The Assessment of Goods and Valuation of Ecosystem Services (AGAVES) Project Working Science Plan

William G. Kepner¹, Darius J. Semmens², Nita Tallent-Halsell¹, David C. Goodrich³, Matthew Weber⁴, David S. Brookshire⁵

¹U.S. Environmental Protection Agency, Office of Research and Development
944 E. Harmon Avenue, Las Vegas, NV 89119

²USGS/Rocky Mountain Geographic Science Center
P.O. Box 25046, Mail Stop 516, DFC, Denver, CO 80225

³USDA/ARS-Southwest Watershed Research Center
2000 E. Allen Road, Tucson, AZ 85719

⁴U.S. Environmental Protection Agency, Office of Research and Development
200 S.W. 35th Street, Corvallis, OR 97333

⁵Science Impact Laboratory for Policy and Economics, University of New Mexico,
Department of Economics, Albuquerque, NM 87131-0001
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1.0 Introduction

The Assessment of Goods and Valuation of Ecosystem Services (AGAVES) project is a multi-institution research effort that seeks to evaluate the consequences of natural and human-induced environmental change in the semi-arid Southwest via initial focus on the San Pedro River Basin (U.S./Mexico; [Figure 1]). The goal of AGAVES is to advance scientific understanding of the role, transfer functions, and value of ecosystem services in arid and semi-arid watersheds, and ultimately to provide useful and reliable information for environmental decision-making. AGAVES will accomplish this through a long-term, integrated program of observation, process research, modeling, assessment, valuation, and information management, using both existing and innovative technologies, and sustained by cooperation among scientists, economists, anthropologists, and decision-makers.

1.1 Purpose and Scope of Science Plan

The purpose of this Science Plan is to guide the long-term (5-10 year), programmatic development of AGAVES and to serve as the basic terms-of-reference for ongoing and proposed AGAVES research activities. Accordingly, the Science Plan defines the AGAVES mission and mode of operation; describes the key societal needs and scientific challenges to be addressed; and outlines the general research approach, components, and expected outcomes of the program. As a “living document,” the Science Plan will be modified occasionally to incorporate major changes in research needs or the needs of decision-makers and managers in the spirit of adaptive management. The Science Plan focuses on program-level science and resource management issues and strategy whereas detailed information on research plans, program structure and function, schedules and budgets will be presented in specific implementation plans and related funding proposals.

Figure 1. San Pedro River Basin, U.S./Mexico (The Nature Conservancy, Arizona Chapter).
1.2 Background

AGAVES grew out of a convergence of several ongoing and proposed efforts to observe, quantify, and model ecological processes throughout the Nation. The research and experimental component of the program follows the format of earlier multi-disciplinary studies, such as the Semi-Arid Land Surface Atmosphere (SALSA) program conducted in southeastern Arizona and northeastern Sonora, Mexico, during 1995-2000 (Chehbouni et al., 2000; Goodrich et al., 2000 – www.tucson.ars.ag.gov/salsa). Scientists from a variety of disciplines, agencies, and nations participated in this research program. Following the SALSA program, NSF funded the multi-institutional SAHRA (Sustainability of semi-Arid Hydrology and Riparian Areas) Science and Technology Center (STC) hosted at the University of Arizona (www.sahra.arizona.edu). The Rio Grande and the San Pedro were designated as SAHRA focus basins. This enabled much of the SALSA-initiated research to continue and expand with a number of former SALSA investigators. More importantly, SAHRA STC resources enabled the expansion of the SALSA disciplinary set to include economists and social scientists, a number of additional agencies, and extensive outreach and education efforts.

Under the auspices of SAHRA several efforts were initiated which directly addressed ecosystem service valuation behavioral experiments. One of these efforts focused on the non-market valuation of riparian attributes in both the Rio Grande and the San Pedro\(^a\). This study was explicitly designed to assess not only the value of the attributes within each basin but enable the testing of benefit transfer methodologies between the more highly studied San Pedro and the well studied but less integrated Middle Rio Grande (Brookshire et al., in press).

The San Pedro effort linked decision-maker generated scenarios thru a decision support system (DSS), designed with elected officials and natural resource managers of the Upper San Pedro Partnership (described below) to a regional groundwater model, to a riparian condition class model, to avian assemblage attributes. The changes to these attributes have been valued with survey instruments using stated preference methods; both contingent valuation and choice modeling. With these linkages, water conservation and/or augmentation decisions are directly linked to changes in the marginal values of riparian ecosystem attributes. Thus the marginal benefits to riparian ecosystem attributes in monetary terms can be directly compared to the marginal costs associated with conservation and augmentation decisions.

In the case of the Middle Rio Grande, the decisions impacting riparian ecosystem change are related to restoration efforts while the San Pedro focused largely on riparian preservation efforts. This study is more fully described below and in Brookshire et al. (in-press). In additional research, a stated preference choice experiment was developed and deployed in the Albuquerque, NM area to investigate public values for ongoing restoration of the Middle Rio Grande. The

\(^{a}\) This research was supported by the U.S. Environmental Protection Agency, “Integrated Modeling and Ecological Valuation,” EPA STAR GRANT Program #2003-STAR-G2 and in part by SAHRA (Sustainability of semi-Arid Hydrology and Riparian Areas) under the STC Program of the National Science Foundation, Agreement No. EAR-9876800 (work related to the avian component), and with in kind contributions from the U.S. Department of Agriculture Research Service, Hawks Aloft Inc and The Nature Conservancy.
survey was designed in partnership with Sandia National Laboratories and the U.S. Army Corps of Engineers, with results in Weber and Stewart (2008). A follow-up to this paper explores a decision support model with explicit treatment of both economic and ecological areas of uncertainty (Weber et al., in press).

Through SAHRA, recreational values for Aravaipa Creek, a tributary to the lower San Pedro were investigated through development of a revealed preference travel cost model, with the results found in Weber and Berrens (2006). Another thrust was the use of revealed preference models such as hedonic methods to assess change in real estate values as a function of its proximity to riparian habitat and as a function of the quality of that riparian habitat (Colby and Wishart; 2002).

In addition, a SAHRA Scenario Development team focused on scenario development specific to the unique problems for natural resources and environmental modeling (http://www.sahra.arizona.edu/scenarios/). Several other research programs, emphasizing groundwater modeling, satellite-sensor testing, landscape change, and human dimensions, have since contributed to the development of AGAVES and will be cited in subsequent sections of this plan.

Building on these experiences, the U.S. Geological Survey (USGS), U.S. Department of Agriculture Agricultural Research Service (USDA-ARS), and the U.S. Environmental Protection Agency (EPA) have proposed a multi-year project to evaluate ecosystem services, with an eye to broader resource management applications over a range of spatial and temporal scales, which could include the entire river basin and adjacent basins throughout the U.S./Mexico borderlands and Southwest U.S. The San Pedro was chosen as an initial AGAVES study area because it exhibits significant topographic and ecological diversity; is the subject of immediate environmental, economic, and other concerns; has significant stakeholder involvement; has a substantial scientific infrastructure already in place; and there is an existing long-term research history and database in the basin from each of the sponsoring organizations.

The challenge posed by this proposal is to evaluate how changes in climate and anthropogenic activities (e.g. land use) will likely affect ecosystem conditions and how these conditions are translated into impacts upon human health and well-being. Alternatively stated, what are the spatial and temporal patterns of ecosystem condition that enhance the value of ecosystem services and how are they likely to change in the future when subjected to multiple environmental stressors?

In January 2009, a group of scientists and resource managers met in Tucson, Arizona, to discuss plans for the AGAVES effort. A broad spectrum of science disciplines were represented, including ecology, economics, soils, meteorology, remote sensing, atmospheric science, and hydrology, among others. During the workshop, participants participated as a single cross-disciplinary group that proposed goals and objectives for specific research projects to be conducted under the umbrella of AGAVES. These initial objectives and associations, along with the general agreement to cooperate toward a common research goal have now evolved into an
operational science plan that will be used to develop focused research proposals and implementation plans.

1.3 Primary Science Questions
A principal outcome of the January 2009 Workshop was to identify how the group could improve the link between science and decision-making in the San Pedro. Addressing this challenge requires the formulation of a series of Primary Science Questions to be addressed by AGAVES researchers, working in concert with resource managers and stakeholders:

How can the AGAVES group work to improve the link between science and decision-making?

What methodologies and frameworks are suitable for ecosystem scenario construction that can dynamically account for complex relationships between system components?

What relationships exist between services that require integrated assessment strategies?

What is the relationship between temporal climatic variability and service provisioning?

What are the likely consequences of future development and climate change (stressor scenarios) on selected ecosystem services?

How does the value of ecosystem services vary both temporally and spatially under alternative climatic and anthropogenic scenarios?

These fundamental questions define the scope of the research problem and serve as the basis for deriving all secondary science questions and science challenges. They purposefully focus on the key scientific challenges associated with completing ecosystem services assessment and valuation projects, as well as the practical challenges associated with utilizing that information in a decision context.

River basins comprise well-bounded hydrological systems, and encompass many biological and cultural systems of interest as well. This is especially true of basins in mountainous regions where the range-and-valley topography strongly influences habitat and land-use patterns. By examining physical, ecological, and social processes at a basin scale, AGAVES results will have direct applicability to resource management activities based on basin or watershed planning units. Similarly, the range of time scales to be examined by AGAVES falls within the effective design and planning horizon for most management decisions.

