Prepared in consultation with the Secretaries of Agriculture and Defense and in cooperation with the Upper San Pedro Partnership in response to Public Law 108-136, Section 321

2009 Appendix A: Progress Toward Achieving and Maintaining Sustainable Yield of the Regional Aquifer of the Sierra Vista Subwatershed, Arizona

U.S. Department of the Interior
U.S. Geological Survey

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Appendix A: Progress Toward Achieving and Maintaining Sustainable Yield of the Regional Aquifer of the Sierra Vista Subwatershed, Arizona

Forward

In the current annual 321 report to Congress and future reports, the bulk of the text and figures previously found in the body of the 321 report (for example, Department of the Interior, 2008[1]) will be found in Appendix A of the report. The intent of this reorganization and revision is to make the 321 report more understandable, a simpler matter to review, and of greater value to both the Members of Congress and the general public. The Upper San Pedro Partnership welcomes and encourages feedback from its readers with regard to these format changes.

Introduction

Groundwater is the primary source of water for the residents of the Sierra Vista Subwatershed, Cochise County, Arizona, including Fort Huachuca, Bisbee, Sierra Vista, Huachuca City, Tombstone, and the rural residents. Groundwater is also the essential component among the water sources that sustain the base flow of the San Pedro River and its associated riparian ecosystem, formally protected

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[1] 321 report dates can be confusing. The 2007 report assesses the hydrologic state of the Subwatershed in calendar year 2006. It was delivered for review in late 2007, and included "2007 Report to Congress" in the title. It was not actually delivered to Congress, however, until late in 2008, and thus 2008 is the citation date: "Department of the Interior, 2008." As a result, each report has 3 years associated with it--the report year (the 2007 321 Report), the data year (the state of the Subwatershed in 2006) and the publication year (Department of the Interior, 2008).

through an act of Congress as the San Pedro Riparian National Conservation Area (SPRNCA). Water outflow from the Sierra Vista Subwatershed (Subwatershed), including water withdrawn by pumping, exceeds natural inflow to the regional aquifer within the Subwatershed. As a result, groundwater levels in parts of the Subwatershed are declining and groundwater storage is being depleted. In the absence of effective management measures, continued decline of water levels and associated depletion of storage will continue to diminish groundwater flow to the San Pedro River.

The Defense Authorization Act of 2004 (Public Law 108-136, Section 321, hereinafter referred to as Section 321 and included as Appendix B) set goals and an end date of 2011 for achieving, by various means, a sustainable level of groundwater use from the Subwatershed. In addition, the Act formally recognizes the Upper San Pedro Partnership (Partnership) and alters the way the Endangered Species Act applies to Fort Huachuca. The Partnership is specified as the regional cooperative organization for recommending policies and projects to mitigate water-use impacts in the Subwatershed. Section 321 directs the Secretary of the Interior, in consultation with the Secretaries of Agriculture and Defense and in cooperation with the Partnership members, to report on the water-use management measures (water-management measures) that are being implemented and those needed to restore and maintain the sustainable yield of the regional aquifer by and after September 30, 2011.

The Partnership, formed in 1998, is a consortium of 21 local, State, and Federal agencies and private organizations whose collective goal is to ensure an adequate supply of water to meet the reasonable needs of the Subwatershed residents and the San Pedro River. Partnership members include owners or managers of land, entities capable of implementing water-management measures, and resource agencies. In pursuit of its goals, the Partnership has initiated and (or) funded studies to better understand the regional hydrologic system, the riparian system, and recharge processes. The Partnership also has invested significant resources into systematically identifying, evaluating, and documenting water-management measures that will be used to attain sustainable yield of the regional aquifer. A complete listing of Partnership members is found in Appendix F, a complete listing of Partnership reports is contained in Appendix C, and additional information about the Partnership is available at: http://www.usppartnership.com.

Because the local groundwater system is complex, the consequences of groundwater use and the effectiveness of alternative water-management strategies will be better understood only through ongoing research and monitoring efforts. The results of monitoring will provide information needed to assess progress toward sustainable use of the regional aquifer and to improve management decisions as part of an adaptive management process. The term “adaptive” is used because decisions associated with sustainable yield must be made today in the absence of a perfect knowledge of the consequences of today’s actions and tomorrow’s conditions. As new information becomes available, resource decisions can be amended or revised. For this reason, the continued operation of a well-designed monitoring program is important to provide useful feedback on the status and trends of aquifer conditions and the impact and effectiveness of mitigation measures.

Description of the Upper San Pedro Basin and the Sierra Vista Subwatershed

Physical System

The Upper San Pedro Basin[2] is a groundwater management unit that extends from the United States-Mexico border to a bedrock constriction called The Narrows about 11 miles north of Benson, Arizona. The Subwatershed is a 950 mi2 area bounded on the west by the Huachuca Mountains and on the east by the Mule Mountains and Tombstone Hills. The southern boundary of the Subwatershed is the

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[2] The Upper San Pedro Basin is formally defined by statute in the Arizona Groundwater Management Act of 1980. The hydrologic boundaries of the Upper San Pedro Basin (a groundwater unit) and the San Pedro surface water drainage do not coincide although the differences are minor. This report makes no attempt to resolve these differences in terminology.

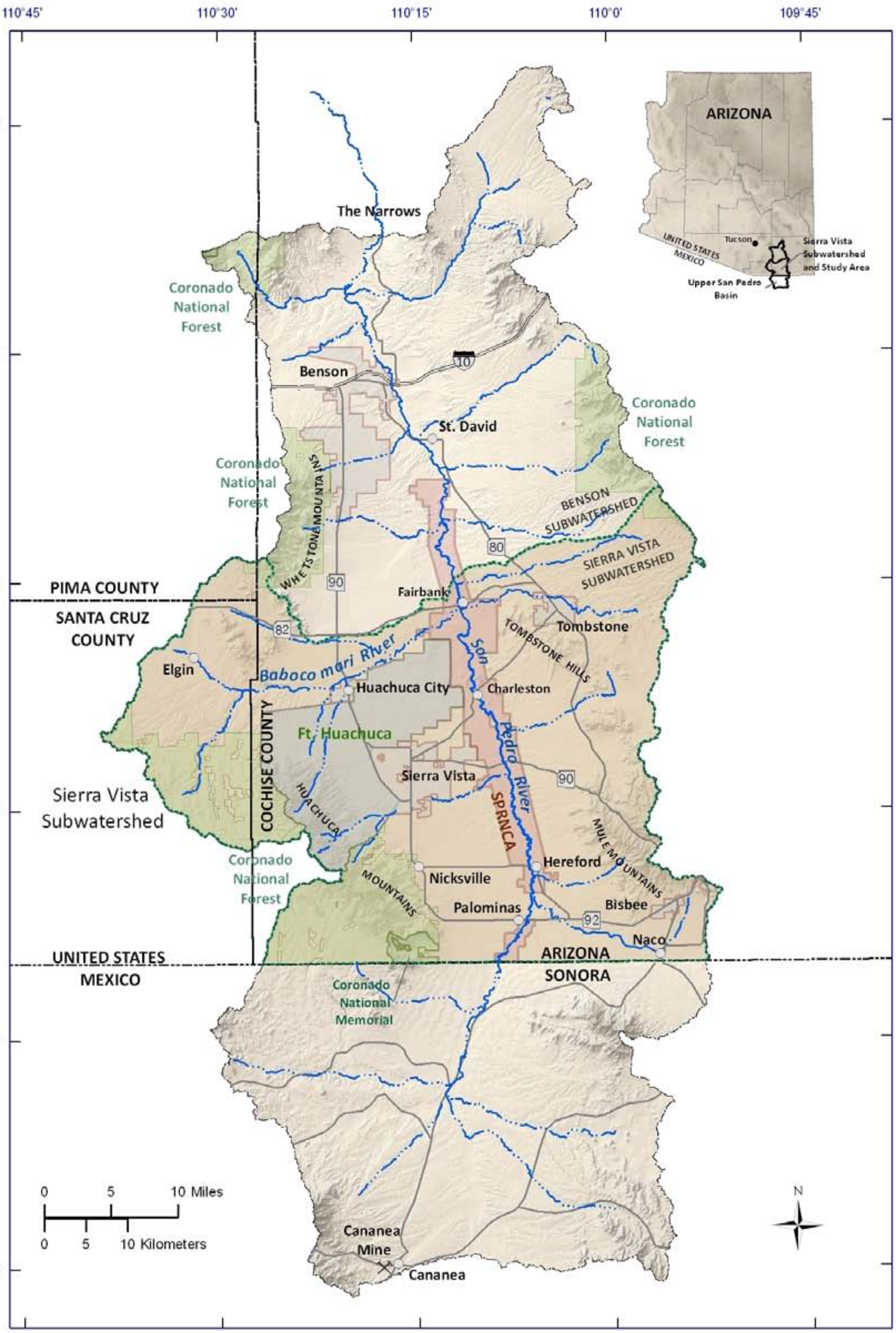

Figure A1. Location of the Sierra Vista Subwatershed, Upper San Pedro Basin, Arizona.

United States-Mexico border, and the northern boundary is a watershed divide across the Upper San Pedro Basin that intersects the river at the gaging station near Tombstone about 1.5 mi downstream from the ghost town of Fairbank. The area within these bounds is an alluvium-filled valley with surfaces that slope gradually down from the base of the mountains to the San Pedro River, which flows north out of Mexico through the center of the valley. The basin's alluvial sediments constitute the Subwatershed's regional aquifer.

The Subwatershed supports an ecologically diverse riparian system along the San Pedro River. In 1988, Congress designated portions of the river as the San Pedro Riparian National Conservation Area (Public Law 100-696) to be managed by the Bureau of Land Management (BLM). The legislation directed the Secretary of the Interior to conserve, protect, and enhance the natural resources of this riparian system—the first riparian national conservation area in the country. The biological significance of the river stems from the contrast between the riparian ecosystem and most of the surrounding area. The riparian system supports a diverse biota comprising approximately 400 avian species, 81 mammalian species, and 43 species of reptiles/amphibians (Bureau of Land Management, 1989) and is a primary hemispheric corridor for migrating birds. The SPRNCA boundaries define a corridor along the San Pedro River up to 5 mi wide and extending about 35 mi north from the international boundary with Mexico (fig. A1). The climate of the Subwatershed is semiarid. The Agricultural Research Service estimated a Subwatershed area average precipitation of about 16.6 in for 2008 (Appendix E). About 65 percent of the annual precipitation arrives in summer thunderstorms with most of the remainder resulting from winter storms (Goodrich and others, 2000).

Because precipitation in the Subwatershed is concentrated in the mountains, most recharge to the regional aquifer system occurs at the periphery of the Subwatershed, near the junction of the mountains and basin floor (Pool and Coes, 1999). Water also enters the Subwatershed through the subsurface as underflow from Mexico. Within the Subwatershed, natural groundwater discharge occurs mostly as outflow to the San Pedro River (base flow) and through consumption by the riparian vegetation along the river corridor (evapotranspiration). Some water also crosses the downstream boundary of the Subwatershed as groundwater underflow.

In the Subwatershed, flow in the San Pedro River is perennial in some reaches and intermittent in others. The ecologic condition of the riparian forest directly depends on the presence of shallow groundwater within the flood plain, whereas the SPRNCA's aquatic habitats are directly dependent on stretches of perennial streamflow. This hydrologic context depends on consistent groundwater flow from the regional aquifer system to the stream (Pool and Coes, 1999). The location of perennial streamflow is controlled by geology as well as by the amount and location of groundwater recharge and discharge. The primary perennial river reach extends from about 7 mi south of Charleston, where the USGS streamflow-gaging station San Pedro River at Charleston (station number 09471000) is located, to one mile north of Charleston.

Socioeconomic setting

The Subwatershed supports a human population of about 81,362 [estimated from Arizona Department of Commerce (ADOC) (2009) data] that is distributed among the unincorporated rural areas and the municipalities of Bisbee, Sierra Vista, Huachuca City, and Tombstone. The population of Sierra Vista, the Subwatershed's largest city, was 45,908 in 2008 (Arizona Department of Commerce, 2009) including the permanent residents of the U.S. Army's Fort Huachuca.

Fort Huachuca is the region's largest employer. The direct, indirect, and induced population in the Subwatershed attributable to the Fort may be more than 32,000 (U. S. Fish and Wildlife Service, 2007). The Fort occupies approximately 78,000 acres in the Subwatershed, much of which remains undeveloped. A recent economic impact analysis of Arizona's military installations estimates Fort

Huachuca’s $2.38 billion annual impact as the greatest of the 9 installations in the State (The Maguire Company, 2008).

Essential Definitions

Sustainable Yield

The Partnership has defined “sustainable yield” as “…managing [groundwater] in a way that can be maintained for an indefinite period of time, without causing unacceptable environmental, economic, or social consequences,” (Alley and others, 1999). Therefore, a sustainable level of groundwater pumping for the Subwatershed could be an amount between zero and a level that arrests storage depletion, with the understanding that to call an amount of pumping other than zero sustainable will entail some consequences at some point in the future. Eight indicators used to assess Partnership progress toward sustainable yield are:

1. Regional aquifer levels
2. Near-stream alluvial aquifer levels
3. Near-stream vertical gradients
4. Spring and artesian well discharge
5. Streamflow permanence
6. Streamflow (summer and winter 7-day low flow)
7. Aquifer storage change measured using microgravity techniques
8. Annual storage deficit

The term “safe yield” is not interchangeable with “sustainable yield” in the context of this report. The State of Arizona defines safe yield as “a water management goal which attempts to achieve and thereafter maintain a long-term balance between the annual amount of ground water withdrawn [by pumping]…and the annual amount of natural and artificial recharge…(A.R.S. § 45-562 (A)).” Therefore, safe yield does not consider the water required to sustain riparian ecosystems and streamflow and therefore is not used by the Partnership as a management concept.

