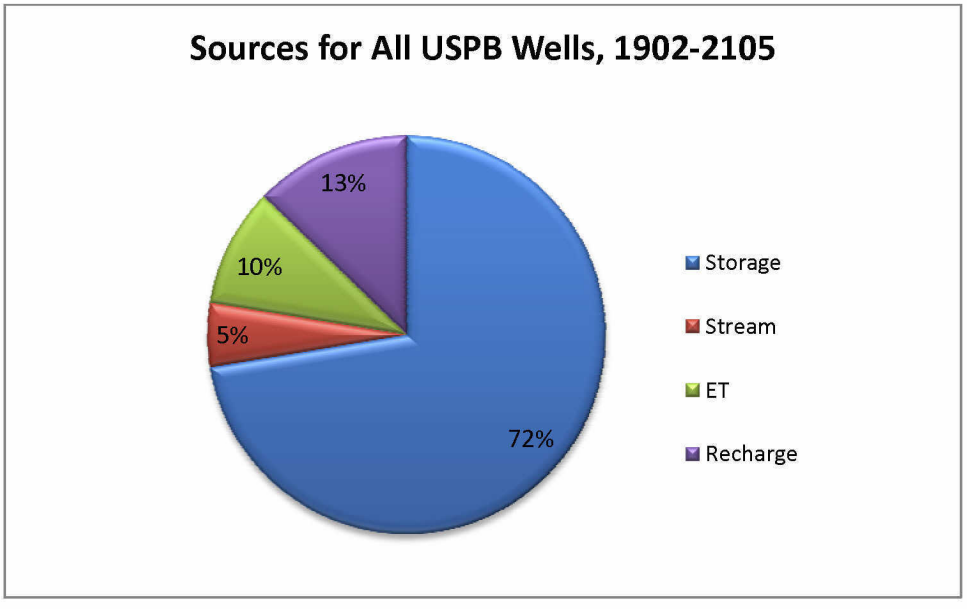

Figure 21. Simulated Sources of Capture for All USPB Wells, 1902-2105.

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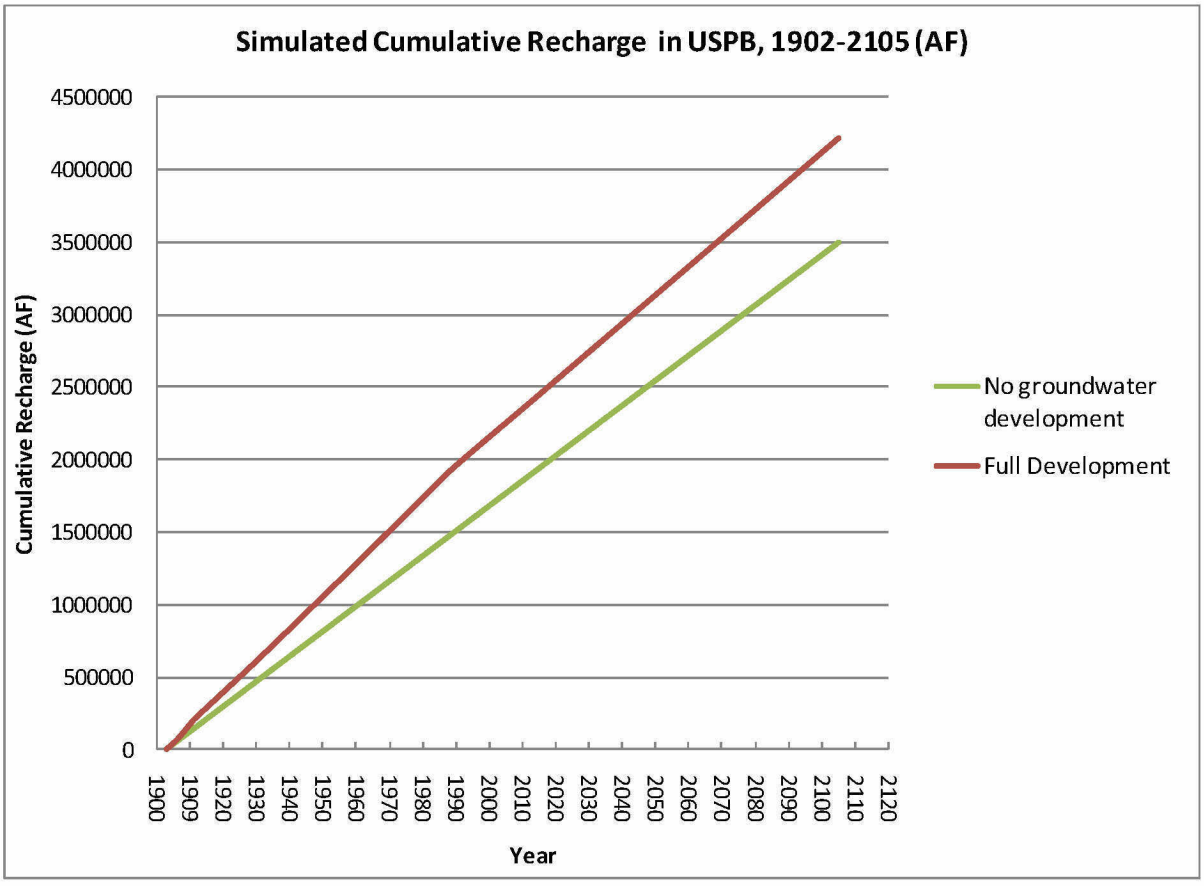

Figure 22. Simulated Cumulative Recharge in the USPB, 1902-2105.

3.3.3 Changes in Stream Baseflow

In order to understand the spatial impacts of simulated Fort-attributable baseflow capture, pumping-induced changes in stream discharge (baseflow) were mapped for three discreet points in time: 2003, 2050, and 2105 (figures Figure 23 through Figure 25). Each river in the model is discretized into 250-meter (820-ft.) long segments, or "reaches." The model then computes a water budget for each stream reach in response to changes in groundwater levels underneath the streambed. Simulated baseflow in each reach is the sum of four computed values for each model time step: 1) streamflow flowing into the reach from the next upstream reach, 2) groundwater flowing from the aquifer into the reach, 3) stream flow leaking from the reach into the aquifer, and 4) stream flow flowing out to the next downstream reach. This final value is the quantity mapped in figures Figure 23 through Figure 25. Importantly, these simulated stream discharge values have *no surface water component*, and they do not necessarily equal the calculated volume of stream baseflow capture (see Section 3.1). Figure 23 maps pumping-induced changes in baseflow for on-post wells only in 2003, 2050, and 2105. Figure 24 and Figure 25 plot the same information for all Fort-attributable pumping, and all USPB pumping, respectively.

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Figure 23 shows that, out of these three years, the simulated impact of on-post wells on baseflow in the Babocomari and the San Pedro rivers peaked in 2003, with the greatest impact, depletions of 1 to 2 cubic-feet per second (cfs), occurring at the confluence of the two rivers. Simulated baseflow impacts from on-post wells diminish somewhat and shift away from the Babocomari over the next century. This diminishing impact of on-post wells reflects ongoing adjustment of the water table to pumping stresses and related demand on sources of supply. By the end of 2105, maximum simulated baseflow depletions from on-post wells are 0.5 to 1 cfs, and are focused on the San Pedro River at its confluence with the Babocomari.

Figure 24 shows simulated stream baseflow depletions attributable to all on- and off-post Fort-attributable pumping in the years 2003, 2050, and 2105. Compared with the graphics in Figure 23, those in Figure 24 reveal a much more pronounced impact on the lower reaches of the Babocomari River (likely due to Fort-attributable pumping in Huachuca City), and several impacted reaches upstream on the San Pedro near the border with Mexico. Again, out of these three years, peak impacts to simulated baseflow occur in 2050, but depletions of 2 to 3 cfs at the confluence of the Babocomari and San Pedro Rivers persist out to 2105, with a significant portion of both rivers showing depletions in the range of 1 to 2 cfs upstream from the confluence.

To put the Fort-related baseflow depletions in perspective, Figure 25 maps baseflow depletions resulting from all simulated pumping in the USPB for the same three years. The cumulative impacts of all basin-wide pumping are pronounced throughout most of the Arizona portion of the model area, and along the main stem of the San Pedro River well into Mexico. Simulated baseflow depletions of 3 to 5 cfs occur at the confluence of the Babocomari and San Pedro rivers and on the main stem of the San Pedro just south of the international boundary in 2050. By 2105, significant portions of the Babocomari and San Pedro Rivers (including the reach with the Charleston stream-gaging station) show simulated baseflow depletions in the range of 2 to 3 cfs, as does the main stem of the San Pedro in the Palominas-Hereford area north of the Mexican border, and along a section of the main stem just downstream (north) of the Rio los Fresnos in Mexico.

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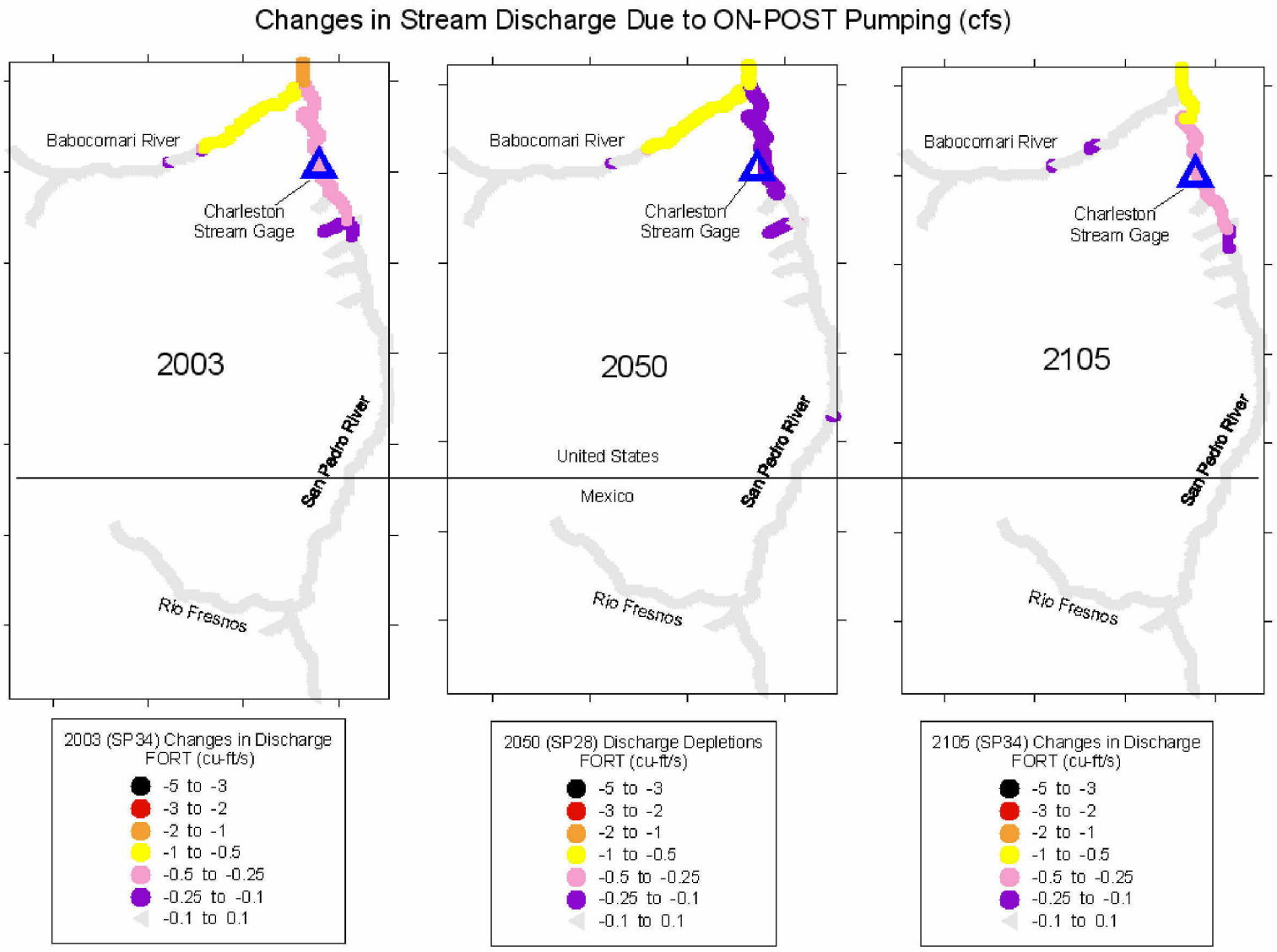

Figure 23. Simulated Changes in Stream Discharge Due to Pumping in On-post Wells Only, 1940-2105.

