INTEGRATED MODELING AND ECOLOGICAL VALUATION

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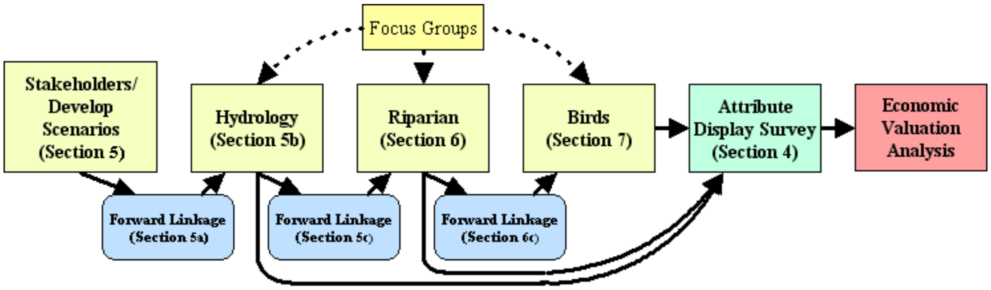
1. OBJECTIVES

Understanding how anthropogenic and climate-induced changes alter ecological systems and evaluating the effects of alternative hydrologic profiles on these ecosystems are important concerns in the semi-arid West. The goal of the proposed research is to incorporate hydrologic, vegetation, avian, and economic models into an integrated framework to determine the value of changes in ecological systems that result from changes in hydrological profiles. We propose to develop a hydro-bio-economic framework for the San Pedro River Region (SPRR) that considers groundwater, streamflow, recreation, riparian vegetation, and the abundance, diversity and distribution of birds in the region that includes the San Pedro Riparian National Conservation Area (SPRNCA). The SPRNCA is in southern Arizona and encompasses a stretch of the San Pedro River, which flows north from Cananea, Mexico, enters the U.S. near Sierra Vista, and eventually reaches the Gila River, a tributary to the Colorado River. The San Pedro River is one of the last free-flowing rivers in the desert southwest. It contains stretches of gallery riparian forest and represents one of the last remaining semi-arid flyways. The SPRR provides critically important habitat for resident, seasonally resident, and migratory birds, but is threatened by a decline in groundwater due to pumping of the regional aquifer (Rojo et al. 1998; Stromberg et al. 1996). Nearly 390 bird species have been recorded in the SPRR; 250 of these are neo-tropical migrants.

Our objective is to link realistic policy scenarios with alternative hydrologic, riparian and bird profiles in order to perform an economic valuation of ecological attributes. Figure 1 gives an overview of the research questions to be addressed.



The arrows between the boxes exemplify our efforts to integrate the various disciplinary models in the project and represent either flows of scientific information or policy changes. Critical tasks are to 1) uniquely define the arrows in Figure 1 by developing information flows that link each discipline with the existing scientific information from each of the other disciplines; 2) use focus groups and stakeholders to define the outputs of the natural science models (e.g., policy changes or attribute vectors); 3) use state-of-the-art techniques to translate and display this information; and 4) apply economic valuation models.

Existing ecological value studies predominantly use the travel cost method (Schwabe et al. 2001; Huszar et al. 1999; Jakus and Shaw 2001; Eiswerth et al. 2000; Cameron et al. 1996) or the contingent valuation method (Kline et al. 2000; Loomis et al. 2000), which focus on a single attribute of an ecological system, usually one that provides direct use value such as duck hunting

(Kinnell et al. 2002), reservoir levels (Eiswerth et al. 2000), or recreational angling (Huszar et al. 1999). Some studies value multiple ecological attributes that are not varied independently, so no assessment of precisely what drives the value statement can be made (e.g., Loomis et al. 2000; Danielson et al. 1995; and Berrens et al. 2000). Further, few studies exploit the ability to measure preferences for multiple attributes that choice models provide (Morrison et al. 2002; Kahn et al. 2001; Stewart et al. 2002; Stevens et al. 2000; Farber and Griner 2000; Johnson and Desvousges 1997; Adamowicz et al. 1998).

In the absence of integrated science information, traditional stated preference valuation studies are forced to rely on vague program descriptions and imperfect measures of the change in resource quality or quantity. This occurs because previous scientific studies were not designed to directly address valuation questions or re-examine the timescales or language that are relevant to the lay public.

Our integrated model will synthesize existing hydrology, vegetation, and bird data on the San Pedro and other southwestern rivers and will make spatial predictions of vegetation change based on projections of groundwater and base flow change from basin-scale hydrologic models. When combined with models that link bird habitat with vegetation structure, our predictions of vegetation change will be used to link the effects of hydrologic changes to songbird abundance, diversity, and distribution, and ultimately to the economic value of SPRR attributes. This framework will represent a significant advance in the methodology of stated preference valuation through its focus on science-based linkages between flow regimes, habitat quality, birds, and human values.

The framework will address many of the major issues in the program announcement: 1) How do individuals value marginal changes in indices of ecosystem health and can such indices be used as proxies for specific benefits? 2) Which benefits contribute most directly to human well-being, what are their relative values, and what are the most efficient methods of valuing them? 3) What is the tradeoff between the accuracy associated with more detailed benefit transfers and the more costly information necessary to provide them? and 4) To what extent can simpler "reduced form" transfer functions mitigate inaccuracies?

The valuation effort will lead to methodological advances in the application of stated-preference techniques to ecological valuation. Two stated-preference methods, choice models (CM) and dichotomous choice contingent valuation models (CVM), will be implemented. Few cross-method comparisons exist (Boxall et al. 1996; Stevens et al. 2000; Stewart et al. 2002). We will examine convergent validity for single attribute and multiple attribute (policy) valuation across methods, conduct traditional tests of scope and embedding, and examine differences between on-site and Internet survey formats. By constructing an integrated model that represents the best science, includes linkages between scientific disciplines, and incorporates stakeholder and focus group input that is meaningful for policy questions, valuation can take place using language and outputs that are relevant to the general public.