Ultimately, the scientific understanding of physical, ecological, and social processes acquired by AGAVES will be used to assess the consequences of environmental change on coupled human-ecological systems within semi-arid basins. Quantification of the human dimensions of change will require cooperation among a broad range of ecological and social scientists. This will be accomplished within AGAVES as well as through interaction and cooperation with other research efforts that specifically address the social impacts of global change. The human
dimension component of global change will serve both to guide AGAVES research and as the endpoint for the research effort.

1.4 Mission Statement

The Mission of the AGAVES is to address the following primary objective:

To understand, model, and predict the consequences of natural and human-induced change on ecosystem services in semi-arid regions, to improve resource management and decision-making.

To accomplish this mission, AGAVES will be modeled after the successful Semi-Arid Land Surface Atmosphere (SALSA) program, a similar interdisciplinary, stakeholder-driven research project conducted in the San Pedro a decade ago. As originally described in the SALSA science plan (Goff et al. 1998), AGAVES must develop and sustain the following:

- a keen awareness of societal concerns and research needs regarding environmental change in semi-arid regions, and the ability to identify and overcome the scientific challenges to addressing these concerns and needs;
- a flexible and adaptive research approach that encourages innovation, collaboration, and a regional perspective among scientists from a wide range of disciplines; and
- a strong core program responsible for coordinating and integrating research activities and developing a publicly accessible “knowledge-base” containing the products of the research effort.

These essential components of the AGAVES mission are discussed in detail below.

1.5 Mode of Operation

AGAVES is also modeled after SALSA (Goff et al. 1998) in that it is a “research enterprise” that operates on the principle of voluntary collaboration whereby researchers interact with one another across disciplinary, institutional, and political boundaries to address particular components of the Primary Science Objective. Collaborators are free to pursue their own lines of scientific inquiry in accordance with their institutional needs and resources, and may join or leave the program as they wish. The purpose of the organized AGAVES “program” is to facilitate these interactions and to serve as a platform for research coordination, data assimilation and synthesis, and information exchange. This is an “open-market” research model as compared to a “centrally-planned” research model where resources are largely held and directed by a small, central group. The ultimate product of the AGAVES effort will be a comprehensive “knowledge-base” of data, information, and tools to aid the assessment and valuation of ecosystem services in semi-arid regions.

The role of the AGAVES core program is to help coordinate and facilitate the problem-solving process, i.e., answering the Primary Science Questions needed to address resource management
issues. The role of the AGAVES researchers is to collaborate with resource managers and stakeholders to answer the questions noted above. How AGAVES collaborators will do this is described in the sections on Research Approach and Program Components below.

2.0 Societal Concerns and Research Needs

Although still a nascent science, ecosystem services research, inventory and monitoring projects and efforts to value ecosystem services are increasing and shaping resource management and policy. The term emerged in the early 1980s to describe the framework for structuring and synthesizing biophysical understanding of ecosystem processes in terms of human well-being (Ehrlich and Mooney 1987, Mooney and Ehrlich 1997, Brauman et al 2007). The Millennium Ecosystem Assessment (MEA 2005) initiated in 2001 by the United Nations Environment Programme, embraced the ecosystem services’ conceptual framework for documenting, analyzing, and understanding the effects of environmental change on ecosystems and human well-being (Carpenter et al. 2009). The MEA synthesized information from the scientific literature and relevant peer-reviewed datasets and models. It focused on the linkages between ecosystems and human well-being, especially in regard to the provision of “ecosystem services” and represented a consensus opinion on the part of approximately 1,400 contributing experts worldwide. The MEA also stresses that investigations should be “designed to meet the needs of decision-makers for scientific information on the links between ecosystem change and human well-being.” Bennett et al. (2005) described how MEA researchers “set out to address the stated needs and concerns of decision-makers and examine the ecological dynamics and uncertainties underlying these concerns” by interviewing 59 decision-makers from five continents.

The report authors defined ecosystem services as those benefits people obtain from ecosystems and divided these into categories of provisioning services, e.g., food, water, timber, and fiber; regulating services that affect things such as climate, floods, and disease; supporting services, e.g., net primary productivity and nutrient cycling; and cultural services that provide recreational, aesthetic, and spiritual benefits. The basic premise of the report is that the human species is fundamentally dependent on the flow of ecosystem services. Particular attention was applied to developing scenarios for plausible future changes in drivers, ecosystems, ecosystem services, and human well-being.

Since the publication of the MEA Report several alternative classification schemes have been proposed (deGroot et al 2002, Boyd and Banzhaf 2007, Wallace 2007, Costanza 2008, Fisher et al. 2009). This is to be expected considering that ecosystem services research is a rapidly evolving field. For the purpose of the AGAVES research enterprise it important that researchers provide clear and concise definitions of ecosystem services and identification of the classification scheme they will be following. We do not want the various components and foci of this multi-disciplinary effort to be encumbered by evolving constructs. Utilizing an inappropriate classification can lead to problems for meaningful and robust research results (Fisher et al 2009). There is, however, a broad framework that the USGS and USEPA are beginning to consider that is contributing to the clarification of the overall ecosystem taxonomy for science understanding as well as valuation and the associated linkages of the two (Ringold et
al. 2009 and Boyd and Brookshire 2010).

2.1 Semi-arid Regions

Over 20 countries worldwide, most of them in arid and semi-arid regions, are considered to be either water-scarce or water-stressed because their growing populations require more water than the hydrological system can provide on a sustainable basis (Watson et al., 1998). Even as the demand for water grows in these countries, the supply is being diminished by human activities that degrade watersheds and threaten natural ecosystems. The “desertification” of drylands negatively affects nearly one billion humans on 35–40 million km$^2$ of land, or about 30% of the world’s land surface (FAO, 1993). While water shortages and desertification affect all dryland areas, developing countries are particularly vulnerable to the economic and social costs associated with the decline of agricultural and natural ecosystem productivity.

The prospect of natural or human-induced global change greatly increases the risks and challenges already faced by developing countries. Under current assumptions of global warming, climate models predict major shifts in world precipitation and evaporation patterns over the next century (UNEP, 1997). Semi-arid regions, many of which are already drought-prone, may suffer longer and more severe dry periods, as well as more destructive flooding and erosion caused by higher-intensity rainfall events. The combined effect of these stresses could permanently alter the water balance in some semi-arid regions, further reducing water availability to human and natural ecosystems.

Ecological services in semi-arid regions are closely tied to water availability and are threatened by the same unsustainable practices that disrupt the water balance (UNEP, 1997). Many organisms and ecosystems in these regions are already experiencing wide-spread habitat destruction, isolation, and fragmentation (Watson et al., 1998). The loss of native species (drylands are the ancestral home of major crop species such as wheat, barley, and sorghum) increases the vulnerability to agricultural systems worldwide. It is predicted that global change will exacerbate these problems, as the physical barriers and environmental stresses caused by human activity prevent organisms and ecosystems from adapting or migrating (Janetos, 1997).

The adverse effects of natural and human-induced environmental change are already manifested in semi-arid regions worldwide. The failure of communities in these regions to protect their natural resource base is due, in part, to an incomplete understanding of the physical and biological processes operating in semi-arid ecosystems, and the inability to monitor these processes over a broad range of time and space scales. Even in developed countries, policy-makers and resource managers often lack the information and tools needed to detect, predict, and mitigate widespread, incremental, long-term change on water and biotic resources. These inadequacies will be greatly magnified in the event of major shifts in global climate patterns. Consequently, there is a need to better understand the key ecological and social processes operating in semi-arid environments, and to develop observation, monitoring, and modeling technologies that can be applied to global change problems in these environments worldwide.
The ultimate goal of AGAVES is to evaluate the consequences of natural and human-induced changes on arid and semi-arid regions with emphasis in the Southwest and provide decision makers with the necessary scientific information in a useful format. Investigators currently involved in AGAVES have considerable experience within other Southwestern Basins, including the Middle Rio Grande, Bill Williams, Hassayampa, and the Santa Cruz where past or current projects are underway. However the near-term research focus of AGAVES will be built on the substantial foundation within the San Pedro. This location provides AGAVES with the opportunity to focus its initial attention on the ability to identify and map ecosystem services and investigate how the potential to maintain and provide these services into the future changes relative to anticipated stressors related to urbanization and climate variability. Each of the basins noted above will be utilized to assess both the transferability of science, and its benefits to decision-making, from and to the San Pedro.

2.2 San Pedro River Basin

The borderlands between the states of Arizona and Sonora are characterized by arid to semi-arid conditions, mountainous terrain, and limited water availability – factors that historically limited human populations in the area (Sheridan, 1995).

Thompson (1997) emphasized that human-induced environmental change has affected the ecological complexity of the Arizona-Sonora borderland. Livestock grazing, fire reduction, habitat loss, and invasion by exotic species have all reduced, to some measure, regional biodiversity (Tellman et al., 1997). This process is not new, but a continuation of the changes brought on by European settlement of the area in past centuries (Bahre, 1991). Even so, the rapid conversion of grassland to shrubland (a form of desertification), the fragmentation and reduction of habitat patches, and the disruption of wildlife corridors by suburban development – as revealed by repeat satellite observation over the past 25 years (Kepner et al., 2003 and 2000) – indicate an overall decline in ecological complexity and service provisioning within the border environment, often in association with changes in surface hydrology.

The Arizona-Sonora borderlands have experienced environmental and societal stresses shared by many semi-arid regions worldwide, i.e., rapid population growth, over-exploitation of water resources, and threatened loss of biodiversity. However, these stresses are only compounded by the fact that the international border divides the watershed into communities having different economic, social, political resources and concerns (West and Vasquez-Leon, 2008). These differences are compounded further by construction of the border fence/wall which will fragment critical wildlife corridors and block numerous ephemeral streams feeding the San Pedro River and floodplain.

