Water Management of the Regional Aquifer in the Sierra Vista Subwatershed, Arizona—2004 Report to Congress

U.S. Department of the Interior

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

March 30, 2005

Agency Representation in the Upper San Pedro Partnership

Local Agencies

Cochise County
Sierra Vista
Huachuca City
Bisbee
Tombstone

Arizona State Agencies

State Land Department
Department of Water Resources
Department of Environmental Quality
Association of Conservation Districts

Federal Agencies

U.S. Geological Survey
Agricultural Research Service
Fish & Wildlife Service
Bureau of Reclamation
Fort Huachuca
Bureau of Land Management
U.S. Forest Service
National Park Service

Non-Governmental Agencies

The Nature Conservancy
National Audubon Society
Bella Vista Ranches
Hereford National Resource Conservation District

Preface

The Defense Authorization Act of 2004, Public Law 108–136, Section 321, stipulates the way in which Section 7 of the Endangered Species Act applies to the Fort Huachuca, Arizona military reservation. Section 321 of this Act further directs the Secretary of the Interior to prepare reports to Congress on steps to be taken to reduce the overdraft and restore the sustainable yield of ground water in the Sierra Vista Subwatershed:

> "The Secretary of [the] Interior shall prepare, in consultation with the Secretary of Agriculture and the Secretary of Defense and in cooperation with the other members of the Partnership, a report on 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 Secretary of the Interior shall submit the report to Congress not later than December 31, 2004."

Pursuant to this requirement, this report is the first in a series that will be prepared annually from 2004 to 2011. The report primarily relies on existing but incomplete information. Data from recently completed or ongoing Partnership research studies of the Sierra Vista Subwatershed were not fully available for inclusion in this report. In future years, these reports to Congress will rely on information from these studies and on data collected by a monitoring program tailored to Section 321 information needs. The authorship of this report is attributed collectively to the Upper San Pedro Partnership (http://www.usppartnership.com), a consortium of Federal, State, and local agencies, and nongovernmental organizations. Information for this report was supplied by several agencies including the Arizona Department of Water Resources, the Arizona Corporation Commission, the U.S. Geological Survey, the Agricultural Research Service, and other Upper San Pedro Partnership member agencies. Some background and context is provided in this first report, such as a basin description, a ground-water budget, and how sustainable yield was determined.

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Submitted to Congress by the Secretary of the Interior, in consultation with the Secretary of Agriculture and Secretary of Defense and in cooperation with the other members of the Upper San Pedro Partnership.

Introduction

Ground water is the primary source of water for the residents of the Sierra Vista Subwatershed (SVS), Arizona, including Fort Huachuca, Bisbee, Sierra Vista, Huachuca City, Tombstone, and the rural residents of the SVS. Ground water also sustains the base flow of the San Pedro River and its associated riparian ecosystem, formally protected through an act of Congress as the San Pedro Riparian National Conservation Area (SPRNCA). Water outflow from the SVS, including water withdrawn by pumping, exceeds natural inflow to the regional aquifer within the SVS. As a result, ground-water levels in parts of the SVS are declining and ground-water storage is being depleted. The continued decline of water levels and associated depletion of storage will eventually diminish ground-water flow to the San Pedro River. The Defense Authorization Act of 2004 (Public Law, 108-136, Section 321, hereafter referred to as Section 321, is included as appendix A) set goals and a timetable of 2011 for achieving, by various means, a sustainable level of ground-water use from the SVS. In addition, the act formally recognizes the Upper San Pedro Partnership (Partnership or USPP) and clarifies the responsibilities of Fort Huachuca. The Partnership is specified as the regional cooperative organization for recommending policies and projects to mitigate water-use impacts in the SVS. Section 321 directs the Secretary of the Interior, in consultation with the Secretaries of Agriculture and Defense and in cooperation with the Partnership, to report on the member agency water-use management measures (hereafter referred to as 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 both of SVS residents and the San Pedro River. Some of the Partnership members are owners or managers of land and may be capable of implementing water-management measures. Other members include resource agencies with expertise in public policy, various scientific fields, and engineering. 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 has also 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 reports is contained in appendix B. Additional information about the Partnership, including access to the Water Conservation Plan, is available at http://www/usppartnership.com.

The local hydrologic system is complex and not fully understood. The consequences of ground-water use and the effectiveness of alternative water-management strategies will be better understood as research and monitoring efforts continue. As a result, an adaptive management process will provide the best means of reaching sustainable yield in the SVS. The term adaptive is used because decisions associated with sustainable yield must be made today in the absence of perfect knowledge about tomorrow's consequences. As new information becomes available, resource decisions can be amended or revised in subsequent years. For this reason, a well-designed monitoring program is important to provide useful feedback on the status and trends of aquifer conditions and the effectiveness of mitigation measures. Without an adequate monitoring program, the future influence of current management decisions cannot be fully evaluated, thereby limiting the precision of future decisions.

Purpose and Scope

The purpose of this report is to address the reporting requirements of Section 321 for 2004. The main body of the report is structured to reflect report elements requested under the Section 321 legislation. More detailed background information is available in appendices A through G. The report first discusses and defines the concept of sustainable yield in the context of the SVS and sets specific goals for the reduction of ground-water overdraft. The report then responds directly to Section 321 by presenting specific planned water-use management and conservation measures intended to facilitate the achievement of sustainable yield. The water-management measures presented in this report were either selected from among the options the Partnership has previously evaluated, or are measures implemented by individual members prior to the Section 321 legislation. Finally, a monitoring plan is outlined that will verify the effectiveness of management measures in reducing overdraft.

The information contained and goals enumerated in this report apply only to the SVS, which is part of the area drained by the San Pedro River (figure 1). The management boundaries of the SVS are defined as extending from the United States-Mexico border in the south to a northern divide drawn across the San Pedro Valley through the U.S. Geological Survey streamflow-gaging station, San Pedro River near Tombstone (station number 09471550). The hydrologic boundary extends to the headwaters of the San Pedro drainage in Sonora, Mexico, near Cananea (figure 1). The period of time considered in this report is 2002 through 2011.

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

The Upper San Pedro Basin[1] is a ground-water 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 SVS is bounded on the west by the Huachuca Mountains and on the east by the Mule Mountains and Tombstone Hills. The southern boundary of the SVS is the 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 miles downstream from the town of Fairbank. The area within these bounds is a sediment-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 sediments constitute the SVS's regional aquifer.

The SVS supports a human population of about 72,500 (Department of Economic Security, 2003; Cochise County estimate) that is distributed among the unincorporated rural areas and the municipalities of Bisbee, Sierra Vista, Huachuca City, and Tombstone. Sierra Vista, the SVS's largest city, had a population of about 40,430 in 2003 (Department of Economic Security, 2003), which includes approximately 9,000 permanent residents of the U.S. Army's Fort Huachuca.

The SVS also 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 (SPRNCA; 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, which was the first riparian national conservation area in the country. The biological significance of the river stems from the ecosystem contrast between the riparian system and most of the surrounding area. The riparian system supports a diverse biota (consisting of 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 miles wide and extending about 35 miles north from the international boundary with Mexico (figure 1).

The climate of the SVS is semiarid; a basin-wide annual average rainfall of 16.1 inches has been calculated using 1956 to 1997 records from four precipitation stations (Pool and Coes, 1999). Precipitation varies by location in the SVS and is typically greater on the basin-bounding mountain ranges than on the valley floor. About 65 percent of the annual precipitation arrives in late summer thunderstorms with the remainder generally arriving in winter storms (Goodrich and others, 2000).

Because precipitation in the SVS is concentrated in the mountains, most recharge to the SVS's regional aquifer system occurs at the basin's periphery, along the juncture between the mountains and basin floor (Pool and Coes, 1999). Water also enters the SVS as underflow from Mexico. Water that recharges along the mountain fronts moves toward lower elevation discharge locations. Within the SVS, natural ground-water 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 ground-water underflow.

[1]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 ground-water 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.

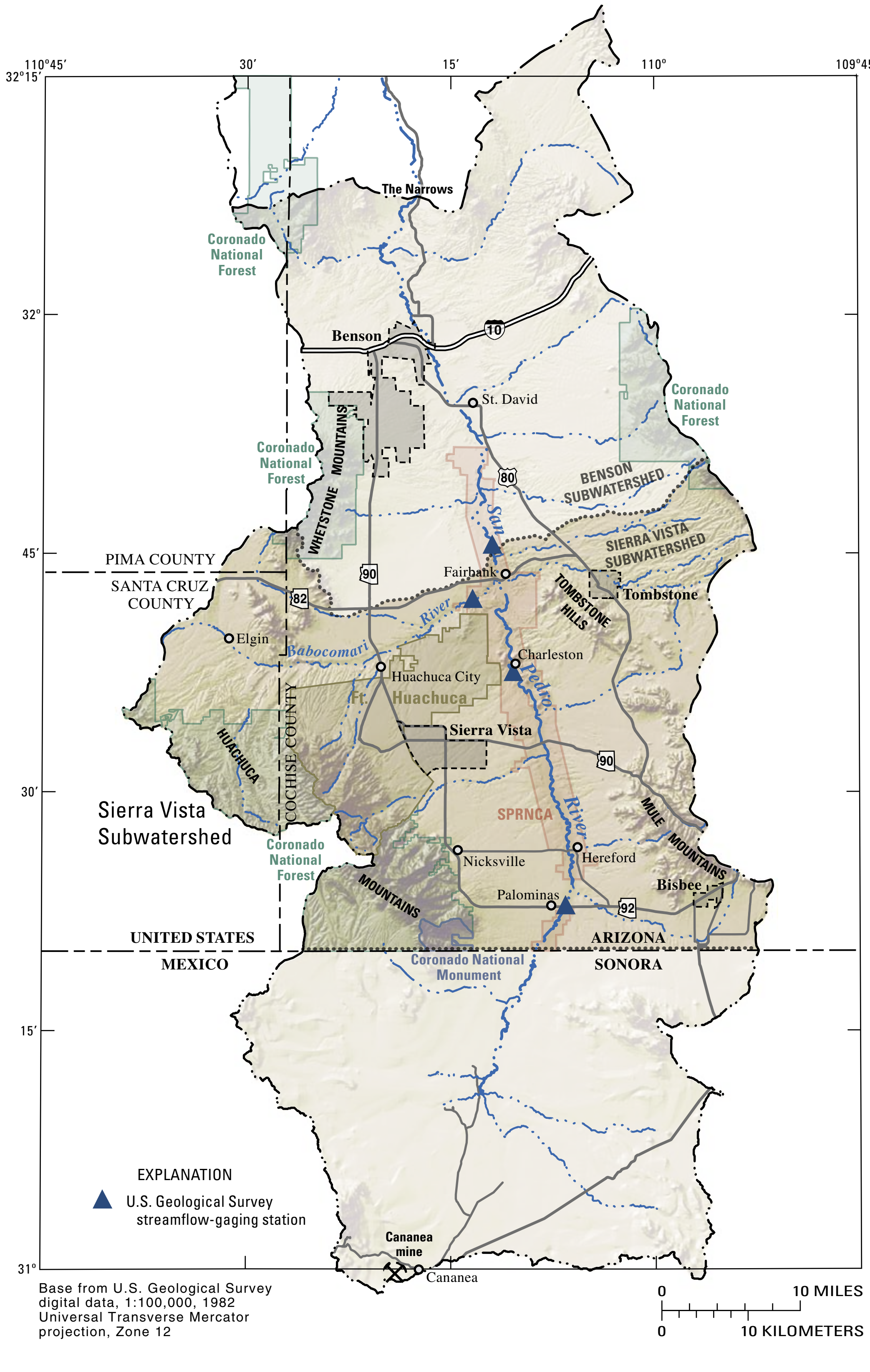


Figure 1. Location of the Sierra Vista Subwatershed (SVS) in the Upper San Pedro Basin, Arizona.

In the SVS, the San Pedro River flows perennially (all year) in some reaches and intermittently in others. The ecologic condition of the riparian forest directly depends on the presence of shallow ground water within the flood plain, whereas the SPRNCA's aquatic habitats are directly dependent on stretches of perennial streamflow. This hydrologic context depends on consistent ground-water 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 ground-water recharge and discharge. The primary perennial reach extends from about 7 miles south to 1 mile north of the town of Charleston, where the USGS streamflow-gaging station, San Pedro River at Charleston (station number 09471000), is located.

For many of the above-mentioned reasons, the SVS has been the subject of substantial scientific study over the last 15 years. Some of these studies have been funded by the Partnership and will provide valuable information for future Section 321 reporting.

Determination of Sustainable Yield

Section 321 requires the formation of a plan to achieve sustainable yield for the SVS by 2011. There is, however, no established method to determine sustainable yield because it is not solely a scientific determination. Rather, identifying a sustainable level of ground-water use involves complex evaluations of society's values, environmental consequences, and economic concerns (Alley and Leake, 2004). There is no volume of ground-water use that can be truly free of any consequence, especially when time is considered, although some consequences may be acceptable.

The Partnership has adopted the definition offered by Alley and others (1999) for sustainable yield, which is "…[the] development and use of ground water in a manner that can be maintained for an indefinite time without causing unacceptable environmental, economic, or social consequences." Therefore, a sustainable level of ground-water pumping for the SVS could be an amount between zero and a level that arrests storage depletion, with the understanding that to call a level of use sustainable (other than zero) will entail some consequences at some point in the future. What consequences are unacceptable are not yet fully defined, but will be decided as a collective result of stakeholder discussion, debate, and consensus. The role for science is to frame the range of options within which a goal can be established and to describe and predict the consequences of a given level of pumping.

The essential goal in achieving sustainable yield is to ensure that water of sufficient quantity and quality is available for the SVS's social, economic, and environmental needs. The Partnership has started to identify some specific elements of sustainability as shown in table 1.