Only a few studies have examined the role of models across disciplines in a benefit transfer setting (Brookshire et al., forthcoming; Brookshire and Chermak, forthcoming). The literature on benefit transfers predominately relies on the science as given (Desvousges et al. 1998).[1] While economic transfer studies are widely used, rarely is the quality of the science information underlying either the study site or transferred site considered. Our focus on integrating the natural and social sciences addresses variations in the quality of scientific information that can be

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[1] The Devosouges et al., study is remarkable in laying out the relevant terrain for handling the economic portion of a BT study. It did not undertake a similar analysis for the physical or natural science underpinnings.

available for benefit transfer studies. We will develop three information gradients: 1) outputs from the integrated model (IM), 2) indices that are typically "off the shelf" science information (INDEX) and 3) traditional surveys where the "good" is not directly anchored in science (TRAD). Using IM, INDEX and TRAD information gradients, we will analyze both *intra*-site and a more traditional *inter*-site transfer for comparison with the intra-site results. Our intra-site efforts will be in the SPRR. The inter-site transfer will be for the Bosque del Apache Wildlife Refuge (BDA) on the Rio Grande, south of Albuquerque, New Mexico.

2. RESEARCH DESIGN

Our team includes hydrologists, ecologists, ornithologists, geospatial geographers and economists; most are centrally involved in ongoing research projects in the SPRR. Some team members also participate in the ongoing Upper San Pedro Partnership, a community watershed organization consisting of 20 federal, state, and municipal agency representatives, environmental NGOs, and local water companies that cooperate to resolve water management issues in the Upper San Pedro.

This project is unique in that it will link a significant amount of research from current projects in the SPRR and will be able to address benefit transfer at varying levels of scientific and socio-economic information at the two sites. Finally, the stated preference valuation instruments will be based upon focus group- and stakeholder-defined information that elicits the scientific information necessary to describe changes in resource flows necessary for valuation.

The following sections describe the economic framework (section 3), methods for displaying the information gradients in the survey instrument (section 4), scenario specification and the hydrologic component (section 5), the riparian component (section 6), and the bird component (section 7).

3. ECONOMICS COMPONENT

The foundation of our proposed research program is framed by the following questions: 1) What is the ideal set of physical, natural, and social science information on which to build an economic research program to value ecological systems? 2) Can alternative suites of natural science information coupled with socio-behavioral information lead to a better understanding of both intra-site and inter-site benefit transfer functions?

Our research will be based on four scenarios (two anthropogenic and two climatic), use two stated preference techniques (CVM and CM), three information gradients (IM, INDEX, TRAD) and two test sites (SPRR and BDA).

3a. Valuation Models – The choice model (CM), a variant of conjoint analysis, elicits an individual's preferences by asking the subject to consider a series of policy options (Ben-Akiva and Lerman 1985; Louviere et al. 2000). In contrast to CVM, which asks individuals to explicitly state their willingness to pay for a proposed policy change, choice models require the individual to choose from a series of possible policies, each having different levels of the attributes (birds, in-stream flow, riparian vegetation and cost, for example). This allows the researcher to obtain the marginal value (implicit price) of each attribute, as well as welfare measures for any policy that has attributes contained within the span of those presented in the survey. Both CVM and CM models utilize a random utility framework to explain individuals' preferences for alternative hydrological/economic profiles in the SPRR and are directly estimable from CM and CVM data (Roe et al. 1996; Stevens et al. 1997).

One frequently mentioned advantage of a CM is that it directly provides marginal values for attributes as well as willingness to pay (WTP) for policies that have multiple effects. In contrast, CVM studies are designed to obtain the value for a single policy change. The policy can represent a change in a single attribute (WTP to protect birds) or multiple attributes (instream flow that protects riparian cover, birds and recreational uses). Marginal values can only be obtained by comparison with other studies that have different levels of the attribute in question. In no instance can the value of a single attribute be disentangled from the value of the policy estimated by CVM when multiple attributes are affected, unless multiple survey versions are employed.

To date there have been few published comparisons of CVM and CM (Boxall et al. 1996; Stevens et al. 2000; Desvousges et al. 1987; Margat et al. 1998; Ready et al. 1995; Barret et al. 1996; Mackenzie 1993). All of these studies found substantial differences in WTP estimates between the various forms of CM and CVM analyses for equivalent policies. Various reasons for the disparity have been offered: the one-shot CVM vs. the iterative nature of the choice model (Takatsuka 2003); presentation of alternative policies in the CM formats suggests substitute (alternative) policies not available in CVM (Boxall et al. 1996; Ready et al. 1995); CMs allow explicit recognition of complements that CVMs may not (Morrison 2000, Stewart et al. 2002); and the effects of the data structure used for conditional logit vs. standard logit estimation vary (Stewart et al. 2002).

In previous comparisons of CVM and CM, it is assumed that WTP derives from the same underlying utility function and thus WTP measures obtained from each method *should* be equivalent. Specification of the welfare calculation in indirect utility space in the two formats illustrates the linkage between theoretical utility specification and applied econometric measurement for the two models.

1) $CVM: v^1(p^1, q^1(protect\ riparian\ system), m - CV, z) + \varepsilon^1 = v^0(p^0, q^0(don't\ protect), m, z) + \varepsilon^0$

2) $ChoiceModel: v^1(p^1, q^1(birds, vegetation, streamflow), m - CV, z) + \varepsilon^1 =$
$v^0(p^0, q^0(birds, vegetation, streamflow), m, z) + \varepsilon^0$

The econometric specification of welfare change is then

3) $WTP_{policy}(CVM) = -(\alpha + \beta_2\overline{Z} + \varepsilon) / \beta_{1(bid)}$

4) $WTP(CHOICE) = -[(\alpha + \beta_1 Bid + \beta_2\overline{Z}* + \beta_3 Birds^1 + \beta_4 Veg^1 + \beta_5 flow^1 + \varepsilon)_{with\ policy}$
$-(\alpha + \beta_1 Bid + \beta_2\overline{Z}* + \beta_3 Birds^0 + \beta_4 Veg^0 + \beta_5 flow^0 + \varepsilon)_{without\ policy}] / \beta_{1(bid)}$

where $\overline{Z}$ represents socioeconomic information and the superscripts 1 and 0 represent with and without policy. Equations 1 and 2 value the same policy, but in Eq. 1, attributes are bundled together, while in Eq. 2 they are not.