The San Pedro River Basin is one of the last unimpounded rivers in the Southwest. The main stem is about 311 km in length and has alternating reaches of perennial and ephemeral flow between its headwaters near the copper mining city of Cananea, Sonora, Mexico, and its confluence with the Gila River near Winkelman, Arizona (Figure 2). It includes two main tributaries, i.e., the Babocomari River in the upper basin and Aravaipa Creek in the lower basin. It is one of only two major rivers that flow north out of Mexico into the United States. A
comprehensive publication entitled “Ecology and Conservation of the San Pedro River” (Stromberg and Tellman, 2009) was recently published that provides an extensive knowledge base on all aspects of the San Pedro compiled by an interdisciplinary team of fifty-seven contributors (biologists, ecologists, geomorphologists, historians, hydrologists, lawyers, political scientists). It describes the flora, fauna, hydrology, human use, as well as the ongoing science-driven efforts to sustain its riparian ecosystems.

Groundwater is an important factor in maintaining flow in perennial reaches of the San Pedro River. Recent isotopic analysis has identified the importance of the timing and magnitude of summer monsoon-generated runoff in maintaining flow in many reaches of the San Pedro by recharging bank storage and the alluvial aquifer, which drains back into the river for periods of months after the runoff events (Bailie, 2007). Average annual precipitation for the basin is 41 cm with greater amounts occurring throughout the higher mountain elevations versus the valley floor. Mountain block or mountain front recharge water can take hundreds to thousands of years to travel in the subsurface from the mountain zones to the riparian zone near the river. Groundwater flow simulations in the upper basin of the river near Sierra Vista, Arizona, indicate that groundwater pumping at current rates for municipal use, with no additional recharge, will eventually dry up the river (USDI, 2005; Leake et al., 2008). The San Pedro River is considered to be threatened by urbanization, especially in the upper reaches near Sierra Vista (Webb et al., 2007; Kepner et al., 2004).

The streamside corridor in the upper reach of the river is characterized by closed gallery cottonwood/willow forests and has internationally recognized importance. Areas between Benson and San Manuel, Arizona, are mostly rural in nature with scattered agriculture and discontinuous riparian vegetation. The lower reach of the river supports extensive galleries of velvet mesquite.
2.3 Upper San Pedro River Basin

The Upper San Pedro River Basin, located in the semi-arid borderland of southeastern Arizona and northeastern Sonora, is characterized as a broad, high-desert valley bordered by mountain ranges and bisected by a narrow riparian corridor sustained by an intermittent stream. For the purpose of the AGAVES project, the San Pedro River Basin is divided into upper and lower sub-basins.
basins at a pour-point associated with the long-term USGS stream gauging station at Redington, Arizona, just east of Tucson (Figure 3).

The primary traditional economic drivers in the valley include the U.S. Army Fort Huachuca on the Arizona side of the border and the copper mining district near Cananea on the Sonora side (CEC, 1998). The population of the city of Sierra Vista, the largest municipality in the San Pedro River Basin, has remarkably increased in recent years, driven by employment capacity of Fort Huachuca and the attraction of the area as a retirement community.

The Upper San Pedro River Basin is one of the most biologically diverse areas of the inland United States. It represents a transition area between both the Chihuahuan and Sonoran desert ecoregions and is known as one of North America’s most important wildlife havens (CEC, 1998). The upper reaches of the river reportedly support nearly two-thirds of the avian diversity in the U.S., approximately 100 species of birds breed around the river and another 200 use the corridor for migration and winter range. It also represents habitat for more than 80 mammal species, 61 reptile species and 16 amphibians which makes it one of the highest diversity vertebrate species areas in the United States (Figure 4). In recognition of its biological importance, the American Bird Conservancy designated the San Pedro as its first “Globally Important Bird Area” in the U.S. and The Nature Conservancy deemed it as one of the “Last Great Places” in the western hemisphere.

Figure 3. Map of the Upper San Pedro River Basin, U.S./Mexico with inclusions showing the Sierra Vista subwatershed (Sec. 321 Report) and the San Pedro Riparian National Conservation Area.
In 1986, private inholdings along the river were acquired by the Federal Government and later, in 1988, the U.S. Congress recognized the value of the streamside corridor by establishing the Nation’s first Riparian National Conservation Area along a 60 km stretch of the upper San Pedro from the international border near Palominas, Arizona, north toward the rural community of St. David (BLM, 1989). The U.S. Bureau of Land Management (BLM) administers the conservation area to conserve, protect, and enhance its riparian values (SPRNCA; Public Law 100-696, 1988). A number of factors outside the control of the BLM make protecting the San Pedro Riparian National Conservation Area problematic, i.e., increased water use by communities near the conservation area, surface diversions, groundwater pumping in Mexico, potential water-rights claims by downstream users, and mine-related pollution (Jackson et al., 1987). By far, the biggest concern is excessive groundwater pumping, which has resulted in a large “cone-of-depression” between the groundwater recharge areas of the Huachuca Mountains to the west and the river to the east (ADWR, 1991). Several hydrogeologic studies indicate that the cone-of-depression is intercepting groundwater that would otherwise contribute to river baseflow (USAG, 1997; Pool and Dickinson 2007).

United in their concern for sustainable services and protection of the environment, local governments, agencies, and community members formed the Upper San Pedro Partnership (USPP, http://www.uspppartnership.com/) in 1998 (Richter et al., 2009). The USPP is a collaboration of 21 member agencies and organizations bound by a common purpose of achieving sustainable yield within the Sierra Vista subwatershed by the year 2011. The purpose
of the USPP is to coordinate and cooperate in the identification, prioritization and implementation of comprehensive policies and projects to assist in meeting water needs in the Sierra Vista subwatershed. In November 2003, the U.S. Congress passed the Defense Authorization Act of 2004, Public Law 108-136, Section 321. This legislation requires the Secretary of the Interior, in consultation with the Secretaries of Defense and Agriculture, and in cooperation with USPP, to prepare an annual report (referred to as the Section 321 Report) to Congress that includes 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.

For AGAVES, the Upper San Pedro River Basin represents an ideal outdoor laboratory containing diverse topographic, climatic, vegetative, and land-use features within a well-defined drainage system about 40 km across and 150 km long from which to initiate its study. The basin contains riparian and upland ecosystems that show evidence of historic human impacts. The study area also includes the USDA-ARS Walnut Gulch Experimental Watershed, a densely instrumented facility that has served as a center for research in the hydroclimatology of semi-arid lands for over 50 years (Moran et al. 2008).

The Walnut Gulch Experimental Watershed is a tributary to the larger Sierra Vista subwatershed (Figure 3). The subwatershed contains the greatest human population in the entire San Pedro river basin. The population in this area was approximately 68,000 in 2002 and is anticipated to grow to more than 83,000 by 2011 (USDI, 2005). The population is divided between rural residences and more concentrated urban centers such as Sierra Vista, Bisbee, and Tombstone. Groundwater is the only source for municipal (domestic and industrial) and agricultural use. Continued pumping at current rates, with little to no recharge, has posed great risk to the floodplain aquifer and the subsequent drop in the water table could destroy the riparian corridor protected by the San Pedro Riparian National Conservation Area (Stromberg, 1993). Thus, an interesting challenge has been posed relative to managing a limited water resource. How can water supply and use be balanced to satisfy ecosystem services, i.e., water provisioning, necessary to sustain human populations, yet protect the rare ecosystem values associated with the San Pedro Riparian National Conservation Area?

AGAVES intends to address resource management needs through a long-term, integrated program of observation, process research, modeling, assessment, and integration with decision-makers. The project will employ a variety of ground-based and remote sensing techniques to acquire new knowledge on key hydrologic and ecological processes operating within semi-arid river basins. AGAVES will use a representative test basin (Upper San Pedro Basin) as its primary experimental and observational area but will incorporate information from related studies into its “knowledge-base.” The relationships and technologies developed in the test basin will then be applied to other semi-arid environments.
3.0 Science Questions and Challenges

A number of key science questions and challenges are posed by the prospect of completing a landscape-scale ecosystem services assessment and valuation project. These are not specific to the San Pedro, but more broadly reflect the challenges posed by incorporating ecosystem services research and information into resource management, with an emphasis on arid and semi-arid regions.

3.1 Service Identification

Perhaps the most fundamental questions when beginning to consider conducting ecosystem services research, assessment and valuation projects are: What is the range of services provided in my area of interest, and which are the most important or valuable services? Answers to these questions allow researchers and decision-makers to prioritize limited assessment resources. Resource management agencies seek viable and flexible methods or tools that enable them to efficiently identify and manage key services throughout their jurisdictions. A closely related challenge is the identification of key values for an area that represent bundles of services that may be assessed collectively rather than individually.