Overdraft

In this report “overdraft” is defined as groundwater consumption in excess of sustainable yield. This is consistent with the concept that pumping beyond a sustainable level is “over pumping.”

Management Measures

“Management measures” are projects and policies that are intended either to reduce water consumption (conservation) or to increase recharge to the aquifer system. Examples include water-conservation ordinances, conservation easements, and municipal wastewater reuse and recharge. Rain-water harvesting and importation also may be considered management measures. The yields from these measures are “management-measure yields.”

Recharge

“Groundwater recharge" is the addition of water to the groundwater system. It can occur either naturally (directly from precipitation or surface flow over pervious surfaces in areas of negative (downward) hydraulic gradients) or artificially (from retention/detention basins or effluent recharge). Water moves from the land surface through the unsaturated zone to the regional aquifer. Over the long term, recharge is balanced approximately by discharge to surface waters, to plants, and to flow of groundwater out of an aquifer. This balance can be altered locally, however, as a result of pumping, land use, and (or) climate changes (Delin and Falteisek, 2007).

Recharge is not equivalent to surface infiltration. In the case of natural recharge in arid or semi-arid climates, most of the water that infiltrates never passes the root zone but rather returns to the atmosphere as soil evaporation or plant transpiration. Typically, only a small portion of water that naturally infiltrates becomes recharge (Todd, 1980). In the case of artificial recharge including that found in the Subwatershed, recharge ponds are designed to maximize the amount of infiltrating water that recharges the groundwater system.

Spatial Water Management

"Spatial water management" refers to decisions made based on knowledge that the location from which water is pumped from an aquifer influences where and when streamflow depletions will occur. As a general rule, pumping farther from a stream delays the onset of streamflow depletion (Alley and others, 1999). Spatial water management considers the effect of the distribution of pumping as part of decision making, but does not necessarily regard the total amount of groundwater pumping. It is a strategy that can either be used to protect particular areas from streamflow depletion or to delay the effects of pumping further into the future.

Strategy to Attain Sustainability

The Partnership continues to work to put in place a strategy to attain a sustainable yield of groundwater withdrawals in the Subwatershed. It involves implementation of a variety of specific management measures that are designed to reduce the net impacts on the groundwater system and includes: conservation, reuse, recharge, importation, engineered augmentation, redistribution, and spatial water management.

The identification and implementation of management measures by the Partnership and its members occur within the context of adaptive management. The underlying premise is that the management process should improve through time, or adapt as additional information about the success of prior measures becomes available and (or) as the physical context changes within which the measures are applied. As monitoring and project data are evaluated, the Partnership will know better what existing measures work, and what additional measures may be needed to reach a sustainable level of groundwater withdrawals. An advantage of the adaptive-management process is that measures with a high level of certainty (in yield and funding) can be implemented immediately, and less-certain measures can be evaluated for later implementation.

The ultimate goal of water-use management in the Subwatershed is to attain a sustainable yield of groundwater withdrawals (pumping) from the regional aquifer system. What yield is considered sustainable has yet to be quantified, however, partly because this would depend on a definition shared by all stakeholders of unacceptable consequences, and partly because sustainability depends, at least in the short term, on where groundwater is pumped. The impacts of sustained drought and climate change also may affect the quantification of sustainable yield. The Partnership has agreed on 8 indicators that, beginning with the current report, will be used to assess Partnership progress toward sustainable yield in the Subwatershed. Thus, while an explicit quantification of Subwatershed sustainable yield does not exist, the Partnership does agree on the spectrum of Subwatershed conditions that will be used to measure sustainability.

The knowledge gained in preparing prior Section 321 reports has made it clear that no single management measure or category of measures will achieve a sustainable yield because various management measures serve different purposes. Conservation measures, for example, improve water-use efficiency, while recharge and reuse of wastewater reduce the net withdrawals from the aquifer. Some techniques, such as spatial water management, do not necessarily reduce water use, but rather serve to ‘buy time’ by delaying the effects of pumping on streamflow depletion.

In 2006 and early 2007, the Partnership completed a key step toward developing a strategy to attain sustainability. Specifically, the Partnership worked closely with the U.S. Bureau of Reclamation (Reclamation), a Partnership member, to develop a detailed problem statement with a specific goal to augment the area's water supply by approximately 10,000 acre-ft/yr by 2011 and 26,000 acre-ft/yr by 2050. A 2050 Subwatershed population of 170,000 using water at a gross per- person rate equal to that estimated for 2002 is assumed. Congress more recently has authorized a feasibility study with a 55 percent local cost share; Reclamation is currently in the process of formulating the scope of work and the text of an Intergovernmental Agreement in order to proceed with the study.

Specific management measures planned through 2011

The Partnership and its members maintain a roster of deficit reducing water-management measures that either are implemented currently and planned for continuation, or are planned for implementation before 2011 (table A1). The yields from these projects constitute the foundation of deficit reducing measures currently planned by Partnership members. The projects generally represent conservation, recharge, reuse, or land-management measures that are possible within the resource limitations of the members. In keeping with the adaptive management process, some future planned yields (2009–11) have been modified from prior Section 321 reports to reflect improved knowledge and potential new projects (table A1). The future-year management measures and yields continue to evolve in each annual Section 321 report as needed to reflect the changing state of knowledge. Projected yields for 2009–11 have been modified from the projections in prior Section 321 reports on the basis of improved knowledge about yields actually obtained during 2002–08. Assuming the currently projected yields are obtained using only the current suite of management measures, the projected aquifer storage deficit will not reach zero by 2011 (fig. 1). The estimation of future deficits includes a projection of population through 2011 based on the increase from the 2000 census (U.S. Census Bureau, 2000) to the

Table A1. Planned annual yields for 2009 through 2011 of Partnership member management measures to reduce aquifer overdraft.

[Yields are in acre-ft/yr; Conservation yields in each year are relative to a zero yield in the baseline year of 2002; Recharge yields are total values and are relative to a baseline of zero acre-ft; projections provided by respective jurisdictions]

		2009 Yield	2010 Yield	2011 Yield
Description	Measure type	Planned	Planned	Planned
Fort Huachuca[1]				
Conservation measures[2]	Conservation	1,000	1,000	1,000
Effluent recharge	Recharge	200	400	400
Stormwater detention basins	Recharge	50	50	50
Cochise County				
Conservation measures[3]	Conservation	120	120	120
Stormwater detention basins[4]	Recharge	30	30	30
Sierra Vista				
Conservation measures[2]	Conservation	1,600	1,600	1,600
Improved golf course efficiency	Conservation	15	15	15
Effluent recharge[5]	Recharge	2,800	3,000	3,000
Stormwater detention basins	Recharge	240	300	300
Bisbee				
Conservation measures[1]	Conservation	40	50	60
Reduced groundwater pumping through effluent reuse	Conservation	0	485	485
Effluent recharge	Recharge	470	5	15
Huachuca City				
Conservation measures[1,6]	Conservation	20	20	20
Tombstone				
Conservation measures[1]	Conservation	10	10	20
Effluent recharge[7]	Recharge	100	100	100
Bureau of Land Management				
Mesquite reduction[8], and retirement of agricultural groundwater pumping[9]	Conservation	615	615	615
Urban enhanced ephemeral-stream channel stormwater recharge				
Increase in stormwater recharge in ephemeral channels by urbanization[10]	Recharge	2,300	2,300	2,300
Incidental Yields				
Retirement of agricultural pumping	Conservation	2,070	2,070	2,070
Total yields				
Total yield[11]		10,700	11,200	11,200

[1] Fort Huachuca is wholly contained within the boundaries of the City of Sierra Vista, and Fort Huachuca's anticipated conservation yields are also included in the Sierra Vista yields shown in table A1. The Total yield found at the bottom of this table does not include the values from the Fort Huachuca Conservation Measures line. Fort Huachuca's yields were double counted in previous 321 reports.

[2] Yield relative to 2002 baseline of zero. Conservation efforts started earlier than 2002 that continue to provide yields do not display a yield in the table because they are already incorporated in actual water-use figures. Yields for 2009–11 are projected yields based on additional planned measures. Actual water use will vary annually owing to effectiveness of conservation, weather, and other factors.

[3] Conservation yield attributable to Cochise County cannot be quantitatively projected owing to the large number of small unmetered wells. The reported yield is attributable to toilet-replacement rebates and assumed savings from code changes. Cochise County has enacted various code changes that should yield future water savings that will increase in proportion to population. Conservation measures enacted include: hot water on demand, gray water plumbing, high-efficiency commercial laundry facilities, humidity sensors on outdoor irrigation, new turf restrictions, limits on evaporative coolers, and a ban on artificial water features (lakes, ponds, or fountains).

[4] Detention basin yield derived from a study of urban runoff and recharge in ephemeral-stream channels and detention basins (Stantec Consulting and GeoSystems Analysis Inc., 2006).

[5] The City of Sierra Vista has known for some time that several hundred additional acre-ft of incidental recharge have been infiltrating through the bottoms of the EOP wetlands ponds, although the amount of that additional recharge has not been known. A recent consultant's study of the city's recharge facility establishes 800 acre-ft/yr of incidental and additional recharge from the wetlands that is not reflected in the current recharge total. That number will be added to future recharge totals once appropriate coordination/validation has been completed by the city.

[6] Huachuca City's waste water will be treated at Fort Huachuca's waste-water treatment plant and the effluent recharged on Fort Huachuca beginning in 2010. The Huachuca City planned effluent recharge yield is included as part of Ft. Huachuca's planned effluent yield beginning in 2010.

[7] Pat Kelly, Tombstone Public Works, written commun., June 16, 2009. This is effluent produced by residents of Tombstone that is released to and recharged in Walnut Gulch; 95% of total effluent discharged is assumed to recharge the groundwater system.

[8] Water-use savings through management of invasive mesquite using various treatments. Mesquite reduction reduces water use by replacing mesquite with more shallowly rooted plants. Yield from mesquite reduction estimated using an Agricultural Research Service model of riparian evapotranspiration in the San Pedro Riparian National Conservation Area. Water conservation is greatest initially following treatment and decreases over time.

[9] Retirement of irrigated agriculture or other high water-consumption uses by consensual agreement.

[10] Urbanization in semiarid climates can increase recharge by concentrating rainfall runoff in ephemeral-stream channels. Initial estimates provided by the Agricultural Research Service of natural recharge enhanced beyond predevelopment levels by urbanization—credit not claimed by any particular Partnership member. These preliminary estimates will be refined through ongoing research and monitoring programs. Increased water use due to urbanization likely exceeds increased recharge. All urban-enhanced recharge estimates represent quantities expected in an average year—no current monitoring can provide year-specific values. Projections for 2009–11 are based on 2001 land-cover data and do not account for increases that likely will occur as impervious-surface area increases.

[11] Total yields rounded to nearest 100 acre-ft. Yields based on the best current data and assumptions. Yield values differ from the prior Section 321 reports owing both to changes in implemented and planned projects and to the use of improved methods to reanalyze yields.

2008 population estimated by the ADOC (Arizona Department of Commerce, 2009). The ADOC population estimates do not report population by subwatershed, so for the purposes of Section 321 calculations the ratio of incorporated to unincorporated population was assumed to equal that for the last available data—the 2000 census. The Partnership is actively investigating other management approaches to address the shortfall in yields. The current and future deficits depicted (fig. 1) cannot be compared directly to similar results in Section 321 reports prior to the 2007 report because those reports relied on an earlier estimate of riparian evaporation and plant transpiration (Department of the Interior, 2005, 2006, 2007). The 2007 (Department of the Interior, 2008), 2008, and current, 2009 report use the more recent riparian evaporation and plant transpiration estimates of Scott and others (2006). The deficit currently projected is 3,100 acre-ft larger than what would have been calculated using the earlier estimates of evapotranspiration.

The Partnership also recognizes the importance of spatial water management in mitigating impacts to the base flows of the San Pedro River. Partnership-initiated science (for example, Leake and others, 2008) has begun to quantitatively define the relation between the location of a management action and the timing of effect on streamflow. An example of this recognition is the March 2006 resolution by the Cochise County Board of Supervisors to prohibit increased residential densities within 2 mi of the SPRNCA boundary. Assuming a given total rate of pumping, this effort will restrict the most intense pumping from new developments to greater distances from the river, thereby increasing the time before streamflow is reduced and giving additional time for planning. The Partnership also is considering locating some future recharge projects near the river where benefits to streamflow will be realized relatively quickly.

Strategy to Assess Sustainability

The language of Section 321 specifies that reports shall be prepared annually through 2011 discussing “the water use management and conservation measures that have been implemented and are needed to restore and maintain the sustainable yield of the regional aquifer by and after September 30, 2011.” The Section 321 language leaves “sustainable yield” largely undefined other than to require that overdrafts from the aquifer be reduced. The Partnership therefore adopted the definition of sustainable yield stated previously: “…managing [groundwater] in a way that can be maintained for an indefinite period of time, without causing unacceptable environmental, economic, or social consequences.”