The components of the policy change suggest that ecological attributes enter directly into the WTP equation in the CM, while they do not in the CVM. The ecological attributes are explicit components of an individual's utility function in CM, while in CVM utility comes from the policy being evaluated, which implicitly assumes the same attribute levels. For the two methods to provide identical welfare measures, significant restrictions on the estimated parameters are required. For a given policy change, utility should be equivalent for the two methods; the value elicitation procedures and the econometric estimation drive the difference.[2] We will test the implied restrictions for equivalence.

3b. Benefit Transfer – CMs are ideal for use in benefit transfer (BT) because evaluation of a range of attribute levels is part of the construction of the WTP function. Better still, if the original data are available, a WTP function can be estimated that restricts the model to consider attribute levels that are relevant for the transfer site.

We will develop BT functions for both *intra*-site and *inter*-site transfers.[3] For the SPRR, the intra-site effort, we will apply the CM and the CVM model frameworks using IM, INDEX, and TRAD. Intra-site analysis will illuminate the role of the natural science information in the valuation of the good. Inter-site comparison of results will provide insight into the traditional BT framework where restrictions are required. This analysis will be done using a CM and information level INDEX, which will allow issues of transferability to be evaluated in a multiple treatment framework. This should provide BT tools that better represent how individuals think about the value they place on riparian ecological systems, provide more accurate values of ecological components, and establish the conditions for which a benefit transfer of riparian values is meaningful.

3c. Scope, Embedding, and Definition of 'The Good' – Our integrated science model should lead to scientific outputs that are more meaningful to subjects than previous efforts and lessen the potential for scope and embedding effects. Scope tests for internal validity of stated preference models require that WTP increase as the quantity of the good being valued increases, while embedding occurs when individuals provide WTP responses for a good other than the exact one elicited in the survey. Equation 1 illustrates the increased potential for embedding in CVM. If individuals consider a good that is different than the one intended by the CVM researcher (the value of protecting the riparian system), i.e., they infer that some complementary change will occur along with the one that the surveyor intends to value, the WTP estimates derived from the CVM and the CM will likely produce disparate results.

We will examine hypotheses along the substitutes/complements lines and consider what restrictions on utility theory are necessary to bring CVM and CM estimates into alignment. The complements and substitutes arguments are fundamentally tied to the definition of the good. We expect that our integrated framework, which allows decomposition of the good (e.g., ecological protection) into its constituent parts (stream flow, vegetative cover, birds), may serve to improve welfare calculations.

By determining what the relevant or appropriate 'good' is through focus group contact and pre-testing of the survey instrument, potential scope and embedding effects can be diminished (Smith and Osborne 1996). Even for a given natural environment, the characteristics that are important may vary across individuals, space, and time. For experienced birders, spotting previously unseen species may be most important. For inexperienced bird watchers or casual visitors, seeing many different types of birds, large numbers of birds or other aspects such as vegetation, streamflow, or trails may be more important. The CM format allows examination of a suite of goods and thus ensures that the survey is relevant for a broader subject pool.

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[2] The conditional or mixed logit routines used to estimate CMs use the attributes of all policies that the individual considers, both those chosen and those not chosen to estimate parameters, while the standard logit used in CVM only considers the attributes of a single policy.

[3] One prior study conducted in the SPRR that was designed to test inter-site benefit transfer (Kirchhoff et al. 1997) will be used as a point of comparison for the BT and CVM results. The authors found benefit function transfer was preferable to benefit value transfer, but all transfers are significantly affected by scenario descriptions.

3d. Defining 'The Good': Linking to the Natural Sciences – There are two major challenges in meeting the goals of this project. First, credible measures of economic value must be linked to endpoints of the hydrologic, riparian, and bird models. Secondly, the techniques used in the study must be consistent with economic principles of individual welfare maximization. In measuring changes in the stocks, flows and distribution of birds, riparian vegetation, and water, we must make sure that definitions and terminology are consistently understood and applied by the researchers, the public, and across populations of users. Many of the outputs produced in the natural sciences are not the type of information considered by ordinary citizens in day-to-day life. Focus groups are necessary to bridge the gap between the specialized knowledge possessed by the scientists and the general knowledge and perceptions of the lay public. A unique feature of our study is that the focus groups will actually help determine what scientific information is collected and hone in on those attributes correlated with water management changes that are likely to be important to visitors to the SPRR. The attributes identified as important by the focus groups will be measured by the natural scientists and included in the choice model.

CM surveys are by nature complex. Each possible choice comprises bundles of attributes (streamflow, bird diversity, vegetation, cost, etc.) with each attribute having different levels (100 cubic feet/second [cfs], 300 cfs, or high, low, etc).[4] The large number of combinations of attributes and levels precludes analysis of each potential "policy" or combination. We will use a modified fractional factorial design for our analysis that will allow us to span the attribute space with 16 choice sets.[5] The sets will be blocked into groups of eight for presentation to subjects.

3e. Index Issues – Given the prevalence of indices produced in the natural sciences (index of biotic integrity, habitat suitability index, and Palmer Drought Severity Index, etc.) and their utility in standardizing measurements across sites, indices likely provide a reasonable account of the stocks and flows of natural resources and represent features of ecosystems that individuals care about. Valuation of the indices can occur indirectly if the attributes used in the CM scenarios can be linked back to the index. In addition, direct valuation of indices in a separate CM may provide a means for calculating values for many sites at low cost, especially by using BT for sites that may be fairly homogeneous to the relevant public. However, it is very important to ascertain that the index used actually captures the characteristics that individuals care about when valuing a site.[6]

We propose to 1) examine whether indices are meaningful to the relevant public through critical examination using focus groups; and 2) create an "index survey" that includes as attributes existing indices of riparian health and avian diversity for both the SPRR and BDA.

