

MUDDY WATERS: CASE STUDIES IN DRY LAND WATER  
RESOURCE ECONOMICS

By

Rosalind Heather Bark

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As members of the Dissertation Committee, we certify that we have read the dissertation prepared by Rosalind Heather Bark entitled Muddy Waters: Case Studies In Dry Land Water Resource Economics and recommend that it be accepted as fulfilling the dissertation requirement for the Degree of Doctor of Philosophy

\_\_\_\_\_  
Bonnie Colby Date: 27 October, 2006

\_\_\_\_\_  
Stuart Marsh Date: 27 October, 2006

\_\_\_\_\_  
Satheesh Aradhyula Date: 27 October, 2006

\_\_\_\_\_  
Andrew Comrie Date: 27 October, 2006

\_\_\_\_\_  
George Frisvold Date: 27 October, 2006

Final approval and acceptance of this dissertation is contingent upon the candidate's submission of the final copies of the dissertation to the Graduate College.

I hereby certify that I have read this dissertation prepared under my direction and recommend that it be accepted as fulfilling the dissertation requirement.

\_\_\_\_\_  
Dissertation Director: Bonnie Colby Date: 27 October, 2006

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## DEDICATION

To my extended and immediate family, Fran and Gregory.

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## ABSTRACT

Arizona like many other semi-arid regions in the world is facing a suite of policy issues that stem from water scarcity and security of supply issues intersecting with growing and competing water demands. A vexing issue in southern Arizona has been the preservation of riparian habitat. The study of environmental economics provides researchers with techniques to estimate the value of natural resources, such as riparian habitat, to level the playing field in policy discussions on development and water management. In Appendices B-D results from two hedonic property analyses suggest that homebuyers, one of the main consumers of riparian habitat in urban areas, have preferences for greener and higher condition riparian habitat and furthermore that they are willing to pay property premiums to benefit from this resource. There is also some evidence that riparian habitat conservation and restoration can be self-financing. The economics of another water using sector in the state, the recreation sector, specifically winter-based recreation, is assessed in Appendix E. The analysis finds that although ski areas in Arizona are subject to large inter-year variability in terms of snowfall and season length that snowmaking adaptations, a technology that is water-intensive, is financially feasible in the medium term as a climate variability and climate change adaptation. Nevertheless, ski areas in the state are likely to face increased financial pressures if climate change scenarios are realized and will have to implement other adaptation strategies to remain viable. Finally, water competition in the state between Indian and non-Indian users and the techniques used to dispel such tensions, namely water settlements, are discussed in Appendix F. The research finds that settlements offer opportunities for win-win agreements between the

settling tribe and other water users in the same watersheds and for the introduction of new water supply management tools that benefit signatory and non-signatory parties alike.

## INTRODUCTION

*Whiskey is for drinking; water is for fighting over.* Mark Twain

### PROBLEM AND CONTEXT

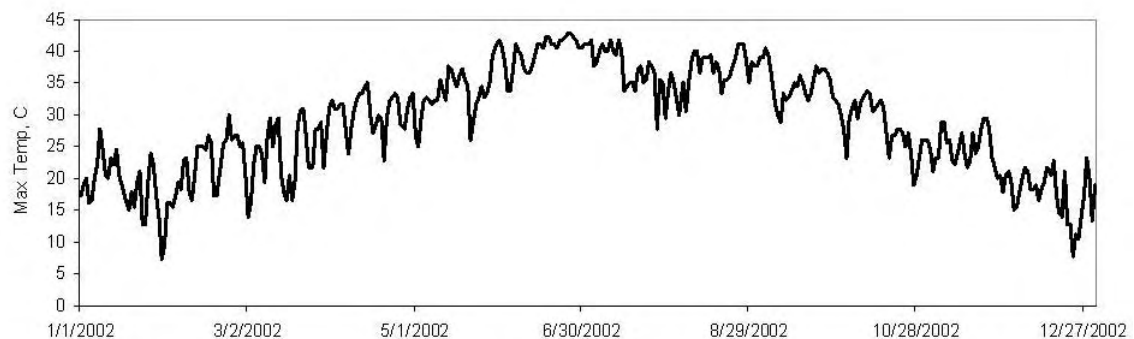
All of the case studies in this dissertation research water resource issues in Arizona, USA. However, the methodologies and conclusions can be applied to other semi-arid regions in the world. This dissertation is in partial fulfillment of a Doctorate in Philosophy in Arid Lands Resource Sciences (ALRS), an interdisciplinary program in the College of Agricultural and Life Sciences at the University of Arizona. The interdisciplinary principles of this degree are encompassed in the research papers presented in the Present Study Chapter and detailed in published and submitted papers in Appendices A-F. The research methods integrated in this dissertation are resource economics with econometrics, remote sensing, geographic information systems, climatology, hydrology, law and policy analysis.

### ARIZONA'S CLIMATE

The environmental, economic, policy and legal consequences of water resource allocation in a semi-arid climate motivate research on the three case studies. Two of the three case studies are located in the semi-arid Sonoran Desert in southern Arizona the remaining case study investigates winter recreation in the high elevation regions of the state. The

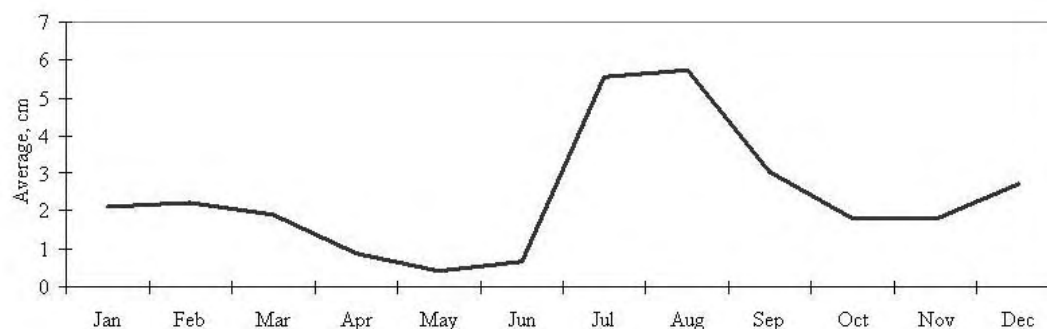
mountainous areas of the state receive annual precipitation totals (508 mm to 1,016 mm) not usually defined as semi-arid (Meigs, 1953); however these regions are subject to high inter-annual precipitation variability, variability that generates uncertainties for areas that are economically dependent on winter recreation.

The Sonoran Desert like many other deserts in the world is located in the sub-tropics in a region of subsidence associated with the Hadley cell circulation. The Hadley cell transports moist warm tropical air north and south from the equator. The down leg of this cell is located near 30° N and 30° S of the equator in the so-called Horse Latitudes, or subtropical latitudes. As air subsides it is adiabatically warmed and its propensity to hold moisture diminishes. These regions are notable for persistent high pressure and consequent cloudless skies, high temperatures (Figure 1), low humidity and low precipitation. The Sonoroan Desert is also dry as a result of its continentality. It is classified as a “semi-arid” not “arid” desert (Meigs, 1953) because two systems seasonally interrupt the prevailing high pressure system allowing annual average precipitation to exceed the 250 mm “arid” threshold at around 300 mm.



**Figure 1: Daily maximum temperature Tucson, AZ: 2002**

These systems, the summer North American Monsoon (NAM) and winter mid-latitude frontal storms produce a distinct bimodal precipitation pattern (Figure 2). But the systems themselves are subject to high degrees of variability in terms of the onset, intensity, and duration of the NAM season and the location of the jet stream which influences the number of anticyclones that develop over the Sonoran Desert in the winter months. The outcome is highly variable annual and multi-year precipitation totals. A consequence of low overall precipitation and high inter-annual precipitation variability is that short term and longer term hydrologic droughts are common in the instrumental and proxy records.



**Figure 2: Average precipitation Tucson, AZ: 1868-2003**

Data from tree rings (dendrochronology) in the southwest USA has enabled dendroclimatologists to extend the historic climate record back to 1200. Tree ring data is calibrated with historic meteorological records to reconstruct past climate. For example, using tree ring data and instrumental records researchers have reconstructed a 1000 year cool-season precipitation record for Arizona and New Mexico (Ni, *et al.*, 2002). Winter precipitation is an important determinant of spring and early summer stream flows and also water supplies. The researchers found that short wet periods in the record are often

followed by long dry periods; for example short wet periods preceded the mega droughts in the 16th and 17th Centuries. The researchers also provide data on extreme (dry and wet) annual, five year and ten year periods. This analysis for Arizona's Climate Division 7, where Tucson is located, shows that the current drought is not one of the five most severe by historic standards even though pictures of dry rivers and low reservoirs are dramatic. It is however shaping up to be the most severe drought in the instrumental record (Cook, *et al*, 2005). This paradox is explained by looking at water demand and water supply simultaneously. Rapid growth in water demand superimposed on highly variable water flows has increased the human impacts of even a 'relatively mild' hydrologic drought.

#### THE DIVISION OF THE COLORADO RIVER

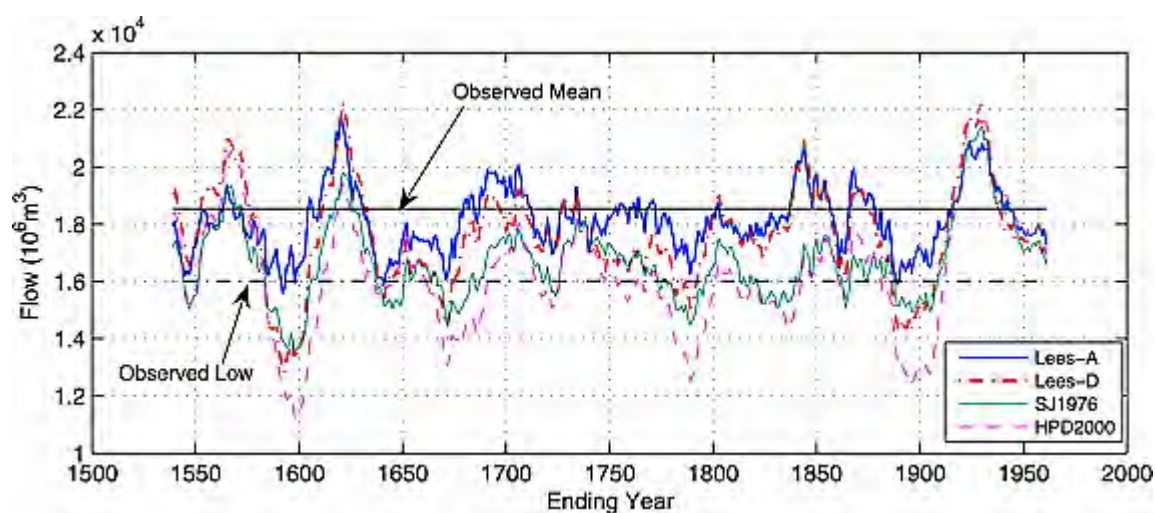
Tree ring data has also been used to reconstruct stream flow in the Colorado River. Stockton and Boggess's (1980) research shows that at the time (1922) water rights to the Colorado River were being divided up by Colorado, Wyoming, Utah, Nevada, New Mexico, Arizona and California the region was in an exceptionally wet period. Simply put more water rights than available water were allocated because of a historic anomaly. More worrying is it seems that the river system's normal condition is a drought-like state. The Bureau of Reclamation estimates that the average flows of the Colorado River in the period 1930-1996 was just 13.9 million acre feet<sup>1</sup> a year (MAFY). Longer-term research

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<sup>1</sup> An acre-foot is equivalent to 43,560 cubic feet or 325,851 gallons or 1,233 cubic meters. In Arizona it is also approximately the amount of water used by 2.5 typical Arizona families a year.



using tree-ring data by Stockton and Jacoby (1976) provides evidence that the average flow of the Colorado River in the past few hundred years was somewhat lower at 13.5 MAFY. Updated streamflow reconstructions by Woodhouse, Gray and Meko (2006) estimate higher average flows of between 14.3 MAFY and 14.7 MAFY.<sup>2</sup> Although there are some differences between these reconstructed flows all the researchers agree that average flow is less than the total 16.5 MAFY required to satisfy all Colorado River Compact water claims. Furthermore, averaging obscures natural variability in flow, including long periods of low flow, see Figure 3.



**Figure 3: Colorado River Reconstructions**

Source: Woodhouse et al., (2006)<sup>3</sup>

The Law of the River is a composite of state and federal laws and international agreements governing the Colorado River. The 1922 Colorado River Compact equally

<sup>2</sup> A reason for the difference in these reconstructed flows is the calibration period used by the researchers. Stockton and Jacoby use a 1914-1961 calibration period whereas Woodhouse, Gray and Meko use a longer period, 1906-1995.

<sup>3</sup> Twenty-year running means of four alternative reconstructions of the annual flow of the Colorado River at Lees Ferry for common period 1520–1961. Lees-A and D are their reconstructions, Stockton and Jacoby's is SJ1976 and HPD2000 is Hidalgo et al, 2000. The horizontal lines are the 1906–2004 observed mean (solid line) and the lowest observed 20-year running mean of the 1906–2004 period (dash-dotted line).

divides the flows of the Colorado River into 7.5 MAFY for the Upper Basin States (UBS) and the Lower Basin States (LBS) see Figure 4.<sup>4</sup> The actual allocations for each state were decided in two separate pieces of legislation. The UBS allocations were established under the Upper Colorado Basin Compact, 1948<sup>5</sup> and the LBS allocations by the Boulder Canyon Project Act, 1928.<sup>6</sup> A treaty between the US and Mexico in 1944<sup>7</sup> settled this downstream country's allocation.

**Table 1: Colorado River Allocations**

Political Entity	Annual allocation, MAF
Upper Basin States	7.5
Colorado	3.9
New Mexico	0.8
Utah	1.7
Wyoming	1
Lower Basin States	7.5
California	4.4
Arizona	2.8
Nevada	0.3
Mexico	1.5
<b>TOTAL</b>	<b>16.5</b>

In practice although the division of waters between the UBS and LBS may seem equitable it is not. The Compact actually requires the Upper Basin to deliver an average

<sup>4</sup> Colorado River Compact, Article III (a) apportions 7.5 MAFY to the upper basin and lower basin.

<sup>5</sup> Upper Colorado River Basin Compact, 1948, Article III a (2). The allocations are designated in percentages of flow not volumes.

<sup>6</sup> Boulder Canyon Project Act, 1928, Pub. L. 70-642, Sec 4(a).

<sup>7</sup> This treaty requires the US to deliver 1.5 MAFY of Colorado River water to Mexico. An additional 200 KAFY is delivered if the Secretary of the Interior determines that there is surplus water on the system in any given year. The treaty was amended in 1973 to incorporate a water quality component. Minute 242 restricts the salinity of Colorado River water when it crosses the border. To date this has been achieved by dilution rather than by operating the bespoke Yuma Desalting Plant.

7.5 MAFY, over every ten-year period, to the Lower Basin at Lee Ferry.<sup>8</sup> Only once this allocation and half of the Mexican obligation is delivered<sup>9</sup> may the Upper Basin develop up to 7.5 MAFY in consumptive uses. Because the river is over-appropriated the Upper Basin allocation is effectively junior in priority to the LBS. The UBS can only develop the difference between annual flow at Lee Ferry and the 8.23 MAFY<sup>10</sup> delivered downstream. The UBS are required to absorb the shortfall resulting from the 1922 over-allocation. For example using Stockton and Jacoby's long term average flow of 13.5 MAFY the Upper Basin is only able to develop a maximum 5.27 MAFY, 2.23 MAFY less than their full allocation. If the UBS develop their full apportionment, and all four have infrastructure plans to increase their diversions up to their permitted allocations, this would open the potential for the Lower Basin to make a "Compact Call". The LBS could insist that the UBS cut off their junior water right holders and deliver this water to fulfill their obligations to the LBS. This outcome has so far been avoided because the UBS do not yet fully utilize their Colorado River allocations, but the threat remains.

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<sup>8</sup> Colorado River Compact, Article III (d).

<sup>9</sup> Id. Article III (b) envisages this obligation will first be met with surplus waters and only once such supplies are exhausted will "the burden of such deficiency (shall) be equally borne by the upper basin and lower basin."

<sup>10</sup> The minimum objective release is 8.23 MAFY or 0.02 MAFY less than a simple addition of releases 8.25 MAFY (7.5MAFY+0.75MAFY) because of a 20 KAFY adjustment for water delivered below Lee Ferry from the Paria River to the LBS.

In fact, California “depends on water surpluses<sup>11</sup> (water amounts that exceed their legal allocations) to keep up with the demand of a growing population and agricultural industry” (Piechota, *et al.*, 2004). This has led to inevitable litigation and ongoing conflicts about allocations. To address the concerns of the other six states California's "4.4 Plan" program is designed to reduce California's use of Colorado River water to its allocated 4.4 MAFY. Currently California exceeds its allocation by around 20% per year. To reduce its take the San Diego County Water Authority and the Imperial Irrigation District (IID) negotiated a water transfer agreement. This will involve the long-term transfer of 200,000 AFY from Imperial Valley farmers to San Diego residents. The IID will achieve these cuts through water conservation or by fallowing fields. The transfer is an opportunity for structural change in water use in the state and San Diego will benefit from this reliable water source. The price for transferred water is indexed to the cost San Diego pays Metropolitan Water District (MWD) for its untreated water supply, plus other MWD rates and charges minus the cost of conveying the water.

The agreement has some foresight, if the Colorado River experiences below average supplies then the transfers to the city would be reduced by an equivalent amount.

Additionally it provides money for environmental mitigation most notably for the Salton Sea which relies on IID backflow. The agreement also incorporates water efficiency

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<sup>11</sup> All three LBS currently use (or store) 100% of their allocations. Conversely none of the UBS fully utilize their allocations: Utah diverts 56% (0.952 MAFY), Colorado 54% (2.106 MAFY), Wyoming around 60% (0.59 MAFY) and New Mexico around 63% (0.634 MAFY). The UBS as a unit diverts around 3.2 MAFY less than their allocation. (<http://www.crwua.org/states.html> accessed September 8, 2006 and Quality of Water Colorado River Basin, Progress Report No. 21, US Department of the Interior, January 2003). <http://www.usbr.gov/uc/progact/salinity/pdfs/PR21.pdf>).

measures such as lining the American Canal which will lead to direct water savings of 77,000 AFY: water that can be used for other purposes.

Since the 1922 Compact rapid agricultural, mining, and municipal development in the seven states has superimposed large and often competing water demands on limited and variable surface water supplies from the Colorado River. Today approximately 25 million people rely on water from the Colorado River. Satisfying associated water demand and planning for future growth has increased pressures to better manage the Colorado River system including managing the system for shortage.

#### SHORTAGE SHARING ON THE COLORADO RIVER

The streamflow averages reported earlier obscure the natural variability in Colorado River stream flow. This variability translates into system-wide management uncertainty. A number of researchers have modeled the consequences of a severe sustained drought on the Colorado River system on stream flows, Compact water deliveries, non-consumptive uses (hydroelectricity generation and the environment), salinity loads, storage, and the economy (WRB, 1995).<sup>12</sup> A paper in this series by Harding, Sangoyomi and Payton (1995) models the impact of a sustained 38 year drought on stream flows and reservoir levels given the legal and administrative constraints imposed by the Law of the River. Their modeling results suggest that stream flows and storage will be more severely

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<sup>12</sup> A collected volume of research papers on all aspects of a Colorado River shortage entitled "Coping with Severe Sustained Drought in the Southwestern United States" can be found in *Water Resources Bulletin*, 1995, vol. 31(5).

reduced in the UBS than in the LBS. Furthermore, given the 'junior' nature of UBS rights under the Law of the River the model predicts that consumptive uses in the UBS would be severely reduced by this sustained drought. Meanwhile, the modeling predicts minimal shortages in the LBS.

The Colorado River basin states are aware that a Compact crisis is looming and could be hastened by global warming. To mitigate this crisis the seven states in cooperation with the Secretary of the Interior have negotiated a shortage sharing agreement. Two prerequisites for understanding the agreement are the priorities implicit in the Law of the River given the 1922 flow overestimate and where and how much storage there is on the river.

Water storage facilities are not only an insurance against drought for the southwestern states but also a water resource management instrument. Lake Powell in the UBS and Lake Mead in the LBS (see Figure 3) with other smaller reservoirs in the watershed can store 60 MAF or the equivalent of four years of 'average' Colorado River flow. The most recent drought proved that these reservoirs do buffer communities reliant on the Colorado waters against drought, however storage was severely tested. Lake Powell dropped to its lowest level since filling to 8.015 MAF equivalent to 33% of maximum capacity at the end of March 2004. This drastic decline also threatened hydrological power production through Glen Canyon Dam. Storage capacity has since recovered with wet winter weather in 2004/2005 and a wet summer in 2006 but elevations remain historically low.

At the end of July 2006 Lake Powell stored 24.3 MAF equivalent to 51% of maximum capacity and Lake Mead 26.3 MAF equivalent to 53% of maximum capacity (National Water and Climate Center). Significantly it does not take many years of drought to severely deplete water storage in the southwest. Conversely it would take many years of above average precipitation to fill the reservoirs. Reclamation predicts the likelihood of filling Lakes Powell and Mead to 90% of their capacity by 2010 at 15%-20%.



**Figure 4: The Colorado River Basin**

The 1922 Compact defines the obligations of the UBS to deliver 75 MAF in a ten year period to the LBS, and supply half of the Mexico allocation, regardless of how these deliveries impact their ability to exercise UBS allocations. The agreement effectively requires the UBS to absorb the entire shortfall resulting from the 1922 flow overestimate. The UBS have not yet felt this constraint because they collectively divert only around 4.3 MAFY but these states all have infrastructure investment plans designed to fully utilize their allocations. Cognizant of these proposals, the risks involved with litigating Compact issues, and awareness that shortages are more probable in the future, the seven states negotiated new Colorado River management and shortage sharing arrangements summarized below.

The broad goals of this Preliminary Seven Basin States Agreement<sup>13</sup> are to minimize shortages, reduce the risk of a “Compact Call” on the UBS, remove the need to modify elements of the Law of River and for litigation, and to provide the Secretary with guidelines for shortage sharing. The main focus of the consensus plan is to introduce policy instruments to improve the management and operation of the Colorado River system. Foremost is a plan to conjunctively manage the two largest storage reservoirs on the system, Lakes Powell and Mead. The goal is to avoid curtailment in the Upper Basin and minimize shortages in the Lower Basin by releasing water from Lake Powell when Lake Mead is low and storing more water in Lake Powell when Lake Mead is high. The

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<sup>13</sup> The 7 Basin States letter to the Secretary of Interior, dated February 3, 2006, referred a Basin States preferred alternative for consideration in the ongoing NEPA process.



two elements of this conjunctive management and relevant trigger elevations are shown in the Figures 4 and 5.

ELEVATION (FEET)	OPERATION	LIVE STORAGE (MAF)
3,700	Equalize or 8.23 MAF	24.32
3,636 - 3,664	8.23 MAF; if Mead <1,075', balance contents with min/max release of 7 or 9 MAF	15.54 – 19.02 (2008-2025)
3,575	7.48 MAF; 8.23 MAF if Mead <1,025'	9.52
3,525	Balance contents with a min/max release of 7 and 9.5 MAF	5.93
3,370		0

**Figure 5: Lake Powell Operation**

MEAD ELEVATION (FT)	STEPPED SHORTAGE	MEAD LIVE SHORTAGE
1,075 to 1,050	400 KAF	9.37 to 7.47 MAF
<1,050 to 1,025	500 KAF	7.47 to 5.80 MAF
<1,025 to 1,000	600 KAF	5.80 to 4.33 MAF
<1,000	Increased reductions to be consistent with consultation(s)	<4.33 MAF

**Figure 6: Lake Mead Step Shortage**

This agreement also specified shortage sharing proportions for the LBS. In times of shortage Nevada will be apportioned between 4%-9%, Arizona between 74%-79%, and Mexico 17% of the LBS shortage. Note that California's 4.4 MAFY apportionment is unaffected by shortage sharing arrangements and that the bulk of the cuts will occur in Arizona's CAP deliveries and to other post-1968 water users. The consequences of the

junior priority of Arizona's CAP allocation are significant and are discussed further below.

The agreement would create a new type of water for the LBS, so called "Intentionally Created Surplus" (ICS). It would allow the LBS states to generate ICS credits for extraordinary conservation measures such as canal lining, land fallowing and desalination. The ICS credits would be stored in Lake Mead and there are various accounting rules for losses. Other settling states would be able to exercise these ICS credits through forbearance type agreements. They would operate like pseudo market transfers. These credits are designed to add flexibility to the system and to defer a future Compact Call.

There are three other types of ICS-like water that LBS want recognized. The LBS would like to gain mainstream water credits by introducing non-system water, such as treated wastewater or retired tributary water rights to the system, if those rights were appropriated before the Boulder Canyon Project Act, 1928. A final type of ICS water would generate system efficiency credits for projects that capture water that would be otherwise lost to the system. An example project is the Drop 2 Reservoir. Reclamation has proposed the building of a reservoir north of Mexico to better manage treaty obligated deliveries to Mexico. It seems likely that Nevada will pay for this \$80M project for a share of the saved water. Excess deliveries to Mexico can range from 25 KAFY to 100 KAFY, depending on the weather and the timing of water orders from farms in the

Imperial Valley. In all cases ICS water would be treated as additional to the State's basic apportionment and would be available during shortages after accounting for a 5% cut for the river.

These proposals and other more long-term augmentation plans, such as desalination, form the seven states consensus plan to reduce the probability of shortages through improvements in Colorado River operation and through the utilization of innovative water augmentation instruments. This negotiated plan will undergo the lengthy federal environmental review process (NEPA) and it is expected that the Secretary of the Interior will announce any changes to the operation of the Colorado River system and new shortage criteria by the end of 2007.

This plan if ratified would reduce the uncertainty associated with Arizona's Colorado River allocations in times of shortage and would give Arizona and Nevada new policy instruments to mitigate the impacts of such shortages.

#### CLIMATE CHANGE

Flow variability combined with rapid growth in water consumption in the Compact states are just two challenges facing federal and state water managers another as yet undefined threat is climate change. The simple fact is "86% of the Colorado River's flow originates in a small region of the Rocky Mountains, less than 15% of the total watershed (Stockton,

*et al.*, 1991).” Snowpack in the Rocky Mountains is vulnerable to climate change.

Possible impacts are reduced overall snowpack resulting from less overall precipitation, precipitation falling as rain, higher evaporation losses, and earlier spring melt. In sum the size of the snowpack ‘reservoir’ is likely to diminish impacting downstream users.

Furthermore, alternations to the timing and intensity of spring flows will stretch storage capacity on the river. Many of the states reliant on this water source may have increasing concerns about supply reliability and the timing of water deliveries.

Recent dendrochronology-based research in the Colorado River basin attempts to project future drought and water supply conditions under climate change scenarios. The results are somewhat disquieting. The current drought and increased aridity in the southwest may be early signs of climate warming. The troubling implication is that future warming could result in drought conditions becoming the new baseline in the western USA rather than an anomalous condition (Cook *et al*, 2004). In a recent paper Meko and Woodhouse (2005) report that water management in the arid southwest is likely to become more challenging with the superimposition of both increased demand and anthropogenic warming on natural climate variability. The results from reconstructed flow conditions in the Sacramento and Upper Colorado River basins find that droughts have occurred simultaneously in both watersheds in the reconstructed record. This means that Southwestern water managers have to prepare for concurrent droughts in these two main watersheds. Finally the new Intergovernmental Panel on Climate Change report and AR4 models are scheduled for release in early 2007. This new data will be incorporated into

river basin models to project future water supply scenarios, including the Colorado River Basin and will provide new data for water managers in the southwest.

#### *WINTERS RIGHTS*

*You can't lose what you ain't never had. Muddy Waters*

Another wild card in many western states water rights picture are tribal water claims. The seniority clause was the legal basis for water reallocation in the 1908 Supreme Court decision, *Winters vs. United States*:<sup>14</sup> “The Court concluded that the Indians had priority of claim, had in fact a special, unique right to water based on their treaty with the American government. When they came to terms with their conquerors, the tribe reserved enough water for all their future needs. Whether the right had ever been claimed or not was immaterial; the water must be there waiting for the Indians whenever they decided to use it. The white man’s laws of appropriation, which gave a water right to whoever first put a river to use, could not affect those reserved native rights” (Worster, 1985, p298).

To fit into the prior appropriation water rights framework present in the southwest the seniority of tribal rights was as per the date the reservation was established by an Act of Congress. Significantly, the landmark *Winters* case did not specify quantities of water for each tribe. There are two main problems when water ‘access’ is unquantified: the rights themselves are unprotected against water development in the same watershed(s) and the

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<sup>14</sup> *Winters v. United States* 207

claims pose a risk to current and future water use in the watersheds(s). Tribes have three options to realize *Winters* rights, they can await decades-long stream adjudications, litigate against other water rights holders in their watersheds, or negotiate a comprehensive water rights settlement.<sup>15</sup> Although many tribes simultaneously pursue all these options in many cases the actual reallocation of water to Native American tribes to fulfill federal reserved rights is achieved through settlement.

Almost sixty years after *Winters* the Supreme Court offered guidance on the quantification of these rights. In the 1964 Supreme Court decision *Arizona v. California*<sup>16</sup> the court gave several Indian tribes the right to “irrigate all practicably irrigable acreage (PIA) on the reservation.” This standard quantifies *Winters* rights by determining the amount of water necessary to irrigate all practicably irrigable acreage within the reservation. This PIA standard is not without its flaws (Smith, 2005) and an alternative standard recently articulated by the Arizona Supreme Court is the homeland test.<sup>17</sup> This test would allow tribes to prosecute for water to meet all their future needs, such as water for growth, industry and recreation. As with tribal water rights quantified through PIA, the development of these tribal water uses can pose a threat to junior water rights holders in an over-allocated watershed. It is this threat that creates incentives to settle outstanding claims.

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<sup>15</sup> For a review of such negotiations see Colby, Thorson and Brittan (2005).

<sup>16</sup> 373 U.S at 600, 83 S. Ct. at 1498

<sup>17</sup> In *re* the Gen. Adjudication of All Rights to Use Water in the Gila River Sys. & Source, 35 P/3d68, 79 (Ariz. 2001).

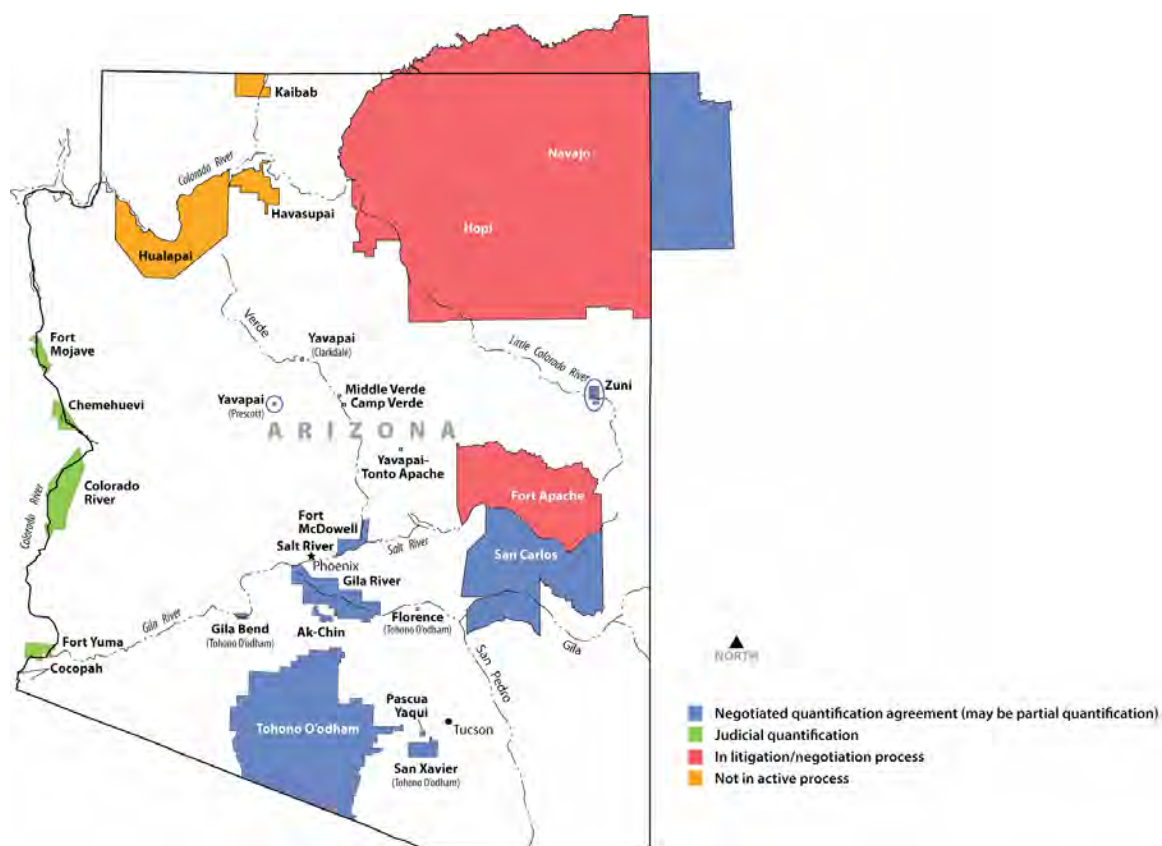
*Winters* rights are a great concern to non-Indian water users in the Arizona because the State is home to 21 federally recognized Indian tribes and reservations cover 25% of the land area of the state (CALs). To date eight Arizona tribes have settled, or partially settled, *Winters* rights with state parties, the State and Federal governments, see Figure 7.<sup>18</sup> In total these tribes secured 1,063,185 AFY of water (Colby, Thorson and Britton). This is equivalent to 13.5% of the State's annual water consumption (7.87 MAFY). Much of the water used to settle these claims is CAP water, water that is first in line for cuts in times of declared shortage on the Colorado River system.

The Arizona Water Settlements Act, 2004 (AWSA, 2004)<sup>19</sup> is appraised in Appendix F in order to understand the apportionment of settlement costs and benefits between signatory and non-signatory parties. In addition innovative water resource management and supply reliability enhancement policy tools are identified that could be adopted by other states in their water reallocation negotiations.

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<sup>18</sup> The Ak-Chin Indian Community in The Ak-Chin Water Rights Settlement Act (1978, 1984 and 1992), The Tohono O'odham Nation in The Southern Arizona Water Rights Settlement Act (1982, 1992, 2004), The Salt River Pima-Maricopa Indian Community in the Salt River Pima-Maricopa Indian Community Water Rights Settlement Act (1988), The Fort McDowell Indian Community in the Fort McDowell Indian Community Water Rights Settlement Act (1990), the San Carlos Apache Tribe in the San Carlos Apache Tribe Water Rights Settlement Act (1992), the Yavapai-Prescott Tribe in the Yavapai-Prescott Indian Tribe Water Rights Settlement Act (1994), the Zuni Pueblo in the Zuni Indian Tribe Water Rights Settlement Act (2003) and the Gila River Indian Community in the Arizona Water Settlements Act (2004). Judicial settlements cover four tribes along the main stem of the Colorado River.

<sup>19</sup> Pub. L. 108-451



**Figure 7: The Status of Water Claims Settlement, Litigation and Adjudication**

## ARIZONA WATER LAW

In the 1870s Colorado was the first state to adopt the doctrine of prior appropriation of surface water. This doctrine means that whoever first claimed the water from a stream has the rights over this use. “Under this doctrine, it mattered not at all how far from the river he lived or how far he diverted the water from its natural course, mattered not at all if he drained the river bone-dry (Worster, 1985).” This doctrine encouraged settlers in the American Southwest to fully exploit all surface water resources. Seven states



immediately followed Colorado<sup>20</sup> in adopting prior appropriation, rather than the English common law riparian doctrine, which predominates in the eastern USA.<sup>21</sup>

There are some important corollaries to the doctrine of prior appropriation. Water rights are an economic asset owned by private concerns in the western US, although many cities own rights and manage water sources as a public service. It is a paradox that ownership or ‘property rights’ the cure all for the ‘tragedy of the commons’ (Hardin, 1968) have not generated incentives for economic efficiency in part because water markets are not fully developed.

The order in which these water rights were taken is important, as is the fact that they were denominated in a specific volume not a specific proportion of the annual flow. For example, in a drought year, those with senior rights could by fulfilling their water rights divert all available water, leaving those with more junior water rights with no water to divert. As there was no constituent for environmental protection or for recreation, water rights were not appropriated for these uses, and therefore it is only through litigation or the permanent or temporary extinguishment of the senior water rights of farmers, or others, that water is made available for these purposes. A similar conversion process is underway to meet the water demands of a growing population.

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<sup>20</sup> Wyoming, Montana, Idaho, Nevada, Utah, Arizona, and New Mexico.

<sup>21</sup> The underlying basis for this principle is to protect the river: adjacent landowners only have the “rights to use the flow for “natural” purposes like drinking, washing, or watering their stock, but it was a usufructuary right only—a right to consume so long as the river was not diminished (Worster) p 88.”

Legally a water right is a property right. The property right is a triadic relationship between the holder and all others with respect to the object (Bromley, 1991). In this case the surface water flow is the object, and the owner of the water right is allowed to use this water without regard to others, including the right to misuse or waste the water. A water right is the claim to the income stream generated by use of the water. All others have duties under this system with respect to the water rights held by others, which they must not diminish or otherwise interfere with. As property the owner of a water right can make contracts on them, they can be inherited, they are enforceable by the legal system, and enforcement can be called upon to uphold them. The most significant aspect of water rights in this property context is that these rights require an authority system to defend the right holder's interest and therefore water rights are not static. As public attitudes change the authority system may alter priorities and water rights may become open to challenge.

In fact the legal system contributed to making water so valuable an asset that latecomers were compelled to challenge the system in order to gain access to water rights. The success of this litigation was to require water right holders to "put every drop of water to work", the beneficial use doctrine, or risk losing their water rights. An unfortunate by-product of this rule is that it gives a zero weight to non-consumptive water uses such as instream flows or water for a wetland. In the late nineteenth century another rule "reasonable use" was added to water law, whereby property rights could be challenged if water was being used non-economically or inefficiently. In this way the latecomer could have water reappropriated. The court's judgment was based on what use had the highest

economic return. Note that this modification again does little for environmental or recreation reallocation as it is difficult and controversial to value natural resources such as lakes or wetlands.<sup>22</sup>

Meanwhile groundwater pumping ‘rights’ are appurtenant to land ownership. There are two major controls on groundwater pumping in State legislation the Groundwater Management Act (GMA) and well-spacing rules. Groundwater protection in the state was bifurcated in the 1980 GMA between five newly established Active Management Areas (AMA)<sup>23</sup> and non-AMAs. The overarching goal was to reduce groundwater overdraft in the most severely impacted basins, the AMAs. New Assured Water Supply (AWS) rules<sup>24</sup> promulgated in 1995 established goals for groundwater management in AMAs. The management goal in the Pima and Maricopa AMAs is to establish ‘safe yield’ by 2025 however, Pinal AMA has a non-sustainable ‘planned depletion’ goal. Meanwhile, in non-AMA areas the only protection of groundwater supplies are non-binding “adequate yield rules”. Although only 15% of Arizona’s total population lives in non-AMAs growth is rapid raising concerns both about the sustainability of water management in these areas and the downstream consequences of inadequate management.

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<sup>22</sup> For an introduction to this topic, see James R. Kahn *Valuing the Environment for Environmental Decisionmaking* in *The Economic Approach to Environmental and Natural Resources*, Orlando: Harcourt & Brace and Co., pp. 87-109 (1998).

<sup>23</sup> The AMAs comprise Phoenix, Pinal, Tucson, Prescott, and Santa Cruz which was split from the Tucson AMA in 1994.

<sup>24</sup> Assured Water Supply terms are described in A.R.S. §45-576, *et seq.* New rules became effective in 1995.

Well-spacing rules were not designed to limit regional aquifer overdraft per se but rather to protect property rights by prohibiting the drilling of new wells if the modeled hydrologic impacts of the pumping on other nearby wells exceeds certain thresholds. Prior to the promulgation of permanent rules in 2006<sup>25</sup> interim rules governed well spacing for 23 years. The new rules add a prohibition on the drilling of new exempt wells<sup>26</sup> within 100 feet of a municipal water provider that has an assured water supply designation. These new rules have some exceptions but are designed to enhance protection of municipal water rights from the increasing threat posed by the expansion in exempt wells. Furthermore, the buffer concept, in this case a 100 ft buffer, was first introduced in the AWSA, 2004. In the settlement the goal of the buffers is to protect on-reservation groundwater, however, this example shows how innovative water management tools can transition from Indian water settlements to wider application within a state.