Table 1. Initial criteria for sustainability

Social and economic	Environmental
• Sufficient water quantity for human needs • Fort Huachuca remains operational unless for reasons unrelated to water • Cost of living, specifically affordable housing and the cost of doing business, remains within the means of a diverse population • Maintain local participation in water management • Sustain water quality	• Ground-water levels in alluvial aquifer within the SPRNCA maintained • Stream base flow and flood flows maintained • Accrete aquifer storage • Riparian habitat and ecologic diversity maintained • Water quality sustained in SPRNCA • Overall riparian condition maintained • Springs in the SPRNCA continue to flow

The term "safe yield" is sometimes mistakenly interchanged with "sustainable yield"; however, they are significantly different water-management concepts. 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 groundwater withdrawn….and the annual amount of natural and artificial recharge… (A.R.S. § 45-562 (A))." Safe yield, however, only applies as a State-legislated management concept in areas designated as Active Management Areas; the SVS is not so designated. Of key importance to the SVS is that 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. In contrast, the definition for sustainable yield adopted by the Partnership considers the water requirements both of the human population and of the ecologic system.

In order to examine the difference between these water-management strategies more carefully, an analogy is made comparing an aquifer to a reservoir behind a dam on a river. With a full reservoir and a constant rate of inflow, the reservoir level will remain constant if the outflow is equal to inflow (figure 2a). If water is removed from the reservoir by pumping equal to the inflow, the outflow will be zero and the reservoir level is held constant (figure 2b). This condition occurs under safe yield, which means there is no storage depletion. If pumping from the reservoir is less than inflows, then some water is available to be released from the dam to sustain the river, again assuming that the reservoir level is held constant. The river below the dam will flow but at a lower rate than when no pumping occurred (figure 2c). This condition, or amount of pumping, can be defined as a sustainable yield if the reduction in outflow to the river is considered to produce no unacceptable consequences to the riparian ecosystem. The essential variable is not the level of water in the reservoir (a constant in this example), but rather the ability of the reservoir to continue to supply water to the river downstream from the dam without declines in reservoir level.

The same principle can be applied to a ground-water reservoir. If pumping (discharge) equals inflows (recharge), the outflows (subsurface flow or discharge to riparian plants, springs, streams, or wetlands) from the aquifer will decrease to zero eventually, assuming pumping does not alter the flow system to induce additional inflows. To sustain the riparian ecosystem along the San Pedro River, outflow from the SVS (or as in the analogy, from the dam) must be sustained. Therefore, withdrawals or pumping from the regional aquifer will need to be less than recharge. The distinction between safe yield and sustainable yield is discussed in further detail by Alley and Leake (2004).

Sustainable yield, in the case of the SVS, also includes a spatial aspect of ground-water development in addition to the subwatershed hydrologic budget. For example, pumping comparatively small volumes of water very near the San Pedro River could produce unacceptable consequences, whereas pumping an even larger volume of water away from riparian habitat may minimize direct impacts. The spatial component aspect of sustainability may, therefore, lead to distributing pumping where no unacceptable consequences occur, even when pumping continues to cause localized storage depletion.

Sustainability discussions often focus around a yield, or an amount of water that can be pumped. Some aspects of sustainability, however, need to be evaluated using metrics other than water volume within the broad context of the SVS's water budget. For example, the health of the San Pedro River's riparian system is more dependent on depth to ground water in the stream alluvium than the annual storage change within the regional aquifer. Over longer periods of time these factors are interrelated. The interrelation, however, is complex and no single distribution of ground-water levels in the stream alluvium or in the regional aquifer can be defined as a measure of sustainability.

Clearly, defining sustainable yield in an actual system necessitates consideration of many factors. Given the context of these factors, one can define management actions within which system sustainability can be obtained, as illustrated in figure 3. Sustainable yield exists between complete elimination of ground-water consumption at one extreme, and ground-water consumption at a rate that eliminates storage depletion even if the amount of storage accretion is small. Ground-water consumption under the latter scenario will have long-term consequences to the outflows and inflows as the system approaches a new equilibrium. Sustainability is a function of the compromise reached in defining unacceptable consequences. The likelihood of experiencing unacceptable consequences is greater for the riparian system at higher levels of ground-water use, but greater for human residents as pumping becomes more restricted.

From a management perspective, eliminating all ground-water consumption is an unrealistic goal. A point of beginning is to arrest storage depletion, with a management goal to accrete aquifer storage to achieve sustainable yield. Storage accretion will manifest itself by rising water levels in the SVS and in the long term will reduce the unacceptable consequences to the river. For 2004 reporting purposes, a water-budget approach is one of the lines of evidence to determine an initial management target in the SVS, as discussed in the following section.

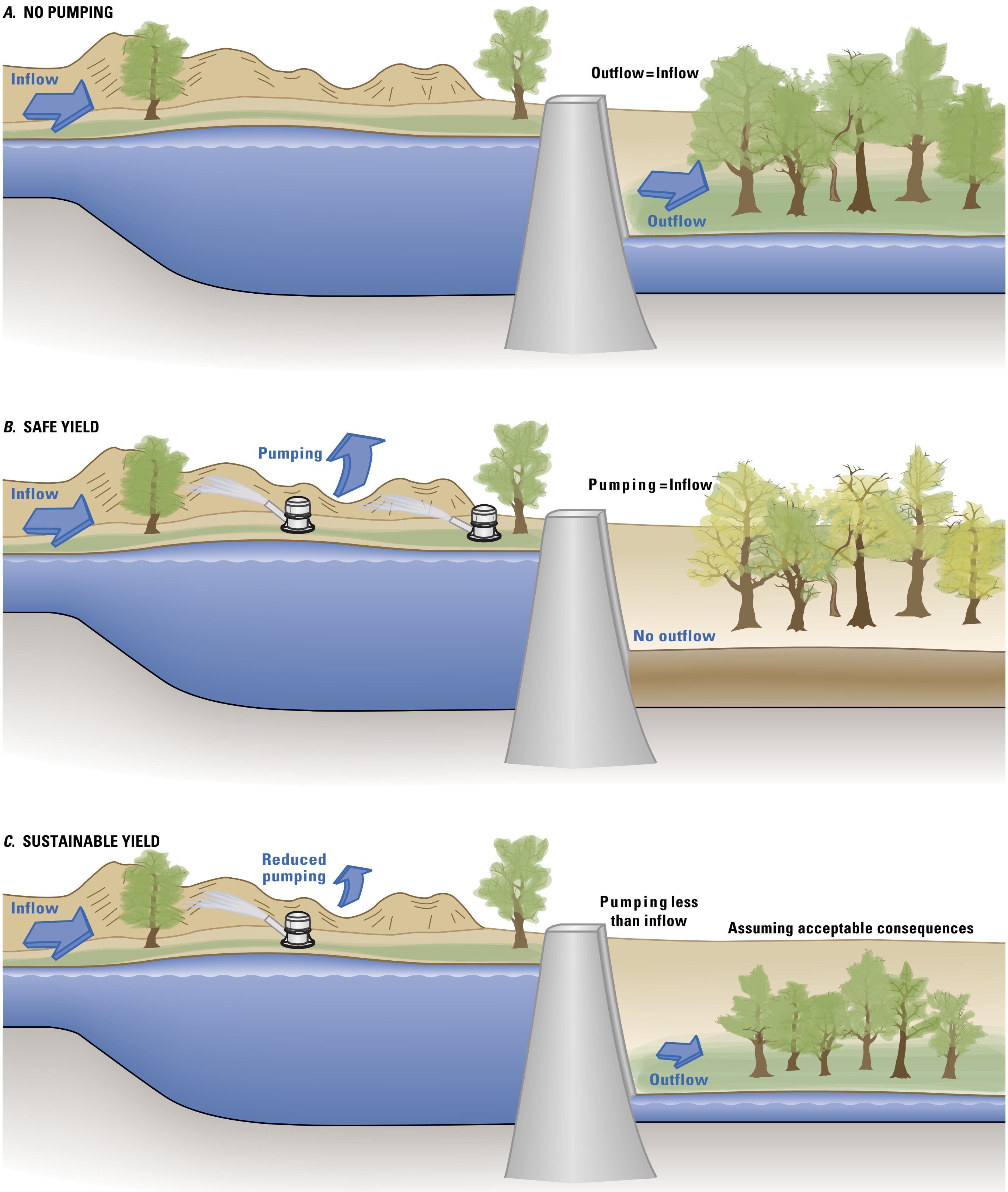


Figure 2. Reservoir analogy to the response of a ground-water system to pumping.

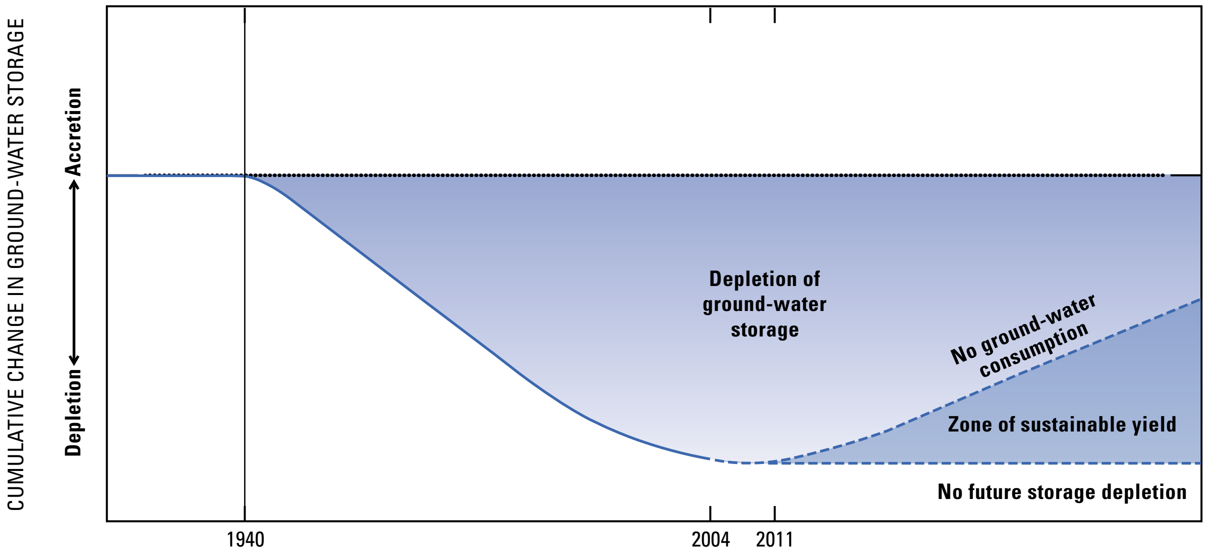


Figure 3. Relation between storage change and sustainable yield for the Sierra Vista Subwatershed.

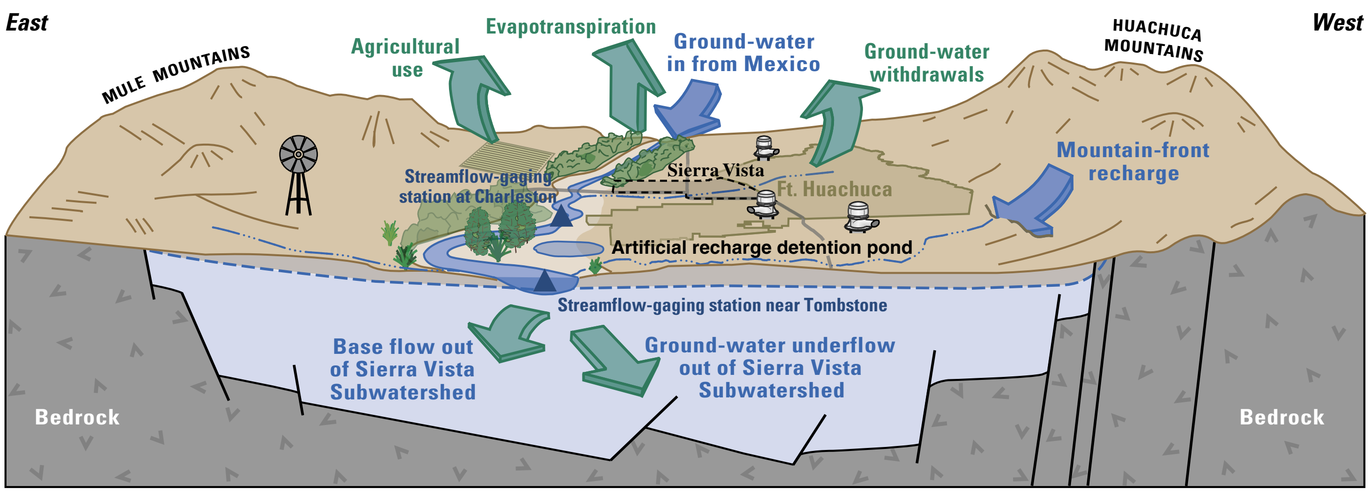
Annual Net Withdrawal and Recharge in the Sierra Vista Subwatershed

A conceptual ground-water budget (figure 4) shows the inflow and outflow components that must be considered in creating a ground-water budget specific to the SVS. The values assigned to each component in the ground-water budget are estimates that have a definite but unquantified uncertainty associated with them. The estimates and the uncertainty will change as more data become available. The most current SVS ground-water budget has been determined for 2002 by the Arizona Department of Water Resources (Arizona Department of Water Resources, 2004).

The Partnership has adopted the Arizona Department of Water Resources (ADWR) water budget of 2002 for the purposes of establishing a water-management target to achieve sustainable yield. Science cannot establish precise values for every component in a ground-water budget but rather can establish a range of values that brackets the true value. Therefore, figure 4 presents value ranges that have been reported in a subset of area studies and includes, for comparison, the ADWR values for 2002. Greater detail on other water budgets and how they were determined are included in appendix C.

Section 321 (part 3(A)) requests a tabulation of net inflows and outflows from the SVS's regional aquifer in the 1-year preceding the submission of the report. Data from the previous year (2003), however, are not currently available to satisfy this request. The ADWR water budget reports pumping specific to 2002. Other inflow and outflow values in the ADWR water budget represent a variety of time periods. Natural outflow is calculated using 1996 to 2002 streamflow-gaging station records and 1986 to 1990 evapotranspiration estimates. The 1996 to 2002 period was dominated by drought in the Southwestern United States; the quantitative effect of the drought on stream base flow is unknown, although drought is likely to have decreased base flows relative to earlier periods of record. Natural recharge is based on analysis of predevelopment stream base-flow data for 1935-40. More recent stream base-flow data cannot be used to calculate recharge because pumping may have affected streamflow in the absence of any changes in recharge.

