RIPARIAN VALUATION IN THE SOUTHWESTERN UNITED STATES

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DEDICATION

For Grandmothers here and there, living and passed.

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ABSTRACT

This research documents the societal worth of riparian resources in the Southwestern United States. Two case studies are developed for this inquiry, the first being Aravaipa Canyon Wilderness in Southern Arizona, an area containing one of the last perennial streams in the Sonoran Desert bioregion. A hiking use value per visitor-day is estimated via the Travel Cost Method at $25.06 and $17.31 (2003 dollars) respectively for two access sites. I hypothesize the value discrepancy to indicate a premium for remote recreation. These valuation results compare well with other published recreational use value estimates, though it is the only valuation study associated with instream recreation in the Sonoran Desert of which I am aware. Indeed the environmental valuation literature is thin for the desert region in any respect.

The second case study values public restoration preferences for the Albuquerque reach of the Rio Grande in Central New Mexico. A Choice Experiment and Contingent Valuation are employed within an original survey instrument to estimate human values for various restoration strategies planned for the region. Through focus groups and stakeholder interactions four restoration attributes were defined: vegetation density; tree type; fish and wildlife population; and natural river processes. Quantified values for Albuquerque area households were estimated for each restoration attribute level of change, allowing construction of total benefits anticipated for various restoration scenarios considered for the region. This research is at the vanguard of quantifying human benefit for saltcedar control, and this particular restoration characteristic was the most highly valued of all, at $59.03 per household per year. Full restoration was valued

at $156.60 per household per year. These results have meaning beyond the study area since river restoration efforts are increasing across the Western US, with many focusing on controlling saltcedar, an exotic invasive plant.

The final phase of this research integrates riparian valuation concepts within a dynamic simulation framework to guide systems-level riparian management. Control variables are combined with known valuation pathways to predict riparian investment funding optimal in benefit-cost ratio. The model is built for the Middle Rio Grande in Albuquerque, however it was designed for easy adaptation to other Southwestern riparian areas. A detailed forest module is included, through which seven defined forest stocks may be managed through thinning, clearing, and revegetation. River management may occur through environmental river flow releases, reconstructing stream-overbank connections, and wetland construction. Recreational amenities may be improved through the four infrastructure categories of trails, toilet facilities, picnic areas, and parking areas. Benefits and costs are estimated through original research and region benefit transfer, and tracked for different investment scenarios to predict the highest-return strategies over a 100 year planning horizon. A sensitivity analysis is used to suggest areas of future research.

1. INTRODUCTION

Our natural environment supports humanity in such a fundamental sense that to associate a dollar value with it seems ludicrous, if not immoral. Yet, practical issues of how to live within and manage our natural resources are absolutely inescapable and essential to society. Difficult tradeoffs abound: Where should the next housing development be located? Should the city begin a recycling program? Would public transportation investment pay off? Should we switch to imported biodiesel or just use more efficient gasoline engines? Should we decommission a hydroelectric dam and thus restore a salmon fishery?

Each resource-impacting decision, the most pernicious being perhaps 'do nothing', carries with it both benefits and costs for society. This research is presented with the belief that environmental decision making could benefit from more quantifying analysis than currently occurs, and that environmental management in general will become more critical. The discipline of environmental economics has matured in recent decades and offers a numeric, scientific perspective on resource management, though not to the exclusion of other decision inputs such as philosophic, moral, or spiritual perspectives a society may hold.

Like many, I moved to the desert from a much different bioregion. I found myself increasingly captivated by desert contrasts, nowhere more striking than where the rare oasis meets surrounding chapparal. Visiting these life zone juxtapositions has become a pastime for me, and in this appreciation I am not alone. Along these lines, while many avenues of riparian valuation exist, this study is most concerned with elucidating the nonmarket benefits of instream flow rather than market uses of the land or its water. Thus this work refers frequently to ecosystem services, as distinguished from extractable ecosystem goods. Ecosystem service valuation is a fantastic challenge, as new pathways of value from nature are continuously recognized (for a classic primer on ecosystem services see Daily 1997). So, the work of the environmental economist is neverending even when sticking to a regional beat, and we risk uncovering more of the problem than we will solve. Yet these initial steps offer perhaps a fair beginning to a journey of unknown length.

The core problem of environmental economics stems from the environment having attributes of a public good. A pure public good is one which all may enjoy (unrestricted access) and one person's enjoyments does not diminish that of another (non-rival in consumption). Since desert riparian areas exhibit varying degrees of public goods, collective management thereof is desired, else optimal provision may not result. This encapsulates both the challenge and the solution. Humankind share equal ownership in public lands, and our collective voice for preservation may be strong indeed. However, organizational barriers exist for combining disparate, small voices into one that may be heard in regards to public land policy debate. Environmental economics may be seen as lowering this organizational hurdle through measurement of human preferences, and thereby documenting public values for a resource. Two classes of techniques are employed: revealed preference, in which actual behavioral observations are used to impute value; and stated preference, in which surveys are used to elicit written or verbal values. Revealed preference techniques have the advantage of behavioral proof, though researcher discretion is necessary in obtaining values, see Randall (1994). Further, only present circumstances can be valued. With stated preference techniques the researcher may formulate any environmental scenario desired, however the values are likewise hypothetical, see Carson et al. (2001).

A few things ought to be made clear in regards to valuation results contained herein. First, the riparian values uncovered are not associated with any particular point of view. These values are built on at-large public preferences through econometric techniques that capture these en-masse. Thus no specific point of view is selectively represented, I cannot represent any particular philosophic or moral argument, nor values "if nature could speak". The results represent simple, blank human preferences with as much fidelity as possible. Second, these riparian values should be considered incomplete. The breadth of ecosystem services offered by environmental resources is yet incompletely understood. Human preferences and value may only be obtained insofar as human perception precedes. Third, the Southwestern focus should not blind us to a larger view of ecosystem service importance. Whereas ecosystem services benefits in the United States are most associated with an additional, almost extracurricular quality of life, in many areas of the world they have a much tighter link to basic survival. The Millenium Ecosystem Assessment (2005) details a more global picture of ecosystem services and impacts of degradation currently, and into the future. Fourth, and finally, contemporary econometric valuation protocol operates under a property rights structure in which people are asked what they would be willing to pay for environmental improvements or to avoid environmental losses. This 'Willingness To Pay' protocol was suggested by a panel assembled by NOAA in the wake of the Exxon Valdez oil spill (Arrow et al. 1993). A competing view is to ask what people would be willing to accept in payment to forego improvements or to accept losses. The willingness to accept paradigm places the right to the environmental resource with the public, and does not limit valuation bids to individual discretionary budget, thus valuation figures results may be larger. A revival of willingness to pay usage was recently suggested by the National Research Council (2004), and this implied change of property right may become more accepted as time goes on.

2. PRESENT STUDY

This dissertation relies on three distinct manuscripts to develop the concept of human value for riparian areas in the Southwestern US. Established econometric and modeling techniques are applied to desert riparian case studies. I purposefully utilized a diversity of econometric techniques to further my own understanding of their various strengths and weaknesses. While there are innumerable case studies for nonmarket values associated with the environment, few references are available for desert regions, fewer still for desert riparian resources, arguably the most critical fraction of that landscape. Notable among these are Crandall et al. 1992, Leones 1997, Berrens 2000, Colby and Wishart 2003, and Bark, 2006. A primary contribution of this dissertation is simply the building of regional environmental valuation knowledge, focused on the resource the desert is defined by having a lack of.

The first case study is a recreation use value for Aravaipa Canyon Wilderness, found in the Sonoran Desert of Southern Arizona, and one of the last perennial streams found in that bioregion. This manuscript appears in the Journal of Water Resources Planning and Management (Jan/Feb, 2006, pp 53-60). Thanks to my co-author, Dr. Robert Berrens, for agreeing to display the article again here as Appendix A. After repeated hiking experiences in Aravaipa, and subsequent exposure to the econometric concept of Travel Cost, I realized the potential for a novel application. The Travel Cost Method has a long history of usage and the notion is attributed to Hotelling (1949). It is perhaps one of the more accepted environmental economic techniques, relying on observed rather than stated preferences. That is, the value observations are not hypothetical, they are derived from observations of actual behavior. The core idea is that distance and time are costly, thus expenditures incurred to visit a recreation site help form a traditional price-quantity demand curve for the site. This case study offers one of very few recreation use value estimates available for the entire Southwestern bioregion, and the only valuation study of which I am aware for hiking associated with an instream-flow canyon resource in the Sonoran Desert. Further, value comparison between two access sites implies a remoteness premium for recreation. Note that equation 3 is corrected in this dissertation from the previously published version. Visitation data for Aravaipa were obtained from the managing agency that also disperses limited permits. Thus, while still more of a public than a private good, Aravaipa does have limited access, affecting use values of the site.

The second case study documents restoration preferences for the Rio Grande Bosque in Albuquerque. As of this writing the manuscript presented as Appendix B is receiving revisions requested by Journal of Restoration Ecology reviewers. This project area differs strikingly from the first in being urban rather than wilderness. The methodology used is also completely different, and allows a fuller measure of value. Two stated preference techniques are employed, contingent valuation and choice modeling. Use of stated preference techniques necessarily incur a hypothetical nature to value estimates, however the researcher has more control over what aspect of the resource value estimates adhere to, and the portfolio of value types may be expanded. Whereas Travel Cost is limited to direct use values associated with a physical visit, stated preference techniques may be used to capture nonuse values as well, classically defined as existence, option, and bequest values. These values can be significant, and on par or greater than direct use values (e.g. Brown 1992). Contingent valuation and choice modeling have important differences though both are stated preference techniques. Contingent valuation has several formats but is typically used to value a particular resource in its entirety, such as survival of an endangered species, protection of a wildlife refuge, or decommission of a dam to allow salmon run restoration. Choice modeling is best used where options within resource management exist. Both contingent valuation and choice modeling are applied for the river restoration application. Use of these two techniques allows a value cross-check for the full restoration scenario, while the choice model yields valuation estimates for specific aspects of restoration. The river restoration problem for the Albuquerque Bosque is mirrored in other Western regions. A central part of the restoration is saltcedar control, an exotic invasive plant throughout the Western U.S. Our study estimates a human value for control of saltcedar and thus may have significant benefit transfer potential for other regions with the same problem.

The third paper, attached as Appendix C, extends the individual case studies explored in Appendices A and B, and goes on to develop a more complete picture of riparian value using dynamic simulation modeling. The model is built specifically for the Middle Rio Grande in Albuquerque, but the inferences and results are anticipated to be useful for other riparian management scenarios. The target journal for this study is Ecological Economics. Use and nonuse values associated with riparian improvements are estimated, using results found in Appendix B as well as regional benefit transfer. The model includes three classes of riparian investment: forest; water resources; and recreational amenities. Links between human management of these physical variables and sources of nonmarket value are defined. Complex interaction effects and time delays are easily included in the dynamic simulation platform and may offer an improvement over management without the use of a reference model. Costs of different riparian management scenarios restoration are also included, such that the impact of different strategies can be compared based on a quantitative benefit-cost ratio.

3. REFERENCES

Arrow, K., R. Solow, P.R. Portney, E.E. Leamer, R. Radner, and H. Shuman, Report of the NOAA Panel on Contingent Valuation, Federal Register 58, pp 4601-4614, 1993.

Bark, R.H., Muddy Waters: Case Studies in Dryland Water Resource Economics, PhD Dissertation, University of Arizona, 256 p, 2006.

Berrens, R., A. Bohara, C. Silva, M. McKee and D. Brookshire, Contingent Valuation of Instream Flows in New Mexico: With Tests of Scope, Group-Size Reminder and Temporal Reliability, Journal of Environmental Management 58(1):73-90, 2000.

Brown, T.C., Water for Wilderness Areas: Instream Flow Needs, Protection, and Economic Value." Rivers 2(4):311-325, 1992.

Carson, R.T., N.E. Flores, N.F. Meade, Contingent Valuation: Controversies and Evidence, Environmental and Resource Economics 19, pp 173-210, 2001.

Colby, B., and S. Wishart, Quantifying the Influence of Desert Riparian Areas on Residential Property Values, The Appraisal Journal, July 2002.

Daily, G.C., ed, Nature's Services, Island Press, Covelo CA, 392 p, 1997.

Hotelling, H., Letter, In An Economic Study of the Monetary Evaluation of Recreation in the National Parks, Washington, DC, National Park Service, 1949.

Leones, J., B. Colby, D. Cory, and L. Ryan, Measuring Regional Economic Impacts of Streamflow Depletions, Water Resources Research 33(4):831-838, 1997.

Millenium Ecosystem Assessment, Ecosystems and Well-Being, Synthesis, Island Press, Washington D.C., 155p, 2005.

National Research Council, Valuing Ecosystem Services, The National Academies Press, Washington, D.C., 277 p, 2004.

Randall, A., A Difficulty with the Travel Cost Method, Land Economics 70(1), pp 88-96, 1994.

Weber, M., and R. Berrens, Value of Instream Recreation in the Sonoran Desert, Journal of Water Resources Planning and Management, pp53-60, Jan/Feb 2006.

APPENDIX A

Value of Instream Flow and Remote Recreation in the Sonoran Desert

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ABSTRACT

This study investigates recreation use value for access to Sonoran Desert instream flow, and associated riparian areas, through a case study of Aravaipa Creek Wilderness. The Wilderness is one of the last perennial streams in Southern Arizona, tributary to the famed and imperiled San Pedro River. Available permit information is combined with zip-code level census data to estimate a zonal travel cost model of recreation trip demand. Estimated consumer surplus per visitor-day values are $25.06 and $17.31 (in $2003), for two separate access sites. Results indicate a significant recreation value of surface water sites in the Sonoran Desert region, while the value discrepancy implies a premium for remote recreation.

Key words: instream flows, recreation, wilderness

INTRODUCTION

Natural resources management faces the complex challenge of maintaining environmental quality against numerous resource pressures. In the Southwestern United States, and the more specific context of the Sonoran Desert, riparian areas are ribbons of green swirling through a sparse landscape, hosting a concentration of plant and animal life in extreme contrast to adjacent chaparral. These fragile rivers and streams are also impacted by a suite of human activities such as surface water diversions, groundwater pumping, agriculture, cattle grazing, waste disposal, and urban encroachment. In order to reflect an understanding of both natural and anthropogenic concerns, planning and management decisions for riparian areas will be more informed through data collection and analysis regarding diverse resource benefits.

While limited in number, attempts by environmental economists and others to assess the monetary value of protecting instream flow and associated riparian areas now extend back at least several decades (see: Loomis 1987 and 1998). Various case studies identified significant value of water left in its natural channel, previously thought of as 'wasted' water. More and more researchers, particularly in water-poor Western states, are investigating the worth of instream water resources, motivating a conservationist counterpoint to market and cultural forces more traditionally based on resource extraction. Some of the instream values documented across the West include whitewater rafting (Ward 1987; Leones et al. 1997), angling (Duffield et al. 1992; Loomis and Creel 1992), birdwatching (Eubanks et al. 1993), and maintaining endangered fish habitat (Berrens et al. 1996 and 2000).

This case study of Aravaipa Canyon Wilderness (Wilderness) provides a unique look at recreation use value for access to Sonoran Desert sites, with protected instream flow and associated riparian areas. Instream flow advocates argue that increasing scarcity of protected sites with perennial instream flow elevates riparian management to dire importance in the Sonoran Desert bioregion. Thus, valuation results for recreational access to the Wilderness may have important applications (e.g., benefit transfer exercises) to other riparian sites in Southern Arizona, and in particular reaches of the San Pedro River, to which the Wilderness is tributary. The San Pedro watershed includes the San Pedro National Conservation Area, a celebrated riparian area threatened by regional groundwater pumping (Glennon and Maddock 1994). The San Pedro River provides critical habitat for up to four million migrating birds yearly, and supports nearly two-thirds of North American avian biodiversity. The San Pedro River is listed by The Nature Conservancy as one of America's "Last Great Places" (The Nature Conservancy 2000).

For this case study, available permit information is combined with zip-code level census data to estimate a zonal travel cost model (ZTCM) of recreation trip demand. While the ZCTM is open to traditional criticisms of potential aggregation bias, it is not dependent on user surveys, which can bring their own set of selection and responses biases (for a complete review, see Parsons 2003). Further, the simple, robust analysis presented here is easily repeated for other recreation sites, yielding useful information from widely available permit data. Results for Aravaipa Wilderness extend the growing literature assessing nonmarket values for the protection of instream flow in other areas of the Western United States to the specific context of the Sonoran Desert. In addition, value comparison between two sites within the Wilderness allows estimation of a premium on isolated recreation. Evidence for such a premium would at least partially validate current management strategy of permit limits in the Wilderness "to achieve the Wilderness Act mandate of preserving an enduring resource of wilderness composed of natural conditions and outstanding opportunities for solitude" (Bureau of Land Management 1988).

DESCRIPTION OF RESOURCE

The Aravaipa Wilderness is a lush and geologically dramatic riparian canyon in the Sonoran Desert of Southern Arizona. There are two access points with separate visitation. The East site is near Klondyke, Arizona, approximately 170 driving miles northeast from Tucson, the last 70 miles of which are on a graded dirt road. There are seven perennial stream crossings in the last few miles before arrival at the east end of the canyon, limiting access to high clearance and four-wheel-drive vehicles. The West site is near Mammoth, Arizona, and is within 75 paved driving miles of Tucson. The West site is accessible by passenger car, and receives more use, yet is also in a predominantly rural setting. Although the East site is physically situated only five miles from the West site, 11 miles of hiking lie between them, with no direct auto route connecting the sites.

The Wilderness lies in a rift valley between two remote “sky-island” mountain ranges: the Santa Teresa Mountains to the north and the Galiuro Mountains to the south. Currently 5,524 acres have wilderness designation, these surrounded by an additional 51,023 acres of BLM land. Cactus-spiked talus and sheer cliffs separate the main and side canyon floors from the rim country and tablelands above. Stream elevation falls from 3,000 ft at the East site to 2,600 ft at the West site, tablelands reach 3,800 ft and higher. At times the narrow shore is entirely composed of matted roots from the cottonwood/willow forest overhead, in other places sandy banks allow comfortable camping. Species of interest include desert bighorn sheep, black hawks, and seven species of native fish, the densest un-stocked population in the state. Geologic features range from stream-polished Precambrian porphyry schist to extensive Tertiary volcanic and granite units composing upper canyon walls (BLM 2004).

The watershed is approximately 546 square miles, the majority of which is up-gradient of the eastern Wilderness boundary (BLM 1988). All 11 miles of flow within the wilderness are perennial, with knee-deep crossings common, and occasional swimming holes where the stream tumbles against bedrock. Nine major side canyons enter the Wilderness contributing intermittent and ephemeral flows. Based on 46 years of United States Geological Survey (USGS) data, the mean of mean daily flows in Aravaipa Creek is 34.2 cubic feet per second (256 gallons per second). Low flows of about 10 cubic feet per second (75 gallons per second) tend to occur in June, while higher flows above 50 cubic feet per second (374 gallons per second) are common in February and March (USGS 2002). Flood peaks between one and several thousand cubic feet per second are typical in either the winter rainy or monsoonal summer seasons, with an incredible historic peak of 70,800 cubic feet per second (530,000 gallons per second) recorded 1 October 1983 (USGS 2003).

The Wilderness is managed by the Bureau of Land Management (BLM). Users request a permit for either end of the canyon, with visitation limited to 20 persons per day for the East site, 30 persons per day for the West site, a three day stay limit and 10 person party limit apply to both. As a Wilderness, human travel is exclusively on-foot or equestrian. No vehicles, bicycles, or dogs are permitted (BLM 2004). Visitation records include data for each trip leader purchasing a permit. Date of arrival, choice of East site or West site access, length of stay, number in party, and mailing address (with zip-code) are required information.

Aravaipa Creek is the last tributary to the San Pedro River before the San Pedro's confluence with the Gila River. Perennial flow is central to the Canyon's ecology, archeologic significance, and contemporary recreation opportunities. Previous research in the Wilderness found visitors rated water "the most important attribute of the wilderness area" (Moore et al. 1990). This research attempts to quantify the recreational use value for access to this unique area with protected instream flow and associated riparian features. It is hoped that results will help to provide insight for riparian management in the Wilderness and similar sites in the Southwest.

Non-market use value is measured in economic terms as consumer surplus per Recreation Visitor Day (RVD). Consumer surplus is a dollar measure of net-benefit, or satisfaction derived from a Wilderness trip, beyond the enjoyment offset by trip costs. The RVD unit is used to count Wilderness visitors over discrete calendar days. Aggregating consumer surplus across all visitor days allows estimation of recreation value enjoyed over a given period of time (e.g., total visitation for a year or management season).

VALUATION METHODOLOGY

The Wilderness embodies many public goods, and provides diverse benefits. In addition to recreation opportunities, the riparian ecosystem serves water and air quality enhancement functions for the region. Ranching and small-scale agriculture occur at either end of the canyon, reliant on the temperate canyon climate and access to water. Residential property values nearby are enhanced from riparian area proximity[1]. There are also non-use values for the Wilderness, applying to those who appreciate its existence from afar or wish to leave it unmarred for the future. Yet for all Wilderness benefits the only explicit public charge is a recreation access fee of $5.00 per person per day. The value of the recreational experience exceeds this minimal cost, or the Wilderness would have near-zero usage. Using visitation permit information for access to riparian areas with instream flow, this study estimates this recreation use value, a single component of total Wilderness resource value.

Making use of the extensive permit database collected by the BLM, we employ a variant of the Travel Cost Method (TCM). The TCM is a standard technique used in resource planning, required, for example, by the United States Army Corps of Engineers for estimating recreation effects of federal projects (see Loomis 1999). It is a 'revealed preference' approach, using a surrogate market to value a non-market good. Access values to a set of one or more sites is built from explicit and implicit expenditures people make in traveling to the chosen location (Parsons 2003). At a minimum these include

[1] To wit, a boost of several percent was shown for another riparian site near Tucson (Colby and Wishart 2002).

opportunity cost of driving time and vehicular driving costs, but may also include opportunity cost of time on-site, lodging costs, entry fees, or any other expense judged specific to a visit. Under the hypothesis that distance is costly, the core of a TCM is achieving a relationship between trip costs (the price proxy) and the quantity of trips demanded. This results in a traditional Marshallian demand curve. Other characteristics of the resource or visiting population may be included, as expressed in a general demand model:

$$\textit{Visitation Rate}_{ij} = f(\textit{Travel Cost to Site}_{ij}, \textit{Travel Cost to Substitute Site}_{ik}, \textit{Socio-Demographics}_{i}, \textit{Site Characteristics}_{j}) \qquad (1)$$

where i = visiting individual (or representative individual from a zone of origination), j = site in question (the destination), and k = substitute site (with $j \neq k$).