Two other institutional innovations are worth mentioning here. The 1986 Underground Water Storage and Recovery Program hastened recharge efforts in the state. Ten years later the creation of the Arizona Water Banking Authority (AWBA) had a similar goal to store excess water for later use in times of shortage. The AWBA's remit is to store excess Colorado River water thereby fully utilizing Arizona's 2.8 MAFY endowment and developing long-term credits for the state. These credits are used to "firm" municipal and

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<sup>25</sup> Arizona Revised Statute (A.R.S.) § 45-454(C).

<sup>26</sup> An exempt well is defined as a well having a maximum pump capacity of not more than 35 gallons per minute and that is used for non-irrigation purposes.

industrial (M&I) supplies, fulfill tribal water settlements, and to facilitate interstate water banking. These are some of the main laws and rules that provide the legal and administrative context for surface water and groundwater management in the state.

It is important to note that groundwater and surface water are not conjunctively managed in Arizona. A consequence of this administrative, but not hydrologic, disconnect is that surface water diversion and groundwater overdraft has dewatered streams and rivers in the state and collapsed habitats dependent on surface water flows or shallow and stable groundwater. Another consequence is that the main recourse surface water rights holders have to limit groundwater pumping that diminishes their rights is litigation, or in the case of tribal water rights litigation and settlement. These two outcomes of the water rights system in the state motivate the research themes in this dissertation.

#### ARIZONA'S WATER BUDGET AND PRIORITIES

Arizona's 2.8 MAFY Colorado River allocation is the largest single water source in the state (see Table 1). Of this total 1.2 MAFY is diverted directly from the main stem of the Colorado River and around 1.4 MAFY is conveyed by the federally-funded Central Arizona Project (CAP). The stated objective of the project was to reduce groundwater overdraft in the CAP service area which is the three central counties of Maricopa, Pinal and Pima by the direct substitution of surface water for groundwater supplies. The construction of the \$4B CAP system was opposed by California. A deal was reached whereby California's powerful Congressional delegation would remove its objections to

the federal project if Arizona accepted a change in the seniority of its Colorado River allocation, specifically of that portion delivered by the CAP. This 1968 agreement<sup>27</sup> made Arizona's CAP allocation the most junior rights in the Lower Colorado River Basin. This deal has far-reaching implications: in times of declared shortage on the system CAP water rights will be cut first. In turn this agreement has ramifications for the water security of the state and specifically for tribal water settlements as the Federal government's CAP allocation is mandated for such settlements.

**Table 2: Arizona annual water demand by water source**

<b>Source</b>	<b>MAF</b>	<b>% of total</b>
Colorado River	2.8	35.6
on-river	(1.2)	(15.2)
off-river	(1.6)	(20.3)
In-state Rivers	1.4	17.8
Salt	(1.0)	(12.7)
Gila and others	(0.4)	(5.1)
Groundwater	2.9	36.8
Reclaimed water	0.77	9.8
<b>TOTAL</b>	<b>7.87</b>	

*Source:* Arizona Department of Water Resources, 2006

The CAP system has its own shortage sharing provisions based on the priorities of CAP contracts.<sup>28</sup> CAP water was allocated by a different mechanism than all other surface water diverted in the state: CAP subcontracts were allocated by the federal government, specifically the Secretary of the Interior in the 1983 Record of Decision (ROD). CAP water was given one of four priorities: municipal and industrial (M&I), Indian, non-

<sup>27</sup> Note that this agreement was negotiated before Stockton and Jacoby's (1976) seminal work on the over-appropriation of the Colorado River system.

<sup>28</sup> This section is based on information provided in the following link access September 9, 2006. [http://www.azwater.gov/dwr/Content/Find\\_by\\_Program/Colorado\\_River\\_Management/AZ\\_CO\\_files/short\\_age\\_sharing\\_background.doc](http://www.azwater.gov/dwr/Content/Find_by_Program/Colorado_River_Management/AZ_CO_files/short_age_sharing_background.doc)

Indian agriculture (NIA) and other. The ROD decreed that in times of shortage “other” contracts would be cut first, followed by NIA contracts. If further cuts were still required M&I and Indian contracts would share the shortage in a complex arrangement that was modified in 1992 and 2004 following Indian water rights settlements. Complicating the matter further Indian CAP water has two designations: tribal homeland and irrigation water. Of the initial 309,828 AF of Indian water allocated in 1983, 255,400 AF was designated as irrigation, and the remainder as tribal homeland. The Gila River Indian Community’s (GRIC) 1983 173,100 AF allocation was designated as irrigation water. In times of shortage the ROD states that after “other” and NIA contracts are cut to zero then the GRIC allocation will be cut 25% and other Indian ‘irrigation’ water cut by 10%. If still further cuts were required the remaining Indian allocations (258,323 AF) would share priority with the originally contracted 638,823 AF of M&I water. In summary some of the Indian CAP water has a higher priority than NIA contracts but a lower priority than M&I contracts and some has M&I-equivalent priority. This confusing arrangement was further complicated in 1992 when 33,215 AF of NIA water was converted to Indian priority for the Fort McDowell Indian Community settlement, but the type of Indian priority water was not specified.

The latest iteration of shortage sharing provisions was decreed in a side agreement to the AWSA, 2004, the Gila River Indian Community Water Rights Settlement Agreement. This agreement states that if the available CAP supply is less than or equal 853,079 AF then 36.37518% of this supply will be available for delivery as CAP Indian Priority

Water and the remainder will be delivered as CAP M&I priority water.<sup>29</sup> Whereas if the supply is greater than this threshold the amount available for delivery as CAP Indian priority water will be determined by a complex equation and the remainder will be available for M&I delivery.<sup>30</sup> These rules determine the supply reliability of water allocated to many Arizona tribes under tribal water settlements.

Reclaimed water once considered a waste stream now accounts for almost a tenth of the State's total 7.87 MAFY water supplies. The transformation of this water source can be attributed to water scarcity and water security. In some cities where alternative water sources are constrained the proportion of reclaimed water reused is higher, for example Flagstaff reuses around 20% of its reclaimed water for irrigation (Springer, Schwartzman and Avery, 2003). Two typical uses for reclaimed water in Arizona are golf course and agricultural irrigation where it substitutes for groundwater or surface water supplies. It is not (re)used yet for direct potable consumption anywhere in the state. Reclaimed water is also a reliable water source a characteristic that enhances its value including as a secure water source for tribal water settlement (Appendix F) or for other uses, such as snowmaking (Appendix E).

Excepting Native American federal reserved rights, the predominant sectors with senior water rights are irrigation districts and mines. Incidentally neither sector has a replenishment obligation for mined groundwater unlike the municipal sector which

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<sup>29</sup> GRIC Settlement, Article 8.16.2.1.

<sup>30</sup> Id. 8.16.2.2.



fulfills these obligations through participation in the Central Arizona Groundwater Replenishment District (CAGRD). The largest single user of water in the state is the agricultural sector accounting for 68% of total water consumption (McKinnon, 2005). Future (water sustainable) growth in the state is predicated on the assumption that agricultural water rights, and a proportion of tribal water settlements water, will be transferred to M&I uses and that a market (or market-like voluntary negotiations) will facilitate such reallocation. Such market-based transfers are also incorporated in tribal water settlements, examples are detailed in Appendix F.

#### WATER RESOURCE ECONOMICS

The link methodology in all these papers is the application of economic principles (and in Appendices A, B, C, and E econometrics) to applied policy-relevant issues of water management and reallocation in the state.

The climate, water rights system and rapid metropolitan and rural growth in Arizona have created conditions for competition between water users for water resources. The fundamental issue is that when water supplies are limited and there are multiple competing claims for its use, the outcome of any negotiation or reallocation, by the market or otherwise, could be viewed as a zero sum game. In this context the value of each water use is an essential concept to ensure optimal water resource allocation. This includes water for environmental resources in the state and for recreation.

Although Arizona is a state that is synonymous with wide open space and natural desert landscapes: from high elevation pinon-juniper forests, to the iconic Saguaro forests, to lowland desert scrub and cactus interrupted by ribbons of green, densely vegetated areas concentrated in wet and dry river beds (riparian areas), protections for these ecosystems are limited. The natural environment is important to many people from an existence point of view; however, there are also economic reasons for open space conservation.

Researchers have found a positive correlation between the natural amenities of a given locality and its growth rate (Carruthers and Vias, 2005) and between vegetation-based amenities and rural property values (Sengupta and Osgood, 2003) and urban property values (Appendices B and C). These relationships may provide incentives for some cities and towns to reallocate water rights to the environment. Such reallocations might be achieved through the market or by other means, for example Pima County's Sonoran Desert Conservation Plan dedicates a proportion of wastewater supplies to support riparian habitat.

Economics provides tools to estimate the value of environmental amenities, for example the implicit value of a natural habitat, such as riparian habitat could be estimated in terms of the replacement cost of the stream of ecosystem services it provides. Examples of such services are the provision of habitat for birds, bats, fish and plants, bank stabilization, flood peak reduction, and the promotion of water infiltration into the banks and aquifer.

Riparian habitat may also provide aesthetic, recreation and open space ‘services’ that might be partially captured in nearby private property values. Homeowners are often a key ‘consumer’ of riparian habitats and are one set of economic agents that are often willing to pay private property premiums for aesthetics and access to natural resources. The hedonic property price method (Rosen, 1974) is a statistical technique that can be used to estimate homebuyers’ willingness to pay for natural resources. The method monetizes the ‘value’ of the resource to this group of natural resource consumers and thereby provides a partial estimate of the value of the resource, value that is often overlooked when natural resources are not monetized. Monetizing natural resources allows policymakers to incorporate such estimates thereby leveling the playing field for resource protection and water resource reallocation.

Economic principles can also guide decision-making in the recreation sector. In Appendix E winter-based recreation at two Arizonan ski resorts is modeled and each resort’s snowmaking investment plan is assessed under four different climate scenarios, one of which is a climate change scenario. Warmer temperatures as well as water scarcity are found to be binding constraints to snowmaking adaptation later in this century.

The final paper in this dissertation investigates a major US tribal water rights settlement through an economics lens. The eighteen year negotiation of the settlement, the large number of signatories and side agreements to it, were indicators of economic-based motivations for settlement vis-à-vis litigation and adjudication. The settlement removed

uncertainty and risks associated with litigation and the Gila River System General Stream Adjudication, enabled the signatory parties and the Community to negotiate win-win agreements, including leases and exchanges and the use of preexisting water storage and conveyance infrastructure, and state and federal government agencies the opportunity to introduce watershed-based water resource management and supply reliability enhancement policy instruments.

The application of economic principles to riparian protection and restoration, the future of snow-based recreation, and tribal water reallocation in Arizona was a central methodology but the resulting research papers also combine an understanding of riparian ecology and hydrology, climate, law and policy.

#### DISSERTATION FORMAT

Arid Lands Resource Sciences permits students to fulfill the requirements of the PhD dissertation by appending published and publishable research to the dissertation. The outcome of this option is an alternate format for the dissertation consisting of an introductory chapter and a chapter entitled Present Study which summarizes the methods, results and conclusions of the doctoral research appended to the dissertation. In this dissertation there are six appendices (Appendix A through Appendix F) comprising a book chapter, two papers accepted for publication in refereed scholarly journals, and three publishable papers submitted to refereed scholarly journals.

## STUDENT CONTRIBUTION TO RESEARCH AND PAPERS

### **Papers 1-4: Valuation of urban riparian habitat**

Three research papers developed from a project funded by Sustainability of semi-Arid Hydrology and Riparian Areas (SAHRA) a National Science Foundation Technology and Research Center, to value heterogeneous urban riparian habitats. The principal investigators on this project are Drs. Bonnie G. Colby, Daniel E. Osgood and Julie Stromberg. The main research question motivating this series of papers is do homebuyers have preferences for riparian habitat condition. The results of this research are important because riparian habitat type, extent and condition varies considerably in metropolitan Tucson and treating all riparian habitat, however degraded, as equal in economic analysis is likely to bias results. A side project related to this research was a book chapter reviewing the use of remote sensing data in economic studies. Daniel E. Osgood, a co-advisor on this research project, had been commissioned to write this chapter; however, I researched and completed the main writing of this work with close supervision by Dr. Osgood. The final draft was edited by Drs. Colby and Osgood.

The first paper in a series of three categorized the heterogeneity in riparian habitat using remote sensing vegetation index data. The vegetation index was calculated by Dr. Osgood and Jason Schuminski. This data was incorporated into a hedonic property price model to test for homebuyers preferences for 'greenness'. For this project I cleaned the sales data and assessor data from Pima County and joined the two databases by their

unique parcel identification number. The resulting dataset of single-family residence sales data with assessed characteristics was joined with other GIS datasets, such as flood zones and school districts. Working with Dr. Osgood I developed the model, ran tests on the model and drafted a paper first as a term project for Dr. Aradhyula's AREC 549 class and later for submission to a scholarly journal. The paper has been submitted to a scholarly journal.

A second paper utilized a unique dataset collected for this project by Drs. Stromberg and Katz. Detailed vegetation data was surveyed at 51 stratified-random sites in the study area. This data was then incorporated into an econometric model to test for homebuyers' preferences between habitat conditions, such as density of vegetation, plant species diversity, and habitat type. Again I developed a hedonic model with the supervision of Dr. Osgood and wrote a draft paper for submission to a scholarly journal. Drs. Osgood and Colby edited the work. Dr. Osgood and I worked extensively on edits and a rewrite of this manuscript.

A third paper began as a submission to the 2005 Central Arizona Project Research Paper Award. The paper was reworked for submission to the *Natural Resources Journal* with Dr. Colby. It was accepted with revisions. The research idea of assessing the Sonoran Desert Conservation Plan and the methodology were my contributions to this research. The paper applies estimates of the value of stable-groundwater-dependent riparian habitat

from the aforementioned research paper. Dr. Colby assisted with redrafting and editing the paper for submission and with subsequent edits suggested by the journal.

#### **Paper 5: The economics of snowmaking**

Dr. Bonnie G. Colby is one of the principal investigators on a multi-PI CLIMAS funded interdisciplinary grant. This research began as a study investigating the local economic impacts of winter recreation in the project study area, the White Mountains, Arizona. The research paper accepted with revisions to *Climate Research* however models the impact of inter-annual variability in snowpack and a climate change scenario on threshold days open and minimum snowpack at the two largest ski areas in the state. These results were then utilized to assess the economics of snowmaking investments. This refocus was my contribution to the project. Dr. Colby assisted with drafting and edits. A final theme is the evaluation of climate prediction products for use by ski area managers and season ticket buyers. This aspect of the research was suggested by another CLIMAS PI, Dr. Gregg Garfin. He also provided IPCC AR4 climate change scenario results for Arizona's Climate Division 2 for this paper. This data was used to assess the viability of snowmaking adaptation in the future.

#### **Paper 6: Tribal water settlements**

The principal investigator on this SAHRA funded project is Dr. Bonnie G. Colby. Katharine Jacobs, SAHRA also co-manages this project. The project seeks to identify innovative water resource management and supply reliability enhancement tools

incorporated into Indian water rights settlements. My role in this research has been to investigate the latest tribal water settlement in Arizona, the Arizona Water Settlement Act, 2004 (AWSA) and its many attached side agreements. I am second author on a paper written with Dr. Colby for the 'Water Law and Policy: A Symposium' conference, October, 2006 titled "Innovations for Regional Supply Reliability in Agreements with Native American Tribes" which will be published in the Spring 2007 edition of *Arizona Law Review*. A side paper from this research is a single-authored paper that began as a submission to the 2006 Central Arizona Project Research Paper Award. The paper won joint first prize. The paper focuses on the division of benefits and costs between signatory and non-signatory parties to the AWSA. This paper was revised and submitted to a scholarly journal.



## PRESENT STUDY

The methods, results and conclusions of this study are presented in the papers appended to this dissertation. The following is a summary of the most important findings in this document.

### PAPER 1 – APPENDIX A

Researchers from many fields are utilizing remote sensing data and geographic information systems (GIS). Paper 1 is a book chapter in ENVIRONMENTAL VALUATION: INTERREGIONAL AND INTRAREGIONAL PERSPECTIVES (Carruthers and Mundy, 2006). The chapter is a literature review on the use of remotely sensed vegetation indices data in applied economic analysis with a particular focus on the innovative use of such data to characterize vegetation amenities in hedonic property analysis. The chapter also explains how these indices are calculated, what they measure on the ground, and the technical challenges of using such data.

An increasing number of economics papers utilize remotely sensed data. The advantages of these datasets are they provide information on vegetation cover over large areas and are a relatively inexpensive data source particularly when compared to field survey data. For example, a straightforward application of vegetation indices in the Midwest is to proxy agricultural production in a rural hedonic analysis. Vegetation indices were

designed for such tasks and perform well in such research. Other relatively uncomplicated applications are to monitor land use change or environmental compliance.

A more recent and challenging application is the characterization of landscape for hedonic analysis. Researchers have long assumed that nearby open space is an important determinant of property value variation and have modeled the influence of this amenity in terms of proximity, type, for example a lake or golf course, and size. However the heterogeneity in vegetation extent and condition is often overlooked even though homebuyers may have preferences for habitat condition. Remotely sensed vegetation indices offer an opportunity to test for such preferences by characterizing vegetation over large areas. A limitation of such data is that it maybe difficult to disaggregate the information incorporated in a vegetation index.

A small number of papers have found that the ‘greenness’ of a parcel is a significant determinant of the variation in rural and urban property values. The difficulty arises in explaining what homebuyers are valuing. It is likely that green vegetation is a proxy for aesthetic values but greenness itself is often correlated with other amenities such as flowing surface water making it challenging to disaggregate the results. The chapter concludes that although difficulties remain with the interpretation of vegetation index results that improvements in the resolution of remote sensing images combined with additional experience using such datasets and analyzing the results is likely to increase their usefulness in economic studies.

## PAPER 2 – APPENDIX B

The second paper provides an example of how such remote sensing vegetation index data can be used in a hedonic property analysis in an urban setting. A previous study by Sengupta and Osgood (2003) modeled the effect of greenness in a rural setting. This research is innovative in that it attempts to incorporate information on the heterogeneity of landscape amenities beyond the typical controls of proximity to and the size of the open space. The research develops previous research by Colby and Wishart (2002) that investigated property premiums associated with proximity to riparian corridors. This new research investigates how the heterogeneity of riparian habitat influences property values. Such results if statistically significant would provide more policy-relevant information for habitat conservation and rehabilitation.

Paper 2 uses a greenness index to characterize vegetation amenities at both the household parcel level and in the nearest riparian corridor to each parcel. An assumption implicit in this research is that vegetation amenities are an important determinant of house price variation in a semi-arid urban environment where the supply of native vegetation is limited. Using a single Landsat Enhanced Thematic Plus image the soil adjusted vegetation index (SAVI) was calculated for each section of the riparian corridor and for each parcel centroid in the study area. The addition of the SAVI dataset made it possible to test whether homebuyers have preferences for ‘greener’ lots and ‘greener’ riparian corridors.

The hedonic model used incorporated variables describing the structural characteristics of the home and neighborhood and other study area specific variables such as Federal Emergency Management Act designated flood zones, and greenness values at both the household parcel and at the nearest riparian corridor to each parcel. Because of endogeneity in the dataset an instrumental variable (IV) estimation approach was utilized. The greenness variables were instrumented using appropriate physical and census variables. IV estimation improves the confidence in the results because it removes correlation between the error terms and the explanatory variables in the model.

The results from the research suggest that homebuyers do have statistically significant preferences for greener lots and for a greener nearest riparian corridor. The SAVI variable measures vegetation cover and health therefore it seems that homebuyers are willing to pay a premium for a home that has more and healthier vegetation or is located nearby a riparian corridor that supports healthy riparian habitat. Interaction variables also suggest that these preferences might be substitutes, that is a homebuyer might accept a less green lot if their nearest riparian corridor is greener and vice versa. This result has implications for water resource management at the county level because it may be less water intensive to preserve and rehabilitate riparian habitat that benefits large numbers of homebuyers whilst simultaneously increasing incentives to reduce domestic outdoor water consumption for water-intensive landscaping.

The history of water resource allocation in the state has created the current situation where dewatering of streams and aquifers has resulted in the disappearance of much of the stable-groundwater-dependent riparian habitat. This habitat is embodied by tall, leafy riparian trees such as the willow and cottonwood and mesquite bosques, or woods. Such habitats offer a startling visual contrast to other desert landscapes. This research tests whether homebuyers have preferences for habitat quality.

One limitation of the single SAVI image used in Paper 2 is that it is difficult to discern the source of the ‘greenness’ that is the vegetation might be native riparian trees and shrubs or invasive grasses and salt cedar stands.<sup>31</sup> In this paper riparian habitat is characterized by detailed vegetation site analyses at 51 stratified-random selected sites in the study area to determine whether homebuyers have preferences for riparian habitat characteristics. Data on vegetation types, density, and species diversity were collected. Each surveyed segment of riparian corridor was bounded by a 1/5 mile buffer in a GIS and all (geocoded) house sales within the five year study period were captured. These house sales were used in a hedonic analysis.

The regression model controlled for other factors that influence house prices such as structural and neighborhood variables as well as variables that described the condition of

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<sup>31</sup> It should be noted that a more sophisticated remote sensing protocol using multiple images coinciding with the phenology of native species would be better able to discern species types. Alternatively species could be discerned using high resolution imagery.

their nearest riparian habitat. The modeling results indicate that homebuyers have preferences for habitat condition that is they are not indifferent to the heterogeneity present in this habitat. Specifically homebuyers are willing to pay significant premiums to live near stretches of riparian habitat that still support stable-groundwater-dependent trees and species rich habitat.

Furthermore this research suggests that habitat characteristics are a significant determinant of value. This finding is important because most areas of open space are not homogenous; they likely are a mixture of habitat conditions from degraded to pristine native habitats. Consequently hedonic studies that use proximity measures alone to value open space are likely measuring a composite value of heterogeneous vegetation amenities. This suggests that other natural resource hedonic research should attempt to characterize heterogeneity in the relevant habitat to disaggregate the value of different conditions of open space.

#### PAPER 4 – APPENDIX D

The final paper in this series uses results from Paper 3 research to assess the economics of the Sonoran Desert Conservation Plan. This paper applies estimates of the value of stable-groundwater-dependent riparian habitat and calculates the property tax premiums accruing to the county. These benefits are then compared to estimates of the costs of delivering wastewater to the riparian corridor, in the same study area as Paper 3, for

riparian habitat protection and restoration. The results of this analysis suggest that the property price premiums associated with healthy riparian habitat raise sufficient incremental property tax revenues to cover riparian rehabilitation costs; specifically the cost of reclaimed water delivered to selected riparian corridors and fixed rehabilitation costs. This research indicates that open space conservation and rehabilitation can be self-sustaining.

#### PAPER 5 – APPENDIX E

Paper 5 assesses the economics of snowmaking investment plans in Arizona's ski industry as a mitigation response to inter-seasonal snowfall variability and longer-term climate change. The connection to water resources is that snowmaking requires large volumes of water, water that could be used for other competing economic activities, such as municipal growth or for industry. Ski area expansion plans at the second largest ski area in the state, Arizona Snowbowl, which is located on U.S. Forest Service land near Flagstaff, were particularly contentious because the snowmaking plan proposed to utilize up to 486 AFY of A++ treated wastewater from the City of Flagstaff. The ski area is located in the sacred San Francisco Peaks and thirteen Native American tribes objected to the ski area expansion plan and the use of wastewater at the site whilst others objected to the allocation of this valuable community wastewater stream to the ski area.

Snow data was collected from the U.S. Department of Agriculture's Natural Resources Conservation Service's National Water and Climate Center. Ski visitor data for the Arizona Snowbowl was collected from their Environmental Impact Statement (EIS, 2005) and Sunrise Park Resort visitor data was estimated using National Ski Areas Association Arizona and the aforementioned EIS data. The first modeling exercise tested for statistically significant differences in ski season outcome and the phase of the ENSO cycle. The results from a logit model estimate that the odds of reaching minimum ski season length in a La Niña season are lower than a non-La Niña season. This suggests that snowmaking could be a useful mitigation strategy in reducing inter-seasonal variability and confirms assumptions in the Arizona Snowbowl EIS that the volumes of manmade snow required are likely to be higher in La Niña seasons. The results also suggest a role for climate prediction. Analysis of a forecasting tool, the Climate Forecasting Evaluation Tool, indicate that climate prediction of the ENSO cycle in Arizona is good, meaning that mountain managers and potential season ticket buyers could use such forecasts in their decision-making. For example, El Niño seasons are probabilistically good seasons for both ski areas and skiers, thus if the climate forecasts in the August prior to the November-April ski season predict strong El Niño conditions mountain managers may plan to hire more staff or market out-of-state whilst skiers might decide to buy an early, less expensive, season ticket. Conversely, if a La Niña season is forecast mountain managers might stagger their hiring, time snowmaking efforts to coincide with peak seasons and skiers may decide not to buy a season ticket.



The paper also estimates the snowmaking costs under the three phases of the ENSO cycle at both the Arizona Snowbowl and Sunrise Park Resort. The data suggest that both snowmaking investments are financially viable and a useful medium-term mitigation strategy. Finally, using the most recent IPCC AR4 model results snowmaking adaptation is assessed in 2030, 2050, 2080 and 2099. The analysis suggests warmer temperatures will preclude snowmaking adaptation in the shoulder seasons under some scenarios by 2030. By 2099 the ski industry in Arizona is likely to be drastically shortened as winter temperatures increase turning snow to rain and melting snow earlier in the spring. These results indicate that climate change could superimpose additional management concerns and costs on the Arizonan ski industry and that if climate change is realized mountain managers may need to implement more adaptations to keep their ski areas open.

#### PAPER 6 – APPENDIX F

The final paper examines the water supply reliability innovations incorporated in and the division of costs of benefits between the signatory and non-signatory parties to the Arizona Water Settlement Act, 2004 (AWSA).

Indian water rights settlements bring together state's parties, such as water service providers, large industrial and municipal users and irrigation districts, with Tribal, State and Federal governments. The main benefit of settlement to tribes is the delivery of 'wet' water in fulfillment of 'paper' federal reserved rights, whilst the state shares the costs of the agreement with the federal government and various signatory parties. Moreover, such

settlements are often least disruptive to incumbent water rights holders as a direct result of one of the 16 Federal criteria<sup>32</sup> for Indian water rights settlements that strives to maintain incumbent rights in affected watersheds.

The AWSA is the largest single tribal water settlement in Arizona. Although this was a multi-tribe settlement, the key settlement was with the Gila River Indian Community. The annual water budget for the Community was settled at 653,500 AFY or 8% of the State's estimated total annual water consumption. The actual water reallocation to the Community is 193,300 AFY because of previously held CAP contracts, decreed water, and on-Reservation groundwater. Nevertheless, this is a landmark settlement because of the number of signatory parties to it, the large number of side-agreements between the Community and other parties attached to it, and the incorporation of water resource management policy tools. The settlement achieved something more than reallocation of water it also introduced innovative market-based and regulation-based policy tools that have the potential to improve water resource reliability and management in upstream watersheds and on-Reservation. Some of these policy instruments might be transferable to other states wishing to settle outstanding claims and for more widespread application in Arizona.

The division of benefits and costs in terms of the flow of water and money between the various signatory and non-signatory parties to the settlement are also examined. The

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<sup>32</sup> *See*, 33 Fed. Reg. 9223 (1990).

conclusions of this analysis are that a significant share of the water for this agreement was reallocated from state's parties. Furthermore, these water sources are more secure than the bulk of the federal share to the agreement. Second, the largest portion of costs falls on the federal government as a direct result of an inventive funding mechanism. However, leases and provisions to transport water using the existing canal system greatly reduced the cost of the overall agreement. Additionally these measures will enable the Community to invest in on-Reservation activities and infrastructure and will ensure that water delivery extends to several districts on the Reservation resulting in wider distribution of the benefits of the agreement on-Reservation.

#### FUTURE RESEARCH

There are several future research projects that have or might develop from this dissertation research. The results in Paper 5 on skiing in Arizona were accomplished with limited datasets. Future collaboration with ski area management to gain access to detailed daily data and with climate change scientists could improve the forecasting of climate change effects on Arizona's ski sector. Additionally, similar analyses could be undertaken at ski areas in neighboring states.

The results from Papers 2 – 4 suggested a research project correlating greenness as measured by a remotely sensed vegetation index at the lot-level with outdoor water consumption data and the relationship between proximity to different types of open space

and outdoor water demand in metropolitan Tucson. I developed and wrote a research proposal titled “Modeling outdoor residential water use”. In January 2006 this \$45,111 proposal was funded by the Technology and Research Initiative Fund of the Water Sustainability Program at the University of Arizona. Another possible research agenda to develop is the relationship between access to open space in the Tucson metropolitan area and housing density controlling for zoning.

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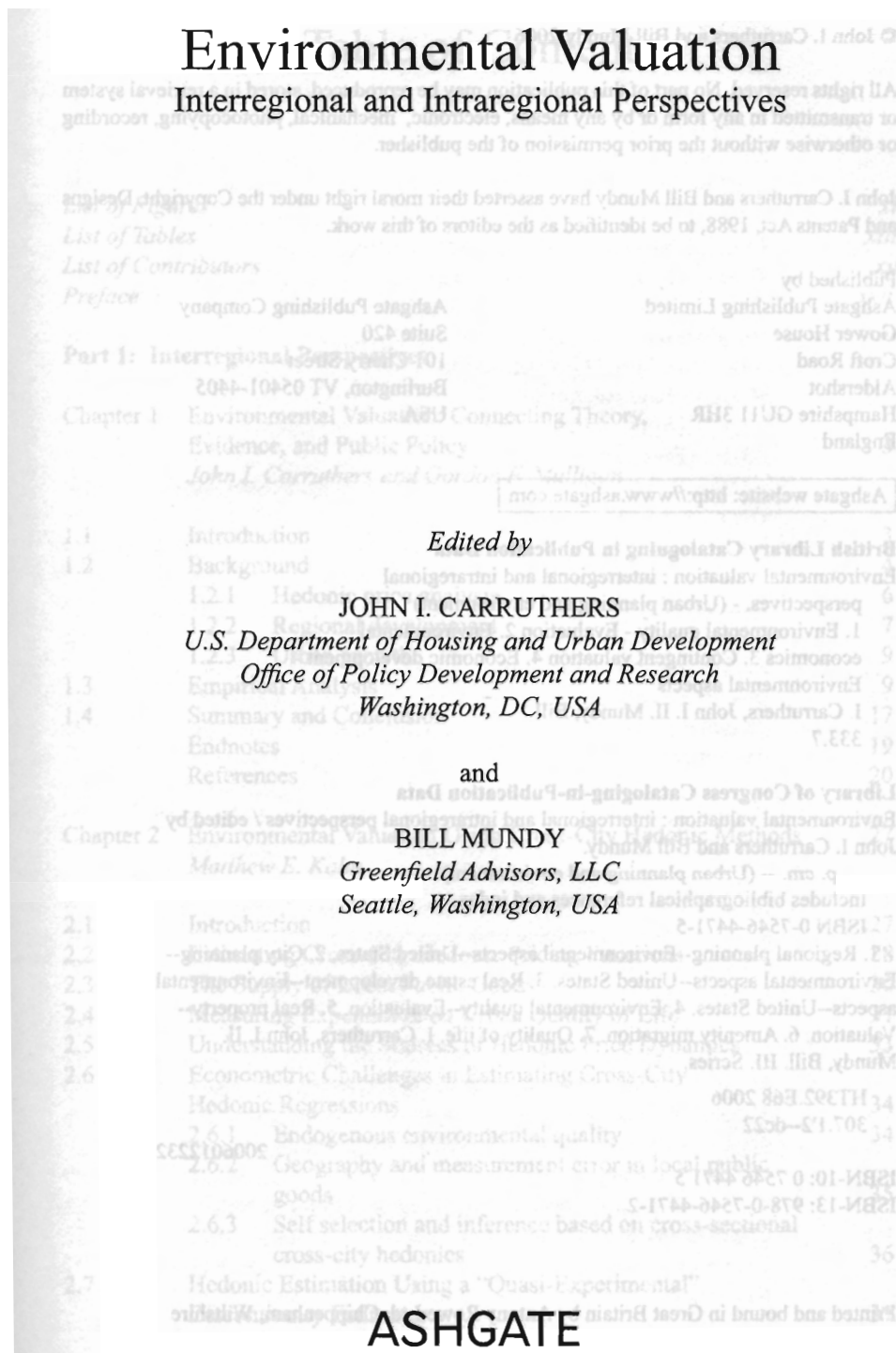
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APPENDIX A: REMOTELY SENSED PROXIES FOR ENVIRONMENTAL AMENITIES IN HEDONIC ANALYSIS: WHAT DOES “GREEN” MEAN?



## Chapter 9

# Remotely Sensed Proxies for Environmental Amenities in Hedonic Analysis: What Does “Green” Mean?

Rosalind H. Bark-Hodgins

*University of Arizona*

Daniel E. Osgood

*Columbia University*

Bonnie G. Colby

*University of Arizona*

## 9.1 Introduction

Remote sensing<sup>1</sup> has been used by economists to establish a baseline of natural resources or, conversely, to monitor change, and to proxy productivity in agricultural land hedonic analyses. This chapter focuses on the new and innovative use of remote sensing in hedonic price analyses, either to control for amenities or to proxy difficult-to-measure environmental amenities or ecological benefits that are the subject of valuation.

A large literature reports that nearby natural resources – including open space, lakefront amenities, visibility, views, urban wetlands, coastal water quality, and ecological diversity, and connectivity – are often capitalized into property values (Geoghegan et al. 1997; Benson et al. 2000; Leggett and Bockstael 2000; Mahan and Adams 2000; Acharya and Bennett 2001; Irwin and Bockstael 2001; Shultz and King 2001; Spalatro and Provencher 2001; Geoghegan 2002; Paterson and Boyle 2002; Smith et al. 2002). These studies tell us that, although the specific type of environmental resource varies by geographic location, homebuyers in many different markets care about the relative location of their home *vis-à-vis* natural amenities or open space.

In semi-arid and arid regions, the relative scarcity of vegetation-based amenities may be a significant determinant of house price variation and, in response, methods for characterizing such resources are being developed by researchers. Remotely sensed vegetation indices hold some promise in differentiating such “green” amenities and as a proxy for other amenities in arid or semi-arid areas, such as flowing water or

cooler temperatures (and, potentially, related disamenities, such as mosquitoes). This chapter discusses the use of such vegetation indices in the literature and associated difficulties and advantages.

This chapter is organized as follows. Section 9.2 provides a short summary of the hedonic property price method and the use of proxies to differentiate neighborhoods and to characterize environmental amenities. Section 9.3 discusses the meaning and value of “greenness” and Section 9.4 provides some background on remote sensing vegetation indices and their particular use in arid and semi-arid riparian habitats. Section 9.5 summarizes how greenness indices have been used in economic studies. Section 9.6 focuses on their use in hedonic price analyses both in their more familiar form as a direct measure of productivity and in new studies as a proxy for aesthetic and riparian habitat quality. A discussion is presented in Section 9.7.

## **9.2 Hedonic Price Analysis and Valuing Environmental Amenities**

The hedonic property price method was developed by Rosen (1974). The price of a property, which is observable, represents the value of the particular collection of attributes that the house encompasses. Observing how property values change as the level of various attributes, such as proximity to riparian habitat or the seashore, change provides a way to estimate the marginal value of these attributes. Economic valuation methods that focus on property values are useful for policy decisions in a political climate sensitive to the impact of regulations on landowners. Tucson, Arizona provides a particularly salient example of the necessity of understanding the attributes of open space. It is the study site for many of the works that we discuss, including the exploratory work presented in this chapter.

Fast growing Sunbelt cities such as Tucson must carefully manage their open space. In these areas, buyers can enjoy more “elbow-room” as well as the beauty of the desert. Those rushing to these cities are consuming the environment they love, with a County Administrator complaining that “urbanization eats away at ten square miles of desert every year, destroying the habitat and lessening the natural beauty that brings people to the region” (Schleisman 2002). In addition, natural habitats often compete for scarce water with golf courses and parks. As in many such cities, there are several growth-related policies that have been in the public debate. These include the Sonoran Desert Conservation Plan and critical habitat for the Pygmy Owl.<sup>2</sup> Since different policies impact open space, greenness, and habitat differently, separating premiums for greenness from those for space itself is critical.

### *9.2.1 Hedonic price analysis and proxies*

Proxies are often used to extrapolate neighborhood or environmental attributes. For example, Geoghegan (2002) uses three demographic/socioeconomic measures from census block data – population density, median income and percent of population with a bachelor’s degree – to proxy neighborhood characteristics. To measure the

impact of environmental attributes on house price variation, researchers typically use the distance from each property in the sample to the amenity to measure the relative quality of the location. Examples include the distance to a lake- or oceanfront (Acharya and Bennett 2001), to urban wetlands (Mahan and Adams 2000), and to vacant land, golf courses, and public land as a measure of the value of open space (Smith et al. 2002). More sophisticated measures have also been used. For example, Legget and Bockstael (2000) use fecal coliform bacteria counts as a proxy for a complex environmental factor, in this case water quality.

Economic models intended to value terrestrial habitat typically have been limited to measures of proximity to, and simple descriptive characteristics of, the habitat. In order to develop economic demand functions that capture the value of habitat quality differentials, more sophisticated quality indicators would be useful. In this chapter, we review the use of remotely sensed data as it has been used in economic, and, specifically, hedonic studies, to measure land use change and productivity and as a proxy for the quality of a vegetation-based amenity. Ideally, remote sensing data should be calibrated with ground-truthed biological vegetation measures, such as vegetation density or leaf area index. However, the fieldwork and analysis required to implement such verification protocols should not be underestimated: They are time-consuming and perhaps not practical for most economic valuation studies that cover large regions and seek to produce timely and cost-effective results. Nevertheless, there may be opportunities to transfer the results from the applied remote sensing literature to similar environments for use in hedonic analysis of vegetation-based resources.

### **9.3 The Marginal Value of Greenness to Homebuyers**

The value of greenness is likely to be a function of the overall level of greenness in a specific location, the source of the greenness, and any correlations with nuisance animals and insects. Vegetation varies by climatic zone. In desert locations, such as southwest Arizona, vegetation is scarce and highly localized in belts of greenness that follow streams or dry riverbeds. These factors likely impact the marginal value of greenness with respect to house prices. In contrast, subtropical Florida is lush and the marginal value of additional greenness to homebuyers is likely to be low. In this part of the United States, dense vegetation may be more associated with nuisances posed by mosquitoes or deer. In addition, the most common remotely sensed vegetative indices saturate easily in high biomass conditions (Huete 2004). Their dynamic range is stretched in favor of low biomass conditions in which they can accurately differentiate small changes in vegetation. Thus, remote sensing products tend to be more useful in arid and semi arid regions, areas in which they are more sensitive and where vegetation-based amenities may be more important because of their scarcity.

Remotely sensed vegetation indices are designed to detect the vegetation signal. They are a robust spectral transformation of two or more spectral bands<sup>3</sup> designed to

enhance the vegetation signal and allow reliable spatial and temporal comparisons of terrestrial photosynthetic activity and canopy structure variations. Specifically, vegetation indices measure the near infrared portion of the electromagnetic spectrum (sunlight) reflected by the spongy mesophyll leaf structure and the absorption of the red portion of the electromagnetic spectrum by chlorophyll (Tucker 1979; Jackson et al. 1983; Tucker et al. 1991). Vigorous, healthy vegetation absorbs most of the red light (low red-light reflectance) and it reflects near-infrared light; these two phenomena combine to produce a high vegetation index value. Conversely, bare soil or dead vegetation (perhaps as a result of drought) reflects more red light and less near-infrared light, resulting in a lower vegetation index value. Note that vegetation indices do not discriminate the source of these vegetation processes. It is likely that different vegetation types enter a homebuyer's utility function in different ways. For instance, greenness that results from weedy grasses is likely to be valued lower than greenness from mature trees. To address this problem, remotely sensed data might be verified with ground-truthed vegetation data.

Vegetation indices were designed to measure vegetation-based data such as the biomass and percent land cover in the target area, but the indices can also be highly correlated with other factors. For example, in arid regions, healthy, green vegetation can be correlated with other site-specific amenities, such as habitat for birds and other wildlife, cooler temperatures, and the availability of water. Thus, a greenness index may contain a lot of site-specific information, information that could be used by researchers in a novel way to value environmental amenities.