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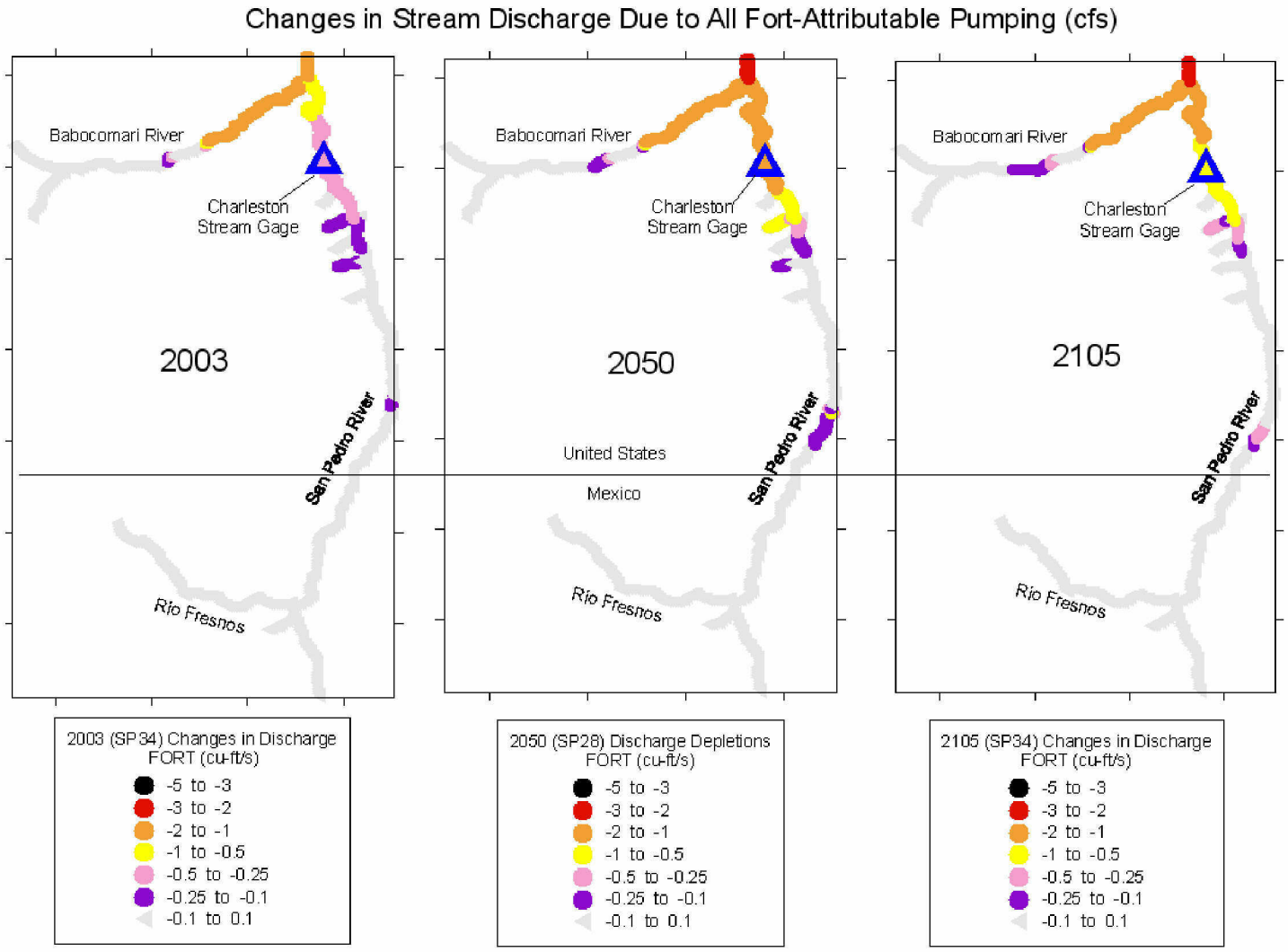

Figure 24. Simulated Pumping-induced Changes in Stream Discharge from All Fort-attributable Pumping, 1940-2105.

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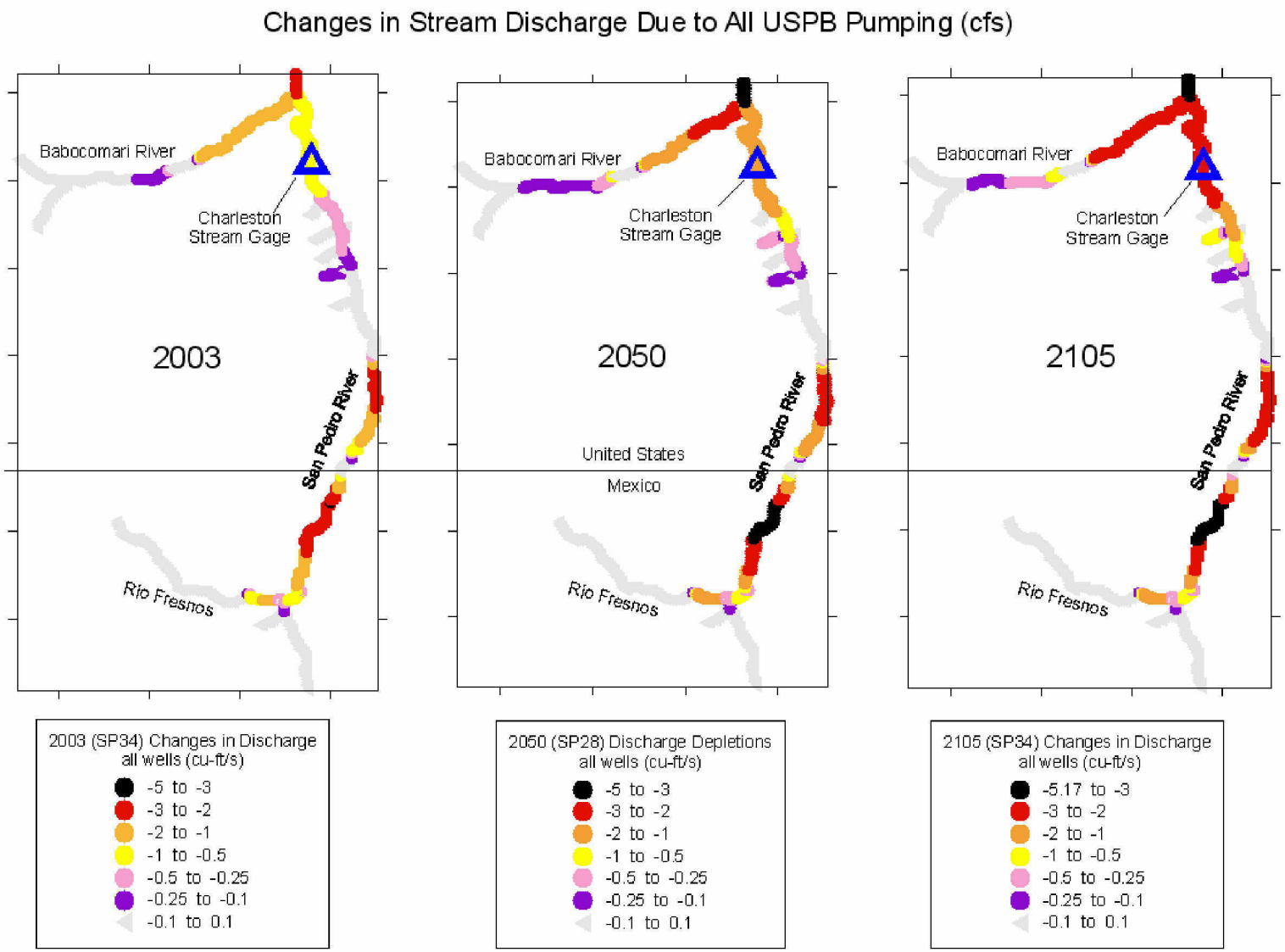

Figure 25. Simulated Changes in Stream Discharge Due to All USPB Pumping, 1902-2105.

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After a persistent period of baseflow depletions, some river reaches in the USPB model go dry, as determined by a stream stage level below the top elevation of the streambed in MODFLOW. Figures 26-28 map the stream reaches that were simulated as having gone dry as a result of groundwater extractions from on-post wells, from all Fort-attributable pumping, and from all USPB wells, respectively. Figure 26 shows that in 2050, two reaches in the Babocomari were simulated as being "pumped dry" by on-post wells. By 2105, however, these wells' simulated impacts had diminished and they were no longer responsible for any dry reaches.

Figure 27 shows a similar pattern of peak number of pumped-dry reaches in 2050 resulting from all Fort-attributable pumping. In this case, simulated Fort-attributable pumping produced two dry reaches in 2003, five in 2050, and three in 2105. When all simulated pumping wells in the USPB were considered together, seven stream reaches were pumped dry in 2003, fourteen in 2050, and fifteen in 2105 (Figure 28).

DISCLAIMER: While the maps in figures 23 through 28 provide a good visual guide for the spatial distribution of stream impacts from the various pumping simulations described, these results should be interpreted with a sound appreciation for the limitations of this model. The groundwater model used in this study (MODFLOW) has only rudimentary capacity to simulate stream baseflow, and is virtually incapable of simulating total streamflow. Total streamflow has components such as surface runoff and short-term "bank storage" which are completely absent from this model. The simulation of baseflow depends on a highly accurate numerical representation of a very complex physical system (the stream channel). The stream simulation package utilized in the model published by Pool and Dickinson (2007) is fairly simplistic in its approximation of the stream-aquifer connection, and cannot distinguish between stages at upstream and downstream ends of each reach, for example. Aquifer mechanics operate on a much slower time scale (years, decades, or even centuries) than riverine processes (minutes, days, or weeks), and the task of linking these two processes numerically is very challenging. Thus, stream stage and discharge are likely among the least accurate (though most readily measured in the field) components of the USPB model used in this study. Simulation outputs such as trends over time and spatial distributions of stream impacts can provide very useful information, but little stock should be placed in absolute values of stream stage or discharge, even insofar as they are used to determine wet versus dry stream reaches.

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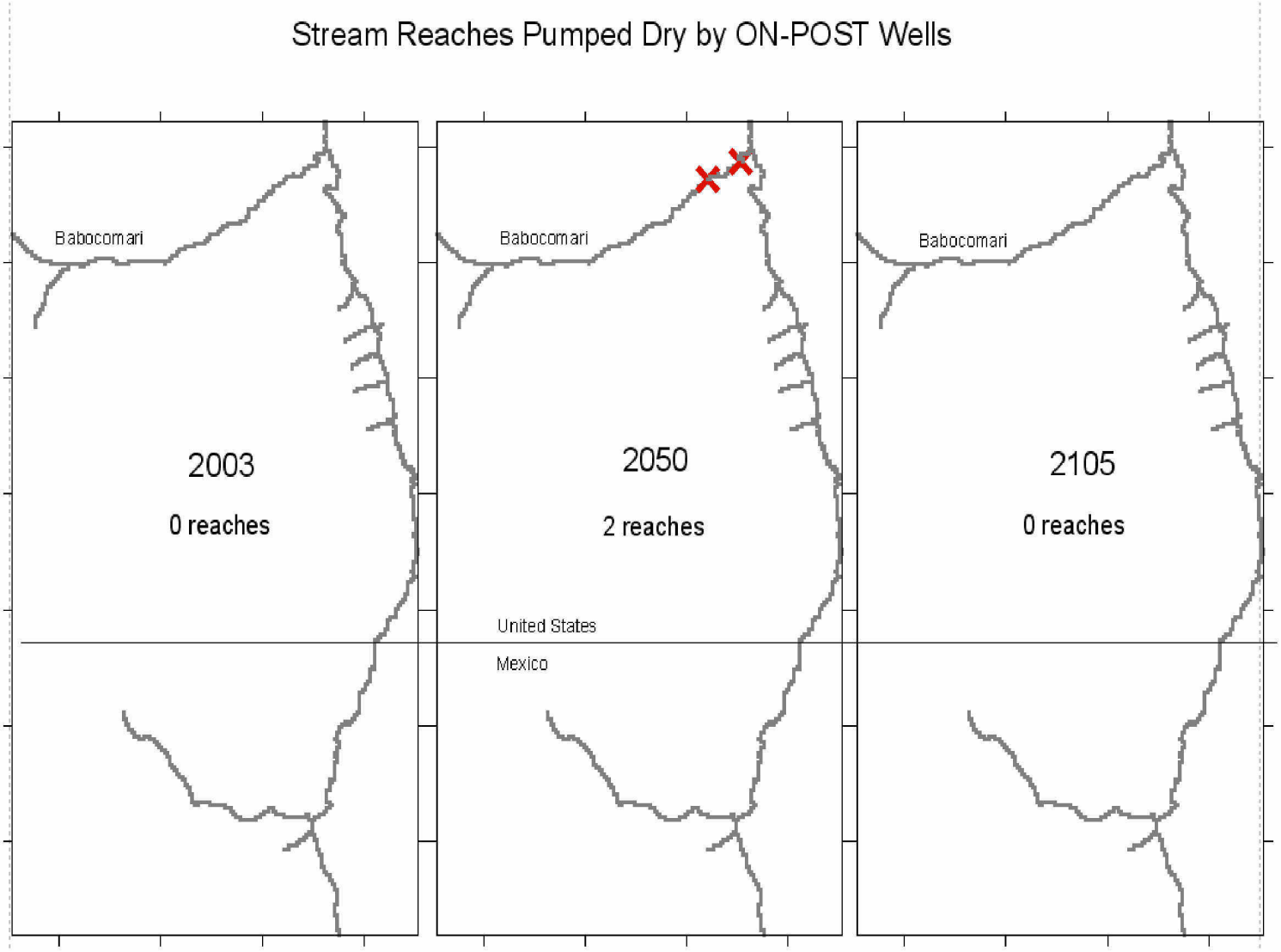

Figure 26. Stream Reaches Simulated as Being Pumped Dry by On-post Wells.