Once the TCM demand curve is estimated econometrically, value calculation is often limited to Marshallian Consumer Surplus (MCS) for seasonal access to the site in its current form, but there are extensions to quality changes as well (Parsons 2003)[2]. A total access value can be obtained by entering the average travel cost value in the fitted

[2] Hicksian welfare measures of compensating or equivalent surplus are preferred; the choice between them depends on the location of property rights in the status quo or some proposed change. Bounded by these two measures, the Marshallian consumer surplus measure, as available through the TCM, provides a reasonable approximation in many cases (see Willig 1976), such as when income effects are limited and the good represents a small proportion of income. However, Hanemann (1991) shows that for non-market goods with poor substitutes, the gap between equivalent and compensating surplus can be unbounded, and the use of Marshallian consumer surplus measure must be used with caution.

demand model, and integrating up to a 'choke price' (where predicted trip demand is driven to zero). Then, by dividing through by the predicted number of trips, the resulting MCS estimate can be calibrated down to a value per Recreation Visitor Day (RVD).

The classic TCM approach separates visitation into zones (ZTCM), often counties, or cities, but most commonly zip-codes. A unique travel cost for each geographic zone is then estimated. Data costs for a ZTCM are usually low, since public land management agencies often collect visitation information and record an address for entrants. However the ZTCM may suffer from aggregation bias in building a model based on homogenized (representative) persons from each zone. There may be significant differences in driving costs to a site from within a zip-code, or there may be high intra-zonal income diversity, varying the opportunity cost of travel time.

In reality, every visitor represents unique characteristics. An Individual Travel Cost Model (ITCM), based on survey data, recognizes this and remedies aggregation bias, but incurs primary data collection costs. Further, statistical problems of truncation (no data on non-visitors) and endogenous stratification (more likely to sample repeat visitors) occur with ITCMs, and many require strong assumptions regarding the probability distribution of demand (Hellerstein 1995). By running simulations on an artificial dataset with known parameters, Hellerstein (1995) found aggregate models often perform as well or better than individual models, concluding "it is an empirical question as to which modeling strategy is best." Further, when average per capita demand is small and the visitation base large, aggregate models can dominate individual models. Such a situation seems to fit the Wilderness, although our choice for the analysis was largely driven by budget and data availability. Conveniently, the thorough database maintained by the BLM in conjunction with a ZTCM forms a reasonable basis for examining recreational values without the need for original survey data.

A ZTCM is more robust through inclusion of socio-demographic data (Moeltner 2003). Recent United States Census 2000 (Census) data releases are available by zip-code, and are ideally suited for this purpose. Commonly, average zonal income is a significant predictor of recreation, though other regressors can be used if hypothesized as important factors for the recreation model at hand. Aggregation bias potentially can be minimized if the variability of the dependent variables is included in the predictive model (Hellerstein 1995). However, a recent econometric test based on a similar ZTCM to that presented here found only a 5% value discrepancy between ‘corrected’ and ‘uncorrected’ models (Moeltner 2003). For our purposes, this small gain is outweighed by the conceptual, operative, and interpretive ease of the classic ZTCM in this case study. To bracket final valuation figures we instead perform a sensitivity analysis on driving cost per mile and carpooling, which are both key choices made by the researcher in construction of the travel cost variable.

EMPIRICAL APPLICATION

Visitation data for Aravaipa Creek Wilderness was obtained from the BLM Safford Field Office. The BLM deleted street addresses prior to making the data available for research, though zip-codes were retained, allowing ZTCM development. We focus on visitation records for the five-year period from 1998 through 2002 since these were the most recent contiguous and consistently collected data, and also surround 2000 Census data. Conversation with BLM staff indicated there were no important changes in management during this period of time (T. Schnell, personal communication). Use of multiple data years increases model statistical power, though the span is not so long as to require significant inflation adjustment. Travel costs are calculated in 2000 dollars, the center of the data span. Final valuation figures are adjusted to 2003 dollars.

This study assumes permit data capture visitation. A full-time BLM ranger is stationed near the West site, and the Nature Conservancy employs a full-time steward near the East site. Permits are checked against parked vehicles at both canyon entrances, and there is some patrolling of the Wilderness interior. Known no-show and cancelled permits were deleted from this study. An uncertain number of additional no-show permits and illegal visitation does exist (Patrick O'Neill, personal communication), the former somewhat reducing actual visitation and the latter somewhat increasing actual visitation.

Since the Wilderness is unique for Southern Arizona as a whole, the East and West sites are treated as substitutes for one another. The landscape is comparable between the two though access is distinctly separate. Further, only single-day trips to either site were included in the estimation to maintain as much uniformity of the recreation 'good' as possible, and to avoid handling multi-site trips and allocation of travel costs (Parsons 2003). Single-day trips constitute 30% of visitation to the East site and 40% of visitation to the West site. For final aggregation we assume multiday trips represent net benefits (consumer surplus) directly proportion to single-day trips.

An available online program (Mapquest™) was used to calculate driving mileage and time for each unique zip-code in the database, to both the chosen access site as well as the substitute access site. The program finds the quickest route accounting for slower travel on backroads, which is particularly important as East site access includes extensive unpaved travel.

To ensure that we are isolating the value for our target sites, multi-purpose and multi-site trips were also controlled by excluding starting locations with an estimated driving times beyond five hours, one-way. This time cap choice had the effect of eliminating distant zip-codes within Arizona and virtually all out of state visitors. The remaining pool of zip-codes within five hours of both sites limits single-purpose trips to 82% of single-day RVDs for the East site and 90% of single-day RVDs for the West site. These percentages were also applied towards separating the number of single-purpose multi-day trips to either site from total visitation. Table 1 summarizes basic visitation statistics for the two sites. Note that visitation to the West site is approximately twice that of the East site.

Less than 10% of the permits had city and state information but no usable zip-code. These permit records with a city origin within the five hour criteria were assumed to correspond with the distribution of zip-codes meeting the five hour criteria, in both distance to site and RVDs per permit. Visitation from city permit data was added to zip-code permit data, weighted by counts observed in zip-code permits. A few permitted zip-codes were not found in Census results, these were spread proportionately across zip-codes to maintain total visitation.[3]

The Aravaipa Wilderness ZTCM was built to estimate consumer surplus per individual rather than by household, thus the travel cost variable is on an individual basis. The trip leader's zip-code is assumed representative of the party as a whole. To achieve a unique travel cost by zip-code, the average party number by zip-code was calculated. A recent forest recreation study in the Southwest found a per-car occupancy of 4.2, and employed a driving cost of $0.33/mile in 2002 dollars (Starbuck et al. 2004). For this case study, individual driving cost was calculated with a step function, matching the permitted party size up to a maximum of four persons per car. Driving cost per mile was adjusted down to $0.31 for the year 2000 using the Consumer Price Index, and apportioned equally among all party members. Individual opportunity cost was calculated using a third of Census per capita income, multiplied by the round-trip travel time, divided by 2,000 hours worked per year. Since Census income figures are for 1999, these were adjusted up to 2000, again using the Consumer Price Index. The total individual travel cost (TC) is then individual <u>round-trip</u> driving cost plus individual time cost plus the $5.00 access fee. Travel cost to the substitute site was calculated the same way.

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[3] Zip-codes missing in the Census are those areas split after 2000.

The Wilderness demand curve for each site was estimated with a multiple regression model. The visitation rate (V) to the site across zip-codes is a continuous dependent variable, with independent variables of travel cost to the site (TC), travel cost to the opposite canyon entrance substitute site (TC-SUB), and selected or constructed socio-economic variables from Census information. A semi-logarithmic model form was hypothesized following previous ZTCM work (Moeltner 2003; Henderson et al. 1999). The model followed from a series of tested relationships, balancing fit, as indicated by the R^2 value, and predictive power, indicated by ratio of estimated RVDs to actual RVDs. For both the East and West sites the same regressors (explanatory variables) were employed. The final model chosen was:

$$Ln(V_{ij}) = \beta_0 + \beta_1(TC_{ij}) + \beta_2(TC\text{-}SUB_{ik}) + \beta_3(APARTY\#_i) + \beta_4(\%URBAN_i) + \beta_5(\%YOUTH_i) + \beta_6(\%MIDAGE_i) + \beta_7(APC\text{-}INC_i) + \beta_8(\%HH\text{-}OWN_i), \quad (2)$$

where i = visiting zip-code, j = the destination site (East or West), and k = the substitute site (East or West, with $j \neq k$). Full definitions and descriptive statistics for the explanatory variables in (2) are provided in Table 2. Note in particular the difference in average travel costs (TC) between sites. A Chow Test rejects the null hypothesis that estimated coefficients (the β vectors) for East and West site data are similar at the 95% confidence level. Thus we present results from separate regressions for each site.

A sensitivity analysis of driving cost per mile was conducted, with parallel regressions using driving costs of $0.34/mile and $0.28/mile to bracket a range 10% above and below the primary $0.31/mile figure. A carpooling step function with a maximum of three instead of four persons per car was also tested. This results in a total of six regressions for each site. One outlier was noted for the three regressions involving the West site with the four-person carpooling function, this part of the analysis was re-run omitting this case.

Using the β vector estimated for a given regression, average values of the independent variables across zones were inserted into the prediction equation. The logarithmic prediction equation was then exponentiated and multiplied by cumulative zonal population, resulting in a traditional demand curve relationship. Marshallian Consumer Surplus estimates (MCS) for each driving cost/carpooling/site combination were calculated by direct integration of the demand curve, evaluated between the average travel cost (TC*) up to the choke price (TCch), the latter being the maximum travel cost observed in the sample. The formula for the single-day MCS for a given site j (East or West) is:

$$MCS_j = (Cum.\ Zonal\ Population) \int_{TC^*}^{TCch} [exp(\beta_0{*}_j + \beta_1 TC_j)]dTC$$

$$= (Cum.\ Zonal\ Population / \beta_1)\ [exp(\beta_0{*}_j + \beta_1 TCch_j) - exp(\beta_0{*}_j + \beta_1 TC{*}_j)] \quad (3)$$

where β_0* is a “grand intercept” (evaluated at the appropriate sample means for all other explanatory variables except travel cost). Since our MCS is calculated on the 5-year period (which negates variation due to single-year weather effects, etc.), the MCS per season was taken as one-fifth of this value, adjusted to $2003. Single-day MCS per season is divided by the number of trips predicted in (2) to yield MCS per RVD. Yearly

MCS values reported in tables 3 and 4 are ramped up to include single-purpose multiday trips as well as single-purpose single-day trips.

RESULTS AND DISCUSSION

Tables 3 and 4 summarize the multiple regression results for the model and sensitivity analysis for the East and West sites, respectively. In all cases the expected negative relationship between travel cost and trip rate is found, along with a positive relationship with income as expected of a normal good. These regressors are highly significant and stable across regressions, with a larger visitation effect from income seen for the East site.

An interesting result is the negative effect of urban population percentage on visitation. Any higher visitation due only to population density is accounted for through conversion of absolute trip number to trip-rate by zone. Other factors being equal, the Wilderness is slightly more popular with rural visitors, perhaps because of the crowding limits administered by the BLM. The final significant regressor in almost all cases is household ownership. Visitation rates are higher from zip-codes with a lower percent of homeownership. Renters seem more likely to visit, perhaps because of fewer opportunities for solitude, lack of their own backyards, or fewer property maintenance responsibilities and commitments reasonably associated with homeownership. Other variables, including travel cost to the substitute site, fluctuate in significance across the two sites[4].

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[4] Though only significant for the West site, the sign of the travel cost to the substitute site is positive for the West site and negative for the East site. There is a possibility that the East site serves as a spillover substitute when West site permits are booked, but that a complementary relationship holds in the reverse case. Brief examination of visitation data suggests permit limits are more binding for the West site.

The sensitivity analysis shows consumer surplus follows the 10% increase or decrease in driving cost per mile, though somewhat damped. As the maximum number of persons per car drops from four to three, estimated consumer surplus increases 18-30%. Model fit and estimation performance is similar within the six regressions tested for each site, with a slight edge for driving cost set at $0.28/mile and the carpooling function set at four. The range of consumer surplus estimates, $23.00 to $35.05 per RVD for the East site, and $16.25 to $22.07 per RVD for the West site, compare reasonably well with other work, though slightly on the conservative side. A recent meta-analysis of outdoor recreation value (Rosenberger and Loomis 2001) finds a mean value of $37.31 and a median value of $34.75 for five intermountain- region hiking studies (adjusted to 2003 dollars). These values are not site or instream-specific, but they do offer a general guide. Instream flow recreation in the Sonoran Desert clearly represents significant worth to society, consistent with other recreation values found using a variety of estimation techniques for the Western U.S. and elsewhere.

Perhaps the most interesting result from this analysis is the premium on MCS per RVD displayed by the East site over the West site. For all driving cost and carpooling combinations, the consumer surplus per RVD of the East site is 40-60% larger than that of the West site. Many factors are potentially represented by this premium, though a few striking differences between the sites allow some speculation. The East site is accessed through far more rustic means, is permitted for and receives lower visitation, and offers a higher probability of encountering wildlife. It is noteworthy that “peace, quiet, and wildlife” are factors ranked second only to perennial flow as those most important to the

Wilderness (Moore et al. 1990). Permit limits not only reduce visual encounters between hikers, they also reduce overall stress on the resource, increasing sustainability. Though visitation is twice as high at the West site, consumer surplus per season is only between 46% and 63% higher. One may infer that solitude is not only a philosophic goal of the Wilderness Act, it is also of demonstrated economic value on an RVD basis in this case study.

As shown in the last lines of Tables 3 and 4 for the separate sites, we can also aggregate recreational values across visitors. We can further aggregate across years if we assume a similar pattern of visitation and valuation for the site. For example, despite its fairly strict restrictions on access and limited size, total <u>recreational</u> Net Present Value (NPV) for the Aravaipa Wilderness, using the base case and a discount rate of 4%, is estimated at $3.6 million, and as high as $4.7 million under different combinations of parameters from the sensitivity analysis.

CONCLUSIONS

Desert life revolves around water. Aravaipa Canyon Wilderness, one of the last perennial streams in Southern Arizona, offers testimony to the value of instream flow and the associated riparian areas it supports. The BLM's 1981 priority instream flow permit of 5 cubic feet per second indicates a proactive step towards protecting the flow and thus the resource. Valuation of recreational uses in this study is a starting point for demonstrating how important that instream flow permit is to maintain, if not expand.

Remoteness and permit limits are also shown to have a significant role in consumer surplus benefit, exemplified by the premium paid on East site visits. A solitude value is also embedded in West site consumer surplus, since both sites are managed with permit limits. Further, restricted visitation assists resource sustainability (i.e., meeting assessed carrying capacity constraints), extends future benefits, and is aligned with the original vision of the 1964 Wilderness Act.

From a broader perspective, the attempt to assign recreational use values to Aravaipa Creek may be seen as a first step in understanding the benefits of other riparian areas in the Sonoran Desert. Exploring the multi-year Wilderness visitation data presented here adds to regional riparian understanding. Relevance to the greater San Pedro River watershed is most direct, with a pending struggle to maintain instream flow and riparian habitat in the face of increasing human water extractions. Cogent applications are also found in nearby Pima County, where government agents have worked to pass, and now work to enact the Sonoran Desert Conservation Plan, perhaps the most ambitious regional planning effort in the West today. The Plan hinges on protection of core environmentally and culturally significant sites in the greater Tucson area, many of which are riparian areas (Pima County 2004).

Complex ecosystems are built around natural water features. In the Western US, acute water resource issues are often centered on the few remaining free-flowing streams. Here all the extractive use values of agriculture, industry, and municipality play against instream use and non-use values. Because traditional extractive economies have been so important in the past, an incredible amount of inertia has blocked support of reallocating water back to streams. Non-market valuation of riparian areas offers a way to view this recurrent conflict in terms of raw dollars, assisting choices in regards to efficient use of precious water resources. Further, it can be argued that this recreational value study encompasses only a fraction of total resource value. Ecosystem service values of wilderness areas, such as air and water quality enhancement, or contributions to the larger habitat of critical fish and wildlife species, are barely understood and largely unquantified. In addition, non-use values of river systems have been reported in some cases to be much larger than use values (Brown 1992). In closing, while the complexity of riparian systems and associated instream flows has slowed the full understanding of their benefits, investigation of the recreational use values of the remaining protected areas -- in the Sonoran Desert and elsewhere -- can be an important input to environmental planning and decision-making.

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REFERENCES

Berrens, R., P. Ganderton, and C. Silva. 1996. "Valuing the Protection of Minimum Instream Flows in New Mexico." *Journal of Agricultural and Resource Economics* 21(2):90-104.

Berrens, R., A. Bohara, C. Silva, M. McKee and D. Brookshire. 2000. "Contingent Valuation of Instream Flows in New Mexico: With Tests of Scope, Group-Size Reminder and Temporal Reliability." *Journal of Environmental Management* 58(1):73-90.

Brown, T.C. 1992. "Water for Wilderness Areas: Instream Flow Needs, Protection, and Economic Value." *Rivers* 2(4):311-325.

Bureau of Land Management. 1988. "Wilderness Management Plan, Aravaipa Canyon Wilderness, Arizona." United States Department of the Interior.

Bureau of Land Management. 2004. "Aravaipa Canyon Wilderness." *http://azwww.az.blm.gov/sfo/aravaipa/*, accessed 8/02/04.

Colby, B., and S. Wishart. 2002. "Riparian Areas Generate Property Value Premium for Landowners." Manuscript, University of Arizona, Dept. Agric. & Resource Economics.

Duffield, J., C. Neher and T. Brown. 1992. "Recreation Benefits of Instream Flow: Application to Montana's Big Hole and Bitterroot Rivers." *Water Resources Research* 28:2169-2181.

Eubanks, T., P. Kerlinger, and R.H. Payne. 1993. "High Island, Texas: A Case Study in Avitourism." *Birding* 25(6):415-420.

Glennon, R.J. and T. Maddock III. 1994. "In Search of Subflow: Arizona's Futile Attempt to Separate Groundwater from Surface Water." *Ariz. Law Review* 36(3):567-610.

Hanemann, M. 1991. "Willingness to Pay and Willingness to Accept: How Much Can They Differ?" *American Economic Review* 91:635-647.

Hellerstein, D. 1995. "Welfare estimation using aggregate and individual-observation models: a comparison using Monte Carlo techniques." *American Journal of Agricultural Economics* 77:620-630.

Henderson, M., K. Criddle, and S. Lee. 1999. "The Economic Value of Alaska's Copper River Personal Use and Subsistence Fisheries." *Alaska Fishery Research Bulletin* 6(2):63-69.

Leones, J., B. Colby, D. Cory, and L. Ryan. 1997. "Measuring Regional Economic Impacts of Streamflow Depletions." *Water Resources Research* 33:831-838.

Loomis, J. 1987. "The Economic Value of Instream Flow: Methodology and Benefit Estimates of Optimum Flow." *Journal of Environmental Management* 24:169-179.

Loomis, J. 1998. "Estimating the Public's Values for Instream Flows: Economic Techniques and Dollar Values." *Journal of the American Water Resources Association* 34:1007-1114.

Loomis, J. 1999. "Contingent Valuation Methodology and the US Institutional Framework." Pages 613-627 in I. Batemen and K. Willis (Eds.). *Valuing Environmental Preferences: Theory and Practice of the Contingent Valuation Method in the US, EU and Developing Countries*. Oxford University Press: New York.

Loomis, J., and M. Creel. 1992. "Recreation Benefits of Increased Flows in California's San Joaquin and Stanislaus Rivers." *Rivers* 3(1):1-13.

Moeltner, K. 2003. "Addressing Aggregation Bias in Zonal Recreation Models." *Journal of Environmental Economics and Management* 45:128-144.

Moore, S., M. Wilkosz, and S. Brickler. 1990. "The Recreational Impact of Reducing the 'Laughing Waters' of Aravaipa Creek, Arizona." *Rivers* 1(1):43-50.

Parsons, G. 2003. "The Travel Cost Model." Pages 269-330 in P. Champ, K. Boyle, and T. Brown (Eds.). *A Primer on Nonmarket Valuation*. Kluwer Academic Publishers: Boston.

Pima County. 2004. "Sonoran Desert Conservation Plan: A Long Term Vision for Protecting the Heritage and Natural Resources of the West." *http://www.co.pima.az.us/cmo/sdcp/*, accessed 8/02/04.

Rosenberger, R., and J. Loomis. 2001. "Benefit Transfer of Outdoor Recreation Use Values: A Technical Document Supporting the Forest Service Strategic Plan (2000 revision)." USDA, Forest Service, Rocky Mountain Research Station.

Starbuck, C., R. Berrens, and M. McKee. 2004. "Simulating Changes in Forest Recreation Demand and Associated Economic Impacts due to Fire and Fuels Management Activities". *Forest Economics and Policy* forthcoming.

The Nature Conservancy. 2000. "San Pedro River, Arizona." *http://nature.org/initiatives/freshwater/work/sanpedroriver/html*, accessed 8/02/04.

United States Geological Survey. 2002. "Calendar Year Streamflow Statistics for Arizona." *http://nwis.waterdata.usgs.gov/az/nwis/annual/?site_no=09473000&agency_cd=USGS*, accessed 8/02/04.

United States Geological Survey. 2003. "Peak Streamflow for the Nation." *http://nwis.waterdata.usgs.gov/nwis/peak/?site_no=09473000*, accessed 8/02/04.

Ward, F. 1987. "Economics of Water Allocation to Instream Uses in a Fully Appropriated System: Evidence from a New Mexico Wild River." *Water Resources Research* 23: 381-392.

Willig R. 1976. "Consumer's Surplus Without Apology." *American Economic Review* 66:589-597.

Table 1: Wilderness Visitation Summary Data for the 5 Year Span 1998-2002

	East Site	West Site
Total Permits	1,797	4,272
1-day RVDs	2,700	7,549
2 or 3-day RVDs	10,767	17,886
Total RVDs	13,467	25,435
Single-purpose 1-day RVDs	2,204[1]	6,814[1]
Single-purpose 2 or 3-day RVDs	8,789[2]	16,142[2]
Total single-purpose RVDs	10,993	22,995
Avg # visitors / day	7.37	13.93
Avg # single-purpose visitors / day	6.02	12.57

Notes:

1. 82% and 90%, respectively, of 1-day trips were within 5 hrs drive for the East and West sites.