Although we recognize that lists and definitions of ecosystem services will continue to evolve (Daily 1997, Constanza et al. 1997, deGroot et al. 2002, MEA 2005; Farber et al. 2006, Wallace 2007) as ecosystem research matures, Table 1 (Farber et al. 2006) is provided as an example of functions and services that may be considered in AGAVES. For the AGAVES project within the Upper San Pedro, several meetings between researchers and resource managers have been conducted to prioritize which ecosystem services to address. Four primary categories were identified with more specific service types identified in three of the four primary types. They include:

- **Water**
  - Ground water for drinking and irrigation
  - Surface water for recreation and aesthetics

- **Biodiversity**
  - Habitat maintenance

- **Carbon sequestration and storage**

- **Cultural services**
  - Recreation
  - Aesthetic
  - Spiritual

Further efforts are underway to more carefully identify the characteristics of the ecosystems and the services they provide; identify specific human beneficiary groups for each service; delineate specific research questions within our overarching conceptual framework; and, specify the spatial and temporal bounds of their foci.
3.2 Scenario Construction

The incorporation of scenario analysis with ecosystem services assessment enables researchers, decision makers, and stakeholders to ask the question: What are the consequences of future development, climate change, and other stressors on ecosystem services? Utilizing a scenario analysis approach actually represents a necessary compromise; it involves evaluating outcomes for a small set of possible future conditions rather than identifying conditions that will yield the best possible outcomes given specific objectives or criteria. As methods and tools mature the latter may ultimately be possible, but in the mean time scenario analysis provides a convenient means of constraining unknown future conditions and identifying management actions that will at least set us on the right course.

Several key challenges are associated with developing future scenarios within the context of an ecosystem services assessment and valuation study.

1) Develop methods for generating spatially explicit representations of scenario definitions.
   • Develop methods for linking climate change and associated changes in vegetation (e.g., land cover).

Table 1. Ecosystem functions and services (from Farber et al., 2006).

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<thead>
<tr>
<th>Ecosystem functions and services</th>
<th>Description</th>
<th>Examples</th>
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<tbody>
<tr>
<td><strong>Supportive functions and structures</strong></td>
<td>Ecological structures and functions that are essential to the delivery of ecosystem services</td>
<td>Nitrogen cycle; phosphorous cycle</td>
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<tr>
<td>Nutrient cycling</td>
<td>Storage, processing, and acquisition of nutrients within the biosphere</td>
<td>Plant growth</td>
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<tr>
<td>Net primary production</td>
<td>Conversion of sunlight into biomass</td>
<td>Insect pollination; seed dispersal by animals</td>
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<tr>
<td>Pollination and seed dispersal</td>
<td>Movement of plant genes</td>
<td>Refugium for resident and migratory species; spawning and nursery grounds</td>
</tr>
<tr>
<td>Habitat</td>
<td>The physical place where organisms reside</td>
<td></td>
</tr>
<tr>
<td>Hydrological cycle</td>
<td>Movement and storage of water through the biosphere</td>
<td>Evapotranspiration; stream runoff; groundwater retention</td>
</tr>
<tr>
<td><strong>Regulating services</strong></td>
<td>Maintenance of essential ecological processes and life support systems for human well-being</td>
<td>Biotic sequestration of carbon dioxide and release of oxygen; vegetative absorption of volatile organic compounds</td>
</tr>
<tr>
<td>Gas regulation</td>
<td>Regulation of the chemical composition of the atmosphere and oceans</td>
<td>Direct influence of land cover on temperature, precipitation, wind, and humidity</td>
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<tr>
<td>Climate regulation</td>
<td>Regulation of local to global climate processes</td>
<td>Storm surge protection; flood protection</td>
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<tr>
<td>Disturbance regulation</td>
<td>Dampening of environmental fluctuations and disturbance</td>
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<tr>
<td>Biological regulation</td>
<td>Species interactions</td>
<td>Control of pests and diseases; reduction of herb ivory (crop damage)</td>
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<td>Water regulation</td>
<td>Flow of water across the planet surface</td>
<td>Modulation of the drought–flood cycle; purification of water</td>
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<tr>
<td>Soil retention</td>
<td>Erosion control and sediment retention</td>
<td>Prevention of soil loss by wind and runoff; avoiding buildup of silt in lakes and wetlands</td>
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<tr>
<td>Waste regulation</td>
<td>Removal or breakdown of nonnutrient compounds and materials</td>
<td>Pollution detoxification; abatement of noise pollution</td>
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<tr>
<td>Nutrient regulation</td>
<td>Maintenance of major nutrients within acceptable bounds</td>
<td>Prevention of premature eutrophication in lakes; maintenance of soil fertility</td>
</tr>
<tr>
<td><strong>Provisioning services</strong></td>
<td>Provisioning of natural resources and raw materials</td>
<td>Provision of fresh water for drinking; medium for transportation; irrigation</td>
</tr>
<tr>
<td>Water supply</td>
<td>Filtering, retention, and storage of fresh water</td>
<td>Hunting and gathering of fish, game, fruits,</td>
</tr>
<tr>
<td>Food</td>
<td>Provisioning of edible plants and animals</td>
<td></td>
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<tr>
<td>Raw materials</td>
<td>Building and manufacturing</td>
<td>Lumber; skins; plant fibers; oils; dyes</td>
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<td></td>
<td>Fuel and energy</td>
<td>Fuel wood; organic matter (e.g., peat)</td>
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<td></td>
<td>Soil and fertilizer</td>
<td>Topsoil; frill; leaves; litter; excrement</td>
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<tr>
<td>Genetic resources</td>
<td>Genetic resources</td>
<td>Genes to improve crop resistance to pathogens and pests and other commercial applications</td>
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<tr>
<td>Medicinal resources</td>
<td>Biological and chemical substances for use in drugs and pharmaceuticals</td>
<td>Quinine; Pacific yew; echinacea</td>
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<tr>
<td>Ornamental resources</td>
<td>Resources for fashion, handicraft, jewelry, pets, worship, decoration, and souvenirs</td>
<td>Feathers used in decorative costumes; shells used as jewelry</td>
</tr>
<tr>
<td>Cultural services</td>
<td>Enhancing emotional, psychological, and cognitive well-being</td>
<td>Ecotourism; bird-watching; outdoor sports</td>
</tr>
<tr>
<td>Recreation</td>
<td>Opportunities for rest, refreshment, and recreation</td>
<td>Proximity of houses to scenery; open space</td>
</tr>
<tr>
<td>Aesthetic</td>
<td>Sensory enjoyment of functioning ecological systems</td>
<td>A &quot;natural field laboratory&quot; and reference area</td>
</tr>
<tr>
<td>Science and education</td>
<td>Use of natural areas for scientific and educational enhancement</td>
<td>Use of nature as national symbols; natural landscapes</td>
</tr>
<tr>
<td>Spiritual and historic</td>
<td>Spiritual or historic information with significant religious values</td>
<td></td>
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</tbody>
</table>

- Develop methods for downscaling GCM outputs such that they can be effectively incorporated into process-based assessment tools.
- Create more user-friendly and readily transferrable tools for generating urban growth scenarios, with the flexibility to incorporate regulatory policy constraints.

2) Determine if and how spatial and temporal ecosystem dynamics can be represented in a static scenario context.

3) Model multi-dimensional scenarios (e.g., climate change, urbanization, and water use where the scenarios lead to science driven futures) in terms of their impact on ecosystem properties and functions as a precursor to a service assessment.

4) Establish and test methods for determining, forecasting and representing change in ecosystem values in association with scenario definitions.

3.3 Service Assessment

Research on methods for quantitative ecosystem services assessment, although founded on decades of work in the environmental sciences, has really only just begun. Key challenges include developing robust and flexible methods for addressing the following questions:

**How can probabilistic and deterministic environmental assessment model outputs be translated into quantitative estimates of provisioning by individual or bundled services as they change due to climatic and human use impacts?**

**What are the relationships between spatial and temporal ecosystem variability and service provisioning?**

**What are the pathways of service provision over time as the result of climatic and human**
impacts? Are there thresholds?

Do preference structures map into biophysical thresholds?

What are the spatial linkages between ecosystems and people, and how do these influence service provisioning?

How can cultural services be assessed quantitatively across the landscape?
  - How are cultural values influenced by the landscape?
  - How can cultural values be associated with environmental change?

How can results of a wide variety of assessment methodologies be integrated in space and time to develop maps of service provisioning?

How should uncertainty be managed during assessment integration and between a number of alternative future scenarios?

How can these methods be made more applicable to decision making (government, business, etc.)?

3.4 Service Valuation and Tradeoffs

Valuation of service provisioning will, like the assessment step, require a number of different techniques appropriate to the specific services. Some, like market commodities, will be relatively straightforward in terms of assigning a value. Others, like cultural services, are likely to require new approaches. Economic valuation of ecosystem services using stated-and revealed-preference techniques has advanced greatly in the past two decades as have benefit transfer techniques. Within the context of a comprehensive ecosystem services assessment, the challenges associated with economic valuation across the full range of services assessed will involve addressing the following questions:

Do preference structures coincide with physical thresholds?

How can spatial and temporal dynamics of service provisioning be accounted for within an economic framework?

How can market and non-market ecosystem services valuations be structured such that their values can be integrated and utilized in the evaluation of management alternatives?

How can we assess values and tradeoffs for widely different stakeholders and cultural groups, with different preferences, in different parts of the San Pedro watershed, including Mexico (Ready and Navrud, 2006)?

How robust are ecosystems valuations across multiple sites?
3.5 Integrated Risk Assessment/Management

The goal in performing an ecosystem services assessment and valuation exercise is to identify how humans can adjust their utilization and management of ecosystems such that service provisioning and hence sustainable economic outputs are optimized. The objective of integrated risk assessment and management involves reconciling the results of a service assessment and valuation study with existing conditions and available management and policy alternatives to identify courses of action that will enhance the sustainable economic output from ecosystems. There are several key challenges associated with applying ecosystem service provision and value information. Key questions related to these challenges include the following:

How can spatially and temporally distributed service provisioning and value information be utilized to identify well suited locations for sustainable development, management, and other activities?

How can an array of potential future conditions be utilized to identify the most effective management and policy alternatives, and where to implement them on the landscape?

How can management actions be adaptively employed to further ecosystem services assessment research?