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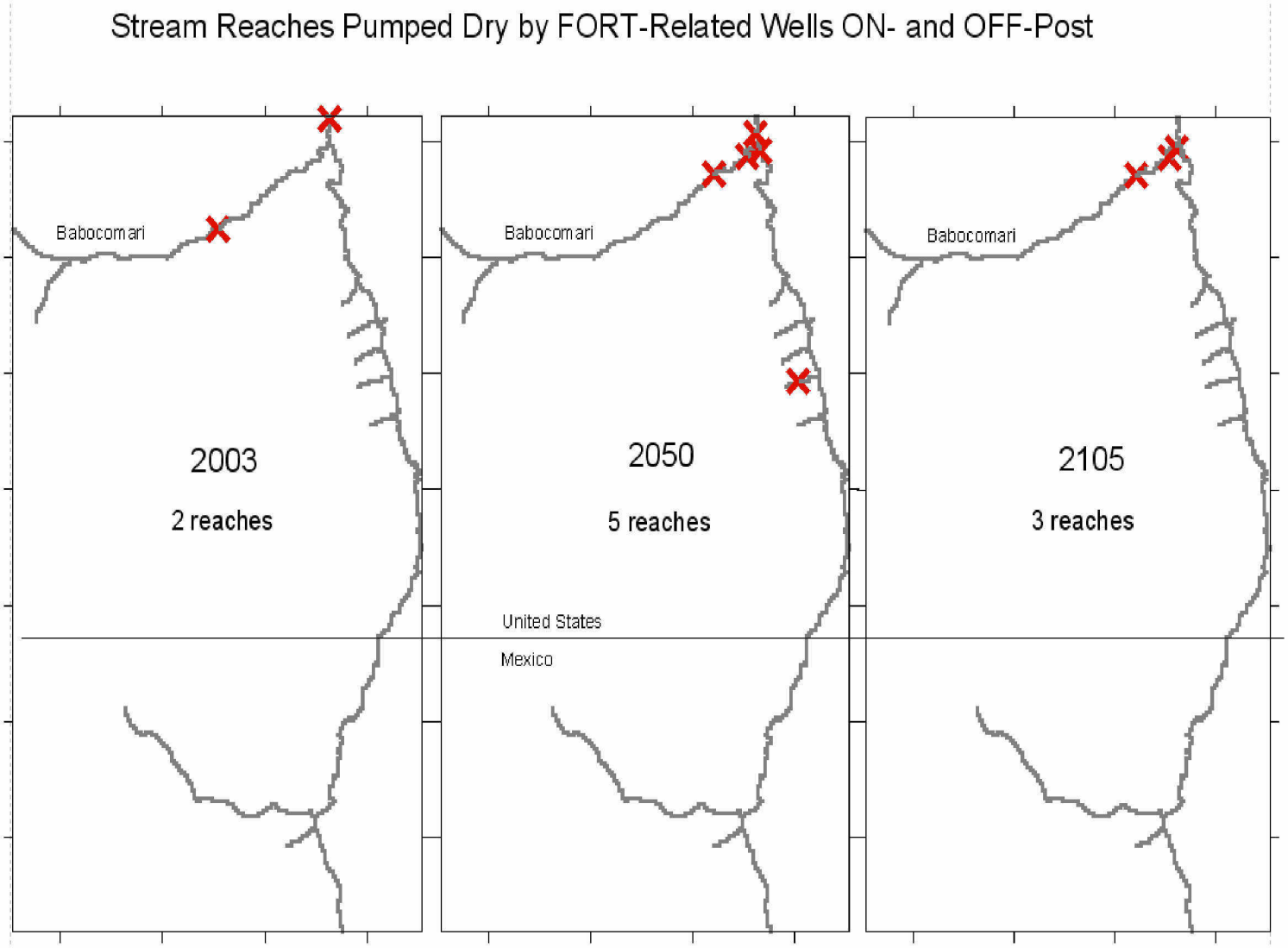

Figure 27. Stream Reaches Simulated as Being Pumped Dry by Fort-attributable Pumping On and Off post.

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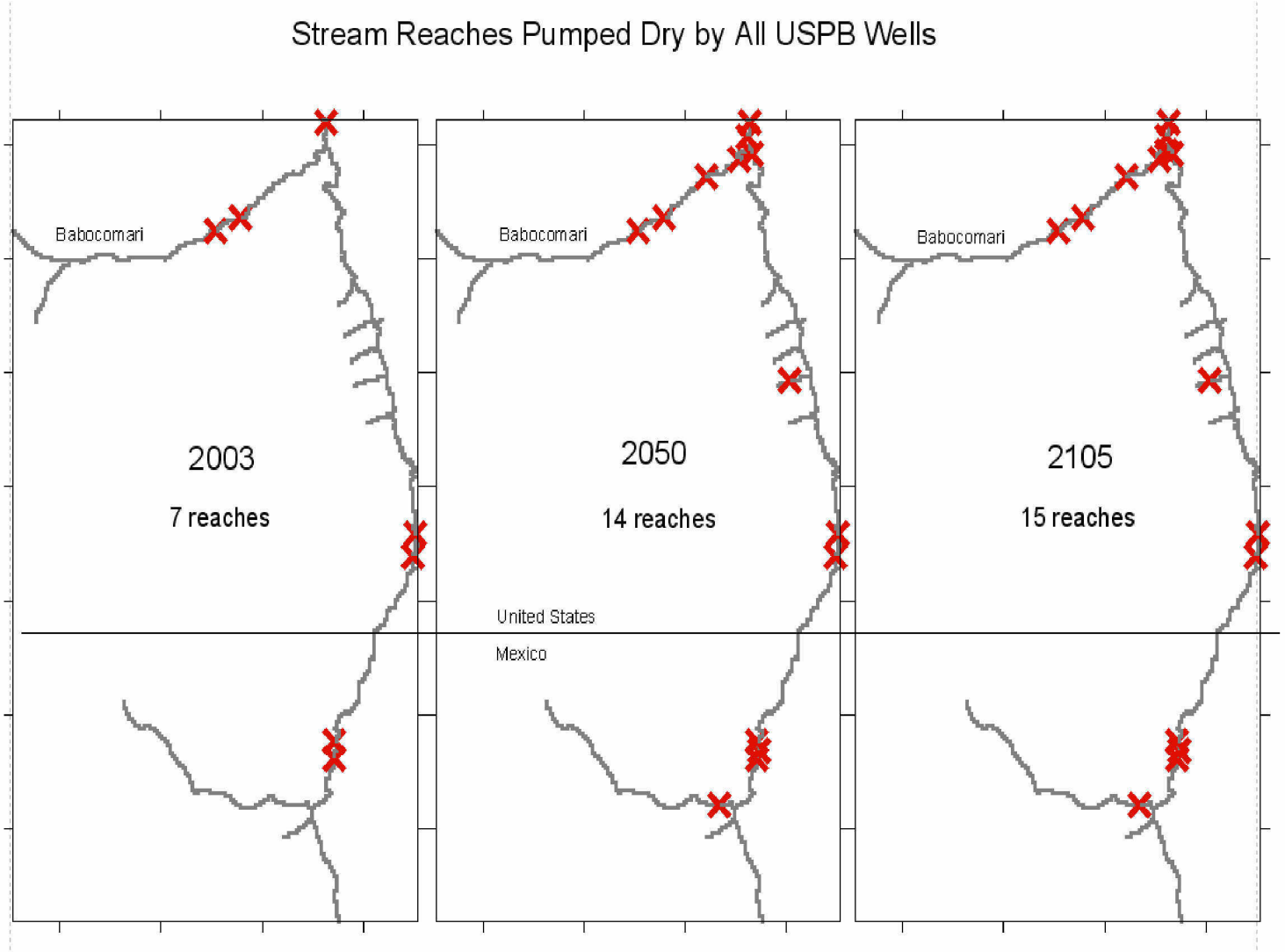

Figure 28. Stream Reaches Simulated as Being Pumped Dry by All USPB Wells.

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4.0 SUMMARY AND CONCLUSIONS

4.1 SUMMARY OF RESULTS

This study simulated four 203-year groundwater scenarios in order to calculate pumping-induced storage depletion and capture from ET and stream baseflow (refer to Table 1):

1) "No groundwater development" (ND) (no pumping wells; no artificial recharge),
2) "Full development" (FD) (all USPB pumping wells; all artificial recharge),
3) "No on-post pumping" (NOP) (all USPB pumping wells EXCEPT those on post; all artificial recharge),
4) "No Fort-attributable pumping" (NFA) (no Fort-attributable pumping on or off post; all artificial recharge; reduced incidental recharge from septic tanks).

From these four scenarios, three capture analyses were conducted: 1) for all wells in the USPB, 2) for on-post wells only, and 3) for all Fort-attributable pumping (on- and off-post). Table 2 summarizes the results of the three capture analyses.

Table 2. Comparison of Capture Analyses (1902-2105)

	All USPB Wells	On-Post Wells Only		All Fort-attributable Pumping	
	AF	AF	% of Total USPB	AF	% of Total USPB
Pumping	5,703,997	289,456	5%	1,082,045	19%
Storage Depletion	4,129,324	183,699	4%	850,791	21%
ET Capture	551,682	14,734	3%	41,024	7%
Baseflow Capture	293,383	91,583	31%	186,237	63%
Recharge Capture	727,604	0	0%	0	0%

The results in Table 2 reveal several important findings:

- The Fort's simulated total impact to ET capture is fairly limited (3 to 7% of basin-wide ET capture), even when considering all off-post pumping attributable to the Fort.
- The Fort's simulated impact on stream baseflow capture is significant for both on-post wells only (31% of basin-wide baseflow capture) and the combined on- and off-post pumping attributable to the Fort (63% of basin-wide baseflow capture).
- On-post wells account for a disproportionately large share of simulated total baseflow capture (31%) relative to their share of total pumping (5%).
- Simulated artificial recharge is not being captured by Fort-related wells on or off post.

Simulated baseflow impacts from on-post wells occurs primarily near the confluence of the Babocomari and San Pedro rivers and several miles upstream on each river, including the reach of the San Pedro containing the Charleston stream-gaging station. When all on- and off-post Fort-attributable pumping is considered, the Fort's impact on stream baseflow extends to a small area in the Hereford area of the San Pedro River, and includes larger portions of the

USF200010743

Babocomari and San Pedro rivers upstream of, and just below, the confluence of the two rivers. Simulated baseflow impacts from Fort-attributable pumping decrease slightly near the end of the 203-year simulation (year 2105) relative to conditions in middle of the 21st Century.