2. Calculations by authors based on single-purpose trip percentages for 1-day trips

TABLE 2: Descriptive Statistics, by East and West Site

		East Site Destination (with 83 zones of trip origination)		West Site Destination (with 143 zones of trip origination)	
Variable Name	Description	Mean	St. Dev.	Mean	St. Dev.
V_{ij}	Individual visitation rate zone i to site j	0.00233	0.00513	0.00317	0.00792
TC_{ij}	Travel cost ($) zone i to site j	75.621	22.675	53.055	22.737
$TC\text{-}SUB_{ik}$	Travel Cost ($) zone i to substitute site k ($k \neq j$)	42.856	14.439	90.494	30.481
$APARTY\#_i$	Average number in party traveling from zone i	4.482	2.069	3.538	1.673
$\%URBAN_i$	Percentage of urban population in zone i	82.160	32.212	80.598	32.574
$\%YOUTH_i$	Percentage of population less than 18 yrs in zone i	24.593	6.595	25.321	7.114
$\%MIDAGE_i$	Percentage of population between 34 and 64 yrs old, zone i	37.990	6.138	38.335	6.702
$APC\text{-}INC_i$	Average Per capita income in zone i, thousands of dollars	22.812	10.052	23.527	10.707
$\%HH\text{-}OWN_i$	Percentage of owner-occupied dwellings, zone i	69.257	19.015	71.916	16.868

Table 3: East Site Demand Model Coefficients, Sensitivity Analysis, and MCS Results

	Sensitivity Parameter: Persons per car (max)/Driving cost per mile					
Variable	4/$0.31	4/$0.34	4/$0.28	3/$0.31	3/$0.34	3/$0.28
Constant	-3.764**	-3.785**	-3.741**	-4.341**	-4.362**	-4.317**
TC	-0.042**	-0.038**	-0.046**	-0.031**	-0.028**	-0.035**
TC-SUB	-0.004	-0.004	-0.005	-0.002	-0.002	-0.003
APARTY#	0.047	0.047	0.046	0.083	0.084	0.082
%URBAN	-0.018**	-0.018**	-0.018**	-0.016**	-0.016**	-0.016**
%YOUTH	-0.025	-0.025	-0.025	-0.037*	-0.037*	-0.037*
%MIDAGE	0.032	0.032	0.032	0.040	0.040	0.039
APC-INC	0.090**	0.083**	0.098**	0.062**	0.056*	0.068**
%HH-OWN	-0.018*	-0.018*	-0.018*	-0.014	-0.014	-0.014*
R^2	0.497	0.494	0.501	0.461	0.459	0.464
%Est./Actual RVDs	85%	85%	86%	81%	81%	82%
$ MCS/day	25.06	27.50	23.00	32.35	35.05	29.25
$ MCS/year[1]	55,106	60,451	50,571	71,129	77,055	64,306
$ MCS NPV[1] with r =0.04	1,377,653	1,511,283	1,264,268	1,778,220	1,926,384	1,607,647

Notes:

* = 0.05 significance level, 2-tailed

** = 0.01 significance level, 2-tailed

[1]Includes estimated single-purpose multiday trips

Table 4: West Site Demand Model Coefficients, Sensitivity Analysis, and MCS Results

	Sensitivity Parameter: Persons per car (max)/Driving cost per mile					
Variable	4/$0.31	4/$0.34	4/$0.28	3/$0.31	3/$0.34	3/$0.28
Constant	-5.368**	-5.373**	-5.363**	-4.659**	-4.667**	-4.650**
TC	-0.061**	-0.057**	-0.065**	-0.051**	-0.047**	-0.054**
TC-SUB	0.025**	0.023**	0.026**	0.019**	0.018**	0.020**
APARTY#	0.277**	0.277**	0.276**	0.304**	0.304**	0.303**
%URBAN	-0.018**	-0.018**	-0.018**	-0.021**	-0.021**	-0.021**
%YOUTH	-0.034**	-0.034**	-0.034**	-0.041**	-0.041**	-0.041**
%MID-AGE	0.039**	0.038**	0.039**	0.034*	0.034*	0.034*
APC-INC	0.028*	0.027*	0.029*	0.031*	0.030*	0.033*
%HH-OWN	-0.018**	-0.018**	-0.018**	-0.021**	-0.021**	-0.021**
R^2	0.656	0.654	0.657	0.625	0.624	0.626
%Est./Actual RVDs	71%	71%	72%	71%	71%	71%
$ MCS/day	17.31	18.51	16.25	20.40	22.07	19.28
$ MCS/year[1]	88,049	94,135	82,675	103,798	112,270	98,062
$ MCS NPV[1] with r =0.04	2,201,224	2,353,381	2,066,872	2,594,941	2,806,760	2,451,542

Notes:

* = 0.05 significance level, 2-tailed

** = 0.01 significance level, 2-tailed

[1]Includes estimated single-purpose multiday trips

APPENDIX B

Public Valuation of River Restoration and Saltcedar Removal on the Middle Rio Grande

Keywords: river restoration, choice experiment, contingent valuation, Rio Grande, saltcedar

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ABSTRACT

River restoration is a nationwide phenomenon. This reflects strong public values for conservation, though missing are studies explicitly justifying restoration expenditures. Public restoration benefits are not well quantified, nor are public preferences amongst diverse activities falling into the broad category "restoration". Our case study for estimating public restoration values is linked to a US Army Corps of Engineers project on the Middle Rio Grande in New Mexico. Stakeholder interactions and public focus groups guided development of a restoration survey mailed to Albuquerque area households. Four restoration categories were defined: Fish and Wildlife; Vegetation Density; Tree Type; and Natural River Processes. Survey responses supplied data for both Choice Experiment and Contingent Valuation analyses, two established environmental economics techniques for quantifying public benefits of conservation policies. Full restoration benefits are estimated at over \$150 per household per year via the Choice Experiment, and at over \$80 per household per year via Contingent Valuation. The Choice Experiment allows value disaggregation for different restoration categories. The most highly valued category was Tree Type, meaning reestablishing native tree dominance for such species as cottonwood (*Populus deltoides* ssp. *wislizenii* S.Wats.) and eradicating non-native trees such as saltcedar (*Tamarix ramosissma* Ledeb.). The high public values we have found for restoration offer economic justification for intensive riparian management, particularly native plant based restoration in the Southwest.

INTRODUCTION

The National River Restoration Science Synthesis lists more than 37,000 restoration projects, with associated expenditures of over one billion dollars per year (Bernhardt et al. 2005). This funding commitment implies strong values for riparian enhancement, however we know of only a handful of recently published studies attempting to quantify social benefits of riparian restoration (Loomis et al. 2000; Holmes et al. 2004; Collins et al. 2005). Whereas the natural science approach in monitoring restoration is to document the achievement of desired ecological endpoints (e.g. Palmer et al. 2005), a companion perspective offered by social science is to explicitly include the human view. Under this model, public support is recognized as a critical factor for success. We believe both natural and social science inputs are needed for restoration assessment. Our submission comes from environmental economics, a growing social science subdiscipline. We apply two methodologies to quantify the human value of river restoration with data obtained from a mail survey. Our primary investigation is a Choice Experiment, from which preferred restoration types are identified. Relative values between restoration options are established, as well as the combined value for full restoration. A Contingent Valuation question in the survey allows a secondary, independent value estimate for the full restoration scenario.

Our case study is the Middle Rio Grande Bosque in Albuquerque, New Mexico (Bosque). Bosque is a traditional spanish term for forest. Our research was done in cooperation with the United States Army Corps of Engineers (Corps), whom are in the midst of ongoing and planned large-scale restoration impacting the riparian forest and river. Our study area corresponds to that of the Corps, approximately 17 miles (27 km) of river and 4,000 acres (1,619 ha) of riparian area (channel and adjacent vegetation) (US Army Corps of Engineers et al. 2003). The Bosque runs directly through the heart of Albuquerque, and is impacted by several anthropogenic factors including: wetland loss; channel stabilization; levee constrictions; upstream and downstream impoundments; loss of hydrograph variability; residential encroachment; legal and illegal recreational activities, and point and non-point source pollutants (ibid). Although the width of the historic floodplain was measured in miles, the entire riparian area today is constrained to approximately one-half mile (0.8 km) in width. A major factor impacting the Middle Rio Grande is invasion by the exotic saltcedar (*Tamarix ramosissma* Ledeb.).

Despite these impacts, the reach retains a highly scenic character providing lush contrast to the surrounding urban area and high-desert landscape. It is considered the best surviving Cottonwood (*Populus deltoides* ssp. *wislizenii* S. Wats.) bosque in the entire 180 miles (290 km) of the Middle Rio Grande, defined as the reach between Cochiti and Elephant Butte reservoirs. Further, the Bosque harbors the Rio Grande silvery minnow *(Hybognathus amarus)*, the Southwestern Willow Flycatcher *(Empidonax traillii extimus)* , and the American Bald Eagle *(Haliaeetus leucocephalus)*. These species are federally listed as endangered, endangered, and threatened, respectively. Migratory bird populations and numerous other plant and animal species also rely on Bosque habitat. The historic importance of the Rio Grande for Albuquerque cannot be overstated; it inspired the founding of the city, and has allowed its continued development as the most important urban center of New Mexico. For a region averaging just nine inches (229 mm) of precipitation per year, the presence of this perennial river has been the key resource.

The Rio Grande Nature Center State Park was included along with 29 other New Mexico State Parks for a tourism survey study (Ward & DeMouche 2004). The focus of their study is recreation rather than restoration, and is limited to interception surveys at a single Bosque access. More applicable background for our investigation is a telephone survey of New Mexico conducted by The University of New Mexico Institute for Public Policy on the subject of Water Issues (Brown et al. 2000). Their survey used a qualitative scale for agreement with numerous questions regarding water management in New Mexico, with specific questions about the Middle Rio Grande Bosque. When asked about seven different 'water problems', respondents rated "Having enough water in our rivers to protect endangered fish and to keep the trees, vegetation, and other wildlife along the riverbanks healthy" second only to "The quality of the water that my family and I drink and bathe in". When asked about their 'values in relation to water' respondents rated "Preserving the native cottonwood forest and vegetation along river banks known as the bosque, that creates habitat for a variety of different animal species", second only to "Indoor use in existing homes". The Brown et al. study is a high quality survey and an extremely important reference for qualitatively documenting public importance of the Bosque. Our study complements their results by estimating a quantitative value for different Bosque restoration types, and a combined value for full restoration.

METHODS

CHOICE EXPERIMENT

Several meetings were held with Corps biologists, hydrologists, and planners to gain in-depth understanding of the types of restoration that were planned. In addition, public opinion the Corps had thus far received was reviewed. This background seeded several Focus Group discussions in 2005 with thirty-six participants total. These stakeholder and public interactions helped design the survey instrument, particularly the core restoration attributes to be valued. Restoration attributes summarize four categories of feasible changes anticipated in the Bosque (Table 1). Every attribute has a status quo level and at least one restoration level. The last column shows the incidence of each restoration level as tallied from returned surveys. These discrete changes necessarily abstract from the continuum of possible outcomes, but do capture the essence of the restoration program. Note the final restoration attribute is Cost of Bond to Household (attribute 5). Restoration funding was posed as a hypothetical sales tax bond, presented as a payment per household per year. For a discussion of cost level design see Boyle et al. (1998).

Restoration attributes and levels composed elements of the Choice Experiment (CE). This disaggregation allows examination of the relative value between types of restoration. For example, the public value for a shift in tree species from Non-Native Dominant (attribute 3, level 1) to Equally Native and Non-Native (level 2) may be estimated independently of the public value for a shift in wildlife numbers from Current Population (attribute 1, level 1) to a 10% Population Increase (level 2). Furthermore, multiple levels defined within an attribute allows value resolution within a restoration type. For example, the public value of a shift from No Thinning to Moderate Thinning (attribute 2, level 1 to level 2) may be estimated independently of the public value for a shift from No Thinning to Full Thinning (level 1 to level 3).

An example of the CE question format is shown in Fig. 1. Three unique options were presented, distinguished by their restoration attributes and associated cost. Option A and option B entail various combinations of restoration along with some yearly cost to the household, while option C is always no restoration, and no cost. The choice of option A, B, or C to each question yields information as to the rank of each scenario for that respondent. Analysis of numerous such responses, while sets of options change between questions, allows statistical estimation of the value for each restoration attribute level.

Experimental design is important for CE research since scenario permutations are large compared to the number of choice questions that may be asked. The statistical software SAS was employed to generate an efficient CE design (Kuhfeld 2005) allowing model estimation with just 32 unique choice questions. To ease respondent burden these 32 questions were blocked into eight survey versions each having four unique choice questions (Louviere et al. 2000, see pp89-94). An simple additional choice question was composed manually, to allow respondents a chance to learn the CE process. Thus each respondent was presented a total of five choice questions. All responses from an individual are assumed to be independent, so the sample size for regression reflects not the number of persons sampled, but the total number of valid choice question responses.

Preceding the CE section of the survey were two full pages of preparatory information, with a dedicated section describing each restoration attribute. For Tree Type, the survey lists the native trees to be cottonwood, coyote willow (*Salix exigua* Nutt.), and New Mexico olive (*Forestiera neomexicana* A. Gray.). Non-native trees listed are saltcedar and russian olive (*Elaeagnus angustifolia* L.). A photo was included contrasting the appearance of saltcedar with cottonwood. Debriefing questions were posed after the CE section of the survey to expose any protest responses, and also to gain more qualitative information regarding the choices that were made. Sociodemographic questions were asked at the end of the survey, where they are less likely to be skipped or incite non-response (Dillman 2007). A local phone number and email address were offered in case respondents desired assistance with any part of the survey. We are happy to furnish a copy of the survey to any interested readers.

Respondents' selections allow construction of a discrete choice model for restoration. Our analysis follows a conditional logit specification (sometimes called multinomial logit). Equations (1) through (4) are adapted from Ben-Akiva and Lerman (1985).

Let U = Utility, a measure of a household's well-being. Consider U to be a function of a vector z_{in} of attributes for alternative i, as perceived by the household respondent n. The variation of preferences between individuals is partially explained by a vector S_n of socio-demographic characteristics for person n.

$$U_{in} = V(z_{in},S_n) + \varepsilon(z_{in},S_n) = V_{in} + \varepsilon_{in} \qquad (1)$$

The "V" term is known as indirect utility, and together with the error term "ε" defines a utility model. The error term is treated as a random variable (McFadden 1974), making utility itself a random variable. An individual is assumed to choose the option that maximizes their utility. The choice probability of any particular option (A, B, or C) is the probability that the utility of that option is greater than the other two options in the choice set C_n:

$$P(i|C_n) = Pr[V_{in} + \varepsilon_{in} \geq V_{jn} + \varepsilon_{jn}, \text{ all } j \in C_n] \quad (2)$$

$$P(i|C_n) = Pr[U_{in} \geq U_{jn}, \text{ all } j \in C_n] \quad (3)$$

If error terms are assumed to be independently and identically distributed, and if this distribution can be assumed to be Gumbel, the above can be expressed in terms of the logistic distribution:

$$P_n(i) = e^{\mu V_{in}} / \Sigma_j e^{\mu V_{jn}} \quad (4)$$

The assumption of independent and identically distributed error terms implies independence of irrelevant attributes, meaning the ratio of choice probabilities for any two alternatives is unchanged by addition or removal of other unchosen alternatives (Blamey et al. 2000). The "μ" term is a scale parameter, a convenient value for which may be chosen without affecting valuation results if the marginal utility of income is assumed to be linear.

The analyst's task is to specify the deterministic portion of the utility equation, the vector V, with sub-vectors z and S. The CE data supply z, while follow-up questions in the survey instrument supply S. The econometrics software LimDep was used to estimate the regression coefficients for z and S, with a linear-in-parameters model specification. Coefficients for z and S are interpreted similar to those for multilinear regression, and have corresponding t-statistics and levels of significance. These coefficients are used in estimating average household value for a particular restoration attribute, or for combined restorative changes. This is known as welfare estimation. Welfare of a change is given by (Holmes & Adamowicz 2003):

$$\$\text{ Welfare} = (1/\beta_c)[V^0 - V^1] \qquad (5)$$

Where β_c is the coefficient on cost (effectively the negative of marginal utility of income), V^0 is the base scenario, and V^1 is a restoration scenario.

CONTINGENT VALUATION

In addition to the CE, a Contingent Valuation (CV) question was included in the survey. Whereas CE investigations are relatively uncommon, thousands of CV studies have been conducted (Carson et al. 2001). An advantage of our study is the opportunity to cross-check CE and CV welfare results. The CV question immediately followed the CE section, with a similar presentation, shown in Fig. 2. The funding mechanism was reiterated to be a sales tax bond, all of the funds from which would go towards restoration. Only one scenario is offered in the CV, full restoration. The CV also requires the respondent to explicitly choose the maximum household willingness-to-pay. Our CV format is known as payment card, though we included an open-ended (write-in) bid option. To save space we refer the reader to Cameron and Huppert (1989) for a guide to analysis of interval CV data with maximum likelihood estimation.

SURVEY INSTRUMENT

The data collection mode is a mailing survey, the thriftiest means of collecting mass public opinion (Boyle 2003). Further, mailing allowed us to easily sample not just Bosque visitors but all residents of the Albuquerque area. While recreational use values for the Bosque are more recognized, non-use values were expected to be important since the Rio Grande is iconic for the region. The mailing list is a population-weighted sample of 2,200 names and addresses for several zip-codes covering the greater Albuquerque area. A pilot survey was mailed to 200 addresses in August of 2005, with a single follow-up postcard mailed to all recipients a few days later. The final survey was revised based on pilot results, and was mailed to 2,000 addresses in May of 2006, again with a single follow-up postcard. All mailed materials were personally signed in blue ballpoint ink. For the final survey an overall response rate of 16.9% was obtained, this includes an allowance for 10% undeliverable addresses noted by the list supplier. Final response rates used for the CE and CV analyses were 12.6% and 15.1% respectively, after protest bids and responses that expressed confusion were removed from the sample. While a larger response rate would have been preferable, the cost of sending additional surveys or reminders was beyond the budget. The reader should be aware an unquantifiable amount of nonresponse bias may affect results.

RESULTS

From a variety of restoration utility models hypothesized and tested, the final specification is shown below. Variable descriptions are in Table 2 and regression results are shown in Table 3.

$$V_{in} = \beta_0\text{*ASC} + \beta_1\text{*cost} + \beta_2\text{*WILDPOP} + \beta_3\text{*MODTHIN} + \beta_4\text{*FULLTHIN} + \beta_5\text{*EQUALTREE} + \beta_6\text{*NATTREE} + \beta_7\text{*RIVPROCESS} + \beta_8\text{*ASC*MINMILE} + \beta_9\text{*ASC*visitor} + \beta_{10}\text{*ASC*aware} + \beta_{11}\text{*ASC*BORNNM} + \beta_{12}\text{*ASC*income} \quad (6)$$

Since sociodemographic variables don't vary for a given respondent as they select options A, B, or C for each choice question, these variables must be interacted with something that does vary. We chose an interaction with the ASC, thus sociodemographics enter the model as intercept shifters. The sociodemographic vector for this regression was: MINDIST = 9.56; visitor = 0.664; aware = 10.5; BORNNM= 0.284; income = 4.18. The preceding are sample means or sample proportions, except the last, which is based on Census American FactFinder 2005 Median Household Income for Albuquerque (the sample mean for income was 7.39).

All restoration attributes are highly significant predictors of respondent choices. Most importantly, the cost attribute has a negative sign as hypothesized, meaning respondents are sensitive to price signals, and are less likely to choose higher-priced restoration options. All other restoration attributes have a positive sign as hypothesized. The ranking of restoration attributes was a primary goal of the CE, and is indicated by their coefficient weights. Coefficients on variables visitor, aware, BORNNM, and income as interacted with the ASC are all positive as expected; as familiarity with the Bosque increases, or as wealth increases, the more likely a respondent is to choose a restoration option. The positive sign on MINDIST implies close proximity is not a requirement for valuing restoration. This highlights the importance of having surveyed the greater Albuquerque area rather than just homes near the river. The negative sign on the ASC reflects a combination of status quo bias and an overall negative effect of any unobserved variables. Since our analysis (and most discrete choice modeling) relies on maximum likelihood estimation, overall model performance is different from the familiar R^2 of OLS (see Greene 1997). The pseudo-R^2 is most useful for comparing competing model specifications (Ben-Akiva & Lerman 1985) though values of 0.2 or above indicate an extremely good fit (Morrison et al. 1999).

Household welfare estimates calculated from CE results are shown in Table 4, including 95% confidence intervals found using the Krinsky and Robb (1986) method. The first six rows show welfare results associated with the listed single attribute change. The seventh row shows welfare for full restoration, which includes WILDPOP, FULLTHIN, NATTREE, and RIVPROC. The full restoration estimate is larger than the sum of welfare changes from each of these four attribute separately due to how the ASC enters equation (5). Each time welfare is calculated for restoration the negative effect of the ASC factors into V^1, this has a proportionally greater impact on welfare from a single attribute change than welfare for full restoration.

The CV results are shown as the final line in Table 4, presented as a cross-check on the CE. For our CV model we converted income categories to a continuous scale and used this as the predicting variable for bid amount. Since the CV question was posed only once, the sample size for CV analysis is a fraction of that available for the analysis, and a more detailed regression model was not supported. The 95% confidence interval for CV reflects the 0.05 and 0.95 percentiles from bids predicted using the maximum likelihood model. The mean value for full restoration estimated with CV is roughly half the value estimated with the CE, and variation of the CV estimate is large.

DISCUSSION

The restoration type estimated to yield the largest public welfare is reestablishing native tree dominance, a change valued at nearly $60 per household per year. This value is important for stakeholders involved in riparian restoration and conservation throughout the West, since saltcedar is perhaps the most notorious exotic invasive plant in these areas, already occupying over a million acres in the western US and northern Mexico (Shafroth et al. 2005). Saltcedar is particularly invasive in areas that have been cleared, have regulated hydrographs (lack of flooding), or have a relatively large depth to groundwater. These are increasingly common conditions for riparian settings, and a recurrent theme in Western river restoration is saltcedar removal. Our results provide a quantification of human preference for native tree species such as Cottonwood over non-native tree species such as saltcedar. Furthermore, these values are high on a per household per year basis, and summed over a population yield significant public benefits. Economic rationale may now be added to any biologic and ecologic arguments that may exist for native plant restoration and conservation in the Middle Rio Grande and other applicable locations.