3f. Sampling – While we ultimately wish to value some aspect of recreational bird watching, the use of focus groups composed of the general public, serious bird watchers, policy makers, and non-birding recreational visitors will allow us to hone in on specific aspects (diversity

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[4] As an example of the potential complexity, if the focus groups were to determine that bird abundance, bird diversity, stream flow, and forest cover were the most important attributes of a visit and the scientists determined that the bird attributes needed three levels each to represent potential variation, the streamflow needed four, forest cover needed four, and cost needed six, there would be $3^2 * 4^2 * 6^1 = 864$ possible combinations of attributes and their levels.

[5] While CMs allow valuation of any policy spanned by the levels of the attributes presented in the choice set, we wish to ensure that respondents directly evaluate several of the "alternative futures" or other scenarios discussed in section 4. Thus we will modify the CM design to include several policy options that mirror the hydrological profiles presented in the alternative futures study or other scenarios developed with stakeholders.

[6] For birders visiting the San Pedro, it may be that one or a combination of the Simpson's or Shannon-Wiener diversity or evenness indices captures the most salient elements of a birding trip.

abundance, distribution, native vs. non-native, rarity, life list additions, vegetation, streamflow, etc.) of the SPRR that are important to birders and other users. We suspect that other aspects of the recreational experience such as the presence or absence of developed trails, picnic facilities, and viewing towers may be important as well. CM and CVM surveys will be developed to ensure that survey language, attributes, and attribute levels are consistent between them.

Because visitors to the San Pedro tend to be diverse and reside throughout the U.S. (Leones et al. 1997, 1998) and since world-class birding sites tend to be distant from population centers, we will rely on both Internet and on-site surveys. While Internet surveys still face criticism for not providing a random sample, more than 50% of U.S. households have computers in the home and Internet access is increasing (Rainie et al. 2001).[7] We will design the survey instrument and sampling strategy following Internet sampling procedures outlined in Couper (2000) and Alvarez et al. (2003), as well as principles from the Dillman Tailored Design Method (Dillman 2000). The survey will be designed such that laptops can be used on-site as well as over the Internet. We will survey several different populations: U.S. residents in general; U.S. birders drawn from Audubon Society membership rosters; residents and birders living in the Southwest; members of the Nature Conservancy in southeastern Arizona; and visitors to the study sites. Participants in the survey will be randomly assigned to either a CM or CVM treatment that considers scenarios for the SPRR or BDA using sampling methods and experimental design protocols described in Kish (1965), Cochran (1977), Mitchell and Carson (1989), and Cooper (1993).

To encourage participation and completion of the survey, on-site and Internet respondents will receive nominal compensation. For the Internet, we will contact individuals by mail and email to invite them to log on to our site. After completing the survey, participants will be able to print out a form that can be mailed back to us. We will confirm the authenticity of the form and mail back a payment. This approach was successfully used in a recent research project (Bernknopf et al. 2003). We will design three each of the CM and CVM surveys to examine the IM, INDEX, and TRAD information gradients formulations for the SPRR. The IM-CM model, as the foundation of the study, will require 400 completed surveys. The INDEX and TRAD-CM surveys will require 200 observations each. Sample sizes for the INDEX-CVM and TRAD-CVM surveys will require 400 completions each, while the IM-CVM setting will require 800 observations to allow for two different policy evaluations and a scope test of the CVM data. These surveys will form the basis of the methodological tests and the intra-site BT estimations.

The inter-site BT tests will be based on two CM surveys collected on-site and over the Internet for the BDA. The first test will be across the INDEX information setting. This will require a sample of 200 observations from the BDA that will allow us to value an additional site using CM and INDEX. These results will be compared to the SPRR results. The second BT test will be based on a CM survey conducted using the TRAD model for the BDA.

3g. Linkages to the Natural Sciences – One key component of this effort is the use of state-of-the-art science and linkages between the sciences for the development of changes in resource stocks and flows. Another is the use of economics to inform the structure of the information flowing from and between the natural sciences. Much of the groundwork has already been laid for the information flow to the economics model. We will use the Alternative Futures Study (AFS; Steinitz et al. 2003) and/or results from the Upper San Pedro Partnership efforts to provide

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[7] There are ways around the non-representation problem. If the characteristics of the relevant population are known, the sample can be weighted such that the estimation takes place as if the sample is representative. However, weighting samples does not address the problem fact that some groups, especially low income households, may not be represented because of lack of Internet access.

a link between probable urban population growth scenarios and hydrological profiles for the San Pedro Valley. The AFS provides the hydrologic scenarios that drive the water-limited riparian system. Members of our research team have partially established the linkage between alternative surface and groundwater regimes to riparian habitat. The essential components have also been partially developed for linking the avian population and avian diversity resulting from changes in the San Pedro riparian system. What remains to be done is to uncover the attributes of the San Pedro system that are important to visitors and to create the information flows between the hydrologic, biologic, and economic sub-models necessary to meaningfully describe them.

4. VALUATION AND VISUALIZATION PROJECTIONS FOR THE SURVEY

Effective decision-making, model evaluation, and experiment execution for this project require efficient representation of input parameter values and model results. The explicitly spatial nature of all project components (hydrologic characteristics, vegetation distribution and characteristics, geologic and soil data, avian species distribution, and recreational sites in the SPRR) suggests that the most appropriate tools for displaying these data must retain and emphasize the spatial variation inherent in all of these datasets. The generation, storage, integration, and visualization of these data require a combination of geographic information technologies including geo-databases for data storage and database integration, geographic information systems (GIS) for data production and processing, Internet-enabled mapping technologies, and integrated technologies for linking these components with the economic models developed. The result will be a Web-enabled, science-based Economic Valuation and Visualization System (EVVS). This system will allow direct user interaction with model-based projections of environmental characteristics affecting valuation. By presenting these projections in a user-friendly and easily interpreted geographic context, participants will be better able to assess the consequences of the alternative scenarios.