Table 3 presents simulated *future* water required to offset pumping-induced capture across the entire USPB. Again, water needs are based on three sets of capture results: 1) for all USPB wells, 2) for on-post wells only, and 3) for all Fort-attributable pumping. These results, however, reflect simulated future capture from 2005 to 2105, and do not include historic capture prior to 2005. The year 2005 was selected as a starting point for "future" capture calculations in order to correspond to the latest BA (ENRD, 2006). As indicated in the table, 18% of all simulated Fort-attributable future pumping (2005-2105), or 147,230 AF, is predicted to derive from stream baseflow. By contrast, baseflow capture is anticipated to supply 46% (59,326 AF) of all on-post pumping during that same period. Interestingly, 40% of all simulated Fort-attributable future baseflow capture results from future pumping of on-post wells *only*, even though simulated on-post pumping only comprises 16% of all future Fort-attributable pumping in the USPB.

Table 3. Simulated Future Water Needs (2005-2105)

	All USPB Wells		On-Post Wells Only		All Fort-attributable Pumping	
	AF	% of Pumping	AF	% of Pumping	AF	% of Pumping
Pumping	4,303,001		129,761		823,777	
Storage Depletion	3,421,944	80%	58,155	45%	634,788	77%
ET Capture	407,970	9%	12,241	9%	37,629	5%
Baseflow Capture	230,074	5%	59,326	46%	147,230	18%
Recharge Capture	237,896	6%	0	0%	0	0%

4.2 CONCLUSIONS

The capture findings in this study hinge on pumping estimates, both past and future. Estimating these pumping values involved numerous assumption-laden steps, each with its own significant uncertainty. First, we had to project total basin pumping to 2105 using population projections that extend only to 2055 (refer to Appendix B). Long-range population projections are notoriously inaccurate, so projecting these questionable values out another 50 years into the future only increases their uncertainty. Second, we converted population projections into estimated pumping values. To do this, we applied per capita pumping rates (urban and unincorporated) from the Fort's 2006 BA (ENRD, 2006), but these rates include another suite of assumptions, including the one that assumes a constant per capita pumping rate over time in the future. Finally, in order to estimate Fort-attributable pumping off post, we had to estimate the fraction of the off-post basin population attributable to Fort Huachuca. Data relating the Fort's population to that of the entire basin are minimal (a combination of data from 2005 and 2008 were used), and several important assumptions were required (refer to Appendix C). Once a relationship between Fort-attributable and total population was developed for various subdivisions of the basin for a single moment in history (2005), this relationship had to be

USF200010744

projected backward and forward in time from 2005 to estimate all Fort-attributable pumping in the simulation period. A key assumption, and possibly a significant weakness, in this process is that the Fort-attributable population grows at the same rate as the total basin population.

In spite of the uncertainty in the pumping estimates, one significant feature of the model simulations and capture analyses stands out and may be of significant interest to Fort Huachuca leadership. The strong hydrologic connection reflected in the capture calculations between on-post wells and the neighboring Babocomari and San Pedro River stream reaches suggests that these wells may be the most important targets for reduced or eliminated production in the Fort's efforts to mitigate its pumping-induced stream and ET depletions. Likewise, increased strategic artificial recharge in the area southwest of the confluence of the Babocomari and San Pedro Rivers may be significantly offset the Fort's pumping-induced stream and ET capture. Detailed simulations and in-situ field investigations will be required to determine the potential for near-stream or other artificial recharge in this area, and the likely impacts of that recharge on Fort-attributable pumping-induced capture.

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USF200010746

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USF200010747

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USF200010748

APPENDIX A

SIMULATED PUMPING RATES AND ARTIFICIAL RECHARGE AT FORT HUACHUCA 2003-2105

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A.1 METHOD FOR DISTRIBUTING ESTIMATED FUTURE FORT HUACHUCA PUMPING IN ON-POST WELLS

Fort Huachuca's Public Works Department provided monthly pumping data from the eight active wells operating within the external boundaries of Fort Huachuca for the period 2003-2009 (T. Runyon, email comm., 2007 and 2010). Table A.1 shows the average seasonal contribution to total annual pumping for the eight wells for 2003-2007. SP1 and SP2 in Table A.1 represent model stress periods, with SP1 being the summer period (mid-March through mid-October), and SP2 being the winter period (mid-October through mid-March). Because Fort Huachuca's pumping data were provided on a monthly basis, pumping for the months of April through October was assigned to SP1, while November through March pumping fell into SP2.

Table A. 1. Seasonal Contributions of Individual Wells to Total Fort Huachuca On-post Pumping, 2003-2007.

Ft Huachuca Pumping Distribution by Well and by Season									
	WELL #1	WELL #2	WELL #3	WELL #4	WELL #5	WELL #6	WELL #7	WELL #8	Annual
2003									
SP1% of total Q for all wells	0%	26%	19%	15%	3%	4%	0%	1%	67%
SP2 % of total Q for all wells	0%	11%	10%	0%	3%	10%	0%	0%	33%
2004									
SP1 % of total Q for all wells	0%	20%	5%	0%	16%	23%	0%	0%	65%
SP2 % of total Q for all wells	1%	17%	6%	4%	5%	2%	0%	0%	35%
2005									
SP1 % of total Q for all wells	1%	26%	20%	0%	18%	0%	0%	1%	65%
SP2% of total Q for all wells	0%	13%	6%	0%	15%	0%	0%	0%	35%
2006									
SP1 % of total Q for all wells	0%	24%	2%	17%	17%	1%	0%	0%	62%
SP2 % of total Q for all wells	0%	3%	3%	11%	7%	15%	0%	0%	38%
2007									
SP1 % of total Q for all wells	0%	0%	15%	21%	21%	7%	0%	2%	66%
SP2 % of total Q for all wells	1%	5%	9%	6%	1%	11%	0%	0%	34%
Average - Summer	**0%**	**19%**	**12%**	**11%**	**15%**	**7%**	**0%**	**1%**	**65.0%**
Average - Winter	**0%**	**10%**	**7%**	**4%**	**6%**	**8%**	**0%**	**0%**	**35.0%**

SP = model stress period (217 days March-October; 148 or 149 days October-March)

Fort Huachuca's simulated on-post total pumping rate was held constant at 1300 AF/yr for the period 2009-2105, as directed by ENRD Hydrologist, Tom Runyon (pers. comm., 2010), and as supported by the 2006 BA (ENRD, 2006).[6] We estimated and assigned seasonal pumping rates to each of the eight active wells on post by applying the appropriate average percentage from the last 2 lines in Table A.1 to the total annual rate of 1300 AF/yr. Table A.2 shows the resulting estimated seasonal pumping rates for Fort Huachuca wells #1 through #8. Table A.3 lists all reported pumping data by season for 2003 through early 2009, and estimated seasonal pumping data for late 2009 through spring 2011. All simulated Fort Huachuca pumping remained at 2010-11 rates for the period 2012-2105.

[6] At the time of this analysis, only 6 months of 2009 pumping data were available.

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Table A. 2. Projected Pumping Rates for On-post Wells Based on Distribution in Table A.1, 2009-2105.

Projected Pumping ON POST									
	WELL #1	WELL #2	WELL #3	WELL #4	WELL #5	WELL #6	WELL #7	WELL #8	Annual
	2009-2105								Total[1]
	AF								
Spring-Summer (SP1)	2.23	250.18	161.16	137.63	192.90	88.54	2.24	10.32	845.20
Fall-Winter (SP2)	4.54	125.71	89.77	57.07	78.55	98.36	0.34	0.46	454.80
								Total	1300.00
	cu-m/d								
Spring-Summer (SP1)	13	1422	916	782	1096	503	13	59	4804
Fall-Winter (SP2)	38	1046	747	475	654	818	3	4	3784
								Total	8588

Table A. 3. Projected Pumping Rates for On-post Wells Based on Distribution in Table A.1, 2009-2105.

		Reported and Estimated Pumping Rates for Fort Huachuca Wells, 2003-2011 (cu-m/d)															
		REPORTED													ESTIMATED		
		SP1	SP2	SP3	SP4	SP5	SP6	SP7	SP8	SP9	SP10	SP11	SP12	SP13	SP14	SP15	SP16
Well Name (GWSI/ADWR)	Fort ID	2003	2003-2004	2004	2004-2005	2005	2005-2006	2006	2006-2007	2007	2007-2008	2008	2008-2009	2009	2009-2010	2010	2010-2011
626105	8	73.62	7.34	12.69	0.00	56.78	12.47	10.58	0.00	138.25	0.00	13.76	5.03	56	4	56	4
626105	8	3.36	0.34	0.58	0.00	2.60	0.59	0.48	0.00	6.32	0.00	0.48	0.23	2.56	0.169	2.56	0.169
626106	7	18.52	1.57	8.84	0.00	17.02	13.01	10.19	0.00	13.04	0.00	36.72	4.66	13	3	13	3
626108	5	243.91	334.56	1333.14	668.84	1388.15	1636.33	1156.87	650.76	1495.80	50.98	2.65	0.00	1096	654	1096	654
626109	4	1302.73	4.23	0.00	514.57	0.00	41.16	1141.28	1061.42	1517.81	616.52	813.24	2.24	782	475	782	475
626110	3	1697.70	1206.35	452.57	775.53	1577.60	694.66	153.36	286.56	1090.98	932.66	1086.32	861.73	916	747	916	747
626107	6	341.75	1287.46	1985.55	235.97	0.00	0.00	38.15	1379.59	466.30	1115.73	1169.73	1416.94	503	818	503	818
313313110182301	1	0	0.00	0	71.60	43.30	0.00	20.55	0	0.00	116.10	50.73	0.00	13	38	13	38
626111	2	2291.47	1322.25	1755.05	2050.26	2053.67	1447.58	1609.03	258.46	0.00	528.24	978.67	1267.57	1422	1046	1422	1046
TOTAL	**cu-m/d**	**5973**	**4164**	**5548**	**4317**	**5139**	**3846**	**4140**	**3637**	**4728**	**3360**	**4152**	**3558**	**4804**	**3784**	**4804**	**3784**
	AF/yr	**1550**		**1494**		**1366**		**1165**		**1235**		**1157**		**1299**		**1299**	

source: Raw data provided by Fort Huachuca Public Works Dept. via T. Runyon, ENRD (email comm., 2007, 2010)

NOTE: 2012-2105 simulated pumping replicates 2010-2011 rates.

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A.2 METHODOLOGY FOR ESTIMATING FUTURE EFFLUENT RECHARGE AT FORT HUACHUCA FOR THE SIMULATION PERIOD 2010-2105

The 2006 Programmatic Biological Assessment for Fort Huachuca (BA) (ENRD, 2006) projects artificial recharge in the effluent basins at Fort Huachuca, as shown in Table A.4. Values in the third row of Table A4 provided the basis for estimating future effluent recharge based on projected pumping rates.

Table A. 4. Projected On-post Pumping and Effluent Recharge at Fort Huachuca, 2005-2015.

	On-Post Pumping and Artificial Recharge - Projected (AF/yr)							
	2005	2006	2007	2009	2010	2011	2014	2015
On-Post Pumping (AF/yr)	1403	1391	1387.3	1316.4	1315.9	1315.4	1300.70	1287.00
Effluent to Basins	426	517	547	506	506	505	497.00	489.00
Effluent as % of Pumping	30.4%	37.2%	39.4%	38.4%	38.5%	38.4%	38.2%	38.0%
Contribution from Huachuca City	0	0	0	0	200	200	200	200
Evaporative Losses (2.5%)	-10.65	-12.925	-13.675	-12.65	-17.65	-17.625	-17.425	-17.225
Total Recharge	415.35	504.1	533.3	493.4	688.4	687.4	679.6	671.8
Source: 2006 Programmatic Biological Assessment - Appendix H (ENRD, 2006).								

Table A. 5. Reported Basin Influent (After Re-Use), Reported Pumping, and Estimated Recharge for Fort Huachuca, 2002-2009.

Table A. **5** provides reported values for influent recharge[7] and pumping, as well as estimated recharge corrected for evapotranspiration (ET) loss. The 2.5% ET loss rate comes from the 2006 BA (ENRD, 2006), as shown in Table A. 4. The bottom two rows of Table A. **5** calculate seasonal recharge and pumping as percentages of total annual recharge and pumping, respectively. These seasonal values are utilized in Table A. 6 to parse annual recharge and pumping values into seasonal components for the purpose of simulation. Table A. 6 lists projected artificial recharge at the Fort Huachuca recharge facility for the simulation period 2010-2015. From 2015 to 2015, simulated artificial recharge remains constant at 2015 values with the same seasonal distribution.