Respondents were asked for the most important consideration guiding their choice of Tree Type. The only listed option was "Tree Appearance", checked by 44% of the sample. The most popular write-in comment included the word "native", with many additional comments being something regarding naturalness or ecosystem health. Thus, most of the welfare associated with native trees appears to be related either to aesthetics or connotations of native-ness. The survey did not include a check-box for water use as a consideration, yet the second most common write-in option included the word "water", with an implication of excessive water use. Saltcedar are broadly believed to use more water than native tree species. However, this claim is challenged by recent research which links water use not so much to tree species, but to overall vegetation density or leaf area index (Dahm et al. 2002; Shafroth et al. 2005). In the survey we explicitly stated native and non-native trees use about the same amount of water. The number of persons writing in water use as a choice factor indicates a significant component of public desire to restore the Bosque to native tree dominance is based on potential misinformation that this will result in water savings.

Thinning is the second most highly valued component of restoration, with values between $35 and $40 per household per year. Thinning is a known method of exacting water savings, and the Vegetation Density attribute description in the survey notes both this and fire danger reduction from thinning. Full Thinning is valued slightly less than Moderate Thinning, thus negative marginal value of clearing is implied within the range of No Thinning and Full Thinning. No Thinning was described as 75% mature forest, while Moderate Thinning and Full Thinning were described as leaving 60% and 50% of the mature forest intact, respectively.

The welfare estimates for Fish and Wildlife and Natural River Processes both represent significant per household per year benefits, though their confidence intervals dip into the negative range. It is possible that the lack of focus on a particular charismatic species contributed to the relatively low value found for Fish and Wildlife, though perhaps such a focus would have effected an upwards bias in value. It may also be that a

10% increase in Fish and Wildlife populations was not considered a very meaningful change.

The Natural River Processes attribute was complex, yet still elicited a mean value of about $15 per household per year. This may indicate philosophic support for a freer-flowing river or appreciation of process-oriented restoration amongst Albuquerque citizenry. This is a potentially exciting result since process-oriented restoration is a more abstract and somewhat newer concept in the field (see Postel & Richter 2003). As revision of dam and floodplain operations for environmental benefit is increasingly discussed throughout the West, we believe more public welfare research in this area is warranted.

Our estimated welfare from the CE for full restoration is $156.60 per household per year for 17 miles of river, or $9.21 per household per year per mile ($5.73/km). The full restoration scenario combines the top restoration levels for Fish and Wildlife, Vegetation Density, Tree Type, and Natural River Processes. This documents significant potential public benefits for the Albuquerque citizenry from restoration of the Middle Rio Grande. Our results are within the range of per household per year values found for other regional river restoration studies but are somewhat higher on a per-mile basis. Loomis et al. (2000) find a value of $252 per household per year for restoration of a 45 mile reach of the South Platte River in Colorado, or $5.60/mi ($3.48/km); Holmes et al. (2005) find a value of $27.26 per household per year for restoration of six miles of the Little Tennessee River in North Carolina, or $4.54/mi ($2.82/km); Collins et al. (2005) find values between $148 and $193 per household per year for restoration of the 23.7 miles of

Decker Creek, West Virginia or \$6.24/mi to \$8.14/mi (\$3.88/km to \$5.06/km). Base year of dollar estimates vary across these studies though most important are contextual project differences. Our value estimates may be higher owing to the specific character of the restoration program, or due to the relative lack of surface water substitutes in Albuquerque. This study is the only one to include benefits of non-native vegetation control, and features the most arid region.

Our secondary analysis using CV also shows high per household per year values for full restoration (\$83.07 per household per year), though it is interesting that the mean estimate is barely more than half that found with the CE. Other studies comparing CE and CV have also found welfare discrepancies of similar or higher magnitudes, though CV estimates tended to be highest (Adamowicz et al. 1998; Boxall et al. 1996). The variance of our CV results easily encompass the mean welfare estimate for full restoration using the more extensive CE data, and the upper bounds of the 95% confidence intervals for the two estimates are nearly the same. Although we prefer the statistically stronger results given by the CE, it is possible to conservatively interpret our results by centering welfare for full restoration on the CV, and scaling relative welfare for restoration categories according to the CE.

CONCLUSIONS

The ecologic concentration hosted by riparian areas, reinforced by strong public identification with waterways, combine to make river restoration a flashpoint environmental issue. We believe investigation of public values is essential to guide enormous public expenditures on river restoration. Public preferences may be measured with surveys designed to support valuation techniques, estimates from which may directly enter a cost-benefit analysis. We submit this research as one of few studies to address the human benefits of river restoration, though we endorse a plurality of natural and social science inputs for restoration decision-making. The reader should note the values presented here are limited to human values, which in turn are limited to human perception. This likely excludes some ecosystem services offered by riparian areas, such as their capability to assimilate air and water pollution.

Although there are important limitations with survey analysis, and with valuation, we believe the inclusion of numerical estimates of benefits, based on carefully collected and professionally analyzed public preference data, offer a significant improvement to public land management decision-making in the absence of any such information. Given finite budgets for environmental management, increased allocative efficiency in restoration dollars for the study site, and perhaps similar Southwestern case studies, is our goal.

Our approach of separating restoration into categories is somewhat anathema to ecology, yet in practical terms many areas are managed in this fashion. This is due to bureaucratic bounds of jurisdiction and responsibility, and the disconnections that exist in highly managed systems. For example, although natural flooding may promote native species recruitment, flooding is an imperfect weed control, and adequately large flood pulses are unlikely in the extensively impounded and legally regulated Rio Grande system. Thus if public support calls for removal of exotic species such as saltcedar, ongoing mechanical efforts will be needed with a renewable budget, irregardless of other restoration measures. The decomposition of values for each type of restoration is important since the Corps does have discretion as to which restoration programs to prioritize.

Our CE confirms high public value for full restoration planned for the Bosque. We find the most highly valued types of restoration to be non-native tree control and thinning efforts. Removal of non-native trees such as saltcedar and planting native trees such as Cottonwood is the highest-valued restoration type. This result has broad implications since non-native species control is a common theme in Western river management. This is evidenced by the "Saltcedar Bill" (H.R. 2720) signed into law in 2006, authorizing 80 million dollars through 2010 for saltcedar eradication throughout the West. We know of no other study providing a quantified human benefit associated with this restoration paradigm.

With our estimates of restoration benefits, an obvious question is to compare these to restoration costs. As of this writing the Corps had not yet completed cost estimates for any of the restoration components. However initial project costs are expected to be tens of millions of dollars. Benefits too sum to tens of millions of dollars, if we extrapolate our sample results to the approximately 200,000 households in

Albuquerque. This neutral cost-benefit ratio increases over time, as operations and maintenance costs are expected to decrease, while benefits are expected to persist in future years. Thus the provisional cost-benefit analysis for restoration investment is favorable.

We have conducted this study and present the results in hopes of maximizing its practical application, both for the project at hand and similar river restoration projects. The sociodemographic vector is explicitly reported in the Methods to facilitate benefit transfer, the practice of using a valuation study as a precedent and (cautiously) applying it to a new case. We recommend original research whenever possible, though our results may extend to other urban areas in the Southwest where riparian restoration is considered, especially areas challenged by saltcedar encroachment.

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REFERENCES

Adamowicz, W., P. Boxall, M. Williams, and J. Louviere. 1998. Stated Preference Approaches for Measuring Passive Use Values: Choice Experiments and Contingent Valuation. American Journal of Agricultural Economics 80:64-75.

Ben-Akiva, M., and S. R. Lerman. 1985. Discrete Choice Analysis. MIT Press, Cambridge, Massachusetts.

Bernhardt, E. S., M. A.Palmer, J. D.Allan, G. Alexander, K. Barnas, S. Brooks, J. Carr, S. Clayton, C. Dahm, J. Follstad-Shah, D. Galat, S. Gloss, P. Goodwin, D. Hart, B. Hassett, R. Jenkinson, S. Katz, G. M. Kondolf, P. S. Lake, R. Lave, J. L. Meyer, T. K. O'Donnell, L. Pagano, B.Powell, and E.Sudduth. 2005. Synthesizing U.S. River Restoration Efforts. Science 308:636-637.

Blamey, R. K., J. W. Bennett, J. J. Louviere, M. D. Morrison, and J. Rolfe. 2000. A Test of Policy Labels in Environmental Choice Modelling Studies. Ecological Economics 32:269-286.

Boyle, K. J., H. F. MacDonald, H. Chang, and D. W. McCollum. 1998. Bid Design and Yea-Saying in Single-Bounded, Dichotomous Choice Questions. Land Economics, 74:49-64.

Boyle, K. J. 2003. Contingent Valuation in Practice. Chp 5 in P. A. Champ, K. J. Boyle, and T. C. Brown, editors. A Primer on Nonmarket Valuation. Kluwer Academic Publishers, The Netherlands.

Boxall, P. C., W. L. Adamowicz, J. Swait, M. Williams, and J. Louviere. 1996. A comparison of stated preference methods for environmental valuation. Ecological Economics 18:243-253.

Brown, J. R., N. Carrillo, and H. Jenkins-Smith. 2000. Attitudes and Preferences of Residents of the Middle Rio Grande. Summary Report to the Action Committee of the Middle Rio Grande Water Assembly and the Middle Rio Grande Council of Governments. University of New Mexico Institute for Public Policy, Albuquerque, New Mexico.

Cameron, T. A., and D. D. Huppert. 1989. OLS versus ML Estimation of Non-market Resource Values with Payment Card Interval Data. Journal of Environmental Economics and Management 17:230-246.

Carson, R. T., N. E. Flores, and N. F. Meade. 2001. Contingent Valuation: Controversies and Evidence. Environmental and Resource Economics 19:173-210.

Collins, A., R. Rosenberger, and J. Fletcher. 2005. The economic value of stream restoration. Water Resources Research 41:W02017.

Dahm, C., J. R. Cleverly, J. Allen-Coonrod, J. R. Thibault, D. E. McDonnell, and D. J. Gilroy. 2002. Evaporation at the land/water interface in a semi-arid drainage basin. Freshwater Biology 47:831-843.

Dillman, D. A. 2007. Mail and Internet Surveys: the tailored design method. 2nd edition. Wiley & Sons, Inc., New York, New York.

Greene, W. 1997. Econometric Analysis. 3rd edition. Prentice Hall, New Jersey.

Holmes, T. P., and W. L. Adamowicz. 2003. Attribute-Based Methods. Chp 6 in P. A. Champ, K. J. Boyle, and T. C. Brown, editors. A Primer on Nonmarket Valuation. Kluwer Academic Publishers, The Netherlands.

Holmes, T. P., J. C. Bergstrom, E. Huszar, S.B. Kask, and F.Orr III. 2004. Contingent valuation, net marginal benefits, and the scale of riparian ecosystem restoration. Ecological Economics 49:19-30.

Kuhfeld, W. F. 2005. Marketing Research Methods in SAS. SAS 9.1 edition, manual TS-722. SAS Institute Inc., Cary, NC.

Krinsky, I., and A. L. Robb. 1986. On Approximating the Statistical Properties of Elasticities. The Review of Economics and Statistics 68:715-719.

Loomis, J., P. Kent, L. Strange, K. Fausch, and C. Covich. 2000. Measuring the total economic value of restoring ecosystem services in an impaired river basin: results from a contingent valuation survey. Ecological Economics 33:103-117.

Louviere, J., D. Hensher, and J. Swait. 2000. Stated Choice Methods: Analysis and Applications. Cambridge University Press, New York, New York.

McFadden, D. 1974. Conditional logit analysis of qualitative choice behavior. Chp 4 in P. Zarembka. P. editor. Frontiers in Econometrics. Academic Press, New York, New York.

Morrison, M., J. Bennett, and R. Blamey. 1999. Valuing improved wetland quality using choice modeling. Water Resources Research 35:2805-2814.

Palmer, M. A., E. S. Bernhardt, J. D. Allan, P. S. Lake, G. Alexander, S. Brooks, J. Carr, S. Clayton, C. N. Dahm, J. Follstad-Shah, D. L. Galat, S. G. Loss, P. Goodwin, D. D. Hart, B. Hassett, R. Jenkinson, G. M. Kondolf, R. Lave, J. G. Meyer, T. K. O'Donnell, L. Pagano, and E. Sudduth. 2005. Standards for ecologically successful river restoration. Journal of Applied Ecology 42:208-217.

Postel, S., and B. Richter. 2003. Rivers for Life. Island Press, Covelo, CA.

Shafroth, P. B., J. R. Cleverly, T. L. Dudley, J. P. Taylor, C. Van Riper III, E.P. Weeks, and J. N. Stuart. 2005. Control of Tamarix in the Western United States: Implications for Water Salvage, Wildlife Use, and Riparian Restoration. Environmental Management 35:231-246

United States Army Corps of Engineers, Middle Rio Grande Conservancy District, City of Albuquerque Open Space Division, Bohannan Huston, Inc., and Sites Southwest, LLC. 2003. "Middle Rio Grande Bosque Restoration Supplemental Planning Document", (no publisher cited), Albuquerque, New Mexico.

Ward, F. A., and L. S. DeMouche. 2004. Economic Analysis of State Park Management in New Mexico, unpublished report prepared for the State of New Mexico, State Parks Division.

Table 1: Restoration Attributes and Attribute Levels used in the Survey

Restoration Attributes	Restoration Attribute Levels	Level Frequency
1. Fish and Wildlife	1. Status quo, current populations	1. 66%
	2. 10% increase in populations	2. 34%
2. Vegetation Density	1. Status quo, no thinning	1. 55%
	2. Moderate Thinning	2. 20%
	3. Full Thinning	3. 25%
3. Tree Type	1. Status quo, non-native dominant	1. 55%
	2. Equally native and non-native	2. 18%
	3. Native dominance	3. 27%
4. Natural River Processes	1. Status quo, no change in management	1. 64%
	2. Controlled Spring flooding, floodplain management to facilitate river/overbank interaction	2. 36%
5. Cost of Bond ($ per household per year)	1. Status quo, zero cost	1. 33%
	2. $5	2. 8%
	3. $10	3. 10%
	4. $20	4. 24%
	5. $30	5. 9%
	6. $50	6. 8%
	7. $75	7. 6%
	8. $125	8. 2%
	9. $250	9. 0%

Table 2: Conditional Logit Model Variable Descriptions

V_{in}	Indirect utility of alternative "i" for person "n"
ASC	Alternative Specific Constant, a dummy variable set to 1 if any alternative besides the status quo is chosen (options A or B) and set to 0 if the status quo (option C) is chosen
cost	The dollar cost per household per year associated with the restoration alternative, nine possibilities from $250 to $0 (status quo)
WILDPOP	Dummy variable, value 1 to indicate a 10% increase in wildlife population, 0 for status quo, i.e. current wildlife population levels
MODTHIN	Dummy variable, value 1 to indicate moderate thinning of the Bosque, 0 for status quo, i.e. no thinning
FULLTHIN	Dummy variable, value 1 to indicate full thinning of the Bosque (it is stated that 50% of the mature forest would remain undisturbed), 0 for status quo, i.e. no thinning
EQUTREE	Dummy variable, value 1 to indicate equal proportions of native and non-native trees in the Bosque, 0 for status quo, i.e. non-native tree dominance
NATTREE	Dummy variable, value 1 to indicate native tree dominance, 0 for status quo, i.e. non-native tree dominance
RIVPROC	Dummy variable, value 1 to indicate controlled but higher Spring flows, 10% removal of bank stabilization, and 10% lowering of floodplains to allow limited overbank flooding, 0 for status quo management
MINDIST	The minimum distance in kilometers via roadways between respondent's

	household address and the closest Bosque access
visitor	Dummy variable with value 1 if the respondent's household has more than zero visits to the Bosque in a year, 0 otherwise
aware	Integer scale based on four separate 3-point likert scale questions regarding awareness of the present state of the Bosque. Min value 4, max value 12
BORNNM	Dummy variable with value 1 if household respondent was born in New Mexico, and 0 otherwise
income	Seven categories for 2005 household income were used in the survey, the responses are modeled as a continuous variable. Value represents midpoint of range defined by the category, divided by $10K

Table 3: Conditional Logit Model Regression Results

Variable	Coefficient	Standard Error	t-ratio
ASC	-2.58	0.561	-4.61 [a]
cost	-0.0186	0.00322	-5.77 [a]
WILDPOP	0.384	0.0864	4.44 [a]
MODTHIN	0.999	0.133	7.52 [a]
FULLTHIN	0.899	0.110	8.14 [a]
EQUTREE	0.875	0.143	6.11 [a]
NATTREE	1.34	0.151	8.90 [a]
RIVPROC	0.528	0.108	4.88 [a]
MINDIST	0.0673	0.0183	3.67 [a]
visitor	0.919	0.202	4.55 [a]
aware	0.0929	0.0505	1.84 [c]
BORNNM	0.363	0.213	1.70 [c]
income	0.0589	0.0235	2.50 [b]

[a] = Significant at the 1% level

[b] = Significant at the 5% level

[c] = Significant at the 10% level

n = 1137

pseudo R^2 = 0.21

Table 4: Welfare Estimates from Restoration, Per Household Per Year (2006 Dollars)

Restoration Scenario	Mean Welfare ($)	95% Confidence Interval ($)
WILDPOP	7.34	-12.89 to 25.05
MODTHIN	40.49	22.57 to 62.86
FULLTHIN	35.08	16.29 to 58.75
EQUTREE	33.81	15.11 to 56.81
NATTREE	59.03	40.97 to 83.03
RIVPROC	15.11	-4.17 to 31.56
Full Restoration: CE	156.60	127.21 to 203.17
n=1137		
Full Restoration: CV	83.07	11.21 to 196.19
n=273		

Figure 1: Choice Experiment Question Example

For Questions 19-23 choose the option and cost you most prefer for the Albuquerque Rio Grande Bosque, Option A, Option B, or Option C.

Option C is always the same, it is the Current Condition with no restoration. Shading is meant to show you which options are the same as the Current Condition.

Your choices help us understand the tradeoffs you make between restoration categories and what they are worth to you.

CONSIDER EACH RESTORATION SCENARIO SEPARATELY.
FOR EACH QUESTION, CHOOSE THE OPTION YOU MOST PREFER.

	Option A:	**Option B:**	**Option C:** Current Condition
Fish & Wildlife	Current Population	10% Population Increase	Current Population
Vegetation Density	Full Thinning	No Thinning	No Thinning
Tree Type	Native Dominant	Non-Native Dominant	Non-Native Dominant
Natural River Processes	No Additional	Additional	No Additional
Cost of Bond to Household As Yearly Payment	$**20**	$**20**	$**0**

Please check the one option you most prefer

19	O **Option A**	O **Option B**	O **Option C**

Figure 2: Contingent Valuation Question

This question asks the total amount your household would agree to pay for the following restoration possibility. As in previous questions, imagine the money is collected by a city sales tax increase. Money would be used exclusively for the following restoration possibility:

	Restoration Possibility	Current Condition
Fish & Wildlife	10% Population Increase	Current Population
Vegetation Density	Full Thinning	No Thinning
Tree-Type	Native Dominant	Non-Native Dominant
Natural River Processes	Additional	No Additional
Cost of Bond to Household As Yearly Payment	$_________________	

24 **Write Yearly Maximum Cost to Household Here**

Choose from these values (or write in your own):

$250 $125 $75 $50 $30 $20 $10 $5 $0

APPENDIX C

Interactive Physical and Economic Model for Exploring Riparian Restoration Options: Application to the Middle Rio Grande

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ABSTRACT

We present an integrated dynamic simulation model to compare the costs and benefits of alternative riparian restoration and management options. The model is built from original valuation data, regional benefit transfer studies, and extensive stakeholder input. The case study considers the riparian corridor along the Rio Grande in Albuquerque, New Mexico, though the concepts are applicable to other riparian resources in the Southwestern United States. Dynamic simulation is an ideal framework since numerous and interacting variables, with feedback loops and time delays, exist in the natural and economic system. Management without the assistance of a dynamic decision support tool may lessen the opportunities for adaptive management, presentation of strategies to stakeholders, and transferance of information to management teams or the public. The model includes a forest management module, a process-oriented river restoration module, and a recreation amenity construction and management module as three control variable sectors. These sectors are influenced by human-controlled restoration investment, which in turn interacts with the natural system and modifies the flow of ecosystem service and recreational amenity benefits to the regional population. Tradeoffs between benefits and costs for particular types of riparian management may be examined individually and the efficacy of various investment possibilities may be tested through comparison of benefit-cost ratios. Fire frequency and non-native plant infestation rates are subjects of a sensitivity analysis, with radical impacts on restoration strategizing as these key values change. Limitations in current environmental valuation research are found when attempting to build continuous resource demand curves required

for the model, particularly if environmental conditions are predicted to degrade rather than improve. Over the 100 year planning horizon and for the range of assumptions tested, the costs of not doing restoration are estimated to accumulate to between one and two billion dollars. With optimized restoration investments on the order of 100 million dollars (approximately $1 million per year), benefit returns accumulate to about one billion dollars, with benefit-cost ratios ranging from 7.7 to 12.5 depending on model assumptions.

INTRODUCTION

Human appreciation of natural areas often focuses upon water-related resources. Wildlife and biodiversity also tend to concentrate in water-rich zones. Despite the importance of these areas, environmental degradation is a familiar story. A counterpoint to this is the increasingly popular phenomenon of river restoration. The National River Restoration Science Synthesis lists more than 37,000 restoration projects, with associated expenditures of over one billion dollars per year (Bernhardt et al. 2005). The funding for and number of restoration projects are an indication of public support for increased riparian management. Yet, lacking are economic analyses to demonstrate overall benefits outweigh overall costs, or that in the spectrum of possibilities certain restoration strategies are superior from a benefit-cost standpoint. Such economic input is vital to make the most of limited restoration spending.

The primary barrier to benefit-cost analysis in restoration is the difficulty and expense of nonmarket valuation, i.e. quantifying public values for an restorative environmental change. Nonmarket valuation has matured as a subdiscipline in ecological economics, however very few studies have dealt with quantifying social benefits of river restoration specifically; see Loomis et al. 2000; Holmes et al. 2004; Collins et al. 2005; and Weber and Stewart (2007). What may be more surprising, Jenkinson et al. (2006) note even restoration cost data, requiring no more than the documentation of project costs, are also rare. Cost data alone, even in the absence of benefit data, could offer meaningful reference and an improvement in restoration planning for future efforts.