To make the adopted definition meaningful in the context of management decisions, indicator trends (for example, declining groundwater levels in a near-stream well) and potential consequences for the system (for example, a loss of riparian diversity) must be evaluated. Indicators ideally are easily measured aspects of the system that are clearly related to a potential consequence and thus provide useful information about the system as a whole. Defining specific indicators helps to evaluate system status and trends (Farrell and Hart, 1998). An indicator can be evaluated relative to a threshold value (or metric) that has been determined to indicate system health (or with respect to the Subwatershed, sustainable yield). Indicators also can be evaluated relative to overall progress toward sustainable yield without necessarily defining specific numerical thresholds.

The first Section 321 report (Department of the Interior, 2005) and the subsequent annual reports considered a single quantifiable indicator – aquifer storage deficit calculated from the water budget. The calculated value of aquifer deficit in each year represents the numeric value of the indicator. The threshold for sustainable yield was defined as an aquifer storage deficit of zero; a zero or positive deficit (accreting aquifer storage) was defined as sustainable and a negative storage deficit was considered unsustainable.

The intent of the Partnership from the beginning of the Section 321 reporting process has been to define and report on a suite of sustainability indicators, including the aquifer storage deficit. In 2009 the Partnership agreed upon 7 additional indicators which will be evaluated annually to assess progress toward system health and sustainable groundwater use in the Subwatershed. These indicators are introduced below. Six of the eight indicators will be used in this appendix to assess overall progress toward sustainable yield; the assessment is based on data collected from monitoring sites throughout the Subwatershed (fig. A2). Measures of two additional indicators (alluvial aquifer groundwater elevations and near-stream vertical hydraulic gradients) will not be available until the 2010 321 Report.

Groundwater indicators

There are four groundwater indicators. They are based on a combination of data from completed scientific projects and the established and active monitoring program. The groundwater indicators include regional aquifer water levels, storage change, water levels in the San Pedro River stream alluvium, and near-stream vertical hydraulic gradients.

Regional aquifer water levels

The most immediate and direct effect of groundwater pumping is a decline in aquifer water levels. Declines in water levels beneath long-term pumping centers in the Subwatershed have been measured over decades and indicate a general trend of loss in aquifer storage (Arizona Department of Water Resources, 2005a; Schmerge and others, 2009). As a direct measure of pumping effects, monitoring of both water levels and aquifer storage change using gravity techniques (discussed below) will serve a primary role in ascertaining the success of Partnership efforts to achieve a sustainable level of groundwater pumping in the Subwatershed. Water levels are measured to provide a sense of storage change; water-level decline indicates storage loss while water-level recovery indicates storage increase.

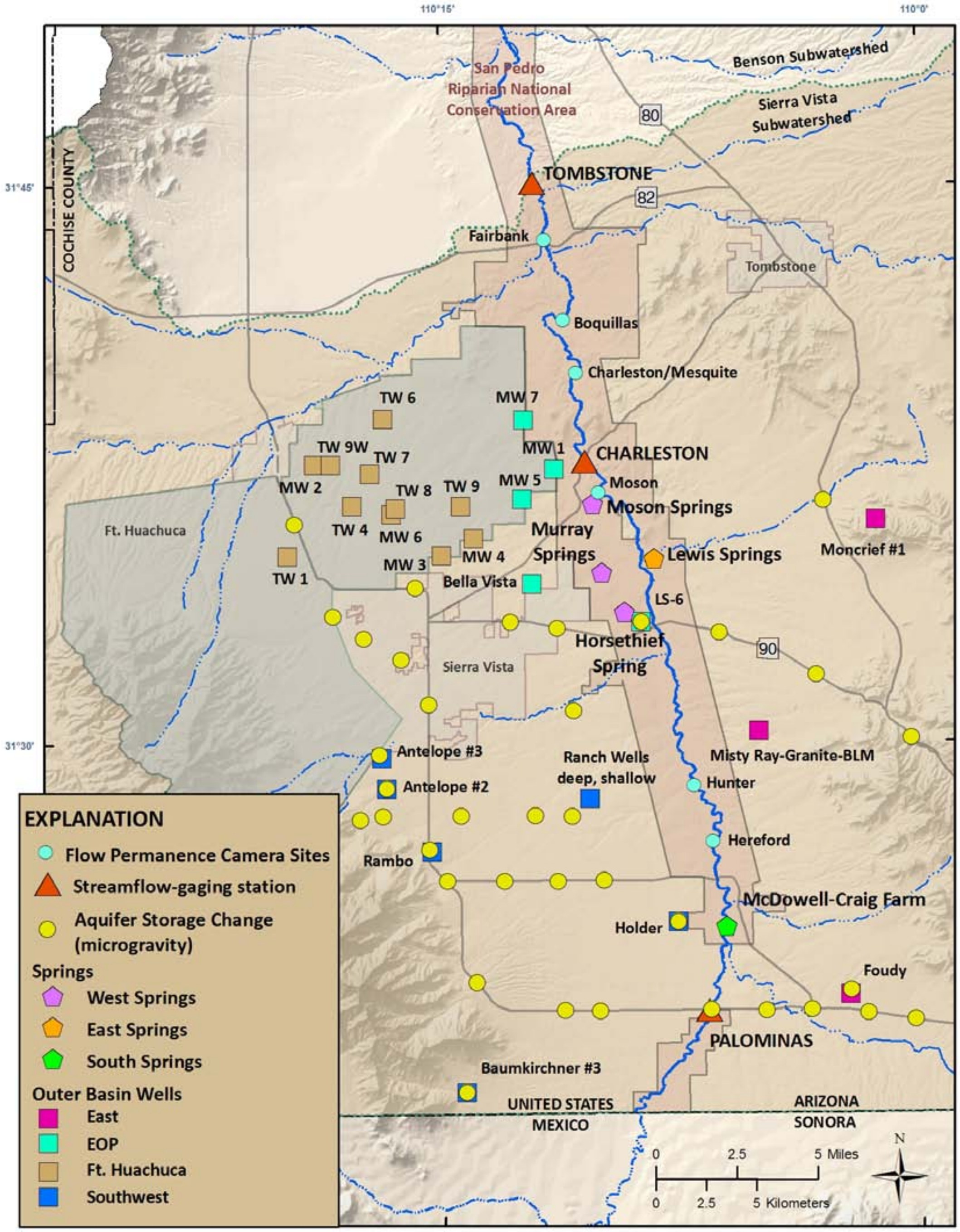

Figure A2. Monitoring locations in the Sierra Vista Subwatershed, Upper San Pedro basin, southeastern Arizona. The indicators of Subwatershed sustainability are evaluated annually using the data collected at these locations to assess progress toward system health and sustainable groundwater use in the Subwatershed.

Changes in water levels, however, typically cannot be used to accurately quantify storage change because the storage coefficient (capacity of the aquifer system to hold water) is generally not well known. Although water-level changes do not directly measure storage change, they are important for several reasons:

- They provide a direct indication of the direction of groundwater flow and of the hydraulic gradient driving this flow;
- Water levels have been measured at many locations in the Subwatershed for decades and therefore provide a historical context within which to interpret changes;
- They are easily measured and measurements can be made with millimeter precision.

A regional aquifer network of about 30 wells (figs. A3a and A3b) has been monitored since about 2000, although records are longer or shorter depending on the well. Fifteen of these wells have been monitored by the USGS through periodic (quarterly) measurements and continuous data collection using data loggers. The remaining 15 wells are on Fort Huachuca and have been monitored bimonthly by the Fort, USGS, or Arizona Department of Water Resources (ADWR) personnel. The distribution of these wells is concentrated in areas most likely to be influenced by pumping in the Sierra Vista/Fort Huachuca area, but the distribution of the monitoring wells span from the mountain front to near the river. ADWR also conducts periodic water-level measurements of large numbers of wells, including pumping wells, throughout the Subwatershed about every 5 years (Schmerge and others, 2009).

Groundwater storage change—direct measurement

Since about 2005, direct measurements of groundwater storage change have been made using microgravity methods at 36 stations across the Subwatershed (figs. A4a and A4b). Gravity methods quantify changes in groundwater storage by measuring changes in total mass beneath a point on the Earth’s surface. When a gravity-measurement site remains undisturbed throughout a study period, a reasonable assumption can be made that the only change in mass through time is due to the removal or addition of underlying water (Pool and Eychaner, 1995). Because this method directly measures changes in mass (water), estimates of storage change are not limited by uncertainties in hydraulic properties such as the storage coefficient mentioned with regard to water-level measurements in the previous section. Another advantage is that microgravity measurements integrate mass change within a radius up to about 1 km, depending on the depth to water, while water levels reflect conditions only in the immediate vicinity of a well. On the other hand, microgravity measurements can be less precise than water-level measurements and feasibly cannot be made continuously, as can water-level measurements made in a well equipped with a pressure transducer and a data logger.

Near-stream alluvial aquifer water levels

Much of the riparian vegetation along the San Pedro River can thrive only with direct access to shallow groundwater in the stream alluvium near the river, and thus the effect on vegetation of declines in the stream-alluvium water levels is relatively rapid. For this reason, near-stream alluvial water levels are among the most important indicators of riparian system health adopted by the Partnership. A Partnership-initiated investigation determined the relation between riparian vegetation variables and hydrologic conditions (Leenhouts and others, 2006). This study drew its conclusions on the basis of a variety of hydrologic measures, including groundwater levels in approximately 64 wells, and measurements of riparian vegetation and evapotranspiration. One outcome of the study was a map that divided the SPRNCA into 14 reaches and assigned a riparian condition class (dry, intermediate, or wet) to each reach. The condition-class assignment was based solely on the various measurements of riparian vegetation. The condition classes were then related to groundwater depth and streamflow permanence (the percentage of time in a year a stream flows), thus providing information about the hydrologic conditions that support particular riparian conditions. Specifically, the investigation found that the average maximum flood-plain (alluvium) groundwater depth in dry, intermediate, and wet condition-class reaches was 3.5 m, 3.0 m, and 1.7 m respectively (using Water Year 2002 data). The within-year average fluctuations of groundwater depth were 1.8 m, 0.9 m, and 0.3 m for dry, intermediate, and wet condition-class reaches, respectively.

From this information the Partnership has defined a specific set of groundwater indicators pertaining to the hydrologic conditions along the San Pedro River: the average and maximum groundwater depth, and within-year fluctuation in wells screened in the stream alluvium. Many of these wells are identical to those monitored in the Leenhouts and others (2006) study.

Vertical hydraulic gradients

Water flows from areas of higher water levels to lower water levels (or more precisely, from areas of higher potential energy to areas of lower potential energy). The difference in levels divided by the distance between the points where the levels were measured is a hydraulic gradient. In an aquifer, differences in water levels, or hydraulic head, can occur across both vertical and horizontal distances. Measurements of the changes in water levels provide a sensitive measure of changes in the force that moves water from one place to another. Some locations, such as gaining reaches of the San Pedro River, have vertical hydraulic gradients that drive water upward from deeper parts of the aquifer into the stream system (Leenhouts and others, 2006). Vertical hydraulic gradients have been measured continuously at the Lewis Springs monitoring station near the junction of highway 90 and the San Pedro River for about 15 years, and at various other locations along the river for about 9 years. The Partnership has decided that the vertical hydraulic gradients near the San Pedro River are another important indicator of progress toward sustainability in the Subwatershed.

Streamflow

Like the groundwater indicators, the two streamflow indicators are based on a combination of data from completed scientific projects and the established and active monitoring program. The streamflow indicators are related to winter and summer low flow or annual days of no flow, and streamflow permanence.

Low flow and days of no flow

The USGS operates 9 streamflow-gaging stations in the Subwatershed, 3 of which are on the main stem of the San Pedro River (fig. A5a and A5b). Data applicable for evaluating changes in the hydrologic system and progress toward sustainability are collected at the gaging stations. The periods of record vary:

- more than 100 years at the streamflow-gaging station at Charleston (station number 09471000; continuous in time and location since 1935);
- 54 total years at the stream-flow gaging station at Palominas (station number 09470500; includes three major data gaps since 1930);
- 32 total years at the streamflow-gaging station at Tombstone (station number 09471550; includes one ten-year data gap since 1967);
- about 8 years at several tributary stations

These data provide a spatially distributed look at how streamflow varies. Stations located along the San Pedro River downstream of groundwater discharge locations indicate changes in outflows from the regional aquifer system. The monthly streamflow records for each gaging station show the seasonal patterns imparted by the annual recurrence of summer precipitation events and winter reduction of evapotranspiration.

Two specific indicators of sustainability adopted by the Partnership are the 7-day winter and 7-day summer low flows of the San Pedro River at Charleston. A 7-day low flow is the lowest value from a series of 7-day moving averages through a period of interest, and provides a sense of how much groundwater is discharging to the stream. The winter 7-day low flow at Charleston is calculated from data collected between January 15 and March 15 and the summer low flow is calculated using June data.