3.6 Scale and Transferability Issues

Management agencies traditionally do not focus on particular uses/services and thus the issue often becomes the transferability of the assessment process itself.

How can assessment strategies be designed to permit efficient application at multiple spatial scales and thereby facilitate transferability?

Can ecosystem service values be robust across alternative semi-arid areas?

It is recognized that the circumstances that have resulted in the exceptional scientific foundation and the integration with policy and decision-makers in the San Pedro is quite unique and would be difficult to replicate in others areas or watersheds. The San Pedro characterization/research/decision-maker enterprise that currently exists took much more time than a three-year grant cycle or five-year agency planning cycle and it could not have been accomplished by a single agency or university alone.

To capitalize on this exceptional foundation, researchers, working together with decision makers and stakeholders, need to develop and implement a very high standard for science-based ecosystem valuation. We can then test the transferability of San Pedro methods and results to other areas. This will allow us to evaluate the applicability of ecosystem values in locations that have garnered less funding but have similar issues and characteristics (e.g., semi-arid areas).
For example, a comparison of riparian resources and services is possible with the Middle Rio Grande (MRG) in New Mexico, which parallels the San Pedro but has distinctly different drivers causing changes in riparian vegetation and associated bird communities. In the case of the MRG, declining surface water supplies, controlled primarily by reservoir releases, and active restoration (e.g., burning, bulldozers, and planting of native species) are driving change in the riparian system. Beyond the question of determining the ecosystem values for certain services in the SPRNCA area, research is currently underway to address the same questions of value determination in the MRG (Brookshire et al., *in-press*). More specifically, we are interested in the robustness of the relative ecosystem values of the two sites: SPRNCA and MRG. That is, can the ecosystem values measured for one site be transferred to another site? The importance of this issue lies in the possibility of extending the SPRNCA ecosystem values to a larger area than just the SPRNCA per se, or even other areas in the Southwest.

The use of benefit transfer studies has been growing over the years, not only as a recognition that original studies cannot be done in all locations due to their high cost, but also from the required expanded use of benefit cost analysis by governmental organizations (Brookshire and Neil, 1992; Desvousges et al., 1998; Brookshire and Chermak, 2007; Brookshire et al., 2007). We seek to expand this discussion to consider issues of how the science from multiple locations should be organized in generating the ecosystem attribute bundles for multiple valuation purposes (and inherently for decision-making purposes as well).

### 4.0 Research Approach

To address the research questions outlined above, AGAVES has adopted a research approach based on the principle of voluntary collaboration and opportunistic investigation. AGAVES maintains an open research framework: new researchers, resource managers, and projects can be added or subtracted to the program to suit particular needs. Each project contributes something to answering the research and management questions, while benefiting from the collaborative interaction. Knowledge is accumulated incrementally in the AGAVES “knowledge-base” which will be the ultimate program product.

#### 4.1 Interdisciplinary Research

To accomplish its multifaceted mission, AGAVES must draw on the expertise and research skills of researchers from a variety of natural, economic, and social science disciplines. Hydrologists, biologists, ecologists, and other earth scientists will work to quantify key hydrologic and ecological processes and interactions within semi-arid basins. Physical scientists will collaborate with earth scientists to develop and apply the remote sensing and GIS technologies needed to measure and monitor surface processes over a broad range of spatial and temporal scales and develop spatially explicit models. Economists and modelers will use the knowledge generated by AGAVES and prior experiments and observations to create Decision Support Systems (DSS) in

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*b* We refer to the Middle Rio Grande as roughly being from Cochiti Dam to Socorro, NM. The actual study area is within the boundaries of the MRG, from Corrales to Bernardo.
direct cooperation with decision-makers. Costs of management, alternative water sources, and conservation measures will also be incorporated into the DSS. Future scenarios and decisions will perturb linked physical and ecological models to derive changes in ecosystem attributes, or bundles of attributes. Changes in ecosystem service attributes may be presented directly in biophysical terms, or valued with survey techniques such as Contingent Valuation (CV) and Choice Modeling (CM) stated preference techniques.

When possible the results will provide the marginal dollar values for changes in specified ecosystem attributes. Just as the coupling of the science models allows for an evaluation of alternative water supply alternatives, the integration into the DSS of the ecosystem values will allow for evaluation of more detailed and robust scenarios. The scenarios that could then be considered would move beyond basic planning efforts (e.g., where to allow wells and recharge basins) to formally integrate behavioral relationships. Thus, a variety of behavioral incentives, such as urban water pricing schemes, could then be explored and the evaluation would draw directly upon the underlying ecosystem values as various tradeoffs are identified.

Different types of research will require different levels of interaction among the disciplines. Many process studies and monitoring activities will be uni-disciplinary, while field campaigns, sensor development, modeling, and assessment activities will require a high degree of inter-disciplinary and cross-disciplinary collaboration and cooperation. AGAVES provides a common platform for scientists from various disciplines to come together and share resources and data to their mutual advantage. Any researcher and/or resource manager that seeks to answer some component of the primary research questions is welcomed to join the AGAVES effort.

4.2 Phased Implementation

The components of the AGAVES research program will not all be active simultaneously. They will be phased in and out according to need and available program resources. In the early stages, significant effort will focus on identifying the ecosystem services to be investigated in greater detail. This will entail an iterative process of assessing priorities from decision-makers and stakeholders, assessing whether sufficient background data and science is in place to address those needs, and if needed, acquiring the data, developing the science and models to enable ecosystem service valuation. Wherever possible, simultaneous consideration must be given to determine if and how efforts in the San Pedro can be transferred to other arid and semi-arid systems in the Southwestern U.S. and other regions. Due to limited resources, the program will have to prioritize its assistance to investigators and in pursuing funding opportunities.

4.3 Innovative Technologies

A vital part of AGAVES research is the use of innovative technologies to measure the characteristics of the ecosystem, model these systems and integrate them into a decision-making framework so the value of ecosystem services can be compared directly to costs for conservation and preservation decisions. The Southwest Regional Gap Analysis Project (SWReGAP) data (http://earth.gis.usu.edu/swgap/) will provide a baseline source of land cover classification data (circa 2000) derived from Landsat for the project area. Associated with this dataset is the
development of “predicted habitat for 817 vertebrate species that reside, breed, or use habitat in the five-state region for a substantial portion of their life history. These models are based on the concept of Wildlife Habitat Relationships (WHRs), defined as a statement describing resources and conditions present in areas where a species persists and reproduces or otherwise occurs. Relationships can be modeled to predict habitat composition, and if the relationships are represented in a cartographic plane they can predict the presence of habitat spatially. For each species, these relationships were identified by reviewing the available literature and then generating a spatial representation of habitat within the species known range (from: http://fws-nmcfwrufwru.nmsu.edu/swregap/habitatreview/instructions.htm). This dataset is also being extended to cover the Mexican portion of the Upper San Pedro Watershed. That data and all easily obtainable GIS data will also be verified and assembled into a second generation San Pedro Geodatabase covering not only the upper watershed but the entire basin to its confluence with the Gila River.

Portions of the Upper San Pedro Watershed covering Fort Huachuca and Sierra Vista are also being flown as part of the DOD, ITAMS program to acquire 15 cm resolution RBG and CIR ortho-imagery with multi-return LIDAR (4 returns per pulse). Acquisition of Quickbird 2.4 m multispectral imagery at nadir is also anticipated in FY10 over the remaining portions of the U.S. portion of the Upper San Pedro Watershed from the border, north, to approximately the USGS Tombstone gage. The USDA-ARS Walnut Gulch Experimental Watershed and a portion of the Upper San Pedro Watershed and are also 2 of the 20 Global Fiducial Network sites distributed within the conterminous United States (http://gfl.usgs.gov/ and http://gfl.usgs.gov/USsites.shtml#sanPedro). The Global Fiducials Program (GFP) is a collaborative effort between federal civil agencies, academia, and the intelligence community. The goal of the GFP is to build and maintain a long-term record of data to support scientists and policy makers. At the inception of the Program, it was hoped that at some point – perhaps as much as 25 years into the future – the acquired data could be openly released to support future scientists and policy makers as well. Since the 1990s, the Global Fiducials Program has been periodically collecting images of environmentally significant sites around the world. The Upper San Pedro Watershed is also a NASA EOS Land Validation (http://landval.gsfc.nasa.gov/coresite.php?SiteID=22) site. Both of these programs will ensure the ongoing acquisition of a rich array of classified and unclassified imagery over the study area.

Physical and ecological models will also be developed as part of AGAVES to enable prediction of effects from external drivers of change (e.g., management decisions, growth, conservation, climate change) on selected ecosystem services. These models or their outputs will then need to be bundled into a Decision Support System (DSS) framework for decision-makers and stakeholders to assess and evaluate alternative futures and decisions. It should be stressed that the DSS must be developed directly with stakeholders and decision-makers. The USPP, in partnership with SAHRA has developed a functioning, internet-based DSS for the Sierra Vista sub-basin of the Upper San Pedro (http://www.usppartnership.com/plan_groundwtr.htm). This DSS incorporates many of the functionality discussed above and will provide an excellent foundation to further DSS expansion. Ultimately the ecosystem valuations should also be incorporated within the DSS so that benefits and costs in monetary form can be directly
compared to the costs of controllable management decisions (e.g., conservation costs, augmentation costs, avoided costs, and infrastructure changes and their costs). In addition to non-market values, market-based costs and benefits related to ecosystem attributes (e.g., recreation, tourist related income, real estate value enhancements) will also be ultimately incorporated into the DSS.