The goal of this paper is to develop and apply an integrated dynamic simulation model to compare the costs and benefits of alternative riparian restoration and management options. We know of no previous work addressing restoration investment in a holistic or interactive sense. The model is built from original valuation data, regional benefit transfer studies, and extensive stakeholder input. The case study considers the riparian corridor along the Rio Grande in Albuquerque, New Mexico (locally termed the Bosque, meaning forest in Spanish). In the desert Southwest, riparian and wetland zones are especially important for the public land portfolio since surface water oases are exceedingly rare. The concepts presented here are applicable to other riparian resources in the Southwestern United States.

The model includes a forest management module, a river restoration module, and a recreation amenity construction and management module as three control variable sectors. These sectors are influenced by restoration as represented by human-controlled investment, which in turn interacts with the natural system and modifies the flow of ecosystem service and recreational amenity benefits to the regional population. Tradeoffs between costs and benefits for particular types of riparian management may be examined individually and the efficacy of various investment possibilities may be tested through comparison of respective benefit-cost ratios.

Dynamic simulation is a useful approach for tracking the numerous variable interactions and time delays associated with natural systems and human management thereof (e.g. Ruth and Hannon 1997). Model construction forces an integrated hypothesis of system processes, with future embellishments easily incorporated with new information. The modeling process is as much a means of integrating the system components that are known, as it is a means of identifying system components with less understanding. Creating an integrated system dynamics model is an excellent way to discover data weaknesses, and to guide methodology for future research. Whereas no model of a complex system will be perfect or as rich as reality, it often affords insight into system processes and feedbacks not otherwise apparent. Most management is guided by a de facto model, even if only a loosely constructed "mental model" of a single decision-maker. A dynamic simulation model allows a transparent, common management reference, and can be constructed with interface tools to easily bring complex issues before stakeholder teams and the public (Sterman 1991).

Within the growing discipline of ecological economics, a contemporary problem has been identifying and valuing ecosystem service flows. Innumerable valuation case studies now exist utilizing a diversity of econometric techniques. As the field develops, some studies have gone the next step in developing system dynamics models that use ecosystem service valuation concepts and analyses as inputs for larger-scale management questions. One of the largest-scale and most known of these was the Costanza et al. (1997) study valuing the World. Bockstael et al. (2000) argue more realistic applications are found with smaller-scale, regional modeling. This allows analysis of practical management problems and avoids inaccuracies with scaling data up to a global level. Several such regional-scale case studies have been published, see Higgins et al. 1997, van Beukering et al. 2003, and Spring and Kennedy 2005. Still other dynamic simulation contributions have been theoretic, see Bockstael et al. 1995, Costanza and Ruth 1998, Low et al. 1999, Bockstael et al. 2000, Eppink et al. 2004, Winkler 2006a and 2006b, Victor and Rosenbluth 2007, and a special issue of Ecological Economics, vol 41, 2002.

Our dynamic simulation study is unique on numerous levels. First and perhaps most important, the model is an interactive tool designed specifically to increase efficiency in river restoration, a topic under-served by economic analysis. Cost-benefit analysis is central to the model rather than an afterthought. Second, multiple public benefits from restoration are represented, all of which are modeled continuously. We consider three sectors of riparian investment with sixteen possible restoration actions. Most contemporary valuation studies do attempt to include numerous ecosystem service benefits, in contrast to early studies focusing on single-good valuation and corresponding one-dimensional management. However we know of no other instance in which continuous relationships for numerous ecosystem service benefits are simultaneously modeled. Continuous relationships are expressed using anchor values and incorporating diminishing marginal returns. Third, it is the first dynamic simulation valuation case study of a desert region of which we aware. We note Costanza et al. (1997) identified a lack of desert valuation data with their summary $0 value for the world's desert ecosystems. Furthermore, our study features a riparian resource, arguably the most important fraction of desert lands.

In the succeeding sections we describe each of the physical model components in more detail, followed by our techniques in modeling restoration costs and benefits in the economic system. Current conditions in the Bosque as well as the result of "No-Action" after 100 years are presented, followed by conditions under management optimized for benefit-cost ratio. Restoration optimization under base assumptions and after adjusting both fire frequency and non-native infestation rate in turn form a limited sensitivity analysis.

METHODS

The model may be envisioned as an accounting system for physical environmental variables and economic variables, see figure 1. Restoration proceeds as financed investment (costs) to modify the environment in the sectors of forest resources, river resources, or recreational infrastructure. These changes give rise to public benefits directly, and indirectly through habitat changes which in turn affect wildlife populations. Since long-term solutions for riparian management are desired the simulation runs are 100 years (2006-2106) with a yearly timestep. The model addresses the publically managed riparian area along the Rio Grande defined laterally by constructed riverside levees, and stretches from the North Diversion Channel to the South Diversion Channels in Albuquerque, see figure 2. This area totals 3,912 acres, and is a tiny fraction of the Rio Grande Watershed in the United States.

To the extent possible, the model was developed from the collective knowledge and values of the residents of the Albuquerque area, and the US Army Corps of Engineers (Corps). The Corps are currently in the midst of large-scale restoration of the area, and were integral in advising the development of this project. Given the potentially broad application, the model was constructed as transparently as possible with extensive documentation, to maximize ease-of-use and flexibility to assimilate future improvements. In keeping with the adaptive management envisioned for this project, a free run-time version of the model is available from the authors.

Environment

Three areas of human control are included in the environmental sector: forest management; river management; and recreation infrastructure management. An ecology model is included with wildlife being indirectly human-controlled via habitat restoration.

Forest Management

The forest module is organized around seven stocks of forest patch types, reported in acres, with the sum being the total vegetated project area of 3,700 acres. These forest stocks are: Open Area; Intermediate Age Native Forest; Mature Age Native Forest; Intermediate Age Mixed Forest; Mature Age Mixed Forest; Intermediate Age Non-Native Forest; and Mature Age Non-Native Forest. These divisions along the axes of maturity and "nativeness" are meant to capture important distinctions in vegetation density and tree type across forest patches. Mixed forest indicates a combination of native and non-native trees in a patch. The distinctions of forest patch types are aggregated from the more detailed classification system of Hink and Ohmart (1984) in use by the Corps. Initial values for each forest stock were determined by aggregating initial conditions data obtained from the Corps, see table 1.

Forest succession dynamics are a key part of the model, and are on the scale of a conceptual patch of forest, e.g. 1 acre. See table 2 for assumptions controlling succession. Starting from the youngest type of forest, a forest patch transitions from Open Area into Intermediate Age forest of either Native, Mixed, or Non-Native type. To account for the invasive character and faster growth rate of Non-Native tree species, the allocation of Open Area amongst Intermediate Age forest categories is weighted towards Non-Natives, and the rate at which Non-Native patches mature is quicker. Mature forest patches are reset to Open Area through natural decay and average fire return period. No significant difference in lifespan between Native and Non-Native trees is documented, however an order of magnitude difference in fire frequency has been suggested (Chuck Maxwell US Fish and Wildlife Service fire forecasting, personal communication 4/07). For the base model fire frequency was calibrated to be once every 1,000 years for Native patches and once every 200 years for Mixed or Non-Native patches, this yields burn rates of 8 acres per year. In reality there is no average year, with most prior years showing only minimal fire damage in the study area while 2003 yielded hundreds of acres burned. Fire frequency is an important and uncertain variable and is thus explored later in the sensitivity analysis. Infestation is included in the model, being another extremely important factor threatening riparian resource quality. A Native patch is assumed to transition to a Mixed patch in 10 years, and in turn transition to a Non-Native patch in 50 years. Infestation rates are uncertain, thus this factor is also examined later in the sensitivity analysis.

Human management within the forest module occurs through clearing a forest patch to make it Open Area, thinning a forest patch to make it more native in character, or in revegetation of Open Area to encourage native tree species. The degree of clearing, thinning or revegetation applied to each patch type are investment variables set by the analyst for different scenarios.

<u>River Management</u>

Management of the river and wetlands comprises the second module of control variables. Although historically the Corps focused on stabilizing the riverbed and regulating riverflows, efforts are now directed towards process-oriented river restoration, such as recreating a significant Spring flood pulse, excavation to reconnect the incised river with the overbank, and removal of bank stabilization. Furthermore, associated with the constricted river channel, a lack of wetland areas has been identified relative to historic conditions.

The Corps views an effective flood for the riparian system as an interrelated function of release flow level, background flow level, release duration, release frequency, and overbank area wetted by the flood. Through discussion with the Corps it appears an optimal flood flow would be 10,000 cfs, with duration of 10 days, and frequency of at least once every four years. Since natural floods do still occur despite upstream reservoir operations, we assumed managers will seek to take advantage of these natural peaks and augment them with planned flood releases. Time series data for flow in the Rio Grande (post-Cochiti dam construction upstream) were analyzed to estimate average natural flood levels in Albuquerque. Spring flood flows for durations varying between 3 and 10 days were estimated. Release flow, duration, and frequency decisions may be easily adjusted for different model runs.

The degree of overbank and wetland restoration can also be controlled in the model. Whereas the construction of numerous braided channels paralleling the main rivercourse are possible, the optimal length of overbank excavation was taken as 20 miles, the length of river in the project area. Target wetland acreage was taken as 10% of the project area as suggested by a Corps biologist.

Depth to groundwater is the final important variable for the river module. Depth to groundwater for our simulations were adapted from a comprehensive basin groundwater model by the USGS (McAda and Barroll 2002). A healthy riparian ecosystem requires shallow groundwater depths, thus a mechanism is included to progressively negatively impact vegetation should depth to groundwater increase in the study area overall.

Recreational Infrastructure

The Corps is taking this period of intensive riparian restoration to also update the recreational facilities, focusing on Trails, Bathroom sites, Parking areas, and Picnic ground infrastructure. Status quo levels of these stocks were set, and maximum target levels defined such that no funding scenario would overbuild. Depreciation for each of these infrastructural stocks were set at 5% as a means of including long-term operations and maintenance costs.

Ecology

Riparian management has both human esthetic and wildlife habitat concerns as motivating factors. Since the presence of wildlife is itself a valued part of the landscape, a means of connecting habitat modification via restoration investment to wildlife population changes was necessary. The base concept used for this conversion was the

Fish and Wildlife Service's Habitat Suitability Index (HSI), a protocol utilized by Corps. A series of government documents discuss HSI including guidelines for usage (manuals ESM 101, ESM 102, and ESM 103, US Fish and Wildlife Service 1980-1981). The HSI is a unitless index ranging from 0 to 1, with "0" representing totally unsuitable habitat and "1" meaning suitable for supporting the carrying capacity of a species, or the largest population density observed. Each increase of one-tenth increases wildlife populations by the same amount, by definition. HSI is normally applied to a single indicator species, but has also been used for a "guild" of related species.

We apply the HSI concept to the riparian habitat of the Bosque in general. This is the approach planned for the Corps' Bosque Community Model currently under development (based on personal communication with Corps staff and review of the draft Corps model, 6/07). We must stress our model does not replicate the Corps HSI model, but may be seen as a spatially and informationally aggregated version. The Corps separates the study area into five river reaches and ten cover types, whereas we model a single reach and only eight cover types. Furthermore, we oriented physical forest and river variables to correspond to simplified changes that could be conveyed in the public survey instrument and then valued by the choice experiment. The Corps directly measured numerous biological variables at 36 references sites allocated across five demarcated river reaches, and make use of these and other data. These differences notwithstanding, extensive effort was made to ensure compatibility between habitat predictions made by the dynamic simulation model and those to be determined directly by the Corps.

Review of the draft Corps HSI model afforded an understanding of important variables and functional relationships. The essence of the Corps method is employed by establishing individual Suitability Index curves for each crucial variable, and combining these to obtain HSI within three designated HSI categories Biota, Water, and Landscape. A simple average of these categories then yields overall HSI. We note the Corps often uses distinct Suitability Index curves for different cover types, whereas our model uses a Suitability Index curves for the entire forest for each crucial variable. Calibration to the draft Corps HSI model was achieved for the current condition and the situation of no additional restoration (i.e. degradation). Revised calibration will occur when the Corps model is complete. The current overall HSI for the Bosque is 0.51, dropping to 0.47 after fifty years without additional restoration. The Corps estimates the maximum possible value for HSI to be 0.8; a value of 1 is not considered achievable due to the limited spatial extent of the management area and proximity to urban areas. Whereas HSI is typically calculated as a static point value, dynamic simulation allows including a delay between changes in habitat and impacts on wildlife. We estimated the time delay to be 5 years, though for some species it is likely to be shorter, for others, longer.

Our Biota HSI was based on how forest stocks rated on the axes of vegetation density and vegetation "nativeness", with all eight forest stocks bearing on the relationship. A diversity of forest ages is desired for improved vegetation density, whereas solely native stocks are desired for the vegetation "nativeness" factor. As a forest stock strays from its ideal levels, its Suitability Index falls and Biota HSI falls. The Corps Biota HSI expression is more complex, and is a function of the Suitability Indices of seventeen crucial biological variables as measured at their references sites in each reach. The positive relationship of forest age diversity and native species health to Biota HSI is thus more detailed. Our Water HSI is based on Suitability Indices for flood duration, flood frequency, percentage of overbank area wetted during a flood (a function of flood volume and overbank regrading), and depth to groundwater. These are the same factors used in the Corps expression for Water HSI. Figure 3 shows an example of a Suitability Index curve, namely that of depth to groundwater. This curve was borrowed from the Corps relationship applying to forested cover types. Landscape HSI is included in the model as a placeholder and calibration variable, since as mentioned above our dynamic simulation model does not currently spatially resolve the study area. The Corps Landscape HSI includes Suitability Indices for patch size, distance to nearest patch, and adjacent patch similarity. Finer spatial resolution is possible in future versions of our model if warranted.

Restoration Investments

There are sixteen possible areas of discretionary restoration investment, listed in table 3. The cost of supplemental streamflows was estimated using a $100 per acre-foot value for water leasing in the Middle Rio Grande. Substantial uncertainly exists as to what water lease rates would actually be, thus this number is adjustable by the user via a slide switch. Emergency firefighting, the last entry in table 3, is considered non-discretionary. Costs of firefighting per acre were estimated through consultation with the Corps as well as Fire Management within the State of New Mexico Energy, Minerals, and Natural Resources Department. All other costs in table 3 were found through consultation with the Corps.

Restoration Valuation

Each of the three control variable groupings (forest, river, and recreation) give rise, directly or indirectly, to estimable human values. Results from an original choice experiment survey of restoration preferences for the Middle Rio Grande is the primary data source for valuation estimates in the model (Weber and Stewart 2007). This choice experiment was designed in conjunction with the Corps to apply specifically to restoration plans in the study area. Incorporation of benefit transfer from other relevant studies in the region is also used.

We distinguish **ongoing** ecosystem services of the riparian resource from ecosystem service **changes** in response to investment. To focus on impacts of investment and resulting cost-benefit ratios, we only estimate changes in ecosystem service flows resulting from physical variable investment, or neglect, as the case may be. For example, although enormous property value premiums are associated with those parcels located near the riparian zone, these status quo value premiums are not included in the model. We do model increases in property value as the area is restored, or erosion of property value as the area degrades. Establishing this zero baseline for all ecosystem services somewhat alleviates the problem of imperfect information regarding the full suite of benefits associated with the resource.

Environmental values are separated into use and non-use categories. Use values are divided into direct recreational use values and indirect property value premiums. All use values are linked to natural variables such that human management changes impact value. Recreational use values are estimated by first calculating a visitation rate, and then calculating a consumer surplus per visitor-day. Weber and Stewart (2007) found study area visitation rates for the Albuquerque-area populace, with the most prevalent recreational activities being walking, bicycling, and birdwatching, in that order. To be conservative in estimating visitation, and to account for possible self-selection bias in survey response, the median visitation rate per household of two trips per year was used in the model rather than the mean. The visitation rate is aggregated across the 255,489 households present in Bernalillo county in 2006 (extrapolated from Census 2000 data and Census 2005 update). Consumer surplus per visitor-day was estimated using a weighted average of recreational use-value estimates for walking, bicycling, and birdwatching to equal $16.35 per household trip (see Hansen et al. 1990, Bergstrom and Cordell 1991, and Rosenberger and Loomis 2001 respectively). This value per trip may be conservative as it is based on reference values for individuals, while our visitation rates are based on household trips that may involve multiple household members. Previous research prepared for New Mexico State Parks (Ward and DeMouche 2004) established a regression equation for visitation based on recreational amenities at a site. This supplies a means of weighting different recreational amenities and calculating an overall recreational infrastructural score. Their relationship is adapted for our model variables that were somewhat different from those in their study, and then calibrated to predict visitation found from independently estimated visitation rates in the study area before recreational amenity changes. The recreational infrastructural score equation is: $Toilets^{0.325} * TrailMi^{0.325} * PicnicSites^{0.02} * ParkingSites^{0.05} * CountyPop^{0.21}$. County population was found using 2.37 persons per household (Census 2005 update for Bernalillo County).

Property value premiums associated with the study area were estimated through benefit transfer from hedonic studies in the Southwest. Numerous hedonic studies have found proximity to water to positively affect home prices (Netusil 2005, Acharya and Bennett 2001), though these results were for wetter U.S. regions. Colby and Wishart (2002) found home prices to decline several percent with increasing distance from a riparian zone in a southwestern locale, however no riparian quality variable was included to show how property premiums may change with riparian area management. Bark (2006) documents a relationship between hydromesic vegetation diversity and property value for homes near riparian zone in a southwest urban area, finding a premium of 8.6% on diversity. Since restoration will increase tree diversity, the Bark premium was adapted to a continuous percentage increase applied to homes within 0.3 miles of the riparian zone as forest restoration proceeds. The model uses changes in Biota HSI relative to starting conditions as the tree diversity metric, see figure 4. The derived relationship incorporates diminishing marginal returns and is mirrored for degradation in Biota HSI. A model allows the user to easily modify the premium itself or the distance buffer to which it will apply.

The choice experiment by Weber and Stewart (2007) estimates the benefits of competing river restoration strategies on a per household, per year basis for the study area. The restoration attributes valued were: vegetation density, tree type, wildlife population, and natural river process-based restoration. The choice experiment estimated two points on the demand curve for the first two attributes, and one point on the demand curve for the latter two attributes. The payment vehicle was a sales tax bond, presented as hypothetical per household per year payments. The discrete changes valued via the choice experiment allowed anchor value estimation for hypothesized benefit curves for each attribute, then interpolated and extrapolated to form demand curves conforming to the law of diminishing marginal returns. The choice experiment concentrated on forest attributes and did not address changes in Open Area, thus penalties for forest management resulting in Open Area beyond target levels were hypothesized for both vegetation density and tree type benefit curves. Figures 5 and 6 show the vegetation density and tree type benefit curves when Open Area is at or below its target level, with choice experiment anchor values shown. The anchor values were adjusted since initial conditions detailed in the early 2006 survey are different from those received from the Corps for the start of the model since restoration has been ongoing. Reestablishing a zero value baseline for vegetation density and tree type was achieved by subtraction of $28.37 and $27.42 per household per year from the respective benefit curves, the estimated household values of the vegetation density and tree type improvements between the date of the survey and the starting date of the model. The benefit curve for wildlife (as controlled by HSI) is shown in figure 7. The anchor value is shown, and the curve incorporates sharply diminishing returns as wildlife populations continue to increase. Note the extrapolation into negative values assumed if degradation in wildlife occurs relative to initial conditions. The benefit curve for Natural River Processes is shown in figure 8 with its anchor value. The Suitability Index for Wetted Area, as used in the Water HSI component of overall HSI, is the trigger variable reflecting improvements in Natural River Processes.

Since the choice experiment bids did not distinguish between recreational use and nonuse values, no attempt is made to distinguish these here. Recreation is assumed to be solely dependent on infrastructure amenity changes as described above, though some change in recreation is likely due to changes in the forest and river. Thus the choice experiment-based benefits may be seen as having some use value fraction. Another complication is that property value interests may have motivated choice experiment bids, especially for those respondees living near the river. Since the survey was across the entire Albuquerque area we believe any such impact on the estimated average household values to be minimal. In fact the regression bid function shows a negative coefficient for proximity to the resource.

The model allows discounting of future benefits and costs, however discounting was not applied in this analysis. Most of the restoration measures involve recurrent investments in the forest, river, and recreational infrastructure throughout the 100 yr model horizon. Because of the long-term management required, and concomitant continuous accumulation of benefits, the model is not particularly sensitive to discounting in any case. Use of a zero discount rate is also a means of enforcing intergenerational equity in environmental decision-making.

As a final note on value sources, we have made every effort to include all ecosystem services as data permit. This portfolio approach is an improvement over single-good valuation, but may yet be considered conservative. For example, restoration may reasonably increase the air and water cleansing capability of the study region, though this and other less-studied avenues of value are neglected in this analysis. Such benefits may be incorporated in future model versions as research allows.

RESULTS

We exercise the model with a "No-Action" scenario and an Optimal restoration funding scenario. We then include a limited sensitivity analysis on two physical model variables. The No-Action and Optimal scenarios are useful to compare conditions with and without a restoration project. No-Action means no investments in the forest, river, or recreational infrastructure, resulting in environmental and economic conditions that continue to worsen through time. For the Optimal scenario, maximizing the benefit-cost ratio was the decision rule for finding the optimal funding array across the sixteen possible restoration types. Computer-aided optimization results were manually verified and adjusted to the nearest $10,000 per year, with a cap of $500,000 per year on any single measure. The $500,000 per year cap on any particular restoration measure keeps the total yearly restoration budget within feasible bounds, and also serves to limit expenditures on any particular restoration strategy in the event it proves less effective than predicted.

A sensitivity analysis was included since substantial uncertainty exists for a predictive model running for 100 years on a complex physical and economic system such as the Bosque. Our limited sensitivity analysis offers a way to bracket likely outcomes and associated management inference as key assumptions change. We envision the model not so much in absolutes, but rather as an adaptive management tool for system insight subject to improvement, a tool in fact meant to invite revision. We chose the physical variables fire frequency and infestation rate for the sensitivity analysis as we found these to be two very influential parameters that are not well understood. The sensitivity analysis presents No-Action and Optimal funding runs for the "High-Burn" and "Low-Infest" cases described further below. The dynamic simulation framework easily allows additional sensitivity analyses hypothesized beyond these.