## 9.4 Remote Sensing

### 9.4.1 Remote sensing vegetation indices

There is a large ground-truthed remote sensing literature that has established the effectiveness of vegetation indices "to measure and monitor plant growth (vigor), vegetation cover, and biomass production."<sup>4</sup> The normalized difference vegetation index (NDVI) is commonly used and was developed by the EROS Data Center, a division of the United States Geological Survey (USGS). Initially, NDVI was calculated using Advanced Very High Resolution Radiometer (AVHRR) multi-spectral data. This satellite has a rather coarse 1.1 km<sup>2</sup> resolution, which is adequate for regional-scale studies, plus good temporal coverage. A global NDVI dataset is available from April 1992 as a result of a USGS-NASA-led effort to collect, process, archive and disseminate the data.<sup>5</sup> Meanwhile, for the contiguous 48 states, NDVI data is available from 1989. The Global Inventory Modeling and Mapping Studies data product has been explicitly calibrated to reduce systematic measurement errors across time. Data is available at a lower resolution, but its coverage begins in 1981 and is more accurate for temporal comparisons.<sup>6</sup> These datasets allow examination of changes over a longer time span than other indices based on newer satellites.

However, higher resolution images might be required for urban private property hedonic analyses.

Vegetation indices (VIs) are calculated for each picture element (pixel) in a remotely sensed image. The size of the pixel is determined by the remote sensing detector and it, in turn, determines the spatial resolution of the image. The resolution is the smallest object that can be resolved by the satellite. For example, the National Ocean and Atmospheric Administration's (NOAA) AVHRR NDVI pixels are 1.1 km<sup>2</sup>, whilst Landsat Thematic Mapper pixels are 30 m<sup>2</sup>. The NDVI is calculated using the following spectral bands and formula:

$$(\rho_{\text{NIR}} - \rho_{\text{Red}})/(\rho_{\text{NIR}} + \rho_{\text{Red}}), \quad (9.1)$$

where NIR is near infrared. The formula is thus the difference in NIR and red reflectances normalized by the total radiance. This weighting by the sum of the two reflectances achieves two things: It compensates for different amounts of insolation (incoming solar radiation or sunlight) and forces the index to range between negative one and one. In actuality, the index tends to fall in a range of 0.1–0.9, with the low value associated with bare soil and the highest value with densely canopied areas. The range in a semi arid environment that supports less dense vegetation is contracted to around 0.2–0.6.

Although VIs are widely used and numerous ground-truthed studies have shown that they are good at predicting a number of biological indicators – such as leaf area index, standing biomass, green-leaf biomass, canopy coverage, net productivity, and absorbed photosynthetically active radiation (Nagler et al. 2001 page 92) – researchers need to understand their limitations. Even though the formula for calculating NDVI is simple, problems can result from technical reasons having to do with the sensor and the algorithms used to convert digital numbers to reflectance values and, also, with environmental factors in the target area, such as the spectral properties of the vegetation, litter, and atmospheric effects.

Remote sensing of vegetation in a semi-arid riparian habitat is complicated by fragmented vegetation cover and species-rich habitats. There are also scaling issues: Researchers often use lower resolution images that are free and have a better temporal coverage although high-resolution images are available. For example, Landsat's ETM+ satellite pixels are 30 m<sup>2</sup>. Because of this low resolution, the images usually combine several landscape features, soil, water, and different types of vegetation, including dead vegetation, within each pixel. This is problematic because each feature has its own unique spectral signature and, for this reason, some researchers have coined the term “mixel” for a mixed pixel. The vegetation index value per pixel is an average for the pixel and the dominance of one landscape feature can therefore determine the vegetation index value the pixel will have.

NDVI is sensitive to the brightness of the soil background. Darker soils have higher NDVI values than light soils with the same biomass, and, therefore, it is not an ideal choice for measuring vegetation in a semi-arid environment where canopies are fragmented and soils exposed. The response to this problem has been

the development of vegetation indices designed to measure the vegetation signal in semi-arid and arid environments. The soil-adjusted vegetation index, or SAVI (Huete 1998), is like NDVI but it is explicitly modified for remote sensing in areas where vegetative groundcover is fragmented or largely absent; it does this by adjusting the index for the brightness, or reflectivity, of the background soil. The formula for the index is:

$$((\rho_{\text{NIR}} - \rho_{\text{Red}})/(\rho_{\text{NIR}} + \rho_{\text{Red}})) * (1+L), \quad (9.2)$$

where the L term is allowed to vary between zero and one depending on the proportion of visible rock or soil in the scene. Given that the researcher is unlikely to know this proportion, a value of  $L = 0.5$  is often used as a reasonable global approximation. An L value of 0.5 minimizes soil brightness and eliminates the need for additional calibration for different soils (Huete and Liu 1994). This L factor optimizes the vegetation index, ensuring that a leaf area index of two receives the same SAVI value whether the background soil is wet, dry, dark, or light, this is particularly useful for remote sensing in semi-arid environments.<sup>7</sup>

#### 9.4.2 Remote sensing data processing

If a researcher decides to use remote sensing data, remote sensing computing software and some expert knowledge are necessary. These requirements can be reduced if pre-processed data is obtained. For example, Bark-Hodgins et al. (2005a) obtained an image which had been georectified, and atmospherically and radiometrically corrected for their research. Remotely sensed data is often only useful when integrated in a Geographic Information System (GIS), which adds another prerequisite skill set. For these reasons, the researcher must be confident that the data will add value to the study or be willing to accept that the vegetation index might not be a good proxy for the variable under consideration.

#### 9.4.3 Vegetation indices in riparian or arid lands

Although such studies are uncommon, new research statistically correlates remote sensing products with biological site surveys in a semi-arid riparian ecosystem. These landscapes are inherently difficult for remote sensing because canopies are fragmented and, therefore, the brightness of the background riverbed can impact the vegetation index. Plus, semi-arid ecosystems support many tree and shrub species all of which have different spectral signatures. Research in a partly vegetated landscape found that NDVI in landscape is more closely related to percent cover than to differences in the reflectance among plants (Carlson and Ripley 1997). In another study, Purevdorj et al. (1998) found similar results in a rangeland setting: A high coefficient of determination was found between vegetation indices and fractional vegetation cover. To establish what exactly vegetation indices measure in such environments Nagler et al. (2001) explicitly tested the efficiency of NDVI and SAVI



at predicting on-the-ground riparian vegetation in the semi-arid Colorado River delta, in Mexico. This study uses low-altitude aerial high spectral resolution images and Landsat Thematic Mapper satellite remote sensing to generate three vegetation indices: NDVI, SAVI, and the enhanced vegetation index (EVI). Additionally, the low-level aerial data was used to determine percent cover in the entire field area. The vegetation indices and aerial data were assessed against three biological measures of vegetation (species, percent cover, and leaf area index) at nine ground-truthed field sites.

There are a number of significant results from the Nagler et al. (2001) study – results that are also highly relevant to the studies discussed above, because the survey environment is also a semi-arid riparian area with a patchwork of trees and low-lying shrubs on a background of light-colored riverbed sand. The authors found that there was an almost perfect correlation between the low-altitude and satellite NDVI values, meaning that satellite-derived data can be used for this type of ecosystem. All indices performed well in predicting leaf area index and ground cover, but not at differentiating species types. In this ecosystem, percent ground cover and leaf area index are also highly correlated. The authors (page 103) estimate this relationship between NDVI and percent vegetation cover as:

$$\text{Percent Vegetation Cover} = 180 * \text{NDVI} + 7.95. \quad (9.3)$$

This statistically significant result is key to extending the results over the entire study area. The authors can be confident in transforming NDVI values into percent ground cover, which, in turn, can be used to monitor changes in riparian habitat extent in response to climatic events, such as drought, or to monitor the effectiveness of riparian habitat restoration projects. The authors conclude that similar riparian habitats to their study site are found all over the Southwest and, therefore, that remote sensing could find wider application in measuring and monitoring these ecosystems. This study showed that remotely sensed data could be scaled down to extrapolate on-the-ground measures of vegetation cover and, as such, the procedure and, in some instances, the results have obvious applications in hedonic studies that value vegetation-based environmental amenities in semi-arid regions.

The authors report one limitation to the research, namely, that they could not differentiate particular plant species either by visual inspection of the low-level aerial images or by differences in the vegetation indices. This inability to differentiate between plant types is disappointing because riparian habitats support different habitat types – only some of which are habitat for endangered species and support high biodiversity values. Other degraded habitats have been colonized by invasive species, the extent of which is a growing issue in fire and water management and also in riparian restoration projects. Another reason habitat type may be important, is the aesthetic quality of different riparian species; in a Southwestern semi-arid ecosystem, the extremes might be a prized view of a mature cottonwood tree (*Populus fremontii*) compared to a view of the invasive salt cedar bush (*Tamarix ramosissima*). Although it is possible to apply a more intensive, multiple-image remote sensing protocol

in order to identify and map individual tree and shrub species, the relative costs and time requirements of this intensive remote sensing protocol and of field-based surveys must be weighed when the researcher is concerned with distinguishing between plant species.

### 9.5 Greenness Indices in the Economic Literature

NDVI and SAVI have typically been used to model agricultural production or to measure land use change over time. More recently, such indices have also been used to proxy amenity values and habitat health. Examples of such uses are summarized below. An example of a study that uses NDVI to measure vegetation cover and to track land cover change is Millington et al. (1994). The authors combine existing estimates of woody biomass with a remote sensing vegetation index (AVHRR's 1.1 km<sup>2</sup> NDVI) and land use data in their regional study area, sub-Saharan Africa. The aim of the study is to map woody biomass inventory, the dominant domestic fuel (including charcoal), in the region. The authors argue that such an inventory is a prerequisite for developing an overall sustainable energy strategy for the region.

Schweik and Thomas (2002) assess remote sensing as a tool to evaluate and monitor habitat conservation plans submitted to the U.S. Fish and Wildlife Service to fulfill Endangered Species Act requirements. Their motivation is the large number of habitat conservation plans submitted that cover tens of millions of acres and the difficulties in forming a baseline dataset and then monitoring change on such a large scale using other techniques. Remote sensing in this study was used as a straightforward measure of land use change; however, it was applied to a novel problem of monitoring habitat conservation plans.

Bhattacharya (2003) uses a simultaneous equations model to test for a bidirectional interaction between population change and change in environmental quality in India. In a nation with one billion people, seventy percent of whom live in rural areas, one might expect *a priori* that the interaction between population growth and environmental quality is strong. She uses the change in NDVI over a short-run and longer-run period to proxy natural resource (forest cover) change and its interaction with population change in both rural and urban areas. The results of her modeling show that a positive change in NDVI is significant and positively related with a decline in rural births and with an increase in urban births and migration in the short-run. She postulates that, as environmental quality improves, as measured by increased greenness, rural families have less need for more children whilst urban families take advantage of what they view as improved living conditions. Conversely, a decline in NDVI is associated with higher rural fertility in the short-run as children are viewed as extra hands needed for resource extraction when times are hard (Dasgupta 1995; Nerlove 2000). In this study, NDVI is again used in a standard form to measure productivity and land use change but it is applied to an interesting bidirectional interaction.

## 9.6 NDVI and SAVI in the Hedonic Literature

The hedonic method allows researchers to test the significance of different variables in determining wages, land, or house values. Investments in property are often long-term and the subject of complex decision-making. An agricultural land buyer may assess a parcel's productivity or expected profits, whilst a suburban homebuyer is likely to be more concerned about the school district and, perhaps, the maturity of trees on the lot. Greenness indices are now used in hedonic studies as a straightforward measure of land use change, productivity, or as a novel proxy for difficult-to-measure environmental amenities. Exactly what greenness proxies will vary by location and it may proxy more than one variable, for example water availability and elevation. Vegetation indices are a new tool that can control for vegetation and new research should help determine the reliability and potential usefulness of such information as an indicator of site-specific environmental amenities.

### 9.6.1 Valuing agricultural land

In Nivens et al. (2002), the authors use a hedonic model to analyze agricultural land value in Kansas. They posit that "the best estimator of agricultural land price variation is probably the underlying productivity of the land parcel sold (page 476)." However, in the absence of publicly available field-specific production data, they use AVHRR NDVI data as a proxy for agricultural productivity. The remote sensing literature supports this use: They cite empirical research that has demonstrated the ability of NDVI to predict agricultural productivity, specifically corn and wheat yields in the Midwest. This sensor has a relatively coarse resolution of 1.1 km<sup>2</sup>, which, in this application, is not an obstacle because of the large size of the agricultural parcels. The authors also use remote sensing to proxy the urban effect and (water) recreational effect (the proportion of land within a 10 mile radius such classified).

The results confirm that NDVI is a statistically significant factor in determining agricultural land value. The NDVI coefficient is positive, meaning that agricultural land with a higher NDVI value (a greener parcel) sold at a higher price per acre, *ceteris paribus*. For example, the model predicts land price at \$590.33/acre with an NDVI value of 134 compared to a lower land price of \$550.09/acre, when the NDVI is just 130. A one-standard deviation increase in the NDVI value at the parcel results in land prices increasing by 7.3%. Note that the authors record NDVI as a digital number (ranging from zero to 255), so it has not been converted to the negative one to one index discussed earlier in the chapter. They conclude that, although NDVI was a significant variable, it only increased the predictive power of the model from 31% to 33% (an approximate 6.5% increase in the adjusted R<sup>2</sup>) and, therefore, that some may question the added value of using such data, particularly given the cost, expertise and time requirements involved in its use. More importantly, the results from this study show that NDVI is a positive and significant variable in explaining agricultural land price variation. A new body of literature seeks to answer whether

or not such vegetation indices can be used in the valuation of exurban and urban environmental amenities.

### *9.6.2 Valuing aesthetic qualities*

Sengupta and Osgood (2003) use a hedonic analysis to investigate the determinants of ranchette land value in Yavapai County, Arizona. Ranchettes are recreational land holdings that support cattle and or horses and offer city dwellers the opportunity to be “weekend cowboys.” The authors use almost 9,000 ranchette sales in the period 1991 to 2000. One of the variables utilized in the model is the greenness of the parcel as measured by NDVI. This variable was not included in order to explicitly value greenness, but to control for otherwise unobserved variation of environmental amenities. The variable was positive and significant, with substantial explanatory power. In the model, a one-percent improvement in the NDVI value increased ranchette values by \$1,416 per acre. The authors stress that the NDVI variable could encompass a lot of information, such lower temperatures, the presence of water, elevation, topology, and contiguity with public land. However, it is possible that NDVI also proxies some aesthetic values connected to a ranchette, particularly in arid and semi-arid lands of Yavapai County, where greenness is scarce.

This study is of interest in that it suggests that there is a detectable signal in NDVI that may proxy valuable amenities. Another hedonic study, not utilizing NDVI, by Torell and Bailey (2000) models ranch values in New Mexico. Even though this work addresses production ranches as opposed to recreational ranchettes, it has similar findings for amenity values. They conclude that only 27% of the market value of large northeastern New Mexico ranches is justified by long-term average livestock returns. They assess the importance of other factors using data from Farm Credit Services appraisers. Their results show that quality of life (amenity) values, such as a scenic location, views and recreational and hunting opportunities, are more important determinants of ranch value than present value long-term commercial returns.

### *9.6.3 Valuing riparian habitat quality*

In more urban arid lands, riparian habitats may be the dominant form of set-aside open space. Riparian habitat is a treed corridor that coincides with perennial, intermittent, or dry streams. In the desert, where views of arid landscapes dominate, these ribbons of green are extraordinary and many desert dwellers cherish them for their recreational and aesthetic values. These ecosystems have been the subject of previous hedonic valuation research. In Colby and Wishart (2002), the authors used a hedonic property model to estimate the value placed on such habitat by nearby residents in semi-arid Tucson, Arizona. They found that by reducing the distance to the riparian corridor from 1.5 miles to 0.1 miles that the sample mean house price rose by 6%. However, this study did not control for any characteristics of the corridors. They did not take into account, that, like houses, riparian habitats in urban

areas are themselves heterogeneous; ranging from concrete-lined ditches to natural habitat.

The complexities of remote sensing ecosystems with fragmented vegetation cover were discussed above. The key paper Nagler et al. (2002) concluded that the remotely sensed vegetation index, NDVI, is closely correlated with on-the-ground measures of vegetation cover. This is an important first step; however, they also concluded that a single TM-resolution NDVI image cannot distinguish between species types. Section 9.2 showed that the biological and aesthetic value of “greenness” is probably dependent on the source of the greenness – that is, greenness derived from weeds probably is not equivalent to the greenness associated with mature native riparian trees. Therefore, in order to analyze whether different states of riparian habitat health impact nearby house prices differently, more information than that provided in such a single NDVI image is required.

In Bark-Hodgins et al. (2005a), the authors assess whether riparian vegetation data collected by trained ecologists can be calibrated with remote sensing data in an urban riparian setting. If these datasets cannot be combined the researcher has to make tradeoffs between the two techniques: Remote sensing data covers a large area and is relatively inexpensive, but the data collected would be difficult to interpret, whereas survey data is comprehensive but expensive and covers a limited area. The authors use parcel and riparian corridor level SAVI data to determine how homebuyers in Tucson value greenness on their lot and at their nearest riparian corridor. The complexity and diversity of this ecosystem, particularly in an urban setting where bank stabilization, flood control infrastructure, groundwater pumping, and river diversions all impact the extent and quality of riparian habitat are arguments for using more than just proximity measures in hedonic valuation models. It also provides a diverse environment in which to test remote sensing data calibrated with survey data.

The variability in the riparian habitat in Tucson prompted the following research questions: Do homebuyers value proximity to a riparian zone differently dependent on the greenness at the nearest wash? And, do homeowners value distinctive riparian habitats differently? In work under way (Bark-Hodgins et al. 2005b) the authors use a hedonic model to answer the proximity and greenness questions. The authors generated a SAVI image for the entire field area and then joined the SAVI values in the GIS to each parcel, survey site and wash “arc” in the riparian corridor.<sup>8</sup> After data cleaning, 9,462 sales were recorded in the study in the period 1998–2003.

We utilize their dataset in this chapter for an exploratory regression to illustrate the potential role of remotely sensed indices in hedonic valuation. We designed the hedonic model with the goal that the hedonic price calculated for the riparian corridor was a net value, following Chao et al. (1998). For example, flood risk, a disamenity coincident to proximity to a riparian corridor, was controlled by a binary variable that equaled one if the parcel was in the FEMA designated 100-year flood zone and zero otherwise. By discounting for such factors and controlling for other positive factors, such as a sought-after school district, we made efforts to recover a more accurate estimate of the hedonic value for the riparian habitat variable.

The regression model comprised typical structural attributes and four environmental variables: Parcel greenness and wash greenness (the SAVI values at the parcel and nearest wash), wash size (CFS1, 4 and 6), and the Euclidean distance to the nearest wash from each parcel in feet. The exploratory model was well explained; see Table 9.1, which includes data on the marginal implicit price (MIP) of each attribute. The exploratory findings suggest that homebuyers pay a premium for parcels that are green (their immediate viewscape) and if their nearest wash is green. Although it is unlikely that any homebuyer would be able to tell the difference between a parcel with a SAVI value of 100 (the lowest value recorded) or 101, they would probably be able to discern that a 198 (the highest value recorded) was unambiguously greener.<sup>9</sup> Why? In a semi-arid environment, SAVI values are closely related to percent vegetation ground cover and healthy vegetation – two measures that are easily assessed by homebuyers. For an approximate 10 percent increase (a 10-unit increase in the SAVI value) at the parcel and at the nearest wash, homebuyers were willing to pay \$9,489 and \$8,680 more, respectively. Homebuyers also preferred smaller “intimate” washes or, conversely, the main wash in the study area. The distance coefficient to the wash was negative – that is, proximity to the wash raises house prices, *ceteris paribus*.

These preliminary findings imply that vegetation-based amenities in a semi-arid environment are indeed capitalized into home prices. Homebuyers pay a premium to live near a riparian corridor and an additional premium to live nearby a green segment of the riparian corridor even when accounting for the greenness in their immediate neighborhood. Following the conclusions of Nagler et al. (2001), NDVI and SAVI are good indicators of land cover in semi-arid riparian ecosystems. The results of the hedonic analysis suggest that homebuyers prefer a higher percent vegetation cover on their lot and at neighboring riparian corridors.

This research has policy implications. Vegetated riparian corridors have significant associated property values in the Tucson region. However, these habitats are threatened directly by infrastructure and river diversions and from meeting growing water demand. Riparian trees require shallow and stable groundwater levels. There is sound economic rationale for riparian habitat protection and restoration and for instream water/wastewater flows because greener riparian corridors raise home values and, in turn, property tax revenue. This research also provides an indication of the cost in terms of private property values of a long-term drought, costs that may not typically be included in drought impact estimates. Note, though, that the results only show that homebuyers prefer vegetated areas – the remote sensing protocol used could not differentiate between vegetation types.

#### 9.6.4 Quality of the estimates

An objective of Bark-Hodgins et al. (2005a) is to test whether remote sensing data can provide more policy-relevant information – that is, whether riparian habitat quality indicators can be derived from widely available remote sensing data. In this case, the authors used a single pre-processed Landsat ETM+ image that has a pixel



size of 30 m<sup>2</sup>. The use of remote sensing data would enable researchers to take an inventory of the state of the riparian corridors over a large area, whereas increasing the number of washes that can be examined in any one study by a plant biologist is time and cost intensive. In this paper, remote sensing was assessed for its efficacy in describing on-the-ground habitat realities.

Vegetation data was collected at 51 stratified-random riparian survey sites in the same field area as Bark-Hodgins et al. (2005b). The stratified-random selection procedure generated a dataset with a variety of habitat qualities. The authors tested to see whether either of the two greenness indices, NDVI or SAVI, could predict survey data, specifically vegetation density (m<sup>3</sup>/m<sup>2</sup>), woody species richness, and hydro and mesoriparian species richness. The results showed that neither vegetation index was a significant predictor of any of these more sophisticated vegetation indicators. The results confirm those found in Nagler et al. (2001) that a single remote sensing image at this resolution is unable to differentiate between plant species, which is essential for studying species-diverse habitats. (Note that the Nagler et al. 2001 study was more sophisticated in that they combined fine scale aerial mapping, remote sensing, and field measurements.) Although the preliminary results were not significant, the coefficient signs were of the expected sign. Fifty-one survey sites is a large dataset for plant biology studies, but it is a small sample size in statistical analysis, particularly in such a diverse ecosystem.

There are many ways that the remote sensing protocol could have been improved. The authors' data choice was based on the availability of free and pre-processed remote sensing data; it, however, had limitations, the most significant of which is the coarse resolution of the pixel compared to the target (i.e. riparian corridors less than 30 m wide). An obvious improvement would be to use finer resolution images, such as from Quickbird (2.44 m<sup>2</sup>). However, such commercial imagery is expensive, costing \$24/km<sup>2</sup> for pre-processed images or \$4,800 for this study. Compounding this issue, the vegetation surveys were completed in spring 2003 before all of the deciduous riparian trees had leafed out, thus the full leafed-out data had to be estimated. In addition to improving the remote sensing protocol, there are data issues that we did not address. The study seeks to understand if the greenness of the parcel and the nearest riparian corridor to the house impact sales price. However, the wash and parcel SAVI data are those from July 1999; a better, though more labor intensive, protocol would have been to generate a SAVI image for each month for each year in the study period 1998–2003 (i.e. 72 sets of SAVI data) and then to link a one- or two-month-lagged SAVI value to each house sale. The lag would be required because of the delay between making an offer on a home (the first viewing of the greenness of the parcel and the nearest wash) and the closing of the sale, which is typically a minimum of one month. In this way, we would know whether the greenness at the time of sale was important in influencing house price. Note that this method would have required us to use not only data from Landsat 7, which was launched April 1999, but also data from Landsat 4 or 5 data to cover the period January 1998–June 1999. Finally, a related point is that the remote sensing image was acquired in July 1999, the second year of the current six-year drought, whilst the survey data was collected



in 2003. Riparian ecosystems are dynamic: Vegetation health and extent responds temporally and spatially to changing water flows resulting from climatic effects and from people's interaction with the environment (Poff et al. 1997). Therefore, in the intervening four years, the riparian habitat is likely to have changed.

Given the statistical limitations of calibrating the survey dataset with remote sensing data the authors decided to use a different analysis to determine whether the premiums identified in Bark-Hodgins et al. (2005b) are affected by the type of riparian vegetation in the corridor. The explanatory power of the vegetation survey dataset was explored in Bark-Hodgins et al. (2005a) by buffering the wash "arcs," or segments, on which the survey sites were located by a 1,056-foot (0.2 miles, 0.32 km) buffer zone. Those homes within the buffer that sold in the study period whose nearest riparian corridor was that surveyed were selected for a hedonic analysis. The advantage of this method is that actual survey data could be used in lieu of SAVI data. The reason this is important, is that SAVI is a measure of greenness regardless of the origin of the greenness.

The regression model included typical structural variables and also habitat variables, specifically vegetation density, the ratio of hydriparian and mesoriparian species in the density measure, and species richness. The model explained 86 percent of house price variation in the 692-sale sample. The preliminary results show that homebuyers positively value a densely vegetated wash, washes with a high overall species richness, and those washes with a greater proportion of hydro and mesoriparian species. The premium for all these factors is 20 percent on the mean home value of \$196,481. The significance of these results is that the source of greenness matters: The type of vegetation in the wash does seem to enter the homebuyer's utility function in different ways. Specific ecosystems are capitalized differently into property values. The results of the hedonic analysis indicate that homebuyers place the most value on those sections of the riparian corridor where water still flows perennially or intermittently. But, such habitats are particularly threatened by continued groundwater over-drafting. Research by Lite and Stromberg (2005) shows that, as streams are dewatered and groundwater levels decline, riparian tree communities shift from higher human valued hydro and mesoriparian species to more mesic species, which have lower value to people. The results have implications for those concerned with water management and riparian habitat preservation and restoration. There are sound economic reasons to limit groundwater pumping, stream diversions and new flood control infrastructure whilst supporting public purchases and rewatering of riparian habitat. Another key implication is that it is important to differentiate between species in a riparian habitat for conservation and riparian restoration reasons and also to more accurately measure associated amenity values.

For the time being, a single image of readily available remote sensing vegetation indices is unable to differentiate species and, therefore, either a modified remote sensing protocol involving multiple images is required or survey data will continue to be important in such amenity valuation studies.

### 9.7 Discussion

The discussion here may lead readers to question the utility of relatively low-resolution (i.e. AVHRR and ETM+ data) remote sensing vegetation indices<sup>10</sup> for determining the source of greenness (i.e. species identification) and, therefore, whether such data is useful in hedonic studies that seek to value vegetation-based environmental amenities. However, such data does provide information on greenness at the crudest level. Crop productivity (Nivens et al. 2002) and vegetation indices are related to vegetation cover (Nagler et al. 2001), which might be an important variable in arid and semi-arid regions. Moreover, NDVI and SAVI can proxy other amenities, such as elevation, water availability, lower temperatures, and wildlife habitat, which might, in fact, be the objective variable in the hedonic study. Furthermore, such studies could be improved specifically to determine species types, as different tree species seem to enter a homebuyer's utility function in different ways (Bark-Hodgins et al. 2005a). The improvement would require the researcher to use a series of NDVI or SAVI images at dates coincident with the known leafing out times of the target species. For example, in semi-arid riparian corridors of the Southwest, the leafing out time of the deciduous hydriparian cottonwood species is earlier than the deciduous mesoriparian mesquite. The remote sensing literature supports the efficacy of combining spectral and such phenology<sup>11</sup> information to differentiate tree species in riparian habitat (Weber and Dunno 2001; Congalton 2002). Using this method a large area inventory of tree species and specific habitat types could be generated relatively inexpensively for use in a large-scale hedonic study of amenity values – for example, for different qualities of riparian habitat in the urban Southwest.

The inclusion of remote sensing data in hedonic analyses is not without complication. Nevertheless, vegetation indices allow researchers to estimate agricultural land productivity and to model habitat quality effects on the value of vegetation-based amenities. The studies presented here also provide suggestions on how to improve remote sensing protocols to better utilize remote sensing data. The use of remotely sensed greenness data in the hedonic analysis of vegetation-based amenities in semi-arid environments does have its limitations. However, remote sensing has considerable promise as a proxy to control for otherwise unobserved characteristics, and, when applied with care, as an indicator of environmental characteristics.

### Endnotes

<sup>1</sup> Remote sensing is the science of acquiring, processing and interpreting measurements acquired from aircraft and satellites (Sabins, 1997); it is the science of observation from a distance (Jensen 2000).

<sup>2</sup> <http://www.co.pima.az.us/cmo/sdcp/>.

<sup>3</sup> All vegetation indices ratio reflectances from the near infrared (NIR) and red bands; the Enhanced Vegetation Index (EVI) has a third band, blue, which is added to correct for atmospheric effects.

- <sup>4</sup> See EROS Data Center <http://edc.usgs.gov/greenness/whatndvi.html>.
- <sup>5</sup> See: <http://edcdaac.usgs.gov/1KM/paper.asp#defn1>.
- <sup>6</sup> See: <http://glcf.umiacs.umd.edu/data/gimms/animations.shtml>.
- <sup>7</sup> Although the distinction between SAVI and NDVI is important in many remote sensing applications, most econometric specifications will adjust for the multiplicative term when a uniform L is assumed.
- <sup>8</sup> In the GIS, the wash coverage consisted of almost 1,000 wash “arcs,” or segments, that together form the riparian corridor. An arc is thus analogous to blocks on a road.
- <sup>9</sup> The range for the riparian corridors was larger: 101–221.
- <sup>10</sup> Note that higher resolution aerial borne image data (Lonard et al. 2000, identified dominant species, not all species) and color-infrared photography data (Davis et al. 2002) is more successful at discriminating individual plant species in riparian habitats.
- <sup>11</sup> Phenology is the study of periodicity phenomena of plants, for example, time of flowering in relation to climate (Abercrombie et al. 1973).

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## APPENDIX B: VALUING PRIVATE AND PUBLIC GREEN SPACE USING REMOTELY SENSED VEGETATION INDICES

Bark-Hodgins R. H., D.E. Osgood, and B. G. Colby

### ABSTRACT

Using remotely sensed vegetation index data the heterogeneity in lot-based and riparian habitat is characterized in metropolitan Tucson, Arizona. The greenness measure is positively correlated with percent ground cover and vegetation health: two features that are also easily discerned by homebuyers. The results of a hedonic property price analysis indicate that homebuyers in the study area have preferences for greener lots and greener riparian corridors. Furthermore, there is some evidence that these preferences are substitutes which could have implications for the efficient use of limited water supplies in this semi-arid metropolitan area.

### INTRODUCTION

A growing body of literature seeks to understand preferences for open space resources. Nearby natural resources such as: open space, lakefront amenities, visibility, views, urban wetlands, coastal water quality, and ecological diversity and connectivity are often capitalized into property values (Irwin & Bockstael, 2001, Geoghegan, 2002, Shultz & King, 2001 and Smith, Poulos & Kim, 2002; Spalatro and Provencher, 2001; Benson et al., 1998 and Paterson and Boyle, 2002; Mahan et al., 2000 and Acharya & Bennett, 2001; Leggett and Bockstael, 2002; and Geoghegan, et al., 1997). A motivation for this research is the desire to provide useful information to natural resource planners in a policy environment of rapid growth and concerns about quality of life. Essential elements

of open space are its presence or absence, its size, its proximity to communities, and the quality of the open space habitat. Geographic information system (GIS) technology has reduced the data collection burden for the first three features of open space. However, another method is required to measure habitat quality because people may care about the lushness of publicly- and privately-owned green space. The challenge is to find a good proxy for lushness and then to identify any relationships between lushness and preferences.

In this paper remotely sensed vegetation index (VI) data is used as a proxy measure for the extent and vigor of lot- and community-based vegetation amenities in Tucson, Arizona. This differentiation between private and public open green space is important from a policy standpoint because although the homebuyer has direct control (at least after some time lag) over vegetation amenities on their lot, through landscaping and watering decisions, the same homebuyer has at most indirect control over community-based vegetation amenities through voter initiatives on preserving open space. Tucson voters approved such an initiative the acclaimed Sonoran Desert Conservation Plan. This plan incorporates a riparian habitat protection and restoration component and this type of habitat is the designated community-based open space in this research.

A small number of studies have combined remote sensing data and economic analysis. Remote sensing products are typically used in one of two ways in such research: to inventory and map land uses and land use change (Millington, et al., 1994) or conversely

to monitor regulatory compliance (Schweik and Thomas, 2002); or by using VIs as a proxy for agricultural productivity (Nivens et al, 2002) or landscape amenity (Sengupta and Osgood, 2003) in property price studies. In this latter study the authors used the normalized difference VI (NDVI) in a hedonic analysis of ranchette land value in Arizona, USA. The authors use almost 9,000 ranchette sales in Yavapai County, Arizona in the period 1991 to 2000 and ten years of NDVI data in their modeling. The results of their analysis show that a one percent improvement in the NDVI value increased per acre value by \$1,416. The authors stress that the NDVI variable encompasses a lot of information: “the explanatory power of NDVI could either be due to the vegetation, or other correlated factors that increase ranchette value (p.99).” Examples are lower temperatures, the presence of water, and contiguity with public land. Another aspect of value could be aesthetic value, this may be particularly important in arid and semi-arid lands where greenness is scarce and therefore commands an added premium. Remote sensing data, when used appropriately can greatly add to the richness of data for economic analysis.

Remote sensing of vegetation in a semi-arid riparian habitat is complicated by the fact that vegetation cover is fragmented and habitats are often species rich; therefore each pixel<sup>1</sup> is a mixture of bare ground and numerous plant species. However, previous research in partially vegetated landscapes has shown that vegetation indices are positively correlated with percent vegetation cover (Carlson and Ripley, 1997 and Nagler *et al.*,

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<sup>1</sup> A pixel, or picture element, is the on-the-ground measuring area of the remote sensing satellite. The Landsat 7 data used in this study has a pixel size of 30m<sup>2</sup>.



2001) and furthermore that percent ground cover is positively correlated with a biological measure of habitat health, the leaf area index (Nagler *et al.*, 2001). This research gives us confidence that vegetation indices can be used to measure meaningful vegetation characteristics; percent ground cover and vegetation vigor, two measures that are also easily assessed by homebuyers. Furthermore remotely sensed data can be used to classify vegetation over a large area: an exercise that would be overly costly using fieldwork surveys.

In the Sonoran Desert where Tucson, Arizona is located natural lush vegetation comprising shrubs and trees is concentrated in and on the banks of the often dry washes (rivers) because of the relative abundance of water availability. Washes channel water downstream after infrequent rainstorms and are areas where groundwater levels tend to be more stable and therefore are areas that can support riparian trees. However, water and residential development have negatively impacted riparian habitats with the result that few stretches of riparian habitat remain in the Tucson basin. To counter this decline policy initiatives, such as the Sonoran Desert Conservation Plan, propose to protect remaining riparian habitat and restore this habitat to some stretches of the riparian corridor. It is thus important to understand preferences for riparian habitat to further inform the policy debate.

In this paper prices of single family residences (SFR) in north central and northeast Tucson, Arizona are estimated using a hedonic price model with typical structural and

neighborhood variables and also two sets of remotely sensed vegetation index data. The greenness index at each wash “arc” or stretch and at each parcel is used as a proxy for the variation in natural habitat extent and quality and also the variation in landscaping at the lot level. The addition of vegetation index data allows us to control more closely for the amenity value of vegetation in this desert city, than could be achieved using other variables such as the distance to the nearest riparian corridor. The remotely sensed vegetation data also allows us to see how homebuyers value different levels of greenness, different sources of greenness, and the interactions between them.

#### DATA

Three different data sets were collected or generated for the research: house sales and associated assessed characteristics, geographic information system (GIS) data, including a riparian corridor dataset, and remotely sensed vegetation indices. These datasets provided the information for the variables comprising the vector of structural (**S**), neighborhood (**N**) and environmental (**E**) characteristics.<sup>2</sup> The source of the residential sales data and assessed structural characteristics was Pima County. 9,405 single family residence sales data for the period 1998-2003 (**P**) were joined each year to the Assessor’s data on structural characteristics (**S**) by the unique parcel identification number. The vector **E** incorporated remotely sensed vegetation index data.

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<sup>2</sup> SAS 9.0 for Windows and Stata 7.1 were used in the data analysis. The geographically-referenced data was processed mostly in the more powerful ArcInfo program but the resulting data was imported into ArcView 3.3 for mapping.

The VI data was calculated from a single Landsat Enhanced Thematic Mapper Plus (ETM+) image with the acquisition date July 30, 1999.<sup>3</sup> This preprocessed image was available through the Arizona Regional Image Archive. The metadata recorded preprocessing steps. The image had been corrected for geometric and radiometric distortions or errors, thereby eliminating the need for such expertise. The choice of acquisition date was determined by phenology. The mid-summer date coincides with the full leafing out point of riparian species and therefore is an optimal remote sensing date to measure peak vegetation extent and health. Two vegetation indices the normalized-difference vegetation index (NDVI) and the soil-adjusted vegetation index (SAVI, Huete, 1988) were generated. SAVI was chosen as the most appropriate vegetation index for this study because it has been explicitly modified from NDVI for remote sensing in areas where a vegetative groundcover is fragmented. It does this by adjusting the index for the brightness, or reflectivity, of the background soil (Huete and Liu, 1994). The SAVI variable is incorporated into the model as a digital number (DN). The possible range of SAVI in DNs is from 0 to 255, but the actual range of greenness in our study area was narrower: 100-198 for the parcels and 101-221 for the riparian corridors.

The study area covers 200 km<sup>2</sup> and contains a total 380 km of riparian corridors. Values from our chosen vegetation index, the soil adjusted vegetation index (SAVI) were joined to the georeferenced riparian corridor (Figure 1) and parcel data (Figure 2) in a GIS. At

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<sup>3</sup> The results presented in this paper incorporate sales data from 1998-2003, however, we also modeled only those sales in 1999. The signs and magnitudes of the coefficients for the OLS and IV 2SLS models are very similar for the six year period and 1999 data only: the 1999-data models explain slightly more of the variation in prices (Adjtd R<sup>2</sup>=0.88 and 0.84, respectively).

this stage the SAVI image was smoothed<sup>4</sup> to resolve a slight geographic offset between the raster data and GIS coverages. The smoothing of SAVI data at the parcel level has a beneficial outcome in that it accounts for neighborhood effects and is part of our identification strategy. Although the parcel owner has control over their parcel's SAVI value through landscaping and irrigation decisions, the owner cannot control what their neighbors do; therefore smoothing over a larger area filters out some endogeneity.

Nevertheless, there were remaining concerns about endogeneity. Using the Hausman test the SAVI variables were tested for endogeneity. This test assumes that the model and instruments chosen are appropriate. The results of this test found evidence at the tenth of a percent level that endogeneity was present in both SAVI-based variables (LOTSAVI and WASHSAVI); therefore it was decided to instrument these variables (and an interaction variable LOTWASH) and run an instrumental variable two stage least squares (IV 2SLS) regression. The choice of instruments is fraught with difficulties: the instrument must be highly correlated with the endogenous variable but must not suffer from the same problems as it, namely correlation with the error term.

In choosing instruments for WASHSAVI and LOTSAVI we relied on the physical determinants of natural vegetation distribution such as aspect, slope, and soil types (NORTH, SOUTH, EAST, WEST, SHALLOW, STEEP, STEEPEST, SOIL18, SOIL34,

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<sup>4</sup> This spatial filtering procedure used an algorithm which assigned a weighted average to each pixel in a 5x5 pixel neighborhood. The algorithm weighs the center pixel the most and therefore is not a straight averaging mechanism.

SOIL49, SOIL51, SOIL52)<sup>5</sup>, and also Census, riparian characterization, and space instruments. The Census tract-based instruments were chosen with the intention of instrumenting LOTS<sub>AVI</sub>. The three variables a priori might explain greener lots: the percent of owner-occupied homes in each tract (%OO), the percent of non-workforce population as a proxy for retirees and stay-at-home parents and children (%NON-LAB), and the percent employed (%EMPD). Two instruments characterizing the physical condition of the riparian corridor were chosen they are: BANK\_PROTN which is a binary variable equal to one if the riparian corridor has been bank protected (concrete-lined) and CFS\_NO which describes the size of the corridor: CFS1 is the smallest designation and CFS6 denotes the largest washes in the study area. A final group of instruments describe space: POP\_DENS is the density of each Census tract a priori it might be expected that less dense areas support more natural vegetation, and the X and Y coordinates of each house in the study area (X-CRD and Y-CRD).

#### ESTIMATION

After Rosen (1974) the following semi-log hedonic model was estimated<sup>6</sup> using ordinary least squares estimation with robust estimators.

$$\ln(\mathbf{P}_i) = [\mathbf{S}_i, \mathbf{N}_i, \mathbf{E}_i, \mathbf{T}_i]' \boldsymbol{\beta} + \boldsymbol{\varepsilon}_i \quad [1]$$

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<sup>5</sup> The soil types are Pinaleno-Nickel-Palos Verdes, Anklam-Pantano-Chimenea, Tanque-RiverRd-Arizo-Riggs, Hayhook-Sonoita and Mohave-Sahuarita-Cave, respectively.