Table 2 lists SVS ground-water budget components and specifies the net inflow and outflow values determined by the ADWR for 2002. These values are used in subsequent calculations in the plan to reach sustainability for the SVS. In order to maintain water-accounting consistency, however, effluent recharge credit has been moved from the ADWR budget for 2002 (appendix D) to the Partnership's water-management plan tables. As a result, the storage change numbers in the tables of this report differ from the value presented in the draft ADWR budget for 2002.



Simulated annual water budget for a ground-water-flow model — Values are in acre-feet per year

GROUND-WATER INFLOW

	Estimated range	2002 Estimates	2011 Projections
—Natural recharge	11,200–16,000	15,000	15,000
—Underflow from Mexico	3,000–3,400	3,000	3,000
—Total		18,000	18,000

GROUND-WATER OUTFLOW

	Estimated range	2002 Estimates	2011 Projections
—San Pedro base flow	3,250–6,290	3,250	3,250
—Net ground-water withdrawals		16,500	18,600
—Riparian and wetland evapotranspiration	6,230–7,700	7,700	7,700
—Ground-water underflow at Tombstone streamflow-gaging station	300–440	440	440
—Total		27,900	30,000

ANNUAL STORAGE CHANGE (no management measures)

—2002 Estimated	–9,900
—2011 Projected	–12,000

Figure 4. Ground-water budget for the Sierra Vista Subwatershed. Value ranges obtained from studies detailed in table C2.

Table 2. Water recharged to and withdrawn/discharged from the regional aquifer underlying the Sierra Vista Subwatershed in 2002 in the absence of overdraft reduction measures—Response to Section 321 part 3(A)

[Water-budget volumes in acre-feet/year]

Component	Annual volume[1]	Description
Natural recharge	15,000	Inflow largely from percolating waters on and around mountains and through ephemeral-stream channels
Additional recharge	(2)	Human caused recharge—artificial recharge projects, and enhanced ephemeral-stream channel recharge due to urbanization[3], and detention basins
Ground-water inflow	3,000	Subsurface inflow from Mexico
Ground-water outflow	440	Subsurface outflow at USGS San Pedro River near Tombstone streamflow-gaging station (09471550)
Stream base flow	3,250	Ground-water discharge to the river that flows out of the subwatershed
Evaporation and plant transpiration	7,700	Ground water consumed in the riparian system exclusive of evapotranspiration supplied by near-riparian recharge from precipitation or flood runoff
Pumping	[4]16,500	Direct ground-water extractions for human uses
Aquifer storage loss	[5]9,900	Additions or reductions in stored aquifer water

[1]Ground-water budget annual flow volumes as estimated by the ADWR (2004). All budget components except for streamflow are calculated estimates not directly measured.

[2]Additional recharge tabulated in Partnership water-use management plan tables.

[3]Urbanization causes enhanced recharge by concentrating storm runoff in ephemeral-stream channels. Recharge in arid and semiarid environments is more likely to occur if runoff from precipitation reaches permeable stream-channel sediments. Recharge caused by urbanization only partially mitigates the increased pumping that accompanies increased urbanization.

[4]Mix of net and gross pumping – return flow recharge from septic tanks, golf courses, and other sources has been subtracted from total agricultural and private domestic pumping. Private and municipal water supplier pumping is gross pumping. The artificial recharge of effluent originating from water pumped by private and municipal water suppliers is included in Partnership water-management tables.

[5]Value rounded to nearest 100 acre-feet/year. Number differs from the ADWR reported storage change listed in appendix D; the ADWR budget includes effluent recharge in the storage calculation, whereas the Partnership includes effluent recharge in its water-management measures.

The ADWR water budget was adopted by consensus within the Partnership as a tool to establish initial goals in planning for sustainability. The inflows and outflows of the ADWR budget listed in this report are not intended to define the total water needed to sustain the SPRNCA.

Reduction of Overdraft to Achieve Sustainability through Water-Management Measures

Section 321 requests a plan that specifies "the quantity of overdraft of the regional aquifer to be reduced by the end of each of fiscal years 2005 through 2011 to achieve sustainable yield." Overdraft is typically defined as pumping in excess of safe yield (Freeze and Cherry, 1979), and safe yield is defined, in Arizona, as pumping equal to recharge; this definition does not adequately encompass circumstances in the SVS. Rather, overdraft in the SVS may best be defined as ground-water consumption in excess of sustainable yield. Sustainable yield, however, cannot currently be quantitatively determined. Therefore, this report does not assign numerical values to overdraft but does present quantities of planned reductions in net ground-water withdrawals. Reductions in net ground-water withdrawals represent reductions in overdraft from the regional aquifer.

In seeking sustainable yield for the SVS, what ultimately matters is not whether a specific calculation of storage deficit or overdraft is correct, but how the aquifer system responds through time both to human attempts to eliminate the storage deficit and to natural climatic variability. When storage depletion is reversed and accretion begins, water levels will gradually begin to rise. In the future, monitoring in the SVS will track water-level changes, and new measurement techniques to directly monitor storage change will be implemented.

For water-management planning, however, a management target equal to annual storage depletion is useful for the Partnership to set conservation and water augmentation goals to 2011. Sustainability is conceptually illustrated in figure 3 as ground-water use resulting in any value of storage change within the zone of sustainable yield, acknowledging that some consequences may still result. The minimum level of reduction in ground-water use to enter that zone requires elimination of current annual aquifer storage depletions and initiation of storage accretion. In this report, the management target of eliminating annual storage depletion serves as a metric to evaluate progress toward sustainable yield.

Annual aquifer storage depletion has been calculated using a water-budget approach. Measured or estimated annual inflows and outflows of water are subtracted to estimate annual change in aquifer storage. Calculations assume natural recharge has remained constant at predevelopment levels and climate change has not altered recharge. This assumption is necessary because natural recharge cannot be calculated using available streamflow data for the period in which development occurred. For the SVS ground-water budget, inflows, outflows, and storage change are related in this simple expression:

$$\text{Natural recharge} + \text{Additional recharge} + \text{Ground-water inflow} = \text{Ground-water flow} + \text{Stream base flow out} + \text{Evaporation and plant transpiration} + \text{Pumping} + \text{Water from storage}$$

A water-budget approach is an accounting technique that is a tabulation of inflows and outflows representing a particular time. This approach has no ability to predict ongoing or future changes in the hydrologic system that may result from past and present pumping. For example, a water budget approach cannot predict times when or locations along the river where changes caused by pumping may capture base flow. Only a physically based ground-water model can provide an evaluation of the temporal and spatial effects of pumping. Such a model is currently in development and will be helpful in the future.

The Partnership has chosen the annual storage deficit value of 9,900 acre-feet/year (rounded to 10,000) derived from ADWR's 2002 water budget, and calculated assuming no water-management measures or urban-enhanced recharge are in effect, as a minimum management target. The Partnership plans to offset net ground-water use in excess of 10,000 acre-feet/year.

Given the planning horizon of 2011, the Partnership plans to mitigate overdraft considering both the expected population growth and needed water-management measures. Population growth rates were determined by Cochise County on the basis of population estimates by the Arizona Department of Economic Security. The water-planning values presented in this report reflect the projected population increase shown in table 3. Additional information regarding population growth and water-use projections to 2011 are contained in appendix E.

Table 3. Projected population growth rates in the Sierra Vista Subwatershed from 2000 to 2011

	Census population, 2000	Projected population, 2011
Sierra Vista (exc. Fort)	29,350	36,800
Fort Huachuca	8,585	9,100
Bisbee	6,090	7,100
Huachuca City	1,750	2,050
Tombstone	1,500	1,800
Unincorporated areas	20,810	26,300
Total	**68,085**	**83,150**

By considering population growth, the Partnership projects that annual storage depletion will increase to 12,000 acre-feet/year by 2011, if yields from management measures and urban-enhanced recharge are omitted from the calculation. Fluctuations in future human water demand, climatic variability, and other factors that are currently difficult to predict could influence inflows and outflows during this time period; these values of population growth and ground-water storage deficit are merely estimates. Additional detail regarding 2011 water-budget projections is contained in figure 4.

The 2002 and 2011 storage-depletion values (10,000 and 12,000 acre-feet/year, respectively) are used in subsequent calculations showing the effect of planned and current Partnership water-management measures on annual aquifer storage change. These storage depletions are baseline values calculated assuming the absence of any water-management measures—existing or planned—and without considering any enhanced recharge generated by urbanization. Omitting current and future management measures in the baseline deficit calculations facilitates consideration of population growth. Water-management activities in the SVS, both conservation and recharge, serve to offset these calculated baseline storage-depletion values. The year 2002 was chosen as the first year for calculations because it is the most recent year for which the ADWR pumping and water-budget estimates are available.

Annual Reduction of Overdraft to Achieve Sustainability

The water-management plan presented in this document includes only existing water-management measures that have already been implemented by member agencies or potential future measures that have been evaluated for pros, cons, costs, and benefits by the Partnership in their annual Water Management and Conservation Plan (http://www.usppartnership.com/documents.html) and through consultation with other documents listed in appendix B.

The criteria by which existing measures were evaluated and accepted for implementation cannot be categorically stated. One reason for this is that some of the current Partnership members were planning management measures prior to the formation of the Partnership and before the enactment of Section 321. Each of these entities utilized its own selection criteria. Generally, these criteria included total water yield, total cost, cost/yield ratio, and community acceptance.

The Partnership, soon after its formation, commissioned a detailed study of the costs and yields of a wide variety of possible management measures (BBC/Fluid Solutions, 2003). These measures included approximately 55 options for conservation, recharge/reclamation, and augmentation. In addition, the Partnership is and will continue to be engaged in an ongoing evaluation process both for member agency and Partnership-conceived management measures. These evaluations are facilitated through regular meetings of member-agency technical staff. Criteria vary depending on appropriateness to evaluate a particular measure, but include yield, cost, cost/yield ratio, and feasibility for community acceptance.

The measures already enacted and those suggested in this report for continuation and initiation in the future eliminate annual storage depletion and begin accreting storage by 2009. The types of measures enacted to achieve overdraft reduction are detailed further in the following tables and text. The overall planned effect of these measures is depicted in figure 5. This plot of aquifer-storage change shows a decline in the depletion of storage through 2008, followed by accretion of storage for the period 2009-11. Two sets of information demonstrate the planned transition to sustainability (table 4). The first is the projected annual yield of management measures beginning in 2002. The second is projected annual storage change calculated as the difference between the management-plan yield and the annual storage change if no management actions are taken. The difference between the no-management action storage depletion for 2002 of 10,000 acre-feet and the estimated 6,400 acre-feet of water yield from management-measures in operation as of 2002 results in an estimated aquifer-storage depletion of 3,600 acre-feet for 2002 (table 4). Details regarding which measures were implemented as of 2002 are found in appendix F; measures included in the 2002 through 2004 columns have been implemented. Similarly, the projections of annual storage change for each year from 2003 to 2011 are the difference between projected no management action annual storage depletion and annual management plan yields.

The yields considered in the calculations represent best estimates of expected water savings and recharge through management actions in each year from 2002 through 2011. Currently, insufficient information is available to evaluate the actual yields derived from management measures in 2002 through 2004. An intrinsic component of the adaptive-management strategy adopted by the Partnership is that information documenting the success of management measures will be used to reevaluate the plan, and projects may be added, deleted, or modified accordingly. This report outlines the initial plan to attain sustainability in the SVS; future annual Section 321 reports to Congress will evaluate the combined success of the various measures in reaching that goal.

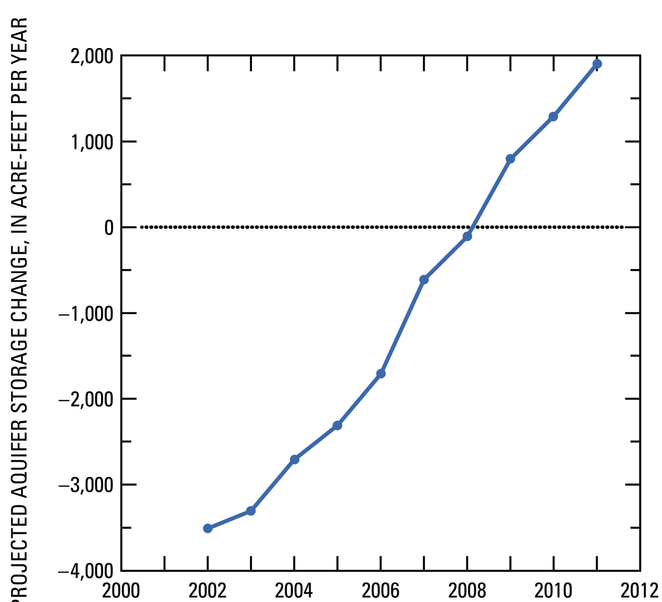


Figure 5. Effect of planned water-management measures on annual aquifer-storage change (calculated as the difference between projected annual aquifer-storage depletions if no management measures are taken and estimated yields from planned management measures).

Table 4. Projected yield of Partnership water-management plan measures and estimated annual change in aquifer storage—Response to Section 321, part 3(B)

[Yield in acre-feet/year; The planned yields are based on the best information currently available to the Partnership and on current agency commitments. The Partnership is continuing to collect data and develop tools to analyze potential and planned projects, and it intends to review this plan at least annually. Projects may be added, deleted, or modified to this plan periodically, but the Partnership is committed to assure the implemented projects plus planned projects meet the stated goal and objective of the partnership and the congressional intent of achieving sustainable yield by 2011 and beyond; Numbers compiled in May–July 2004]

	Year									
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Management-measure yield[1,2]	6,400	6,800	7,700	8,300	9,100	10,500	11,200	12,300	13,100	13,900
Aquifer storage change in year[1,3]	-3,600	-3,400	-2,700	-2,400	-1,800	-600	-100	700	1,300	1,900

[1]Values rounded to nearest 100 acre-feet/year.

[2]Details regarding the derivation of these yields are contained in water-use management tables in appendix F; documents consulted to estimate yields are listed in appendix B.