Fire is perhaps the most important wildcard emerging in the study area. The Base case sets fire recurrence intervals for Native, Mixed, and Non-Native forest patches at 1,000 years, 200 years, and 200 years respectively, yielding overall burn rates of about 8 acres per year in the study area. A "High-Burn" case was hypothesized by dropping the fire recurrence intervals each by an order of magnitude, yielding burn rates of about 80 acres per year. While this may seem excessive, the Atrisco-Montano fire burned 263 acres of the project area in 2003, and the Isleta fire just to the south of the project area burned between one and two hundred acres of riparian vegetation in 2006. Thus an aggressive fire regime seems plausible, especially given multidecadal drought possible for the Southwestern US (Seager et al. 2007).

Another high-profile issue in the Bosque, and one the public may be more aware of, is infestation by non-native plants, especially salt-cedar. In the model this is represented by Native forest stocks constantly being infested to being first Mixed in character and finally exclusively Non-Native. Since non-native infestation is relatively recent, the speed of this transition is uncertain. To test this, the rate at which Mixed patches transition to being Non-Native was extended from 50 to 150 years. The rate at which Native patches transition to being Mixed was left unchanged at 10 years.

Results for No-Action and Optimal restoration funding for base assumptions, the High-Burn assumption, and the Low-Infest assumption are shown in tables 4, 5, and 6.

Table 4 shows forest stocks initially and after 100 years of simulation. Benefits and costs in each category and summed are shown in tables 5 and 6, respectively. Benefit-cost ratio is tracked in the bottom row of table 6. All model runs are 100 years with a yearly timestep, with a 0% discount rate attached to all future benefits and costs. The 0% discount rate means the benefits and costs for future generations are just as important for the decision as the benefits and costs of the current generation. Graphs 1 and 2 show how forest conditions change over the simulation for the No-Action and Optimal scenarios. Graphs 3 and 4 show how ecosystem service benefits accumulate differently for the No-Action and Optimal scenarios. Graphs 5 through 8 show the parallel results for the High-Burn assumption, and graphs 9 through 12 correspond to the Low-Infest assumption.

DISCUSSION

No-Action

The three No-Actions runs are better described as "stop restoration" since the Corps has already made much headway when the model begins in 2006. In all No-Action runs, stopping restoration causes declines in native tree stocks. Mature Non-Native stocks rise, first at the expense of Mature Native forest, then at the expense of Mature Mixed forest. Predictions are that the exchange of mixed forest for exclusively non-native forest will continue even after 100 years for both the base assumptions and the Low-Infest case, though the High-Burn case reaches equilibrium. Recreational amenities depreciate from their current levels to being essentially zero. Habitat measured as unitless HSI falls from 0.51 to 0.47. Cumulative burned acreage is almost six times higher in the High-Burn case, equivalent to the entire study area burning twice over the 100 year simulation. Firefighting costs were treated as nondiscretionary, and so represent direct costs of No-Action regardless of the absence of a restoration budget. These costs are estimated to be 13.5 million for the Base and Low-Infest cases, and 78.6 million for the High-Burn case.

Aside from direct firefighting costs, total benefits from all No-Action runs are overwhelmingly negative, meaning that because of study area degradation the public is much worse off than under initial conditions. The High-Burn case predicts positive benefits in the single category of vegetation density; fire has effectively done the work of manual clearing and thinning to increase the age diversity of the forest. Since public valuation of vegetation density reduction was surveyed under the assumption of manual clearing, it may be hypothesized that fire as a vehicle of achieving density reduction has uncounted negative impacts on the public, eliminating modeled benefits. In any case this small benefit erodes to negative a few years after 2106, as overall forest degradation continues. Tree-type benefits are less negative for both the High-Burn and Low-Infest cases relative to base assumptions. In the former, fire acts again as a positive influence since mixed and non-native stocks are more likely to burn than native stocks. In the latter, Low-Infest simply limits tree-type degradation by assumption.

Optimal Restoration Funding

Across optimizations, the most striking difference in 2106 forest stocks are the much higher and lower levels of Mature Native forest relative to base assumptions for High-Burn and Low-Infest, respectively. Mixed Mature forest levels show exactly the reverse result. The High-Burn optimization shows somewhat more Open Area, and burned acreage is several times higher, with all optimizations showing substantially less burned acreage relative to their respective No-Action runs. The lowest Benefit-Cost Ratio occurs with the High-Burn case. This forest changes aggressively through infestation and fire, and requires aggressive management expenditures, particularly in thinning Mature Mixed forest and firefighting. No funding for clearing Mature Non-Native patches is recommended, this stock drops to minimal levels already through thinning and fire. High levels of native trees are maintained because the reduced threat of fire makes this all the more worthwhile.

A Benefit-Cost Ratio higher than the Base is available for Low-Infest. Low burn rates and low infestation mean a more stable forest, and managers can get away with fewer costs. The most surprising result here is the optimized negative value for Tree-Type benefits. This is especially interesting since Tree-Type is the single most highly valued forest attribute. The recurrent expenditures of thinning Mature Mixed forest called for by the other optimizations simply do not show a positive net benefit, it is better to clear patches only after they become Mature Non-Native. The potential gains of converting the substantial amount of Mixed forest to Native forest do not outweigh the restoration expenditures that would be necessary to achieve them.

The reader may note several restoration possibilities remain unfunded for all optimized runs, as shown in table 6. Conspicuous among inferior investments are overbank reconfiguring and lease of water to augment Spring floods, though these remain primary goals of the Corps' restoration package. Improvements to river ecology from these strategies are also indispensable for the Corps' HSI goal of 0.8. The choice experiment supplying a public value for improvements in Natural River Processes did not specify how value should be distributed amongst its two factors of connected overbank construction and augmented Spring flooding. The Base model uses a multiplicative functional form in the Natural River Processes valuation expression, meaning an improvement can't occur unless investments are made in both factors. Multiplication captures a hypothesis that these improvements will be synergistic. However, natural floods do still occur despite upstream reservoirs, thus overbank improvements may make a difference without additional flood releases. Also, augmented flooding may independently be an attractive concept to the public. Thus, a functional form adding improvements in either connected overbank or flooding was also hypothesized, resulting in a different optimization. The recommended funding is the same as the Base, except overbank reconfiguration is funded at the $500,000/yr maximum such that the 20 mile reach is reconditioned as quickly as possible. The Benefit-Cost Ratio jumps from 11.2 to 15.3, highest of any scenario. Furthermore, Natural River Process-based benefits become the most significant value source in that optimization. The model is thus sensitive not only to physical variables but also competing economic hypotheses of how to interpret valuation data. With this last optimization considered, augmenting Spring flooding remains an inferior investment at the assumed lease rate of $100 per acre foot. Given that the use of leased water would be nonconsumptive perhaps a lower lease rate could be negotiated. Indeed the $100 figure is very much an estimate since only an extremely limited water lease market exists in the basin. Using the additive valuation hypothesis for Natural River Processes benefits, the model predicts it will be worthwhile to start leasing water when the lease rate drops to between $5 and $10 per acre foot.

CONCLUSIONS

Optimized funding yields significant gains from restoration spending across the base assumptions and sensitivity analysis. Forest stocks, river conditions, and recreational amenities improve, yielding huge public benefits from restoration. These contrast with large negative public impacts predicted if the resource is allowed to degrade further. Benefit-cost ratios for the optimizations range from 7.7 to 12.5. Restoration budgets, a small percentage of which is firefighting, come to between 0.7 and 1.5 million per year, easily within the region's taxing ability.

A key feature of the model is inclusion of feedback and time delay interactions impossible with static models. The ecologic and economic systems are each modeled organically, responding to changes in complex fashion over time. This is contrast to the simpler, flat input-output approach more common in modeling. This can lead to surprising inferences unlikely with static modeling, for example, the unexpected result of purposefully maintaining high levels of Mixed forest under the Low-Infest optimization.

The dynamic simulation model allows rapid analysis of competing restoration strategies, with background ecologic or economic assumptions easily changed, as seen in the sensitivity analysis presented. Reality may prove to be no single scenario tested but shades of all considered here; the model offers a common decision support tool reference with the ability to test these complex interactions and uncertainty. Important differences in public benefit do occur across these scenarios with tailored implications for management. The model offers an adaptive management reference tool as both economic and ecologic research continue. Model inputs and outputs are transparently utilized for presentation to public or interest groups, and updates are easily incorporated from such conferences to help direct revised management. We note this model is simply a small portion of a much larger watershed-scale dynamic simulation planning tool under development for the Middle Rio Grande, see Tidwell et al. 2006.

The physical possibilities for our study area range from extensive restoration to extensive degradation, with innumerable permutations within. The choice experiment survey research designed to individually value multiple restoration attributes in the study site was absolutely vital for the rich output the model is able to provide. However, modeling across the spectrum of change possible exposes a severe limitation in contemporary ecosystem service benefit research. Even with the choice experiment results, an improvement over typical single-good, single-level valuation, we have barely a starting point for developing environmental good demand curves. This is the necessary relationship to develop continuous economic impacts in response to continuous environmental change. More distressing than spotty demand curve data in positive space is utter lack of valuation data if conditions degrade. Estimating loss to society of degrading environmental resources is less frequent than valuing improvements., but since so many of our environmental management decisions are in fact "No-Action", the implied degradation has potentially huge hidden costs. The accumulated costs of No-Action for this study are estimated to be between 1.5 and 2.3 billion by the end of the simulation.

Beyond the economic efficiency analysis we offer, other decision-making modes apply to the study area. For example, the Corps has an HSI goal of 0.8, although we do not find this goal to optimize the benefit-cost ratio. The Corps has a federal mandate to improve conditions in the riparian area that supersedes economic argument. Indeed, the Corps prefers not to use Benefit-Cost Analysis at all for its environmental projects, federal researchers have deemed the uncertainties in valuation overly risky for decision-making (e.g. Stakhiv et al. 2003). We are sympathetic to this view, and the conservative stewardship implied. Yet we believe ecosystem service valuation remains absolutely relevant as one criteria among many for validating large public expenditures by agencies such as the Corps. For example, these valuation results may be used to predict whether restoration plans seem to err on the side of over or under-protection. Over-protection may be preferable if additional ecosystem service benefits of the study area are likely but are yet uncharacterized.

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REFERENCES

Acharya, G. and L.L. Bennett, Valuing Open Space and Land-Use Patterns in Urban Watersheds, Journal of Real Estate Finance and Economics 22(2), pp 221-237, 2001.

Bark, R.H, Muddy Waters: Case Studies in Dryland Water Resource Economics, PhD Dissertation, University of Arizona, 256 p, 2006.

Bergstrom, J., and H. Cordell, An Analysis of the Demand for and Value of Outdoor Recreation in the United States, Journal of Leisure Research, 23(1) pp67-86, 1991.

Bernhardt, E. S., M. A.Palmer, J. D.Allan, G. Alexander, K. Barnas, S. Brooks, J. Carr, S. Clayton, C. Dahm, J. Follstad-Shah, D. Galat, S. Gloss, P. Goodwin, D. Hart, B. Hassett, R. Jenkinson, S. Katz, G. M. Kondolf, P. S. Lake, R. Lave, J. L. Meyer, T. K. O'Donnell, L. Pagano, B.Powell, and E.Sudduth, Synthesizing U.S. River Restoration Efforts. Science 308:636-637, 2005.

Bockstael, N., R. Costanza, I. Strand, W. Boynton, K. Ball, and L. Waigner, Ecological economic modeling and valuation of ecosystems, Ecological Economics 14 pp 143-159, 1995.

Bockstael, N., A.M. Freeman III, R.J. Kopp, P.R. Portney, and V.K. Smith, On Measuring Economic Values for Nature, Environmental Science & Technology 34(8), pp 1384-1389, 2000.

Colby, B., and S. Wishart, Quantifying the Influence of Desert Riparian Areas on Residential Property Values, The Appraisal Journal, July 2002.

Collins, A., R. Rosenberger, and J. Fletcher, The economic value of stream restoration. Water Resources Research 41:W02017, 2005.

Costanza, R., R. d'Arge, R. de Groot, S. Farber, M. Grasso, B. Hannon, K. Limburg, S. Naeem, R.V. O'Neill, J. Paruelo, R.G. Raskin, P. Sutton, and M. van den Belt, The value of the world's ecosystem services and natural capital, Nature (387), pp 253-260, May 1997.

Costanza, R., and M. Ruth, Using Dynamic Modeling to Scope Environmental Problems and Build Consensus, Environmental Management 22(2) pp 183-195, 1998.

Eppink, F.V., J.C.J.M. van den Bergh, and P. Rietveld, Modelling biodiversity and land use: urban growth, agriculture and nature in a wetland area, Ecological Economics 51 pp 201-216, 2004.

Hansen, W., A. Mills, J. Stoll, R. Freeman, and C. Hankamer, A case study application of the contingent valuation method for estimating urban recreation and benefits. U.S. Army Corp of Engineers, IWR Report 90-R-11, 1990.

Hink, V.C., and R.D. Ohmart, Middle Rio Grande Biological Survey. US Army Corps of Engineers, Albuquerque District, New Mexico. Contract No. DACW47-81-C-0015, Arizona State University. 193p, 1984.

Higgins, S.I., J.K. Turpie, R. Costanza, R.M. Cowling, D.C. Le Maitre, C. Marais, G.F. Midgley, An ecological economic simulation model of mountain fynbos ecosystems Dynamics, valuation and management, Ecological Economics 22 pp 155-169, 1997.

Holmes, T. P., J. C. Bergstrom, E. Huszar, S.B. Kask, and F.Orr III, Contingent valuation, net marginal benefits, and the scale of riparian ecosystem restoration. Ecological Economics 49:19-30, 2004.

Jenkinson, R.G., K.A. Barnas, J.H. Braatne, E.S. Bernhardt, M.A. Palmer, J.D. Allan, and the Nation River Restoration Science Synthesis, Stream Restoration Databases and Case Studies: A Guide to Information Resources and Their Utility in Advancing the Science and Practice of Restoration, Restoration Ecology 14(2), pp 177-186, 2006.

Loomis, J., P. Kent, L. Strange, K. Fausch, and C. Covich, Measuring the total economic value of restoring ecosystem services in an impaired river basin: results from a contingent valuation survey. Ecological Economics 33:103-117, 2000.

Low, B., R. Costanza, E. Ostrom, J. Wilson, and C.P. Simon, Human-ecosystem interactions: a dynamic integrated model, Ecological Economics 31 pp 227-242, 1999.

McAda, D. P., and P. Barroll, Simulation of Ground-Water Flow in the Middle Rio Grande Basin Between Cochiti and San Acacia, New Mexico. U.S. Geological Survey Water-Resources Investigations Report 02-4200, Albuquerque, New Mexico, 2002.

Netusil, N.R., The Effect of Environmental Zoning and Amenities on Property Values: Portland, Oregon, Land Economics 81(2), pp 227-246, 2005.

Rosenberger, R.S., and J.B. Loomis, Benefit Transfer of Outdoor Recreation Use Values: A technical document supporting the Forest Service Strategic Plan (2000 revision) Gen. Tech. Rep. RMRS-GTR-72. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 59p. 2001.

Ruth, M., and B. Hannon, eds., Modeling Dynamic Systems, Springer, New York, 399p, 1997.

Seager, R., M. Ting, I. Held, Y. Kushnir, J. Lu, G. Vecchi, H. Huang, A. Leetmaa, N. Lau, C. Li, J. Velez, and N. Naik, Model Projections of an Imminent Transition to a More Arid Climate in Southwestern North America, Science, Vol 316, pp1181-1184, May 2007.

Spring, D.A., and J.O.S. Kennedy, Existence value and optimal timber-wildlife management in a flammable multistand forest, Ecological Economics 55 pp 365-379, 2005.

Stakhiv, E.Z., Cole, R.C., Scodari, P., and L.R. Martin, Improving environmental benefits analysis in ecosystem restoration planning, Institute for Water Resources, Research Report 03-PS-3, U.S. Army Institute for Water Resources, Alexandria, VA., 2003.

Sterman, J.D., A Skeptic's Guide to Computer Models, In Barney G.O. et al. (eds.), *in* Managing a Nation: The Microcomputer Software Catalog, Westview Press, Boulder, CO, pp 209-229, 1991.

Tidwell, V.C., L.A. Malczynski, H.D. Passell, W.J. Peplinski, M.D. Reno, J. Chermak, D. Brookshire, J. Thacher, K. Grimsrud, C. Broadbent, J. Hason, J.F. Roach, E. Vivoni, C. Aragon, H. Hallett, K. Cockerill, and D. Coursey, Integrated System Dynamics Toolbox for Water Resources

Planning, SANDIA REPORT 2006-7676, Sandia National Laboratories, Albuquerque, NM, 312pp, 2006.

United States Army Corps of Engineers, Middle Rio Grande Conservancy District, City of Albuquerque Open Space Division, Bohannan Huston, Inc., and Sites Southwest, LLC., "Middle Rio Grande Bosque Restoration Supplemental Planning Document", (no publisher cited), Albuquerque, New Mexico, 2003.

United States Fish and Wildlife Service, Ecological Services Manual: ESM 101, Habitat as a Basis for Environmental Assessment; ESM 102, Habitat Evaluation Procedures; and ESM 103, Standards for the Development of Habitat Suitability Index Models, 29 p., 130p., and 171 p. respectively, 1980-1981.

Van Beukering, P.J.H., H.S.J. Cesar, and M.A. Janssen, Economic valuation of the Leuser National Park on Sumatra, Indonesia, Ecological Economics 44 pp 43-62, 2003.

Victor, P.A., and G. Rosenbluth, Managing without growth, Ecological Economics 61 pp 492-504, 2007.

Weber, M., and S. Stewart, Public Valuation of River Restoration and Saltcedar Removal on the Middle Rio Grande, unpublished manuscript, 2007.

Winkler, R., Valuation of ecosystem goods and services Part 1: An integrated dynamic approach, Ecological Economics 59 pp 82-93, 2006.

Winkler, R., Valuation of ecosystem goods and services Part 2: Implications of unpredictable novel change, Ecological Economics 59 pp 94-105, 2006.

Table 1: Initial Conditions of Forest Resources

Tree Type	Open Area (ac)	Middle-Age (ac)	Mature Age (ac)
Native	N/A	243	1090
Mixed	N/A	267	1058
Non-Native	N/A	518	353
Total	385	1028	2501

Table 2: Forest Succession Assumptions

Tree Type	Proportion Allocated from Open Area	Transition Time Open Area to Intermediate-Age (yr)	Transition Time Intermediate-Age to Mature Age (yr)	Fire Return Period for Patch (yr)	Average Patch Life Span (yr)
Native	0.3	10	20	1,000	100
Mixed	0.3	7.5	17	200	100
Non-Native	0.4	7.5	17	200	100

Table 3: Possible Restoration Investment Types

Restoration Type	Cost Including Overhead
Clear Mature native trees	$3,250/ac
Clear Intermediate age native trees	$1,950/ac
Revegetate with Native trees	$1,950/ac
Thin Intermediate Mixed Forest	$1,950/ac
Thin Mature Mixed Forest	$3,250/ac
Clear Intermediate Mixed Forest	$1,950/ac
Clear Intermediate Non Native Forest	$1,950/ac
Clear Mature Non-Native Forest	$3,250/ac
Clear Mature Mixed Forest	$3,250/ac
Trail Construction	$100,000/mi
Toilet Construction	$50,000/site
Parking Area Construction	$7,778/site
Picnic Area Construction	$10,000/site
Wetland Construction	$32,500/ac
Connected Overbank Construction	$585,000/mi
Controlled Flooding	$100/acft/yr
Emergency Firefighting	$10,000/ac

Table 4: Forest Stocks in Acres

Restoration Variable	Initial Conditions 2006	No-Action 2106	High-Burn No-Action 2106	Low-Infest No-Action 2106	Optimal 2106	High-Burn Optimal 2106	Low-Infest Optimal 2106
Open Area	385	345	750	345	743	825	646
Intermediate Native	243	65	143	65	753	837	674
Mature Native	1090	35	69	35	1203	1693	358
Intermediate Mixed	267	258	561	310	97	108	87
Mature Mixed	1058	591	500	1153	1053	272	1870
Intermediate Non-Native	518	400	871	348	39	44	250
Mature Non-Native	353	2218	1019	1656	23	134	27
Burned	N/A	1,349	7,858	1,349	652	4,080	937

Table 5: Cumulative Benefits of Restoration Investment after 100 years by Category, in Millions of Dollars

Benefit Type	No-Action	High-Burn No-Action	Low-Infest No-Action	Optimal	High-Burn Optimal	Low-Infest Optimal
Vegetation Density	-824.0	2.0	-824.0	334.8	341.5	362.2
Tree Type	-744.9	-702.4	-575.3	260.0	306.1	-8.4
Prop Value	-65.7	-64.0	-66.2	69.1	63.4	60.9
Wildlife	-85.1	-75.7	-86.1	71.9	55.7	60.8
Rec. Use	-610.8	-610.8	-610.8	351.1	349.9	350.4
Total Cumulative Benefits	-2,330.6	-1,450.9	-2,162.3	1,087.0	1,116.6	825.9

Table 6: Cumulative Restoration Costs after 100 years by Category, in Millions of Dollars, and Overall Benefit-Cost Ratio

Restoration Type	Optimal	High-Burn Optimal	Low-Infest Optimal
Clear Mature Native Trees	0	0	0
Clear Intermediate Age Native Trees	0	0	0
Revegetate with Native Trees	0	0	0
Thin Intermediate Mixed Forest	19.2	20.2	17.0
Thin Mature Mixed Forest	29	49.8	0
Clear Intermediate Mixed Forest	0	0	0
Clear Intermediate Non-Native Forest	8.9	8.8	4.0
Clear Mature Non-Native Forest	8.2	0	10.6
Clear Mature Mixed Forest	0	0	0
Trail Construction	21.7	21.6	21.6
Toilet Construction	2.1	2.1	2.1
Parking Area Construction	0.5	0.5	0.5
Picnic Area Construction	0.8	0.7	0.7
Wetland Construction	0	0	0
Connected Overbank Construction	0	0	0
Controlled Flooding	0	0	0
Emergency Firefighting	6.5	40.8	9.4
Total Cumulative Costs	96.8	144.6	66.0
Benefit-Cost Ratio	11.2	7.7	12.5