[7] Influent is the inflow to the recharge basins, and is comprised of total effluent minus any effluent "re-use" for irrigation.

USF200010752

Table A. 5. Reported Basin Influent (After Re-Use), Reported Pumping, and Estimated Recharge for Fort Huachuca, 2002-2009.

REPORTED INFLUENT TO RECHARGE BASINS (after re-use)							ESTIMATED RECHARGE CORRECTED FOR ET LOSSES*				REPORTED ON-POST PUMPING				
											Annual		Seasonal		
Annual Influent to Basins (after re-use) (AF)	Start Date	Seasonal Break-down (AF)	#days	% Diff. Between Seasons	% of Seasonal Pumping	% of Annual Influent	Total Recharge (97.5% of Influent) (AFY)	Seasonal Recharge (97.5% of influent) (AF)*	cu-m/d	cu-m/d per 250m x 250m cell (2 cells)	Kgal	AF	Kgal	AF	% of Annual Pumping
	4/1/2002	248.91	214		25%	50%	493	246	1420.35	0.01136283			322348	989.25	68%
497.8	11/1/2002	248.89	152	0%	53%	50%	493	246	1999.55	0.015996383	475645	1459.70	153297	470.45	32%
	4/1/2003	237.13	214		23%	51%		225	1299.67	0.01039733			337674	1036.28	67%
465.9	11/1/2003	228.77	152	4%	45%	49%	452	226	1837.91	0.014703253	504880	1549.42	167206	513.14	33%
	4/1/2004	223.19	214		23%	48%		212	1220.05	0.009760369			313668	962.61	65%
460.84	11/1/2004	237.65	151	-6%	45%	52%	447	235	1921.89	0.015375131	485864	1491.06	172196	528.45	35%
	4/1/2005	203.43	214		23%	50%		193	1114.31	0.008914442			290529	891.60	65%
404.25	11/1/2005	200.82	151	1%	43%	50%	392	199	1624.04	0.012992357	443938	1362.39	153409	470.79	35%
	4/1/2006	214.33	214		30%	58%		205	1182.56	0.00946046			234074	718.35	62%
366.6	11/1/2006	152.27	151	29%	34%	42%	356	151	1231.42	0.009851341	379146	1163.55	145072	445.21	38%
	4/1/2007	182.17	214		22%	48%		173	994.97	0.007959726			267315	820.36	66%
382	11/1/2007	200	152	-10%	48%	52%	372	200	1621.87	0.012975	402242	1234.43	134927	414.08	34%
	4/1/2008	248	214		34%	52%		236	1359.24	0.010874			234742	720.40	62%
477	11/1/2008	230	151	7%	52%	48%	465	230	1875.02	0.015000	377626	1158.89	142884	438.49	38%
	4/1/2009	182	214			51%		174	1000.30	0.008002			need 1st quarter 2010 data		
356	11/1/2009	173	151	5%		49%	347	173	1415.63	0.011325	1250	4224.25	14275.45	estimated	
416.1	7-yr avg			4%	35%	50%									
			Average Summer Influent as a % of Annual Influent			51%					Average Summer Pumping as a % of Annual Pumping				65%
			Average Winter Influent as a % of Annual Influent			49%					Average Winter Pumping as a % of Annual Pumping				35%

* ET Losses estimated at 2.5% annually (ENRD, 2006 - App. H)

source: Fort Huachuca Dept. of Public Works via T. Runyon, ENRD Hydrologist (pers. comm., 2007, 2010).

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Table A. 6. Projected Effluent Recharge Rates and Pumping Rates at Fort Huachuca, 2010-2015.

Projected Artificial Recharge Values										
Annual Influent (after re-use)	Start Date	Seasonal Influent	Notes	Annual Recharge (97.5% of Influent)	Seasonal Recharge (97.5% of Influent)*		Recharge Rate per 250m x 250m Model Cell (2 cells)	Annual Pumping		Seasonal Pumping
AF		AF		AF	AF	cu-m/d	cu-m/d	AF	cu-m/d	AF
	4/1/2010	256	no Huachuca City Effluent Contribution		244	1405.64	0.011245			845.2025
500	11/1/2010	244		487	244	1989.26	0.015914	1300	4393.22	454.7975
	4/1/2011	256			243	1403.39	0.011227			845.2025
499	11/1/2011	243		487	243	1973.02	0.015784	1300	4393.22	454.7975
	4/1/2012	255			243	1399.51	0.011196			845.2025
498	11/1/2012	242		485	242	1980.59	0.015845	1300	4393.22	454.7975
	4/1/2013	358	Huachuca City Effluent Added (200 af/yr)		340	1960.58	0.015685			845.2025
697	11/1/2013	340		680	340	2774.62	0.022197	1300	4393.22	454.7975
	4/1/2014	357			340	1959.16	0.015673			845.2025
697	11/1/2014	339		679	339	2772.60	0.022181	1300	4393.22	454.7975
	4/1/2015	356			339	1951.30	0.015610			845.2025
694	11/1/2015	338		677	338	2743.32	0.021947	1300	4393.22	454.7975
	4/1/2016	356			339	1951.30	0.015610			845.2025
694	11/1/2016	338		677	338	2761.48	0.022092	1300	4393.22	454.7975
	4/1/2017	356			339	1951.30	0.015610			845.2025
694	11/1/2017	338		677	338	2761.48	0.022092	1300	4393.22	454.7975
	4/1/2018	356			339	1951.30	0.015610			845.2025
694	11/1/2018	338		677	338	2761.48	0.022092	1300	4393.22	454.7975
	4/1/2019	356			339	1951.30	0.015610			845.2025
694	11/1/2019	338		677	338	2743.32	0.021947	1300	4393.22	454.7975

*All evaporative losses applied in summer.

Note: Seasonal values of simulated artificial recharge repeat from 2015-2105.

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Appendix B

ESTIMATION OF BASIN-WIDE PUMPING RATES FOR THE SIMULATION PERIOD 2003-2105

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B.1 METHODOLOGY FOR ESTIMATING PUMPING RATES IN THE UPPER SAN PEDRO BASIN, 2003-2105

The Upper San Pedro Basin (USPB) groundwater model published by the U.S. Geological Society (USGS) simulates pumping from 1902 to early 2003 (Pool and Dickinson, 2007). We developed estimates of future pumping in the Arizona portion (Sierra Vista subwatershed) of the USPB in order to run groundwater simulations out to 2105, thereby extending the total simulation period to 203 years.[8] Arizona Department of Commerce (AzDC) population estimates (2003-2009) and projections (2009-2055) were used to estimate future domestic, municipal, and industrial pumping demand in the Sierra Vista (SV) subwatershed portion of the USPB. AzDC projections are grouped by Census County Divisions (CCDs) for population centers, and population growth outside of the CCDs is covered under an "unincorporated" area estimate (refer to Cochise County link at http://www.azcommerce.com/EconInfo/Demographics/Population+Projections.html). Figure B.1 shows U.S. Census Bureau CCDs in the SV subwatershed as slightly modified for this study.

Table B. 1 lists AzDC population estimates for select communities in Cochise County from 2002 to 2009, and shows the percent change from one year to the next as well as the 7-year average rate of change for each Census County Division (CCD) listed and for the unincorporated area of the county outside of any CCD.

Table B. 1. Arizona Department of Commerce Population Estimates for Select Portions of Cochise County.

	2002	2003	2004	2005	2006	2007	2008	2009	
Census County Divis	**1-Jul-02**	**1-Jul-03**	**1-Jul-04**	**1-Jul-05**	**1-Jul-06**	**1-Jul-07**	**1-Jul-08**	**1-Jul-09**	7-yr avg
COCHISE COUNTY									
Bisbee	6,140	6,360	6,585	6,570	6,355	6,310	6,389	6,423	
% change		3.6%	3.5%	-0.2%	-3.3%	-0.7%	1.3%	0.5%	0.7%
Huachuca City	1,800	1,825	1,830	1,830	1,825	1,832	1,952	1,955	
% change		1.4%	0.3%	0.0%	-0.3%	0.4%	6.6%	0.2%	1.2%
Sierra Vista	40,415	40,410	42,725	43,690	44,870	44,736	45,908	46,597	
% change		0.0%	5.7%	2.3%	2.7%	-0.3%	2.6%	1.5%	2.1%
Tombstone	1,535	1,570	1,585	1,610	1,655	1,682	1,709	1,720	
% change		2.3%	1.0%	1.6%	2.8%	1.6%	1.6%	0.6%	1.6%
Unincorporated	48,505	49,565	51,150	52,270	54,055	55,583	56,336	56,723	
% change		2.2%	3.2%	2.2%	3.4%	2.8%	1.4%	0.7%	2.3%

Sources: http://www.azcommerce.com/econinfo/demographics/Population+Estimates.html (AzDC, 2009) and http://www.azcommerce.com/doclib/econinfo/FILES/2009Estimates.pdf (AzDC, 2010).

[8] Pumping for the Mexico portion of the USPB and for all mining and agricultural pumping in the SV subwatershed was maintained at 2002-2003 levels throughout the 2004-2105 simulation period in lieu of any appropriate population or water-use projections for those sectors.

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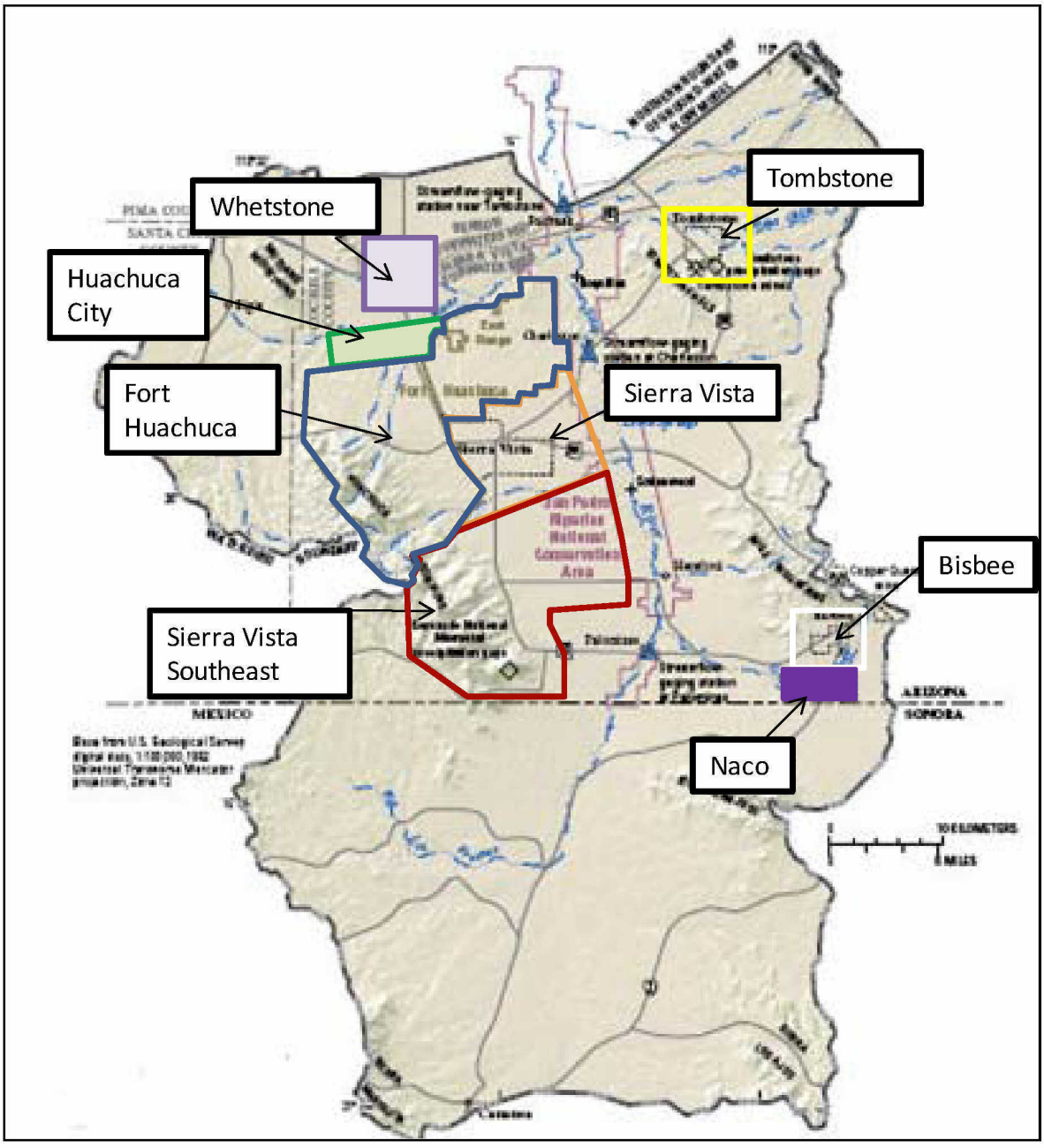

Figure B. 1. Modified Census County Divisions Overlaid on Groundwater Model Area in Upper San Pedro Basin.