4.4 Interagency Cooperation

AGAVES will strive to serve as a model of interagency cooperation. Scientists from a number of universities and agencies have participated in initial AGAVES meetings and the Tucson workshop. The intent is to readily share resources and data with other AGAVES researchers, agency personnel and stakeholders. An established and well organized entity in the San Pedro that AGAVES will work closely with is the Upper San Pedro Partnership. As noted before, AGAVES will also build not only on SALSA, but extensive research conducted under the SAHRA NSF Science and Technology Center. Cross-border cooperation involving the Mexican National Water commission, Comisión Nacional del Agua (CNA), and the International Boundary Waters Commission (IBWC) is also envisioned to enable assessment of cross-border ecosystem services.

4.5 Links to Other Programs

In 2007 the U.S. Environmental Protection Agency’s Office of Research and Development created the Ecological Services Research Program (ESRP). The goal of the ESRP is to transform the way decision-makers understand and respond to environmental issues by making clear how their policy and management choices affect the type, quality, and magnitude of the goods and services ecosystems provide to sustain human well-being. The goal requires the ESRP to conduct research and development to produce four general types of outputs: i) measures and dynamic maps of ecosystem services, ii) predictive models relating ecosystem service response to stressors, iii) management options and alternative futures, and iv) decision support systems. The ESRP is conducting five “place-based” studies that compare and contrast ecosystem services at different scales and in geographic locations. These studies focus on the environmental and social issues unique to each place, and collectively provide the opportunity to evaluate broader science questions through the variation they represent. The study areas are the Midwest agricultural belt; Tampa Bay, FL; Willamette River Basin, OR; Albemarle and Pamlico Estuaries, NC and VA; and the Southwest. The Southwestern U.S. is unique in the ESRP because this arid to semi-arid region is heavily dominated by the availability of water that is being impacted by climate change, urbanization, grazing and nitrogen loading. The Southwest Ecosystem Services Project (SwESP) is focusing on the Santa Cruz and San Pedro River basins on the U.S.-Mexico Border area and is a member of AGAVES.

As a result of the 2008 Farm Bill, a government-wide Environmental Services Board (ESB) has been established. A primary goal of the ESB is to develop guidelines and science-based methods to measure the environmental benefits from conservation and land management activities in support of emerging environmental services markets. The ESB will also set priorities for research on environmental services and methods for how to measure benefits. In addition, a
Federal Advisory Committee of stakeholders will be established to provide advice and counsel to the ESB. Within the USDA Office of the Secretary, the Office of Ecosystem Services and Markets (OSEM) has been established to provide administrative and technical assistance to assist the Secretary of Agriculture in the duties as Chair of the ESB. AGAVES will attempt to communicate and interface directly with the ESB not only to work with them but to demonstrate the foundation of ecosystem services valuation work that has already been accomplished by the SAHRA STC and AGAVES.

As a result of enacting legislation in the 2002 Farm Bill the USDA-Natural Resources Conservation Service (NRCS) in cooperation with the USDA-Agricultural Research Service (ARS) and other Federal agencies are undertaking a national Conservation Effects Assessment Project (CEAP) to determine the benefits of monetary expenditures for land conservation practices (http://www.nrcs.usda.gov/TECHNICAL/NRI/ceap). The initial focus of CEAP was on traditional Midwest and Eastern croplands. Recently CEAP is expanding west into rangelands and the San Pedro has been designated as a pilot basin for rangeland CEAP efforts in the Southwest with additional pilot basins in Nevada, California, and Idaho.

AGAVES, indirectly or directly, is also linked to several other international, regional, and global change research programs, primarily through its collaborating scientists whose agencies and institutions typically have their own global change research emphasis. AGAVES will engage and interact with the U.S.-Mexico Transboundary Aquifer Assessment Program (TAAP) in which each border state has designated two shared aquifers for further study. In Arizona, the Santa Cruz and San Pedro Aquifers have been selected as part of this program. As the ARS Walnut Gulch Experimental Watershed and the San Pedro are within a NASA TERRA validation site, we anticipate ongoing interaction with various NASA and ESA instrument teams to both use and validate their products. Several projects have recently been awarded via the Strategic Environmental Research and Development Program (SERDP) to assess the importance of ephemeral and intermittent streams to improve their management on DOD lands. A primary goal is to assess the impacts of perturbations on the hydrologic regimes and habitats of these systems, and the threatened, endangered, and at-risk species that depend on them. A number of these projects will be focusing parts of their program on Fort Huachuca.

A USGS-BLM Pilot Study on ecosystem services valuation has been initiated in 2010 and is designed to compliment AGAVES research. The pilot project will address two main objectives: to determine which, if any, methods and tools for valuing ecosystems are ripe for operational use at the BLM; and to explore the usefulness of an ecosystem services valuation framework to BLM’s land use decision-making process. Planning for both AGAVES and the USGS-BLM Pilot Study is being closely coordinated to maximize the efficiency with which both projects are conducted. It is anticipated that BLM, responsible for managing the SPRNCA and other lands within the San Pedro Basin, will represent one of the primary stakeholders for AGAVES research products. Services to be assessed by the AGAVES project will be guided in part by BLM management needs, and can in turn be valued through the USGS-BLM Pilot Study. BLM management priorities identified through the Pilot Study will also inform the Integration and Risk Assessment component of the AGAVES Program by defining the decision context.
necessary for interpreting AGAVES research products, which is described in more detail in Section 5.7.

### 5.0 Program Components

The AGAVES research program is designed as a series of orchestrated components that correspond to the activities necessary to establish methods and tools for ecosystem services assessment and valuation, as well as those necessary to explore the utility of the generated information for stakeholder management decisions. The core program component provides for the coordination of the other components. Stakeholder interaction is intended to provide both research direction and applications for research results. Process studies and field campaigns are necessary to collect information required to assess services for which no methods have been established. Data are organized, managed, and served via the data assimilation component, and applied in the modeling and prediction component to quantify service provisioning and how it responds to various stressors. The valuation component involves establishing values for selected services. Finally, the integration and risk assessment component of the program is designed to help translate new knowledge and understanding gained through AGAVES research into a format that is useful to the stakeholders for specific management and planning activities.

#### 5.1 Core Program

Maintenance of a strong core program component is critical to the success of the AGAVES project and its component research and development activities. The purpose of the core program is to provide long-term project management for AGAVES, particularly in terms of coordination, strategic planning, and information management. The core program is intended to provide the oversight necessary to ensure that the research of individual participants can be integrated and applied as parts of a coherent whole to support specific stakeholder or client management needs.

The agencies responsible for the core program component include the DOI-USGS, USEPA-ORD, and USDA-ARS. Co-chairs from each agency will take the lead in promoting AGAVES project objectives, coordinating funding proposals among collaborators, creating funding opportunities, and serving as liaisons between the researchers and the stakeholder community. Most importantly, these agencies will ensure the successful close-out of the program at the end of its tenure, including the incorporation of research findings into the greater body of knowledge on ecosystem services assessment, valuation, and applications in environmental management.

The three agency leads for AGAVES have all worked in the San Pedro for many years and share in the wealth of scientific knowledge, data, and infrastructure that have been established in the basin. Further, they all have established close working relationships with cooperators at the University of Arizona, which will be a key partner in performing program tasks. It is the intention of the lead agencies to share the expense of hiring a non-federal project coordinator via the University of Arizona, who can serve with the agency co-chairs in managing the core program and take the lead role in coordinating project activities, facilitating collaboration with
related projects, and managing communication between project participants and with stakeholders.

The AGAVES project will be conducted as a scenario analysis, largely following the formal framework proposed by Liu et al. (2008b) and Mahmoud et al. (2009). This framework (Figure 5) outlines five general steps and the appropriate division of involvement with each by stakeholders and scientists.

![Figure 5. The five phases of scenario development (Liu et al., 2008a; 2008b; Mohammed et al., 2009).](image)

The remaining AGAVES program components largely correspond with the major elements of Figure 5, with exceptions to account for the additional requirements of an ecosystem services assessment and valuation project. The modified process outlined below, and described in more detail in subsequent sections, will be coordinated via the core program element.

1. *Service identification* – Work with stakeholders and scientists to identify specific goods and services to be valued by the project.

2. *Scenario definition* – Work with stakeholders and scientists to identify key environmental stressors and management options that must be considered.
3. **Scenario construction** – Scientists to translate scenario definitions into geospatial scenario representations, such as downscaled GCM climate scenarios or modeled urban growth and associated land-use/cover change. These scenario representations will be used as the input data for model-based ecosystem service assessments (scenario analysis).

4. **Ecosystem goods and services assessment** – Scientists to develop and/or apply methods to quantify the provisioning of identified goods and services under baseline (current) conditions and alternative future scenarios.
   a. **Process studies and field campaigns** – primary studies and data collection necessary to establish assessment methodologies where none presently exist.
   b. **Modeling and prediction** – develop and/or apply models that can quantify current levels of service provisioning, and predict changes associated with alternative future conditions.

5. **Valuation** – Scientists to develop and apply methods and tools to assign market and non-market value to quantified services.

6. **Integrated risk assessment** – Scientists and decision-makers help place results into the context of important management decisions faced by stakeholders. This involves analysis and reporting of comprehensive scenario impacts & tradeoffs to facilitate risk management by stakeholders.