Figure 1: Simplified Model Structure

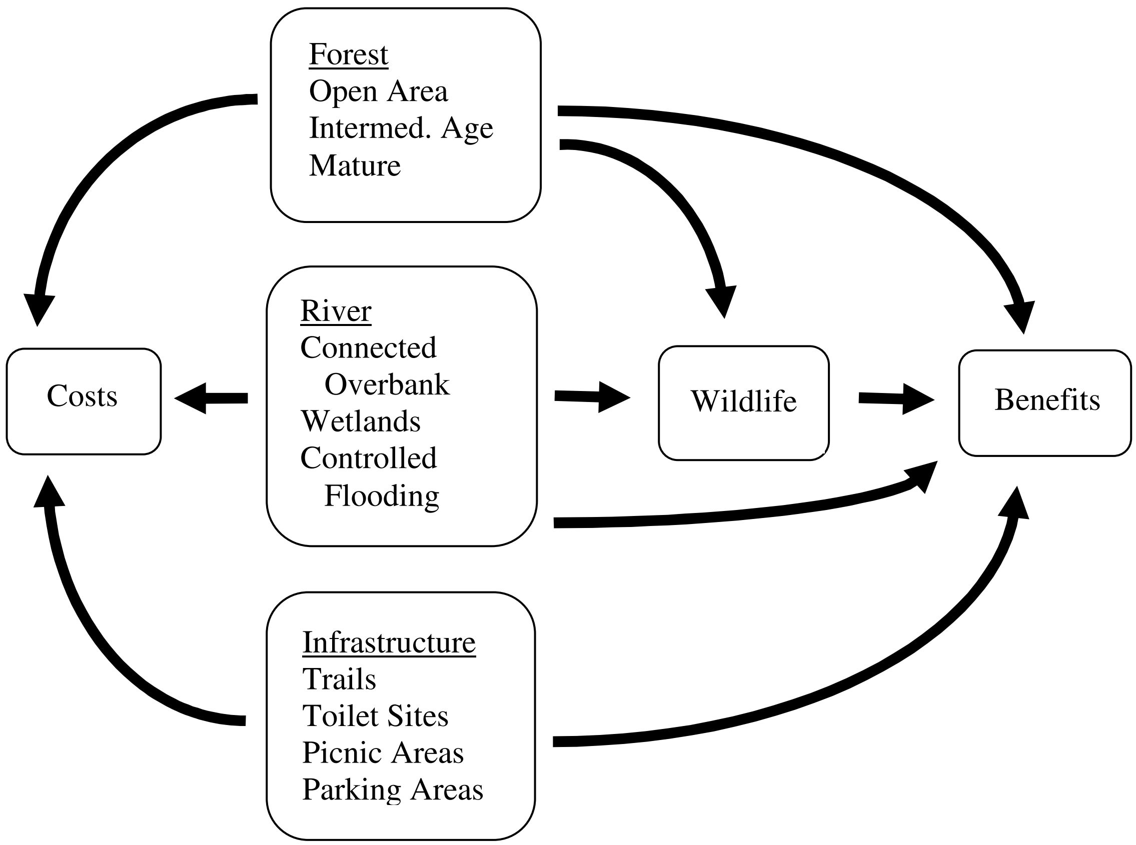


Figure 2: Middle Rio Grande Bosque in Albuquerque, Part of the Rio Grande Watershed

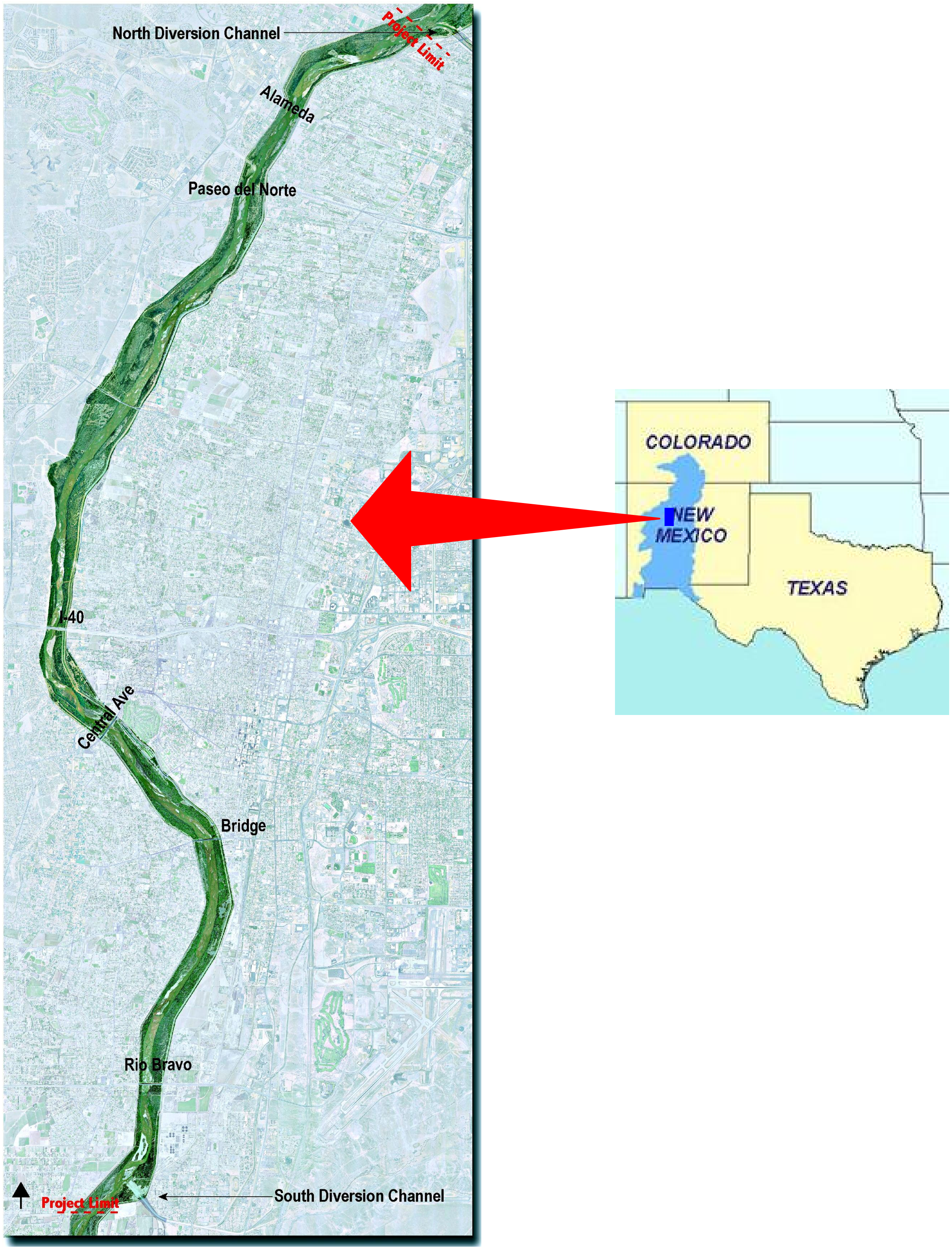


Figure 3: Suitability Index Curve For Depth to Groundwater

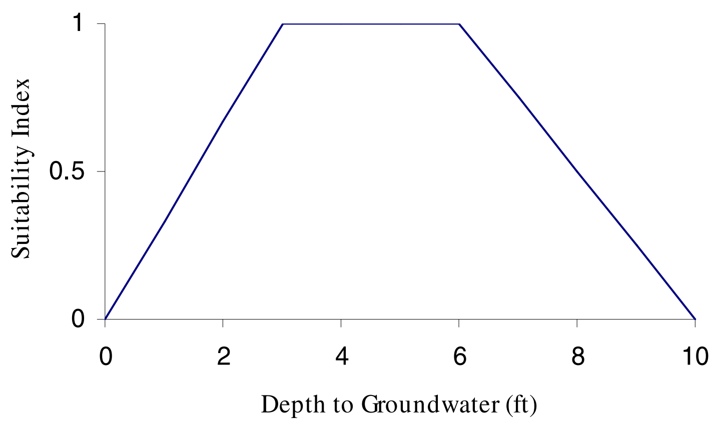


Figure 4: Property Value Benefit Curve

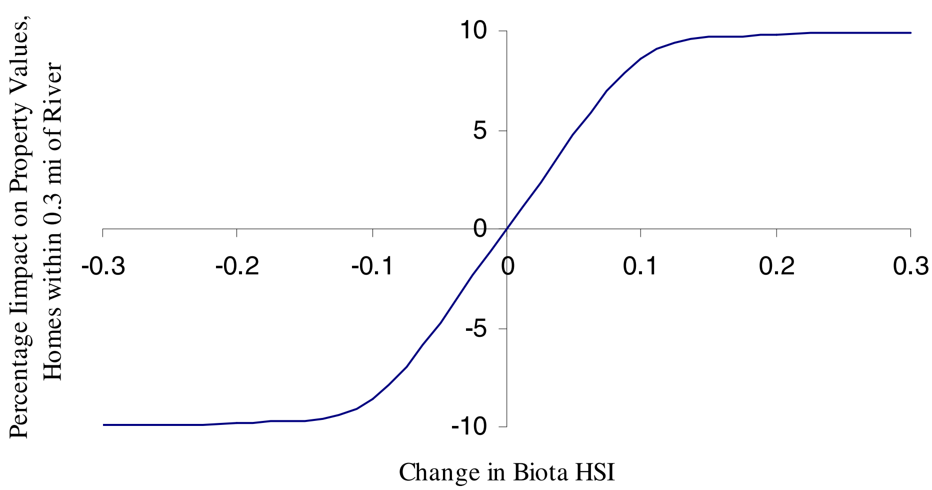


Figure 5: Vegetation Density Benefit Curve

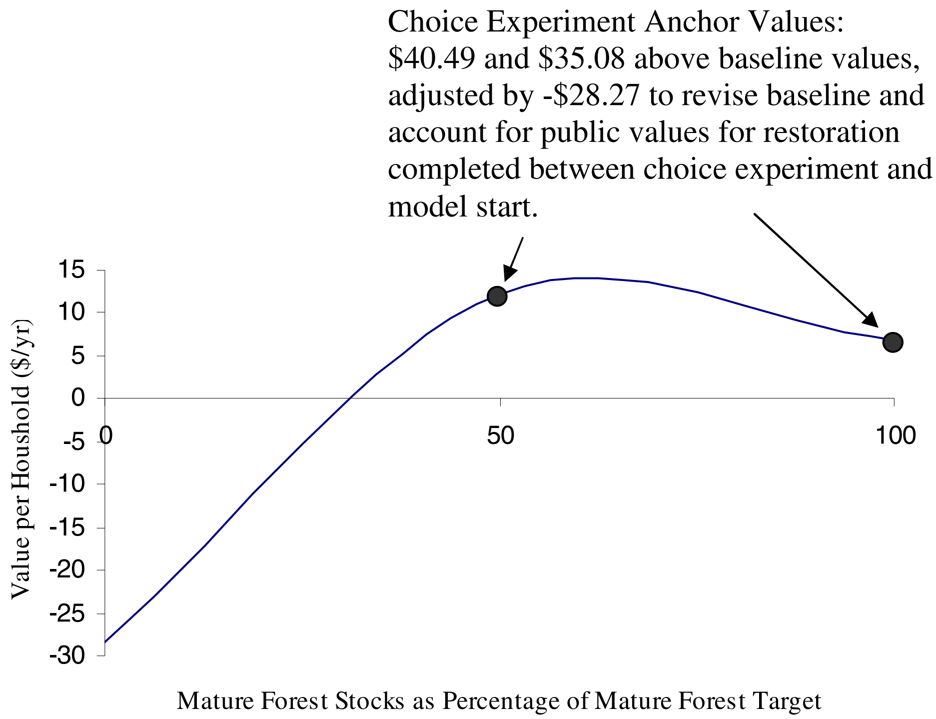


Figure 6: Tree Type Benefit Curve

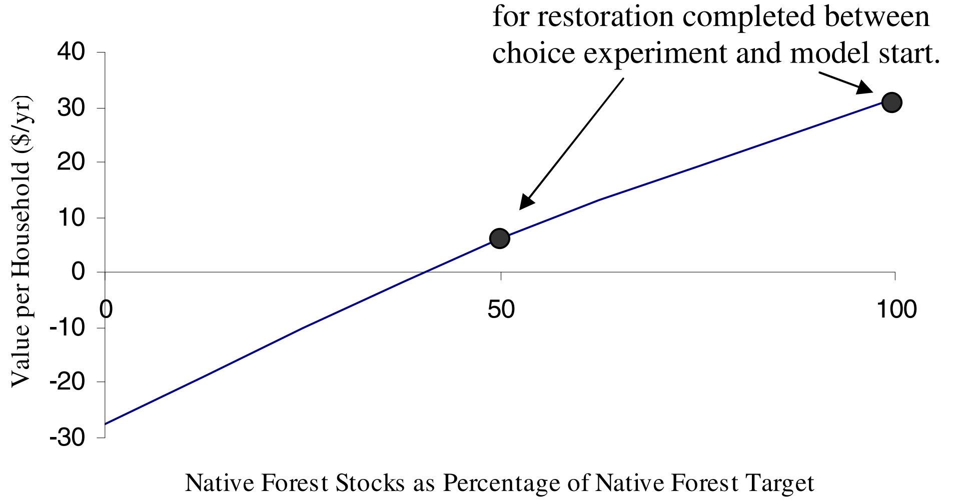


Figure 7: Wildlife Benefit Curve

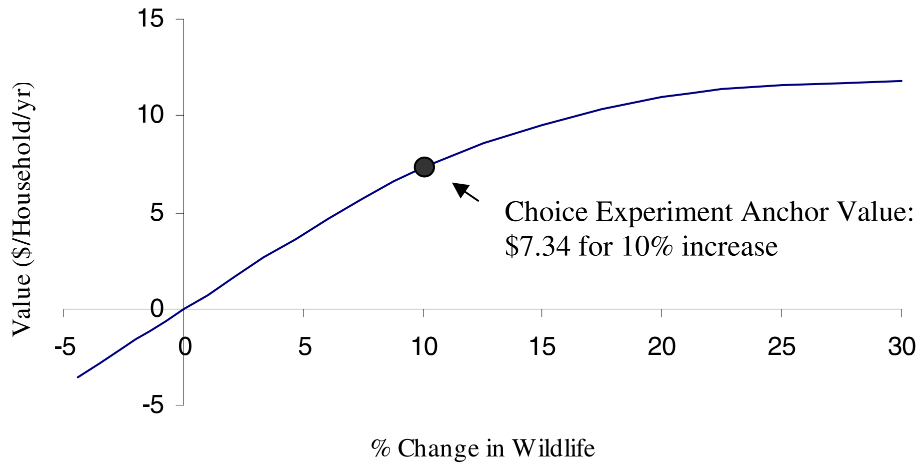
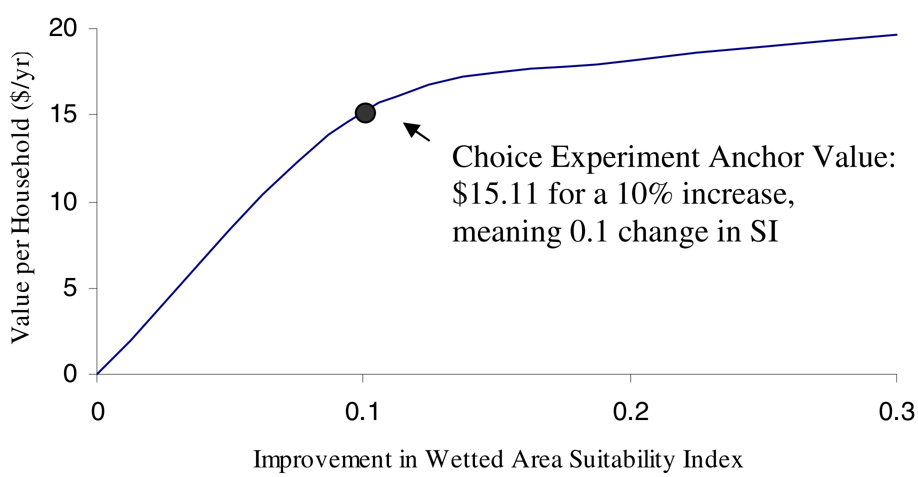
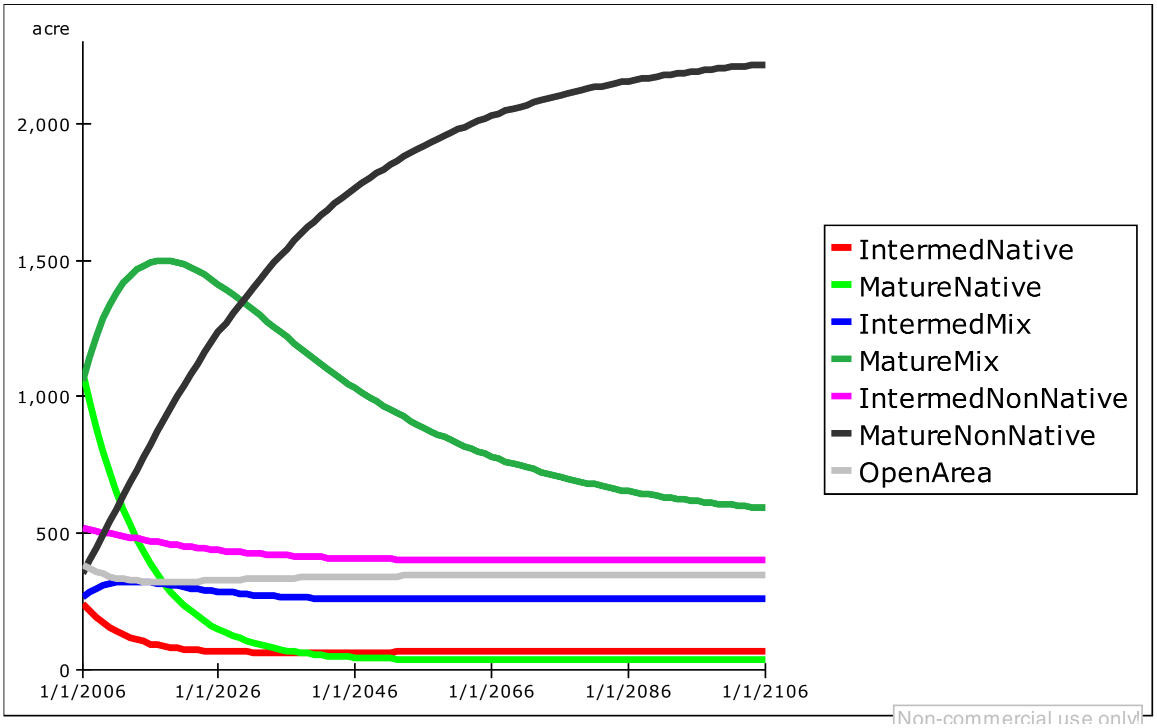


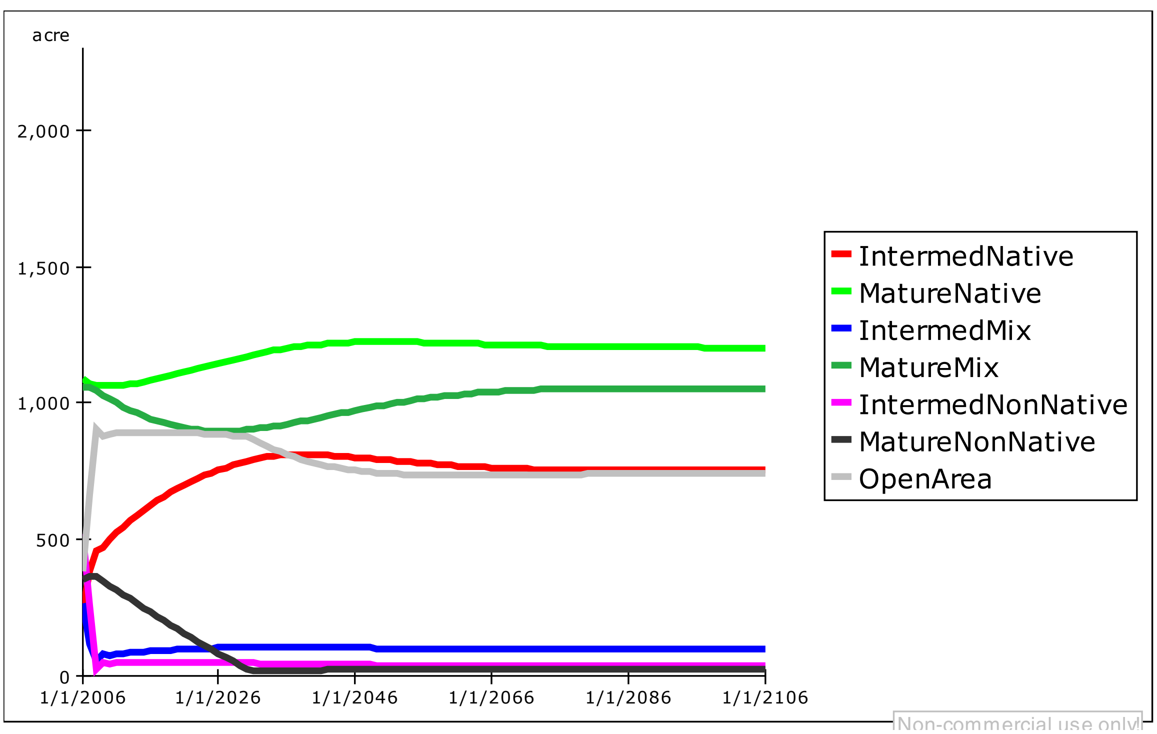
Figure 8: Natural River Processes Benefit Curve