Source: U.S. Census Bureau online Reference Maps
(http://factfinder.census.gov/jsp/saff/SAFFInfo.jsp?_pageId=referencemaps&_submenuId=maps_2)

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Table B.2 provides AzDC population projections for Census County Divisions within the Sierra Vista subwatershed (AzDC, 2006). Table B.3 shows projected population developed by TischlerBise (2009) for the City of Sierra Vista including Fort Huachuca. Projected populations for the City of Sierra Vista in 2006 through 2009 differ significantly from estimates in Table B. 1. In order to adjust the projections to the more dependable estimates, we replaced the 2006 "projected" value for the City of Sierra Vista in Table B.2 with the 2006 estimate for the City in Table B. 1, and applied the projected annual growth rates from Table B.2 to that starting value to produce the set of adjusted projections out to 2055 in Table B.2.

USF200010758

Table B. 2. Arizona Department of Commerce Population Projections for Census County Divisions within the Sierra Vista Subwatershed Area of Cochise County.

Census County Division	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Bisbee	6,673	6,772	6,870	6,965	7,057	7,147	7,236	7,322	7,406	7,489	7,569	7,647	7,723	7,796	7,867
% change		1.5%	1.4%	1.4%	1.3%	1.3%	1.2%	1.2%	1.2%	1.1%	1.1%	1.0%	1.0%	1.0%	0.9%
Naco	869	875	881	887	893	899	904	910	915	920	925	930	934	939	943
% change		0.7%	0.7%	0.7%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.5%	0.5%	0.5%	0.5%	0.5%
Huachuca City	1,847	1,863	1,879	1,895	1,910	1,925	1,940	1,954	1,968	1,981	1,994	2,007	2,020	2,032	2,043
% change		0.9%	0.9%	0.8%	0.8%	0.8%	0.8%	0.7%	0.7%	0.7%	0.7%	0.6%	0.6%	0.6%	0.6%
Tombstone	1,633	1,655	1,676	1,697	1,718	1,738	1,757	1,776	1,795	1,813	1,831	1,848	1,865	1,881	1,896
% change		1.4%	1.3%	1.3%	1.2%	1.2%	1.1%	1.1%	1.0%	1.0%	1.0%	0.9%	0.9%	0.9%	0.8%
Whetstone	2,810	2,888	2,965	3,039	3,111	3,182	3,251	3,319	3,385	3,449	3,512	3,573	3,632	3,690	3,746
% change		2.8%	2.6%	2.5%	2.4%	2.3%	2.2%	2.1%	2.0%	1.9%	1.8%	1.7%	1.7%	1.6%	1.5%
All Sierra Vista City	44,954	46,184	47,386	48,560	49,694	50,805	51,895	52,959	53,997	55,010	55,999	56,961	57,892	58,797	59,674
% change		2.7%	2.6%	2.5%	2.3%	2.2%	2.1%	2.1%	2.0%	1.9%	1.8%	1.7%	1.6%	1.6%	1.5%
All Sierra Vista corrected to 2006 estimate in Table 1	44,870	44736	45908	46597	47685	48751	49797	50818	51814	52786	53735	54658	55552	56420	57262
All Sierra Vista Southeast	16,551	16,929	17,298	17,658	18,006	18,347	18,681	19,008	19,327	19,638	19,941	20,236	20,522	20,800	21,069
% change		2.3%	2.2%	2.1%	2.0%	1.9%	1.8%	1.7%	1.7%	1.6%	1.5%	1.5%	1.4%	1.4%	1.3%
All remainder SV and Bisbee	6,063	6,154	6,243	6,330	6,414	6,496	6,577	6,656	6,732	6,807	6,880	6,952	7,021	7,088	7,152
% change		1.5%	1.4%	1.4%	1.3%	1.3%	1.2%	1.2%	1.2%	1.1%	1.1%	1.0%	1.0%	1.0%	0.9%

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Table B.2 (continued)

Census County Division	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Bisbee	7,936	8,004	8,069	8,133	8,195	8,256	8,315	8,373	8,428	8,483	8,536	8,587	8,637	8,685	8,731
% change	0.9%	0.8%	0.8%	0.8%	0.8%	0.7%	0.7%	0.7%	0.7%	0.6%	0.6%	0.6%	0.6%	0.6%	0.5%
Naco	948	952	956	960	964	968	971	975	978	982	985	988	991	994	997
% change	0.5%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%
Huachuca City	2,055	2,066	2,077	2,087	2,098	2,107	2,117	2,127	2,136	2,145	2,154	2,162	2,170	2,178	2,186
% change	0.6%	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%
Tombstone	1,912	1,927	1,941	1,955	1,969	1,982	1,995	2,008	2,020	2,032	2,044	2,056	2,066	2,077	2,087
% change	0.8%	0.8%	0.8%	0.7%	0.7%	0.7%	0.7%	0.6%	0.6%	0.6%	0.6%	0.6%	0.5%	0.5%	0.5%
Whetstone	3,800	3,853	3,904	3,954	4,003	4,050	4,096	4,141	4,185	4,228	4,270	4,310	4,349	4,386	4,422
% change	1.4%	1.4%	1.3%	1.3%	1.2%	1.2%	1.1%	1.1%	1.1%	1.0%	1.0%	0.9%	0.9%	0.9%	0.8%
All Sierra Vista City	60,527	61,357	62,167	62,953	63,720	64,466	65,196	65,903	66,590	67,264	67,921	68,550	69,163	69,754	70,326
% change	1.4%	1.4%	1.3%	1.3%	1.2%	1.2%	1.1%	1.1%	1.0%	1.0%	1.0%	0.9%	0.9%	0.9%	0.8%
All Sierra Vista corrected to 2006 estimate in Table 1	58080	58877	59654	60408	61144	61860	62560	63239	63898	64544	65175	65779	66367	66934	67483
All Sierra Vista Southeast	21,331	21,586	21,834	22,075	22,311	22,540	22,764	22,981	23,192	23,398	23,600	23,793	23,981	24,163	24,338
% change	1.2%	1.2%	1.2%	1.1%	1.1%	1.0%	1.0%	1.0%	0.9%	0.9%	0.9%	0.8%	0.8%	0.8%	0.7%
All remainder SV and Bisbee	7,216	7,277	7,337	7,395	7,452	7,507	7,561	7,613	7,664	7,714	7,763	7,809	7,855	7,898	7,941
% change	0.9%	0.9%	0.8%	0.8%	0.8%	0.7%	0.7%	0.7%	0.7%	0.7%	0.6%	0.6%	0.6%	0.6%	0.5%

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Table B.2 (continued)

Census County Division	2036	2037	2038	2039	2040	2041	2042	2043	2044	2045	2046	2047	2048	2049	2050
Bisbee	8,776	8,819	8,861	8,902	8,943	8,983	9,023	9,062	9,101	9,140	9,180	9,219	9,259	9,300	9,341
% change	0.5%	0.5%	0.5%	0.5%	0.5%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%
Naco	1,000	1,003	1,005	1,008	1,010	1,013	1,015	1,018	1,020	1,023	1,025	1,028	1,030	1,033	1,035
% change	0.3%	0.3%	0.3%	0.3%	0.3%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%	0.3%
Huachuca City	2,193	2,200	2,207	2,214	2,221	2,227	2,234	2,240	2,247	2,253	2,260	2,266	2,273	2,279	2,286
% change	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%
Tombstone	2,097	2,107	2,116	2,125	2,134	2,143	2,152	2,160	2,169	2,178	2,186	2,195	2,204	2,213	2,222
% change	0.5%	0.5%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%
Whetstone	4,457	4,491	4,524	4,556	4,588	4,619	4,650	4,681	4,712	4,743	4,774	4,804	4,836	4,867	4,900
% change	0.8%	0.8%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.6%	0.7%	0.7%	0.7%
All Sierra Vista City	70,872	71,406	71,924	72,433	72,934	73,423	73,914	74,397	74,880	75,365	75,852	76,336	76,829	77,326	77,841
% change	0.8%	0.8%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.7%	0.6%	0.6%	0.6%	0.6%	0.6%	0.7%
All Sierra Vista corrected to 2006 estimate in Table 1	68007	68519	69016	69505	69985	70454	70925	71389	71853	72319	72785	73250	73723	74200	74694
All Sierra Vista Southeast	24,506	24,670	24,829	24,985	25,139	25,289	25,439	25,588	25,736	25,885	26,034	26,183	26,334	26,487	26,645
% change	0.7%	0.7%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%	0.6%
All remainder SV and Bisbee	7,981	8,021	8,059	8,097	8,134	8,170	8,206	8,242	8,278	8,313	8,349	8,385	8,422	8,459	8,497
% change	0.5%	0.5%	0.5%	0.5%	0.5%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%	0.5%

Census County Division	2051	2052	2053	2054	2055
Bisbee	9,384	9,427	9,471	9,515	9,561
% change	0.5%	0.5%	0.5%	0.5%	0.5%
Naco	1,038	1,040	1,043	1,046	1,049
% change	0.3%	0.3%	0.3%	0.3%	0.3%
Huachuca City	2,293	2,300	2,307	2,315	2,322
% change	0.3%	0.3%	0.3%	0.3%	0.3%
Tombstone	2,231	2,241	2,251	2,260	2,270
% change	0.4%	0.4%	0.4%	0.4%	0.4%
Whetstone	4,933	4,967	5,001	5,036	5,072
% change	0.7%	0.7%	0.7%	0.7%	0.7%
All Sierra Vista City	78,361	78,893	79,437	79,986	80,542
% change	0.7%	0.7%	0.7%	0.7%	0.7%
All Sierra Vista corrected to 2006 estimate in Table 1	75193	75703	76225	76752	77285
All Sierra Vista Southeast	26,804	26,968	27,134	27,303	27,474
% change	0.6%	0.6%	0.6%	0.6%	0.6%
All remainder SV and Bisbee	8,535	8,575	8,615	8,655	8,697
% change	0.5%	0.5%	0.5%	0.5%	0.5%

Source: http://www.azcommerce.com/EconInfo/Demographics/Population+Projections.htm (AzDC, 2006).

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Figure B.2 plots estimated and projected growth rates for the City of Sierra Vista from AzDC (2006, 2009, 2010) and TischlerBise (2009). While the shapes of the projected growth rate curves for the two sources diverge in the early years (2010-2020), the projected growth rates remain fairly similar through mid-century.