[3]Change in aquifer storage calculated as the difference between the annual deficit if no management action were taken and the yield of Partnership water-management efforts. The no-management-action storage deficit (10,000 and 12,000 acre-feet losses in 2002 and 2011, respectively) accounts for projected population growth.

Other aspects of sustainability, including spatial ground-water management issues, cannot be adequately addressed in this report. A ground-water flow model will be used in conjunction with a decision support system (DSS) to evaluate and plan for projects and water-management strategies that can address the spatial aspects of ground-water management associated with sustainability.

The prior-year success of water-management measures will be evaluated in future reports to Congress relative to several metrics, including reductions in ground-water consumption, and responses of water levels and ground-water storage in the regional aquifer system.

Member-Agency Contributions to Reduce Overdraft

The Partnership is charged with the responsibility to plan and implement various actions to reduce ground-water overdraft in the SVS. Each water-use controlling member of the Partnership is expected to contribute to the reduction of the overdraft according to an allocation of responsibility. The term “water-use controlling” is a Partnership-assigned identifier of members who own or manage land and are capable of implementing management measures. No water rights or regulatory capacities are implied. Table 5 lists the contribution each year, in acre-feet/year, of each water-use controlling member of the Partnership. Additional detail regarding planned management measures is contained in appendix F.

Also included in table 5 is a row indicating a volume of recharge, enhanced beyond the natural recharge, attributable to urbanization and caused by concentration of rainfall runoff into ephemeral-stream channels. In arid and semiarid climates, the opportunity for recharge is increased (and the likelihood of loss by evaporation is decreased) if runoff is concentrated in channels. Most precipitation that wets soils but does not run off is evaporated or transpired; the water that escapes evaporation and plant transpiration infiltrates very slowly so only a small percentage recharges the aquifer. Water that runs off into ephemeral-stream channels can collect in sufficient quantity to exceed the immediate demands of evaporation and plant transpiration and therefore recharge the regional aquifer.

Covering soils with impermeable surfaces increases the amount of water that runs off into channels. Although the areas of greatest urbanization generate the greatest enhancement in recharge, the effect is not intended by a particular Partnership member, so the yield is listed separately from intended efforts. Increased recharge due to urbanization is expected to only partially mitigate the increased pumping that accompanies increased urbanization. The stormwater recharge value included in table 5 was based on Partnership sponsored research intended to better understand recharge processes and their relation to impervious surfaces (GeoSystems Analysis, 2004). This value, although preliminary, is based on the best available information.

Table 5. Planned contribution by each Partnership water-use controlling member to overdraft reduction—Response to Section 321, part 3(C)

[Yields in acre-feet/year; ---, indicate no yield during year. The planned yields are based on the best information currently available to the Partnership and on current agency commitments. The Partnership is continuing to collect data and develop tools to analyze potential and planned projects, and it intends to review this plan at least annually. Projects may be added, deleted, or modified to this plan periodically, but the Partnership is committed to assure the implemented projects plus planned projects meet the stated goal and objective of the Partnership and the congressional intent of achieving sustainable yield by 2011 and beyond. Numbers compiled in May–July, 2004]

Partnership member	Planned water yield[1]									
	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Fort Huachuca	570	760	1,380	1,690	1,740	1,950	2,000	2,350	2,400	2,470
Cochise County	90	90	100	150	200	250	310	360	410	460
Sierra Vista	2,310	2,430	2,650	2,750	3,130	3,410	3,630	3,720	3,820	3,910
Bisbee	---	---	---	---	10	590	610	630	650	670
Huachuca City	---	---	---	---	---	180	180	190	190	200
Tombstone	---	---	---	---	---	---	10	10	10	20
Bureau of Land Management	240	320	410	490	580	660	750	830	915	1,000
The Nature Conservancy and Fort Huachuca	---	---	---	---	250	250	500	1,000	1,500	2,000
Storm-water recharge[2]	3,200	3,200	3,200	3,200	3,200	3,200	3,200	3,200	3,200	3,200
Total[3]	6,400	6,800	7,700	8,300	9,100	10,500	11,200	12,300	13,100	13,900

[1]Documents consulted to estimate yields listed in appendix B.

[2]Initial estimates provided by the U.S. Department of Agriculture–Agricultural Research Service of natural recharge enhanced beyond predevelopment levels by urbanization–credit not claimed by any particular Partnership member. These preliminary estimates are based on the best available information derived from a Partnership funded study of recharge (GeoSystems Analysis, 2004) and will be refined through ongoing research and monitoring programs. Enhanced recharge only partially mitigates the increased pumping that accompanies increased urbanization.

[3]Total yields rounded to nearest 100 acre-feet/year.

Water-Management Measures to Reduce Overdraft

The Partnership's current water-use management plan consists of two broad categories of measures—conservation and recharge/reuse. Table 6 contains details regarding the most feasible management measures among the group of measures comprehensively evaluated by the Partnership. The information in table 6 has been condensed from existing Partnership management-measure evaluations and formatted to respond directly to the Section 321 legislation by including cost, an implementation schedule, and anticipated water yields in 2002 and 2011. The measures are categorized with respect to the water-use controlling member of the Partnership. Each measure comprises one or more specific projects that may differ from member to member. The projects, together with potential legal impediments to full implementation, are described subsequently in further detail. Additional detail regarding specific project water yields by year is provided in appendix F. Documents consulted to help estimate expected water yields from management measures are listed in appendix B.

The Partnership recognizes that the planned water-management measures listed in this report may not be sufficient to provide long-term ground-water sustainability and that an adaptive management approach will be needed in the years ahead.

This report utilizes the best information currently available; future reports will update that information as conditions change and/or additional information becomes available. It is important to note that in addition to the conservation, reuse, and recharge projects identified within this report, other measures may be needed to attain sustainability. Such measures may include further conservation, reuse, and recharge projects, or may include the augmentation of water supplies, through either water transfer and/or import projects or additional stormwater recharge measures. As part of the adaptive-management process, the Partnership is continuously evaluating management options; future additions to the management plan will likely be selected on the basis of these evaluations.

Table 6. Water-management measures planned by the Partnership to mitigate aquifer overdraft—Response to Section 321 part 3(D)

[Yields in acre-feet/year; TBD, to be determined; UNK, unknown. The planned costs, start dates, and yields are based on the best information currently available to the Partnership and on current agency commitments. The Partnership is continuing to collect data and develop tools to analyze potential and planned projects, and it intends to review this plan at least annually. Projects may be added, deleted, or modified in this plan periodically, but the Partnership is committed to assure the implemented projects plus planned projects meet the stated goal and objective of the partnership and the congressional intent of achieving sustainable yield by 2011 and beyond; Numbers compiled in May–July, 2004]

Type	20-year life local operation and maintenance	Local capital invested	Federal funding obtained	Funding needed for completion	Yield start year[1]	2002 estimated annual yield	2011 estimated annual yield
Fort Huachuca							
Conservation[2]	TBD	TBD	$50,000	TBD	2001	320	990
Recharge/reuse	TBD	TBD	$500,000	TBD	2001	250	1,480
Cochise County							
Conservation[3]	TBD	$267,000	$98,000	TBD	2001	90	460
Sierra Vista							
Conservation	TBD	$465,000	$25,000	TBD	2001	170	520
Recharge[4]	$3,650,000	$1,858,000	$500,000	$1,470,000	2001	2,140	3,390
Bisbee							
Conservation	TBD	TBD	TBD	TBD	2006	0	60
Recharge/reuse	TBD	$2,000,000	$12,000,000	$0	2007	0	610
Huachuca City							
Conservation	TBD	TBD	TBD	TBD	2006	0	20
Recharge/reuse	$240,000	$240,000	$292,500	$5,652,000	2007	0	180
Tombstone							
Conservation	TBD	TBD	TBD	TBD	2006	0	20
Bureau of Land Management							
Conservation[5]	TBD	TBD	TBD	TBD	2003	240	1,000
The Nature Conservancy and Fort Huachuca							
Conservation[6]	TBD	TBD	TBD	TBD	2006	0	2,000
Urban Stormwater Recharge							
Recharge enhanced by urbanization[7]	0	0	0	0	UNK	3,200	3,200

[1]Year of initiation for first project in measure category. Other projects in same category may begin in later years.

[2]Conservation of on-base use.

[3]Includes measures such as public education, code changes, and rebate programs.

[4]Includes recharge of municipal effluent in constructed facilities, reuse of effluent in lieu of ground water, and/or recharge of stormwater in constructed detention basins. Recharge values based on engineering reports used for recharge facility site location selection (Fluid Solutions, 1999). Values indicate actual recharge and exclude water lost to evaporation and diversion from direct recharge.

[5]Water use savings through management of invasive mesquite through various treatments, and retirement of irrigated agriculture or other high-water consumption uses by consensual agreement. Mesquite reduction reduces water use by replacing mesquite with more shallowly rooted plants. Yield from mesquite reduction estimated using a U.S. Department of Agriculture - Agricultural Research Service model of riparian evapotranspiration in the SPRNCA.

[6]Retirement of irrigated agriculture using conservation easements obtained only from willing sellers.

[7]Urbanization in arid climates can increase recharge by concentrating rainfall runoff in ephemeral-stream channels. This is an initial estimate provided by the U.S. Department of Agriculture–Agricultural Research Service. Estimates will be refined through ongoing monitoring and research programs.

Water-Management Measures and Legal Impediments

Subsections (c)(2) and (c)(3)(D)(v) of Section 321 require that this report identify existing laws or gaps in enabling legislation that may inhibit full implementation of current or future management measures under consideration by the Partnership. Consistent with this requirement, the following chart lists potential legal impediments identified by the Partnership. No specific actions to overcome these legal impediments are contemplated in Partnership plans at the moment. Future reports will, as required, report on the status of these impediments. The inclusion of this list carries no explicit or implicit recommendation or endorsement for any legislative action by any Partnership member, Federal, State, local, or other entry.

The impediment groups listed to the left column below correspond to specific water-management measures listed in appendix F. Some legal impediments may be politically difficult to modify given divergent and often contentious stakeholder interests and the challenge of fashioning solutions in light of the requirement for State-wide application of law. Thus, some management measures may ultimately be eliminated from consideration or be substantially modified owing to these legal impediments. Any progress made each year by the Partnership in overcoming legal impediments will be reported in subsequent reports, as required by subsection (d)(2)(C) of Section 321.

Conservation Measures:

Code Changes

- Limited authority exists for local (city, county) action with respect to modifying human behavior subsequent to final building inspection or for actions not related to development (i.e., water-wasting ordinances).
- Current State law does not provide any effective mechanisms for local/regional water management authority, or local ability to create funding mechanisms outside of Active Management Areas (AMAs) (A.R.S. 45-1942).
- Current State law is ambiguous regarding appropriate actions by counties when ADWR determines “water inadequacy.” (ADWR’s “groundwater adequacy certificate” considers only availability for human use, not ecological considerations.). Recent case law appears to prohibit county government from denying subdivision approval for lack of water adequacy.

Zoning

- Current State law limits counties from applying subdivision standards (with respect to water-resource management) to lot splits of five or fewer (A.R.S. 11-806/11-809).

Conservation Easements

- Current State law does not provide for Transfer Development Rights for counties, denying that management option to counties for anything other than encroachment on military airports.
- Current State law regarding the establishment of “Irrigation Non-expansion Areas” applies to entire basins or sub-basins and cannot be applied to a subwatershed such as the Sierra Vista Subwatershed (A.R.S. 45-432).
- Current State law regarding establishment of “Irrigation Non-expansion Areas” (INAs) does not include non-irrigation water conservation criterion, and no conservation requirements are established for non-irrigation water uses within an INA.
- Currently, there are no matching funds from State sources for conservation projects outside of the riparian zone to help address water-management issues.

- Current tax policy provides incentives for water-consuming uses but not for water-conserving uses on undeveloped land (A.R.S. 42-15004).
- The priority date for a surface water right (including subflow) severed and transferred for instream flow can currently only be protected if the right is transferred to the State or its political subdivisions; the priority date cannot be protected by transfer to a Federal entity.

Conservation Pricing

- The Arizona Corporation Commission (Arizona's public utilities commission) is limited in its ability to consider area-wide conservation pricing for the private and individually owned water providers who serve about 95 percent of the area's population (A.R.S. 4-257).

Technology Incentives

- Currently, there are no matching funds from State sources for conservation projects outside of the riparian zone to help address water-management issues.

Recharge/Reuse Measures:

Effluent Recharge/Reuse

- Currently, there are no matching funds from State sources for conservation projects outside of the riparian zone to help address water-management issues.
- Sufficient funding is not available for communities to meet the Environmental Protection Agency/Arizona Department of Water Quality's high water-quality standards for effluent to be recharged through shallow basins.

Stormwater Recharge

- Currently, Arizona limits the disposition and/or use options for State trust lands. Such options could permit construction of optimally located recharge facilities.
- Current tax policy penalizes undeveloped vacant land (A.R.S. 42-15004).

Augmentation/Importation Measures:

Augmentation/Importation Strategies

- Currently, Arizona limits the disposition and/or use options for State trust lands. Such options could permit construction of optimally located augmentation projects.
- Current State law generally prohibits interbasin transfer of ground water, and intrabasin transfer of ground water between sub-basins may be subject to the payment of "damages."

Monitoring and Reporting

Section 321 requests a description of monitoring and verification activities to be undertaken by the Partnership to measure the reduction of the overdraft to the regional aquifer in the SVS and stipulates the minimum sources of information that will be considered (appendix A). These minimum sources considered alone, however, are inadequate to confidently document reductions in overdraft. For example, the Arizona Corporation Commission annual report of pumping does not include private domestic wells in the SVS. Base flows at the Charleston gaging station may reflect both human-induced and climatic changes and not necessarily within the time scale of Section 321 reporting; recent research has demonstrated the expression of short- and long-term climate change signals in streamflow records (Hanson and others, 2004). While historic ground-water level measurements have demonstrated the impact of pumping on the regional aquifer over large time spans, the annual ground-water levels currently measured in the basin by ADWR will be of inadequate timing and spacing to accurately resolve changes in human water-management activities in response to Section 321 from changes caused by natural variability in the time between 2005 and 2011. A variety of Partnership-sponsored monitoring is ongoing but is oriented toward specific research projects and will not provide data capable of evaluating the success of Partnership efforts to attain sustainable yield in the SVS.