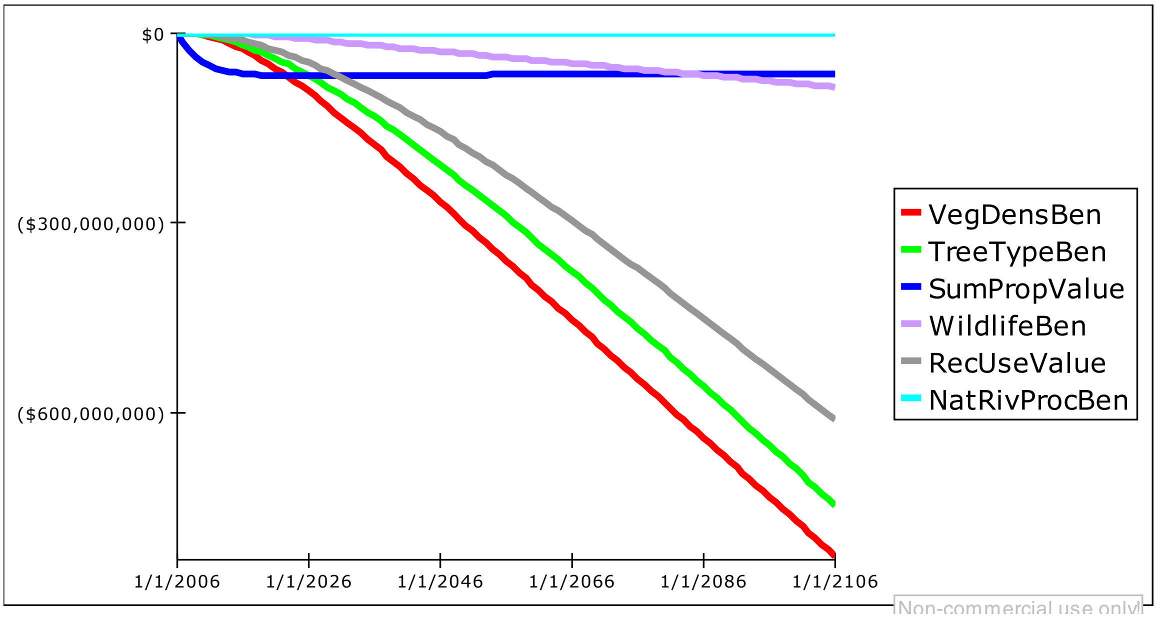
Graph 1: No-Action Forest Conditions



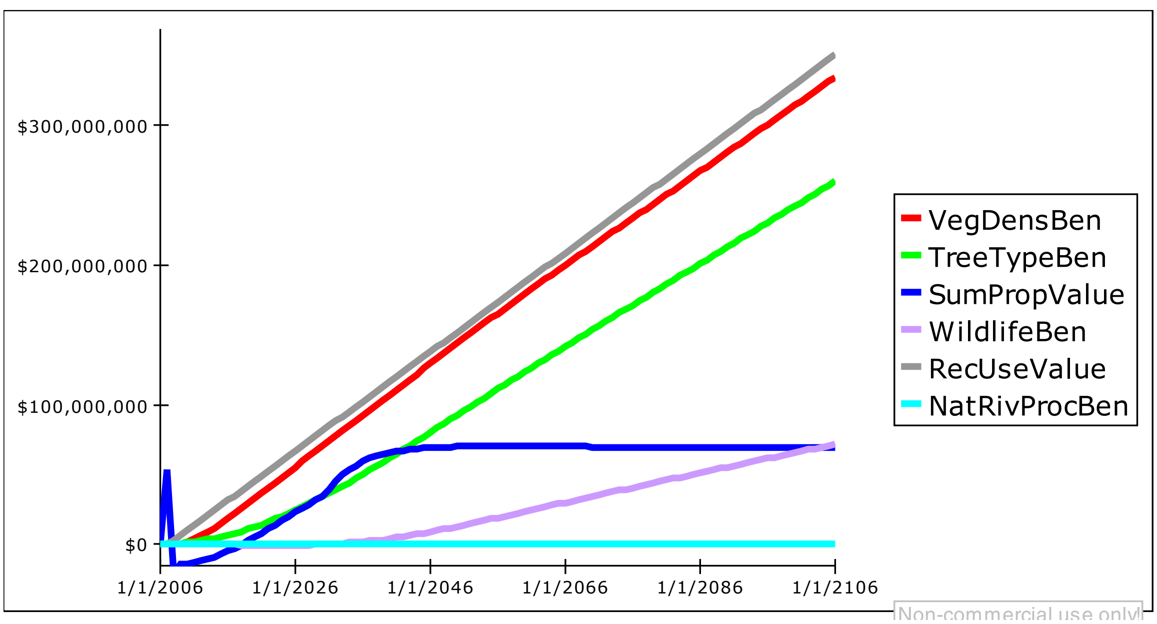
Graph 2: Optimal Forest Conditions



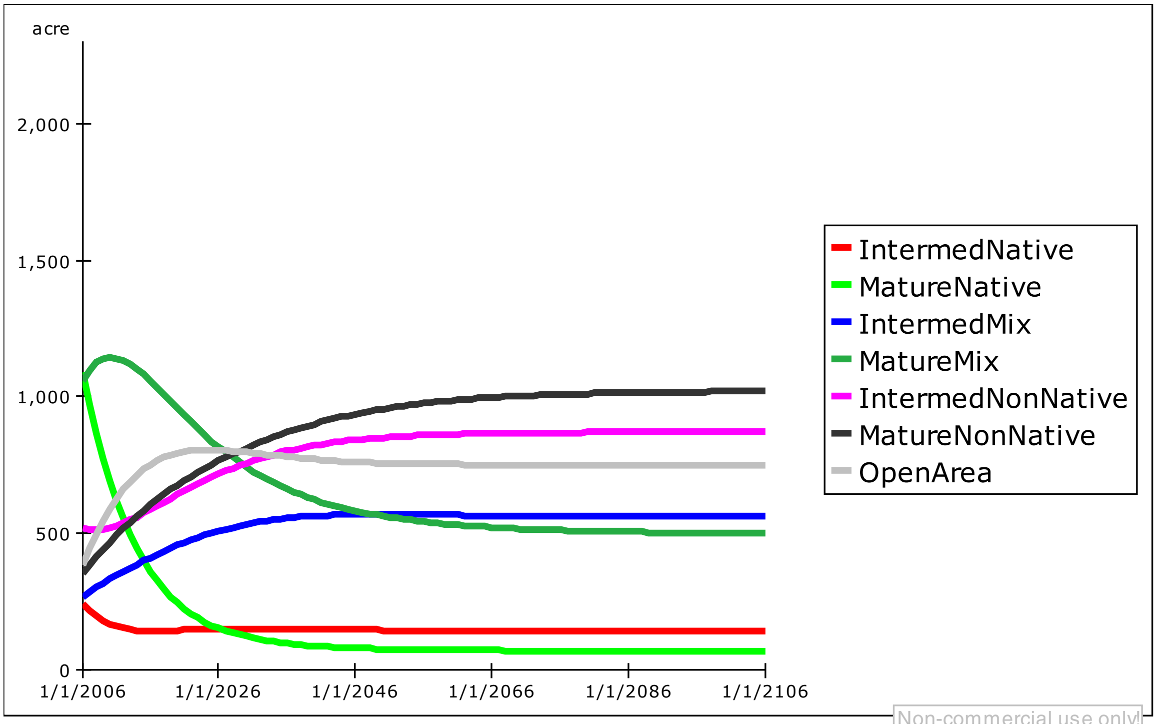
Graph 3: No-Action Benefit Accumulation



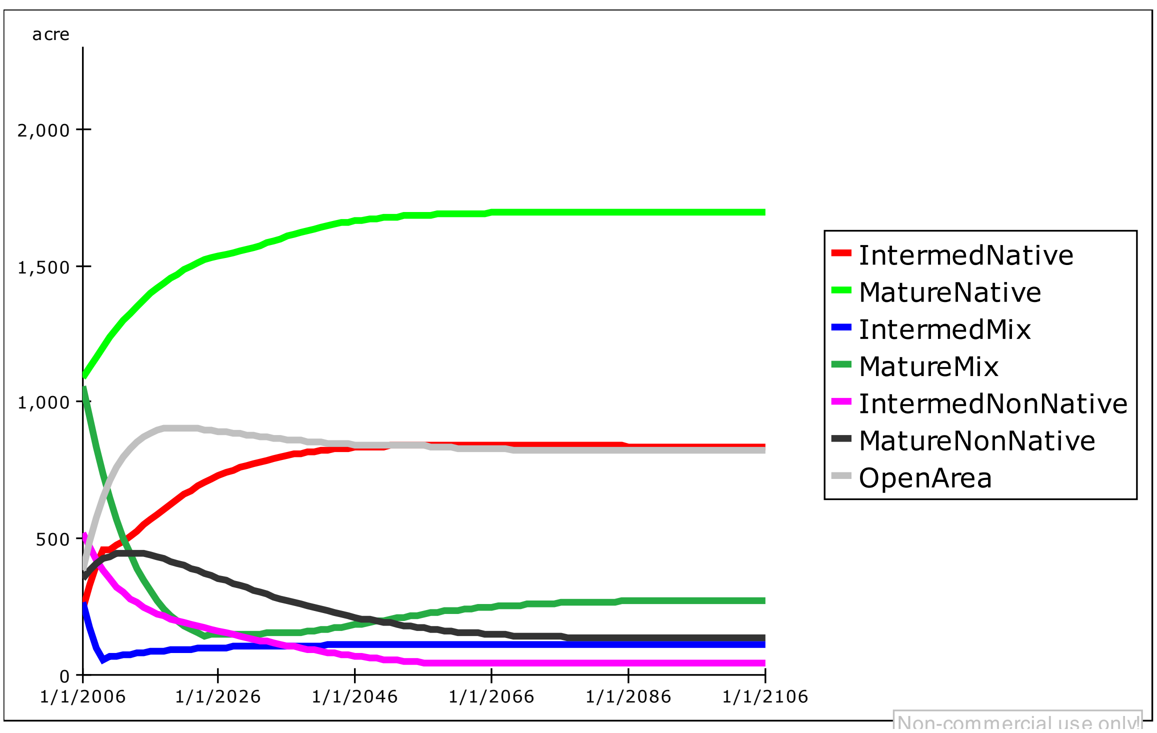
Graph 4: Optimal Benefit Accumulation



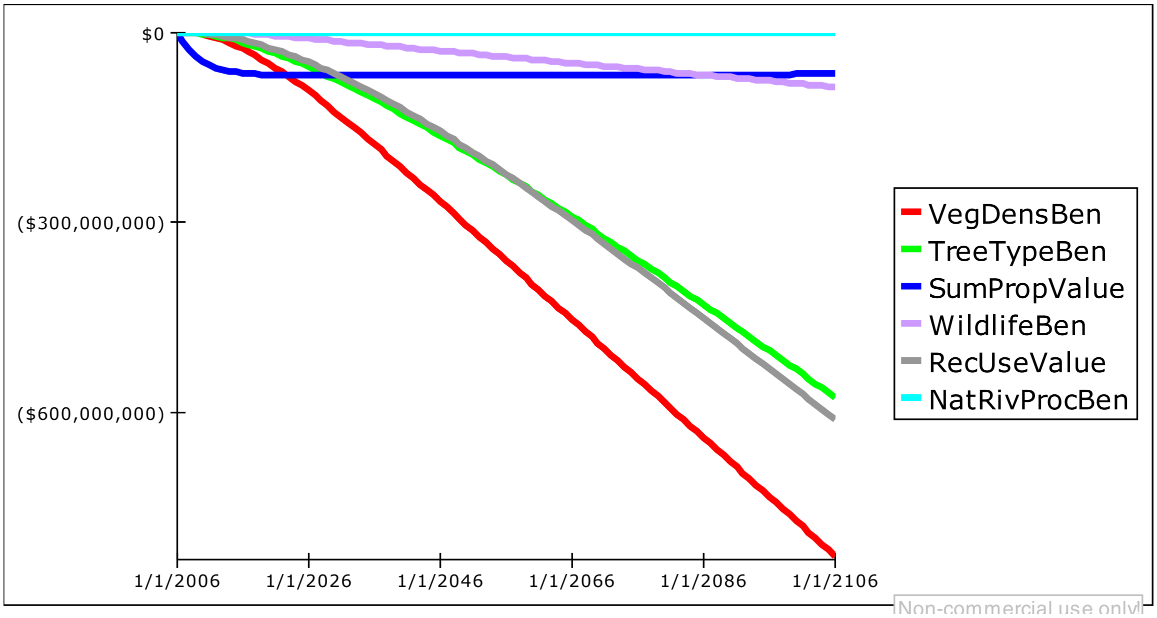
Graph 5: High-Burn No-Action Forest Conditions



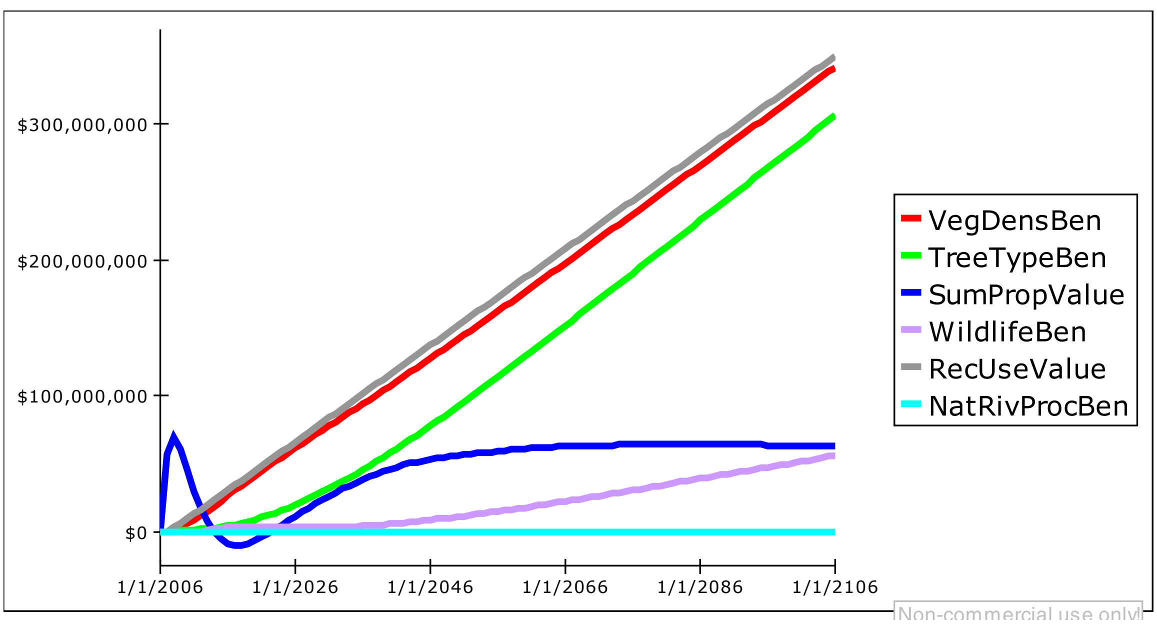
Graph 6: High-Burn Optimal Forest Conditions



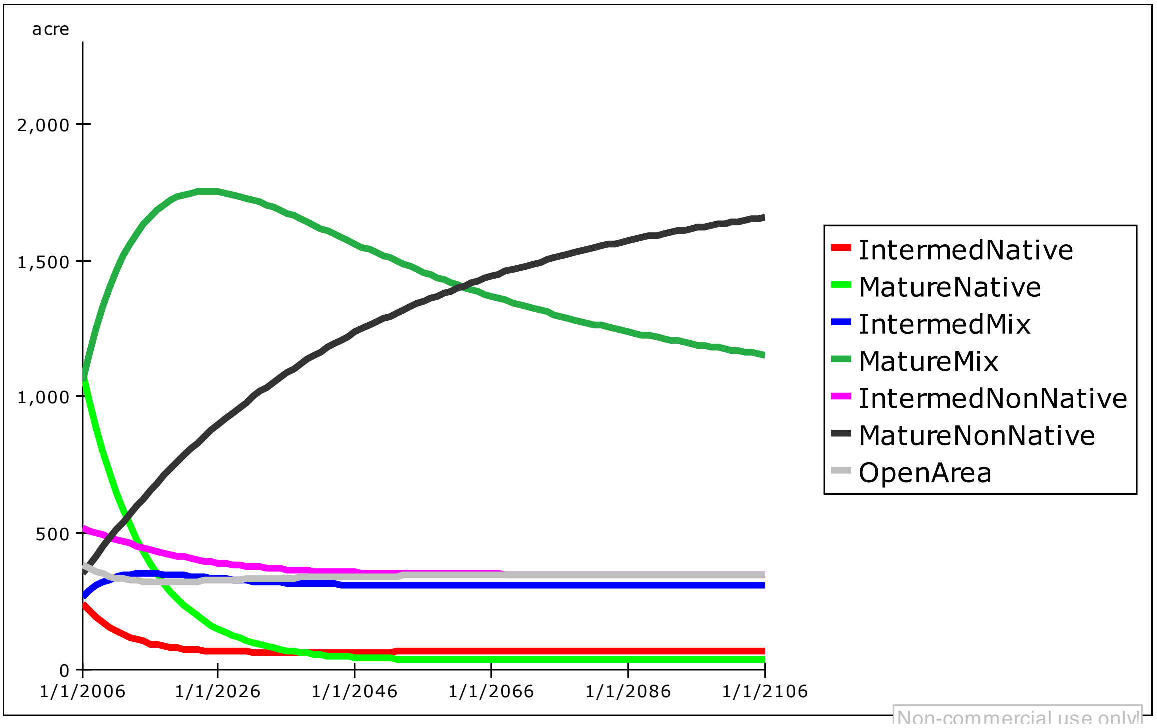
Graph 7: High-Burn No-Action Benefit Accumulation



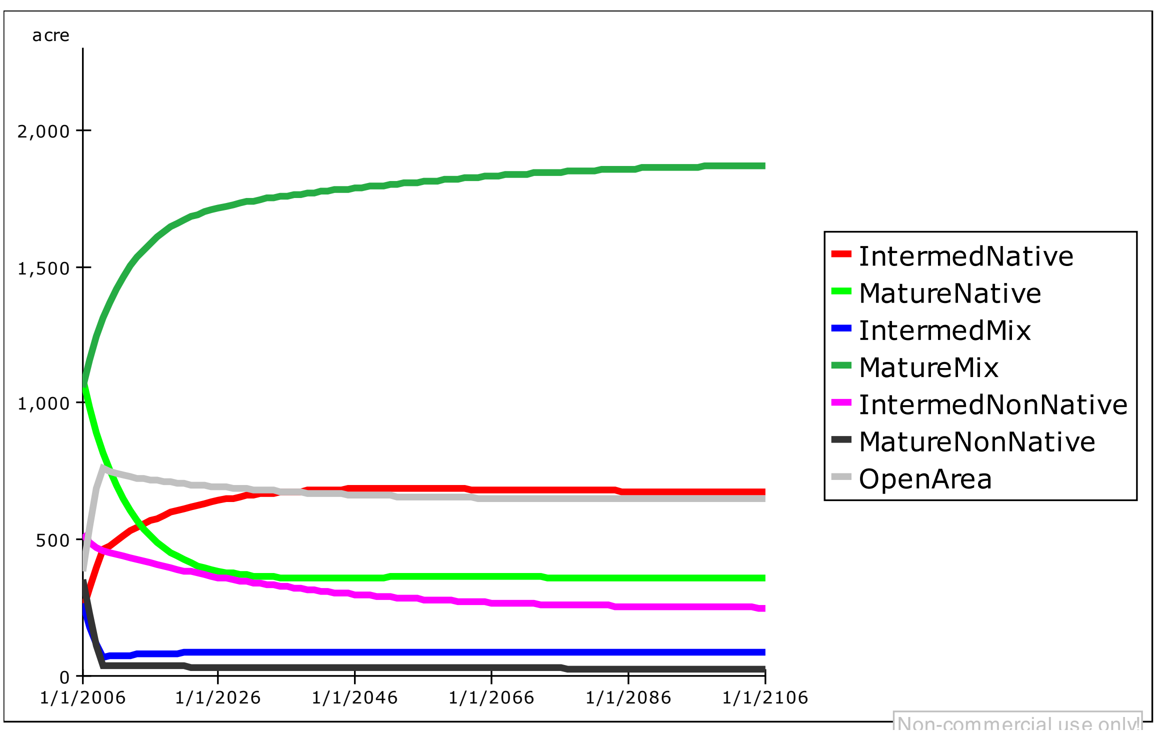
Graph 8: High-Burn Optimal Benefit Accumulation



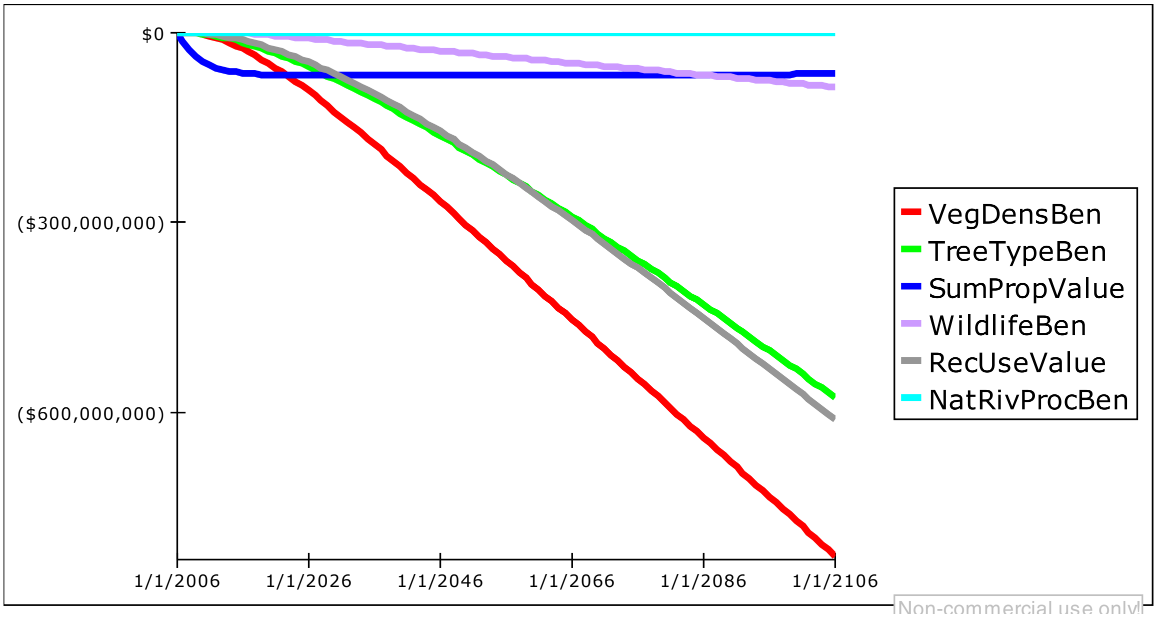
Graph 9: Low-Infest No-Action Forest Conditions



Graph 10: Low-Infest Optimal Forest Conditions



Graph 11: Low-Infest No-Action Benefit Accumulation



Graph 12: Low-Infest Optimal Benefit Accumulation