Table B. 3. TischlerBise (2009) Population Projections for the City of Sierra Vista Including Fort Huachuca.

year	2010	2011	2012	2013	2014	2015	2020	2025	2030	2035	2040	2045
population	46,380	46,834	47,313	47,841	48,406	49,002	52,312	55,999	59,945	64,087	67,380	71,253
annual growth rate		1.0%	1.0%	1.1%	1.2%	1.2%	1.4%	1.4%	1.4%	1.4%	1.0%	1.1%

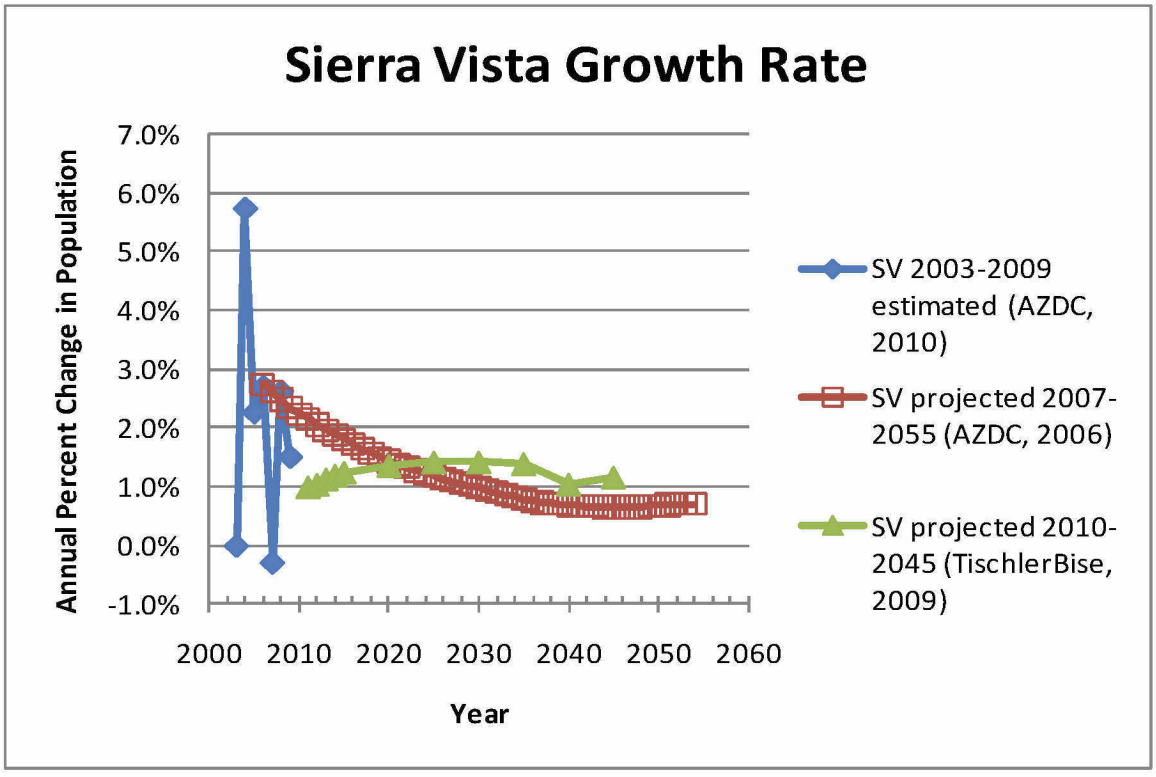

Figure B. 2. Estimated and Projected Population Growth Rates for the City of Sierra Vista (SV) for the Period 2002 to 2055.

Figure B.3 plots estimated and projected population for the City of Sierra Vista from the AzDC (2006, 2009, 2010) and TischlerBise (2009). The purple curve in the plot shows the adjusted population growth curve used in this study (see discussion above). Figure B.4 plots estimated and projected population growth rates for various CCDs within the SV subwatershed.

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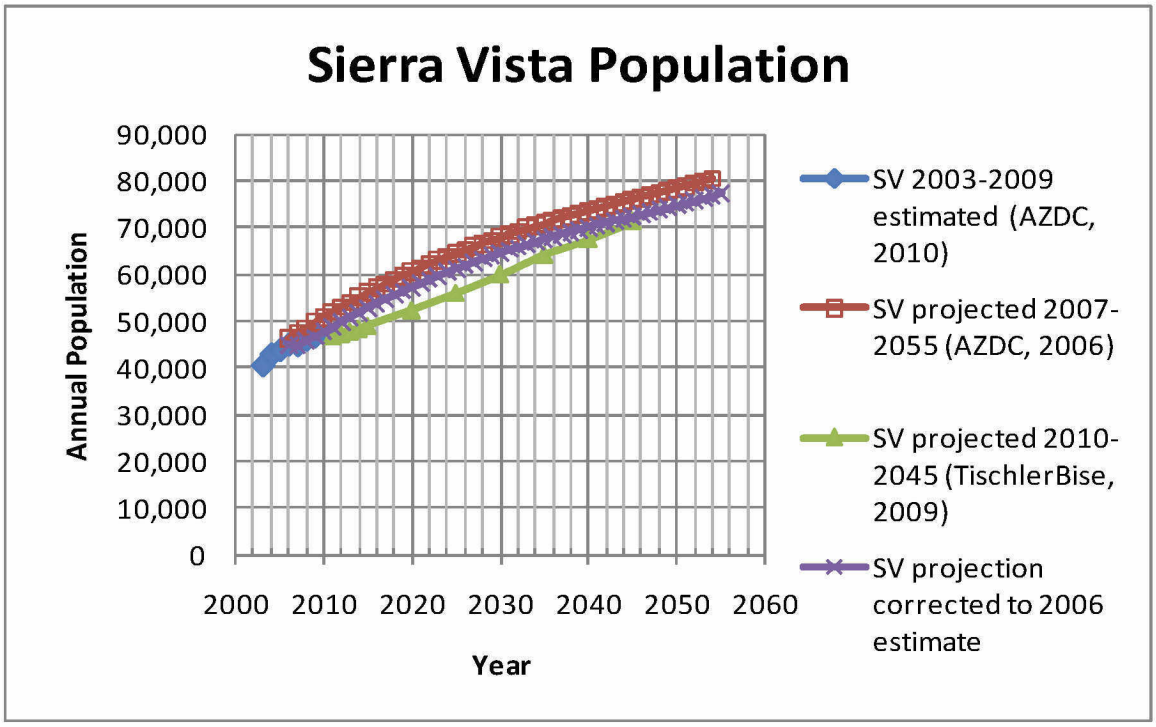

Figure B. 3. Estimated and Projected Population for the City of Sierra Vista (SV) for the Period 2002 to 2055.

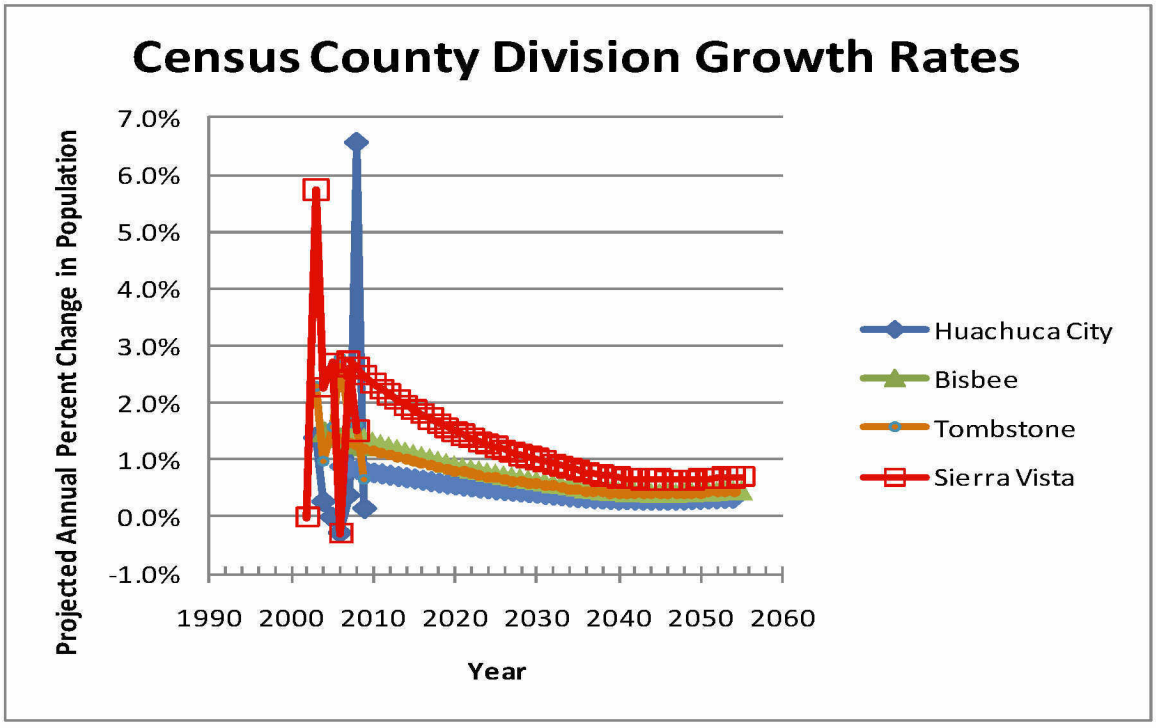

Figure B. 4. Estimated and Projected Population Growth Rates for Census County Divisions Within the Sierra Vista Subwatershed of Cochise County (sources: AzDC, 2006; AzDC, 2009; AzDC, 2010).

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USF200010764

Appendix C

ESTIMATION OF FORT-ATTRIBUTABLE OFF-POST PUMPING FOR THE SIMULATION PERIOD 1940-2105

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C.1 METHODOLOGY FOR ESTIMATING OFF-POST PUMPING ATTRIBUTABLE TO FORT HUACHUCA, 1940-2105

Simulated municipal and domestic pumping in the Arizona portion of the Upper San Pedro Basin (USPB) begins in 1940. Prior to that time, most pumping was done by the mining sector, with agriculture contributing a small percentage of the groundwater withdrawals (Pool and Dickinson, 2007). Estimates of the off-post pumping attributable to Fort Huachuca were needed for the 1940-2105 simulation period in order to deduct this pumping from total pumping as part of the capture calculation procedure (see discussion in Section III.1 of the main report).

Table C. 1 provides a distribution of off-post civilians in March of 2009 by zip code (C. Howard of Vernadero Group, Inc. email comm. via T. Runyon, July 2010). Fort Huachuca's Environment and Natural Resources Division (ENRD) provided cumulative (up to 2008) actuary data on military retirees from Fort Huachuca by zip code (T. Runyon email comm., July 2010), as shown in Table C. 2. These zip code distributions formed the basis for distributing the Fort's off-post population as described in Table 7 of the 2006 Programmatic Biological Assessment (BA) (ENRD, 2006). Table C.3 reproduces Table 7 from the 2006 BA and documents how the Fort's off-post population (direct, indirect, and induced) was derived from the original (2005) total numbers in the BA table.

Figure C.1 shows the SV subwatershed CCDs overlaid on the Cochise County zip code map. For the purpose of distributing the groundwater demand associated with the Fort's direct, indirect, and induced population, zip code population estimates were mapped to CCDs according to the process illustrated in Figure C.2. Once the percentage of total population attributable to the Fort in each CCD was determined for the year 2005, the groundwater demand for the Fort's off-post population was estimated by multiplying the number of people in each CCD by the appropriate annual groundwater consumption rate, as provided in Appendix K of the 2006 BA (ENRD, 2006).[9] Table C.4 provides a summary of all off-post population values used to develop off-post groundwater demand attributable to Fort Huachuca's direct, indirect, and induced population. Table C. 5 translates the estimated Fort-attributable off-post groundwater demand to pumping rates as well as the computed percentage of total pumping in each affected CCD that is attributable to the Fort. In order to determine total Fort-attributable groundwater capture, total off-post pumping was reduced by the percentages shown in the last column of Table C. 5 in each of the affected CCDs, and all simulated pumping on post was set to zero to achieve a "no Total Fort" scenario. The difference between groundwater capture calculated for all simulated basin pumping and that calculated for "no TOTAL Fort" pumping equals groundwater capture attributable to the Fort's total population on and off post.

[9] 160 gallons per capita per day for incorporated areas; 0.132 acre-feet per person per day for unincorporated areas.

USF200010766

Table C. 1. Fort Huachuca Civilian Population Distribution

Civilians by Zip Code-March 2009			OFF-POST CIVILIANS	
Adr Mail ZIP	Local Addr City	Count of SSNs	% of total	% of total w/in SV Subwatershed
Various	Out of State	32	1%	
85028 - 85392	Phoenix Metro/Gila Bend/Surprise/Casa Grande	11	0%	
85602	Benson	20	1%	
85603	Bisbee	18	1%	0.9%
85606	Cochise	2	0%	
85607	Douglas	3	0%	
85609	Dragoon	1	0%	
85610	Elfrida	1	0%	
85611	Elgin	8	0%	
85613/85670	Fort Huachuca (ON POST)	118	0%	
85615	Hereford	203	9%	10.0%
85616	Huachuca City	131	5%	6.4%
85617	Mcneal	2	0%	
85625	Pearce	1	0%	
85626	Pirtleville	1	0%	
85629	Sahuarita	3	0%	
85630	Saint David	5	0%	
85635 - 85636	Sierra Vista	1104	46%	54.2%
85637	Sonoita	12	1%	
85638	Tombstone	17	1%	0.8%
85641	Corona/Vail	35	1%	
85648	Rio Rico	1	0%	
85650	Sierra Vista	563	24%	27.7%
856521201	Cortaro	1	0%	
85704 - 85757	Tucson/Oro Valley	89	4%	
		2,382	TOTAL	
		2,036	TOTAL IN SV subwatershed	
		85.5%	% in SV subwatershed	

USF200010767

Table C. 2. Actuary Zip Code Data on Fort Huachuca Military Retirees.