A well-designed monitoring program is needed to provide the annual reporting to Congress and provide a feedback mechanism for the adaptive management process. Without an adequate monitoring program, the feedback mechanism to the adaptive management process will not provide sufficient information to fully evaluate the effects of prior management decisions.

In order to satisfy the requirements of future Section 321 reporting, monitoring will track regional hydrologic conditions, riparian ecosystem trends, and also the progress of Partnership member agency projects. Regional monitoring and project-specific monitoring will be conducted separately. Some project monitoring will be borne by pertinent Partnership member agencies. To improve management of large datasets and support future reporting, an SVS-specific database will be created. The following outline of monitoring for future Section 321 reporting has been divided into factors related to the SVS's regional aquifer system and riparian system, and to water-use management projects. This monitoring outline is expanded with additional detail in appendix G.

The estimate of total annual monitoring costs for fiscal years 2005 through 2011 is $1,700,000.

Regional Hydrologic Monitoring

Monitoring of the SVS's regional hydrologic system is intended to verify the cumulative effectiveness of water-management measures in reducing aquifer overdraft as part of an adaptive management approach. Components to be monitored include factors associated with storage change in the regional aquifer, and metrics associated with the riparian ecosystem.

Estimates of Regional Storage Change

This aspect of monitoring will tabulate system inflows, outflows, changes in aquifer storage, changes in hydraulic gradients, and conditions in the riparian system.

- **Inflows**

  Natural Recharge.—An assessment of variations in natural recharge during the reporting period using streamflow data from mountain-front and ephemeral–stream channel gaging stations.

  Enhanced Recharge of Stormwater due to Urbanization—Improved estimates of enhanced ephemeral-stream channel recharge predicted to occur from concentration of rainfall runoff through monitoring at key locations.

- **Outflows**

  Stream Base Flow and Springs.—Measurement of ground-water outflow to the San Pedro River at USGS streamflow-gaging stations. Discharge will also be measured from selected index springs.

  Riparian Evapotranspiration within the SPRNCA.—Continuation of existing efforts to estimate total ground-water outflow through direct evaporation and plant transpiration by monitoring at key locations.

  Ground-Water Withdrawals (Pumping).—Annual tabulation and estimation of ground-water pumping by industrial users, municipal providers, private water companies, private-well-supplied households, and agricultural users.

- **Change in Storage and Hydraulic Gradients**

  Changes in Regional Ground-Water Levels and Storage.—Monitoring of water-level changes in selected SVS wells. Measurement of changes in aquifer storage using microgravity measurement techniques.

  Changes in Hydraulic Gradients between the Regional Aquifer and the River.—Determination of the hydraulic gradients that move water from the regional aquifer to the river.

Riparian Ecosystem

Stream and Shallow Ground-Water Conditions within the SPRNCA.—Direct measurements of streamflow conditions and stream-aquifer water levels at key sampling locations along the river.

Riparian Vegetation Condition.—Observations of changes in riparian vegetation condition at key sampling locations as an indicator of hydrologic changes.

Monitoring of Water-Management Measures

An essential element in the adaptive management process is verifying the efficacy of the Partnership's conservation, recharge/reuse, and augmentation measures. Such monitoring will confirm if actual water yields match projected yields at planned costs. Management plans included in future annual reports will reflect needed changes indicated by monitoring results.

Reporting, Water-Use Accounting, and Database Management

Each future annual report to Congress will require a reevaluation of the most current science and monitoring data. Acceptable thresholds for all metrics being monitored will need to be established, quantified, and subsequently used to evaluate progress toward sustainable yield as it relates to the criteria established in table 1. The Partnership will consider these data and adapt the management plan as needed to continue approaching sustainable yield in the SVS's regional aquifer.

These iterative assessments will rely on available estimates of water use and an accounting of benefits accrued from member agency projects. To facilitate integration of these data, a Web-based Partnership project management tool will be developed by the USGS to enable the Partnership to track water use, regional hydrologic trends, changes in the riparian ecosystem, and the timing and implementation of member agency projects.

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Glossary

Base flow
The sustained flow in a stream that comes from ground-water discharge or seepage.

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

Deficit
Synonymous with aquifer storage loss.

Management target
A quantified goal to reduce net ground-water 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 ground-water consumption
Ground water removed from the regional aquifer of the SVS that is not returned through incidental or artificial recharge or replaced through enhanced recharge.

Overdraft
Net ground-water consumption from the regional aquifer of the SVS 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 (SPRNCA).

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

Recharge, artificial
Ground-water recharge of municipal effluent in specifically engineered recharge facilities.

Recharge, enhanced
The increase in naturally occurring ground-water recharge through ephemeral-stream channels due to urbanization.

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

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 ground-water use that can be maintained for an indefinite period of time without causing unacceptable environmental, economic, or social consequences.

Appendix A—Public Law 108-136 (Section 321)

SEC. 321. COOPERATIVE WATER USE MANAGEMENT RELATED TO FORT HUACHUCA, ARIZONA, AND SIERRA VISTA SUBWATERSHED.

(a) LIMITATION ON FEDERAL RESPONSIBILITY FOR CIVILIAN WATER CONSUMPTION IMPACTS.—

(1) LIMITATION.—For purposes of section 7 of the Endangered Species Act of 1973 (16 U.S.C. 1536), concerning any present and future Federal agency action at Fort Huachuca, Arizona, water consumption by State, local, and private entities off of the installation that is not a direct or indirect effect of the agency action or an effect of other activities that are interrelated or interdependent with that agency action, shall not be considered in determining whether such agency action is likely to jeopardize the continued existence of any endangered or threatened species or result in the destruction or adverse modification of designated critical habitat.

(2) VOLUNTARY REGIONAL CONSERVATION EFFORTS.—Nothing in this subsection shall prohibit Federal agencies operating at Fort Huachuca from voluntarily undertaking efforts to mitigate water consumption.

(3) DEFINITION OF WATER CONSUMPTION.—In this subsection, the term ''water consumption'' means all water use off of the installation from any source.

(4) EFFECTIVE DATE.—This subsection applies only to Federal agency actions regarding which the Federal agency involved determines that consultation, or reinitiation of consultation, under section 7 of the Endangered Species Act of 1973 (16 U.S.C. 1536) is required with regard to an agency action at Fort Huachuca on or after the date of the enactment of this Act.

(b) RECOGNITION OF UPPER SAN PEDRO PARTNERSHIP.—Congress hereby recognizes the Upper San Pedro Partnership, Arizona, a partnership of Fort Huachuca, Arizona, other Federal, State, and local governmental and nongovernmental entities, and its efforts to establish a collaborative water use management program in the Sierra Vista Subwatershed, Arizona, to achieve the sustainable yield of the regional aquifer, so as to protect the Upper San Pedro River, Arizona, and the San Pedro Riparian National Conservation Area, Arizona.

(c) REPORT ON WATER USE MANAGEMENT AND CONSERVATION OF REGIONAL AQUIFER.—

(1) IN GENERAL.—The Secretary of [the] Interior shall prepare, in consultation with the Secretary of Agriculture and the Secretary of Defense and in cooperation with the other members of the Partnership, a report on 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 Secretary of the Interior shall submit the report to Congress not later than December 31, 2004.

(2) PURPOSE.—The purpose of the report is to set forth measurable annual goals for the reduction of the overdrafts of the groundwater of the regional aquifer, to identify specific water use management and conservation measures to facilitate the achievement of such goals, and to identify impediments in current Federal, State, and local laws that hinder efforts on the part of the Partnership to mitigate water usage in order to restore and maintain the sustainable yield of the regional aquifer by and after September 30, 2011.

(3) REPORT ELEMENTS.—The report shall use data from existing and ongoing studies and include the following elements:

(A) The net quantity of water withdrawn from and recharged to the regional aquifer in the one-year period preceding the date of the submission of the report.

(B) The quantity of the overdraft of the regional aquifer to be reduced by the end of each of fiscal years 2005 through 2011 to achieve sustainable yield.

(C) With respect to the reduction of overdraft for each fiscal year as specified under subparagraph (B), an allocation of responsibility for the achievement of such reduction among the water-use controlling members of the Partnership who have the authority to implement measures to achieve such reduction.

(D) The water use management and conservation measures to be undertaken by each water-use controlling member of the Partnership to contribute to the reduction of the overdraft for each fiscal year as specified under subparagraph (B), and to meet the responsibility of each such member for each such reduction as allocated under subparagraph (C), including—

(i) a description of each measure;

(ii) the cost of each measure;

(iii) a schedule for the implementation of each measure;

(iv) a projection by fiscal year of the amount of the contribution of each measure to the reduction of the overdraft; and

(v) a list of existing laws that impede full implementation of any measure.

(E) The monitoring and verification activities to be undertaken by the Partnership to measure the reduction of the overdraft for each fiscal year and the contribution of each member of the Partnership to the reduction of the overdraft.

(d) ANNUAL REPORT ON PROGRESS TOWARD SUSTAINABLE YIELD.—

(1) IN GENERAL.—Not later than October 31, 2005, and each October 31 thereafter through 2011, 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 toward achieving and maintaining the sustainable yield of the regional aquifer by and after September 30, 2011.

(2) REPORT ELEMENTS.—Each report shall include the following:

(A) The quantity of the overdraft of the regional aquifer reduced during the reporting period, and whether such reduction met the goal specified for such fiscal year under subsection (c)(3)(B).

(B) The water use management and conservation measures undertaken by each water-use controlling member of the Partnership in the fiscal year covered by such report, including the extent of the contribution of such measures to the reduction of the overdraft for such fiscal year.

(C) The legislative accomplishments made during the fiscal year covered by such report in removing legal impediments that hinder the mitigation of water use by members of the Partnership.

(e) VERIFICATION INFORMATION.—Information used to verify overdraft reductions of the regional aquifer shall include at a minimum the following:

(1) The annual report of the Arizona Corporation Commission on annual groundwater pumpage of the private water companies in the Sierra Vista Subwatershed.

(2) The San Pedro base flow monitoring record of the Charleston flow gauge of the United States Geological Survey.

(3) Current surveys of the groundwater levels in area wells as reported by the Arizona Department of Water Resources and by Federal agencies.

(f) SENSE OF CONGRESS.—It is the sense of Congress that any future appropriations to the Partnership should take into account whether the Partnership has met its annual goals for overdraft reduction.

(g) DEFINITIONS.—In this section:

(1) The term ‘‘Partnership’’ means the Upper San Pedro Partnership, Arizona.

(2) The term ‘‘regional aquifer’’ means the Sierra Vista Subwatershed regional aquifer, Arizona.

(3) The term ‘‘water-use controlling member’’ has the meaning given that term by the Partnership.

Appendix B—List of Partnership Reports and Other Documents Consulted to Calculate Management-Measure Water Yields

Biological Assessment for the Sierra Vista Water Reclamation Facility Effluent Recharge Project. U.S. Department of the Interior, Bureau of Reclamation, for Sierra Vista. August 1998.

City of Bisbee Wastewater Rehabilitation Project Summary. From project design documents by Russell McConnell, City of Bisbee Public Works Director, for USPP. October 10, 2002.

City of Sierra Vista Water Reclamation Facility Final Report. Fluid Solutions, for City of Sierra Vista. May 13, 1999.

Comparison of Methods to Estimate Ephemeral Channel Recharge, Walnut Gulch, San Pedro River Basin, Arizona, in Groundwater Recharge in a Desert Environment: The Southwestern United States. Agricultural Research Service and U.S. Geological Survey. Goodrich , D.C. , D.G. Williams, C.L. Unkrich, J.F. Hogan, R.L. Scott, K.R. Hultine, D. Pool, A.L. Coes, and S. Miller. 2004. Edited by J.F. Hogan, F.M. Phillips, and B.R. Scanlon, Water Science and Applications Series, vol. 9, American Geophysical Union, Washington, D.C., 77–99.

Cost Share Agreement between Sierra Vista, Bureau of Reclamation, and Arizona Water Protection Fund. 1996.

Environmental Assessment for the Sierra Vista Water Reclamation Facility Effluent Recharge Project. Fluid Solutions, ENTRANCO, ASL Hydrologic and Environmental Services, and Department of the Interior, Bureau of Reclamation, for City of Sierra Vista. December 1998.

A Groundwater Flow Model of the Sierra Vista Subwatershed of the upper San Pedro Basin—Southeastern Arizona—Modeling Report No. 10. Arizona Department of Water Resources Hydrology Division. December 1996.

Groundwater Flow Model Scenarios of Future Groundwater and Surface Water Conditions: Sierra Vista Subwatershed of the upper San Pedro Basin- Southeastern Arizona-Supplement to Modeling Report 10. Arizona Department of Water Resources Hydrology Division. November, 1996.

Preliminary Cost/ Benefit Analysis for Water Conservation, Reclamation and Augmentation Alternatives for the Sierra Vista Subwatershed. Fluid Solutions/ BBC Research & Consulting for the USPP. November 2003.

Programmatic Biological Assessment for Ongoing and Programmed Future Military Operations and Activities at Fort Huachuca, Arizona. Environmental and Natural Resources Division, Directory of Installation Support, U.S. Army Garrison, Fort Huachuca, Arizona. July 2002.

Project SP- 0011 Storm Water Recharge Feasibility Analysis. GeoSystems Analysis, Inc., for the Upper San Pedro Partnership. February 24, 2004.

Proposed Sewage Work Improvements for Town of Huachuca City, Arizona. Entellus Inc., for USPP and Huachuca City. July 1, 2002.

Proposed Water Management Strategy. City of Sierra Vista, in support of the Fort Huachuca Biological Opinion. October 8, 2002 and February 12, 2003 update.

Rapid Infiltration Basin Recharge System Design Concept Report for Sierra Vista Water Reclamation Facility. ASL Hydrologic & Environmental Services, for City of Sierra Vista. November 26, 1997.