Implementation of the EVVS will employ a combination of commercial off-the-shelf and open source applications. Building on work being done for the Environmental Protection Agency by Brookshire et al. (in prep.) on economic and physical systems modeling for water allocation, the EVVS will provide intuitive Web-based interfaces linking science-based models with spatial data display. What appears as a simple Attribute Display in Figure 1, for example, represents the integration of outputs from, and inputs to, multiple spatial and aspatial models of bird habitat and diversity, hydrology, and riparian ecology, all developed using a common scenario. The model outputs will be integrated using the Powersim modeling framework.[8] The calibrated Powersim model will allow for an understanding of the linkages and feedbacks between the natural science and economic submodels and presentation of the workings of the hydro-bio-economic system in an intuitive format that can be easily displayed in the EVVS. Powersim displays will facilitate understanding by participants and will integrate participant choices to better assess and value natural resources under changing environmental conditions. The display of the consequences of environmental variability and change in a spatial context provides contextual information to the participant allowing more informed choices. The integration of science-based models with environmental consequences mapping presents a

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[8] While Powersim is not a spatially explicit framework per se, it can be used to develop a semi-distributed model that can capture relevant spatial characteristics. This can be used to examine the dynamics of water, vegetation, and birds distributed across the watershed, their interactions, and their effects on economic values at different points in the SPRR.

unique and innovative perspective, allowing the presentation of complex and environmental relationships in an easily understood and interactive form.[9]

5. SCENARIOS AND HYDROLOGY COMPONENT

The valuation effort will be conducted within the context of specific future scenarios in the SPRR. Considerable effort has been expended in developing a framework of scenarios and understanding the hydrology. These efforts set the basis for determining the changes in vegetation and birds.

5a. Scenarios – If the future were known, there would be only one scenario, and planning for it would be a simple task. However, planning for the future is a complicated process. Since no single vision of the future is likely to be accurate, it is helpful to consider a set of alternative futures that encompasses a spectrum of possibilities.

The objective of scenario development is to provide a framework for analyzing anthropogenic and climatic changes in the SPRR that affect the service flows of the ecological system. The Alternative Futures Study (AFS) is a well-developed and available framework. An alternative scenario framework is being developed by the Upper San Pedro Partnership. We will discuss with them the possible use of their scenarios either in addition to or as a replacement for the AFS. Both frameworks address, in part, how regional growth and climate change in the rapidly developing Upper San Pedro Basin might influence the hydrology and biodiversity of the area.

Scenarios allow choices to vary within the selected areas of policy concern; different points of view are represented by specific choices. The process investigates a number of futures, and allows for a diversity of opinion within the same study. Because each scenario describes the future in similar terms of policy choices, there is an opportunity to compare the outcomes of individual policy decisions. The AFS scenarios, as a case in point, respond to several recognizable patterns of observed interests of the local community; each of these patterns was developed into a set of scenarios. One scenario, referred to as PLANS, is based on current plans in Arizona and accepts the current population forecasts. Another, called CONSTRAINED, directs development in Arizona into currently developed areas, and reduces the forecast population. The third, OPEN, removes most constraints on land development, and assumes a higher population than was forecast. Each scenario is further modified by selected policy changes resulting in additional but closely related scenarios.

5b. Hydrologic Models – Co-investigators of this proposal and their colleagues have developed and parameterized three relatively mature models of the San Pedro Basin hydrology. They include a GIS-based MODFLOW groundwater model (Goode and Maddock 2000), a GIS-based set of daily and event-based surface water runoff models (Miller et al. 2002), and a Penman-Monteith Riparian evapotranspiration model of the San Pedro Riparian National Conservation Area (Goodrich et al. 2000). The groundwater model is well calibrated and has already been parameterized and applied under ten different spatially explicit growth scenarios to 2020 in the SPRR (Steinitz et al. 2003). In addition, models with a more realistic representation of riparian

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[9] The development and implementation of EVVS will involve both commercial and open source applications. Software applications that will play a crucial role in EVVS include: geodatabases such as ESRI's Spatial Database Engine (SDE) and PostGIS, built on Microsoft SQL Server 2000 and PostgreSQL, respectively, and GIS applications including ArcGIS and GRASS. Standards-based Internet technologies will be used for the MapServer Internet mapping application including HTML- and Javascript-based client interfaces generated using PHP, Perl, and the Powersim Software Development Kit for developing custom Web-interfaces to the Powersim integrated model.

evapotranspiration (ET) will be incorporated into this study (Maddock and Baird 2002). The surface runoff models in the American Ground Water Association modeling system have also been parameterized and applied to the San Pedro with remotely sensed land cover from the 1970s, '80s, and '90s (Hernandez et al. 2000; Miller et al. 2002). These models are currently being parameterized for the alternative future land cover scenarios specified by Steinitz et al. (2003) under an Interagency Government Agreement between the EPA Landscape Ecology Branch and the U.S. Department of Agriculture and Arizona Research Service-Southwest Watershed Research Center. Upper San Pedro Partnership funding is currently in place to complete an update of the daily Riparian ET model (Goodrich et al. 2000) and provide a GIS interface for ready evaluation of scenarios by January 2004. The NSF Center for the Sustainability of semi-Arid Hydrology and Riparian Areas (SAHRA, http://www.sahra.arizona.edu) is supporting research to more explicitly link these three modeling systems. However, we are confident that even in their current form, the three modeling systems are capable of providing valid estimates of the changes in hydrology for the economic valuation analysis proposed herein.

5c. Forward Linkages to the Riparian Component – The models described in 5b. can be used to produce maps and spatially explicit point predictions of groundwater depth and surface flow frequency under a range of alternative future scenarios. These predictions can be provided over biologically meaningful "seasons," with groundwater depths predicted to a resolution of approximately 1 meter under both equilibrium and transient conditions. High resolution (<0.1 m) floodplain topography and riparian canopy geometry data for each reach will be obtained from an independently funded effort scheduled for the summer of 2003.

5d. Forward Linkages to the Survey Display – Using the hydrologic models discussed above, the hydrologic response of the San Pedro River to a variety of realistic scenarios ranging from pumping demand changes, to land cover/land use changes, to climate change, to water conservation scenarios, to climate change can be evaluated. These will be used as inputs to the survey display component.