Because there are often periods of no flow at both Palominas and Tombstone, 7-day low flow values are not useful indicators of progress toward sustainability at those locations. Instead, total days of annual no-flow have been calculated as a proxy for low flow—as less groundwater discharges to the stream and (or) as more surface water discharges from the stream into the ground, the number of no-flow days each year will generally increase. As with most proxies, this one is not perfect. The number of days of flood flows each year can increase or decrease the number of days of no-flow. Annual no-flow data can be inverted to provide additional streamflow permanence data points (discussed next) along the San Pedro River.

Streamflow Permanence

In Leenhouts and others (2006), the relation of streamflow permanence to the three riparian condition classes referenced in the “Near-stream alluvial aquifer water levels” section, above (wet, intermediate, and dry) was also reported (fig. A6). Average flow permanences of 48, 78, and 100 percent for dry, intermediate, and wet classes were reported for water year 2002, and 17, 63, and 98 percent for water year 2003. Subsequently, the Agricultural Research Service installed automatic digital cameras at 8 sites along the San Pedro River (6 along the Subwatershed reach). BLM has since taken over the camera data collection, and has categorized the photos of the river into dry (no water visible) and wet (water visible, ponded or moving) from which they calculate annual streamflow permanence at each of the sites. Steamflow-gaging stations at Palominas, Charleston, and Tombstone, and a stage recorder near Lewis Springs provide additional streamflow permanence data for a total of 10 streamflow permanence sites in the Subwatershed reach of the river (fig. A6).

Springflow

In addition to stream base flow, springs represent another path through which water leaves the groundwater system and as such can indicate how natural and human-induced changes to the hydrologic system affect the aquifer. Infrequent measurements of spring flow were collected between 1988, when the SPRNCA was established, and 2003. Additional measurements were begun in 2003, and a systematic network of quarterly discharge measurements at four springs was initiated in response to Section 321 needs in early 2005. A fifth spring was added to the monitoring network in 2007 (fig. A7).

Water Budget

In previous Section 321 reports covering years prior to 2007 (Department of the Interior, 2005, 2006, 2007), a water-budget approach was used to define an initial goal for attaining a sustainable yield of groundwater use. The goal was defined relative to a calculated annual aquifer-storage deficit of about 10,000 acre-ft/yr for 2002. In the initial, 2004 321 Report (reporting on data year 2002) (Department of the Interior, 2005) this goal was specifically stated: “The Partnership plans to offset net groundwater use [by an amount] in excess of 10,000 acre-ft/yr.” This goal was based on the rationale that continued storage depletion would contribute to the cumulative storage deficit and increase the long-term risk of continued reduction in base flow in the San Pedro River. Beginning to accrete storage initiates the process of reducing the cumulative deficit.

The water-budget approach used to create the initial goal for sustainability has some advantages. A water budget can be calculated relatively quickly using mostly existing information. A water budget is similar in some ways to a fiscal budget, and is easily expressed and understood by people with a variety of experience.

Water budgets, however, also include significant limitations because they summarize a complex time-varying, three-dimensional flow system of large areal extent in a few numbers. As a result, a traditional water budget cannot be used to evaluate spatial water-management aspects of sustainability. For example, it may be possible to pump groundwater in a deficit condition in a particular area of the regional aquifer without changing base flow in sensitive reaches of the riparian system, whereas pumping relatively small quantities of water near the river and upstream from sensitive reaches may have significant impacts over long reaches of stream. A water budget is unable to forecast time-varying consequences to outflows caused by pumping, although removing water from an aquifer without replenishing it has the eventual effect of reducing outflows through the natural discharge locations. A water budget also does not provide any measure of how pumping is changing water levels in the aquifer. Differences in water levels throughout an aquifer are the driving force that moves water through the system. Changing those levels modifies how groundwater moves. An additional problem with a water budget approach alone is that the annual groundwater storage deficit could be offset after groundwater elevations have dropped below the riparian root zone—clearly an unsustainable condition for the SPRNCA.

The Partnership has included the aquifer storage deficit calculated from the water budget as an indicator of sustainability, and further agreed to a sustainable yield threshold of zero acre-ft per year. An annual loss from storage, therefore, is not sustainable, and a zero change or gain is sustainable.

Progress toward Sustainability

The 2004, 2005, and 2006 321 Reports—reporting on years 2002, 2004, and 2005—(Department of the Interior 2005, 2006, 2007) focused primarily on year-to-year changes in the aquifer-storage deficit calculated using a water-budget approach. The 2007 and 2008 reports that reported on years 2006 (Department of the Interior, 2008) and 2007 include a general discussion of some indicators . Beginning with this year's report, progress toward achieving a sustainable yield of groundwater use in the Subwatershed is assessed using 6 of the 8 indicators described above. In future years, all 8 indicators will be used. A matrix that includes 6 of the 8 indicators and an evaluation of the Partnership's progress toward sustainable yield based on changes in each indicator is shown in table 4 of this report.

All 8 indicators are affected by climate in addition to human-induced changes, although some are more sensitive than others. For this reason, it is important to consider annual changes of indicators as well as short-term (multi-annual) and long-term trends (multi-decadal) when attempting to understand hydrologic trends in the Subwatershed. Indicators in the matrix are thus assessed with regard to (1) annual change, (2) short-term trends (2002 – 2008), and, (3) the longest term trends available (table 4). In addition, a statistical analysis was run on the short-term and long-term data trends in order to assess the persistence of any trends over the period of interest. In figures where a trend is considered persistent ($p \leq 0.05$)[3], the p-value and coefficient of determination, R^2, are in green font; where no trend is discernable the font is red. Regardless of whether or not trends are discernable, the reader should keep in mind that both annual change and short-term trends in the Subwatershed are typically driven by intermittent recharge events and intervening dry years as well as decadal scale wet periods and droughts. Thus, short-term trends may not be indicative of longer term movement toward or away from sustainable groundwater use in the Subwatershed.

Owing to both human causes and natural conditions, data trends in different parts of the Subwatershed may be different. For example, we might anticipate indicators to respond differently in the vicinity of the City of Sierra Vista's effluent recharge facility [Environmental Operations Park

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[3] A p-value is the probability of obtaining by chance a result at least as extreme as the one that was actually observed. For example, where $p = 0.05$, there is a 5% chance that the observed trend occurred by chance rather than due to a cause or causes.

(EOP)] than in the urbanized areas of Fort Huachuca and Sierra Vista, or on the east side of the river, distant from the most densely developed and rapidly growing region of the Subwatershed. For this reason, where appropriate, the indicators are analyzed first by subregion, and then for the entire Subwatershed.

Groundwater Indicators

Regional aquifer water levels

An analysis of historical water-level trends is provided in Pool and Coes (1999), and in the ADWR’s Active Management Area review report (Arizona Department of Water Resources, 2005b). In the regional aquifer system, a general and widely distributed decline of 0.3–0.5 ft/yr occurred from the 1940s through the 1970s followed by a period of no decline or slight recovery. Pool and Coes (1999) suggest that this regional pattern of decline followed by cessation of decline or recovery resulted from shifting precipitation patterns. Rates of water-level declines have been larger in the Sierra Vista-Fort Huachuca area. Long-term records along the San Pedro River near Palominas show only a few feet of decline resulting from historic near-stream agricultural pumping, but the on-going decline has been sufficient to convert a stream reach that was perennial as recently as the early 1960’s to intermittent. Southwest and EOP subregions include wells with very long records which support the Pool and Coes (1999) historical analysis, with low points in the record around 1970 followed by some recovery.

As the historical analysis above implies, water-level trends in different parts of the Subwatershed are different because of differences in hydrogeology and human impacts. Therefore, evaluation of the regional aquifer water-level indicator is separated into four subregions: East, EOP, Fort Huachuca, and Southwest. The East subregion includes all regional aquifer wells monitored east of the San Pedro River (three wells). The EOP subregion includes all wells that reasonably could be influenced by Sierra

Vista’s EOP. This includes three wells along the northeastern boundary of Fort Huachuca (five wells total). The Fort Huachuca subregion includes all other monitoring wells on Fort Huachuca, found primarily on the Fort’s east range (11 wells). The Southwest subregion includes wells found south of Fort Huachuca and west of the San Pedro River (seven wells).

Depending upon subregion, the annual change is either a modest rise or modest decline in the regional aquifer since 2007. The short term trend (2002–08) in the Fort Huachuca wells provides the most interesting contrast to the annual trend. What had been a linear rate of decline of 0.5–0.75 ft/yr since 2002 decreased considerably from 2007 to 2008 to 0.11 ft/yr (fig. A3a; table 4). A review of the long term record for these wells shows that from 2000 to 2001, a period that included a high-precipitation event, there was a similar interruption in the otherwise linear water-level decline in these wells; these periodic reductions in the rate of decline appear to be in response to major recharge events in ephemeral channels proximate to a number of the Fort Huachuca wells (fig. A3b). The East, Southwest, and EOP subregions all show declining water levels from 2002 to 2005 or 2006, followed by recovering water levels through 2008; the EOP subregion wells show the smallest decline and subsequent rebound, and the Southwest subregion wells show the greatest decline and largest variation. This response may relate to the drought that began in the late 1990’s followed by the relatively heavy summer rains in 2005–2008.

Water levels in the EOP subregion show two distinct short-term trends. Bella Vista and LS-6 have been generally increasing since 2002 while the monitor wells at the east end of Fort Huachuca have steadily decreased over the same period. This may be a function of proximity to the EOP and (or) to the geology of the well locations. The subregional grouping of these wells will be reconsidered in advance of next year’s 321 report (fig. A3a).

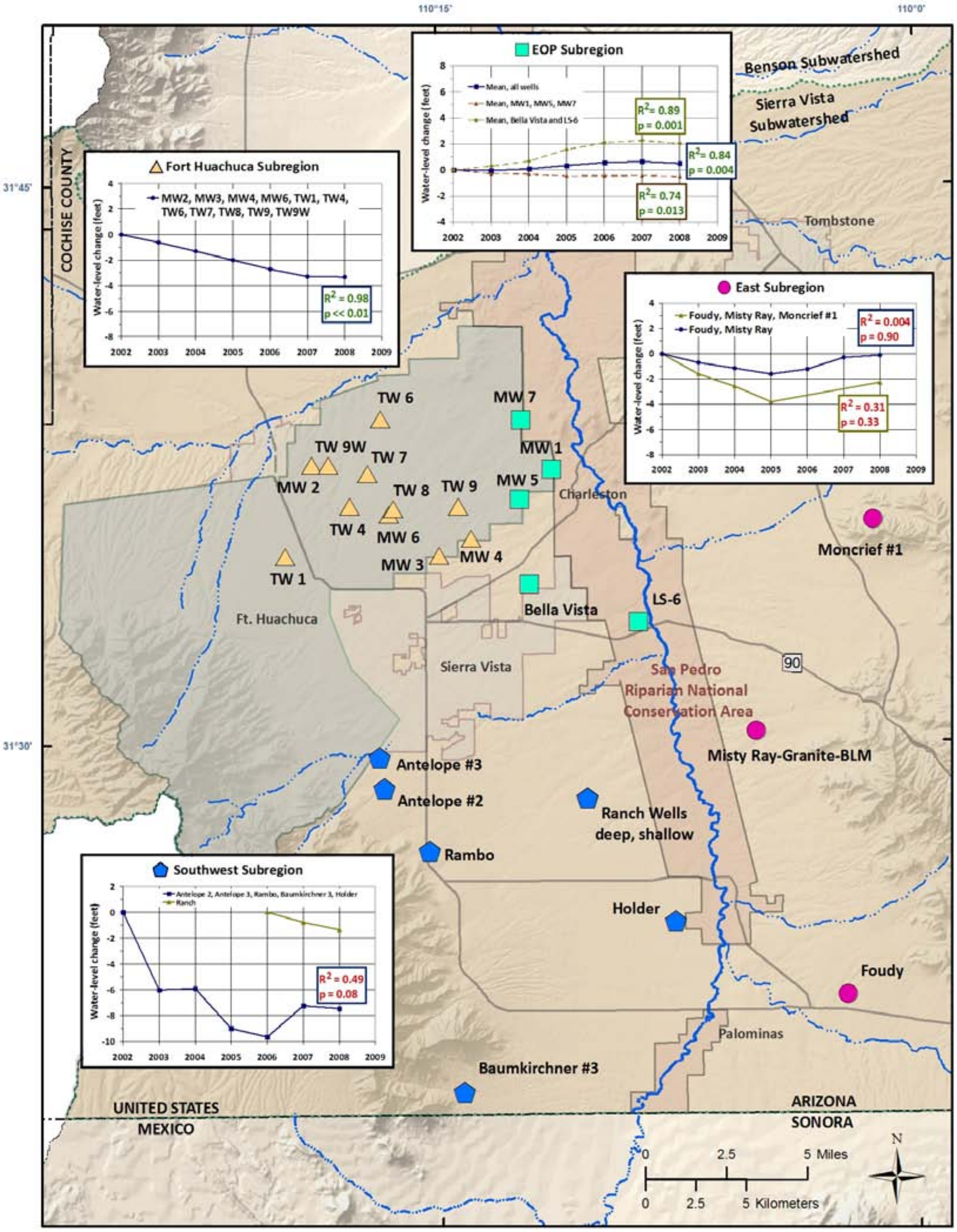

Figure A3a. Short term trends of average annual water levels for regional aquifer wells, Sierra Vista Subwatershed, Upper San Pedro Basin, Arizona. Water level trends in EOP subregion show two distinct trends and are both included in addition to the mean trend of all EOP wells. Moncrief #1 is missing 2 years of data but trend is similar to other East subregion wells; plots with and without Moncrief #1 are provided. Record for Ranch wells in Southwest subregion is just 3 years, but trend is similar to other wells; plots with and without Ranch wells are provided.