MILITARY RETIREES AS OF FY2008		
ZIP CODE	**NUMBER RETIRED**	**% in SV subwatershed**
85602	190	
85603	72	2%
85606	16	
85607	89	
85610	24	
85611	19	
85613	11	
85615	589	12%
85616	317	7%
85617	26	
85624	13	
85625	45	
85626	4	
85629	284	
85630	51	
85635	2,320	48%
85636	210	4%
85637	33	
85638	38	1%
85641	522	
85650	1,238	26%
85670	90	
TOTAL	6,201	
TOTAL in SV subwatershed	**4,784**	**100%**

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Table C. 3. Table 7 from 2006 BA (ENRD, 2006) with Off-post Direct, Indirect, and Induced Off-post Population Attributable to Fort Huachuca Shown on Right (Column 3).

Table 7 - 2006 BA (ENRD, 2006)										
2005 Fort Huachuca Pop. Adjusted for Double Counting										
Personnel Category	No. of people after adj. for double counting	**Off Post Tally**								
Active Military living on Post	1772									
Students on Post	2252									
Military family members on Post	2887									
Active Military living off Post	1683	1683								
Military family members off Post	2624	2624								
Govt. Civilian employees	1880	1786	Fr. Cris Howard email on 7/29/10							
Govt. Civilian family members	3027	2876		5% of civilians live ON post (95% live OFF post)						
Contractors working on and off Post	2937	2585	Fr. "POST POP 30 SEP 09.XLS" - 12% of contractors live OFF post (88% live ON post)							
Contractor family members	4729	4162		provided by T. Runyon						
2 Wage Earners in Household family members	953	477								
Military Retirees	498	498								
Military Retirees Family Members	498	498								
Survivors	444	444								
Subtotal	26184	17631	67%	of subtotal						
Less 3% living outside subwatershed	-786	-3%								
Total	**25398**	17102	67%	of subtotal						
Total induced pop =	6781	6781	26.7%	of Total Fort Population						
Total direct, indirect & induced in Sub-watershed	**32179**	**23883**	**Total living OFF Post**		74%					
		8296	Total living ON Post							

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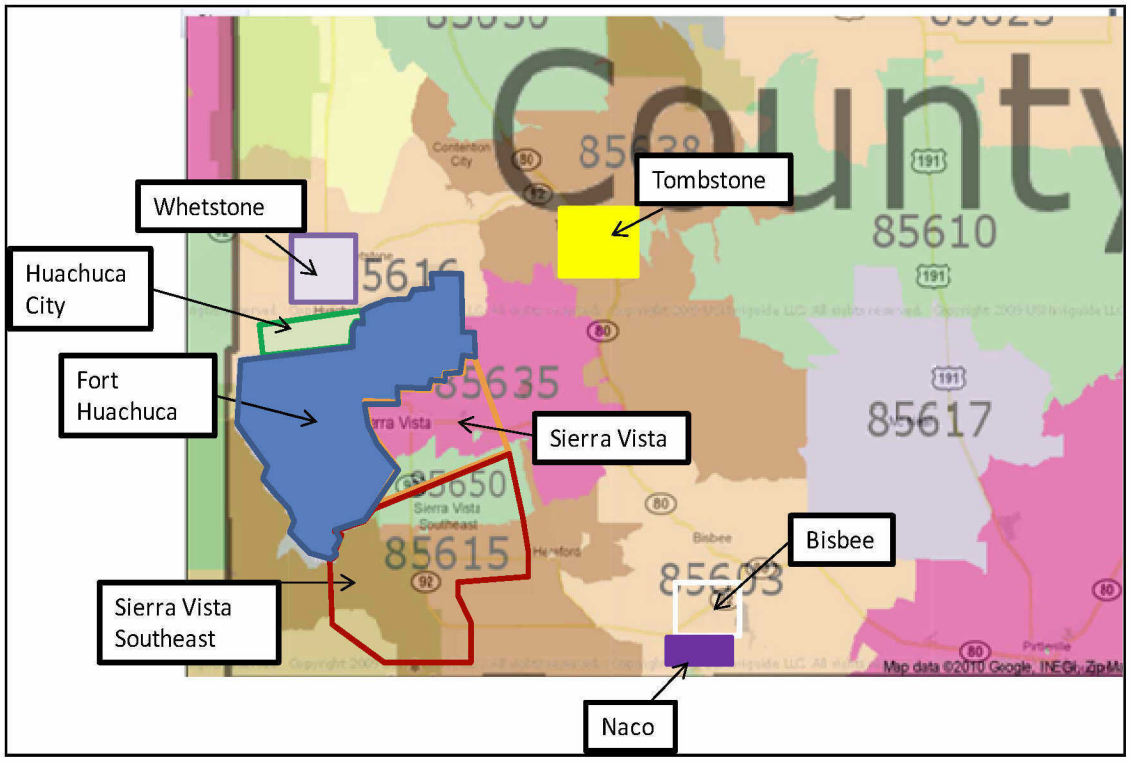

Figure C. 1 Sierra Vista Subwatershed Census County Divisions Overlaid on Cochise County Zip Code Map.

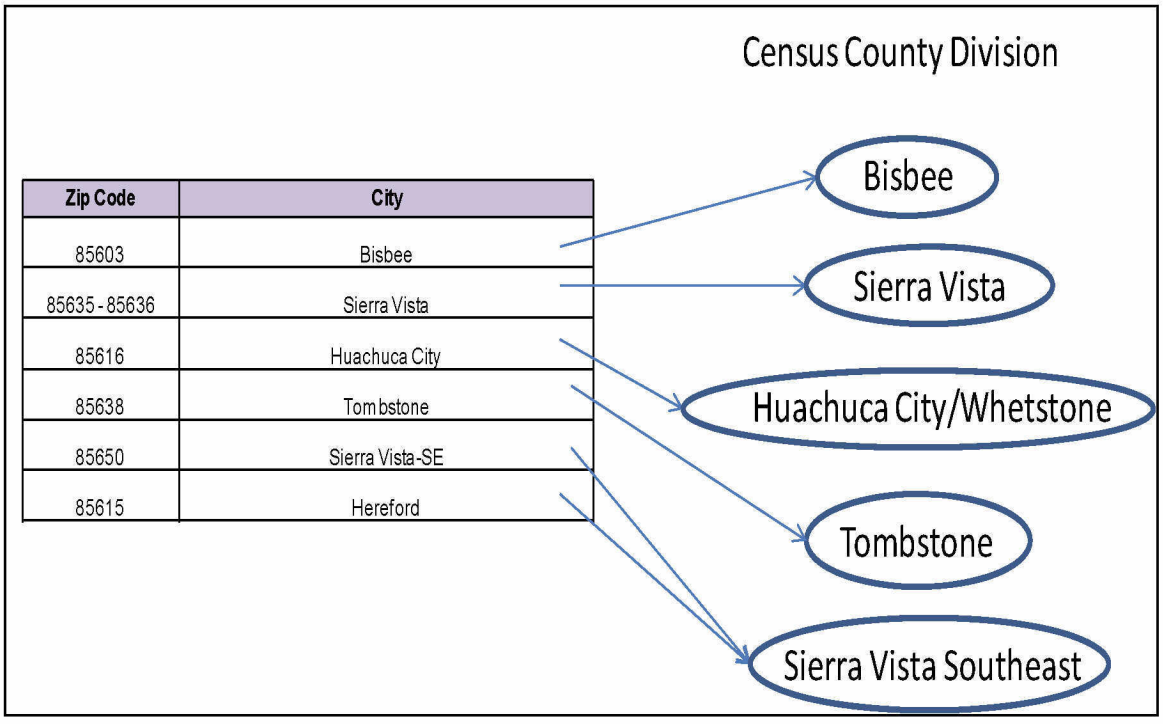

Figure C. 2 Mapping of Zip Code Population Data to Census County Divisions.

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Table C. 4. Estimated Fort-related Off-post Population and Associated Groundwater Demand Within the Sierra Vista Subwatershed as of 2005.

Estimated Civilians, Contractors, and Induced by Zip Code within Sierra Vista Subwatershed

Zip Code	City	% of Off-Post Civilians in SV Sub-watershed[a]	Civilians Count[b]	Contractors[b]	Induced**	Active Military + Families[b]	2 wage earners families[b]	% Retirees in SV Sub-watershed (as of FY08)[d]	Retiree + families & Survivors Count	**Total Count of Off-Post Pop**	Annual GW Demand based on incorp. area demand rate of 160 gpdc[e]		Annual GW Demand based on unincorp. area demand rate of 0.132 af/pers/yr[e]	
			Estimated Off-Post Population Based on Off-Post Civilian Zip Codes								AF	cu-m/d	AF	cu-m/d
85603	Bisbee	0.9%	40	58	60	37	4	2%	21	**220**	39	133.1		
85615	Hereford	10.0%	451	652	676	417	46	12%	172	**2414**				
85616	Huachuca City	6.4%	291	421	436	269	30	7%	93	**1539**			203	686.7
85635 - 85636	Sierra Vista	54.2%	2,452	3548	3677	2265	251	53%	739	**12932**	2318	7832.3		
85638	Tombstone	0.8%	38	55	57	35	4	1%	11	**199**	36	120.4		
85650	Sierra Vista-SE	27.7%	1,250	1809	1875	1155	128	26%	361	**6579**			1187	4011.8
	TOTAL	100.0%	4,522	6544	6781	4178	462	100%	1397	**23883**	**2393**		**1390**	

[a] source: Vernadero Group, Inc. (provided by C. Howard via T. Runyon, July 2003); data are for March 2009
[b] source: Table 7 of 2006 Biological Assessment (ENRD, 2006);
all totals reduced by 3% from BA values to reflect off-Post population living outside SV subwatershed
[c] induced population not reduced by 3% (see Table 7 from 2006 BA)
[d] source: Fort Huachuca ENRD (provided by T. Runyon, July 2003)
[e] source: App. K of Biological Assessment (ENRD, 2006)

GW=groundwater
gpcd = gallons per capita per day
AF = acre-feet
cu-m/d = cubic-meters per day
af/pers/yr = acre-feet per person p

USF200010771

Table C. 5. Total Off-post Simulated Pumping in USGS Model (Pool And Dickinson, 2007) for Winter of 2002-2003, and Estimated Off-post Pumping Attributable to Fort Huachuca, by Census County Division (CCD), and as a Percent of Total Simulated Pumping within Each CCD (cubic-meters).

Census County Division (CCD)	Simulated Groundwater Pumping (cu-m)		**% of Total Pumping attributable to Fort**
	Total Annual	Fort-related Off-Post Annual	
BISBEE	-1278058	-48596	**3.8%**
HUACHUCA CITY	-133933	-125320	**93.6%**
SV	-5911428	-2858799	**48.4%**
SV-SE	-2446756	-1464313	**59.8%**
TOMBST	-391039	-43960	**11.2%**
WHETSTONE	-204396	-125320	**61.3%**

cu-m = cubic meters

The method of attributing a fixed percentage of each CCD's total annual pumping to Fort Huachuca based on the percentages calculated for the year 2005 (Table C.5) is imprecise, but is considered the best approximation in lieu of detailed population figures for on- and off-post Fort population for the entire simulation period 1902-2105.[10] For historic pumping, these fixed percentages of each CCD's total pumping may be reasonable, as little population growth occurred in the basin outside of that related to the Fort (T. Runyon, pers. comm., 2010). For future (post-2005) off-post pumping projections, however, the method may be less appropriate because much of the recent growth in the USPB has not been associated with the Fort, and that trend is expected continue as the state's total population grows (T. Runyon, pers. comm., 2010). Thus, future off-post pumping projections could be refined with estimates of the Fort's future total population, as well as estimates for what percentage of the Fort's total population will be induced in the future.

As indicated in Table C.3, of the Fort's total 2005 on- and off-post direct, indirect, and induced SV subwatershed population of 32,179 (adjusted for double-counting), 74% (23,883) were estimated to live off post .

[10] Estimating the Fort's historic off-post water demand as a function of its on-post demand is not feasible since the Fort's on-post per capita water consumption has fallen dramatically over time.

USF200010772