6. RIPARIAN COMPONENT

The objective of the riparian component is to determine how riparian vegetation distribution, composition, and structure respond to changes in surface flow and groundwater levels in the SPRR. We will synthesize existing vegetation-hydrology data for the San Pedro and other southwestern rivers and make spatial predictions of vegetation change based on projections from basin-scale hydrologic models of groundwater and base flow change described in section 4. Our projections of vegetation change, when combined with bird habitat models, will be used to predict the effects of hydrologic changes on songbird populations along the San Pedro River.

6a. Existing Information – The riparian component is highly leveraged from previous and ongoing research funded by several organizations.[10] Substantial information exists on how San Pedro vegetation structure, composition, and dynamics are related to floodplain groundwater depths (see budget justification) (Stromberg et al. 1996). For example, Stromberg (1998) showed that woodlands of exotic tamarisk are replacing native Fremont cottonwood and Goodding willow stands due to declining groundwater depths along some reaches in the upper

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[10] Funding provided to Stromberg by the U.S. Bureau of Land Management/ Upper San Pedro River Partnership (BLM/Upper San Pedro Partnership's SPRNCA Water Needs Study), the NSF Center for Sustainability of Semi-arid Hydrology and Riparian Areas, and a subcontract on an EPA Climate Change grant to the American Bird Conservancy.

SPR. Data on the relationships between mesquite stand structure and groundwater depths (Stromberg et al. 1992, 1993) are also available. Response of stand structural traits (e.g., canopy height, vegetation volume, canopy cover) to ground and surface water fluctuation are being addressed by ongoing studies (Lite and Stromberg, in prep.), as are response of diversity and richness of herbaceous and woody plants classified within stress-disturbance functional groups (Bagstad and Stromberg, in prep.). These known bio-hydrology relationships are being used to develop statistical and simulation models that project changes in vegetation communities with changes in groundwater depths and provide the necessary linkages for the bird modelers.

6b. Riparian Component Development – Using the backward linkages and extending the existing knowledge of riparian vegetation dynamics, we will generate outputs for the bird change model. 1) We will use hydrologically and geomorphically distinct reaches within the SPRNCA, the mapped distribution of riparian vegetation alliances, and field data from the delineated reaches to identify relationships between riparian vegetation structure and composition and reach hydrology (groundwater depth and surface flow frequency). On the Upper San Pedro, fourteen discrete reaches (1 to 5 km long) have been defined, based on floodplain width, spatial flow intermittency, and channel sinuosity. A map of vegetation types has been developed for the entire SPRNCA, including all study reaches, based on analysis of aerial photographs and field ground-truthing. Patch types are defined according to physiognomy (e.g., woodland, forest, shrubland) and dominant species or species group (e.g., mesquite, cottonwood). 2) We will develop reach-scale indices of vegetation composition and structure based on the above bio-hydrology relationships and a longitudinal gradient in site hydrology[11] that exists within our delineated reaches. Using space-for-time substitution, these indices can be used to project reach-scale changes in riparian vegetation structure and composition (e.g., relative abundance of cottonwood vs. tamarisk), given scenarios of hydrologic change for each reach. This will provide a course-scale, first approximation of vegetation change under the selected scenarios. 3) We will model finer-scale, patch level riparian vegetation change in response to scenarios of groundwater decline and changes in surface flow frequency. We are developing a computer model in Powersim to simulate the effects of changes in hydrologic and other physical drivers on the distribution and dynamics of riparian vegetation alliances on the San Pedro floodplain. The model simulates successional dynamics in southwestern riparian plant communities by representing the establishment, growth, and mortality of different species or functional groups in relation to environmental conditions and competitive interactions in the patch. Results from patch-level projections will be scaled up to the reach by running the model within each cell of a gridded landscape and displaying the results in GIS.

6c. Forward Linkages to the Bird Component – The bird component will be provided with projections of changes in vegetation composition, structure, and distribution that can be used in modeling changes in bird habitat quality and quantity. Model results will yield spatially explicit reach- and patch-level projections of change in the distribution of vegetation alliances under scenarios of hydrologic change. Specifically, the riparian component will 1) quantify differences in vegetation composition and structure among delineated reaches according to surface flow frequency, groundwater depth, and physical site conditions, 2) develop statistical and simulation models linking riparian vegetation dynamics with surface and groundwater hydrology, and 3)

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[11] We have established 29 field sites along the San Pedro River from the international border to the confluence with the Gila River. Seventeen of these occur within the SPRNCA, representing most of the delineated reaches (about one site per reach). The sites were selected to capture the wide range of hydrologic variation along the San Pedro River and include ephemeral, intermittent, and perennial reaches.

project compositional and structural changes in vegetation under different groundwater scenarios in a form that can be used by the bird modelers.

6d. Forward Linkages to the Survey Display – While the riparian outputs will be incorporated indirectly in economics through their effects on the bird model, some components will be incorporated directly in the choice sets because we expect that birders and others who visit the San Pedro value the qualities of the riparian habitat as well as the birds.

The economic model will be fed spatially explicit projections of vegetation structure and composition, including: characterizations of canopy height, volume, and stem densities of Fremont cottonwood, Goodding willow, mesquite, and tamarisk; cover of marshlands, sacaton grasslands, and xerophytic shrublands; and possibly other characteristics that may be identified by the focus groups. Maps and characterizations will be provided for each hydrologic scenario that the economists will analyze in the choice model, including the distribution of vegetation under the current regime and approximately sixteen others, representing feasible future states of the hydrological profile.

7. BIRD COMPONENT

The objective of the bird component is to determine the impact of vegetation changes on bird populations and communities for differing type of reaches of the SPR. Further, the bird component will provide characterizations of bird abundance, productivity, and diversity for economic valuation models.