<sup>6</sup> Box-Cox procedures recovered a transformation parameter of -0.777. We present and discuss the log linear estimates because they, are relatively easy to interpret, and comparable with much of the hedonic literature.

Where,  $\ln(\mathbf{P})$  is a vector of the log of house sales prices. The structural vector  $\mathbf{S}$  consists of typical hedonic variables, lot size  $100 \text{ m}^2$  (LOT), living area  $\text{m}^2$  (LIVING), number of bath fixtures<sup>7</sup> (BATH), age in years (AGE), and also less familiar features that are important in the desert heat: number of garage spaces (GARAGE) and pool area  $\text{m}^2$  (POOL). Neighborhood variables are also important in explaining house price variation in the study area. Three variables were identified and incorporated in the neighborhood vector,  $\mathbf{N}$ : school districts, flood district and golf course variables. Two binary variables identified the Catalina Foothill School District (CFSD); the elite school district in the area, and the Tanque Verde School District (TVSD): both are compared to the lower-achieving Tucson Unified School District (TUSD). Another binary variable was set equal to one if the property is within the Federal Emergency Management Agency flood zone and equal to zero otherwise (FLOOD); properties with such a designation are at risk of floods and also are required to purchase mandatory flood insurance if they have a mortgage. Golf courses have been identified as significant variables in explaining house price variation (Do and Grudnitski, 1995) and therefore are incorporated into this model. ADJTGOLF is a binary variable that equals one if the property is located either on a golf course or immediately adjacent to a golf course and zero otherwise, and DISTGOLF is the distance from each property to the nearest golf course in kilometers. A final variable ELEV measures the elevation of each property in meters above sea level. It is a proxy variable for view and marginally lower summer time temperatures.

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<sup>7</sup> Three bath fixtures is equivalent to a full or half bath and two bath fixtures to a half bath.

The environmental variables were chosen to characterize the heterogeneity in open space resources and accessibility to these resources. The **E** vector consists of the SAVI measure at each lot (LOTSAVI ) and at the nearest riparian corridor to each property (WASHSAVI) and the interacted variable (LOTWASH). A binary variable tests homebuyers' preferences for a property that is adjacent to, and therefore has a view of and access to, a riparian corridor (ADJTWASH). This variable may also incorporate privacy benefits resulting from County regulations that forbid building in a floodway. DISTWASH measures the distance from each parcel to the nearest wash in kilometers. In order to account for SFR property appreciation for the **T** vector dummies for the year of sale (D99-D03) were generated and are compared to sales in 1998.

The mean house sales price in the study area in the period was \$224,731. Tables 1 and 2 below report variable descriptions and also summary statistics for the variables used in the model.

#### RESULTS: OLS

OLS results are presented first followed by the IV 2SLS results. The OLS robust estimators for the benchmark model are provided in Table 3 with the marginal implicit prices (MIP). The results demonstrate that homebuyers in this market prefer newer, larger houses on larger lots, with more garage spaces and a larger swimming pool. ELEV is also positive and significant indicating that homebuyers in this market have preferences for higher elevations: this result may proxy premiums for a view. The model predicts

premiums associated with the two school districts, CFSD and TVSD, compared to the lower-achieving TUSD. This result is expected: realtors in this area spotlight these school districts, in particular the high-achieving CFSD in their sales literature. The discount for FLOOD is also expected.

The adjacency variables (ADJTWASH and ADJTGOLF) are both significant at the ten percent level and the expected sign. The ADJTGOLF variable is over three times larger than the ADJTWASH variable which is to be expected given the heterogeneity of washes in the study area: some are concrete lined and weed filled whilst others are almost 'pristine' habitats. The distance measures are also significant but of different signs. Homebuyers in this area are only willing to pay premiums for proximity to washes (DISTWASH) not for proximity to golf courses (DISTGOLF). This result is somewhat unexpected but may be capturing the fact that washes are community, open space recreation resources that can be accessed by nearby homeowners whereas golf courses restrict access to golfers and therefore are closed to nearby residents.

The two SAVI variables indicate that homebuyers have preferences for greenness at the lot level and in their nearest riparian corridor. The coefficients for the WASHSAVI and LOTSAVI are very similar, furthermore, the significant and negative WASHLOT coefficient indicates that a homebuyer living near a greener wash values a greener lawn less and vice versa, that is there is evidence that these vegetated areas are substitutes. The



significance of the greenness variables also indicate that it is important to control for the heterogeneity in vegetated-amenities at least in this desert city.

#### RESULTS: IV 2SLS

The first-stage regression results are provided in Tables 4a-4c. The instruments chosen for LOTSAPI performed particularly well (Adjusted  $R^2=0.53$ ) and slightly less well for WASHAPI (Adjusted  $R^2=0.45$ ). The results for the interaction variable LOTWASH are shown in Table 4c. For the instrumented LOTSAPI variable positive and significant instruments at the 10 percent level are: northern exposures (NORTH), two of the Census variables as expected (%NON-LAB, %EMPD), CFS\_NO and Y-CRD. The CFS\_NO results shows that parcels are greener near larger washes: in fact very large washes in the area sometimes support wide, mesquite-tree woods that extend into nearby lots. The Y-CRD results suggests that parcels further north in the study area are greener, this may reflect that these northern most parcel about US National Forest land and were developed with greater care. Many of the soil variables are negative and significant with the exception of SOIL49. Without more knowledge of the relationships between soils and vegetation we can only suggest that some soils are more suitable for vegetation establishment. The POP\_DENS variable as expected was negative and significant.

The results for WASHAPI indicate that those washes which run east-west in the study area are less green (EAST, WEST). This describes one of the main washes in the study area, the Rillito River: although there are areas of dense vegetation along this wash other

sections have been flood protected and are degraded. In fact the BANK\_PROTN variable is a negative and significant instrument. The CFS\_NO instrument suggests that larger washes are greener. Again as with the LOTSAVI results some of the soil variables are significant. The Census variables are as expected except for %OO; the negative result might suggest that, at least in the past, homeowners have pressured the county to flood protect their neighborhoods resulting in concrete-lined, less green washes. The POP\_DENS results are as expected. Those areas with lighter populations can perhaps preserve more open space resources. Finally the X- and Y-CRD results suggest that areas in the north and east have greener washes. This describes the least developed regions in the study area.

The IV (2SLS) regression with robust standard errors results are shown in Table 5. There are some noticeable differences with the OLS estimation. The coefficients for the SAVI variables are much higher. This result suggests that vegetation amenities are highly significant in explaining house price variation in the study area. The IV estimation cancels out the premium associated with proximity to a wash (DISTWASH): proximity per se is less important to homeowners than the greenness of their nearest wash. This estimation reduces the discount on the FLOOD variable perhaps capturing the (vegetation) amenity value of flood zones. The premiums for the school districts are also reduced which demonstrates that it is important in a hedonic study to disentangle neighborhood (schools and environmental) effects. The coefficient for ELEV is higher in the IV 2SLS estimation; higher elevations may receive more precipitation and benefit

from lower temperatures. One troubling result is the ADJTGOLF result. The coefficient is very large in the IV estimation and could be a sign that there are some problems with the model or the instruments chosen, or, it could signify the very large premiums paid in the semi-arid Tucson metropolitan area for a location on an exclusive and green golf resort.

#### CONCLUDING REMARKS

Homebuyers in our study area value greenness that they can control with some time lag, LOTSAMI and also greenness that they cannot directly control WASHAMI. These results raise an interesting policy question because there is no water right for the environment or more specifically for the riparian commons. It is likely that washes are underwatered whilst parcels are more likely to be optimally green<sup>8</sup> as this is greenness that the homebuyer can influence through landscaping and watering. Although washes are for the most part private property, because property lines typically extend to the wash centerline, the vegetation supported in the riparian corridors is a common good because of the water rights system in Arizona.

Beginning in the 1870s surface water rights in the state were allocated by the prior appropriation doctrine (first in line first in right). Later a requirement of beneficial use was added: significantly instream flows were not viewed as beneficial. Meanwhile groundwater pumping rights are appurtenant to land and there are few controls to restrict

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<sup>8</sup> It could be that they are less green than optimal because of externalities. Neighbor A might benefit from Neighbor B's watering and landscaping but is unable to influence Neighbor B's behavior.

groundwater pumping which contributes to degraded riparian habitat. Finally surface and ground waters are not managed conjunctively in the state that is the hydrologic connection between groundwater and surface waters is not recognized in law or water management. One outcome of Arizona's water rights and water management rules is that once flowing rivers now run dry, except after rain, in Tucson because the aquifers sustaining them were exploited at rates exceeding their natural recharge rates. This process of dewatering negatively impacts riparian habitat: recent research shows that as groundwater levels decline, riparian tree communities shift from more ecologically valued shallow groundwater-dependent riparian species to lower value dryland and invasive species communities or to bare ground (Lite and Stromberg, 2005). Such shifts in turn may negatively impact nearby private property values if degraded habitats are less green.

Plans such as the Pima County's Sonoran Desert Conservation Plan that propose to return flows (wastewater) to some portion of the riparian network to conserve and rehabilitate riparian habitat would likely be supported by this study's results. Significantly, at least in some areas of this study area, for example in neighborhoods that ridge riparian corridors (in essence where their backyards are washes), it may be more efficient to return water to/leave water in the washes as homebuyers have preferences for wash greenness (WASHSAVI) which in turn can substitute (LOTWASH)for landscape greenness (LOTSAVI).

The results from this paper also suggest that it is worthwhile to account for the heterogeneity of open space and landscape greenness: this is perhaps particularly relevant in a desert city where the supply of vegetation amenities is limited and therefore commands additional premiums that are significant determinants of SFR price variation.

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## TABLES AND FIGURES

**Table 1: Variable names and definitions**


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<i>Dependent variable</i>	
LNSALESP	Log of unadjusted sales price
<i>Home structure</i>	
LOT	Lot size, 100 m <sup>2</sup>
LIVING	Living area, m <sup>2</sup>
AGE	Age of house in years
BATH	Number of bath fixtures
GARAGE	Number of garage spaces
CARPORT	Number of carport spaces
POOL	Pool size, m <sup>2</sup>
<i>Neighborhood variables</i>	
CFSD	Binary variable equal to one if school district is Catalina Foothills and equal to zero otherwise
TVSD	Binary variable equal to one if school district is Tanque Verde and equal to zero otherwise
ELEV	Elevation of property in meters above sea level
FLOOD	Binary variable equal to one if house is in the Federal Emergency Management Agency flood zone and equal to zero otherwise
<i>Amenity variables</i>	
LOTSAVI	SAVI DN value at parcel, DN
WASHSAVI	SAVI DN value at nearest riparian corridor, DN
LOTWASH	LOTSAVI*WASHSAVI
ADJTWASH	Binary variable equal to one if house is adjacent to a riparian corridor and equal to zero otherwise
DISTWASH	Distance from each parcel to nearest wash in kilometers
ADJTGOLF	Binary variable equal to one if house is adjacent to a golf course and equal to zero otherwise
DISTGOLF	Distance from each parcel to nearest wash in kilometers
<i>Appreciation</i>	
APPREC	Measure of general house price inflation (Year 2003 minus year of sale)
D99-D03	Binary variable for year of sale, 1999-2003 compared to a sale in 1998

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**Table 2: Summary Statistics**

<b>Variable</b>	<b>Mean</b>	<b>Std. Dev.</b>	<b>Min</b>	<b>Max</b>
SALESP	224,731.14	166,386.76	34,000.00	4,500,000.00
LOT	25.38	51.21	1.57	3,350.63
LIVING	194.68	67.96	42.08	1,012.70
AGE	23.40	13.75	0.00	76.00
BATH	2.24	1.96	1.00	9.00
GARAGE	1.26	1.16	0.00	5.00
POOL	17.59	22.12	0.00	185.24
CFSD	0.17	0.38	0.00	1.00
TVSD	0.10	0.30	0.00	1.00
FLOOD	0.03	0.17	0.00	1.00
ADJTGOLF	0.03	0.17	0.00	1.00
ADJTWASH	0.18	0.38	0.00	1.00
ELEV	806.98	35.28	751.89	1,069.75
DISTGOLF	3.12	3.69	0.42	13.97
DISTWASH	0.28	0.24	0.00	1.16
D99	0.18	0.38	0.00	1.00
D00	0.17	0.37	0.00	1.00
D01	0.16	0.37	0.00	1.00
D02	0.16	0.37	0.00	1.00
D03	0.16	0.37	0.00	1.00
LOTSAVI	126.07	9.87	100.00	198.00
WASHSAVI	128.30	10.61	101.00	221.00
LOTWASH	838,247.05	13,637.49	816,582.25	883,378.56

**Table 3: Benchmark model: OLS with robust estimators and MIP**

<b>LNSALESP</b>	<b>Coef.</b>	<b>Std Err.</b>	<b>t</b>	<b>P&gt; t </b>	<b>[95% Conf. Interval]</b>		<b>MIP</b>
LOT	0.0014	0.0005	3.05	0.002	0.0005	0.0024	342.62
LIVING	0.0040	0.0001	26.77	0	0.0037	0.0043	978.92
AGE	-0.0051	0.0003	-15.18	0	-0.0058	-0.0044	(1,248.13)
BATH	0.0131	0.0022	6.02	0	0.0088	0.0173	3,205.98
GARAGE	0.0266	0.0030	8.97	0	0.0208	0.0324	6,509.84
POOL	0.0016	0.0001	15.06	0	0.0014	0.0018	391.57
CFSD	0.0866	0.0093	9.35	0	0.0685	0.1048	21,193.70
TVSD	0.0400	0.0187	2.14	0.033	0.0033	0.0767	9,789.24
FLOOD	-0.0711	0.0161	-4.41	0	-0.1027	-0.0394	(17,400.37)
ELEV	0.0014	0.0002	9.34	0	0.0011	0.0017	342.62
ADJTGOLF	0.0453	0.0253	1.79	0.073	-0.0042	0.0948	11,086.31
ADJTWASH	0.0134	0.0075	1.8	0.073	-0.0012	0.0281	3,279.40
DISTWASH	-0.0331	0.0088	-3.78	0	-0.0503	-0.0160	(8,100.60)
DISTGOLF	0.0063	0.0009	7.35	0	0.0046	0.0080	1,541.81
D99	0.0703	0.0063	11.09	0	0.0579	0.0827	17,204.59
D00	0.1260	0.0065	19.27	0	0.1132	0.1388	30,836.11
D01	0.1840	0.0066	27.88	0	0.1711	0.1970	45,030.50
D02	0.2527	0.0067	37.49	0	0.2395	0.2659	61,843.52
D03	0.3276	0.0072	45.54	0	0.3135	0.3417	80,173.88
WASHSAVI	0.0131	0.0016	8.12	0	0.0099	0.0163	3,205.98
LOTSAVI	0.0153	0.0017	8.86	0	0.0119	0.0187	3,744.38
LOTWASH	-0.0001	0.0000	-6.3	0	-0.0001	-0.0001	(24.47)
CONSTANT	7.6344	0.2729	27.98	0	7.0995	8.1693	

N=9,382  
F=1,935.99  
Adj R<sup>2</sup>=.866

Table 4a: First stage regression

WASHSAVI	Coef.	Std Err.	t	P> t	[95% Conf. Interval]	
LOT	0.0077	0.0018	(1.19)	0.24	0.0042	0.0113
LIVING	0.0036	0.0022	1.67	0.10	-0.0006	0.0079
AGE	0.0594	0.0115	5.17	0	0.0369	0.0820
BATH	-0.0695	0.0586	(1.19)	0.24	-0.1843	0.0453
GARAGE	0.6335	0.1083	5.85	0	0.4213	0.8458
POOL	-0.0172	0.0041	(4.24)	0	-0.0252	-0.0093
CFSD	-4.1530	0.4623	(8.98)	0	-5.0592	-3.2469
TVSD	-0.3866	0.5168	(0.75)	0.45	-1.3995	0.6264
FLOOD	3.0318	0.5168	5.87	0	2.0187	4.0448
ELEV	0.0206	0.0051	4.02	0	0.0106	0.0306
ADJTGOLF	23.0530	0.5217	44.19	0	22.0304	24.0756
ADJTWASH	-0.0803	0.2431	(0.33)	0.74	-0.5569	0.3962
DISTWASH	-1.7386	0.4607	(3.77)	0	-2.6417	-0.8355
DISTGOLF	0.0108	0.0314	0.34	0.73	-0.0508	0.0725
D99	-0.4532	0.2788	(1.63)	0.10	-0.9997	0.0934
D00	-0.4217	0.2833	(1.49)	0.14	-0.9770	0.1336
D01	-0.6733	0.2852	(2.36)	0.02	-1.2325	-0.1142
D02	-0.4446	0.2872	(1.55)	0.12	-1.0075	0.1183
D03	-0.4386	0.2901	(1.51)	0.13	-1.0074	0.1301
NORTH	-0.4212	0.6891	(0.61)	0.54	-1.7719	0.9296
SOUTH	-1.0607	0.6934	(1.53)	0.13	-2.4198	0.2985
EAST	-2.7020	0.7060	(3.83)	0	-4.0858	-1.3182
WEST	-1.2881	0.6826	(1.89)	0.06	-2.6261	0.0498
SHALLOW	0.7443	0.6735	1.11	0.27	-0.5758	2.0645
STEEP	1.4162	0.8940	1.58	0.11	-0.3362	3.1686
STEEPEST	-4.2748	2.0751	(2.06)	0.04	-8.3425	-0.2072
SOIL18	0.4980	0.6806	0.73	0.46	-0.8363	1.8322
SOIL34	-1.6909	0.8031	(2.11)	0.04	-3.2651	-0.1167
SOIL49	1.8741	0.6830	2.74	0.01	0.5352	3.2130
SOIL51	-1.1623	0.7770	(1.50)	0.14	-2.6854	0.3607
SOIL52	1.9712	0.6457	3.05	0.002	0.7054	3.2369
%OO	-0.1072	0.0093	(11.54)	0	-0.1254	-0.0890
%NON-LAB	0.0557	0.0191	2.91	0.004	0.0182	0.0933
%EMPD	0.5667	0.0594	9.54	0	0.4502	0.6832
BANK_PROTN	-6.1712	0.3371	(18.31)	0	-6.8319	-5.5105
CFS_NO	1.0525	0.0692	15.21	0	0.9169	1.1881
POP_DENS	-2.5561	0.2993	(8.54)	0	-3.1428	-1.9694
X-CRD	0.0001	0.0000	5.48	0	0.0001	0.0001
Y-CRD	0.0006	0.0000	26.35	0	0.0005	0.0006
CONSTANT	-274.3970	21.3639	(12.84)	0	-316.2749	-232.5191

N=9,382

F(39, 9,342)=200.66

Adj R<sup>2</sup>=0.454

Table 4b: First stage regression

LOTSAVI	Coef.	Std Err.	t	P> t	[95% Conf. Interval]	
LOT	0.0089	0.0016	0.56	0.579	0.0058	0.0119
LIVING	0.0061	0.0019	3.22	0.001	0.0024	0.0098
AGE	0.1639	0.0099	16.51	0	0.1444	0.1833
BATH	0.0281	0.0506	0.56	0.579	-0.0710	0.1272
GARAGE	0.4352	0.0935	4.66	0	0.2520	0.6184
POOL	-0.0072	0.0035	-2.06	0.039	-0.0141	-0.0004
CFSD	-2.1048	0.3990	-5.27	0	-2.8870	-1.3226
TVSD	5.1785	0.4461	11.61	0	4.3041	6.0529
FLOOD	7.3165	0.4461	16.40	0	6.4420	8.1910
ELEV	0.0069	0.0044	1.57	0.117	-0.0017	0.0156
ADJTGOLF	20.8794	0.4503	46.37	0	19.9967	21.7621
ADJTWASH	0.9508	0.2099	4.53	0	0.5394	1.3621
DISTWASH	-3.5820	0.3977	-9.01	0	-4.3616	-2.8024
DISTGOLF	0.0035	0.0271	0.13	0.896	-0.0497	0.0567
D99	-0.4510	0.2407	-1.87	0.061	-0.9227	0.0208
D00	-0.9151	0.2445	-3.74	0	-1.3945	-0.4358
D01	-0.8472	0.2462	-3.44	0.001	-1.3299	-0.3646
D02	-0.9776	0.2479	-3.94	0	-1.4635	-0.4917
D03	-1.0689	0.2505	-4.27	0	-1.5598	-0.5779
NORTH	1.2168	0.5948	2.05	0.041	0.0508	2.3828
SOUTH	0.4235	0.5985	0.71	0.479	-0.7497	1.5967
EAST	-0.5644	0.6094	-0.93	0.354	-1.7590	0.6301
WEST	0.2899	0.5892	0.49	0.623	-0.8651	1.4448
SHALLOW	-0.8911	0.5814	-1.53	0.125	-2.0307	0.2484
STEEP	-1.1582	0.7717	-1.50	0.133	-2.6709	0.3545
STEEPEST	-1.4755	1.7913	-0.82	0.410	-4.9868	2.0358
SOIL18	-1.6611	0.5875	-2.83	0.005	-2.8128	-0.5094
SOIL34	-3.6058	0.6932	-5.20	0	-4.9647	-2.2470
SOIL49	1.0690	0.5896	1.81	0.070	-0.0867	2.2248
SOIL51	-1.7431	0.6707	-2.60	0.009	-3.0579	-0.4284
SOIL52	-0.9002	0.5574	-1.62	0.106	-1.9928	0.1924
%OO	-0.0102	0.0080	-1.27	0.204	-0.0259	0.0055
%NON-LAB	0.0278	0.0165	1.69	0.092	-0.0045	0.0602
%EMPD	0.1598	0.0513	3.12	0.002	0.0593	0.2604
BANK_PROTN	-0.3094	0.2910	-1.06	0.288	-0.8797	0.2610
CFS_NO	0.6114	0.0597	10.24	0	0.4943	0.7284
POP_DENS	-0.8270	0.2583	-3.20	0.001	-1.3334	-0.3205
X-CRD	0.0000	0.0000	-0.61	0.544	0.0000	0.0000
Y-CRD	0.0004	0.0000	24.03	0	0.0004	0.0005
CONSTANT	-95.7419	18.4418	-5.19	0	-131.8917	-59.5920

N=9,382  
F(39, 9,342)=270.76  
Adj R<sup>2</sup>=0.529

Table 4c: First stage regression

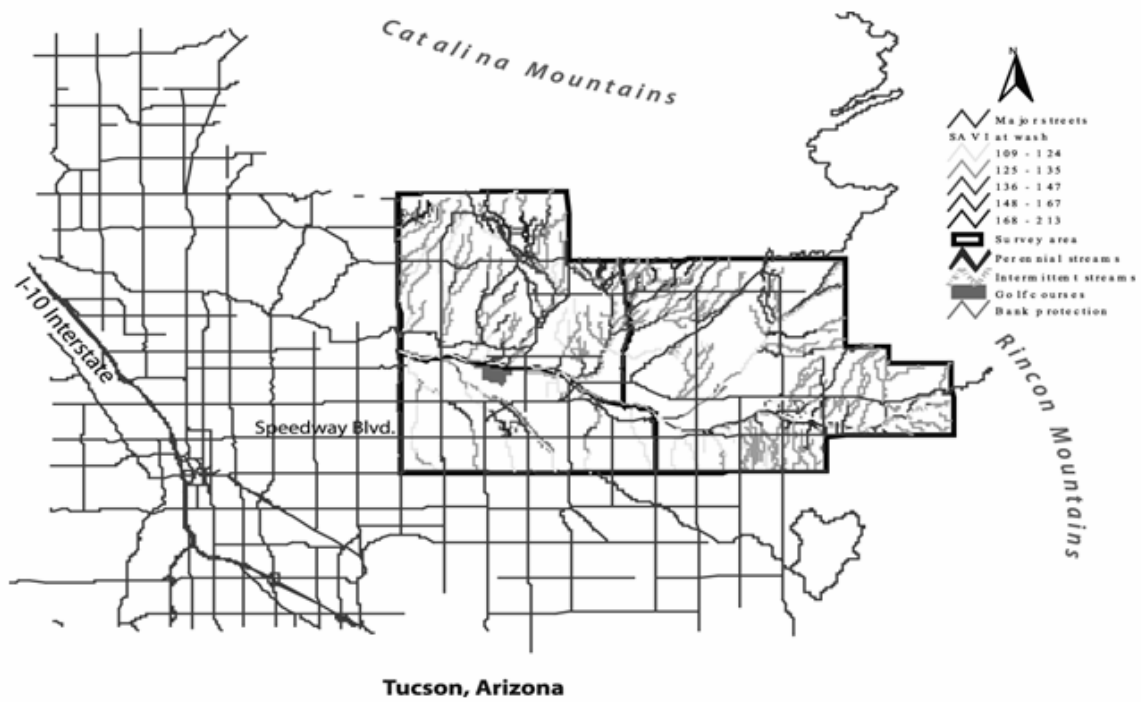
LOTWASH	Coef.	Std Err.	t	P> t	[95%Conf.Interval]	
LOT	2.133	0.382	-0.05	0.96	1.38	2.88
LIVING	1.185	0.461	2.57	0.01	0.28	2.09
AGE	29.506	2.423	12.18	0	24.76	34.26
BATH	-0.635	12.346	-0.05	0.96	(24.84)	23.57
GARAGE	134.890	22.819	5.91	0	90.16	179.62
POOL	-3.199	0.857	-3.73	0	(4.88)	(1.52)
CFSD	-783.342	97.440	-8.04	0	(974.35)	(592.34)
TVSD	513.491	108.924	4.71	0	299.98	727.01
FLOOD	1456.255	108.937	13.37	0	1,242.72	1,669.79
ELEV	3.896	1.078	3.62	0	1.78	6.01
ADJTGOLF	6453.973	109.959	58.69	0	6,238.43	6,669.52
ADJTWASH	149.650	51.243	2.92	0	49.20	250.10
DISTWASH	-675.911	97.111	-6.96	0	(866.27)	(485.55)
DISTGOLF	-3.329	6.628	-0.50	0.62	(16.32)	9.66
D99	-113.509	58.771	-1.93	0.05	(228.71)	1.69
D00	-181.509	59.708	-3.04	0	(298.55)	(64.47)
D01	-209.805	60.125	-3.49	0	(327.66)	(91.95)
D02	-196.119	60.527	-3.24	0	(314.77)	(77.47)
D03	-204.880	61.156	-3.35	0	(324.76)	(85.00)
NORTH	80.276	145.243	0.55	0.58	(204.43)	364.99
SOUTH	-83.485	146.148	-0.57	0.57	(369.97)	203.00
EAST	-448.112	148.803	-3.01	0	(739.80)	(156.43)
WEST	-149.190	143.872	-1.04	0.30	(431.21)	132.83
SHALLOW	11.495	141.955	0.08	0.94	(266.77)	289.76
STEEP	23.044	188.432	0.12	0.90	(346.32)	392.41
STEEPEST	-738.778	437.396	-1.69	0.09	(1,596.17)	118.61
SOIL18	-152.171	143.468	-1.06	0.29	(433.40)	129.06
SOIL34	-718.102	169.273	-4.24	0	(1,049.91)	(386.29)
SOIL49	365.603	143.973	2.54	0.01	83.38	647.82
SOIL51	-419.789	163.776	-2.56	0.01	(740.82)	(98.75)
SOIL52	157.080	136.105	1.15	0.25	(109.72)	423.88
%OO	-15.415	1.958	-7.87	0	(19.25)	(11.58)
%NON-LAB	10.909	4.033	2.70	0.01	3.00	18.82
%EMPD	89.328	12.526	7.13	0	64.78	113.88
BANK_PROTN	-820.736	71.047	-11.55	0	(960.00)	(681.47)
CFS_NO	216.542	14.582	14.85	0	187.96	245.13
POP_DENS	-410.715	63.083	-6.51	0	(534.37)	(287.06)
X-CRD	0.014	0.004	4.05	0	0.01	0.02
Y-CRD	0.130	0.004	29.13	0	0.12	0.14
CONSTANT	(67,833.27)	4,503.13	-15.06	0	(76,660.39)	(59,006.15)

N=9,382  
F(39, 9,342)=323.47  
Adj R<sup>2</sup>=0.573

Table 5: IV 2SLS

	Coef.	Std Err.	t	P> t	[95% Conf. Interval]	
LOTSAVI	0.1265	0.0157	8.06	0	0.0957	0.1573
WASHSAVI	0.1134	0.0156	7.28	0	0.0829	0.1439
LOTWASH	-0.0009	0.0001	-6.94	0	-0.0011	-0.0006
LOT	0.0013	0.0004	3.37	0.001	0.0006	0.0021
LIVING	0.0037	0.0001	26.15	0	0.0035	0.0040
AGE	-0.0071	0.0004	-16.31	0	-0.0079	-0.0062
BATH	0.0162	0.0025	6.41	0	0.0112	0.0211
GARAGE	0.0153	0.0036	4.23	0	0.0082	0.0224
POOL	0.0016	0.0001	12.05	0	0.0014	0.0019
CFSD	0.0303	0.0120	2.52	0.012	0.0067	0.0539
TVSD	-0.0710	0.0197	-3.61	0	-0.1096	-0.0325
FLOOD	-0.0508	0.0332	-1.53	0.125	-0.1158	0.0142
ELEV	0.0018	0.0002	7.69	0	0.0014	0.0023
ADJTGOLF	0.4608	0.1084	4.25	0	0.2483	0.6732
ADJTWASH	0.0304	0.0098	3.1	0.002	0.0112	0.0496
DISTWASH	0.0287	0.0119	2.42	0.016	0.0054	0.0520
DISTGOLF	0.0008	0.0009	0.9	0.368	-0.0010	0.0026
D99	0.0800	0.0097	8.25	0	0.0610	0.0990
D00	0.1311	0.0095	13.77	0	0.1125	0.1498
D01	0.1861	0.0087	21.38	0	0.1690	0.2032
D02	0.2569	0.0089	28.72	0	0.2394	0.2744
D03	0.3350	0.0096	34.86	0	0.3161	0.3538
CONSTANT	-6.7756	2.0792	-3.26	0.001	-10.8513	-2.6999
Instrumented:	LOTSAVI WASHSAVI LOTWASH					
Instruments:	LOT, LIVING, AGE, BATH, GARAGE, POOL, CFSD, TVSD, FLOOD, DISTGOLF, ADJTGOLF, DISTWASH, ADJTWASH, ELEV, D99, D00, D01, D02, D03, NORTH, SOUTH, EAST, WEST, SHALLOW, STEEP, STEEPEST, SOIL18, SOIL34, SOIL49, SOIL51, SOIL52, %OO, %NON_LAB, %EMPD, POP_DENS, BANK_PROTN, CFS_NO, X-CRD, Y-CRD					
N=9,382						
F (22, 9,539)=1,337.25						
R <sup>2</sup> =0.771						





**Figure 1: Study area with riparian corridor SAVI values**



**Figure 2: Study area with parcel SAVI values: darker colors represent greener lots**

APPENDIX C: UNDERSTANDING PREFERENCES FOR ENVIRONMENTAL  
CHARACTERISTICS: CAN HOMEBUYERS DISTINGUISH BETWEEN  
DEGRADED GREENSPACE AND HEALTHY HABITAT?

R. H. Bark-Hodgins\*, D. E. Osgood<sup>†</sup>, B. G. Colby<sup>‡</sup>, G. Katz<sup>±</sup>, J. Stromberg\*.

\* Ph.D. Candidate, Office of Arid Land Studies, The University of Arizona

<sup>†</sup> Associate Research Scientist, Columbia University IRI

<sup>‡</sup> Professor, Department of Agricultural and Resource Economics, The University of Arizona

<sup>±</sup> Assistant Professor, Department of Geography & Planning, Appalachian State University

\* Associate Professor, School of Life Sciences, Arizona State University

*JEL classification:* Q24, Q25, Q51, Q57, Q58

*Keywords:* environmental amenities characteristics, greenspace

## ABSTRACT

This research examines homebuyers' preferences regarding the condition of natural habitats. In order to explore whether homebuyers significantly value habitat quality vegetation surveys were completed in the study area. This data includes detailed information on the characteristics of nearby riparian habitat. A hedonic analysis of house prices within one-fifth of a mile of these survey sites found that instead of indiscriminately valuing "green" open space, homebuyers distinguish between vegetation characteristics. Premiums for natural environmental amenities are substantial, estimated at around \$30,000 for average riparian habitat conditions or 15.6% of the mean study area house value. These premiums outweigh structural factors such as an additional garage or a swimming pool. The results suggest that there are property-value based policy arguments for habitat conservation and restoration, particularly where natural habitats must compete for scarce water with manmade open space. Furthermore this research suggests that it is worthwhile to account for the heterogeneity of natural amenities in hedonic analysis.

## INTRODUCTION

It is well established that urban populations value different types of natural amenities, such as parks, golf courses, wetlands, and river corridors, however, it is not clear what elements of these amenities are valued. Much of the literature on economic valuation of urban amenities focuses on simple measures such as distance to the amenity [1] and the size of the amenity (e.g., the size of the urban wetland, [2]). But, hedonic studies may not provide a measure of the value of the natural environment if homebuyers are indifferent between manmade parks, degraded ecosystems, and vibrant natural habitat. In addition, if people do not value the natural features of environmental amenities, then manmade features could substitute for natural habitat. However, if homebuyers do distinguish between greenspace types, these differences must be addressed in the assessment of property values and valuation of environmental amenities. This exercise is important because in many localities natural habitat competes with manmade greenspace for scarce resources, such as water and land, and therefore urban planners must understand their relative values when making trade-offs.

In this study, a detailed set of data on amenity characteristics is developed and utilized to identify what features contribute to value. Hedonic property price methods are applied to georeferenced vegetation survey and parcel level sales data to test whether the variation in habitat condition impacts human valuation of a riparian corridor.

In semi-arid areas, riparian corridors (perennial and intermittent rivers and streams including banks) channel scarce water resources and support riparian habitats.<sup>1</sup> Riparian habitats have heterogeneous features [3] which may impact human preferences they are also qualitatively different from manmade greenspace. They have been substantially impacted by human actions, leading to habitat losses that may be important in property valuation or urban planning [4, 5, 6]. Specifically, the hedonic model explores whether homebuyers value the condition of the vegetation in their nearest riparian corridor or are indifferent to quality differentials in natural environments, and also how they value manmade recreation environments.

Previous research reports that nearby natural resources: open space, lakefront amenities, visibility, views, urban wetlands, coastal water quality, and ecological diversity and connectivity, are often capitalized into property values [1, 2, 7, 8, 9, 10, 11, 12, 13, 14, 15]. This literature uses the proximity between residential parcels and environmental features, as well as land use patterns, in valuing amenities. It does not explicitly address the site-specific biological features or natural versus manmade qualities of sites.

Previous hedonic valuations of riparian ecosystems also did not account for habitat heterogeneity. King, White, and Shaw [16] examined the effects of proximity to riparian habitat and other natural areas on the sale prices of single family residences (SFR) in the

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<sup>1</sup> A key distinction between habitat types is between dry (ephemeral) xeroriparian habitats and those with shallow groundwater or flowing water that can support shallow groundwater-dependent (mesoriparian and hydriparian) tree species [31]. Groundwater-dependent species are qualitatively different in appearance: tall leafy, deciduous trees versus cactus and creosote bushes.

Tucson metropolitan area. This research identified a three to five percent ‘premium’ in the sales price of SFR located within one-half mile of riparian areas and other wildlife habitat. These results were confirmed in a later study [17]. The authors found that by reducing the distance to the single largest urban riparian corridor from 1.5 miles to 0.1 miles (as per the methodology [2]) the sample mean house price rose by 6%. Neither study measured amenity specific features.

Recent research has begun to control for site-specific environmental characteristics [18, 19, 20] but does not address quality, health, or how artificial the amenity is. For example, Bark-Hodgins, Osgood and Colby [2] investigate not only proximity, but also the impact of wash size and “greenness”, on the hedonic valuation of washes in Tucson, Arizona. The authors found that wash greenness, as measured by a remotely sensed vegetation index, was a large, significant and positive factor in determining house price. The greenness index they used is a proxy for site-specific plant vigor that does not disaggregate the range of qualities that could contribute to greenness, provide a measure of habitat health, or distinguish between natural and manmade features. Our paper adds to the literature by investigating whether the condition of the vegetation in the riparian corridor differentially impacts nearby house prices and how these impacts compare to those of manmade greenspace.

## STUDY AREA

The study area for this research is the desert city of Tucson, Arizona. Metropolitan Tucson in Pima County is an ideal study area because of the intense competition between development and the relatively scarce riparian areas. The US Census Bureau estimated that in 2003 the Tucson metro area had a population of 893,000. Population growth is rapid in this Sunbelt city, averaging an annual 2.7% rate between 1990 and 2000 [21]. The study area covers 77 square miles (200 km<sup>2</sup>) in northeast metropolitan Tucson, Arizona. It contains a total of 236 miles (380 km) of washes.<sup>2</sup>

#### DATA AND METHODS

Residential sales data and assessed structural characteristics for the period 1998-2003 was available for download from Pima County. After data cleaning there were about nine thousand<sup>3</sup> SFR sales in study area over the study period. Riparian corridor and parcel GIS data was obtained from the Pima County Land Information System (PCLIS), which included topology, wash locations, and flow characteristics.<sup>4</sup> Sales were georeferenced to the GIS database using parcel identification numbers.

In order to study the influence of habitat attributes, survey data was collected on the characteristics of riparian sites across the study area. This data was collected in late

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2 This data was calculated in the Geographic Information System (GIS).

3 414 'non-market' sales were excluded from the database, for example sales classified as "sales under duress" and "sales between related parties". Other sales were excluded because assessor characteristics were not available or the data recorded was problematic.

4 In the PCLIS GIS each wash segment of the riparian corridor is classified by size. The classification is based on the volume of flood water a wash can carry in cubic feet per second (cfs). There are six classes ranging from CFS1, <500 cfs to the largest wash size CFS6, >25,000 cfs.

spring and early summer 2003 at 51 stratified-random sites<sup>5</sup> and included measures of vegetation volume ( $\text{m}^3/\text{m}^2$ ), woody species richness, and the proportion of hydro and mesoriparian woody species (species dependent on shallow groundwater), and recreational features, such as a subjectively determined “use by walkers” variable.<sup>6</sup>

To integrate the georeferenced field work dataset, the wash ‘arcs’ or segments on which the survey sites were located were bounded in the GIS by a 1,056 ft (0.2 miles, 0.32 km) zone buffered from the edges of the wash. This distance was chosen as it is the distance used by the Pima County Assessor’s Office in determining ‘comparables’ in the property tax dispute process. Those homes that had sold in the study period within these buffers were selected for a hedonic analysis. The sampling strategy was designed to include the full range of ecological variation available. Therefore the results are representative of the buffered sample only and are more suited for testing if amenities have value than for precisely quantifying their value across the entire population.

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5 In each of the three real estate markets (exurban-east, urban-south, Foothills-north and along the main central urban Rillito Creek/Tanque Verde wash) sites were randomly drawn from each of three wash size categories (‘small’ (CFS1-3), ‘medium’ (CFS4) and ‘large’ (CFS5 and CFS6)). A primary and backup site were drawn in the random sampling to address sites that were inaccessible either because the wash segment was located in a gated community or required traversing private land. The stratification was restricted somewhat by regional homogeneity: most of the washes within the urban-south sub-area were CFS4. Summarizing stratification by market, 13 sites were selected in the East market, 12 in the Foothills-north market, 14 in the Urban-south market, and 12 along the large wash dividing the markets. 5 CFS1 washes were drawn, 5 CFS 2, 7 CFS 3, 22 CFS 4, 6 CFS 5, and 6 CFS 6.

6 This variable was determined by the field researcher. The coding system was 0 for no visible use, 1 for low use, 2 for moderate use, and 3 for high use.



Of the 9,462 house sales in the study area in the study period 708 sales were within the buffer zones.<sup>7</sup> The buffering reduced the number of wash segments used in the analysis to thirty eight, because no sales were recorded in the study period within thirteen of the buffers. The 51 survey sites and buffers are shown on Figure 1. House sales within these buffers are displayed as dots.<sup>8</sup>

The standard hedonic price analysis introduced by Rosen [22] is followed. Let  $P$  be the price of housing and  $x$  the numeraire good, a composite commodity representing all other goods. Housing prices are a function of the typical housing characteristics: defined by a vector of structural attributes,  $\mathbf{S}$ ; neighborhood attributes,  $\mathbf{N}$ ; and environmental attributes,  $\mathbf{E}$ ; which describes the biological characteristics of the nearest riparian corridor. Household utility is a function of these characteristics,  $u(x, \mathbf{S}, \mathbf{N}, \mathbf{E})$ . Agents maximize utility subject to the normalized budget constraint  $Y - rP - x = 0$ . Assuming that house prices are in equilibrium, and that preferences are weakly separable, the hedonic price function can be specified as  $P = P(\mathbf{S}, \mathbf{N}, \mathbf{E})$  [23].