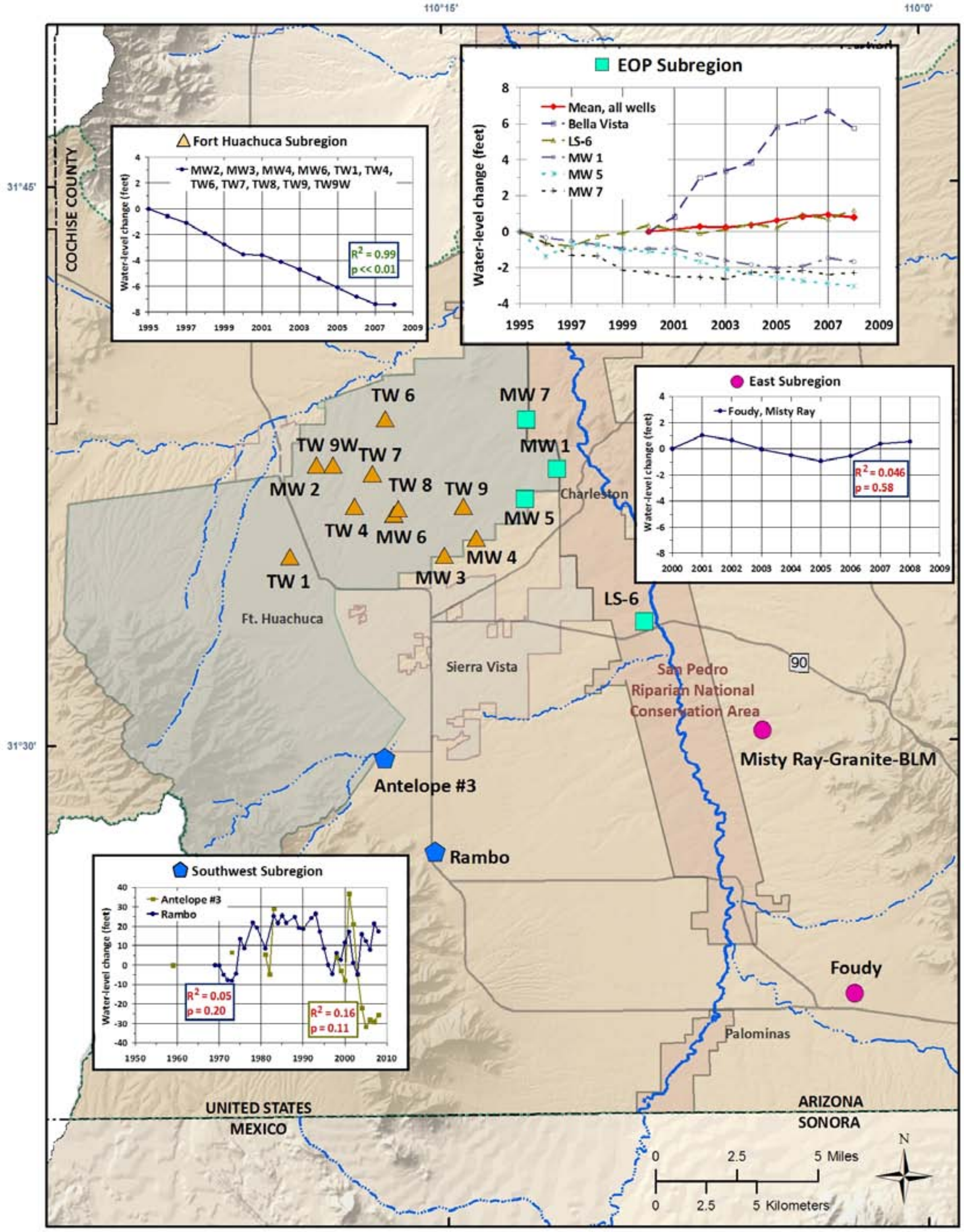

Figure A3b. Long term trends of average annual water levels for regional aquifer wells, Sierra Vista Subwatershed, Upper San Pedro Basin, Arizona. Wells missing from subregion plots are missing significant portions of the early data record. Note that vertical axis on Southwest Subregion plot is significantly greater than other three plots (80 feet versus 10 feet).

Groundwater storage change—direct measurement

Direct measurements of groundwater storage change are made in the Subwatershed using microgravity techniques. These measurements have been made in a broad network of stations in the Subwatershed (figs. A4a and A4b) and can be applied at locations with or without existing wells. Measured changes of 1 μGal equal a little less than 1 in of free-standing water (Pool and Eychaner, 1995). Sufficient periods of record are required to recognize whether observed trends are caused by natural variability or human actions. Gravity measurements in the Subwatershed began in about 2000. In 2005 the network of gravity stations was reconfigured and the data reported here are from 2005 to 2008. From 2007 to 2008, microgravity measurements at 36 stations in the Subwatershed show stable or declining aquifer storage change, although a single gravity station located along Garden Canyon Wash shows an increase in gravity of 41 μGals (fig. A4a). An adjacent monitoring well provides additional evidence of a significant increase in storage; water levels there rose about 15 m between August and November 2008. The storage increase in this area can be attributed to sustained ephemeral streamflow, infiltration, and recharge in Garden Canyon Wash during the 2008 summer monsoon, and is limited to the immediate vicinity of the wash. As with the data from Fort Huachuca wells adjacent to Graveyard Gulch, the gravity and water-level data in the vicinity of Garden Canyon provide evidence that ephemeral channel infiltration is a contributing mechanism to aquifer recharge. The next closest gravity station to the south shows almost no change in gravity, and other surrounding stations show a decrease.

The greatest concentration of gravity stations showing a decline in aquifer storage from 2007 to 2008 is within the City of Sierra Vista and to the southeast of the city. Apart from the Garden Canyon Wash station mentioned above, gravity stations in this area show a uniformly negative change in aquifer storage. Outside of the Sierra Vista area, gravity stations showing a decrease or no change in storage occur in about equal numbers and are distributed evenly; for the time period from December 2007 to

November 2008, regional aquifer storage outside of the Sierra Vista area remained fairly stable. In the vicinity of Sierra Vista, on the other hand, the aquifer experienced greater declines than in other parts of the basin, most likely owing to the relatively greater and more intensive pumping there.

Measured microgravity change from August 2005 to November 2008 shows both a decrease in aquifer storage in southeast Sierra Vista and some recharge from relatively wetter summer monsoons in 2006 and 2008 (fig. A4b). The greatest declines in aquifer storage are in the vicinity of Ramsey Road and Hereford Road. The area within the City of Sierra Vista is generally stable, with two stations on or near Fort Huachuca showing an increase in aquifer storage. As with the period from December 2007 to November 2008, an increase in aquifer storage is seen near Garden Canyon Wash, on the southern boundary of Fort Huachuca. An increase in gravity at a station to the southeast, along Hereford Road near Miller Canyon Wash, also suggests ephemeral channel infiltration and recharge is occurring. The remainder of the gravity stations in the southern part of the study area and east of the river show generally stable to increasing aquifer storage.

Near-stream alluvial aquifer water levels

Near-stream alluvial aquifer water levels are found in the pre- or post-entrenchment alluvium (the old or new river flood plains), and are evaluated in four subregions: North, EOP, Central, and Southern subregional reaches of the river. Owing to the large volume of well data available for this indicator, it was not possible to prepare an assessment in time for this report. An assessment of this indicator will be included in the 2010 report covering year 2009.

Vertical hydraulic gradients

Changes in the vertical hydraulic gradient measured in wells near the San Pedro River help indicate changes in the tendency for water to flow between the stream and the groundwater system.

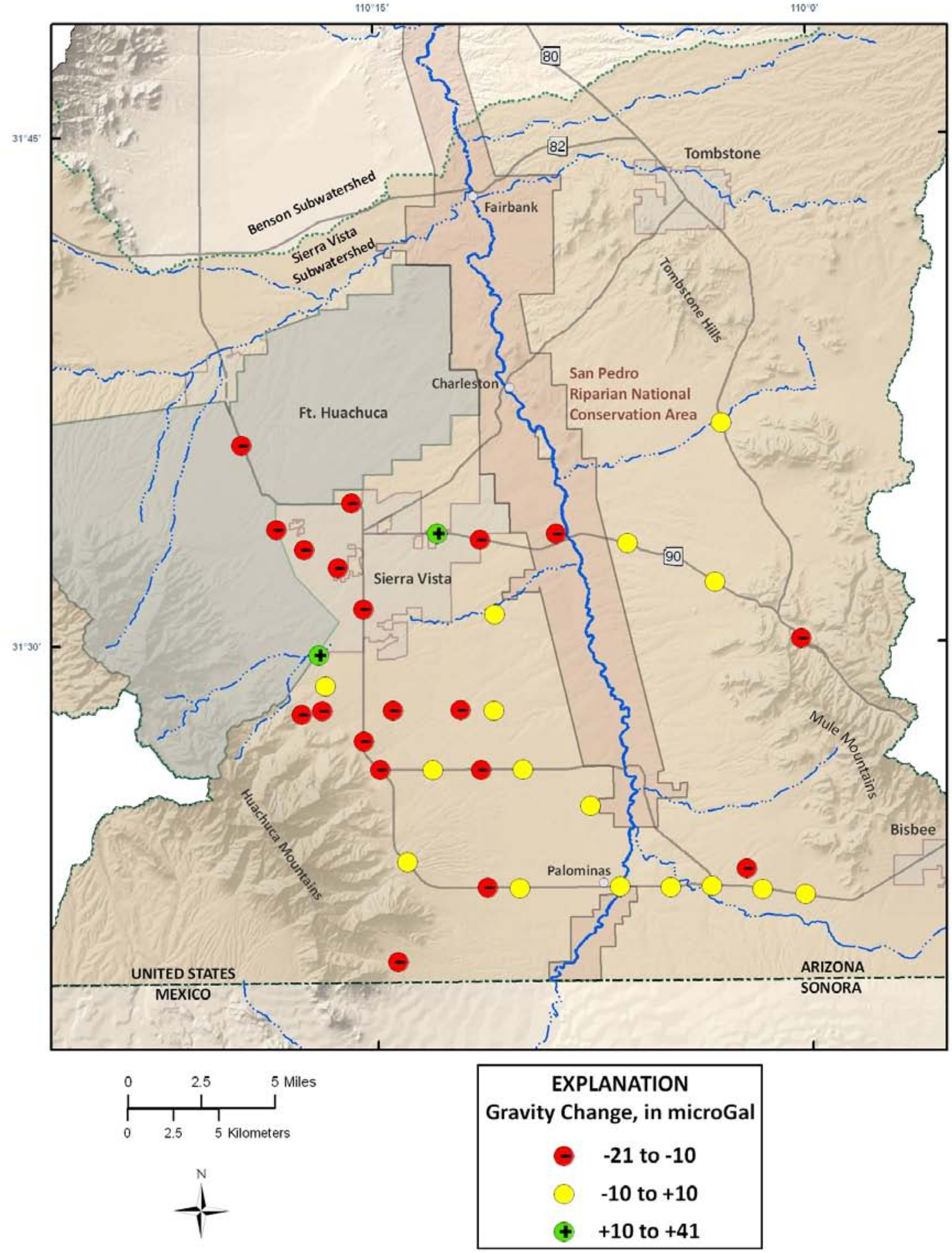

Figure A4a. Aquifer storage change 2007–08 as measured using microgravity techniques, Sierra Vista Subwatershed, Upper San Pedro Basin, Arizona. In general, a change of 1 μGal equals a little less than 1 in of free standing water.