7a. Existing Information – Data has been collected in the upper and middle reaches of the San Pedro River during the 1998 through 2001 field seasons. A total of 23 sampling areas were established on Bureau of Land Management (BLM) and private land on the upper and middle San Pedro. To the extent possible, these locations were placed randomly and selected by use of topographic maps and field reconnaissance. Attempts were also made to co-locate study sites with Stromberg's research such that 17 of 23 sites are in common with Stromberg's. Survey sites were placed at least 4 km apart so that they could be considered independent from the standpoint of bird territories. Sampling areas capture the full range in variability in hydrologic regime and consist of eight ephemeral, seven intermittent, and eight perennial reaches.

A substantial amount of data was obtained from 1998 to 2001 pertaining to avian density, productivity, and habitat utilization, using the most current population estimation methods. This data collection effort was designed to allow assessment of how variation in the hydrologic processes and associated vegetative communities affect avian population and community processes.

Established study sites enable estimation of bird density along habitat gradients perpendicular to the river corridor as well as parallel to the flow regime gradient. More than 19,000 detections of 124 different bird species were made during approximately ten different 5-minute surveys at each of 280 total point count locations during the 1998 to 2001 avian breeding seasons (May through July) following distance sampling methods (Buckland et al. 2001).

Approximately 1000 nests of 18 species were found and monitored during the 1999 to 2001 avian breeding seasons in the 23 sampling areas following BIRD protocol (Martin 1999). The selection of the 18 focal species was based on a number of criteria, including abundance, ease of finding and monitoring the nests, response to hydrologic regime, life history traits, conservation status, migratory status, and different habitat affinities within taxonomic affiliation.

To further characterize bird habitat use, nest vegetation measurements were taken around monitored nests after completion of breeding activity. Measurements include nest height, orientation, and concealment. Ground cover, shrubs and saplings were quantified by species and size class around each nest within a 5-meter radius, and trees were quantified by species and size class within an 11.3 m radius around each nest. Vegetation measurements were obtained at a subset of point count locations. The existing avian data provides a critical starting point to establish linkages and quantify relationships between avian population processes and the riparian plant communities associated with variation in hydrologic processes that can be used in economic valuation.

7b. Bird Component Development – The proposed study will assess bird-vegetation relationships associated with variation in hydrologic regime, and predict the potential impact of alteration of the hydrology-driven vegetation composition and structure on riparian birds, using both standard statistical analyses and by application of a spatial modeling framework called the Effective Area Model (Sisk et al. 1997). The analysis approach will utilize the most current methods for assessing avian abundance (Buckland et al. 2001), productivity (Stanley 2000), species richness (Hines et al. 1999; Boulinier et al. 1998; Nichols et al. 1998) and diversity (Ludwig and Reynolds 1988; Magurran 1988). Specifically, we will: 1) quantify avian diversity and richness, as well as species-specific abundance and productivity patterns based on the three to four reach types identified by Stromberg (coarse-scale modeling approach); 2) estimate avian population parameters at a spatial scale appropriate to explore patterns of covariation between attributes of the vegetation and avian communities and their relation to variation in hydrologic regime; 3) quantify how variation in the structure and composition of vegetation communities along a hydrological gradient affects avian population parameters, and identify hydrologic threshold values for key bird species with respect to riparian vegetation patch types associated with particular groundwater depths and surface flow frequency; 4) develop avian edge response functions using linear and nonlinear models to characterize species-specific bird density as a function of distance from edge; and 5) model avian population change through the Effective Area Model, a fine-scale, spatially explicit modeling framework incorporating avian edge response functions, along with habitat maps to assess the potential impacts of variation in vegetation composition, structure, and spatial arrangement resulting from different groundwater draw-down scenarios.

7c. Linkages to the Survey Display – The "goods" we use in the economic sub-model will include several attributes from the bird sub-models: estimates of avian diversity and richness, as well as species-specific estimates of abundance and productivity for a set of focal species. In addition, we will use one of the indices as the sole component of a valuation exercise with the goal of providing low-cost value estimates for use in benefit transfer.

We expect that the various avian outputs will be useful to different populations of San Pedro visitors. Estimates of avian species diversity will be useful for birders who attempt to maximize their "life lists" or to see as many species as possible in a short visit to the area. Abundance will be useful for birders who value multiple sightings of a given bird species because they may be interested in bird ecology and behavior or enjoy seeing "lots of birds." Bird productivity can be used to economically assess how birders view the resource over the long-term, such as whether it is important that a particular species be present in 10 to 50 years for their children or grandchildren to see.

In addition, the bird modelers will provide characterizations of the relationship between riparian habitat and species diversity, richness, and abundance that are suitable to be included in the presentation of the CM to subjects looking at hydrological/riparian profiles.

8. EXPECTED RESULTS

Riparian areas are typically studied in a piecemeal fashion, with little integration of the natural and social sciences. The proposed research will integrate a substantial amount of what is known about a critical southwestern ecosystem and examine its benefits to society. Such an analysis may be particularly useful on the San Pedro, one of the few remaining free-flowing rivers in the Southwest, where great challenges exist in trying to balance human water needs and uses, a variable climate outlook, and the need to protect a highly valuable ecological resource. Three central results will be obtained: 1) a fully integrated valuation framework using the best science and alternative valuation methods; 2) methodological insights into stated preference valuation frameworks; and 3) alternative benefit transfer functions that rely on alternative information gradients. These results will advance disciplinary and interdisciplinary methodology as well as provide input into public policy questions.

This study will lead to a realistic coupling of climate and anthropogenic change impacts on the hydrology, riparian habitat, avian populations, and economic value of the SPRR. Given the importance of the biotic resources associated with southwestern riparian systems and the threats to these resources from continued groundwater depletion and surface water diversion, a model linking riparian vegetation dynamics to groundwater and surface flow hydrology will provide an important tool for management and planning. The linkage of vegetation models with bird habitat models will be particularly significant, because of the noted conservation value of the SPRR for migratory songbirds. The explicit linkages between the sciences and the provision of information flows influenced by the economic needs should lead to valuation models that more accurately measure public preferences.

The proposed research will lead to advances in the use of stated preference methods to value ecosystem services, especially as related to benefit transfer. The robustness of CM and CVM methods across gradients of natural science information will be examined. Particular attention will be given to how the quality (gradients) of natural science information and representations of that information to the public affect value.