Report on Feasibility of Groundwater Recharge and Sewage Reuse in the Sierra Vista Subwatershed. ASL Hydrologic & Environmental Services, for City of Sierra Vista and U.S. Department of Interior Bureau of Reclamation. June 30, 1995.

Wetland Wastewater Polishing System- Final Design Concept Report- Sierra Vista Water Reclamation Facility. ENTRANCO (for City of Sierra Vista). February 10, 1998.

Partnership planning documents consulted for report preparation

2004 Water Management and Conservation Plan. USPP. February 11, 2004.

Upper San Pedro Partnership Progress Report. USPP Administrative Committee. January 2001.

Upper San Pedro Partnership Semi-annual Report - progress through January 2000. USPP Administrative Committee. February 9, 2000.

Water Conservation Plan- 2002 Progress Report. USPP Administrative Committee. January 2002.

A Working Water Conservation Plan. USPP. February 12, 2003.

Appendix C—Sierra Vista Subwatershed Ground-Water Budget

A ground-water budget accounts for the inflows and outflows of water to a basin and is one way to estimate storage depletion caused by pumping. The change in storage can be determined by simple arithmetic using the measured and estimated terms of a budget equation.

$$\text{Inflows} = \text{Outflows} \pm \text{STORAGE CHANGE}, \tag{1}$$

or specific to the SVS

$$\text{Natural recharge} + \text{Additional recharge} + \text{Ground-water inflow} = \text{Ground-water flow} + \text{Stream base flow out} + \text{Evaporation and plant transpiration} + \text{Pumping} + \text{Water from storage} \tag{2}$$

where:

Natural recharge	=	natural recharge to the SVS from all sources, including mountain front/block, ephemeral-stream channel, and areal recharge,
Additional recharge	=	artificially induced or enhanced recharge,
Ground-water inflow	=	ground-water underflow from Mexico,
Ground-water outflow	=	ground-water outflow from the SVS,
Stream base flow out	=	base flow of the San Pedro River at the Tombstone gaging station
Evaporation and plant transpiration	=	consumptive ground-water use by riparian system,
Pumping	=	withdrawals or pumpage from SVS by all non-natural sources; agricultural and private domestic well pumping is net and private and municipal water provider pumping is gross, and
Water from storage	=	change in ground-water storage.

Budget Terms

In order to assign values to each budget term, this report relies on existing information from previous studies that prepared ground-water budgets for the SVS. Future reports to Congress will rely increasingly on data collected from the monitoring program established for Section 321. A summarization of the values previously reported, along with a simple unpublished base-flow analysis, are presented in tables C1 and C2. Table C1 shows reported values for the predevelopment water budget, and table C2 shows budget estimates for the developed system.

Some of the terms presented in tables C1 and C2 can be measured directly, whereas others are more precisely estimated with the help of a ground-water flow model. The following section provides a brief explanation of how these budget terms can be derived.

Subwatershed Recharge—Natural. SVS recharge (natural recharge plus ground-water inflow in equation 2) cannot be measured directly. Instead, it is calculated from predevelopment ground-water outflow (base flow) data collected at a location where geologic constrictions force most of the SVS ground-water outflow into the stream. This calculation of recharge is based on the fact that, prior to development, average recharge and discharge are equal. Ideally, a recharge calculation would include a long predevelopment period to average the calculation over variations in climate. Unfortunately, long predevelopment streamflow records are rare. In the SVS, data from the USGS streamflow-gaging stations, San Pedro River at Charleston (station number 09471000) and San Pedro River at Palominas (station number 09470500), have been used for recharge calculations. The station at Charleston is particularly useful for recharge calculations as it is near a geologic constriction and has a record extending into predevelopment times. After development occurs, recharge cannot be estimated using base-flow discharge data because one cannot know if reductions in base flow are due to changes in climate or changes in pumping.

Total recharge is distributed among mountain-front, ephemeral-stream channel (combined as natural recharge in equation 2), and ground-water underflow components (ground-water inflow in equation 2). Ephemeral-stream channel recharge is generally lumped with mountain-front recharge owing to a lack of direct measurements. Recent efforts in the SVS have started to identify the relative proportions of mountain-front and ephemeral-stream channel recharge. Ground-water underflow into the upstream end of the SVS can be estimated using hydraulic gradients, aquifer parameters, and aquifer geometry. A ground-water flow model provides further refinement of the recharge distribution and the proportion of mountain-front recharge to underflow recharge.

Subwatershed Recharge—Induced. In the SVS, most of the precipitation evaporates before having the chance to recharge the aquifer. The amount of precipitation that recharges can, at least in local areas, be enhanced either through engineered projects or simply through urbanization (additional recharge in equation 2).

Subwatershed Discharge—Natural. In the predevelopment condition, all ground-water discharges from the system are a combination of stream outflow (base-flow component), plant transpiration and evaporation (evapotranspiration or ET), and ground-water underflow. Base flow is that portion of streamflow derived entirely from ground-water sources. In existing SVS budgets, base-flow discharge measurements were used to quantify both predevelopment and development stream-outflow values.

The average amount of ground water that leaves the subwatershed in a year through streamflow is equal to the total base flow for that year (stream base flow out in equation 2). Because base-flow measurements are a direct measure of outflow, the stream base flow out term in equation 2 can be determined under both predevelopment and development conditions. A base-flow record also contains other information, including information that can be used to estimate ET and total SVS outflow.

ET has been estimated in a variety of ways. Recently developed techniques have provided direct measurements of ET in small areas along the San Pedro River that have been subsequently scaled to estimate ET for the entire riparian system. The water budgets shown in table C2, however, have utilized less direct techniques. Freethey (1982), for example, borrowed ET estimates from other studies and extrapolated to the Sierra Vista Subwatershed. Corell and others (1996) exploited annual changes in base flow to estimate ET. In the winter, when ET is very low, stream base flow contains the full volume of ground water leaving the SVS. In summer, base flow decreases because some of the ground-water outflow discharges through riparian vegetation rather than through the stream channel. The difference between the winter and summer base flows provides a measure of the volume of water exiting the SVS through ET. A calibrated ground-water model provides additional refinement of ET outflow estimates by balancing inflows and outflows in the context of measured water levels and outflows.

Because winter base flow contains the full amount of water leaving the SVS (except for the amount leaving as ground-water underflow), an annualized value of winter base flow is equivalent to the total annual discharge. Therefore, winter base flow can be used to calculate total recharge and total discharge.

Subwatershed Discharge—Pumped. Estimates of ground-water demand in the SVS for 2002 were made by the ADWR and are the basis for this discussion. Water-demand estimates for agricultural use are based on LANDSAT imagery, aerial photography, and field verification of irrigated acreage. Consumptive-use estimates for the crops were applied to the irrigated acreage to determine demand.

Municipal and domestic water-supply demand estimates are based on Arizona Corporation Commission data for private water providers, population data, and estimated per-capita water use. The exempt well population was estimated as the difference between the total population in the area and the population served by the private water providers and estimated population in Fort Huachuca. Surface-water and effluent use were taken into account and were subtracted from the total demand to determine municipal and domestic demand.

Water supply for the industrial sector was estimated on the basis of the demand for water for golf courses and for sand and gravel operations. Stock water demand was estimated by using an annual average usage of 12 gallons per animal per day.

Subwatershed Storage Change. Each budget shown in table C2 indicates an annual decline in aquifer storage. In these budgets, storage change (water from storage in equation 2) has been calculated as a residual from the other budget terms and not been directly measured. As a result, the uncertainty contained in the estimate of change in storage includes the uncertainties inherent in every other term. In future Section 321 reporting, changes in regional aquifer storage will be measured directly through changes in microgravity values, thereby removing the uncertainty propagated by calculating storage as a residual.

Water Budgets and Capture

The predevelopment values listed in table C1 represent estimates from various studies of the SVS ground-water budget in a steady-state condition. A steady-state condition is a simplification of a real system that indicates the budget elements are not changing in time. In a steady-state system, recharge and discharge are equal and storage change is zero. Real ground-water systems fluctuate in time, even in predevelopment conditions. In a basin aquifer system, climatic variations cause recharge and discharge to vary from period to period with the periods ranging from very short to very long times. On average, however, discharge and recharge in an undeveloped aquifer are equal. A condition of continuous variability with long-term stability is termed “dynamic equilibrium.” Given that natural variability does occur, any long-term management plan should evaluate the potential for extended dry and wet periods.

Table C1. Summarization of predevelopment ground-water budgets for the Sierra Vista Subwatershed

[In acre-feet per year. ---, indicates no data]

	Predevelopment									
	Recharge				Discharge					
Source	Mountain-front	Ground-water inflow	Ephemeral channel	Total	Ground-water outflow	Evapotrans-piration	Stream base flow out[1]	Net pumpage	Total	Storage change
Freethey (1982)[2]	12,520	3,190	---	[3]15,710	370	7,820	[3,4]7,520	---	[3]15,710	0
Vionnet (1992)[2]	12,830	3,730	---	[5]16,560	650	7,900	[5,4]8,010	---	[5]16,560	0
Corell and others (1996)[6]	15,000	3,000	1,000	19,000	440	8,020	[4]9,540	1,000	19,000	0
Corell and others (1996)[2]	14,780	3,000	1,000	18,870	440	7,900	[4]9,530	1,000	18,870	0
Base flow analysis-USGS[7,8]	[9]11,200	[10]3,000	---	[7]14,200	450	[11]7,900	[8]5,850	---	[7]14,200	0

[1]Stream base flow refers only to ground-water contributions to streamflow and excludes flood runoff.

[2]Model calibrated steady-state budget based on predevelopment conditions around 1940.

[3]Net recharge and discharge. Recharge and discharge in the model budget include stream losses and gains within the Sierra Vista Subwatershed and represent gross inflows and outflows. Reported gross recharge and discharge are 16,510 acre-feet/year.

[4]Average annual base flow (ground-water outflow).

[5]Net recharge and discharge. Recharge and discharge in the model budget include stream losses and gains within Sierra Vista Subwatershed and represent gross inflows and outflows. Net recharge and discharge are 18,470 acre-feet/year.

[6]Conceptual steady-state budget based on predevelopment conditions around 1940.

[7]Unpublished estimate based on winter (January 15 through February 28) 7-day low flow analysis of U.S. Geological Survey San Pedro River at Charleston (09471000) and U.S. Geological Survey San Pedro River at Babocomari (09471440) gaging stations. Charleston gage winter 7-day low flow averaged over years 1936-40. Historic Babocomari 7-day winter low flow estimated from modern record. Not reviewed and subject to revision.

[8]Analysis based on annualized winter base flow, but stream base flow out is calculated as the difference between annualized winter base flow and evapotranspiration of 7,900 acre-feet/year from Corell and others (1996).

[9]Mountain-front recharge is the residual of the difference between base flow derived total recharge and Corell and others (1996) ground-water inflow value.

[10]Ground water inflow from Mexico from Corell and others (1996). Base-flow analysis does not proportion recharge among specific sources.

[11]Evapotranspiration not measured or estimated using annualized winter base-flow method. Value from Corell and others (1996).

Table C2. Summarization of development ground-water budgets for the Sierra Vista Subwatershed

[In acre-feet per year. ---, indicates no data]

		Development											
		Recharge				Discharge					Capture[1]		
Source	Period	Mountain-front	Ground-water inflow	Ephemeral channel	Total	Ground-water outflow	Evapo-trans-piration	Stream base flow out[2]	Net pumpage[3]	Total	From Recharge	From Discharge	Storage change
Freethey (1982)[4]	[4]1977	12,520	3,400	---	[5]15,920	300	6,230	[6]4,490	10,570	[5]21,590	210	4,690	-5,670
Corell and others (1996)[7]	[7]1940–1990	15,000	3,000	1,000	19,000	440	7,070	[6]6,290	[8]14,500	28,300	0	5,200	-9,300
Base-flow analysis-USGS[9,10,11]	[9,10]1936–2003	[12]11,200	[13]3,000	---	[9]14,200	450	[14]7,070	[10,11]4,230	[8]14,500	26,250	---	2,450	-12,050
ADWR, 2004[15]	[15]1940, 2002	15,000	3,000	---	18,000	440	7,700	[6]3,250	[16]15,000	24,600	0	6,600	-8,400

[1]Capture calculated as the difference between predevelopment and postdevelopment inflow and outflow conditions within a particular budget analysis.

[2]Stream base flow refers only to ground-water contributions to streamflow and excludes flood runoff.

[3]Total (gross) pumping less water returned to the aquifer by incidental return flow and artificial recharge.

[4]Model calculated transient water budget of inflows and outflows in 1977.

[5]Net recharge and discharge. Recharge and discharge in the model include stream losses and gains within the Sierra Vista Subwatershed and represent gross inflows and outflows. Reported recharge and discharge are 17,370 and 23,040 acre-feet/year, respectively.

[6]Average annual base flow (ground-water outflow).

[7]Modeled combination of steady-state recharge from late 1930s period and 50 year (1940 to 1990) average of stream and evapotranspiration outflows, but with the Arizona Department of Water Resources' estimate for 2002 of net agricultural and gross municipal and domestic pumping less 2,000 acre-feet/year incidental return flow and less the Partnership's estimate of 2,000 acre-feet/year of artificial recharge. If natural recharge has decreased with discharge owing to climate change during the transient period, then the storage loss is a low estimate.

[8]Pumping is the Arizona Department of Water Resources w and less the Partnership's estimate of 2,000 acre-feet of artificial recharge in 2002.

[9]Analysis of U.S. Geological Survey streamflow records. Recharge based on winter (January 15 through February 28) 7-day low-flow analysis of U.S. Geological Survey San Pedro River at Charleston (09471000) and U.S. Geological Survey Babocomari River near Tombstone (09471440) gaging stations. Charleston gage winter 7-day low-flow averaged over years 1936 through 1940. Historic Babocomari 7-day winter low flow estimated from modern record. Unpublished, not reviewed, and subject to revision.