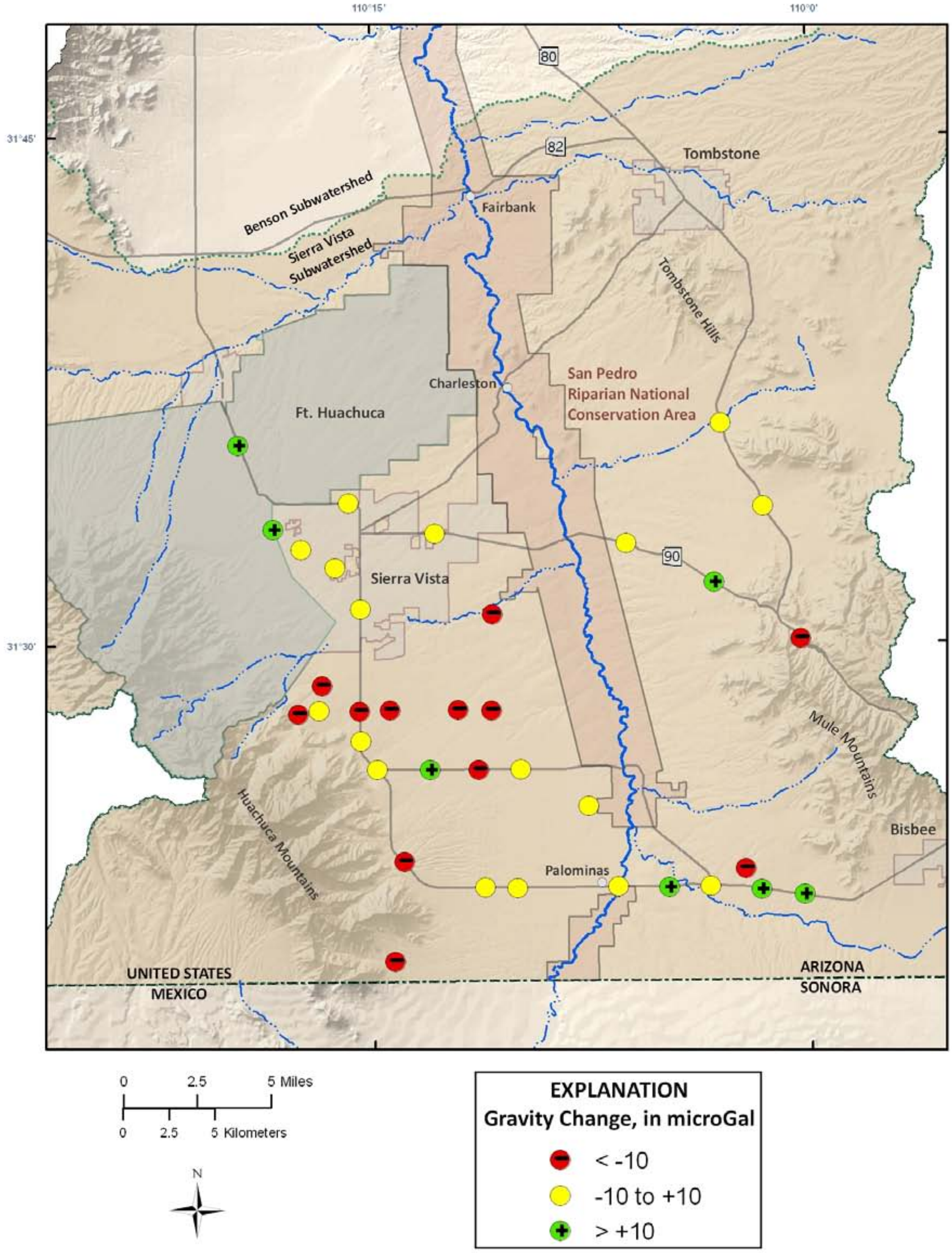

Figure A4b. Aquifer storage change 2005–08 as measured using microgravity techniques, Sierra Vista Subwatershed, Upper San Pedro Basin, Arizona. In general, a change of 1 μGal equals a little less than 1 in of free standing water.

At this time it is intended that the vertical hydraulic gradients in wells will be evaluated in four subregions identical to those used for the near-stream alluvial aquifer water levels. As with the near-stream alluvial aquifer water-level indicator, it was not possible to prepare an assessment of this indicator in time for this report. A complete assessment of this indicator will be included in next year's report.

Streamflow

Low flow and days of no flow

The USGS operates three streamflow-gaging stations along the San Pedro River in the Subwatershed (figs. A5a and A5b) that collect data applicable for evaluating changes in the hydrologic system and progress toward sustainability: the Palominas, Charleston, and Tombstone streamflow-gaging stations. These data provide a spatially distributed measure of streamflow variation. Annual variability in groundwater discharge to the river can be tracked through seasonal low-flow observations at Charleston and through the number of total no-flow days at Palominas and Tombstone. Though the streamflow-gaging station located on the Lower Babocomari may be of equal importance to these three in assessing hydrologic conditions (Pool and Coes, 1999), the period of record at this station is just 9 years, and at this time the Partnership has not included streamflow measured at the Lower Babocomari streamflow-gaging station as an indicator of sustainability.

Base flow at the Charleston gaging station varies seasonally, typically with a higher base flow during the winter months, and the lowest flow in June or early July (fig. A5b). These seasonal variations have several causes, primarily related to changing rates of near-stream withdrawals by riparian vegetation. Pool and Coes (1999) observed that short term trends in both summer and winter base flow are closely related to wet-season runoff. Longer term trends are the result of one or more natural and (or) human caused factors in addition to precipitation trends. For 321 reporting, 7-day summer (June) and winter (January 15 through March 15) low flows of the San Pedro River at Charleston are used as a base-flow proxy to evaluate trends, and thus serve as indicators of sustainability.

In 2008 the June 7-day low flow at Charleston was 0.65 cfs. Although this represents an increase from the 2007 7-day June low flow of 0.37 cfs, it is the fourth year in a row of very low June flows at Charleston, including 2006's record low of 0.07 cfs (fig. A5a). Since 321 reporting began in 2002, 2004 is the single year that the June 7-day low flow has exceeded 1.0 cfs (1.11 cfs; fig. A5a). The 10-year average 7-day June low flow (1999–2008) is 1.12 cfs although this includes some years likely affected by storm runoff. The long term trend shows an ongoing decrease in June low flow (fig. A5b). This has been discussed previously in Pool and Coes (1999) and Thomas and Pool (2006)[4] as well as in previous 321 reports. A significant decreasing trend in June low flows remains after accounting for precipitation trends, and may result from one or more factors including changes in riparian and (or) upland vegetation, changes in stream-channel morphology, near-stream and regional-aquifer pumping, construction of surface-water detention basins and tanks, urbanization, and livestock grazing (Thomas and Pool, 2006). No analysis of the specific causes responsible for the current run of very low June flows at Charleston, including the July 2005 no-flow event, has been made.

The winter 7-day low flow for 2008 was 12.4 cfs compared with 13.9 cfs in 2007 (fig. A5b). The 9-year average winter 7-day low flow is 9.8 cfs (winter 2001 is removed from the 10-year average because of the anomalous effect of a series of large storm-related flows in October of 2000). Since the beginning of 321 reporting in 2002, winter low flows have ranged from 7.1 cfs in 2004 to 13.9 cfs in 2002 and 2007 (fig. A5a). There is no statistically significant short term nor long term trend in winter low flow considering data through 2002 at Charleston (Thomas and Pool, 2006). Winter low flow discharge has ranged from 5.3 cfs in 1999 to 51.4 cfs in 1985, although low flow values above about

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[4] Thomas and Pool (2006) used a three-day low flow period in their analysis

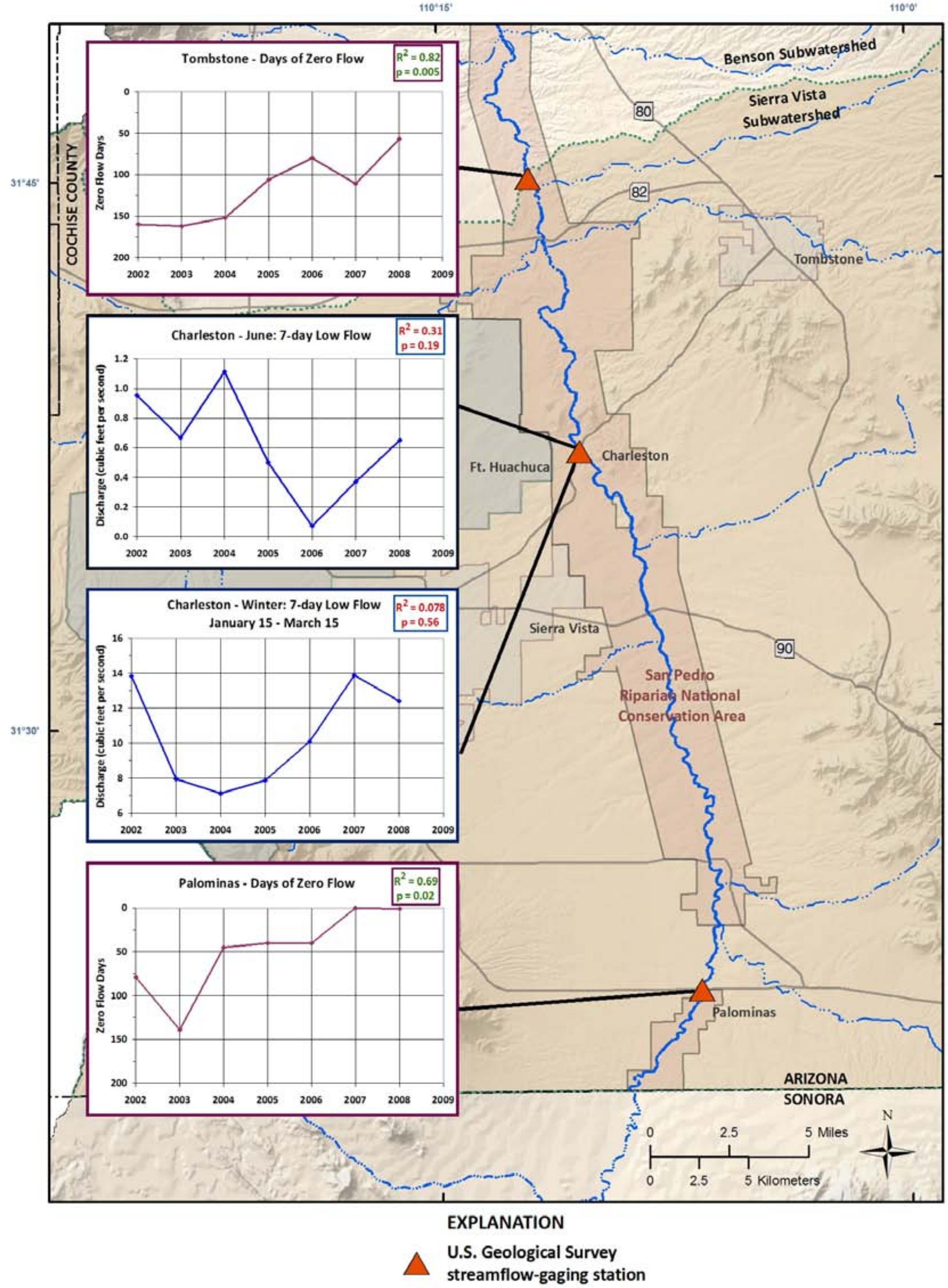

Figure A5a. Short term trends of 7-day June and 7-day Winter (January 15–March 15) low flow at Charleston gaging station, and of total days of no flow at Tombstone and Palominas streamflow-gaging stations, Sierra Vista Subwatershed, Upper San Pedro Basin, Arizona. Streamflow data for 2008 are not yet verified.

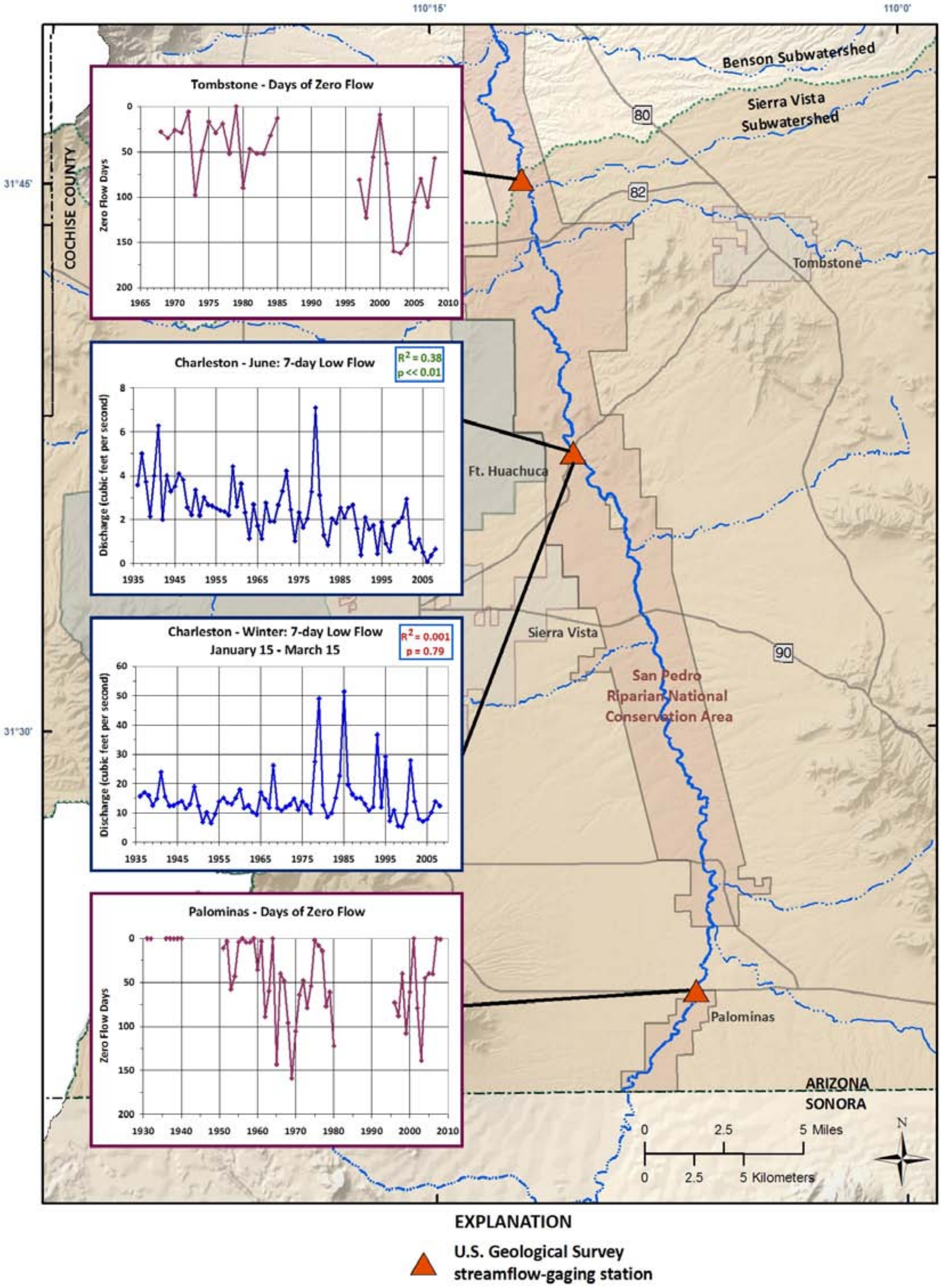

Figure A5b. Long term trends of 7-day June and 7-day Winter (January 15–March 15) low flow at Charleston gaging station, and of total days of no flow at Tombstone and Palominas streamflow-gaging stations, Sierra Vista Subwatershed, Upper San Pedro Basin, Arizona. Periods with missing data are left blank. Streamflow data for 2008 are not yet verified.