#### REGRESSION MODEL

Observed cross-sectional sales prices of SFR are modeled as a function of structural, neighborhood and environmental characteristics. The sample is treated as single cross section because all of the houses sold only once in the study period.

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<sup>7</sup> The breakdown of the size of the nearest riparian corridor to all 708 sales is: CFS1 33, CFS2 59, CFS3 71, CFS4 528, CFS5 15, and 2 CFS6.

<sup>8</sup> The breakdown of the house sales by year are: 1998, 112 sales; 1999, 123 sales; 2000, 124 sales, 2001 116 sales; 2002, 117 sales and 2003, 116 sales.

Our estimation goals are to test for the existence of impacts of separate types of features as opposed to recover a precise quantification of value. Following other researchers [2, 9, 10] a semi-log model was used for the benchmark regression.<sup>9</sup> The econometric model is specified below, where,  $\epsilon$  is assumed to be independent and normally distributed.

$$\ln(P_i)=[S_i, N_i, E_i, T_i]'\beta + \epsilon_i \quad (1)$$

$E$ , the vector of riparian characteristics, is comprised of vegetation volume, ( $m^3/m^2$ ) (VEGVOL), overall woody plant species richness (DIVERSITY), shallow groundwater dependent species richness (HMRICH) measures at each survey site, and a “use by walkers” (WALKERS) variable<sup>10</sup>. To reflect proximity amenities, the DISTWASH and DISTGOLF variables represent the distance from each sale to the nearest wash or golf course in 100 feet.<sup>11</sup> The variables ADJTWASH and ADJTGOLF are set to 1 if the parcel is adjacent to each feature and zero otherwise. To control for effects due to the size of washes, binary variables are included for each category of wash size. The dummy for CFS1, the smallest size category is omitted, and represents the category that the other sizes are compared against.

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9 A log-log specification provided relatively similar results, but the linear model performs badly, with few significant parameters. Experiment parameters have the same signs and roughly similar magnitudes across the three specifications. Box-Cox procedures recovered a transformation parameter of -0.3625. Log linear estimates are presented because they provide the most conservative results of the three specifications, are relatively easy to interpret, and comparable with much of the hedonic literature.

10 The river park system consists of nearly 30 miles pathways for bicyclists, walkers and horse-riders. The river park facilities numerous park amenities including picnic facilities, playground equipment, staging areas, habitat restoration projects, etc. (<http://www.dot.co.pima.az.us/flood/cip/index.htm>).

11 See Figure 1 to locate golf courses in the study area. Three of the seven golf courses in the study area are located in the Foothills neighborhoods, three in the urban southwestern section, and one in the exclusive far eastern sector.

The structural vector  $S$  consists of typical housing value variables, lot size 100 sq. ft. (LOT), living area 100 sq. ft. (LIVING), number of bath fixtures<sup>12</sup> (BATH), age in years (AGE), and also less familiar features that are important in the desert heat: number of covered garage spaces (GARAGE), and pool area sq. ft. (POOL). The neighborhood vector,  $N$ , comprises a variable that measures the elevation of the property in 100 feet (ELEV), and two binary variables for school districts, Catalina Foothills and Tanque Verde (CFSD and TVSD). These school districts are compared to the third school district in the area, the lower achieving Tucson Unified school district (TUSD). Finally, because flooding may impact property values [24], another binary variable was used to control for flood risk (FLOOD). It equals one if the property is within the Federal Emergency Management Agency (FEMA) flood zone and zero otherwise. In order to account for SFR property appreciation, following Mooney [25], the number of years of the sale before 2003 (APPREC) was calculated,  $T$ . Descriptions and summary statistics of these variables can be found in Tables 1 and 2.

## RESULTS

Ordinary least squares (OLS) was used to estimate the parameters in Equation (1). The regression results are shown in Table 3.<sup>13</sup>

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12 Three bath fixtures are equivalent to a full and two bath fixtures to a half bath.

13 The software used for all analysis was SAS 9.0 for Windows, Stata Intercooled 7.0, SpaceStat 1.91, ArcInfo and ArcView 3.3.

The structural variables are significant and of reasonable signs and magnitudes. Homebuyers are willing to pay more for newer<sup>14</sup>, larger houses, on larger lots, with more bathrooms, and more covered garage spaces. House prices appreciate over time. In terms of elasticities, LIVING is the most important determinant of house prices in the study. A one percent increase in LIVING raises house prices by 0.63 percent. Other structural factors are important determinants of house prices in this area. For example, the Marginal Implicit Price (MIP) of a GARAGE is \$5,588.<sup>15</sup>

Two of the habitat health characteristics are significant and positive. They contributed substantially to house value. Homebuyers are willing to pay more to be near a woody plant species-rich wash (DIVERSITY) or one that supports tall leafy tree species (HMRICH). For example, a one percent increase in DIVERSITY raises house prices by 0.14 percent. Homebuyers are willing to pay \$18,983 or 10% of the total average house value for sample average DIVERSITY and HMRICH measures. The environmental premiums for functioning riparian corridors are high, outweighing structural attributes such as a covered garage or a swimming pool. Homebuyers place considerable value on those sections of the riparian corridor that support HMRICH habitats. This habitat provides the greatest visual contrast with the typical upland desert vegetation and is associated with the endangered Sonoran cottonwood-willow forest type. Because this habitat is vulnerable to groundwater over-drafting, its importance is of relevance to urban

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14 The mean house age in the field area was relatively low at 27.04 years. The field area includes only one Historic District, the Fort Lowell Multiple Resource Area (National Register of Historic Districts).

15 The MIP formula for continuous variables was  $MIP_k = \beta_k P$  where  $\beta_k$  is the estimated coefficient for independent variable  $k$  and  $P_k$  is the average value for a home sale in the sample. For dummy variables  $MIP_k = (\exp(\beta_k) - 1) P$ .

planners.<sup>16</sup> On the other hand, the VEGVOL parameter was not significant in this specification. Homebuyers did not exhibit a robustly identifiable preference for densely vegetated habitats *per se*.

The WALKERS parameter was positive and significant.<sup>17</sup> FLOOD was not significant, perhaps because relatively few of the houses in this sample are in the FEMA flood plain. The wash size dummy variables are all significant and negative. Since the wash size dummies could proxy a variety of different amenities, and the analysis has not been designed to accurately identify their impacts, it is not possible to know precisely what drives this result. However one potential explanation could be that homebuyers have a taste for smaller, more private, “cozy” washes. Values for golf course adjacency or wash adjacency or proximity were not significantly detected. Somewhat unexpectedly, DISTGOLF is positive, meaning that a location nearer a golf course negatively impacts house prices.<sup>18</sup>

To test for heteroscedasticity, White’s [26] and Breusch-Pagan [27] tests were applied. Both detected heteroscedasticity beyond the 99% confidence level. White’s heteroscedasticity-consistent covariance matrix of the parameter estimates was calculated and used to correct the OLS standard errors (see Table 4). After adjusting for

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16 The HMRICH habitat condition variable is impacted by water availability. Shallow and stable groundwater levels are necessary to support hydro-mesotropical tree species [5, 32]. Research by Lite and Stromberg [30] shows that as streams are dewatered and groundwater levels decline, riparian tree communities shift away from the hydro and mesotropical species that this research has identified as having significant benefits to homebuyers.

17 This significance is not robust across all regression specifications.

18 This is further investigated in the discussion section.

heteroscedasticity BATH was no longer significant at the ten percent level while VEGVOL was significant, and all other variables significant in the unadjusted benchmark regression maintained significance at the ten percent level. Variance inflation factors were calculated for each of the variables as a diagnostic for the potential for problems driven by correlation between variables. All of the factors were below ten, implying that correlation between right hand side variables is not likely to present a problem.

To investigate the possibility of estimation inefficiency due to spatial error processes, Moran's I [28] t-statistic was applied on the regression residuals. The recovered Moran's I statistic of 0.317 was significant, with a p-value of  $<.0001$ .<sup>19</sup> Therefore maximum likelihood and GMM two step and iterative approaches were attempted to estimate a spatial autocorrelation model. However, a model that would converge could not be found, perhaps because of the structure of our spatially constructed dataset (sampled from parcels surrounding our field sites). The Moran's I diagnostic was not robust in significance or magnitude across residuals from alternate regression specifications. Given concerns raised in the literature that corrections for spatial error processes impose substantial, and perhaps undesirable, structure on the model if the error process is not accurately characterized [18, p472], therefore further measures to re-specify our problem to explicitly model spatial error processes were not pursued.<sup>20</sup>

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19 An inverse squared distance weighting matrix was applied with a cut off distance of 1,000 ft., approximately equal to the distance used to buffer the sites.

20 Unmodeled spatial autocorrelation may lead to inefficiency in the parameter estimation and bias the standard errors recovered in our estimation. Given the low standard errors recovered, bias in the recovery of the standard errors would have to be quite dramatic in order to lead to spurious detections of significance of ecological characteristics such as DIVERSITY.

## DISCUSSION

The findings suggest that homebuyers in the study area may have a preference for environmental amenities over manmade greenspaces. Although homebuyers are willing to pay more to live near a species rich riparian corridor, they prefer to buy further away from a golf course, which embodies a lush, manmade greenspace. This suggests that either these homebuyers do not value such manmade green spaces or any such premium is outweighed by the negative impacts associated with proximity to a golf course, such as traffic, privacy, and safety issues. Results were robust across specifications that included year fixed effects (instead of the appreciation variable) and/or spatial fixed effects (as represented by school dummies).<sup>21</sup>

Golf course impacts may be a combination of the benefits from access to the course as well as any negative externalities the course might impose. The golf course nuisance cost recovered may be the result of how a parcel's relationship to a course was characterized. Sales adjacent to a golf course, which proxy access, could behave differently than sales nearby, which proxy the amenity value of the course. Using adjacency, Do and Grudnitski [29] found that homebuyers were willing to pay a premium of 7.6% for a location adjacent to a golf course in suburban San Diego, California.

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<sup>21</sup> The specification with the appreciation variable instead of year fixed effects is presented in Table 3 because of its ease of interpretation.

Our buffered ecological survey dataset does not have the variation necessary to distinguish between golf course adjacency and proximity effects. Sales beyond 0.2 miles from the 51 ecological survey wash sites are restricted from the dataset and only one sale in the dataset is adjacent to a golf course. Therefore the full (unbuffered) dataset is utilized to perform an exploratory diagnostic regression to investigate adjacency and proximity variables.<sup>22</sup> Given the expense of surveying the ecological sites, it is not possible to develop explicit ecological data for the full, unbuffered, dataset. Thus, the diagnostic regression on the unbuffered data is not intended to address wash ecological characteristics but instead to merely explore implications of adjacency and proximity.

In this regression, the DISTGOLF parameter of 0.0002 is positive and similar in magnitude to the DISTGOLF proximity penalty from our benchmark results. The ADJGOLF parameter is 0.1617.<sup>23</sup> Thus, adjacency and distance appear to be capturing two distinct golf course effects with opposite signs, suggesting that those who have adjacent access to a golf course pay a premium while those not directly benefiting from golf course access face a penalty for proximity. On the other hand, riparian habitats provide premiums for both adjacency (ADJWASH is 0.0110) and proximity

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22 The diagnostic regression used all valid sales within the study boundaries. This non-buffered dataset had 9,462 observations.

23 All adjacency and distance variables were significant beyond the 1% level. The adjusted  $R^2$  of this regression was 0.86 and the F statistic was 2,872.91. The structural, school district, and appreciation variables were significant beyond the 1% level and were similar in magnitude to results from the benchmark regression.



(DISTWASH is -0.0023), reflecting an unambiguous benefit to these resources, and a behavior different to that of golf courses.<sup>24</sup>

## CONCLUSION

Tucson homebuyers appear to be able to discriminate between greenspace characteristics. In riparian habitats, homebuyers pay significant premiums for species richness and specific species types. As a riparian habitat is degraded it is less able to support certain species [30], species that highly valued by nearby homeowners (HMRICH), thus its value might decrease even if the habitat is replaced with dense invasive or nonnative vegetation.

Because homebuyers seem to value habitat quality, other hedonic research that has used aggregate measures such as remotely sensed greenness indices or ‘open space’ may, to some extent, be measuring the value of natural habitats. It is important to understand that these aggregate proxies are implicitly valuing a mix of natural habitats, invasive weeds, and manmade greenspace that homebuyers may value differently. Accurate assessment of the value of a property requires an understanding of the multiple characteristics that greenspace exhibits. Our findings suggest that for some homebuyers, manmade environments are not a substitute for natural habitat, implying that there are property-value based policy arguments for habitat conservation and restoration, particularly in

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<sup>24</sup> Signs and significance of the findings were robust across specifications that included adjacency dummies without distance measures, and specifications that included distance measures without adjacency dummies. Variance inflation factors for the non-buffered regression were calculated to check for spurious results driven by collinearity. There is no evidence that collinearity was a problem.

semi-arid environments where natural habitats must compete for scarce water with manmade open space.

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## TABLES AND FIGURES

**Table 1: Variable names and definitions**

<i>Variable</i>	
<i>Dependent</i>	
LNSALESP	Log of unadjusted sales price
<i>Home structure</i>	
LOT	Lot size, 100 sq ft
LIVING	Living area, 100 sq ft
AGE	Age of house in years
BATH	Number of bath fixtures
GARAGE	Number of garage spaces
POOL	Pool size, sq ft
<i>Neighborhood</i>	
CFSD	Binary variable equal to one if school district is Catalina Foothills and equal to zero otherwise
TVSD	Binary variable equal to one if school district is Tanque Verde and equal to zero otherwise
FLOOD	Binary variable equal to one if house is within the FEMA flood zone and equal to zero otherwise
ELEV	Elevation of house, ft
<i>Amenity</i>	
DISTGOLF	Distance to golf course, 100 ft
ADJTGOLF	Binary variable equal to one if house is located on or adjacent to a golf course and equal to zero otherwise
DISTWASH	Distance to nearest wash, 100 ft
ADJTWASH	Binary variable equal to one if house is located adjacent to a wash and equal to zero otherwise
WALKERS	Index of 'walking', use varies from a low of 1 to high of 5
VEGVOL	Total weighted vegetation volume (m <sup>3</sup> /m <sup>2</sup> )
DIVERSITY	Number of woody species present on the transect
HMRICH	Number of hydro/mesoriparian woody species present on the transect
CFS2	Binary variable equal to one if wash corridor size is CFS2 (>500<1,500 cfs) and equal to zero otherwise
CFS3	Binary variable equal to one if wash corridor size is CFS3 (>1,500<5,000 cfs) and equal to zero otherwise
CFS4	Binary variable equal to one if wash corridor size is CFS4 (>5,000<15,000 cfs) and equal to zero otherwise
CFS5	Binary variable equal to one if wash corridor size is CFS5 (>15,000 <25,000 cfs) and equal to zero otherwise
CFS6	Binary variable equal to one if wash corridor size is CFS6 (>25,000 cfs) and equal to zero otherwise
<i>Appreciation</i>	
APPREC	Measure of house price inflation (Year 2003 minus year of sale)



**Table 2: Summary statistics**

<b>Variable</b>	<b>Mean</b>	<b>Std Dev</b>	<b>Minimum</b>	<b>Maximum</b>
SALES PRICE	196,067.68	179,526.29	45,000.00	2,350,000.00
LOT	210.500	261.071	43.51	1,980.87
LIVING	18.807	7.116	5.34	63.20
AGE	27.035	12.923	1.00	74.00
BATH	6.908	2.560	3.00	21.00
GARAGE	0.863	1.108	-	5.00
POOL	177.962	235.914	-	904.00
CFS1	0.069	0.254	0	1
TVSD	0.106	0.308	0	1
FLOOD	0.047	0.211	0	1
ELEV	26.222	1.095	25.00	32.10
DISTGOLF	95.018	93.396	13.70	458.22
ADJTGOLF	0.003	0.053	-	1.00
DISTWASH	5.103	2.937	0.03	12.72
ADJTWASH	0.168	0.374	-	1.00
WALKERS	1.260	0.953	-	3.00
VEGVOL	0.530	0.289	0.15	1.09
DIVERSITY	10.369	5.333	4.00	25.00
HMRICH	0.049	0.313	-	4.00
CFS2	0.047	0.211	-	1.00
CFS3	0.083	0.277	-	1.00
CFS4	0.100	0.301	-	1.00
CFS5	0.746	0.436	-	1.00
CFS6	0.021	0.144	-	1.00
APPREC	0.003	0.053	-	5.00

N=708

**Table 3: Benchmark regression**

<b>Variable</b>	<b>Estimate</b>	<b>S. Error</b>	<b>t-value</b>	<b>Pr &gt;  t </b>
INTERCEPT	11.8709	0.4324	27.45	<.0001
LOT	0.0002	0.0000	5.36	<.0001
LIVING	0.0337	0.0022	15.04	<.0001
AGE	-0.0086	0.0010	-8.44	<.0001
BATH	0.0125	0.0060	2.08	0.0383
GARAGE	0.0285	0.0103	2.78	0.0056
POOL	0.0002	0.0000	4.71	<.0001
CFS2	0.2318	0.0687	3.38	0.0008
TVSD	0.0383	0.0490	0.78	0.434
FLOOD	-0.0412	0.0432	-0.95	0.3411
ELEV	-0.0172	0.0182	-0.95	0.3438
DIST GOLF	0.0005	0.0001	3.26	0.0012
ADJTGOLF	0.0122	0.0271	0.45	0.6522
DISTWASH	-0.0022	0.0032	-0.69	0.4906
ADJTWASH	0.0094	0.0257	0.37	0.7129
WALKERS	0.0360	0.0134	2.68	0.0075
VEGVOL	0.0595	0.0387	1.54	0.1249
DIVERSITY	0.0139	0.0029	4.80	<.0001
HMRICH	0.0829	0.0404	2.05	0.0404
CFS3	-0.3221	0.0636	-5.06	<.0001
CFS4	-0.4002	0.0576	-6.94	<.0001
CFS5	-0.3226	0.0515	-6.27	<.0001
CFS6	-0.3521	0.0964	-3.65	0.0003
APPREC	-0.3459	0.1924	-1.80	0.0726
	-0.0752	0.0046	-16.32	<.0001
N=708				
F=191.31				
Adjtd R <sup>2</sup> =0.8661				

**Table 4: Heteroscedasticity Correction, MIP, and elasticities**

<b>Variable</b>	<b>Asymptotic S. E.</b>	<b>Chi<sup>2</sup></b>	<b>Pr &gt; Chi<sup>2</sup></b>	<b>MIP</b>	<b>Elasticity</b>
INTERCEPT	0.4934	0	<.0001		
LOT	0.0001	14.0	0.0002	45.62	0.05
LIVING	0.0033	103.7	<.0001	6,603.56	0.63
AGE	0.0012	52.3	<.0001	(1,684.22)	(0.23)
BATH	0.0082	2.3	0.1275	2,443.00	0.09
GARAGE	0.0111	6.6	0.0103	5,587.93	0.02
POOL	0.0000	18.6	<.0001	32.77	0.03
CFS2	0.0734	10.0	0.0016	45,450.45	0.23
TVSD	0.0551	0.5	0.4868	7,517.23	0.04
FLOOD	0.0474	0.8	0.3848	(8,070.15)	(0.04)
ELEV	0.0204	0.2	0.6496	(3,370.40)	(0.45)
DIST GOLF	0.0002	7.9	0.0051	91.99	0.04
ADJTGOLF	0.0249	0.2	0.6239	2,392.03	0.01
DISTWASH	0.0027	0.7	0.4009	(437.23)	(0.01)
ADJTWASH	0.0272	0.1	0.7285	1,850.88	0.01
WALKERS	0.0125	8.3	0.0039	7,066.28	0.05
VEGVOL	0.0309	3.7	0.0541	11,662.11	0.03
DIVERSITY	0.0031	19.8	<.0001	2,731.22	0.14
HMRICH	0.0472	3.1	0.0791	16,252.05	0.00
CFS3	0.1143	7.9	0.0049	(63,143.60)	(0.33)
CFS4	0.1084	13.6	0.0002	(78,458.44)	(0.41)
CFS5	0.1023	10.0	0.0016	(63,247.51)	(0.33)
CFS6	0.1074	10.8	0.001	(69,041.31)	(0.36)
CFS6	0.1744	3.9	0.0472	(67,823.73)	(0.36)
APPREC	0.0051	217.3	<.0001	(14,746.25)	(0.19)
N=708					

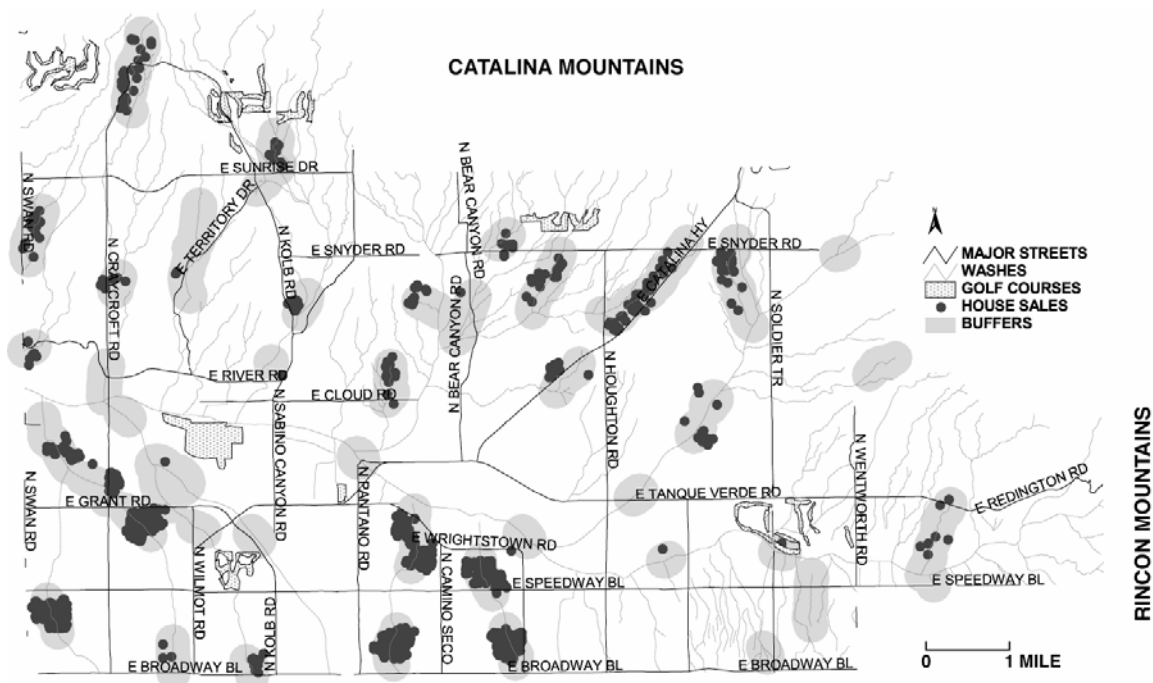


Figure 1: Study area

APPENDIX D: AN ECONOMIC ASSESSMENT OF THE SONORAN DESERT  
CONSERVATION PLAN

Rosalind Bark-Hodgins\* and Bonnie G. Colby\*\*

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ABSTRACT

Riparian corridors supply many environmental and aesthetic services in the arid and semi-arid regions worldwide. Riparian ecosystems provide water filtering, bank stabilizing, and flood mitigating benefits, and are habitat to native birds, bats, fish and other wildlife. The juxtaposition of lush herbaceous and treed areas with upland desert also makes these corridors an aesthetic resource. In Arizona, urban homeowners are one of the primary 'consumers' of the riparian corridor. Recent research demonstrates that riparian corridors are capitalized into nearby home values. Specific to this research, urban and suburban homebuyers are willing to pay high premiums to live near sections of riparian corridors that support dense, species rich and perennial-water-dependent habitat.

In this study we calculate the estimated increases in property values and property tax revenues associated with proximity to healthy urban riparian corridors. These property premiums are then compared to the estimated costs of water leases necessary to support water-dependent habitats as detailed in the Sonoran Desert Conservation Plan (SDCP). The plan aims to protect open space in the Sonoran Desert in southern Arizona,

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\* Contact author. Ph.D. candidate Arid Lands Resource Sciences, The University of Arizona. AREC, Rm 319, Chavez Bldg, P.O. Box 210023, The University of Arizona, Tucson, AZ 85721-0023. rbark@email.arizona.edu.

\*\* Professor, Department of Agricultural and Resource Economics, The University of Arizona.

specifically in Pima County. The plan aims to protect open space in the Sonoran Desert in southern Arizona, specifically in Pima County. The property premiums are estimated at between \$126.54M (Million) and \$253.08M, and generate an estimated \$1.23M-\$2.46M per annum in incremental property tax revenues; whereas, the annual cost of water leases to support the vegetation is \$0.54M. This partial economic analysis demonstrates that urban riparian habitat preservation and restoration with the allocation of renewable water supplies can be financially self-supporting. In addition, the estimated property price premiums indicate potential benefits to modifying current well-spacing rules in Arizona.

## INTRODUCTION

Arizona is one of the fastest growing states in the U.S. Not only are the cities of Phoenix and Tucson expanding rapidly but so too are rural areas. Consequently, strong growth in water demand has hastened not only the conversion of agricultural water rights into municipal water rights but aquifer overdraft as well. This resulting deficit between natural recharge and use is estimated to be an annual 2.5M acre feet (AF)<sup>1</sup> statewide.<sup>2</sup> Drought has also aggravated this shortfall. In many areas, the decline in the groundwater table has severed the hydrologic connection between groundwater and surface water, and transformed once flowing rivers that supported riparian habitat into dry riverbeds. For

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<sup>1</sup> An acre foot of water can support an average 2.7 single family residence (SFR) households for a year. This is based on the following data: average gallons per capita per day (GPCD) for a SFR is 120 GPCD [p 3-6, Water Plan: 2000-2050, City of Tucson Water Department, Final Draft Mayor and Council, November 22, 2004. <http://www.ci.tucson.az.us/water/docs/waterplan.pdf>. Accessed November 5, 2006] and 2.8 persons per SFR [p20, footnote 21, S. Megdal, Water Resource Availability for the Tucson Metropolitan Area, July 2006, The University of Arizona. <http://ag.arizona.edu/azwater/presentations/Megdal.az.water.resource.avail.for.tucson.pdf> Accessed November 5, 2006].

<sup>2</sup> Arizona State University “Investing in Arizona’s Future”, pp3. Accessed March 1, 2006. <http://www.asu.edu/president/azfuture/1.htm>.

example, in Tucson the groundwater table in some areas is now more than 200 ft below the surface under much of the city.<sup>3</sup>

Water demand has fueled interest in ‘new’ water, such as fully utilizing Colorado River water and reclaimed water. Arizona’s Colorado River water allocation, as per the 1928 Boulder Canyon Project Act<sup>4</sup> is 2.8M AF annually. Arizona has an incentive to use or store all of its Colorado River allocation otherwise it is lost to the next priority, which is the downstream state of (southern) California.

In this paper, we examine the economics of dedicating some renewable water to support urban riparian conservation and restoration projects. We note that such a use is compatible with Arizona’s Public Water Code<sup>5</sup> and that it would provide significant private property benefits in addition to flood control and recreation benefits.

Riparian habitat in Tucson, Arizona is highly varied. This heterogeneity is in part a response to water availability, elevation and geomorphic channel processes<sup>6</sup> but is also the result of flood control infrastructure and urbanization.<sup>7</sup> Hydroriparian species such as

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<sup>3</sup> “Tucson Water’s Long-range Resources Planning” *available at* <http://www.ci.tucson.az.us/water/docs/groundwater.pdf> (last visited March 1, 2006).

<sup>4</sup> Boulder Canyon Project Act, 1928, Pub. L. 70-642, Sec 4(a).

<sup>5</sup> A.R.S. Title 45.

<sup>6</sup> Naiman, R. J., H. Décamps, and M. Pollock. “The role of riparian corridors in maintaining regional biodiversity.” *Ecological Applications* 3: 209-212, (1993).

<sup>7</sup> Stromberg, J. C. “Restoration of riparian vegetation in the south-western United States: importance of flow regimes and fluvial dynamism.” *Journal of Arid Environments* 49: 17-34, (2001).

cottonwoods and willows rely on stable and shallow groundwater:<sup>8</sup> habitat conditions that are no longer common in the Tucson metropolitan area. Many sections of the the riparian corridor are without regular flow and are dominated by fragmented shrubland or bare open space.

Plant biologists and ecologists have extensively studied the decline in riparian habitat. For example, Levine and Stromberg note twofold changes resulting from interruption of natural stream flows: native plant recruitment declines and ‘functional gaps’ open that are ripe for invasion by exotic species.<sup>9</sup> Others have also correlated flow frequencies with vegetation cover.<sup>10</sup> However, one aspect of this decline that has not been adequately addressed is the economic cost of such habitat loss, or alternatively the value of conserving the remaining habitat. In this paper we apply property premiums from previous research to value the riparian habitat<sup>11</sup> to Tucson homeowners.

The hedonic property price method can be used to estimate the value of environmental goods, such as open space or a lake view. This technique models private property prices as a function of a house’s attributes, such as the size of the house, lot size, school district,

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<sup>8</sup> Horton J. L., Kolb, T. E., and S. C. Hart. “Physiological response to groundwater depth varies among species and with river flow regulation”. *Ecological Applications* 11 (4): 1046-1059, (2001), at p1058.

<sup>9</sup> Levine, C. M. and J. C. Stromberg. “Effects of flooding on native and exotic plant seedlings: implications for restoring south-western riparian forests by manipulating water and sediment flows”. *Journal of Arid Environments* 49: 111-131, (2001).

<sup>10</sup> Zamora-Arroyo, F., P. L. Nagler, M. Briggs, D. Radtke, H. Rodriguez, J. Garcia, C. Valdes, A. Heute and E. P. Glenn. “Regeneration of native trees in response to flood releases from the United States into the delta of the Colorado River, Mexico.” *Journal of Arid Environments* 49: 49-64, (2001).

<sup>11</sup> In this paper we define ‘riparian habitat’ as hydriparian habitat. That is we only value the benefits to homeowners of shallow groundwater-dependent habitat. Tree species in this type are broad-leaved, deciduous, cottonwoods and willow trees.



and coastal access.<sup>12</sup> The method calculates an implicit value or hedonic price for each attribute. For example a lake view might add twenty percent to a home's value compared to an equivalent home without a lake view in the same study area. A large literature testifies that nearby natural resources such as open space, lakefront amenities, visibility, views, urban wetlands, coastal water quality, and ecological diversity and fragmentation<sup>13</sup> are often capitalized into property values.

Proximity to a natural resource is one aspect of value.<sup>14</sup> Other aspects of a habitat value require more detailed modeling to ascertain the source of homebuyer preference. A recent study uses ground-based survey data to investigate how different types of riparian habitat

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<sup>12</sup> The hedonic property price method is based on the seminal article by Rosen, S. "Hedonic prices and implicit markets: product differentiation in pure competition." *Journal of Political Economy*, 82: 34-55, (1974).

<sup>13</sup> Irwin, E. G and N.E. Bockstael. "The problem of identifying land use spillovers: measuring the effects of open space on residential property values." *American Journal of Agricultural Economics*, v. 83:3, 698-704, (2001); Geoghegan, J. "The value of open spaces in residential land use". *Land Use Policy* 19: 91-98, (2002); Smith, V. K., C. Poulos, and H. Kim. Treating Open Space as an Urban Amenity *Resource and Energy Economics* v24, n1-2: 107-29, (2002); Acharya, G. and Bennett, L.L. "Valuing Open Space and Land-Use Patterns in Urban Watersheds" *Journal of Real Estate Finance and Economics* v22, n2-3: 221-37, (2001); Shultz, S.D., and D.A. King. "The use of census data for hedonic price estimates of open-space amenities and land use." *Journal of Real Estate Finance and Economics*, 22 (2/3), 239-252, (2001); Spalatro, F., and B. Provencher. "An analysis of minimum frontage zoning to preserve lakefront amenities." *Land Economics*, v 77:4, 469-81, (2001); Paterson, R.W., and K. J. Boyle. "Out of Sight, Out of Mind? Using GIS to Incorporate Visibility in Hedonic Property Value Models. *Land Economics* 78 (3): 417-425, (2002); Benson, E. D., Hansen, J. L., Arthur, J., Schwartz, L., Smersh, G.T. "Pricing residential amenities: the value of a view." *Journal of Real Estate Finance and Economics* 16, 55-73, (1998); Mahan, B.L., S. Polasky and R.M. Adams. "Valuing Urban Wetlands: A Property Price Approach". *Land Economics* 76 (1): 100-113, (2000); Leggett, C. G. and N. E. Bockstael. Evidence of the Effects of Water Quality on Residential Land Prices, *Journal of Environmental Economics and Management* v39, n2: 121-44, (2000); and Geoghegan, J., L.A. Wainger and N.E. Bockstael. "Analysis spatial landscape indices in a hedonic framework: an ecological economics analysis using GIS". *Journal of Ecological Economics* 23, 251-264, (1997).

<sup>14</sup> Homes within 200 feet of a river enjoy a large premium in Portland, Oregon, p242 in, Netusil, N. R. "The Effect of Environmental Zoning and Amenities on Property Values: Portland, Oregon." *Land Economics*, 81 (2), May 2005, pp. 227-246 and premiums were also found in a semi-arid market, Tucson, Arizona in Bark-Hodgins, R.H., D.E. Osgood and B.G. Colby "Remotely Sensed Proxies for Environmental Amenities in Hedonic Analysis: What does Green Mean?" In ENVIRONMENTAL VALUATION: INTRAREGIONAL AND INTERREGIONAL PERSPECTIVES, Edited J. I. Carruthers and B. Mundy. Ashgate, October 2006. ISBN: 0 7546 4471 5 [hereinafter Bark-Hodgins, *Hedonic Analysis*].

are capitalized into nearby private property values.<sup>15</sup> The authors found that the most highly valued habitats are densely vegetated washes, washes with higher vegetation species richness, and washes that support shallow groundwater-dependent tree species. Specifically homeowners within 0.2 miles of 51 stratified-random surveyed riparian corridors were willing to pay 16% more for the mean study area home if it was located next to such a wash.<sup>16</sup> Crucially, preferred washes contain species that are dependent on shallow groundwater<sup>17</sup> and winter and spring flood regimes for survival.<sup>18</sup> These washes are particularly threatened by continued groundwater over-drafting and stream flow diversions. This paper applies the results from Bark-Hodgins et al.,<sup>19</sup> in order to (partially) evaluate the riparian habitat conservation and restoration section of the Sonoran Desert Conservation Plan (SDCP). That plan seeks to mitigate the degradation of urban riparian habitat by allocating renewable water resources for instream flows.

In the next section we use a geographic information system with georeferenced parcel and riparian corridor data from Pima County<sup>20</sup> to estimate the value to nearby

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<sup>15</sup> Bark-Hodgins, R.H., D.E. Osgood, G. Katz, J. Stromberg, and B.G. Colby. Understanding preferences for environmental characteristics: can homebuyers distinguish between degraded greenspace and healthy habitat? (Submitted in 2006) [hereinafter Bark-Hodgins, *Homebuyers*].

<sup>16</sup> The model estimated was:  $\ln \text{ sales price} = \beta_0 + \beta_1 \text{ lot size} + \beta_2 \text{ living area} + \beta_3 \text{ house age} + \beta_4 \text{ bathroom fixtures} + \beta_5 \text{ garage spaces} + \beta_6 \text{ pool area} + \beta_7 \text{ distance to golf} + \beta_8 \text{ walking path} + \beta_9 \text{ wash veg. volume} + \beta_{10} \text{ wash veg. diversity} + \beta_{11} \text{ wash hydro-mesoriarian richness} + \beta_{12} \text{ adjacent to wash} + \beta_{13} \text{ Catalina Foothills School District} + \beta_{14} \text{ Tanque Verde School District} + \beta_{15} \text{ FEMA flood zone} + \beta_{16} \text{ elevation of house} + \beta_{17} \text{ appreciation} + \beta_{18} \text{ adjct golf} + \beta_{19} \text{ distance to wash} + \beta_{20} \text{ adjct wash} + \beta_{21} \text{ CFS2} + \beta_{22} \text{ CFS3} + \beta_{23} \text{ CFS4} + \beta_{24} \text{ CFS5} + \beta_{25} \text{ CFS6} + \beta_{26} \epsilon$ . The hedonic price of one unit of hydro-mesoriarian richness was calculated at \$16,252.

<sup>17</sup> Horton et al., *supra* note 8, at 1046 and 1056.

<sup>18</sup> Levine and Stromberg, *supra* note 9, at 113.

<sup>19</sup> Bark-Hodgins *Homebuyers*, *supra* note 15, at Table 4.

<sup>20</sup> Tucson is located in Pima County.

homebuyers of conserved and restored riparian habitat.<sup>21</sup> Then we examine the costs of supplying water to maintain such habitats and conclude with a partial economic analysis of the Sonoran Desert Conservation Plan and a discussion.

Note that we do not value other types of riparian habitat, specifically dryland riparian habitat (xeroriparian), even though it is valued by nearby homeowners. This type of habitat is excluded from our analysis because it does not require supplementary water for survival. Nor do we estimate the vegetation density and species diversity benefits from the Bark-Hodgins et al., study.<sup>22</sup> Moreover, we do not estimate the benefits of flood control, bank stabilization, water infiltration and wildlife habitat provided by riparian habitat. For these reasons, this is not a benefit-cost analysis, but rather a partial economic analysis of specific features of the SDCP.

#### AN ESTIMATE OF THE CAPITALIZATION VALUE OF RIPARIAN HABITAT

A partial estimate of the ‘value’ of the riparian zone is the property price premium accruing to nearby property owners. The hedonic property price method has the advantage that it is based on actual market transactions, or property sales. It is, however, only a partial estimate of the benefits. The values determined in Bark-Hodgins et al.,<sup>23</sup> are those accruing only to homeowners of single family residences (SFRs) within 0.2 miles of riparian habitat. The value of this habitat to those living in townhouses or condos, to homeowners beyond the 0.2 mile buffers, and to visitors, is not estimated in

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<sup>21</sup> *Supra* note 11.

<sup>22</sup> Bark-Hodgins, *Homebuyers supra* note 15.

<sup>23</sup> Bark-Hodgins, *Homebuyers supra* note 15.

their model. Also, although some aspects of riparian corridor services, such as flood mitigation and water filtration may not be explicitly valued by homebuyers, they nevertheless provide benefits to the entire metropolitan area. The value we apply in this paper is the value of the riparian corridor to nearby homebuyers; it is likely a combination of aesthetic and recreation values and also privacy values afforded by a location adjacent to a wash.<sup>24</sup>

In order to assess the Sonoran Desert Conservation Plan we apply the estimated value of shallow groundwater-dependent riparian habitat to nearby homeowners as determined by Bark-Hodgins et al.<sup>25</sup> In their paper, the authors conducted comprehensive field analysis at 51 randomly chosen riparian corridors. These 51 riparian corridors were then buffered by a 0.2 mile buffer and all the sales within these buffers in their study period 1998-2003 were used in their hedonic property price analysis. They estimated the premium paid by homebuyers for proximity to different types of riparian habitat. Specifically, only 5 out of their 51 field sites were classified as “shallow groundwater-dependent riparian habitat”. The total premium paid for this habitat by all nearby homebuyers in the authors’ northwest Tucson study area, in the study period, is estimated at \$568,820. For this current paper we transfer these house sale premiums<sup>26</sup> to all 746 homes<sup>27</sup> within the 0.2

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<sup>24</sup> This privacy results from flood control legislation that prevents building in the floodway. [Pima County Code, 16.24.010, Uses allowed in the floodway].

<sup>25</sup> Bark-Hodgins, *Homebuyers supra* note 15.

<sup>26</sup> In the paper the hydro-mesoriparian richness varied from 1 to 4 at the five sites with this type of habitat. For this current analysis we apply the premium associated with a hydro-mesoriparian richness value of 2 to all homes within the 0.2 mile buffer.

<sup>27</sup> That is we transfer the premium to all the homes within the buffers, not only to those homes that sold within the author’s study period.

mile buffers. By applying these premiums to all homes within these buffers we estimate the value of these five stretches of riparian habitat to be around \$24.25M.

These benefits represent a lower bound estimate for all single-family residences within the buffered zones for three reasons. First, the benefit estimate is modest, as it only includes those single-family residences within 0.2 miles of a surveyed or designated, shallow groundwater-dependent riparian habitat. That is, it does not include the benefits to other property owners or renters, or the value of other preferred habitat conditions such as overall species diversity. Second, statistically measurable property value premiums have been documented to extend well beyond the 0.2 miles.<sup>28</sup> For these reasons, our estimate is conservative but is the best available estimate for the value of this habitat.