[10]Analysis of U.S. Geological Survey streamflow records. Discharge calculated from winter (January 15 through February 28) 7-day low-flow analysis of U.S. Geological Survey San Pedro River at Charleston (09471000) and U.S. Geological Survey Babocomari River near Tombstone (09471440) gaging stations. Charleston station winter 7-day low flow averaged for years 1936 through 2003. Historic Babocomari 7-day winter low flow estimated from modern record. Net pumping is the Arizona Department of Water Resources' estimate for 2002 of net agricultural and gross municipal and domestic pumping less 2,000 acre-feet/year incidental return flow and less the Partnership's estimate of 2,000 acre-feet/year of artificial recharge. Unpublished.

[11]Analysis based on annualized winter base flow, but stream base flow out is calculated as the difference between annualized winter base flow and evapotranspiration of 7,070 acre-feet/year from Corell and others (1996).

[12]Mountain-front recharge is the residual of the difference between base flow derived total recharge and Corell and others (1996) ground-water inflow value.

[13]Ground-water inflow from Mexico from Corell and others (1996). Base-flow analysis does not proportion recharge among specific sources.

[14]Evapotranspiration not measured or estimated using annualized winter base-flow method. Value from Corell and others (1996).

[15]Combination of 1940 annualized winter base flow derived recharge with 2002 net pumping and 1996–2002 U.S. Geological Survey San Pedro near Tombstone (09471550) gaging-station outflows. Budget considers 1,500 acre-feet/year of effluent recharge rather than the 2,000 acre-feet/year the Partnership estimates for 2002 in its water-management plans.

[16]Pumping is the Arizona Department of Water Resources w and less the Arizona Department of Water Resources' estimate of 1,500 acre-feet of artificial recharge in 2002.

The budget elements in table C2 were derived from various studies of the SVS in a developed condition, meaning ground water has been removed for human uses. In the developed condition, the combined annual volume of natural discharge and pumped water is larger than the predevelopment natural discharge. Since total discharge is larger than recharge, the deficit of water must initially come from aquifer storage. Processes and forces in an aquifer, however, will adjust to arrive at a new steady state where recharge and discharge are again equal. In this adjustment action, recharge can increase and/or discharge can decrease in a process called capture. Figure C1 schematically illustrates the capture process. In semiarid regions such as the SVS, capture can cause only small increases in natural recharge, but the natural discharge can decrease from the predevelopment level to zero. If pumpage is less than natural recharge, the aquifer will eventually reach a new steady state and storage change will go to zero.

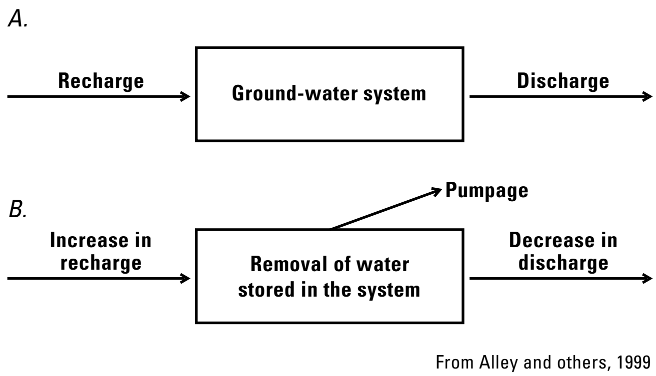

Figure C1. Schematic illustrating water budgets for a ground-water system for predevelopment (A) and development (B) conditions.

The consequence, however, is that the natural discharge will be decreased from its steady-state value by an amount equal to the net pumping withdrawals. Any amount of net pumping will eventually have consequences in discharge from a ground-water basin. Figure C2 illustrates how, over time, the source of water tapped by a pumping well transitions from primarily storage to primarily streamflow capture. The values of ET and stream base flow in table C2 for the Freethey (1982), Corell and others (1996), and ADWR (2004) budgets reflect ground-water model predictions of capture; that is why these values are reduced from the predevelopment conditions. The reduction in stream base flow in the unpublished USGS analysis simply reflects decreases in base flow over the period of record.

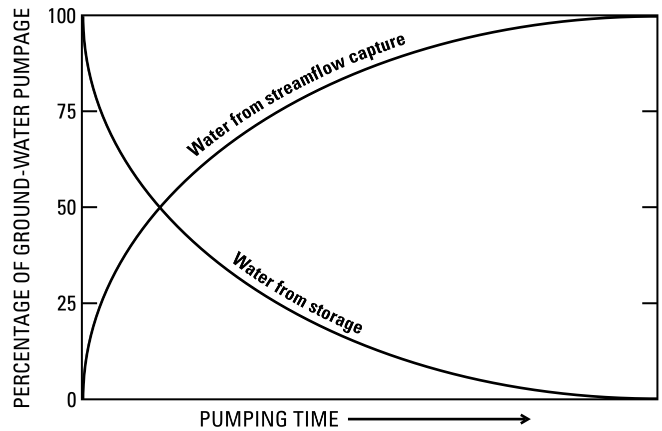

Figure C2. Change in source of pumped water over time.

The values presented in tables C1 and C2 illustrate how different ways of looking at the same system yield different results. In interpreting numbers in table C2, the developed SVS budgets, care is warranted as the studies do not incorporate the same time scales and methods. For instance, Freethey's (1982) report only documents development-period results for 1968 and 1977. Pumping, and perhaps other budget elements, have clearly changed since 1977. ADWR's (2004) budget mixes a predevelopment recharge value with a modern stream-discharge value. The modern stream-discharge value is less than the historical average, possibly owing to recent drought conditions prevalent in the Southwestern United States. The combination of high-recharge and low-discharge values results in a low estimate of annual storage depletion. Recharge cannot be measured directly on a basin scale, but it is likely that recharge during the present drought conditions is lower than during the period used to calculate predevelopment recharge. An analysis by Pool and Coes (1999) using a recharge equation developed by Anderson and others (1992) estimated that mountain-front recharge in the SVS could be expected to vary about 3,700 acre-feet/year between wet and dry periods. Since climate can change dramatically and quickly, attempting to calculate water budgets using short periods of data results in constantly changing results. Clearly, selecting short periods over which to estimate the natural aspects of a water budget is problematic. A more representative approach is to examine long-term averages of measured and model-derived water-budget parameters. In this way, current pumping estimates can be used to determine storage change and aquifer overdraft relative to long-term outflow conditions.

Appendix D—ADWR Ground-Water Budget for the Sierra Vista Subwatershed for 2002

Table D1. Annual ground-water inflows (supply) and outflows (demand) for the Sierra Vista Subwatershed; pumping volume specific to 2002

[Volumes in acre-feet/year]

Budget term	Volume
Ground-water demand	
Agriculture	2,500
Municipal/domestic	14,500
Industrial/stock	1,500
Riparian evapotranspiration	7,700
Base flow and ground-water underflow	3,700
Ground-water supply	
Ground-water supply	
Natural recharge	18,000
Incidental recharge	2,000
Effluent recharge	1,500
Change in aquifer storage	
Supply minus demand	-8,400[1]

[1]Value rounded to nearest 100 acre-feet/year.

Appendix E—Projection of Population and Water Use from 2000 to 2011

Table E1. Population in the Sierra Vista Subwatershed, 2000; and projected populations for 2002, 2010, and 2011

	2000 census population	10-year growth rate[1]	2002 projected population	2010 projected population	2011 projected population
Sierra Vista (exc. Fort)	29,350	23%	30,700	36,100	36,800
Fort Huachuca	8,585	500 people	8,684	9,084	9,100
Bisbee	6,090	15%	6,275	7,000	7,100
Huachuca City	1,750	15%	1,800	2,000	2,050
Tombstone	1,500	17%	1,550	1,750	1,800
Unincorporated areas	20,810	24%	21,800	25,800/	26,300
TOTAL	**68,085**		**70,809**	**81,734**	**83,150**

[1]Cochise county estimate of growth rates for 2000 to 2010.

Table E2. Projected municipal and unincorporated-residential gross pumping and net use in the Sierra Vista Subwatershed for 2011

[values in acre feet]

	2002			2011		
	Total pumping	Incidental recharge[1]	Net ground-water use	Total pumping	Incidental recharge[1]	Net ground-water use
Sierra Vista (exc. Fort)	5,795	200	5,595	6,940	200	6,740
Fort Huachuca	1,500	0	1,500	1,500	0	1,500
Bisbee	1,000	0	1,000	1,130	0	1,130
Huachuca City	275	0	275	310	0	310
Tombstone	250	0	250	290	0	290
Unincorporated areas	5,680	1,800	3,880	6,850	2,370	4,680
TOTAL	**14,500**	**2,000**	**12,500**	**17,020**	**2,370**	**14,650**

[1]Ground-water recharge from sources not specifically engineered to generate recharge, such as septic tanks and golf courses.

Appendix F—Details of Water-Management Measures

Projected annual yields for member agency projects are based on the best information currently available to the Partnership, and current agency commitments. The Partnership is continuing to collect data and develop tools to analyze potential and planned projects, and it intends to review this plan at least annually. Projects may be added, deleted, or modified to this plan periodically, but the Partnership is committed to assure the implemented projects plus planned projects meet the stated goal and objective of the partnership and the congressional intent of achieving sustainable yield by 2011 and beyond. Some of these measures are constrained by legal impediments detailed in the sections entitled "Water-Management Measures and Legal Impediments."

The values presented in table F1 are drawn from comprehensive Partnership evaluations of feasible management options and expected water yields. Some values differ from those in earlier Partnership reports to maintain consistency with the underlying ADWR water budget in the calculation of projected aquifer-storage deficits.

Table F1. Projected annual yields of specific measures planned by Partnership members to reduce aquifer overdraft

[Yields in acre-feet/year; ---, indicate no yield during year. Numbers compiled in May–July, 2004]

Description	Water-budget component[2]	Estimated annual yield[1]									
		2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Fort Huachuca											
Conservation measures	Reduced pumping	320	410	470	530	590	650	710	770	830	870
Effluent reuse	Reduced pumping	---	20	20	120	120	120	120	120	120	120
Effluent recharge	Increased recharge	190	290	520	510	500	490	480	470	460	440
Stormwater detention basins[3]	Increased recharge	60	40	370	530	530	690	690	990	990	1,040
Cochise County											
Public education (water wise)	Reduced pumping	90	90	90	90	90	100	100	100	100	110
Rebates	Reduced pumping	---	---	10	10	10	10	10	10	10	10
Code changes[4]	Reduced pumping	---	---	---	50	100	150	200	250	300	350
Sierra Vista											
Public education (water wise)	Reduced pumping	120	120	130	130	130	130	140	140	140	150
Rebates	Reduced pumping	10	20	30	30	30	30	30	30	30	30
Code changes[4]	Reduced pumping	30	70	100	140	170	205	240	270	310	340
Effluent recharge plant[5]	Additional recharge	2,000	2,050	2,090	2,140	2,190	2,240	2,290	2,350	2,400	2,450
Golden Acres connection to wastewater-treatment plant	Additional recharge	---	---	---	---	60	60	70	70	70	70
Stormwater detention basins[3]	Additional recharge	140	180	290	320	550	740	860	870	870	870

See footnotes at end of table.

Table F1. Continued.

Description	Water-budget component[2]	Estimated annual yield[1] 2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
The Nature Conservancy and Fort Huachuca											
Retire agricultural pumping	Reduced pumping	---	---	---	---	250	250	500	1,000	1,500	2,000
Bisbee											
Code changes[4]	Reduced pumping	---	---	---	---	10	20	30	40	50	60
Reuse effluent on golf courses	Reduced pumping	---	---	---	---	---	420	420	420	420	420
Effluent recharge plant	Additional recharge	---	---	---	---	---	160	170	180	180	190
Huachuca City											
Code changes[4]	Reduced pumping	---	---	---	---	5	5	10	10	10	20
Effluent recharged at Fort Huachuca	Additional recharge	---	---	---	---	---	170	180	180	180	180
Tombstone											
Code changes[4]	Reduced pumping	---	---	---	---	5	5	10	10	10	20
Bureau of Land Management											
Conservation measures[6]	Reduced pumping and evapotranspiration	240	320	410	490	580	660	750	830	920	1,000
Urban stormwater recharge											
Increase in stormwater recharge in ephemeral-stream channels by urbanization[7]	Additional recharge	3,200	3,200	3,200	3,200	3,200	3,200	3,200	3,200	3,200	3,200
Total yield											
Total yield[8]		6,400	6,800	7,700	8,300	9,100	10,500	11,200	12,300	13,100	13,900

[1]Documents consulted to estimate yields listed in appendix B.

[2]Indicates part of water budget where indicated management measure is counted. Reductions in pumping are relative to what would have been pumped if no management measures were enacted; overall pumping increases as population grows.

[3]Recharge increased beyond predevelopment values using basins that slow runoff. Values are preliminary but derive from work done by Geosystems Analysis (SP-0011, 2004) evaluating recharge. Numbers will be revised as additional information becomes available.

[4]Assumes 5-percent reduction in use.

[5]Recharge values based on engineering reports used for recharge facility site location selection (Fluid Solutions, 1999). Values exclude water lost to evaporation and diversion from direct recharge.

[6]Water-use savings through management of invasive mesquite using various treatments and retirement of irrigated agriculture or other high water-consumption uses by consensual agreement. Mesquite reduction reduces water use by replacing mesquite with more shallowly rooted plants. Yield from mesquite reduction estimated using a U.S. Department of Agriculture–Agricultural Research Service model of riparian evapotranspiration in the SPRNCA.

[7]Urbanization in arid 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 owing to urbanization exceeds increased recharge.

[8]Total yields rounded to nearest 100 acre-feet per year.

Appendix G—Monitoring and Reporting

Section 321 requests a description of monitoring and verification activities to be undertaken by the Partnership to measure the reduction of the overdraft to the regional aquifer in the SVS. At a minimum, the information considered must include:

(1) The annual report of the Arizona Corporation Commission (ACC) on annual ground-water pumpage of the private companies in the Sierra Vista Subwatershed.

(2) The San Pedro base-flow monitoring record of the Charleston streamflow-gaging station of the U.S. Geological Survey

(3) Current surveys of the ground-water levels in area wells as reported by the Arizona Department of Water Resources and by Federal agencies.