20 cfs are generally assumed to be affected by storm runoff (fig. A5b).

For gaging stations such as Palominas and Tombstone that stop flowing during the driest times of the year, an analysis of annual no-flow days is used as a surrogate for low flow trends. As previously noted, the number of days of storm flow influences the number of days of no-flow (more storm flows, fewer no-flow days) and thus there is more inter-annual variability in this value than in 7-day low flow values. This is evident when evaluating the long term trends.

The number of no-flow days per year at Palominas is zero in the early part of the record, but once agricultural pumping commenced in earnest in the area in the 1940's (Pool and Coes, 1999) the river ceased to flow in some years for tens of days separated by years with zero or near-zero days of no flow (fig. A5b). In 1969, the river did not flow at Palominas for 159 days, but by 1975 that number had dropped once again to just 2. The short-term trend at Palominas reflects this variability—the third highest number of no-flow days in the record is in 2003 (139) and by 2007 and 2008 the number of no-flow days dropped to zero and one, respectively (fig. A5a).

The Tombstone record is much shorter, beginning in 1968. The number of no-flow days per year varies between near-zero and 100 through 1985, and averages about 37 days for the period, after which there is a 10 year gap in the record. Following the data gap the number of no-flow days per year has increased, varying between 50 and 160 from 1997 through 2008, with the exception of the wet year of 2000 (fig. A5b). The average annual days of no-flow for the latter period (including 2000) is about 97. Given the marked increase in no-flow days per year, the lack of Tombstone streamflow data during 1986–96 is particularly problematic, as the timing and thus potential cause of this change is obscured. Since 2002, the short-term trend has been toward fewer no-flow days per year, with about 160 days in 2002 and 2003 and less than 60 days in 2008 (fig. A5a).

Streamflow Permanence

In spring 2006, ARS installed and began operating eight automatic recording digital cameras at sites along the San Pedro River from Hereford in the south to St. David in the north in order to monitor streamflow permanence. The BLM currently operates these sites. Six of the stations are in the Subwatershed (fig. A6). Streamflow-gaging stations provide similar data to evaluate streamflow permanence, and the Palominas, Charleston, and Tombstone gaging stations, and the stage recorder near Lewis Springs are included in this analysis.

As previously discussed, streamflow permanence provides important information about the health of the riparian system and has been included as an indicator of sustainable groundwater yield in the Subwatershed. Of the 10 streamflow permanence sites, 4 (Hereford, Lewis Springs, Moson, and Charleston) are located in the “wet” ecological condition class identified by Stromberg and others (2006), and the other 6 sites are in the “intermediate” class (fig. A6). Leenhouts and others (2006) found average streamflow permanence for dry, intermediate, and wet classes of 48, 78, and 100 percent, respectively, for water year 2002, and 17, 63, and 98 percent, respectively, for water year 2003. The dry site evaluated in Leenhouts and others (2006) was located outside of the Subwatershed, near St. David. Their methods for identifying “streamflow permanence” were different than those of the BLM, yet it is of interest that in 2007, 9 of 10 of the sites were above the 2002 average streamflow permanence for the respective intermediate and wet classes, and in 2008 all of the sites met or exceeded both the 2002 and higher 2003 averages.

Springflow

As previously noted, springs provide another pathway for groundwater to discharge to the surface. The five Subwatershed spring sites currently monitored are separated into three subregions—West (Murray Springs, Horsethief Spring, Moson Spring), East (Lewis Springs), and South

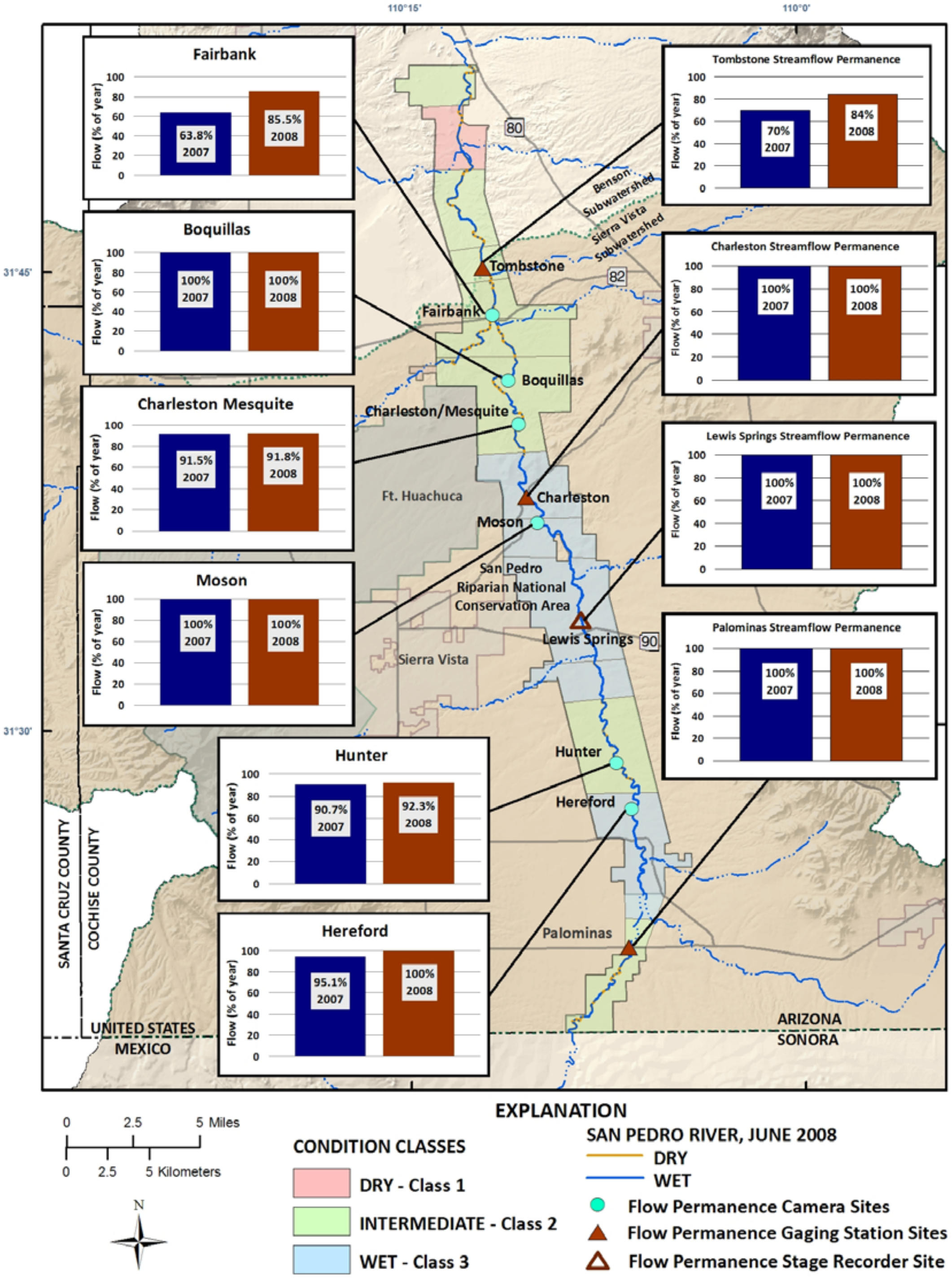

Figure A6. Streamflow permanence, in percent of year for 2007 and 2008, at selected sites, Sierra Vista Subwatershed, Upper San Pedro Basin, Arizona. Condition classes are described in Leenhouts and others (2006). See text for more detail.

(McDowell-Craig Farm flowing well) (fig. A7). All sites are relatively close to the San Pedro River, and the West subregion springs are downgradient from the EOP recharge facility.

From 2007 to 2008, flow measured at the West springs increased by about 68 gallons per minute, a change of about 41 percent. This ranged from a median increase of about 1.5 gallons per minute (8 percent) at Moson Spring, to about a 6 gallons per minute increase (120 percent) at Horsethief Spring, to about a 60 gallons per minute increase (43 percent) at Murray Springs. Of the 232 gallons per minute (0.52 cfs) total discharge from the West subregion springs, about 200 gallons per minute (0.45 cfs) or 85 percent was from Murray Springs. From 2007 to 2008 spring discharge measured in Lewis Springs, across the river due east of the West subregion, increased about 2 gallons per minute (7 percent) and discharge measured at the flowing McDowell-Craig Farm well in the South subregion increased about 20 gallons per minute (93 percent; table 4).

With the exception of Murray Springs, discharge measurements at the springs have been made since 2005. Murray Springs measurements began in 2003. In general, the West subregion springs and in particular Murray Springs show an increasing trend since 321 monitoring began. No clear trend is evident in other subregion springs during this period (fig. A7). Discharge from Murray Springs, located within Curry Draw and down gradient from the Sierra Vista EOP, has increased 575 percent from 32 gallons per minute (0.07 cfs) in March 2003, when monitoring began, to 216 gallons per minute (0.48 cfs) on February 28, 2008. The median discharge in 2008 of 200 gallons per minute (0.45 cfs) equates to about 320 acre-ft of discharge for the year. In addition, the source of emanation has expanded from the original Murray Springs location to farther upstream in Curry Draw. The spring is about 1.5 mi downgradient from the center of the Sierra Vista Water Reclamation Facility, and about 0.9 mi downgradient from the nearest EOP recharge ponds. Recharge at the EOP has averaged 1,797 acre-ft/yr since 2002, with 1,881 acre-ft of total recharge in 2008 (95 acre-ft less than in 2007; 2008 is the second

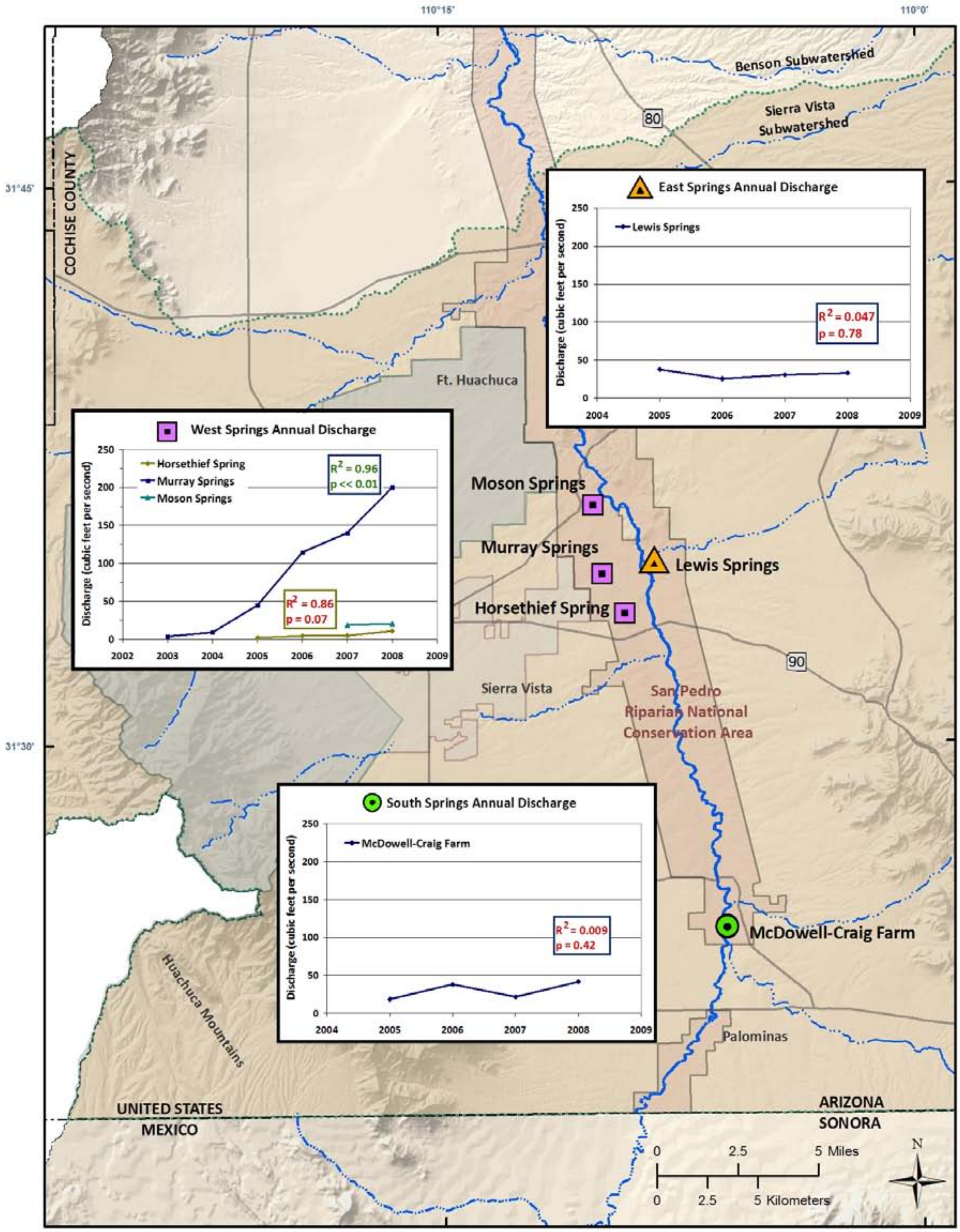

Figure A7. Short-term trends in spring discharge, Sierra Vista Subwatershed, Upper San Pedro Basin, Arizona.

consecutive year of decline). The increased discharge at Murray Springs likely is related to increased recharge (treated effluent) at the EOP.