Next we increase the area of analysis to include a 0.2 mile buffer around all Pima County designated shallow groundwater-dependent riparian habitat in our study area, not just the five sites surveyed (see Map 1). A total 3,893 homes lie within these new buffers. Using the technique above<sup>29</sup> an estimate of the current value of these habitats is around \$126.54M. Note that this estimate of the value of the water-loving habitat is limited to the study area shown in Map 1, although other sections of such habitat are self-sustaining elsewhere in the county (see Map 2). Using this new dataset we investigate the economics of riparian conservation and restoration in our study area.

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<sup>28</sup> Colby B. G. and S. Wishart. "Quantifying the Influence of Desert Riparian Areas on Residential Property Values" *The Appraisal Journal* LXX (3): 304-308, (2002) [hereinafter Colby and Wishart, *Residential*].

<sup>29</sup> *Supra* note 26.

## THE SONORAN DESERT CONSERVATION PLAN (SDCP): BENEFITS

The Sonoran Desert Conservation Plan<sup>30</sup> is an ambitious open space protection plan. It also incorporates measures to protect and restore riparian corridors in metropolitan Tucson that are threatened directly by development and indirectly by continued groundwater overdraft. To implement this specific policy, Pima County has adopted riparian corridor maps that identify proposed areas for regulation (Map 2). Landowners developing parcels within regulated areas are required to avoid impacts to the riparian corridor, or if impacts cannot be avoided, then they are required to minimize the impact and offset or mitigate any damage by revegetating the area. Map 2 identifies the proposed areas for riparian habitat regulation and also identifies the class of habitat, for example “hydro and mesoriparian habitat”.<sup>31</sup> The study area used in Bark-Hodgins et al.,<sup>32</sup> is shaded grey.

The other aspect of the plan is to restore vegetation to stretches of the riparian corridor. It is anticipated that restoration interventions will involve importing reclaimed water, or other sources of water, for habitat restoration. The exact areas for restoration intervention have not yet been determined; however likely criteria for selection are that the riparian corridor must be in an environmentally sensitive area and in an area with a stressed aquifer. The study area chosen for this paper meets both these criteria. Another condition

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<sup>30</sup> Sonoran Desert Conservation Plan: Riparian Protection, Accessed March 1, 2006, pp. <http://www.co.pima.az.us/cmo/sdcp/Riparian.html>.

<sup>31</sup> We treat “important riparian habitat” as “hydro and mesoriparian habitat”.

<sup>32</sup> Bark-Hodgins et al., *Hombuyers supra* note 15.

that is likely to factor into the choice decision is the availability of reclaimed water conveyancy infrastructure. In our chosen study area, Tucson Water, the main water provider in Pima County, is currently extending reclaimed water pipes east along a major east-west road that runs almost parallel to the main riparian corridors in our study area. The rationale for this investment is to switch golf course irrigation from water of drinking water quality to reclaimed water. Although Pima County has not contracted with Tucson Water to use this reclaimed pipeline to deliver its' SDCP environmental allocation of reclaimed water to sites along the main Rillito and Tanque Verde washes, it is one possible option and is the option we assess in this paper. Another argument in support of our choice, is that the SDCP prioritizes the protection of remaining fragments of urban riparian habitat and then the restoration of the main urban degraded corridors; the Santa Cruz, Rillito, and Pantano washes. Large sections of the Rillito and Pantano washes are in our study area.

Incremental property value benefits of the SDCP riparian habitat conservation and restoration plan derive from three distinct areas: preventing degradation of existing habitat threatened by groundwater overdraft, the enhancement of existing habitat and the geographic extension of this habitat. To calculate these benefits properly, a follow-up site survey would need to be completed to assess post-SDCP habitat condition. A naïve, low-bound estimate of habitat enhancement for the outlined study area shown in Map 2 would double the total property premium benefits to \$253.08M, or an incremental increase of

\$126.54M.<sup>33</sup> However, this approach is naïve because without implementation of the SDCP, the quality of self-sustaining habitat would degrade. If we assume that without the SDCP half the current habitat would be degraded, then the *incremental* benefits rise to \$189.81M. Other scenarios focus on changes in the quantity of riparian habitat. For example, *incremental* benefits rise to \$253.08M in the case where we assume half the status quo acreage would degrade without interventions and that the addition of SDCP water would simultaneously increase pre-intervention habitat acreage by 25%<sup>34</sup> and enhance habitat quality.<sup>35</sup> In the remainder of this paper we use the mid-level estimate of \$189.81M as the estimate of property value benefits.

#### THE SONORAN DESERT CONSERVATION PLAN (SDCP): COSTS

In this section we address the fixed and variable costs of urban riparian habitat protection and restoration. We have some indication of the range of fixed costs for urban riparian restoration in Pima County. The lower figures represent passive restoration techniques, such as restoring natural water flows, including spring and winter discharges of water and sediment<sup>36</sup> into degraded reaches that would, without planting, favor the establishment of desired native species. For these techniques, the fixed costs are nearly zero. The higher end of the cost range reflects active measures, such as revegetation and installing irrigation systems to restore higher quality habitat. Per acre restoration costs have been

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<sup>33</sup> This estimate is based on the doubling of hydro-mesori-riparian species richness from 2 to 4. See also note 27.

<sup>34</sup> We assume a straight proportion increase in the number of homes benefiting from the extended habitat. This results in an additional 973 homes (25% of the 3,893 homes located in the buffers) for a total 4,866 homes in this scenario.

<sup>35</sup> *Supra* note 33.

<sup>36</sup> Zamora-Arroyo et al., *supra* note 10, at 61; Levine and Stromberg, *supra* note 9, at 124.



between \$4,000 and \$20,000 per acre whilst per riverine mile costs range from \$84,000 to \$250,000.<sup>37</sup> Using the GIS coverage that is shown in Map 2 we can calculate the proposed acreage of restored “hydroriparian habitat”, shaded in hatch with the descriptor “H”, at 9,432 acres. Using the cost estimates above, the total cost of this restoration would be between \$37.69M and \$188.46M.<sup>38</sup> In our smaller study area the restoration cost is estimated at between \$11.68M and \$58.42M.

The next step is to estimate the costs of water for urban riparian restoration and conservation. In an agreement with the City of Tucson, the SDCP permanently secured a minimum of 5,000 AF of treated wastewater (conservation effluent pool water) per year for riparian restoration, which then increased to 10,000 AF in 2005.<sup>39</sup> This 10,000 AF/yr of conservation effluent pool water is separate and in addition to the 12,559 AF/yr of reclaimed water the city delivers for use on parks, turf and golf courses. To understand how this water will be used for different types of riparian habitats, we use initial habitat restoration descriptions from the Pima County Regional Flood Control District (PCRFCDD) provided for the Paseo de las Iglesias project in Tucson.<sup>40</sup> The project developers anticipated that to support shallow groundwater-dependent riparian trees, one-

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<sup>37</sup> Personal communication: Memorandum to Suzanne Shields, Deputy Director, Pima County Flood Control District from Thomas Helfrich, Division Manager, April 28, 2003. Re: Mitigation Costs Update. These costs are based on previous projects in southern Arizona completed over the last ten years.

<sup>38</sup> We estimate the restoration costs in our smaller study area as a straight proportion of total acreage. This somewhat arbitrary assumption is that the proportion of total costs that would be spent in our study area is based on the proportion of riparian habitat in our smaller area compared to the total area. There are 2,912 acres of shallow groundwater-dependent riparian habitat in our study area, or 31% of the total SDCP regulated 9,432 riparian acres.

<sup>39</sup> Sonoran Desert Conservation Plan: Riparian Protection, Accessed March 1, 2006, pp. <http://www.co.pima.az.us/cmo/sdcp/Riparian.html>.

<sup>40</sup> Pima County Regional Flood Control District (PCRFCDD), 2006. “Paseo de las Iglesias Habitat Explanations”. Accessed March 1, 2006, 1pp. <http://www.rfcd.pima.gov/Envrest/PDLApproaches.htm>

third to two-thirds of all irrigation water used in the entire project would be required to maintain intermittent to perennial flow in the main channel.<sup>41</sup> However, their current proposal anticipates that all water secured for this project will be used to irrigate vegetation, not to sustain flow.

For our project analysis we assume that two-thirds of the total 10,000 AF of water secured for the SDCP will be used to support shallow groundwater-dependent riparian restoration and preservation. We also assume that water costs are \$260.92/AF, resulting in total annual variable costs of \$1.74M. As per the restoration cost calculation above, we estimate that the proportion of water that will be delivered to our study area is 31%<sup>42</sup>, at a cost of \$0.54M.

Although other types of water may be secured for the SDCP, the current water source for the project is priced at the environmental (interruptible) rate specified for riparian rehabilitation projects<sup>43</sup> in a 2000 intergovernmental agreement (IGA) between the City of Tucson and Pima County.<sup>44</sup> This rate is lower than the Tucson Water's published commodity rate for uninterrupted reclaimed water of \$610/AF. The \$260.92/AF is based

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<sup>41</sup> *Id.* This plan incorporates irrigation for the initial establishment of dry (xeroriparian) habitat of mesquite and palo verde shrubland and Sonoran desertscrub species. Intermittent water-dependent (mesoriparian) habitat restoration would restore mesquite-hackberry bosques merging with dry riparian species. This plan requires the installation of a permanent irrigation system. Finally, shallow groundwater-dependent (hydroriparian) habitat restoration would restore cottonwood-willow galleries bordered by the mesoriparian habitat described above. It would require instream flows for restoration.

<sup>42</sup> See Footnote 38. The calculation: 31% of \$1.74M = \$0.54M.

<sup>43</sup> IGA, 2000. A resolution of the Board of Supervisors of Pima County relating to water; authorizing and approving the execution of a supplemental intergovernmental agreement with the City of Tucson and Pima County Flood control District regarding effluent. Pima County Resolution No. 2000-28. Sec. 5.2.2.1.

<sup>44</sup> IGA, 2000

on the actual O&M costs of treatment and distribution (\$197.23 + \$63.69).<sup>45</sup> The inclusion of capital costs would raise water costs to \$551.40/AF.

The next step is to see consider whether the variable costs (annual water costs) of the SDCP can be self-financed by higher property tax revenues. Netusil *et al.*,<sup>46</sup> did a similar analysis of open space policies in Portland, Oregon. According to their study, the possibility for self-financing only occurs in neighborhoods where homes have high-assessed values. Our study area does incorporate some high-income neighborhoods, as well as moderate-income areas.

#### SDCP: PARTIAL ECONOMIC ANALYSIS

We now have all the information necessary to weigh the partial costs and benefits of riparian habitat restoration. We cannot do a full benefit cost analysis, as we have not measured the public good benefits<sup>47</sup> of riparian habitat restoration. This partial analysis uses property premiums and incremental property taxes. We previously estimated property value premiums of around \$189.81M. If we assume an average tax rate of 14.5%<sup>48</sup> on 10% of a home's assessed value for property tax purposes, and if we assume

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<sup>45</sup> Sec. 6.5 of IGA and Sec. 12.3 of IGA

<sup>46</sup> Netusil, N. R., E. Boyd, Z. van Griffen, M. LaMerrill, E. Raisnberger "Can Open Spaces be Self-Financing?" *Choices: The Magazine of Food, Farm & Resource Issues*, 15 (2):21, 2000.

<sup>47</sup> Public good benefits include flood control and water infiltration into the regional aquifer as well as benefits to recreationists and habitat benefits.

<sup>48</sup> In the 2006 tax year property tax rates in the study area average 14.5%. Property tax rates were provided during a telephone call with Peggy, Budget Analyst, Finance Department, Pima County on November 7, 2006. The tax rate is per \$100 assessed value and is 15.3235 in TUSD, 13.4181 in TVSD and 14.6806 in CFSD. We also assume that the property tax rate remains unchanged over the period of the riparian restoration.

that assessed values are 66% of house sales prices,<sup>49</sup> then the \$189.81M property-value-premium attributable to the home's proximity to riparian habitat, results in incremental property tax revenues of \$1.82M.<sup>50</sup> The incremental property tax benefits exceed the annual cost of IGA-supplied water.<sup>51</sup>

The requirement for a 'good' project is that the benefits exceed the costs. In Table 1 we summarize restoration and ongoing costs of riparian habitat. The low scenario reflects the lower cost restoration estimates and the high scenario the higher cost restoration estimates.

**TABLE 1: FIXED AND VARIABLE COSTS OF RIPARIAN HABITAT RESTORATION**

	<b>Low</b>	<b>High</b>
<b>Costs</b>		
<b>FIXED</b>		
Restoration	\$0 to \$11.68M	\$58.42M
<b>VARIABLE</b>		
Reclaimed water IGA2000	\$0.54M	\$0.54M
<b>Benefits</b>		
Property premiums	\$189.81M	\$189.81M
Incremental property tax revenues	\$1.82M	\$1.82M

We have not calculated the benefits from the entire proposed shallow groundwater-dependent riparian habitat restoration project mapped on Map 2. Other stretches of the riparian corridor support such riparian habitat outside of our study area. However, the

<sup>49</sup> This percentage is based on the average (and median) assessed value calculated as a proportion of actual sales price, of 2,265 homes sold in 2003 in the study area.

<sup>50</sup> This calculation is illustrated here in three stages.  $\$189.54\text{M} \times 0.66 = \$125.27\text{M}$ .  $\$125.27\text{M} \times 0.1 = \$12.53\text{M}$ .  $\$12.53\text{M} \times 0.145 = \$1.82\text{M}$ .

<sup>51</sup> These property tax revenues are neither currently spent on, nor are they likely to be spent directly on riparian habitat conservation and enhancement. However, this does not invalidate the comparison of benefits and costs.

SDCP can be recommended for approval, based on our partial financial analysis, because the incremental property tax revenues from our smaller study area alone attributable to the habitat exceed the entire SDCP's annual water costs of conservation. The financial advantages would be stronger still if we added the private property benefits accruing to homeowners living further from the riparian corridor than our 0.2 mile cutoff and to those living in multifamily residences. The case could be further strengthened if we estimated the other considerable benefits accruing from riparian habitat preservation and restoration, such as, flood control, bank stabilization, water infiltration into the regional aquifer,<sup>52</sup> recreation, and wildlife habitat.

## DISCUSSION

The Sonoran Desert Conservation Plan has three priorities: first to preserve remaining functioning riparian habitat; second to sustain water-stressed habitat through the importation of renewable water to the habitat; and finally to restore degraded riparian habitats.<sup>53</sup> Water is the essential resource necessary to regenerate riparian habitat. The SDCP utilizes earmarked wastewater in an intergovernmental agreement. The security of this water source is an important consideration given that young shallow groundwater-dependent trees are particularly susceptible to groundwater declines.<sup>54</sup> We note that the

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<sup>52</sup> The Central Arizona Project (CAP) website states that the most common and most economical method of artificial recharge is surface infiltration via dry streambeds (CAP, 2006, p1). Pima County might be able to receive groundwater credits from measurable recharge which in turn would reduce the costs of the program. Recharge might also reduce land subsidence risks and therefore potential damage claims.

<sup>53</sup> SDCP (2006). Sonoran Desert Conservation Plan: Riparian Protection, Accessed March 1, 2006, pp. <http://www.co.pima.az.us/cmo/sdcp/Riparian.html>

<sup>54</sup> Nadine, M.A. and S.B. Rood. "Comparative tolerances of riparian willows and cottonwoods to water-table decline." *Wetlands* 22: 338-346, (2002).

IGA secures a permanent 10,000 AF annual supply, the price of which is determined by O&M costs. Our partial economic analysis demonstrates net economic benefits accrue from the preservation and enhancement of the riparian corridor by ensuring hydrologic conditions necessary to support high quality riparian habitat, which in turn preserves private property values and secures property tax revenues. Without projects such as the SDCP, the future for riparian corridors in Tucson is uncertain. Growth and associated increased water demand would likely negatively impact remaining riparian habitat. Recent research shows that as groundwater levels decline, riparian tree communities shift from more highly valued shallow groundwater-dependent riparian species to lower value dryland and invasive species communities.<sup>55</sup> Such a shift, would in turn, significantly impact nearby private property values (and property tax revenues) as well as wildlife habitat and recreation activities. Additionally, if groundwater levels decline further herbaceous cover also will decline, thereby reducing bank stabilization<sup>56</sup> and increasing the necessity for expensive flood damage and control infrastructure. Our results are relevant to other current policy discussions, beyond the SDCP. Three are discussed below.

This research suggests that net economic benefits may accrue from legally limiting or curtailing private wells in exurban Tucson.<sup>57</sup> Wells sunk near riparian corridors create a cone of depression, lowering the water table that in turn can kill neighboring riparian

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<sup>55</sup> Lite, S.J., and J.C. Stromberg. "Surface water and ground-water thresholds for maintaining *Populus-Salix* forests, San Pedro River, Arizona." *Biological Conservation*, 125 (2): 153-167, (2005).

<sup>56</sup> Stromberg, J. C., R. Tiller, and B. D. Richter. "Effects of groundwater decline on riparian vegetation of semiarid regions: the San Pedro, Arizona". *Ecological Applications* 6:113-131, (1996).

<sup>57</sup> Colby and Wishart, *Residential supra* note 28.

trees, which rely on shallow groundwater and high soil moisture content: species that are highly valued by nearby homebuyers. Revisions to the current interim Arizona well spacing rules<sup>58</sup> are currently being considered. A number of parties have suggested modifications that would define “damage to surrounding land or (other) water users”<sup>59</sup> to include damage to riparian habitat and surface water rights holders. This analysis provides evidence of the significant property values that could be ‘damaged’ by unregulated groundwater (or subflow) pumping near a riparian corridor.

The study also provides new information that could be disseminated to Pima County homeowners to inform them of the property premiums associated with riparian habitat conservation. Some property owners are concerned about the impact of new riparian protection laws passed in Pima County in 2005.<sup>60</sup> The new policy places limits on property owners ability to manage their land, but offsetting these restrictions are property value premiums accruing from habitat protection.

Pima County has a program to preserve riparian habitat by direct purchase. Such purchases also support wider access to such habitats. However, there are appraisal

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<sup>58</sup> Current well-spacing rules as per A.R.S. §45-598A, Section A are intended to “prevent unreasonably increasing damage to surrounding land or other water users from the concentration of wells”.

<sup>59</sup> A.R.S. §45-598A, Article A.

<sup>60</sup> Pima County Code Chapter 16.30. The Watercourse and Riparian Habitat Protection and Mitigation Requirements as per this chapter requires that all proposed development of more than one-third of an acre in a regulated riparian habitat must undergo a review. This amendment to the code expands the acreage protected in unincorporated areas of the county from 26,251 acres to 87,273 acres. Within the regulated areas developers must replace each old tree removed or protect land elsewhere. A key aim of the new rule is to mitigate flood damage through conservation of riparian vegetation within regulated areas. Landowners must replace vegetation volume removed or protect land elsewhere.

obstacles in the Floodprone Land Acquisition Program.<sup>61</sup> Appraisal practices consider floodplain restrictions, which may limit potential uses of parcels in the floodway.<sup>62</sup> Current appraisal practices do not consider the value of the vegetation to private property owners and thereby discount property values in the floodplain fringe. However, the program may allow the use of ancillary data, such as an estimate of the ‘value’ to nearby property owners of the particular type of riparian habitat considered for purchase. Such house price premiums can be large. Nevertheless, without water policies designed to maintain habitat, such as those incorporated in the SDCP, the outright purchase of parcels that contain significant riparian habitat is not a guarantee to these ecosystems’ survival.

In concluding, we consider whether Arizona’s water law allows such water non-consumptive water use. Arizona’s water rights system is based on the doctrine of prior appropriation of water use. This ‘first in time, first in right’ policy was modified with the 1919 Public Water Code (PWC)<sup>63</sup> that manages surface water in the state. From that date, a person had to apply for and receive a permit in order to appropriate surface water for a beneficial use.<sup>64</sup> The PWC A.R.S. § 45-151(A) lists the following as beneficial uses domestic, municipal, irrigation, stockwatering, water power, *recreation*, *wildlife* including fish, *nonrecoverable water storage*, and mining uses (our emphasis). Specifically the code allows a person to apply for a permit for instream flow

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<sup>61</sup> Pima County Flood Control District (PCFCD), 2006. “Floodprone Land Acquisition Program”. Accessed March 1, 2006, 2pp. <http://rfcd.pima.gov/landacq/> and personal communication.

<sup>62</sup> Pima County Code, Chapter 16.24

<sup>63</sup> A.R.S. Title 45 - Waters, Chapter 1, Articles 4 and 5.

<sup>64</sup> Arizona Department of Water Resources (ADWR). “Surface Water Rights: Public Water Code”, 4pp. Accessed March 1, 2006.

[http://www.azwater.gov/WaterManagement\\_2005/Content/WaterRights/default.htm](http://www.azwater.gov/WaterManagement_2005/Content/WaterRights/default.htm)



maintenance<sup>65</sup> necessary to support preserve wildlife, fish and recreation. Additionally, a permittee must demonstrate that he or she is using the instream flow water right in a manner consistent with the terms of the permit or the right will be forfeited. In western Arizona, along the Colorado River, the Colorado River Compact's Article I<sup>66</sup> permits restoration and conservation of riparian corridors for flood mitigation.

Perhaps the most difficult riparian protection policy issue is that homeowners fear that riparian habitat protection “may threaten livelihood and lifestyle.”<sup>67</sup> Therefore, policy-relevant research needs to investigate how property owners are affected when riparian corridors are preserved or restored. In this paper we have applied results from a recent hedonic price analysis and demonstrated that a healthy riparian corridor increases nearby property values and that restoration and preservation projects can be self-financing. A fuller benefit cost analysis would seek to estimate the other benefits provided by riparian habitat such as flood control, infiltration to the regional aquifer, bank stabilization, open space, recreation, aesthetic and ecosystem values. Such a study would improve the benefit-cost argument for riparian preservation and restoration. This research has wider applicability than in Arizona or to riparian resources. There are a whole class of public goods that add to private property values, such as open space, wetlands, and parks, and there are often questions about the economic cost of providing such public goods. Our

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<sup>65</sup> Application for Permit to Appropriate Public Water of the State of Arizona Instream Flow Maintenance.

<sup>66</sup> Colorado River Compact, Article I. 1922. Accessed March 1, 2006, 4pp., <http://crc.nv.gov/1922coloradorivercompact.htm>. The compact allows the river to be managed for “the protection of life and property from floods.”

<sup>67</sup> Gelt, J. (2005). Managing the flow to better use, preserve Arizona's rivers. Accessed March 1, 2006, 12pp. <http://ag.arizona.edu/AZWATER/arroyo/064rvtxt.html>.

analysis demonstrates an approach to assessing the property value effects of such programs.

#### ACKNOWLEDGEMENTS

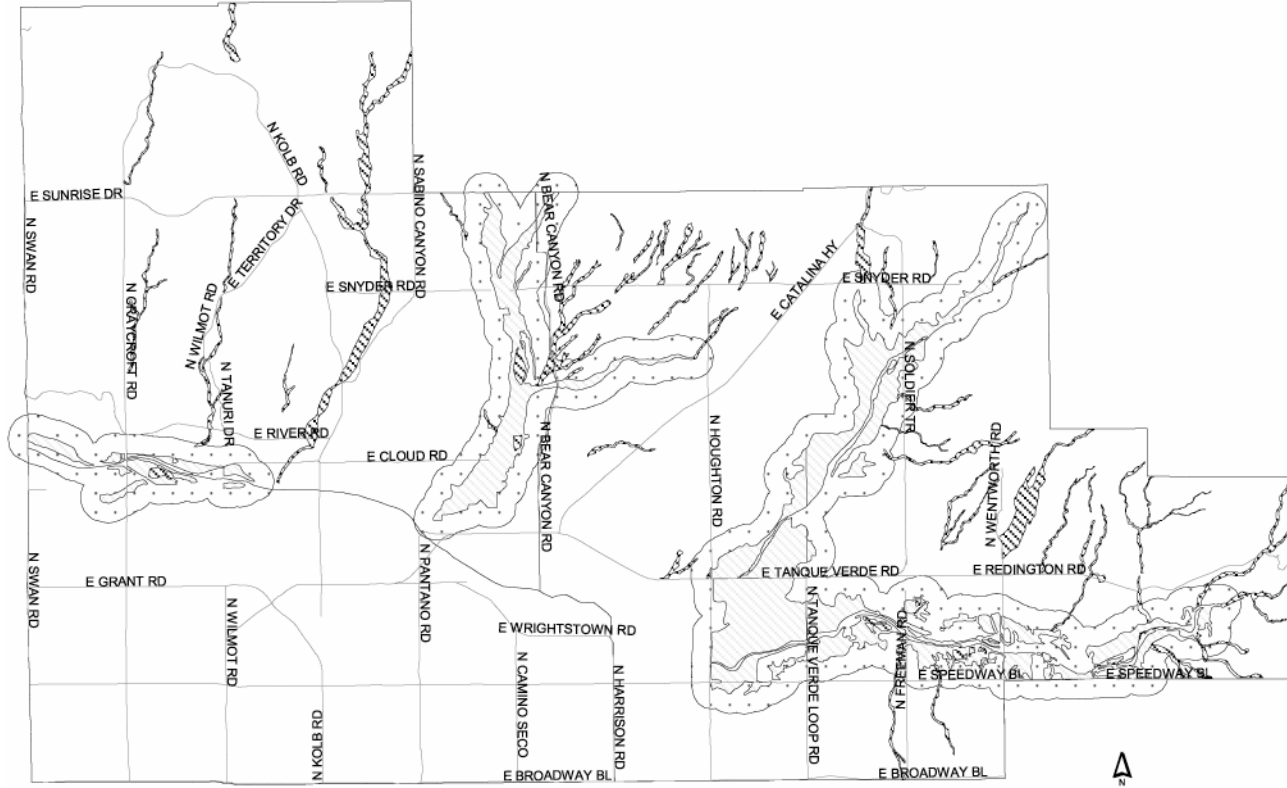
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#### DISCLAIMER

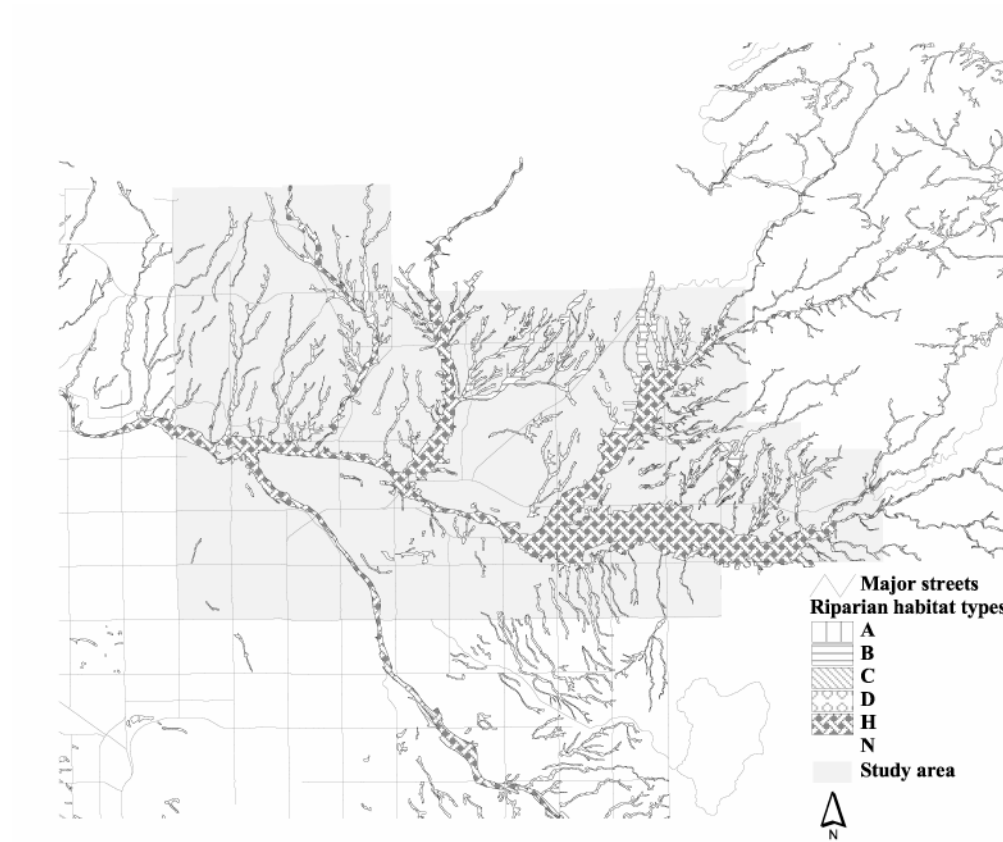
Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of SAHRA or of the National Science Foundation.

FIGURES

MAP 1: STUDY AREA WITH PIMA COUNTY DESIGNATED HYDRO/RIPARIAN HABITAT



**MAP 2: PIMA COUNTY PROPOSED RIPARIAN HABITAT**



APPENDIX E: SNOW DAYS? CLIMATE VARIABILITY AND CHANGE AND THE ECONOMICS OF SNOWMAKING IN ARIZONA, SOUTHWEST USA

Running head: Economics of snowmaking

Key words: climate change, ENSO, snowmaking, economics.

Rosalind H. Bark-Hodgins\*<sup>1</sup> and Bonnie G. Colby<sup>2</sup>

ABSTRACT

Climate adaptation strategies such as snowmaking can reduce climate change vulnerability [1] by increasing snow pack depth, durability and season reliability. However, snowmaking costs in the Southwest are around \$923 per acre foot of snow [2], and snowmaking requires large volumes of water [3]. Previous research has focused on low elevation ski resorts in Europe and Canada. This paper adds to the literature by investigating the impacts of climate variability and change on low latitude, high elevation ski resorts in Arizona, USA. Arizona ski areas already experience high inter-annual variability in snow reliability in terms of total snow pack, season length, and season timing. This variability is closely linked to the El Niño Southern Oscillation: El Niño (La Niña) conditions are a significant predictor of a good (bad) ski season. To mitigate variable snow conditions on ski area profitability the two largest ski areas in the state have investment plans to increase snowmaking capability. The investments pass a cost-benefit analysis; however, there are large uncertainties that could tip the balance against this mitigation strategy, such as higher energy and water costs, and significant winter warming. On the demand side there are uncertainties about consumers' willingness to pay

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<sup>1</sup> PhD Candidate Arid Lands, AREC Rm 319, University of Arizona, PO Box 210023, Tucson, AZ 85721-0023. email: rbark@email.arizona.edu. <sup>2</sup>Professor, Agricultural and Resource Economics, University of Arizona.

higher ticket prices to cover investment costs to ski on an inferior manufactured product, particularly if nearby higher elevation resorts offer powder.

## INTRODUCTION

Climate change models predict declining snow pack, shorter and more variable snow seasons, warmer winter temperatures with increased incidence of winter snowpack melt and sublimation loss, earlier spring snowmelt, and an increase in the elevation needed to maintain seasonal snowpack. The implications are significant for the ski industry because beginner skiers tend to learn at lower elevation 'local' ski areas [4] and beginners are less likely to continue with skiing if nearby conditions are poor [5]. These predictions are worrisome for the ski industry worldwide. This paper adds to the research by assessing climate change impacts on low latitude, high elevation ski resorts, such as those in Arizona. Arizona has two relatively large resorts that (in a good year) host 400,000 total skiers and support jobs and economic development. The paper investigates the influence of ENSO on Arizona ski seasons and its impact on the economics of snowmaking plans. The new Intergovernmental Panel on Climate Change (IPCC) AR4 model results for Arizona's Climate Region 2 are utilized to assess the impact of warming on snowmaking adaptations. Finally the paper identifies needed research in consumer responses to increased snowmaking.

Assessments of climate change impacts on ski resorts have been completed in Australia [5, 6], Austria [7], Canada [8, 9], Scotland [10], Switzerland [11, 12] and the United States [13]. All these studies predict that climate change will have negative consequences

for low elevation ski resorts: without adaptation strategies ski resorts will have to earn their threshold of minimum viable net returns during a shorter season. Warming is predicted to reduce snow cover and thereby fewer days in the season will meet *minimum* operational snow base for winter sports. These thresholds vary with the sport: 10 cm for cross country skiing, 30 cm for downhill skiing and snowboarding, and more than 30 cm above the tree line in rocky terrain [1, 3]. Mountain managers may decide not to open their specific resort until natural and manufactured snow base is deeper than these minimums.

Breiling and Charamza [4] predict that a 2°C warming will reduce snow cover in Austria by between 47% and 79% from a 1965-1995 baseline. Their forecast reduction in skiable days is greater because of the minimum snow depth required for winter recreation. They note that even with the warming there will still be around one year in two where snow depth is within the range of the baseline data. Such increased unpredictability is highly damaging to this infrastructure-intensive industry. They also note that the timing of snowfall is crucially important to the economics of the ski industry. Two key time periods in the Austrian ski season are Christmas/New Year and during spring break in February. The authors conclude that a minimum elevation of 400 m is necessary for profitable winter tourism because it will be uneconomic to make snow at lower elevations [p11]. A similar study in the northwest USA suggests a 75 cm to 125 cm reduction in average snow depth and the movement of the mean altitude ski lift (masl, in meters) from 900 masl to 1,250 masl [14].

Not only is the shift in mass a concern for individual ski resorts but it has implications for the wider ski industry. Skiing in many parts of the world is currently concentrated at low elevations with easy access to population centers. Winter recreation research has shown that these small, 'community' ski areas are essential to the growth of the industry as they cater to novices, families, and skiers getting in shape before a longer vacation at a larger ski resort. For example, Scott, McBoyle and Mills [1] report that 45% of skiers in Toronto, the largest single market of active skiers in Canada, travel less than one hour to ski. If such ski areas are forced to close the 'stock' of skiers may also decline, compounding the negative impacts of climate change.

Consistent operation is important both for consumers and suppliers of snow-based recreation. Many skiers would prefer to plan their skiing activity and vacations with certainty which may be absent if resorts rely on natural snow, whilst consistency allows managers to fully utilize lift, lodge, snowmaking infrastructure and staff throughout the season. An important concept is "snow reliability" [15]. In Switzerland the 'reliability' threshold is assumed to be 7 out of 10 good winter seasons, with a snow cover depth of 30-50 cm, for a minimum 100 days between December 1 and April 15. Currently, just 85% of Swiss ski resorts meet this snow reliability test. However, if, as per one climate change scenario, snow reliability were to rise to 1,500 m in the period 2030-2050, only 63% of all resorts would meet this test. The authors conclude that climate change will alter the ski industry with visitors concentrating in higher elevation, more snow reliable



ski resorts. Such an outcome is not only a concern for the resorts and surrounding communities in the lower elevation preAlps but also for the ecologically sensitive Alps region where pressures to expand skiing are likely to increase. Scott, McBoyle and Mills [1] come to a similar conclusion that the ski industry will become increasingly two-tiered.

Reliability is an important concept: another aspect of reliability is how many consecutively poor snowfall seasons a resort can tolerate. For example a string of three poor seasons in ten, is likely to have a greater impact on financial viability of a ski resort than three poor seasons spaced equally over a ten year period. For some small, lower elevation resorts a couple of consecutive poor seasons combined with water resource constraints, which limit snowmaking adaptation, may usher more rapid restructuring which in turn will impact local economies. Other determinants of reliability are threshold maximum temperatures and rainfall which if exceeded will hasten early ski resort closure [16].

#### ARIZONA SKI RESORTS

Arizona has four ski resorts, two of which are very small and therefore are not considered here. The larger two resorts have more consistent snow conditions and can plan snowmaking investments because of their higher elevation and better financial performance. Arizona Snowbowl (Snowbowl) is located near Flagstaff and Sunrise Park Resort (Sunrise) is located in the rural east central part of the state, see Figure 1. Elevation at Sunrise ranges from 2,836m to 3,354m and at Snowbowl from 2,805m at the base to 3,506m at the peak. Neither resort is world class; they mainly cater to in-state

residents. Two-thirds of Snowbowl's visitors are day trippers whilst Sunrise estimates that eighty percent of its around 200,000 annual skier visits come from in-state, with the remainder drawn from New Mexico, Southern California, and Mexico [17]. Mountain managers at the resorts note that skiers from other Southwest states travel to Arizona if the ski conditions are good in Arizona relative to their home state. For example Sunrise was one of the few Southwestern resorts with good snow during the 1998/99 season and benefited from large numbers of out-of-state visitors. Several factors will determine how any single ski resort fares with respect to climate variability and change: the relative impact of climate change on the resort and its competitors (a function of elevation, aspect, humidity, snow patterns, etc) and any resultant changes in intra and inter-regional skiing market share, the costs of additional snowmaking, how adaptation by skiers could alter skiing demand, and the impact of other adaptation strategies such as business diversification and weather derivatives and insurance [1].



**Figure 1: Arizona's ski resorts**

There are a number of competitive differences between the Sunrise and Snowbowl arising from land ownership and water rights that offer some opportunities for Sunrise. However, it is important to note that management at Sunrise believes that a good season for Snowbowl is also a good season for Sunrise because it increases interest in the sport and because many Arizona skiers ski at both resorts for variety. Snowbowl is constrained by its location on United States Forest Service land (USFS land is federally managed); any plans to expand facilities must pass an environmental impact review and it is prohibited from offering on-site lodging. The facility also lacks water rights for its lodge and for snowmaking. In contrast, Sunrise is tribally owned, lies at the top of the watershed, and is the only resort in Arizona to offer night skiing, snowmaking, and a

casino. It also has on-site lodging at the 100 room Sunrise Lodge and a nearby recreational vehicle park. In addition Sunrise benefits from topology. The resort comprises three peaks, Sunrise, Apache and Cyclone, that enables the mountain manager to control the supply of ski runs to meet demand and save operational costs. For example at the end of the ski season when skiing demand wanes or when natural snowfall is poor skiing is restricted to Sunrise Peak. The other two peaks do not have snowmaking infrastructure and offer fewer facilities. In the future if climate change scenarios are realized the flexibility inherent in the three peaks may enable the resort to remain open by cherry picking runs that have superior snow conditions resulting from preferred aspect, slope and elevation.

Arizona's ski resorts are small relative to the large, commercial resorts in nearby Colorado and Utah. They are however similar in elevation and snow conditions to resorts in New Mexico and also to low latitude, high elevation resorts in the southern hemisphere. However, some South American and New Zealand resorts are world class despite similar snow reliability issues as those in Arizona because they benefit from their 'out of season' southern hemisphere season: viz. June to October, which in turn secures financial resources for snowmaking investments.

Currently Sunrise is the only resort in Arizona with snowmaking capability but it is limited to 10% of skiable terrain. It has plans to extend snowmaking infrastructure to other runs on Sunrise Peak. Meanwhile, Snowbowl's operating company has recently had

its ambitious expansion and snowmaking plans approved. These plans incorporate snowmaking for 100% of its expanded terrain [18]. This large investment is part of a trend at ski resorts around the world that want to ensure that each season meets some predefined minimum skiable days. For example, low elevation-high latitude ski resorts in central Ontario, Canada also have snowmaking capabilities for 100% of skiable terrain [1] whilst snowmaking capabilities of 50% and higher are the norm for top Colorado ski resorts. At Las Leñas, Argentina similar in elevation and snowfall to Snowbowl and Sunrise snowmaking capability covers 40% of all slopes, specifically incorporating all lower runs. La Parra in Chile has recently undergone a \$9.5M expansion project, of which half the investment was earmarked for snowmaking. The snowmaking project will incorporate 60% of the lower mountain and 25% of the mid-mountain runs. Illustrating the significance of elevation, elevation at the Valle Nevado resort in Chile ranges from a somewhat higher 2,860m to 3,670m, and perhaps as a consequence has snowmaking capability for only 30% of terrain. In all these examples investment in snowmaking infrastructure is the key climate adaptation strategy. However, actual snowmaking is constrained by maximum temperature thresholds, energy, water and other operational costs, and in some cases water availability.<sup>2</sup>

#### DATA

Snow data was collected from the U.S. Department of Agriculture's Natural Resources Conservation Service's National Water and Climate Center. Ski visitor data for the

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<sup>2</sup> 1 acre foot of snow = 139,222 gallons or 527,011 liters of water.