Each of these data sources will be utilized in monitoring activities. These sources considered alone, however, are inadequate to confidently document reductions in overdraft. The ACC report, for example, does not include private domestic wells in the SVS. Base flows at the Charleston gaging station may reflect both human influences and climatic variability and not necessarily within the time scale of Section 321 reporting; recent research has demonstrated the expression of short- and long-term climate change signals in streamflow records (Hanson and others, 2004). A well-designed monitoring program is needed to provide the annual reporting to Congress and provide a feedback mechanism for the adaptive management process. In order to satisfy the requirements of future Section 321 reporting, monitoring will track both hydrologic and ecologic conditions and the progress of member agency projects. Regional monitoring and project-specific monitoring will be conducted separately, with responsibility for project monitoring placed on the pertinent Partnership member. The following description of monitoring for future Section 321 reporting has been divided into factors related to the SVS's regional hydrologic system, to the riparian ecosystem, and to member agency projects.

Regional Hydrologic Monitoring

The monitoring plan for the SVS is tailored to the Partnership definition of sustainable yield, the terms of the hydrologic budget, and the reporting requirements of Section 321. The hydrologic budget terms include inflows (recharge), outflows (discharge), storage change, and discharge. An additional parameter related to the budget is ground-water gradient at the interface between the regional aquifer and the perennial stream reaches. Monitoring of flow in mountain-front and ephemeral streams will provide qualitative indications of climate-induced changes in recharge. Change in ground-water storage, a key indicator of sustainable yield, will indicate if combined ground-water withdrawals and natural discharge exceed total recharge. Progress toward a balance of discharge and recharge will result in a diminished, eliminated, or reversed rate of storage loss. Monitoring changes in ground-water gradients between the regional aquifer and the shallow aquifer along the river will enable identification of changes in the rate of ground-water discharge to the riparian system and the river. Finally, monitoring discharges of springs that issue from the regional aquifer and monitoring base flows of the Babocomari and San Pedro Rivers will enable identification of changes in the rate at which ground water is leaving the flow system through the natural sinks. Direct monitoring of three components of the ground-water budget, and the hydraulic links among them, will substantially improve the base of hydrogeologic information available to assess the hydrologic condition of the SVS.

The basic framework of the regional aquifer monitoring network will be established in the first year of Section 321 reporting and will remain unchanged through 2011. Elements may be added as needed, but keeping the initial framework unchanged will ensure that observed trends are due to changes in the aquifer system and not to changes in the monitoring plan.

The Partnership has recently supported the development of a new ground-water flow model that is based on an improved understanding of SVS hydrology. Part of the SVS monitoring activity will include ongoing support for that flow model.

The following sections describe aspects of monitoring regional aquifer inflows and outflows, changes in storage, and changes in hydraulic gradients.

Inflows

Natural Recharge.—The natural regional-aquifer recharge cannot be directly measured on a basin scale, and because development has occurred, recharge cannot be measured indirectly through stream base-flow measurements either. An assessment of flow in ephemeral-stream channels and mountain streams can, however, provide an indicator of variations in natural recharge to the regional aquifer. Six streamflow-gaging stations have been used to measure stream discharge both at the mountain fronts and at a distance from the mountains since 2000. These stations will be maintained through 2011 and used to estimate recharge changes for Section 321 monitoring requirements.

Enhanced Recharge of Stormwater due to Urbanization.—A recently completed Partnership funded study (GeoSystems Analysis, 2004) indicated significant potential for enhanced ephemeral-stream channel recharge due to urbanization in Coyote Wash, a small urban subwatershed in the area of Sierra Vista, Arizona. This modeling study estimated that urban development caused ephemeral-stream channel recharge to increase approximately 200 acre-feet in a dry year to roughly 800 acre-feet in a wet year. The increase is caused by concentration of runoff into ephemeral-stream channels that would otherwise have evaporated or been transpired on upland/hillslope areas. Using an average year, the postdevelopment channel recharge is estimated to be about 400 acre-feet greater than for predevelopment conditions. The Agricultural Research Service estimates that scaling up from Coyote Wash to the SVS using classified 1997 Landsat imagery described in Kepner and others (2000), results in an estimated 3,200 acre-feet of increased recharge relative to predevelopment conditions. The Partnership storm–recharge study also indicated that potential enhanced recharge from flood-detention structures was secondary in comparison to recharge from natural channels. It should be noted that extrapolation from Coyote Wash to the SVS represents a crude first approximation to a SVS estimate of recharge due to urbanization and is based on 1997 land-cover data. Estimates would be improved with updated information. We do not know if less dense development in the unincorporated areas of Cochise County produces comparable runoff to Coyote Wash for the same amount of impervious area. Because of this uncertainty, additional monitoring and study will be done to quantify recharge resulting from enhanced runoff due to urbanization.

A first step in improving this estimate will be acquisition of more contemporary land-cover data. Two sources of imagery will become available for this task in the near future. The Southwest Regional Gap Analysis Project (SWReGAP) will provide detailed, seamless geographical information system (GIS) maps of land cover, all native terrestrial vertebrate species, land stewardship, and management status derived from Landsat imagery circa 2001 to 2002 for the five-State region encompassing Arizona, Colorado, Nevada, New Mexico, and Utah. If more detailed land-cover data is warranted, classified imagery could be produced from hyperspectral Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) imagery acquired in the summer of 2004.

For ground monitoring of rainfall, runoff, and recharge, we will select approximately three small basins: a subwatershed of the Coyote Wash, an undeveloped watershed near Coyote Wash, and a watershed representative of unincorporated development occurring in significant areas of Cochise County. Instrumentation will include, but not be limited to, runoff gages, rain gages with soil moisture sensors, downstream channel-temperature probes for flow duration, and geophysical tools to quantify the amount of runoff that is recharging to the regional aquifer. These measurements can then be used to calibrate the KINEROS2 (http://tucson.ars.ag.gov/kineros) rainfall-runoff model used in the Coyote Wash study. This model can then be used with more confidence in other portions of the SVS to estimate recharge resulting from urbanization. In addition, simplified monitoring of detention structures (stage) with known outflow stage/discharge relations will be undertaken. If initial detention pond measurements indicate significant infiltration losses, we will consider more detailed microgravity measurements to improve recharge estimates from those detention structures.

Outflows

Stream Base Flow and Springs.—Stream base flow is a direct measure of ground-water discharge from the SVS. Streamflow will be monitored at three locations on the San Pedro River and one on the Babocomari River. Winter and summer base flow will be determined at each applicable site. Winter base flow will be defined as the 7-day average low flow during January and February, a period that should represent maximum recovery of base flow between periods of riparian vegetative use. The 2-month winter period should also provide a sufficiently long period of time such that the effects of runoff from large winter flows will be minimized. Summer base flow will be defined as the average 7-day low flow during June and prior to runoff from monsoonal thunderstorms. Spring base flow will be monitored at several sites—Murray Spring, Horsethief Spring, Lewis Springs, and an unnamed spring near Hereford. Climate variability will affect stream and spring base flows and will be considered in the data analysis.

Riparian Evapotranspiration within the SPRNCA.—Water use by riparian vegetation represents a substantial portion of total ground-water discharge from the subwatershed. Earlier Partnership efforts have quantified baseline riparian water use. Continuation of these efforts will track changes in riparian water use during the Section 321 reporting period. This will require continued monitoring of the depth to ground water in the shallow piezometers at study sites established for earlier Partnership funded studies. In addition, basic meteorological variables (temperature, wind speed, humidity, etc.) must also be monitored. Additional rain gages will also be installed along the riparian corridor to better quantify the spatial variability of rainfall. This is important because rainfall water can offset the use of ground water by certain riparian vegetation species. The key quantity in scaling models of various riparian vegetation species water use throughout the SPRNCA is an estimate of the spatial extent of the vegetation types. A baseline U.S. Army Corps of Engineers survey was conducted in 2000 and will be repeated in 2004 and 2008. A GIS-based ET riparian modeling tool was developed as part of a Partnership study of riparian water needs. With new observations of vegetation cover and meteorological variables, this tool can be used to update riparian water use. In addition, the tool can be used by the Partnership to estimate changes in water use resulting from changes in vegetation cover due to active management such as prescribed burns.

Ground-Water Withdrawals (Pumping).—Consumptive ground-water use is the portion of the water withdrawn or pumped that is not returned to the ground-water system because of consumption by humans, use by crops, or loss through evaporation and transpiration. Ground water is used for all water-use categories in the SVS. The primary water-use categories are agriculture, public and domestic supply, and industry.

Ground-water withdrawal for public and domestic supply use represents 78 percent of the total withdrawal in the SVS, according to the ADWR. Water-delivery data from private water companies will be obtained from the annual Arizona Corporation Commission (ACC) report. The timing of the ACC report may not correspond with Section 321 reporting requirements. In that case, the Partnership will need to obtain records directly from the local private water companies, and confirmation will be required as to whether the reported value includes losses. These losses, which can be the result of transmission leakage, breaks in distribution conveyances, and measurement errors, may vary from 10 percent for the larger water providers to 15 percent for smaller water providers (Linda Stitzer, ADWR, oral commun., May 6, 2004). Private water companies also supply water for commercial and industrial use. This task will also include obtaining data on ground water withdrawn for use in Fort Huachuca. Consumptive use will be estimated from the difference between ground-water withdrawal and estimates of intentional and incidental recharge.

Although the annual report of the ACC will document water deliveries by private water companies in the SVS, substantial volumes of ground water are pumped by private domestic/exempt wells, which are not metered or tabulated in the ACC report. The ADWR has estimated current and projected future private domestic/exempt-well water use in the SVS, but accurate accounting for Section 321 reporting will require annually updated estimates of private domestic/exempt well water use. Total ground-water withdrawal and consumptive use in areas that are not serviced by private water companies will be estimated indirectly using population data. The ADWR databases will be searched to identify new wells, and an effort will be made to determine the percentage of new wells in the database that were actually installed.

Ground-water withdrawal for agricultural use, which according to ADWR represents about 14 percent of ground-water withdrawals in the SVS, will be estimated by monitoring irrigated acreage using aerial photography and remote sensing. Field inventory will assist in the verification of the extent and type of crop acreage. Literature-supported consumptive-use values for the crops identified in the SVS will be used to estimate total consumptive use.

Change in Storage and Hydraulic Gradients

Changes in Regional Ground-Water Levels and Storage.—Ground-water storage changes in the regional aquifer will be determined by monitoring water levels and changes in microgravity. Water-level monitoring will indicate the sense of storage change, but will not measure the volume of change. Water-level decline indicates storage loss; water-level recovery indicates storage increase. Gravity methods directly measure the change in volume of ground-water storage. Water-level monitoring is important because it is widely accepted, easily understood by the public, and is the basis for calculating hydraulic gradients. Aquifer storage and water levels will vary from year to year depending not only on Partnership efforts to increase recharge and reduce consumptive pumping, but also on climatic variations. As a result, it is important to consider storage change and other budget elements over several years rather than focusing on single years.

Changes in Hydraulic Gradients between the Regional Aquifer and the River.—Ground-water gradients between the regional aquifer and stream system will be monitored on a continuous basis (hourly to daily measurements) at clusters of wells that are screened in the regional aquifer and the shallow alluvial aquifer near the river. These gradients are a measure of the force that moves water between the aquifer and the river, and they can be monitored very precisely. Changes in gradients are likely to provide an early indication of changes in flow from the regional aquifer into the river.

Riparian Ecosystem Monitoring

Stream and Shallow Ground-Water Conditions within the SPRNCA.—Hydrologic factors that directly affect riparian vegetation in the SPRNCA include ground-water levels in the stream-alluvium aquifer and streamflow conditions. Monitoring at selected locations will document status and trends of these hydrologic factors.

Riparian Ecological Condition.—The status and trends of riparian vegetation within the SPRNCA can best be assessed in terms of abundance and condition. The methodology for measuring the areal coverage of the vegetation types was established by the 2000 survey conducted by the U.S. Army Corps of Engineers using aerial photography (see http://www.epa.gov/esd/land-sci/html2/HTML/PAGES/new_metadata_meta_sprnca_grd.htm. Comparable surveys will be conducted in 2004 and 2008.

Although aerial methods can provide good estimates of the area of coverage, they are not as robust for estimating riparian vegetation condition. Levels of condition are better assessed by measuring indicator variables from ground surveys at transects. A riparian vegetation condition index was developed specifically for use in the San Pedro riparian corridor. This index is based on nine vegetation variables (indicators) that are sensitive to changes in stream- or ground-water availability. Baseline data for this index have been collected at vegetation transects and reaches established for the SPRNCA water needs study. The following cycle of vegetation monitoring will be undertaken to continue to monitor riparian ecosystem condition: (1) the four herbaceous vegetation indicators (including cover and composition of wetland plants in the low-flow stream-side zone) will be surveyed annually, and (2) on a 4-year cycle corresponding to the riparian-vegetation surveys specified in the biological opinion, the five woody-species indicators (including basal area and age structure of cottonwood-willow trees and basal area of tamarisk) survey will be undertaken. Taken together, these metrics can be used to determine trends in the overall ecological condition of the SPRNCA.

Monitoring of Water-Management Measures

Another essential element in the adaptive-management process is verifying the efficacy of the Partnership's augmentation and conservation measures. Such monitoring will confirm that actual water yields match planned yields at planned costs. Management plans included in future annual reports will reflect needed changes indicated by monitoring results.

The potential water saving resulting from some planned conservation measures is small, and monitoring costs to quantify saving from these projects may be prohibitively high. The Partnership Technical Committee, in consultation with other Partnership committees, will develop guidelines and requirements for monitoring requirements and thresholds for the level of monitoring (indirect estimates for small-yielding projects, and direct monitoring for higher-yielding projects). Specific verification measures for conservation and augmentation measures will be established and will be described in future annual reports to Congress.

Reporting, Water-Use Accounting, and Database Management

Each future annual report to Congress will require a reevaluation of the most current science and monitoring data. The Partnership will consider these data and adapt the management plan as needed to continue approaching sustainable yield in the SVS's regional aquifer.

These evaluations will rely on readily available estimates of water use and an accounting of water conservation and augmentation projects. To facilitate this process, a Web-based Partnership project-management tool will be developed by the USGS that will enable the Partnership to track water use, regional hydrologic trends, changes in the riparian ecosystem, and the timing and implementation of member agency projects.