### 5.2 Stakeholder Interaction

**Stakeholder Identification**
The general public, mining, livestock, and commercial industries as well as state, municipal, and county government agencies, non-governmental organizations (NGOs), and commercial endeavors are all stakeholders in the San Pedro Basin. Success of the AGAVES Project will depend upon securing collaborative stakeholder involvement. Fortunately, the efforts of the Upper San Pedro Partnership (USPP), an organized group of stakeholders representing the Sierra Vista subwatershed (Richter et al., 2009) can serve as a template for initiating and maintaining AGAVES stakeholder involvement. The BLM, which manages the SPRNCA and other lands in the San Pedro Basin, is another key stakeholder for AGAVES; their pilot study on ecosystem service valuation will be closely coordinated with AGAVES research efforts to ensure that both local and national information needs are met. Recent interest by governmental agencies, non-profit groups and others in assessing the services that ecosystems provide is the platform on which AGAVES can build sound research that can be used to inform science-based decisions. In addition to generating information, AGAVES research will also serve as a venue for initiating collaborative learning processes with and between groups of scientists and decision-makers. This will motivate all parties to jointly frame their information needs and initiate group processes toward building consensus on key issues.

**Service Identification**
An AGAVES goal is to prioritize research with the inclusion of public input. Selecting ecosystem services to focus on amongst numerous possible choices is a hurdle. When natural scientists measure ecological endpoints the goal is to come as close as possible to the point at which people reveal the prices through choice (Wainger and Boyd, 2009). These endpoints must be linkable to things people recognize as valuable. They must also reflect the quality, quantity, scarcity, and reliability of resources so that changes in indicators may eventually be related to value. Lastly, changes in endpoints should be causally related to aspects of a system that can be managed. To develop a framework of indicators, it can be helpful to separate the selection of ecological endpoints and economic evaluation into two phases of assessments. In the first, the quality and quantity of a service-producing ecological endpoint is evaluated and reported using biophysical endpoints. In the second phase of assessment, the values associated with the ecological endpoints are assessed by considering the supply of and demand for a particular endpoint (Wainger and Boyd, 2009). Stakeholder input on value of the endpoint is required to ensure that management actions are in line with societal perception and preferences.

AGAVES stakeholder outreach and education will be provided through a publically accessible website (http://rmgsc.cr.usgs.gov/agaves/), fact sheets, newsletters, brochures and issue papers. Information repositories will include libraries, city halls, schools and other public facilities where information can be posted, distributed, or both. Public meetings are possible through AGAVES, with facilitated discussions about ecosystem services of the San Pedro Basin to solicit input from the community about their interest, opinions, and values. Another tool that can be employed is the focus group (widely used in the marketing and advertising industry to gauge human preferences). Convening a focus group is a way to identify the concerns, needs, wants, and expectations of a controlled representative sample group of citizens, and inform researchers of the attitudes and values that the citizens hold. It can help drive development of research questions and programs, and the allocation of resources. Several focus group sessions could be convened for separate ecosystem services (i.e., water availability, water quality, soil quality, rangeland quality and availability, habitat provisioning, availability of recreational and cultural areas) to gather perspectives, insights, and opinions. The goal will be to glean rather than shape opinions and perspectives. The above should be considered an incomplete list of ways that AGAVES researchers may interact with the general public and stakeholders to identify services for further research.

Scenario Definition
In addition to service identification, stakeholders must be included when defining the conditions on which alternative future scenarios are based. AGAVES will build upon previous scenario development work in the San Pedro by Steinitz et al. (2003). This study followed a framework that started with a first phase where a broad survey of the major issues and the physical setting of the Upper San Pedro River Basin were conducted, followed by second and third phases where the methodology for studying alternative futures was identified and implemented. Considering that AGAVES will expand the focus in the San Pedro (for some services) from the upper watershed into the lower basin and beyond, stakeholder input will need to be reassessed and expanded. This will include close coordination with the USEPA Global Change Research Program via the Integrated Climate
and Land-Use Scenarios (ICLUS) project to explore cumulative impacts of urbanization and climate change throughout the river basin (USEPA 2009).

**Decision Analysis/Support (Risk Management)**
The final step involving interaction between AGAVES scientists and stakeholders will involve presenting the integrated results of the scenario analysis and the identification of scenario outcomes.

### 5.3 Process Studies and Field Campaigns

Process studies will be a primary mechanism by which AGAVES acquired new knowledge about ecological processes and services (i.e., indicators, surrogates, ecological production functions) operating within semi-arid river basins. To develop ecological production functions that measure the quantity and quality of services produced, we must relate measurable features of ecosystems (e.g., land cover) to the quality and quantity of subsequent ecological endpoints (Wainger and Boyd, 2009). The causal linkages between fundamental inputs and ecological outputs (the endpoints) are described by the ecological production function.

The things we readily measure about an ecosystem are its features (i.e., attributes of systems that can be directly observed, described, and quantified, such as vegetation, depth to groundwater, distance to stream, and type of surrounding land use). The features of the ecological production functions of a given quality produce a given quantity of an output (acre feet of clean drinking water). Thus, ecological features are the processes that generate desirable biophysical outcomes.

Interdisciplinary research is needed to identify indicators that are needed to inform an analysis of ecosystem service value. These may build from the decades of research ongoing in the San Pedro; however, not without consideration of the how the information conforms to an ecosystem services approach.

### 5.4 Data Assimilation

Acquisition of primary spatial data and database development is an initial feature of any landscape indicator and assessment project. Assimilation of new and existing data into a coherent body of scientific knowledge is fundamental to the AGAVES mission. This body of knowledge, or “knowledge-base,” will be one of the principal products of the AGAVES effort. Its purpose is to provide spatial data in an organized, user-friendly, on-line format to agency and university researchers, public land managers, NGOs, decision-makers, and stakeholder user groups. Additionally, this type of product will provide for long-term record keeping (archiving) and ensure an internal consistency for the project.

The AGAVES knowledge-base is envisioned as a “system” that will allow AGAVES-related data sets, metadata, information products, and research tools to be stored, organized, accessed, and retrieved in an efficient and effective manner. A crucial component of the “knowledge-base”
will be the metadata (descriptive information) applied to the digital geospatial files. The metadata include important information relative to acquisition, location, processing level, file size, format, and any relevant comments. Metadata requirements and format are provided by the Federal Geographic Data Committee (FGDC; http://www.fgdc.gov/). The FGDC standards apply to all federal agencies that collect or create geospatial data as of January 1995; state and local governments have adopted this uniform standard as well (see http://www.fgdc.gov/standards/process/index_html for details).

A comprehensive spatial database will be an important mechanism for exchanging data and information during the life of the project. Data sets created by process studies, field campaigns, and observation and monitoring efforts will be used to develop hydrology and ecosystem models, test remote observation systems, and provide baseline data for new process studies and resource assessments. Information products derived from these activities will provide feedback into the database where they will contribute to subsequent research activities. In this way, AGAVES will maximize the benefit obtained from all project participants. A similar geospatial database was developed specifically for the Upper San Pedro watershed during the SALSA campaign (http://www.epa.gov/nerlesd1/land-sci/san_pedro/); however, it does not include the lower basin below Redington, Ariz. (Kepner et al. 2003). Continuing work in the San Pedro has resulted in the accumulation of spectral image files from a variety of satellite and aircraft-based sensor platforms and includes additional spatial data coverages for land, natural resource, and socioeconomic factors. The information contained within the original San Pedro River Geo-Data Browser was acquired from multiple sources and includes data generated within the EPA and USDA-ARS.

Recently, contemporary and ancillary datasets have become available via the Southwest Regional Gap Analysis Project (SWReGAP; Lowry et al., 2007; Prior-Magee, 2007) which can provide important input variables for process models and serve as baseline reference for subsequent habitat and hydrological modeling and conservation assessments for the entire river basin (from the headwaters in Cananea, Sonora, to the confluence with the Gila River at Winkelman, Arizona). The upper watershed encompasses an area of approximately 7,600 km² (5,800 km² in Arizona and 1,800 km² in Sonora, Mexico); the lower basin includes an additional 2,200 km². The most important feature of the SWReGAP data includes both a 30-class digital land cover map classified to the Ecological System level of the National Vegetation Land Cover System and an aggregated 10-class land cover map classified to the National Land Cover Dataset (formation level). This work (vintage 2000-2001) represents baseline or reference condition for the AGAVES project which could also be utilized to create future scenarios related to climate change and urbanization.

Specifically, these datasets cover the entire watershed and include the following:

- AGAVES data sharing policy will encourage timely and full disclosure of research results.
AGAVES collaborators will be expected to abide by these principles. Whenever possible and practical, data sets and information products that are commonly needed by AGAVES collaborators and end-users will be stored on the central AGAVES server where the files can be accessed through the Internet.

5.5 Modeling and Prediction

The AGAVES project endeavors to both develop and improve methods to assess and value the ecosystem services presently derived from the San Pedro Basin, as well as to establish an understanding of how those services may respond to different levels and combinations of environmental stressors and management alternatives. Models are central to this endeavor. They provide a convenient means of synthesizing knowledge of system behavior based on past observation, as well as crucial tools for predicting system response to future conditions. They are also necessary to develop spatial representations of future scenarios (e.g., land-cover change and climate change) that can in turn be analyzed for impacts on service provisioning and values. Given the number of different models likely to be utilized in the project and the goal of promoting transferability to other locations, it is necessary to establish in advance a conceptual outline of how they will be coordinated to represent key system components and processes, as well as ground rules to ensure that scenarios are treated consistently and results are compatible.

A series of conceptual models have been developed, based on Havstad et al. (2007). The first (Figure 6) represents the major ecosystem components and processes and the ecosystem services they provide in the semi-arid San Pedro River Basin. The second (Figure 7) illustrates how example environmental stressors impact ecosystems in the San Pedro. The third (Figure 8) highlights the fact that the San Pedro is an open system, making it necessary to consider inputs to and outputs from the system in terms of flows of goods and services, how they may change over time, and how these flows may be impacted by stressors acting on the system.