The research will provide insight into the use of benefit transfer using science and socio-economic information gradients that are likely to be encountered in the field and examine whether stand-alone scientific indices may be used as proxies for economic value.

9. GENERAL PROJECT INFORMATION

The institutions involved in this project have ongoing research relationships.

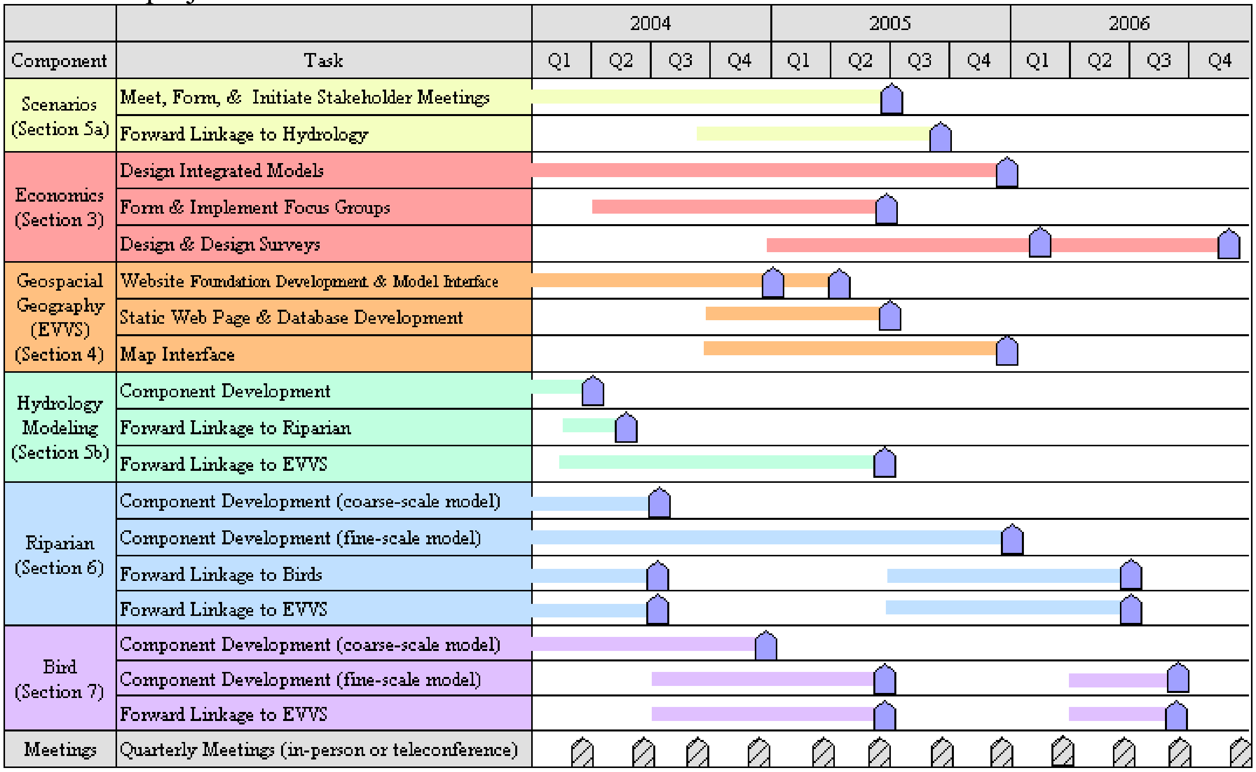
Project Management – David Brookshire (University of New Mexico [UNM]) will serve as overall project manager. Janie Chermak (UNM), Julie Stromberg (Arizona State University [ASU]) and Steve Stewart (University of Arizona [UA]) will serve as Co-PI's. Thomas Maddock III (UA) and Arriana Brand (Colorado State University [CSU]) will serve as investigators. Holly Richter (Nature Conservancy and Upper San Pedro Partnership), David Goodrich (USDA Agricultural Research Service), John Loomis (CSU) and Bonnie Colby (UA) bring complementary backgrounds to the various components and will serve as an advisory panel. David Brookshire will lead the scenario effort and the design of the surveys, conduct focus group efforts, and generally be responsible for the integration of the parts. The hydrologic component will be managed by Thomas Maddock, the riparian component by Julie Stromberg, and the bird component by Arriana Brand. Rick Watson (UNM) will lead the display design and integrate the CM and CVM into the display. Steve Stewart will contribute to the survey design,

design the specific sample plan, and estimate results. The Internet portion will be run on a server at UNM.

Time line – The figure below depicts the approximate flow and interrelationships of the research effort. Quarterly teleconference meetings will be held using a combination of interactive whiteboards and NetMeeting (allowing video and computer images to be projected, annotated or edited, saved, and shared at remote sites). Some quarterly meetings will be held in person with a limited group, most likely at UA or ASU.

Facilities – The necessary equipment is owned by the all of the institutions, and space is available to house graduate and undergraduate students. UNM has 15 laptops for use in focus groups on-site and for the surveys. UNM, UA and ASU have interactive NetMeeting facilities with whiteboards.

Personnel – All of the individuals on this project have worked or are currently working together on various projects.



Component	Task
Scenarios (Section 5a)	Meet, Form, & Initiate Stakeholder Meetings
	Forward Linkage to Hydrology
Economics (Section 3)	Design Integrated Models
	Form & Implement Focus Groups
	Design & Design Surveys
Geospacial Geography (EVVS) (Section 4)	Website Foundation Development & Model Interface
	Static Web Page & Database Development
	Map Interface
Hydrology Modeling (Section 5b)	Component Development
	Forward Linkage to Riparian
	Forward Linkage to EVVS
Riparian (Section 6)	Component Development (coarse-scale model)
	Component Development (fine-scale model)
	Forward Linkage to Birds
	Forward Linkage to EVVS
Bird (Section 7)	Component Development (coarse-scale model)
	Component Development (fine-scale model)
	Forward Linkage to EVVS
Meetings	Quarterly Meetings (in-person or teleconference)

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