Arizona Snowbowl was collected from their Environmental Impact Statement [18] and Sunrise Park Resort visitor data was estimated using National Ski Areas Association Arizona and the aforementioned EIS data. Table 1 records skier visitation data for Snowbowl for 25 seasons and in Arizona for ten seasons. Sunrise data was not available because of tribal privacy issues and is therefore estimated. The two smaller resorts in the state, Williams and Mt. Lemmon are located at significantly lower elevations than Sunrise and Snowbowl and consequently have highly variable snow conditions. Using this fact and lift capacity it is estimated that Sunrise accounts for 96% of the non-Snowbowl Arizona visitation data.<sup>3</sup> The data show that visitor numbers are relatively steady at Sunrise whilst Snowbowl experiences large fluctuations in skiable days and visitors. Two explanations are that Sunrise can manufacture snow to supplement natural snowfall and it also benefits from more consistent natural snowfalls. Nevertheless, although Sunrise is almost six times larger than Snowbowl, in a good snow year, for example the 2004/05 season, skier visits were almost equivalent. This reflects the superior location of Snowbowl to large skier markets in Flagstaff, Phoenix, and Tucson. In contrast, Sunrise is located in a relatively remote region of the state that is not served by major highways.

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<sup>3</sup> This figure is somewhat higher than Sunrise's 85% of non-Snowbowl lift capacity.

**Table 1: Arizona ski data**

SEASON	ENSO PHASE	SNOWFALL, cm	SKIABLE DAYS	VISITORS		
				Snowbowl	Arizona	Sunrise
1981-1982	N	673.1	123	63,000		
1982-1983	EN	701.04	135	99,626		
1983-1984	LN	193.04	64	28,913		
1984-1985	LN	675.64	118	114,707		
1985-1986	N	533.4	124	105,252		
1986-1987	EN	736.6	112	125,026		
1987-1988	EN	462.28	92	119,259		
1988-1989	LN	431.8	79	120,132		
1989-1990	N	609.6	74	99,280		
1990-1991	N	591.82	112	106,000		
1991-1992	EN	914.4	134	173,000		
1992-1993	N	1,168.4	130	181,000		
1993-1994	N	558.8	114	116,388		
1994-1995	EN	657.86	122	176,778		
1995-1996	LN	287.02	25	20,312	102,575	78,972
1996-1997	N	685.8	109	153,176	365,787	204,107
1997-1998	EN	838.2	115	173,962	384,665	202,275
1998-1999	LN	381	60	35,205	246,941	203,267
1999-2000	LN	457.2	45	66,152	243,685	170,432
2000-2001	LN	690.88	138	162,175	355,780	185,861
2001-2002	N	220.98	4	2,875	214,135	202,810
2002-2003	EN	523.24	96	87,354	277,361	182,407
2003-2004	N	368.3	120	72,000	238,420	159,763
2004-2005	EN	1,168.4	133	190,000	370,000	172,800
2005-2006	LN		15			
<b>Average</b>		<b>605.37</b>	<b>93</b>	<b>107,982</b>	<b>279,935</b>	<b>176,269</b>

Source: EIS (2006) and National Ski Areas Association, pers comm. Snowbowl data is shaded gray.

Total snowfall abundance and days open are two significant factors that determine how good a ski season is in Arizona. Using a simple regression model and the Sunrise data a model with snowfall (cm) and days open explains over 80 per cent of the variation in ski visits ( $F=61.28$   $pr>F <.0001$ , the parameter estimates are: CONSTANT -18,584  $pr>|t$  0.14, SNOW 105,  $pr>|t$  .0016 and DAYS\_OPEN 680  $pr>|t$  .0018). Season snowfall is also a significant predictor of days open, explaining 60 per cent of the variation in days

open ( $F=36.28$   $p < .0001$ , parameter estimate SNOW 0.119,  $p < .0001$ ). Another factor that is not possible to test with the data is the timing of the snowfall.<sup>4</sup> For instance the 2000/01 ski season was good at Sunrise, even though snowfall was lower than average, because snow accumulated in October and was present over the financially decisive Thanksgiving and Christmas-New Year holiday season [19]. Timing also in part determines the competitive positions of Snowbowl vis-à-vis Sunrise. For example, in the 2004/05 season Snowbowl received early snow opening on November 26, whilst Sunrise played catch up as its season had a slow start, only picking up after large snowfalls early in 2005.

#### MODELING CLIMATE VARIABILITY

To test the robustness of the ENSO signal on winter precipitation in Arizona a series of models were run. Data used was from Snowbowl for the period 1982/83-2004/05. The influence of ENSO was modeled using a logit regression. The first model regressed a binary dependent variable that was set equal to one if a season met 93 skiable days (the average over the period) and zero otherwise whilst the independent (binary) variable was set equal to one if the season was a La Niña season and zero otherwise. The results of the model report that the La Niña variable is significant at the five per cent level (parameter estimate -1.8,  $p > \text{Chi squared} = 0.07$ ) and that the odds in a La Niña season, versus a non-La Niña season, of meeting minimum season length is 0.17 [95% confidence interval: 0.02-1.16]. These results have implications for Snowbowl's mountain manager, namely

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<sup>4</sup> The peak skier days in the Arizona ski season are Christmas-New Year, Martin Luther King weekend, Tucson's Rodeo week, college and school Spring breaks, every weekend during the season, and Thanksgiving, given early snowfalls.



that without snowmaking capability staffing resources in La Niña seasons are likely to be lower than average. Similarly this result illustrates that such seasons are likely to be more heavily reliant on new snowmaking capability to meet the resort's 125 skiable days goal. This result also has implications for season ticket buyers under current no snowmaking conditions and also in the future when snowmaking investments are operational.

A second logit modeled the odds of covering a late bought \$699 season ticket during La Niña conditions. The La Niña variable is significant at the five percent level (parameter estimate -3.06,  $p > \text{Chi squared} = 0.017$ ) and the odds in a La Niña season versus a non-La Niña season to cover this late-bought season ticket are 0.05 [95% confidence interval: 0.004-0.58]. If season ticket buyers knew in advance the phase of the ENSO cycle for the approaching season they could use this information to decide when and whether to buy a season ticket. Skiers may decide not to buy a season ticket in a La Niña season pre-snowmaking investments because they are unlikely to cover the cost of the ticket. But it also conceivable that some would not buy a season ticket in a La Niña post-snowmaking investments preferring to spend their ski dollars at a higher elevation, higher latitude resort that is more likely to have natural snow. In fact forecast skill in Arizona for ENSO is relatively high [20] and may be useful information for mountain managers to forecast staff, marketing, and snowmaking requirements whilst season ticket buyers could use the same forecasts to help them decide whether or not to purchase season tickets.

SNOWMAKING ADAPTATION

Snowmaking is an adaptation strategy not only to mitigate climate warming but also to mitigate more general inter-annual climate variability. The first study to model snowmaking as a climate adaptation strategy was Scott, McBoyle and Mills [1]. Their study in central Ontario, Canada found that climate change scenarios that double CO<sub>2</sub> concentrations would reduce ski seasons by a smaller 7% to 32% compared with a 40% to 100% loss predicted by McBoyle and Wall [21]. The difference between these studies is a measure of the effectiveness of snowmaking in extending seasons. Furthermore, improved snowmaking capabilities<sup>5</sup> would reduce season losses to just 1% to 21% [1]. Nevertheless, these results rely on large increases in snowmaking by the year 2080 of between 191% and 380%. Such levels of snowmaking may not be financially or environmentally viable.<sup>6</sup> Winter warming is also a threat to ski seasons in the southwestern USA and more general winter climate variability is a significant feature in this ski market.

Investment in snowmaking infrastructure can increase intra- and inter-season consistency by building up snowpack after warm or rain conditions and it can also extend ski seasons by facilitating an earlier start and later finish than natural conditions would allow. An important climatic oscillation that influences inter-annual winter precipitation in Arizona

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<sup>5</sup> Newer snowmaking equipment can efficiently make 15 cm of snow base per day at -2°C compared to older equipment that makes just 10 cm snow base per day and requires lower temperatures of at most -5°C.

<sup>6</sup> Snowmaking is not viable for the snowmobiling, Nordic and cross country skiing sectors because of the huge economic and environmental barriers to snowmaking for tens or hundreds of kilometers of trails [1]. Sunrise and Snowbowl both have vulnerable cross country skiing sectors. However, without detailed information on the size of this specific market relative to the downhill skiing market, the impact of this vulnerability is unknown. Both resorts have however identified snowmaking as an adaptation strategy to climate variability for their downhill ski business.

is the El Niño Southern Oscillation (ENSO). Warm (positive) phase, El Niño conditions tend to bring above normal winter precipitation in Arizona, for example the abundant snowfall 2004/05 season, whilst cold (negative) phase, La Niña conditions are associated with drier conditions. This phase is more reliably dry in Arizona than the warm phase is wet. To illustrate snowmaking timing and volumes snow depth at Sunrise and minimum snow depth thresholds (36cm) during an El Niño episode (1982/83) and a La Niña episode (1998/99) are graphed. Figure 2a shows that during this El Niño episode snowmaking requirements (shaded) would have been limited to early in this arbitrarily chosen season (Thanksgiving through April) whereas in this La Niña episode, Figure 2b, large snowmaking requirements would have been necessary at the start, over spring break, and near the end of the season to maintain adequate snow depths for skiing. Note that if the resort used its 61 cm minimum snow depth base from its snowmaking plan then snowmaking would be required for most of the 1998/99 season. During a severe winter drought it may be unprofitable to make snow particularly if winter temperatures are warm, increasing costs and also sublimation losses.

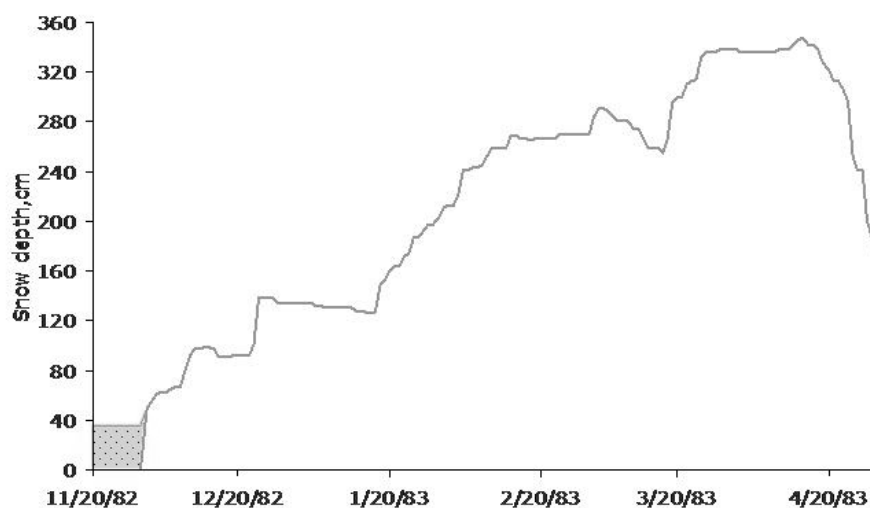


Figure 2a: Snowmaking requirements in an El Niño season, 1982/83<sup>7</sup>

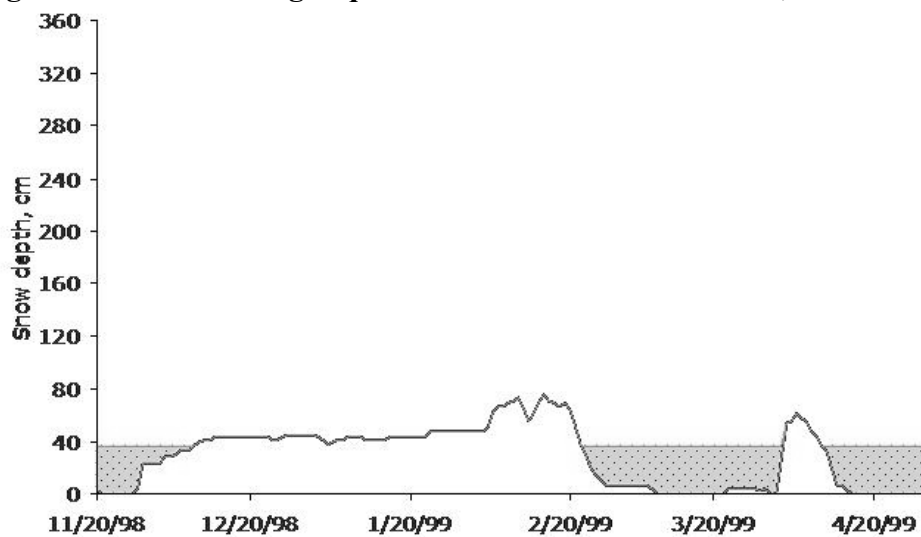


Figure 2b: Snowmaking requirements in a La Niña season, 1988/89

## SNOWMAKING ECONOMICS

<sup>7</sup> Snowdepth data is not available for this entire period. Therefore SWE data was used with average SWE in inches from snow course data. These averages for Baldy over the period 1983-2005 for the months November through April are: 7, 7, 10.9, 8.6, 7 and 6.9.

Scott, McBoyle and Mills [1] make a clear argument for the expansion of snowmaking when profitable and also observe that the success of such supply-oriented changes is dependent on consumer responses. A question that mountain managers at Snowbowl and Sunrise need to answer before committing more resources to expansion and snowmaking plans is does the demand support it? The demand for skiing is not only influenced by snow conditions at the resort, but also relative snow conditions, prices at competing resorts, and the availability of other recreation activities. The Snowbowl EIS attempts to answer this question by calculating the utilization rate at the resort. This is found by dividing skier visits by total capacity. This rate averaged 64% in the period 1990-2004 peaking at 83% in 1998. They comment that US ski areas measure strong demand as a utilization rate above 40%: on this basis they conclude that there is sufficient demand in the region to support expanded ski facilities. However, research has shown that the demand for spring skiing typically “waned before the snow pack is exhausted” [1]. This phenomenon has been recorded at Sunrise and Snowbowl. For example, in the exceptional 2004/05 season Sunrise closed on April 3, 2005 and Snowbowl on April 10, 2005, even though both resorts had sufficient snow to remain open. One reason resorts close ‘early’ is that it can be difficult to keep staff so late in the season, as many seasonal workers move onto their spring employment. Nevertheless, marketing to skiers in the spring season in good snowfall years is a possible strategy for maximizing revenue. In fact Sunrise does target this season by offering reduced lift ticket prices, \$25 for adults and \$15 for juniors, in the last weeks of the season. It also modifies its supply-side by closing two of its three peaks.

Snowmaking is expensive. For example, variable costs at Snowmass, Colorado are \$923 per acre foot (af) of snow. This is a reasonable approximation for costs at Sunrise and Snowbowl even though Snowmass is located at a higher latitude (39.8N 107.5W) and the elevation range is larger than at either Arizonan resort. Actual costs are dependent on system efficiency [22] which is a function of the machinery used and the microclimate, and local costs for energy, water and trained staff. A conundrum for resorts is that as more ski areas invest in snowmaking to reduce the risk of a bad snow year, it may become more difficult to finance such investments. Bürki, Elasser and Abegg [16] found evidence that Swiss banks are becoming more wary of funding infrastructure investments at ski resorts lower than 1,500 m whilst ski area managers in southern Ontario, Canada now have to assess and address climate change impacts in financing negotiations with lenders [1].

A financial analysis of snowmaking has to weigh the investment and variable costs of snowmaking against the expected incremental revenue gains from increased visitation. In the following section an analysis of the snowmaking investment plans at Snowbowl and Sunrise are undertaken. The goal of this exercise is to show how the economics of snowmaking investments hinges on season length and in turn how these investments are vulnerable because season length is likely to be shortened by climate change warming.

### **Snowbowl's snowmaking investment**

Snowmaking could enable Snowbowl to achieve more consistent snow conditions. Under its expansion plan Snowbowl management has a goal to consistently operate 125 days per season plus or minus 15% [18, 3-112].<sup>8</sup> However, by relying exclusively on natural snow Snowbowl actually met its goal only five seasons in the last twenty five (see Table 1). Compounding these poor overall reliability statistics, the distribution of very poor seasons was devastating to the financial position at the resort. Before the banner 2004/05 season, Snowbowl recorded four unprofitable operating seasons (1995/96, 1998/99, 1999/00 and 2001/02) in the last eleven. The combination of poor seasons and the capital intensive nature of the industry meant that all net cumulative profits over the period were reinvested in ongoing maintenance and capital improvements [18]. It is this poor financial performance that has guided the resort's plans to expand and invest in snowmaking.

Snowmaking infrastructure will be constructed to cover the entire 83 ha (205 acre) terrain. Snowmaking operations are restricted to a 119 day period (November 1 through 28 February): this is the period in which the resort has a contract for water deliveries for snowmaking from the City of Flagstaff. The plan envisages applying a base of 64 cm, note that this is higher than the 30-50 cm depth cited for Swiss ski areas [15]. Reasons for this deeper base are the high elevation of the ski resort, consequent steeper slopes, and sublimation losses in the dry interior climate [23]. Another reason is probably practical: it is difficult to imagine that many skiers would be satisfied with the experience of skiing

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<sup>8</sup> Using this goal and the +/- 15% assumption we assume that in a neutral year there are 125 skiable days, 94 skiable days in a dry year, and 156 skiable days in a wet year.

on a 30 cm snow base, particularly skiers who travel long distances for a ski vacation. Significantly the plan also takes into account current inter-annual variability in snow conditions: there are three scenarios which translate into the three phases of ENSO. In a “wet” (El Niño) season managers plan to build up a base early in the season in order to open over the Thanksgiving break. Snowmaking volumes in this season are estimated at 526,662 m<sup>3</sup> (427 af). The volume of snow budgeted for a “normal” (Neutral) season is for one and half applications or 789,376 m<sup>3</sup> (640 af) of snow increasing to two applications in a “dry” (La Niña) season (1,053,324 m<sup>3</sup> or 854 af snow) [18].<sup>9</sup> These snow volumes translate into total water demand of 337 million liters (MI, 243 af) in a wet season, 505 MI (364 af) in an average season and 674 MI (486 af) in a dry season.<sup>10</sup> Using this data it is possible to calculate water use per acre foot of snow: it is one third higher than an industry estimate at 701,984 l (185,401 gal) of water per acre foot of snow. This disparity might reflect a preference for snow with a higher snow water equivalent in the low humidity environment in Arizona.

Snowbowl has no water rights and currently trucks in all potable water. Therefore to support snowmaking Snowbowl management have signed an agreement with the City of Flagstaff that would allow for a maximum transfer of 674 MI of Grade A reclaimed wastewater per season for 5 years with possible renewal for three more five year periods.

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<sup>9</sup> These volumes are average for a typical sized ski resort in the US. On average US resorts manufacture around 500-1,000 af of snow per season at a cost between \$0.25 M-\$4 M and use between 214 af and 427 af of water per season. [6].

<sup>10</sup> Included in these totals is approximately 8.3 MI (6 af) annually for toilet flushing. Snowbowl currently trucks in 5.7 M liters of potable water annually of which 60% is used for toilets. If growth in flushing use rises in line with expected growth in visitors from an annual average 98,000 to 215,000 then flushing volumes increase to 6 af annually.



The use of effluent is controversial. Thirteen tribes are opposed to using reclaimed water for snowmaking on the sacred San Francisco Peaks where Snowbowl is located and environmentalists are opposed to the proposed use of scarce water resources. The water could be used by Flagstaff for alternative uses such as to support nearly 1,312 families,<sup>11</sup> or other alternative economic growth activities. However, these objections were overruled in the recent EIS approval of the plan. Paradoxically, snowmaking investments at Snowbowl may prevent desecration of other sacred sites in the state, sites that might offer superior snow conditions than at Snowbowl.

Actual snowmaking costs are not available for the resort so this analysis is based on reasonable assumptions.<sup>12</sup> The first assumption is that variable snowmaking costs at Snowbowl are \$1,204/af snow in 2013/14 when the investments come online. Snowbowl has to purchase water for snowmaking. There is currently no contract price between the ski resort and the wastewater plant in Flagstaff; however, costs can be estimated based on the city's current non-peak, high volume wastewater charges. The total fixed costs of the investment are \$19.77M, this figure is used rather than the \$8.2M cost for snowmaking because the entire investment is needed to accommodate the expected 215,000 skiers per year. This investment is annualized over a 20 year time frame and a third of the cost is

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<sup>11</sup> An acre foot of water supports an average 2.7 Arizonan families a year [24].

<sup>12</sup> These assumptions are: variable snowmaking costs \$923/af in 2005, variable and water costs increase at a 3% rate (this is approximately the average annual inflation rate in the period 2000-2006), fixed costs are per Snowbowl and Sunrise plans, present values are calculated using a 6% discount rate (the Federal Reserve Bank's primary credit rate in May 2006).

allocated to each ENSO phase.<sup>13</sup> The variable and fixed costs are presented in present value terms in Table 2.

On the revenue side incremental visits resulting from the investment in each of the three scenarios: wet year, dry year and neutral year are estimated. Incremental visits are determined by calculating the average skier numbers in past La Niña (dry) years, El Niño (wet) years and ENSO neutral years (averages are shown in Table 2). The three phases of ENSO are shown on Table 1. The snowmaking proposal assumes that visits will increase to 215,000 skiers a year. Therefore incremental visits are calculated by subtracting average visits for each ENSO phase from this 215,000 goal. Average ticket prices are assumed at \$38 in the 2013/14 season. Using calculated incremental visits and this ticket price incremental present value revenues are estimated. Incremental revenues from the snowmaking investment are calculated by subtracting pre-snowmaking investment revenues based on average annual visits of 108,000 in the 1981/82 through 2004/05 seasons. The benefit cost ratio between revenues and costs for this investment is positive in all three season types; this result confirms the financial viability of this management-led investment. However, there are many uncertainties in this analysis such as the costs of energy and water, interest rates, and consumer responses to skiing on predominately manufactured snow in a dry season, particularly if nearby, substitute resorts have powder conditions.

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<sup>13</sup> This assumes snowmaking investments will be operational for 20 years, the same period as the wastewater contract with the City of Flagstaff. In the 25 year data period approx. a third of the years are classified as each of the three ENSO phases.

**Table 2: Snowbowl cost-benefit analysis of snowmaking**

<b>Incremental PV costs and revenues, 2013/14</b>	<b>Representative “water” year</b>		
	<b>Wet</b>	<b>Neutral</b>	<b>Dry</b>
<b>Costs</b>			
Water	53,393	73,645	89,791
Other variable	295,512	442,921	591,023
Total Variable	348,904	516,566	680,814
Fixed (annualized)	274,763	274,763	274,763
<b>TOTAL</b>	<b>623,668</b>	<b>791,329</b>	<b>955,577</b>
<b>Revenues</b>			
Average visits, 1981/82-2004/05	142,001	99,886	78,228
Incremental visits	72,999	115,114	136,772
Incremental revenues	1,642,046	2,589,379	3,076,546
<b>BC ratio</b>	2.6	3.3	3.2
Profit (# lift tickets)	47,313	26,797	55,810
<b>Skiable days</b>			
Skiable days pre-investment	117	101	68
Skiable days with investment	156	125	94
Incremental skiable days post-investment	39	24	26

The investment ‘buys’ the resort an average 25 more skiable days in a neutral year, 26 days in a dry year and 39 days in a wet year. However these results rely on there being sufficient demand and the ability to manufacture snow. These incremental days are important and are returned to in the climate section below. The importance of season length is also illustrated in the calculation of ‘profit’ in each season type in terms of lift tickets. Maximum capacity at the resort is 8,000 skiers per day: therefore the curtailment of the season by even a few days significantly affects the economics of the resort.

### **Sunrise’s snowmaking investment**

A similar analysis for Sunrise finds that its snowmaking expansion plans are also financially viable at present. Sunrise currently operates for around 122 days during the

season.<sup>14</sup> Snowmaking expansion plans at Sunrise are more modest than at Snowbowl. Management has two plans; both are restricted to increasing snowmaking capability on Sunrise Peak.<sup>15</sup> These plans are not public and therefore approximations are used; the first more comprehensive plan anticipates increasing snowmaking from the current 32.4 ha to around 55 ha to a depth of 61 cm. This option would mean 100% snowmaking capability for Sunrise Peak. A second scaled down option reduces the depth of the snowpack to 41 cm and the number of trails with snowmaking, reducing the total area to around 45 ha. Note that like Snowbowl this base is deeper than the 30 cm standard, furthermore it is less deep than that planned for Snowbowl. Possible reasons for the difference between the two sites are the steeper slopes, high wind conditions, and the suboptimal southwest-west aspect of the pod of ski slopes at Snowbowl. The timing of snowmaking in both plans is for the preseason to enable the resort to open for the Thanksgiving and Christmas holidays.

The initial capital investment is estimated between \$4M and \$9M. Operating costs will depend on the efficiency of the system, the number of snowmaking applications, and the temperatures at which snow is made. In the analysis it is assumed that the mountain manager would opt for an early season base application that would enable skiing over Thanksgiving and that the investment will come on-line in five years time. The plan provides no estimates on expected increased ticket sales, but increased snowmaking might enable the resort to consistently attract 224,000 skiers per year (approx. 140-146

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<sup>14</sup> In the relatively poor 2003/04 season Sunrise only operated 100 days.

<sup>15</sup> Personal communication.

skiable days). Current average annual visitation is reported to be around 200,000.

Incremental visits by season type are estimated using data from the 1995/96 through 2004/05 seasons at: 32,470 in a wet year, 57,716 in a dry year and 27,897 in a neutral year. Given average ticket prices of \$34 and the other assumptions both the full and reduced plans pass the BCA test in all six of the scenarios tested.<sup>16</sup> The investment enables the resort to 'buy' around 18 additional skiable days in an average year and 40 days in a poor snow year.

#### CLIMATE CHANGE AND SNOWMAKING

Even without further warming there are times in the data record when it would have been too warm to make snow at Snowbowl and Sunrise. SNOTEL data for Mt Baldy<sup>17</sup> (near Sunrise) for the period 1988/89 to 2005/06 indicates that average monthly minimum temperatures exceeded the -2°C threshold for efficient snowmaking technology in April 2006 and exceeded the -5°C threshold for less-efficient snowmaking technology in March 2006 and in April for five seasons in 1989, 1992, 2002, 2005 and 2006. Note that the warm period at Sunrise is the end of the season. The results of a similar assessment are worse for Snowbowl. Using data from the SNOTEL site at Snowslide<sup>18</sup> for the (shorter) period 1997/98 to 2005/06 average monthly minimum temperatures exceeded the -2°C threshold in April 2002 and April 2006 and exceeded the -5°C threshold in

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<sup>16</sup> The full and reduced investment plans under each of the three ENSO phases.

<sup>17</sup> Site Number: 310, Station ID: 09s01s, State: Arizona, Latitude: 33.978830, Longitude: -109.503440, Elevation: 9125 feet.

<sup>18</sup> Site Number: 927, Station ID: 11p08s, State: Arizona, Latitude: 35.341600, Longitude: -111.650583, Elevation: 9730 feet.

November 1998, December 2000, March 2001, and April 2000, 2001, 2002 and 2006.

Warm months at Snowbowl have occurred at both shoulder seasons. Significantly these warm spells correlate with poor seasons at Snowbowl: the 1998/99, 1999/00, 2001/02 and 2005/06 seasons. The exception is the 2000/01 season; this season had relatively high overall snowfall ameliorating the impact of warming on snowpack. Even if average temperatures are below this threshold, a series of warm spells may curtail the season if Snowbowl approaches its water supply constraint and is unable to manufacture more snow.

The most reliable output from climate change models is temperature data yet new and improved Intergovernmental Panel on Climate Change models for the Fourth Assessment Report (IPCC AR4) now provide more dependable precipitation data. These models indicate a drier (and warmer) southwest USA resulting from possible northward shifts in the jet stream. It is likely that these conditions will result in reduced snowpack and shorter snow seasons as more precipitation falls as rain not snow and snow melts earlier in spring. The simulations indicate that Arizona mountain managers must prepare for warmer winter temperatures, more frequent heat waves [25], less overall snow and wetter snow. The latter impact might prove beneficial in building a better snow base [14]. Warming, if realized, will also reduce potential snow manufacturing days as temperatures exceed the  $-2^{\circ}\text{C}$  threshold.

Climate change is likely to shorten ski seasons in Arizona. There are three mechanisms: if temperatures are above 0°C precipitation is more likely to fall as rain than snow, if temperatures exceed technical snowmaking thresholds ski areas will not be able to manufacture snow, and warming may alter climate patterns resulting in less overall precipitation. Using data from the IPCC AR4 temperature model for Arizona's Climate Division 2<sup>19</sup>, the division where both Sunrise and Snowbowl are located, warming is measured in the years 2030, 2050, 2080 and 2099 compared to the average (and 95% confidence interval) temperatures recorded over the data period at nearby SNOTEL sites.<sup>20</sup>

The warming and its impact at the two resorts is shown in Tables 3a and 3b. Boxes shaded in light gray are for temperatures  $\geq -5^{\circ}\text{C}$  and in darker gray for temperatures  $\geq -2^{\circ}\text{C}$ : these represent the two snowmaking temperature thresholds. The data indicate that higher temperatures may increasingly preclude snowmaking adaptation in the shoulder seasons later in the century. The outlook is somewhat poorer for Snowbowl than Sunrise but by the end of the century ski seasons are likely to be severely shortened at both resorts. Note that this data predicts that by 2030 under the 95% CI High scenario that snowmaking will not be viable in April at Sunrise and not in November and April at Snowbowl. The snowmaking economics section above noted that Snowbowl's investment plan buys between 25 and 39 skiable days and between 18 to 40 skiable days

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<sup>19</sup>Data accessed 5/23/2006 from <http://www.ncdc.noaa.gov/oa/climate/onlineprod/drought/ftppage.html>. The data are monthly temperature (Celsius) and precipitation (mm) output values from the AR4 Model for Arizona Climate Division 2.

<sup>20</sup>Note the reference period for Sunrise is 1988-2006 and is 1997-2006 for Snowbowl.

at Sunrise. Yet if snowmaking is precluded in November and April approximately 25 skiable days (10 in November and 15 in April) are lost which in turn would alter the economics of the investments. It may take mountain managers some years to adapt to a changing climate regime and to formulate an appropriate and efficient snowmaking regimen that focuses on snowmaking to extend skiing in the shoulder seasons or to recover snowpack after mid-season heat waves. Mountain managers may also have to adopt other strategies to ensure that every good snow day is a good ski day.



**Table 3a: Average minimum monthly temperatures, °C: historical and projected at Sunrise**

<b>Historical</b>	<b>Nov</b>	<b>Dec</b>	<b>Jan</b>	<b>Feb</b>	<b>Mar</b>	<b>Apr</b>
Mean 1988-2006	-9.8	-11.5	-11.3	-9.7	-8.7	-6.3
95% CI Low	-11.6	-12.9	-12.9	-12.1	-10.0	-7.8
95% CI High	-8.1	-10.1	-9.8	-7.4	-7.4	-4.8
<b>IPCC AR4 warming</b>						
2030	1.2	1.2	0.7	1.1	1.1	1.0
2050	1.8	1.5	1.3	1.7	1.7	2.5
2080	3.1	2.5	2.8	2.7	3.0	3.3
2099	3.2	3.4	3.4	3.7	3.8	3.8
<b>Forecast mean</b>						
2030	-8.6	-10.3	-10.6	-8.7	-7.7	-5.3
2050	-8.0	-10.0	-10.1	-8.0	-7.1	-3.8
2080	-6.8	-9.0	-8.6	-7.0	-5.8	-3.1
2099	-6.6	-8.1	-7.9	-6.1	-4.9	-2.5
<b>Forecast 95% CI Low</b>						
2030	-10.4	-11.6	-12.2	-11.0	-9.0	-6.8
2050	-9.8	-11.4	-11.6	-10.3	-8.4	-5.3
2080	-8.5	-10.3	-10.1	-9.3	-7.1	-4.5
2099	-8.4	-9.4	-9.5	-8.4	-6.2	-4.0
<b>Forecast 95% CI High</b>						
2030	-6.9	-8.9	-9.1	-6.3	-6.4	-3.8
2050	-6.3	-8.6	-8.5	-5.6	-5.8	-2.3
2080	-5.0	-7.6	-7.0	-4.7	-4.5	-1.6
2099	-4.9	-6.7	-6.3	-3.7	-3.6	-1.0

**Table 3b: Average minimum monthly temperatures, °C: historical and projected at Snowbowl**

<b>Historical</b>	<b>Nov</b>	<b>Dec</b>	<b>Jan</b>	<b>Feb</b>	<b>Mar</b>	<b>Apr</b>
Mean 1997-2006	-7.5	-10.0	-9.3	-9.7	-8.1	-6.0
95% CI Low	-9.1	-11.8	-10.4	-11.5	-9.5	-8.2
95% CI High	-5.9	-8.1	-8.2	-7.9	-6.7	-3.8
<b>IPCC AR4 warming</b>						
2030	1.1	1.0	0.5	0.9	1.0	0.9
2050	1.7	1.2	1.1	1.6	1.6	2.3
2080	2.9	2.3	2.6	2.6	2.9	3.1
2099	3.1	3.2	3.3	3.6	3.7	3.6
<b>Forecast mean</b>						
2030	-6.5	-9.0	-8.7	-8.8	-7.1	-5.1
2050	-5.9	-8.7	-8.1	-8.1	-6.5	-3.7
2080	-4.6	-7.7	-6.7	-7.1	-5.2	-2.9
2099	-4.5	-6.8	-6.0	-6.2	-4.4	-2.4
<b>Forecast 95% CI Low</b>						
2030	-8.1	-10.9	-9.8	-10.6	-8.5	-7.3
2050	-7.5	-10.6	-9.2	-9.9	-7.9	-5.9
2080	-6.2	-9.6	-7.8	-8.9	-6.6	-5.1
2099	-6.1	-8.7	-7.1	-8.0	-5.7	-4.6
<b>Forecast 95% CI High</b>						
2030	-4.9	-7.1	-7.6	-7.0	-5.8	-2.9
2050	-4.3	-6.9	-7.0	-6.3	-5.2	-1.5
2080	-3.0	-5.8	-5.5	-5.3	-3.9	-0.7
2099	-2.9	-4.9	-4.9	-4.4	-3.0	-0.2

#### CONSUMER RESPONSES: CLIMATE CHANGE AND SNOWMAKING

Scott, McBoyle and Mills [1] note that there is little current understanding “how recreational users and tourists respond to climate variability (whether or not to participate or purchase equipment, activity substitution, use patterns, destination choice).” Some researchers have attempted to answer the question as to how different types of skiers might respond to climate change. Skier survey results from Switzerland found that during a poor season 49% of skiers would switch to a more snow-reliable resort, but more

worrying for the industry, 32% of respondents said they would ski less often [16]. Only 4% of the survey respondents said that they would abandon skiing. The broader issue is the differential impact of such demand changes. It is likely that smaller ski resorts would suffer most as young skiers, day skiers, and novice skiers, their predominant clientele, are the most likely to respond negatively to poor seasons. In fact König's [12] study of skiers in Australia supports this conclusion. She found that half of all advanced skiers would travel overseas for quality snow conditions, whilst only 18% of novice skiers would, and 16% of this group would give up skiing altogether. Therefore, a large uncertainty in any modeling of the impact of climate change on winter recreation is the response of local skiers to changes in ski season length, timing, and relative quality. Scott, McBoyle and Mills [1] argue that one scenario that would leave resorts as well off, is if skiers adjust their recreation behavior by skiing more frequently in the shorter season. A sensitivity analysis could address this uncertainty in consumer response and estimate future ski recreation demand.

Snowmaking is the current adaptation strategy of choice around the world to mitigate the impacts of climate variability and change. One aspect of snowmaking not yet addressed is whether customers will still visit the resort if it relies more heavily on manufactured snow. The answer probably depends in part on the volume of manufactured snow used. In the southwest USA manufactured snow typically provides a durable base that is subsequently covered by natural snow. If, however, a resort gets a reputation for 100% manufactured snow there is little doubt that this will impact demand. The bottom-line is

that the ride on manufactured snow is not equivalent to that on natural snow, and particularly to skiing on powder which is a feature of southwest USA skiing.

Compounding this quality issue could be price issues. It is conceivable that a resort might need to raise lift ticket prices to cover the additional costs of large-scale snowmaking (and snowmaking at higher temperatures) and that skiers might balk at paying these higher prices given the relative snow conditions of nearby resorts. The ski industry may become increasingly two-tiered between resorts that can offer skiers natural snow and those which can only offer skiing on manufactured snow. It is likely that local resorts will continue to cater to local novices and families; skiers who are either indifferent between manufactured snow and powder, or are constrained by time and cost considerations. However, a proportion of skiers are willing to travel and pay for good ski conditions. In this way the ski industry may become more product differentiated as a result of climate change and climate change adaptation and skiers will have to choose their “product” given their budget.

## DISCUSSION

Climate change models for the southwest USA predict shorter snow seasons which if realized will undermine the longer-term economics of Arizona’s ski resorts; however, snowmaking investments at least in the medium term will enable resorts to ameliorate inter-annual climate variability as well as warming. The snowmaking assessment is based on forecasts of skier visits. These forecasts assume skiers are indifferent to manufactured snow and will pay higher prices to cover the costs of the snowmaking infrastructure.

There are other uncertainties inherent in the cost benefit analysis including energy and water prices and climate change impacts on winter precipitation and temperatures.

An alternative strategy to snowmaking is to extend runs into higher altitude. In Switzerland the ski industry has used climate change as an argument to extend existing runs and open new ski runs at high (environmentally-sensitive) Alpine regions above 3,000 m. This approach is opposed by environmentalists [16]. It is an unlikely option at either Sunrise or Snowbowl because there are few alternatives sites that would be at higher elevation. However, if climate change does increase temperatures to a threshold at which it is uneconomical to make snow, then one possible mitigating strategy would be to close low elevation ski runs and limit skiing to the higher elevation, more snow reliable terrain, or cherry pick runs that have higher snow reliability. Such an option might require some redesigning of lifts, runs, and the placement of facilities.

Another adaptation is to diversify risk. Large corporate ski companies such as Vail Resorts and the American Skiing Company may be less vulnerable to climate change than single resort operators because they are diversified companies, with real estate and warm-weather tourism businesses, and they are also geographically diversified, thereby reducing exposure to poor snowfall in one area [26]. Both Sunrise and Snowbowl have no real estate ventures, their location on a reservation and USFS land preclude such options. However, Sunrise does have the option to further develop on-site accommodation, for example, a new Ski in – Ski out lodge at the resort. The only onsite

accommodation, Sunrise Lodge, is located 11km from the slopes. Large companies are also better capitalized and therefore able to make investments in snowmaking. Financing snowmaking and other expansions is an obstacle for both Sunrise and Snowbowl. Smaller operators may wish to investigate winter tourism weather derivatives to even out good and bad seasons.

Whilst the exact impacts of climate change are still unknown there are other actions that Sunrise and Snowbowl management could take to ensure that every good snow day at the resorts is fully utilized by skiers and profits are maximized. Sunrise's webpage is in need of an update; a new 'public face' could better capitalize on its position as the largest ski resort in the state, its excellent spring skiing conditions, and affordable learn to ski/board packages. Both resorts could review their ski lift prices to ensure that they are not a limiting factor to the growth of skiing. The management may wish to introduce lower half day skiing passes to encourage opportunistic skiers and off-peak prices for mid-week and pre and late season skiing when the resorts are underutilized. Family packages could also be introduced to make the sport more affordable, this might be particularly important if snowmaking investments are realized at the resorts, because with more consistent ski seasons, families might substitute their usual vacation activities for a skiing vacation. Consistent with McBoyle and Wall's [8] insight that small regional ski areas are important in developing and maintaining the ski industry, Sunrise should continue with its free season ticket program for school age children to increase the 'stock' of skiers; skiers who are perhaps more likely to accept changing snow conditions.

## ACKNOWLEDGEMENTS

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## APPENDIX F: WATER REALLOCATION BY SETTLEMENT: WHO WINS, WHO LOSES, WHO PAYS?

Rosalind Bark-Hodgins<sup>1</sup> (July 15, 2006). *ExpressO Preprint Series*. Working Paper 1454.

<http://law.bepress.com/expresso/eps/1454>

### ABSTRACT

The 2004 Arizona Water Settlements Act (AWSA) is the current standard for what a comprehensive, negotiated settlement can achieve in terms of water rights reallocation, water resource management, and water supply reliability enhancement. This note reviews the flows of money and water specified in Titles I and II of the AWSA to identify the signatory and non-signatory parties that benefit from the settlement and the allocation of costs between the various parties to the agreement. Opportunity costs are also considered. Innovative elements of the agreement are discussed particularly those that improve water supply reliability for the Gila River Indian Community and third parties.

### 1. INTRODUCTION

The location of the Gila River Indian Community (GRIC) reservation on the southern border metropolitan Phoenix, a mega-city with two of the ten fastest cities in America<sup>2</sup> and the risk to non-Indian water users in the state inherent in the Community's 1.8 million acre feet (MAF) Gila River Adjudication claim provided impetus for the AWSA.

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<sup>2</sup> Gilbert is the fourth and Chandler the seventh fastest growing cities in the US, U.S. Census Bureau, 2005.