Our objective in this document is not to prescribe or require a particular approach to ecosystem services assessment in the San Pedro, and participants are encouraged to explore whichever models and tools that might be most effective. In general, however, we anticipate that existing models will be used to a large extent, particularly those that have already been built and calibrated in association with previous work in the San Pedro Basin. Existing models are the products of years of research and development, and have been thoughtfully designed to address a range of spatial and temporal scales. Examples include:

- KINEROS2
- SWAT
- MODFLOW
- ATtILA
- Riparian Condition Class Model
Figure 6. General conceptual diagram of ecosystem service provisioning in the San Pedro Basin. Modified after Havstad et al. (2007).

Figure 7. General conceptual diagram of ecosystem service provisioning in the San Pedro Basin with superimposed stressor scenarios impacting service provisioning in the basin.
While there are many advantages associated with using existing models, they were not specifically designed for integrated ecosystem assessment. As such, they pose a significant logistical challenge in that any suite of models designed to simulate processes and their associated ecosystem services in the San Pedro must account for linkages between system components. In other words, their application must be coordinated to permit the exchange of inputs and outputs between them. Compatibility issues, in terms of their data formats and the time and space scale that they are simulating, must be addressed up front to ensure that results are physically and logically consistent. Finally, model outputs must also be carefully considered relative to the subsequent task of valuation to ensure that they are producing the information required.

Modeling should account for the spatial dynamics of ecosystem services, including the regions where ecosystems provide a given service and where human beneficiary groups reside, and the spatial flows of ecosystem services between ecosystems and people (Johnson et al., in press; Tallis, H. and S. Polasky, 2009). These spatial dynamics are an emerging field in ecosystem services research and can help better understand how specific groups are impacted by changes in service delivery. Since not all beneficiary groups for different ecosystem services are located within the San Pedro watershed, estimates of the value of ecosystem services in the San Pedro must account for the spatial diffusion of benefits outside the watershed, in order to avoid underestimating these values. This is particularly important
given the region’s support for migratory bird species at the continental scale, its recreational, cultural, endangered species issues at the national scale, and non-use values from regional to global scales,

5.6 Valuation and Tradeoffs

A centerpiece of the AGAVES effort is coordination between natural, social, and economic sciences to address resource management issues. The challenge is to express ecosystem service changes in terms of human health and well-being impacts. Techniques of environmental economics can partner with natural science to portray these impacts. Economics can help provide information needed to make better choices, such as how to allocate restoration budgets for the highest public good.

It is anticipated that the input of decision makers and stakeholders outlined in Section 5.2 above will provide guidance as to what ecosystem service issues are of concern to the public. This grounding is a crucial step in identifying the ways in which an ecosystem services study would be useful to resource managers and stakeholders, and prioritizing research projects.

With concrete issues identified, environmental economics can be used to investigate ecosystem service tradeoffs in the San Pedro Basin in physical terms. Figure 9 represents a form this might take. The independent variable is a stressor, such as an urban development or climate change, and the dependent variable is a hypothetical ecosystem service, with a hypothetical relationship sketched between them. To the extent the relationship can be modeled and presented in physical units, e.g., number of bird species lost due to climate change, the tradeoff can be expressed without using dollar values. There may be scenarios which change this tradeoff; for example, mitigation under Scenario 2 might be able to increase the ecosystem service at all stressor levels relative to Scenario 1 (Figure 9). For a recent example of ecosystem service tradeoffs presented in biophysical terms, see Nelson et al. (2008).
If quantification of ecosystem service tradeoffs in dollar terms, also called “valuation,” is desired, the preferred course is original environmental economics research. Specific decision contexts, involving incremental or “marginal” changes in ecosystem services aid the research scoping, and the relevance of the results for decision-making. Recursive stakeholder communications, e.g., through focus groups, may be needed in planning some forms of valuation research. The ways in which ecosystem services affect human health and well-being can be separated into two categories: market effects and non-market effects.

Market effects are ecosystem service impacts that involve the market economy. A research example could be testing for a positive influence on property prices from nearby undeveloped land. The ecosystem service in this case would be proximity to open space. Through revealed preference methods, such as hedonic techniques, the effect of marginal changes in nearby open space on property values can be determined. Market effects can also include economic impact analysis, such as when eco-tourism changes local personal income or local jobs.

Non-market effects are ecosystem service impacts that don’t involve the market economy, but which nonetheless represent human value. An example is the value of a recreational experience in the SPRNCA. This experience is not explicitly purchased in a market setting but is valuable to the visitor. For an ecologically rich site such as the San Pedro Basin, one can also reasonably hypothesize that some people will have non-use values for preserving certain ecological features, even if they are not currently or never plan to be visitors to the area. Surveys are typically employed to estimate non-use values.

If original research is not possible or warranted for certain valuation questions, practices of
benefit transfer may also be used in AGAVES. Benefit transfer involves translating valuation information from an outside site having a similar context, to the site of interest. There are different approaches to benefit transfer; guidance may be found in numerous references such as Rosenberger and Loomis (2001) and Smith et al. (2002). Other helpful citations appear in the Scale and Transferability Issues section (3.6) above.

Since valuation results can be easily misinterpreted and misused, within AGAVES, care should be taken such that the full context of all dollar values reported is documented for all valuation expressions and related calculations. In particular, the difference between market and nonmarket values should be made obvious.

Direct health impacts from ecosystem service changes are possible. As one example, an increase in heat-related illnesses, or vector-borne diseases associated with warmer climates, may accompany climate change. Depending on the context, it may be preferable to present direct health effects as a separate category of impacts.

Note that the discussion thus far has only considered impacts of ecosystem services on human health and well-being in the aggregate. For some ecosystem service management issues it is important to analyze the distributional equity of ecosystem service impacts/benefits across different segments of the population. This type of analysis is also called environmental justice.

The following is a working list of environmental economics publications that have been conducted in, or near the San Pedro Basin that can be used as reference materials as AGAVES research proceeds (for more citations see: http://rmgsc.cr.usgs.gov/agaves/). These include ecosystem service issues that have been studied in the past, and in some cases include valuation figures for those ecosystem services:

- Brookshire et al. (in press)
- Weber and Stewart, 2008
- Brookshire et al., 2007
- Bark et al., 2009
- Weber and Berrens, 2006
- Sengupta and Osgood, 2003
- Orr and Colby, 2002
- Colby and Wishart, 2002
- Berrens et al., 2000

5.7 Integration and Risk Assessment

Once ecosystem services have been assessed and valued, including impacts from potential future scenarios, the focus of the project will shift towards putting the information into the decision context of management challenges faced by stakeholders in the basin. At the conclusion of the modeling and valuation work we will have generated an enormous amount
of information. Assuming two climate change scenarios and two urbanization scenarios, there would be four alternative future conditions to assess and then evaluate relative to the baseline conditions (USEPA 2009). Both scenario results and change assessments will be in the form of spatially distributed service provisioning and value data sets (maps), which must be summarized and placed in the context of pending management decisions or options. This will involve both combining maps of individual service values, as well as conducting a spatial analysis of total value relative to the various scenarios and potential management activities.

6.0 Expected Outcomes

6.1 Near-Term Outcomes

It is envisioned that preliminary findings will be released to AGAVES cooperators and information-users primarily through a centralized AGAVES Web site. The research is considered stakeholder driven and thus there is a strong desire to make the source information and research outcomes publically available. In the near-term, AGAVES will develop a centralized “spatial database.” Important common data sets, such as digital land cover, habitat models, and associated GIS coverages will be incorporated into a the AGAVES database with open access to all stakeholders and AGAVES researchers (see Section 5.4).

6.2 Mid-Term Outcomes

We anticipate that AGAVES will acquire funding during the project period that can be directed at specific knowledge gaps. Specifically, the research will relate to answering the Primary Science Questions regarding the consequences of natural and human-induced changes on water balance and ecological diversity. As AGAVES continues to assimilate data from its research collaborators the results from various process studies will be integrated into an assessment for selected ecosystem services. This will include the development of future scenario definitions related to anticipated urban growth and climate variation with spatially explicit representations that link the primary stressors to changes in vegetation and generated as derived digital products (i.e., land cover). Comparison of the scenario results relative to the reference condition (change analysis) can then be undertaken. Additional interim products will include ecosystem service valuation (see Section 5.6). Collectively, the results will be used to make initial assessments of the potential effects of climate variation and urban encroachment within the river basin. Findings will be published in scientific journals as individual papers or combined in special issue publications and agency reports.

6.3 Long-Term Outcomes

The AGAVES research enterprise anticipates that over the project period it would have completed a number of studies that could be integrated in a manner to accomplish its mission of answering the Primary Science Questions both in, and beyond, the San Pedro. Information generated from the modeling activities will allow AGAVES researchers to make reliable assessments of how the water balance and ecological diversity of the San Pedro River Basin will be affected by different natural or human-induced stressors. AGAVES will develop a
“knowledge-base” that will ultimately incorporate the database, as well as analysis tools, models, and other information products into a decision support system that can be used by public information-users related to improved decision-making and environmental risk management.

The AGAVES knowledge-base and decision support system will be ultimate products of this research effort and will be maintained by the collaborating research partners into the future. The knowledge and technology acquired from this project can then be transferred and applied to address similar problems in other adjacent watersheds and semi-arid regions throughout the Southwest U.S. and the U.S./Mexico borderlands.
7.0 References


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