Water Budget

The initial 2004 Section 321 Report (Department of the Interior, 2005) outlined a set of management measures to be implemented in each calendar year through 2011 in order to attain a sustainable yield of groundwater from the regional aquifer of the Subwatershed. These measures can be characterized broadly as conservation and recharge, and categorized more specifically. For example, conservation includes effluent reuse, code changes, and reductions in irrigated agriculture. Recharge includes the effluent and storm-water recharge projects that return or introduce various sources of water to the aquifer.

For the current report, conservation yields were determined specifically for each Partnership member owing to differences in data availability. In rural Cochise County, for example, much of the groundwater is pumped by unmetered private wells and the amount of pumping is estimated from the number of wells and an assumed per-well use. Because actual pumped volumes are unavailable, conservation was estimated for specific projects and summed to create grouped yields. Only yields from projects actually implemented in 2008 were counted. The estimated conservation yields were then assumed to represent actual water savings. For Sierra Vista, Fort Huachuca, and Huachuca City, sufficient data were available to calculate a per capita pumpage value for 2002 (the baseline year) and for 2008. Conservation was then calculated as the difference between actual pumping in 2008 and the pumping that would have occurred in 2008 assuming the estimated population used water at the 2002 per capita rate. The per capita pumping in Sierra Vista (including Fort Huachuca), for example, decreased from 174 gallons per capita per day (gpcd) in 2002 to 138 gpcd in 2008.

The Partnership is continually striving to develop improved estimates of recharge and conservation yields. As a result some yields reported here and in table 1 and table 3 differ from same-category yields reported in the prior Section 321 reports.

Planned and Actual Management Measure Yields

The effect of conservation and recharge, once estimated, may be combined to calculate a total yield of management measures — this combined yield describes the reduction in net groundwater use in the Subwatershed compared with the use that would have occurred in the absence of management measures.

The following discussion and table 3 compare planned management-measure yields with estimates of yields actually obtained for calendar year 2008. Calendar year 2008 is used because the fiscal year (2009) prior to the due date of this report to Congress was still underway during the preparation of this report and therefore was not a useable reporting period.[5] Last year's Section 321 Report (2008, reporting on calendar year 2007) projected a combined deficit-reducing yield of about 9,700 acre-ft for 2008. The actual yield calculated for 2008 is 9,800 acre-ft (table 3), 100 acre-ft less than last year's adjusted projection for 2008, and 200 acre-ft more than the actual yield calculated for 2007 of 9,500 acre-ft. The actual conservation yield for Sierra Vista (including Fort Huachuca) was much greater than projected in the previous (2008) report, and effluent recharge for both locales decreased, as would be expected when conservation increases. The overall yield includes active Partnership member projects, a decrease in agricultural pumping caused by the sale and retirement of agricultural property, and incidental yields from increased recharge caused by urbanization. Urbanization in arid climates can increase recharge by directing additional storm water runoff to ephemeral stream channels where the ratio of infiltration to evaporation is increased (Kennedy, 2007).

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[5] The original 321 legislation indicates that, "…the Secretary of the Interior shall submit, on behalf of the Partnership, to Congress a report on the progress of the Partnership during the preceding fiscal year…."

The Partnership does not suggest that urbanization increases recharge more than urbanization increases pumping, but rather that the increased recharge offsets some of the increased pumping. Please see the 2004 Section 321 Report (Department of the Interior, 2005; http://water.usgs.gov/Section321.2004_050705.pdf) for additional details.

Measures without quantified yields

In some cases, such as for rural areas of Cochise County where pumping is not metered, conservation management measures have been enacted that do not have a yield reported owing to the difficulty in quantifying the yield. In addition, methods such as Transfer of Development Rights have been made available to the development community as part of the strategy of spatial water management. In 2006 Cochise County enacted a conservation management plan that requires developers to limit water use in a planned higher density zoned development to that amount projected for use under the former, lower density zoning. In 2006 the County also established a zoning overlay district within the Subwatershed that requires a number of water-conservation provisions for new-house construction and amends the zoning regulations to allow for formal Transfer of Development Rights away from hydrologically more sensitive areas to areas of lesser impact on streamflow. In addition, future subdivisions within the unincorporated areas of the Subwatershed are now required to be served by a water company or water district rather than unregulated individual wells.

In 2007, the BLM established a similarly preventative policy with regard to land disposals within the Upper San Pedro Groundwater Basin (USPGB; includes the Sierra Vista Subwatershed).The BLM will defer approval of land use authorizations unless the request demonstrates that the intended uses of those lands will not require groundwater from the USPGB (Nathan Dieterich, Bureau of Land Management Hydrologist, written commun., 2008).

Various conservation efforts of Sierra Vista and Fort Huachuca are not included in table 3 owing to the timing of their implementation. The Section 321 reports use a 2002 baseline year for calculations. Any conservation efforts initiated prior to that year are intrinsically included in the baseline value and cannot be separately counted. Nevertheless, water usage would currently be higher in the absence of those measures.

Storage Deficit in 2008

A groundwater storage deficit of about 4,300 acre-ft in the Subwatershed was estimated for 2008 by combining estimated total pumping with management-measure yields in a Subwatershed water budget (table 1). The greatest changes from 2007 were in groundwater pumping. Water company pumping continued to decline in 2008, dropping 850 acre-ft from 2007, while industrial (including golf courses), irrigation, and rural exempt well pumping increased a combined total of about 100 acre-ft for a reduction in total pumping of 780 acre-ft. In the absence of better methods, rural exempt well pumping was calculated using the number of new wells (36) recorded with the ADWR for 2008 multiplied by the ADWR estimated average number of persons per exempt well (4.72 person/well) and the ADWR estimated average groundwater pumped per person (0.35 acre-ft/person) (Arizona Department of Water Resources, 2005b). This amount was then added to last year’s value to derive the 2008 exempt well pumping value of 4,600 acre-ft. An increase of 140 acre-ft of reduced evapotranspiration discharge due to mesquite eradication by the BLM in 2008 and another 80 acre-ft of increased incidental recharge account for the remaining reduction in the annual aquifer storage deficit from 2007.

Values for natural recharge and some values of natural discharge, including the base flow discharge value at the Tombstone gaging station, are derived from an analysis by the ADWR (Arizona Department of Water Resources, 2005a, 2005b). The Partnership recognizes that the Tombstone base flow discharge value originally adopted in 2005 (table 1) may not represent the best estimation of groundwater discharge from the Subwatershed. Depending upon method of analysis and period of record used, this value may be as low as 3,250 acre-ft/yr or as high as 6,230 acre-ft/yr. For example, Freethey (1982) calculated a base flow discharge value at the Tombstone gaging station of 4,490 acre-ft/yr based on 1977 data. Corell and others (1996) used the record before 1986 to estimate a base flow discharge of 6,290 acre-ft/yr. ADWR (2005a, 2005b) calculated a value of 3,250 acre-ft/yr based on 1997–2004 data. The USGS determined a value of 4,230 acre-ft/yr using the entire Tombstone record through 2003 (James Leenhouts, USGS, written commun., 2005). More recently, BLM calculated a base flow value of 5,850 acre-ft/yr at the Tombstone gaging station based on data from 1968–85. This is the period of record BLM determined to be most consistent with the establishment of the SPRNCA by Congress in 1988 (Nathan Dieterich, Bureau of Land Management, written commun., 2009).

Though an increase in the long-term, mean outflow at the Tombstone gaging station would indicate progress toward sustainability—more water is available from the regional aquifer to enter the river and is exiting the Subwatershed as surface flow—in terms of the water budget alone (all other terms held constant), a larger outflow number means a larger annual deficit. During the later part of the Tombstone record (1996–2008) discharge is much reduced from the earlier part of the record (1968–86). As a result, the part of the record that is used to calculate outflow from the Subwatershed likely will have meaningful implications on the Subwatershed aquifer storage deficit. The portion of the Tombstone gaging station record that will provide the Subwatershed discharge value most useful for determining progress toward sustainable yield in the regional aquifer has yet to be determined by the Partnership.

As part of its effort to review and improve all values found in the Subwatershed water budget (for example, evapotranspiration, mountain front recharge, rural pumping, base flow discharge), the Partnership has charged the USGS to make a rigorous analysis of base flow discharge at the Tombstone gaging station. The results of this work will be made available to the Partnership for incorporation into the 2010 321 Report, and to inform its discussion of the Tombstone gaging station record.

The groundwater deficit values calculated for 2006 (Department of the Interior, 2008), 2007, and 2008 (this report) cannot be directly compared to the deficits calculated for 2005 and earlier (Department of the Interior 2005, 2006, 2007) due to the use in 2006–08 of an updated estimate of riparian evaporation and plant transpiration. As part of Partnership-initiated research, Scott and others (2006) reported a range of riparian ET for the Subwatershed from 9,600 to 12,055 acre-ft/yr. As with the past two years, this year’s Section 321 report uses the average of the range reported in Scott and others (2006), a value of 10,800 acre-ft/yr, which is an increase in ET of 3,100 acre-ft/yr. This does not necessarily imply that ET has increased, although that may be a possibility. Rather, what is clear is that the best estimate of ET for the Subwatershed has increased.

The total pumping was the estimated sum of uses by private water companies, municipalities, Fort Huachuca, golf courses, rural residents using exempt wells, agriculture, and industry. The effectiveness of conservation measures is intrinsically included in values for total pumping and is not part of the deficit calculation in table 1. Estimates for conservation yields, however, are included in table 3 and figure 1 to indicate how much water likely was saved compared to a condition where no conservation measures were implemented. An exception is conservation through reduction of mesquite near the San Pedro River; it is independent of groundwater pumping and therefore tabulated separately. In 2008, estimated conservation in groundwater pumping relative to 2002 gpcd usage was about 1,800 acre-ft, an increase of 100 acre-ft from 2007. Rural conservation measures (the combined benefits of mesquite reduction and retirement of agricultural pumping; see table 3) amounted to 2,685 acre-ft in 2008, an increase of 140 acre-ft attributed entirely to further mesquite reduction by the BLM. Additional but currently unquantified mesquite reduction projects may increase this value in the future.

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Glossary

Base flow
The sustained flow in a stream that comes from groundwater discharge or seepage.

Consumptive use
The portion of groundwater pumped that is not returned to the aquifer as recharge.

Deficit
Synonymous with aquifer storage loss.

Management target
A quantified goal to reduce net groundwater consumption as part of reaching sustainable yield. The Partnership has chosen, as a management target, to eliminate aquifer storage depletion and begin accreting storage.

Net groundwater consumption
Groundwater removed from the regional aquifer that is not returned through incidental or artificial recharge or replaced through enhanced recharge.

Overdraft
Net groundwater consumption from the regional aquifer in excess of sustainable yield.

Partnership
An abbreviation of the Upper San Pedro Partnership which is a collaboration of public agencies and organizations that own or control land, or water use, in the Sierra Vista Subwatershed portion of the Upper San Pedro River Basin, and that have the authority and resources to identify reasonable, feasible, cost-effective projects and policies, and the ability to actually implement them. Federal, State, and local governmental and nongovernmental entities whose mission is to create a water-management plan that meets the needs both of Sierra Vista Subwatershed residents and of the San Pedro Riparian National Conservation Area .

Recharge, artificial
Groundwater recharge of municipal effluent in specifically engineered recharge facilities.

Recharge, enhanced
The increase in naturally occurring groundwater recharge through ephemeral channels due to urbanization.

Recharge, incidental
Groundwater recharge from sources not specifically engineered to generate recharge such as septic tanks, golf courses, and agricultural operations.

Regional aquifer
The regional aquifer is defined as the aquifer underlying the Sierra Vista Subwatershed.

Riparian
Vegetation, habitat, or ecosystems that depend on surface and (or) subsurface water flow.

Storage change
The change in the volume of water stored in an aquifer through time. Storage change results from a difference between inflows and outflows. It is often expressed as an annual volume.

Storage depletion
A decrease in aquifer storage.

Sustainable yield
The level of groundwater use that can be maintained for an indefinite period of time without causing unacceptable environmental, economic, or social consequences.