Implicit in any legal proceedings is uncertainty. This negotiated settlement removed these risks and also resolved the allocation of Central Arizona Project (CAP) water between Indian and non-Indian uses. The resolution of these allocation issues also settled a long standing dispute over the repayment of the CAP and numerous disputes between the GRIC and water providers and users in the state. The size of the settlement in terms of water and cost and the number of signatories to it are indicators of the importance of this agreement and the motivation to research the elements of the settlement.

The AWSA contains four Titles, they are the: Central Arizona Project Settlement, Gila River Indian Community Water Rights Settlement, Southern Arizona Water Rights Settlement, and the San Carlos Apache Tribe Water Rights Settlement. The focus of this note is the first two Titles. The main points of these settlements are described and the economic implications are elaborated.

An 1859 Act of Congress created the initial Gila River Indian Reservation in what is the Gila River watershed. It was enlarged seven times over the next 56 years to include a small area within the Salt River watershed. The current reservation is 372,000 acres (see Figure 1). The priority of the Community's water rights, as per the *Winters* Doctrine is 1859.<sup>3</sup> Although the doctrine establishes Federal reserved water rights, they remained unquantified. The risk when water rights are unquantified are several: the pending claims

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<sup>3</sup> *Winters v. United States* 207 U.S. 564 (1908) found that tribes have reserved water rights appurtenant to reservation lands to fulfill the purpose of reservation as a homeland. To fit into the prior appropriation framework predominant in the western US the date of these implicit water rights is the date of the establishment of the reservation.

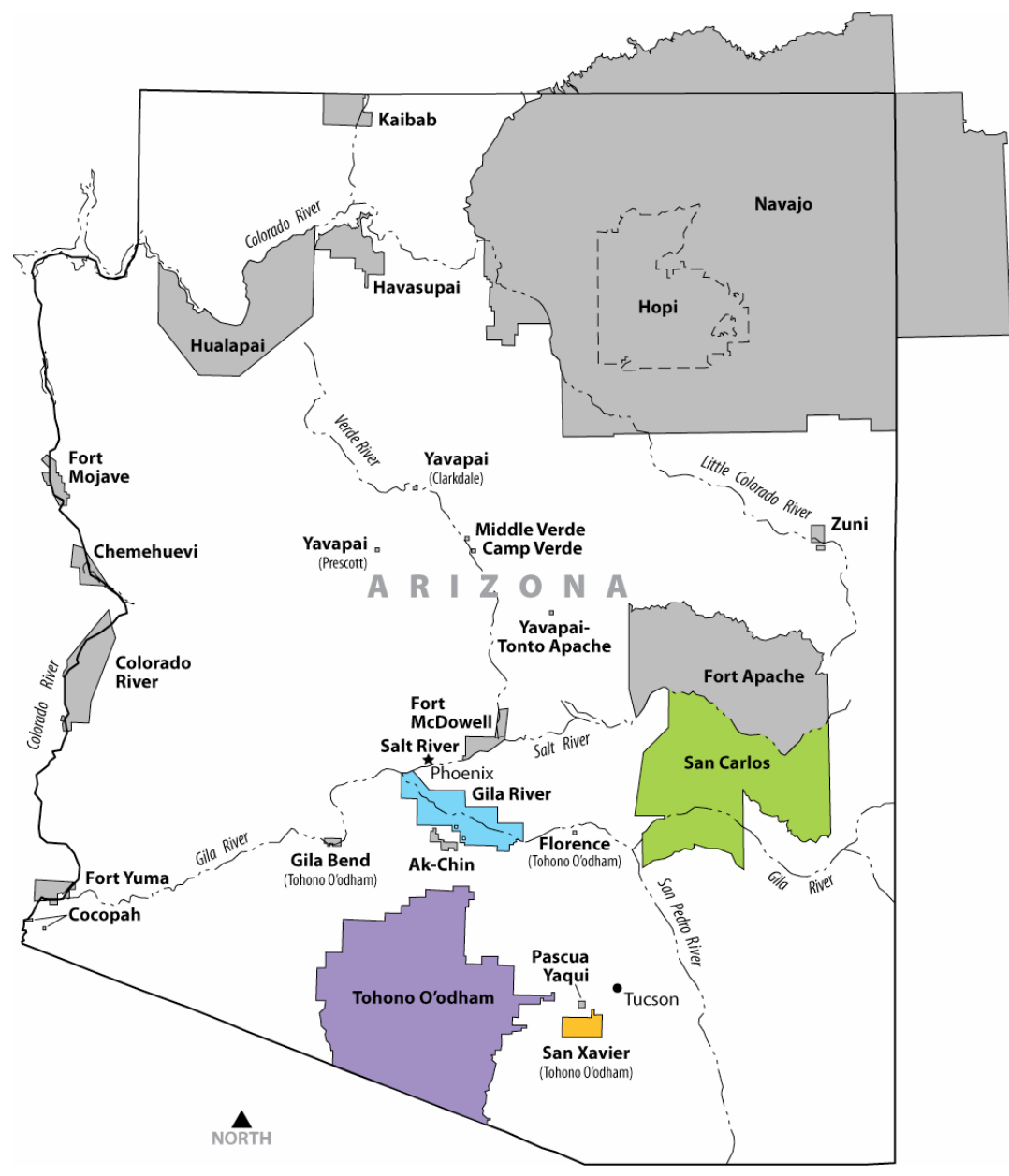
themselves are unprotected against future competing water rights claims, and the claims pose a risk to current and future water use in the affected region. The GRIC reservation lies at the bottom of two watersheds at the confluence of the Gila and Salt Rivers. This geography has meant that their water access has been subject to diminishment from the development of water rights upstream in the Gila River watershed, and to a lesser extent, in the Salt River watershed. From the early 1870s two large irrigation districts<sup>4</sup> upstream of the reservation diverted water from the Gila River impacting downstream availability for the Community. To address growing water access issues the U.S. Congress in 1924 authorized the construction of the Coolidge Dam and San Carlos Irrigation Project (SCIP) to supply irrigation water for 50,000 acres on the GRIC Reservation. A year later the United States on behalf of the Community and San Carlos Irrigation and Drainage District (SCIDD) sued upstream water users to establish the water rights of the Community. After ten years of litigation, the *Globe Equity* decree<sup>5</sup> entitled the GRIC to divert 300 KAFY (thousand acre feet per year) from the Gila River. Despite the decree, these higher priority water rights were not enforced and disputes over the provisions resulted in decades-long-litigation between GRIC and other water users, litigation that has been resolved by the AWSA.<sup>6</sup>

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<sup>4</sup> Water rights were developed in the Safford Valley and the Duncan-Virden Valley, which correspond to current day Gila Valley Irrigation District and Franklin Irrigation District. At the same time the downstream Florence-Case-Grande area, present day San Carlos Irrigation and Drainage District, was also developed.

<sup>5</sup> Globe Equity Decree shall mean the decree dated June 29, 1935 entered in *United States of America v. Gila Valley Irrigation District*, Globe Equity No. 59, *et al.*, in the United States District Court for the District of Arizona.

<sup>6</sup> Pub. L. 108-451



**Figure 1: Arizona’s Indian Reservations and Rivers: Color is for Tribes in AWSA**

A second set of GRIC water claims are centered on the Salt River watershed. The reservation enlargement in 1879 added the lands farmed by Maricopa Colony to the GRIC Reservation. This branch of the GRIC irrigated around 1,000 acres of land from

the Salt River. Again development of non-Indian agriculture challenged the prior rights of the Community and again the United States sued these water users on behalf of the Community. This litigation began in 1901 and in 1903 *United States v. Haggard*<sup>7</sup> adjudicated the Community's right to irrigate 1,080 acres from the Salt River (equivalent to around 5.9 KAFY). This decree was incorporated into the 1917 *Benson-Allison* decree which adjudicated water rights for the Community near the confluence of the Gila and Salt rivers.

These water rights adjudicated in the early 1900s fall far short of the 1.8 MAF<sup>8</sup> GRIC claim in the Gila River Adjudication proceedings. This claim was formulated based on the Practicably Irrigable Acreage (PIA) standard articulated by the courts in *Arizona v. California*.<sup>9</sup> This standard quantifies *Winters* rights by determining the amount of water necessary to irrigate all practicably irrigable acreage within the reservation. This formulaic standard is not without its flaws<sup>10</sup> and an alternative recently articulated by the Arizona Supreme Court is the homeland test.<sup>11</sup> This doctrine allows tribes to prosecute for water to meet their future needs. Permitted water uses explicit in the homeland test include water for population growth, the environment, community development, industry,

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<sup>7</sup> *United States of America, as Guardian of Chief Charley Juan Saul & Cyrus Sam, Maricopa Indians & 400 Other Maricopa Indians Similarly Situated v. N.W. Haggard et al.*, No. 19 (D. Ariz. 3d Jud. Dist.; complaint filed July 17, 1901; decree entered June 11, 1903)

<sup>8</sup> A water right of 1.8 MAF would have reallocated 23% of the State's current water supplies (7.87 MAF, ADWR, 2006) to one tribe and concurrently severely impacted non-Indian water rights holders.

<sup>9</sup> 373 U.S. 546 (1963).

<sup>10</sup> Dana Smith, Note, *Doctrinal Anachronism?: Revisiting the Practicably Irrigable Acreage Standard in Light of International Law for the Rights of Indigenous Peoples*, 22 (3) ARIZ. JNL of INTL & COMPTVE LAW. 712-713 (2005).

<sup>11</sup> *In re the Gen. Adjudication of All Rights to Use Water in the Gila River Sys. & Source*, 35 P/3d68, 79 (Ariz. 2001).



and recreation. As with tribal water rights quantified through PIA, the development of these tribal water uses can pose a threat to junior water rights holders in an over-allocated watershed.

Regardless of which legal doctrine on quantification is applied, the Community's claims remained an exceptional risk for the viability and future development of the central valley cities and also the rest of the state. Many believed that the GRIC had a very strong reserved right claim based on their location at the confluence of two rivers, a documented history of irrigated agriculture, and large tracts of irrigable and developable land on the reservation. Other regional water users were concerned that the Community might also have a strong ability to limit significant groundwater pumping near the reservation boundary. Given this exposure, the surrounding cities were primed for settlement. Furthermore, excess Colorado River water was available for reallocation to the Community: this water will in practice replace a block of *Globe Equity* Decree (Gila River) water; without this 'exchange' the water rights of non-Indian agriculture and municipalities in the Gila River watershed would have to be reduced. Finally, an agreement was bolstered by the Community's acceptance of water leasing.<sup>12</sup> The outcome of multi-party negotiations, the AWSA, not only provides benefits for non-Indian water users whose water rights remain undiminished (or will be compensated) but also for the Community. The agreement substitutes delivered 'wet' Colorado River water and provides funds to develop its use and management. The settlement incorporates a

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<sup>12</sup> Pub. L. 108-451, Title II, Sec. 205(a)(2).

number of water management innovations that should improve water supply reliability for the Community, and for others reliant on the Gila River watershed and its tributaries.

Another aspect of settlements is economic. The core of many of the 16 Federal criteria<sup>13</sup> for Indian water rights settlements relates to allocating costs based on benefits, maintaining status quo in watersheds, promoting efficiency, and removing risk and uncertainty, by attaining past, present and future waivers of water rights,<sup>14</sup> (and waiving claims for water quality<sup>15</sup> and subsidence damages).<sup>16</sup> It is also the policy of the Federal government that the federal contributions to a settlement may not exceed the "calculable legal exposure".<sup>17</sup> Federal contributions to this settlement are significant and long term and also comprise costs for the firming program uncalculated at the time of the Act. The Office of Management and Budget's (OMB) visible non-support for the AWSA might indicate that the actual costs exceed the legal exposure threshold.

This note examines the costs and benefits of Titles I and II of the agreement not only as an accounting exercise, but also as a means to understand the motivation for 35 signatories<sup>18</sup> to and the 85 plus side agreements attached to the settlement. Other than the

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<sup>13</sup> See, 33 Fed. Reg. 9223 (1990).

<sup>14</sup> Pub. L. 108-451, Title II Sec 207(a)(1)(A)-(B) and (F)-(G) for claims against the Salt River Project (SRP), and Id. Sec 207 (a)(3)-(5) for waivers against the Community, the U.S. and the Upper Gila Valley, respectively.

<sup>15</sup> Exceptions from this blanket waiver of rights to remediation for water quality injury are 44 potential and documented contamination sites as per Exhibit 25.4.1.1 and Pub. L. 108-451, Sections 207(a)(1)(C)-(E). The Community is also prohibited from imposing higher water quality standards than the State, Sec (a)(6).

<sup>16</sup> Id. Sec 207(a)(5)(I). Notwithstanding this waiver, Title II, Sec 209(d) specifies specific subsidence areas that will be remediated as per Exhibit 30.21, up to \$4M appropriated for this program (Sec 214(a)(3)).

<sup>17</sup> See, 55 Fed. Reg. 9223 (1990), Criteria No. 5a.

<sup>18</sup> See Exhibit 7.2, para 3 for the names of all the parties to the GRIC settlement.

large number of side agreements, there is another clue that it was these players who were the main drivers for the settlement: there are no explicit Federal penalties owed by the federal government to GRIC associated with the repeal of Titles I and II of AWSA, if the parties do not meet the enforceability date.<sup>19</sup> First the Titles I and II are introduced: the settlement of the Central Arizona Project (CAP)<sup>20</sup> repayment and allocation between Federal and non-federal uses, CAP M&I (municipal and industrial) reallocation to the Phoenix valley cities, water for the tribes, and the proliferation of side agreements that are exhibits to the main settlement. Then the water management implications and water supply reliability outcomes of the settlement are discussed before concluding remarks on what lessons other tribes and states can learn from the comprehensive AWSA legislation.

## 2. THE AWSA

While the AWSA is not quite as comprehensive as its name suggests it resolved major uncertainties within the CAP three county service area<sup>21</sup> and the Gila River watershed. This is no coincidence. Just over half of Arizona's allocation of Colorado River water<sup>22</sup> is

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<sup>19</sup> Pub. L. 108-451, Title I, Sec 111 includes provisions in the event of non-implementation to return all appropriated funds to the Federal Treasury and to void contracts and Title II, Sec 215 provides for the return of Federal and SRP funds. In contrast the SAWRSA Amendments (Title III) includes a provision whereby the Secretary must compensate the tribe \$18.3M if the new San Xavier farm is not completed to take the scheduled 27KAFY, Id at Title III, Sec 304 (c)(3)(a)(ii). There are also penalties for the non-delivery of CAP water even in times of shortage, Id. at Sec 304(c)(d)(ii), Sec 305(a)(2)(A)-(B) and Sec 305(d)(1).

<sup>20</sup> CAP is a reclamation project authorized and constructed by the U.S. in accordance with Title II of the Colorado River Basin Project Act (43 U.S.C. §§ 1521 *et seq.*)

<sup>21</sup> These counties are: Maricopa (Phoenix cities), Pinal (Phoenix cities and Casa Grande), and Pima (Tucson).

<sup>22</sup> The Colorado River Compact, 1922 (Congressional Record, 70th Cong. 2d Sess. At 324-325 ) allocated 2.8 million acre feet (MAFY) to Arizona, of which 1.415 MAFY is delivered by the CAP, the remainder is used directly from the main stem of the Colorado River.

delivered by the federally-funded CAP.<sup>23</sup> This ‘new’, renewable water boosts intra-state water supplies from 6.27 MAFY to a total 7.87 MAF (see Table 1). The CAP delivers an additional water supply that can be utilized to provide water for Indian water rights settlement, or, to support growth, or afford a buffer against future drought, or in the case of the AWSA support all three. Clearly the latter two outcomes could be achieved by other means. For example, voluntary water transfers could facilitate the transfer of agricultural water to municipal use, and the private sector or State agencies could increase water recharge efforts, respectively. However, the momentum to settle the GRIC claims brought all the major water players in the state together and enabled the concurrent discussion of other water management issues. The simultaneity facilitated a relatively comprehensive resolution of water issues within central Arizona (and with New Mexico).

**Table 1: Arizona annual water demand by water source**

<b>Source</b>	<b>MAF</b>	<b>% of total</b>
Colorado River	2.8	35.6
on-river	(1.2)	(15.2)
off-river	(1.6)	(20.3)
In-state Rivers	1.4	17.8
Salt	(1.0)	(12.7)
Gila and others	(0.4)	(5.1)
Groundwater	2.9	36.8
Reclaimed water	0.77	9.8
<b>TOTAL</b>	<b>7.87</b>	

*Source: Arizona Department of Water Resources, 2006*

<sup>23</sup> Pub. L. 108-451, Article I, Sec.104, 2(c), 1(A).

The agreement, specifically Title I, settles outstanding CAP repayment and allocation issues. However, without the numerous side agreements that accompany the legislation, Titles II and III are not stand alone pieces of legislation. It is in the exhibits that the volume and sources of water for the GRIC settlement are specified and that the terms of water exchanges, water leases, and groundwater protection zones are specified. The side agreements are central to the agreement as a whole and facilitated the passage of State legislation.<sup>24</sup> Many of the side agreements reflect mutually-beneficial relationships between tribal and non-tribal interests, not only in settling long-standing disputes but also in working towards improved allocation of water quality to use, such as effluent-CAP exchanges.<sup>25</sup> The side agreements with the State demonstrate how the settlement process enabled problematic issues of water management to be resolved, such as the development of groundwater protection zones and upstream consumptive use forbearance.

### ***2.1 Title I: Central Arizona Project Settlement***

Senator John Kyl (R) was a major proponent of the settlement, particularly this Title of the agreement. The contentious issue of CAP repayment was particularly troubling as it pitted Arizona against the Federal government. The agreement resolved this conflict. The CAP settlement also reallocates CAP water between federal and non-federal uses, from irrigation districts to Indian water settlements and cites, simultaneously resolving

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<sup>24</sup> For example, firming legislation had to be enacted by the State for the agreement to come into force as per Id. Title II, Sec 207(c)(1)(I)(ii). This legislation has passed, see H.B. 2835.

<sup>25</sup> Exhibit 18.1 to the AWSA, 2004.

agricultural debt problems and advancing the stated goal of the CAP board to fully utilize Arizona's Colorado River allocation.

#### 2.1.a. CAP reallocation: Federal: non-Federal

A key provision is the division of CAP water between Federal and non-Federal uses. Of the total 1.415 MAFY stipulated for delivery under long-term contracts by the CAP, 650,724 AFY is contracted to Arizona tribes, or to the Secretary of the Interior for allocation to Arizona tribes, and the remainder, 764,276 AFY is set aside for non-Indian municipal and industrial (M&I) entities, the Arizona Department of Water Resources (ADWR), and non-Indian agricultural (NIA) water.<sup>26</sup> An outcome of this change is that NIA priority water has been converted into fixed volumes and 295,263 AFY in NIA contracts have been voluntarily relinquished. These provisions resulted in excess water available for Indian water rights settlements.

#### 2.1.b. CAP repayment

The allocation between Federal and non-federal uses substantially affects the repayment schedule for the conveyance infrastructure, the CAP. The resolution is also critical for the CAP Board to know with certainty its overall obligation to repay the "project's reimbursable construction costs as provided in its repayment contract with the United

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<sup>26</sup> Pub. L. 108-451, Title I, Sec. 104, (a)(2)(c)(1)(A)(i)

States".<sup>27</sup> The State is not responsible for the Federal uses portion (46%) of the project. In return for this division, the state or state parties benefit from \$73.56M agricultural debt relief,<sup>28</sup> \$2B CAP debt repayment relief, and Indian water cost-reduction benefits.<sup>29</sup> On the other hand a significant share of CAP water is dedicated to Indian settlements and not for the other purposes it might have served.

The settlement went further than just resolving debt-related issues; it also identified a funding source to pay for the settlement through amendments to the Colorado River Basin Project Act of 1968.<sup>30</sup> These amendments allow funds credited to the Lower Colorado River Basin Development Fund (LCRBDF), a portion of revenues derived from the sale of energy for use in the State, and any annual payment made by the Central Arizona Water Conservation District (CAWCD) for reimbursable CAP construction costs, be credited each year against the annual payment owed by CAWCD to the Federal government for the CAP, without the need for further appropriations for specified purposes. Currently around \$55M annually is deposited into the fund,<sup>31</sup> but from 2010

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<sup>27</sup> CAP's Mission Statement, [http://www.cap-az.com/public/cap\\_award/index.cfm?action=award2](http://www.cap-az.com/public/cap_award/index.cfm?action=award2). Accessed May 11, 2006.

<sup>28</sup> This is the debt incurred by non-Indian agriculture (minus a \$85M contribution from CAWCD) and waived in return for the relinquishment of long-term CAP entitlements to NIA water. Sec 106(b)(1). Note that this debt relief will also reduce receipts for CAP capital costs, estimated at \$2M annually, *supra* note 25, p3.

<sup>29</sup> Net 93.5 KAFY (see footnote 92) CAP GRIC water MI&E subsidized costs of approximately \$49/AF, 28.2 KAFY CAP water for Tohono O'odham delivered free (2006 CAP M&I rate \$82/AF), and 67.3 KAFY for other tribes, probably under the same terms as the GRIC water, is equivalent to  $93.5K \times \$49 + 28.2K \times \$82 + 67.3K \times \$49 = \$10.19M$  annually.

<sup>30</sup> 43 U.S.C. 1543

<sup>31</sup> Congressional Budget Office Cost Estimate H.R. 885 AWSA, October 5, 2004, p4.

these accumulated funds will be used to pay down the cost of Indian water<sup>32</sup> and to fund a suite of other projects identified in the settlements.<sup>33</sup> The Fund in essence made this large and expensive settlement possible. The major advantage of this mechanism is that it precludes the need to go to the Congress, at a time of budget deficits and competing policy agendas, for appropriations to fund Indian water rights settlements. On the State side, the funding mechanism limits the financial contribution from the State for the settlement of Indian water claims.

There are a large number of beneficiaries from this Fund and although some funding priorities are detailed, others are not.<sup>34</sup> This could set up future competition for funds; however, the Gila Settlement Agreement Parties have agreed to work together with the Secretary to ensure the funding of all projects in a timely manner. The establishment of the fund and these revenue streams was key in the acceptability of the settlement for Arizona water users: it was also key in the OMB's opposition to the settlement as it deprives the U.S. Treasury of CAP repayment funds: funds that now are redirected to the settlement parties.

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<sup>32</sup> The U.S. is responsible for delivering up to 311.8 KAFY of Community CAP water, Exhibit 8.2, para 5. This is the sum of its initial allocation, new NIA CAP allocation, and relinquished HVID and RWCD CAP allocations (subparas 5.4.1.1-5.4.1.4). This water will be delivered to the Community without CAP OM&R charges. GRIC is not required to repay any of the construction costs of the CAP, Pub. L. 108-451, Title II, Sec 205(a)(7)(B). In addition the Community is also released from paying CAP water service capital charges, Id. at Sec 205(a)(8). In 2006 these charges were \$24/AF for M&I long-term subcontracts and \$2/AF for agricultural long-term subcontracts.

<sup>33</sup> Other uses of this Fund are detailed in Id. at Title I, Sec 107(a) amendments to Id. at 403(f)(2)(A)-(F). Note that revenue funds in excess of those credited against the CAWCD payments will be directed to the Federal government as per Id. at Sec 107 amendments to 403(f)(3)(A)-(G).

<sup>34</sup> Id. at 403(f)(2) and (2)(D), for prioritized and non-prioritized funding, respectively.



### 2.1.c. CAP reallocation: non-Indian Agricultural Priority Water

Resolving CAP issues engaged water users and water managers and identified a category of excess CAP NIA water as water that was available for Indian water rights settlements. The Secretary reallocated 195 KAFY of NIA water for this purpose,<sup>35</sup> of which 102 KAFY is reserved for the GRIC,<sup>36</sup> 28.2 KAFY as part of the SAWRSA Amendments<sup>37</sup> and 67.3 KAFY to other tribes.<sup>38</sup> Of this latter allocation, 6,411 AFY is set aside for a future settlement with the Navajo Nation.<sup>39</sup> This reallocation of NIA water is subject to future reallocation by the Secretary, if any of this set aside water remains unused, before a deadline date of December 31, 2030.<sup>40</sup> Significantly, the federal government has provisions for a \$250M Future Indian Water Settlement Subaccount to the LCBDF to aid in future Indian water rights settlements on the Gila, the Little Colorado and Colorado River systems.<sup>41</sup> Another argument to settle without delay is that only around 71 KAFY of unallocated CAP water remains for delivery under new settlements.

The GRIC also has access to another block of the total 295 KAFY NIA relinquished water. The Secretary in addition to the 195 KAF discussed above also held a total 37,918 AF of CAP relinquished RWCD and NVID water. Of this total, 36.7 KAF has been

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<sup>35</sup> Id. at Sec 103, (a)(A).

<sup>36</sup> Id. at Sec 103, (a)(A)(i).

<sup>37</sup> Id. at Sec 103, (a)(A)(ii). Of which, 23KAF will be delivered to the San Xavier Reservation and 5.2KAF to the eastern Schuk Toak District.

<sup>38</sup> Id. at Sec 103, (a)(A)(iii).

<sup>39</sup> Id. at Sec 103, (a)(B)(ii). This is not a limit on a potential allocation to the Nation but rather an initial identified water source in part fulfillment of a negotiated water budget.

<sup>40</sup> Id. at Sec 103, (a)(B)(i).

<sup>41</sup> Id. at Sec 107(a) amendments to 43 U.S.C. 1543 Sec 403(f)(2)(D)(vi).

reallocated to GRIC and the remaining 1,218 AF will be held in trust for future Indian water rights settlements in either the Gila or Verde watersheds.

Another block of reallocated water is 96,295 AFY reallocated to the ADWR.<sup>42</sup> This water will be held in reserve for future allocation. The motivation behind this staged allocation is to give growing communities that do not yet have the financial means to buy CAP contracts, the chance to participate in future CAP allocations. Without such a provision it is likely that large cities would contract for this water. There is demand for this currently unallocated water. A looming concern for the cities is that once all unallocated CAP water is allocated or leased, they will have to secure new water supplies from other sources, water that could be more expensive than CAP water.

#### 2.1.d. CAP reallocation: AWS

Settling Indian water rights claims requires buy-in from existing non-Indian water rights holders. For an Indian water settlement to be federally supported a necessary condition is that the settlement does not cause harm to non-Indian water rights holders and that uncertain tribal claims are resolved. The sufficient condition for this bill's passage is that the settlement offers non-Indian water users tangible benefits in addition to the removal

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<sup>42</sup> Id. at Sec 104, (a)(2)(A).

of uncertainty over tribal claims, such as increased access to Assured Water Supply (AWS) supplies,<sup>43</sup> and opportunities to lease or exchange water with the Community.

The agreement reallocates 65,647 AFY of uncontracted CAP M&I priority water that was not allocated in the first round of CAP allocations to twenty cities in the three-county CAP area.<sup>44</sup> Not only is this water secure against all but the worst droughts, in terms of its ‘seniority’ in the CAP system, it is also available to the cities at CAP M&I rates, which in 2006 are \$82/af delivered.<sup>45</sup> In contrast, if these same cities were to purchase M&I water through market transaction the cost is likely to be many times this amount. The quid pro quo for reallocating this M&I water to the cities, rather than using it for federal purposes, namely the settlement of Indian water rights claims, was that an equivalent volume<sup>46</sup> of lower priority CAP water would be allocated to Arizona tribes, but that this water would be ‘firmed’ to M&I priority. FIRMING is discussed under supply reliability below.

## 2.2. Title II: Gila River Indian Community Water Rights Settlement

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<sup>43</sup> Assured Water Supply terms are described in A.R.S. §45-576, *et seq.* New rules became effective in 1995.

<sup>44</sup> Pub. L. 108-451, Title I, Sec. 104(a)(2)(b)(1). To put this volume in context, 65,647 AFY of water could supply 65,647 five-person households for a year, ADWR 2006. This context is not theoretical, because the grade of water, M&I, meets AWS standards. Therefore the twenty cities that received a portion of this reallocated supply can use this water for AWS purposes, that is, to support additional growth.

<sup>45</sup> CAP, Final 2006 Water Rate Schedule.

<sup>46</sup> The firming obligations of the Secretary and Arizona add up to 60,648 AF not 65,648 AF because during negotiations of the settlement Asarco agreed to offer 5KAFY to the GRIC settlement reducing the total volume of water to be firmed by 5 KAFY. Of the total the Secretary is obliged to firm 28.2 KAF for the SAWRSA agreement, ADWR 15 KAF for the GRIC agreement and the remaining 17,477 AF responsibility is divided equally between the parties. This water is for future Indian settlements. The State’s total firming responsibility is 23,724AF.

Title II concerns the GRIC water rights settlement. Settlements in the western U.S. facilitate access to ‘wet’ water through the identification of water sources and funds to develop the water for use on reservation. This settlement identifies water sources, pledges low cost water,<sup>47</sup> allocates rehabilitation funds to ensure water deliveries are made,<sup>48</sup> and earmarks a \$200M trust fund for water development.

Before AWSA GRIC had the largest single contract for CAP water: 173,100 AFY of Indian Priority water.<sup>49</sup> This is a non-trivial volume of water; however, given unlined conveyance canals and CAP prices, it was not profitable for the Community to use this water instead of groundwater. The agreement is significant because it not only settles outstanding water rights claims but also provides funds<sup>50</sup> to develop all its water sources whilst simultaneously curbing groundwater pumping.<sup>51</sup> It also buys down the operation costs for water delivered to the reservation.<sup>52</sup> Water is not provided to the Community at zero delivery cost, unlike under the early Ak-Chin settlement.<sup>53</sup> However, even though

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<sup>47</sup> The agreement provides for \$53M to be deposited in the GRIC Water OM&R Trust Fund (Sec 107(a) which amends Section 403(f)(2)(B) of the Colorado River Basin Project Act (43 U.S.C. 1543(f)).

<sup>48</sup> Id. (f)(2)(C) provides for \$147M (adjusted) to rehabilitate the San Carlos Irrigation Project.

<sup>49</sup> Water Delivery Contract No. 3-07-30-W0284, dated October 22, 1992.

<sup>50</sup> Exhibit 8.1 concerns the construction and payment of Project Works to deliver the initial 173.1KAFY CAP allocation (para 2.16). The U.S. agrees to make available to the Community appropriated CAP funds not to exceed \$388M (adjusted for construction cost inflation for the Project Works (para 5.1). The Community will be responsible for capital charges if any of this water is converted into CAP M&I water (para 6.3.5). With certain exemptions, the Community will be responsible for OM&R costs of the completed Project Works (para 11.1.2).

<sup>51</sup> This is in contrast to the San Carlos Apaches who received a large slug of CAP water but were unable to use it so instead have made 100-year leases. That is this water is not responsible for any direct jobs on the San Carlos Apache reservation.

<sup>52</sup> The Secretary’s first priority is to pay for fixed OM&R costs for water deliveries [Pub. L. 108-451, Title II, Sec 205(a)(6)]. These costs are approximately \$40/AF. Significantly, these costs have been increasing at a higher than inflation rate as they are sensitive to healthcare and wage costs. The Community must pay the residual costs which are the electricity costs or Pumping Energy Rate charges, which in 2006 were \$33/AF.

<sup>53</sup> Pub. L. 95-328 and amendments to this Act Pub. L. 102-497.

AWSA water is not costless to the tribe, an advantage in this settlement vis-à-vis the Ak-Chin settlement, is that there is no need secure annual Congressional appropriations to buy down the water cost because of the AWSA's unique funding mechanism.<sup>54</sup> It is also unlikely that a settlement of this size would have passed if OM&R costs were also subsidized.

#### 2.2.a. GRIC water budget

Title II authorizes the Gila River Indian Community's water budget as per the Master Agreement.<sup>55</sup> To make up for the Gila River water that will not be delivered, the GRIC has received 'substitute' quantities of CAP water. This CAP water was available because agricultural interests, the state's largest water users, were not fully utilizing CAP water because of lower cost access to groundwater. Agricultural districts defaulting on their CAP contracts is problematic, therefore the settlement rescues these unexercised agricultural contracts and ensures that the CAP investment is fully utilized. The settlement provides debt relief for contract relinquishment. Of the 350 KAFY relinquished 195 KAFY has been set aside for Community. The AWSA increases GRIC's CAP water allocation from 173,100 AF to 328,800 AF or from 12% to 23% of total CAP water. GRIC's share of CAP water is large and reflects the strength of the GRIC's water rights claims, however, the impact of this reallocation on other water users is mitigated by leasing arrangements embodied in the settlement.

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<sup>54</sup> Previously, the CAWCD fixed the repayment schedule through the Fund, then forwarded it to the Congress, which then reallocated it back to the Community. Now, the money will go straight to the Community without the need for further appropriation.

<sup>55</sup> Pub. L. 108-451, Sec 2: Definitions #34.

The GRIC water budget (see Table 2) demonstrates how a comprehensive agreement can resolve a number of outstanding legal disputes between the Community and other parties. Some smaller cities made relatively large contributions to the overall water budget, such as the City of Chandler. In addition to the water, GRIC also gains access to the existing water conveyance system. Some side agreements do not add to the water budget of the Community, but use exchanges to protect GRIC water rights (for example the agreement between the Community and the Phelps Dodge Corporation, discussed later). The water budget also highlights the diversified portfolio of water rights held by the GRIC which is comparable to those held by other large water providers in the state, such as Salt River Project (SRP) and the city of Phoenix. This diversification will assist the Community in managing its water supplies in times of drought, as its supplies come from three surface water sources, the Gila, Colorado and Salt Rivers, as well as from more drought-proof reclaimed, stored, and groundwater supplies. The agreement elevates the GRIC to a large water manager<sup>56</sup> (and user) in the State. The Community has the opportunity and mandate to refine its institutional and professional capacities for water management. There are numerous provisions in the settlement for the funding of, and the assumption of, responsibility for water measurement and monitoring activities on the reservation.

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<sup>56</sup> Pub. L. 108-451, Title II, Sec 205 (c) allows the Community to lease water, Sec 205 (d) allows the Community to exchange reclaimed water and Sec 205 (f)(3) allows the Community to contract with the Arizona Water Banking Authority. The Community will also need to manage water rights with different priorities and the timing of deliveries. For example, the RWCD allocation has a delivery schedule of January 1 through September 30 (Exhibit 9.1, Sec 5.1.2) whereas other water is available each month of the year, such as CAP water contracts.

**Table 2: GRIC Water Budget**

<b>Water Source</b>	<b>AF</b>
Community CAP Indian Priority	173,100
Groundwater	156,200
Globe Equity Decree	125,000
New CAP non-Indian Agricultural (NIA) priority	102,000
Salt River Project (SRP) Stored	20,500
Roosevelt Water Conservation District (RWCD) CAP	18,600
Harquahala Valley Irrigation District (HVID) CAP	18,100
Asarco CAP	17,000
Haggard Decree <sup>57</sup>	5,900
Mesa reclaimed exchange premium	5,870
RWCD surface water	4,500
Chandler contributed reclaimed	4,500
Chandler reclaimed exchange premium	2,230
<b>TOTAL</b>	<b>653,500</b>

### 3. INNOVATIONS

An innovative feature of the AWSA is the degree to which it incorporates Indian water rights settlements into a comprehensive water bill. While all Congressionally authorized settlements consider water concerns in their region, AWSA does this on a greater geographic scale and across a broad variety of issues. The AWSA resolves multiple water allocation and payment issues between the State and Federal government and, in the process, identifies excess water for Indian water rights settlements; making the agreement least disruptive to existing water users. The GRIC settlement itself, Title II, uses a watershed framework for resolving basin-wide disputes. Solutions negotiated on this scale are more likely to be durable because upstream water users and competing valley

<sup>57</sup> In lieu of Haggard Decree water SRP shall deliver to the Reservation, at no cost to the Community of the U.S. the 5.9 KAFY from a pumping plant, the so-called Booster, on the Maricopa Drain. Exhibit 7.2 Articles I and II. Article IV provides provisions for pumping in excess of this limit from this site, however, the electrical pumping charges would have to be borne by the Community or the U.S. This agreement is in return for waivers of liability for Salt River diversion that may have impacts water supplies for GRIC irrigation (Article X).

water users are integrated into the agreement. The Gila is already one of the most intensively managed and monitored watersheds in Arizona: the settlement will primarily reallocate water and funds in the watershed.

The settlement creatively taps existing financial resources from the LCRBDF, circumventing the need for what would otherwise be very large Congressional appropriations to buy-down the costs of significant quantities of water for the GRIC. While this creative funding was essential to AWSA, it will be difficult to copy for future settlements as the OMB is opposed to future diversions of U.S. Treasury funds. The agreement also contains water and money<sup>58</sup> for future Indian water rights settlements in Arizona. This is an innovative tool to move future negotiations forward. (However, there are suspicions that this is the federal government's final pledge of funds and water for future settlements in Arizona.) Finally, there are numerous side agreements to the AWSA which enabled discrete issues between the Community and other parties (for example, with Phelps-Dodge, SRP, and RWID). These side agreements in part helped to break the logjam in the wider negotiations. These agreements also established good faith negotiations with the Community and got others on board so that the negotiators could move forward to other issues. The next sections highlight some of the market tools, and water resource management and water supply reliability aspects of the AWSA.

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<sup>58</sup> \$250K will be credited to the Future Indian Water Settlement Subaccount of the Lower Colorado Basin Development Fund to fund future settlements (Id at Title I, Sec 107(a) The agreement provides for \$53M to be deposited in the GRIC Water OM&R Trust Fund (Sec 107(a) which amends Section 403(f)(2)(D)(vi) of the Colorado River Basin Project Act (43 U.S.C. 1543(f)).



### 3.1. Market-based tools: lease and exchange reallocation

Two types of market-based tools are discussed here: leases<sup>59</sup> and exchanges.<sup>60</sup> A crucial aspect of the settlement is that the GRIC is permitted to lease water.<sup>61</sup> There are several restrictions: only non-*Decreed* water can be marketed,<sup>62</sup> CAP water can only be leased within Arizona,<sup>63</sup> and water can only be leased for a maximum 100-years.<sup>64</sup> Community CAP water must also be delivered through the CAP system<sup>65</sup> and is subject to the CAP system's priority-based shortage-sharing arrangements in times of drought.<sup>66</sup> Furthermore, to protect lessees, there is a provision that leases and exchanges of Community CAP water will not affect any future allocation or reallocation of water by the Secretary.<sup>67</sup> Leases fulfill a federal objective. Federal criteria require that the beneficiaries of Indian water rights settlements pay in proportion to their benefits. Lease payments to the Community provide a key means for funding economic development on the reservation.

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<sup>59</sup> Pub. L. 108-451, Title II, Sec 205(c) gives the Secretary approval for the lease arrangements with Phelps-Dodge and the seven Phoenix cities attached to the agreement as Exhibits.

<sup>60</sup> Id at Sec 205(d) provides the Secretary approval for the reclaimed water exchange agreements with the cities of Chandler and Mesa, which also appear as Exhibits to the agreement.

<sup>61</sup> Id at Sec 205(a)(2).

<sup>62</sup> Id at Sec 205(f)(2) states that Gila River agreement, Globe Equity Decree, and Haggard Decree water cannot be sold, leased, transferred, or used off-Reservation other than by exchange.

<sup>63</sup> Id at Sec 205(a)(2)(A). This limitation is repeated in Sec 205(a)(8)(f)(1). Exceptions are detailed in Title I, Sec 104(e)(2) for water leased or exchanged with the AWBA or for an exchange with New Mexico as per the NM Consumptive Use and Forbearance Act ratified under Title II, Sec 212.

<sup>64</sup> Id at Sec 205(a)(2)(B).

<sup>65</sup> Id at Sec 205(a)(4)(A).

<sup>66</sup> Id at Sec 205(a)(4)(B).

<sup>67</sup> Id. at Sec 213(d).

At the time of the AWSA, the GRIC had entered into lease agreements with four Phoenix valley cities: Goodyear, Peoria, Phoenix, and Scottsdale.<sup>68</sup> These agreements provide for the leasing of a total 41 KAFY of GRIC (Indian or M&I priority) CAP water to the cities for a period of not less than 100 years. This clause means that the water meets AWS requirements: water that can be used to support growth. Although the volumes leased differ, all the agreements have the same cost terms. There are various payment schedules; all involve an initial lump sum, money that can be used for immediate investments on the Reservation. Water is available for lease at a price determined by a pricing formula. This formula is based on water valuation completed for the Salt River Pima Maricopa Indian Community Water Rights Settlement Act in 1988,<sup>69</sup> but it allows for consumer price inflation over the intervening years.<sup>70</sup> There are several payment plans.<sup>71</sup> If the entire lease is paid for upfront (in March 2006, for example), \$1,743 secures 1 AFY of water over the period of the lease, 100 years. This water is available to the cities without payment of water service capital charges, though operation, maintenance and replacement (OM&R) charges must be paid. This water is also subject to shortage sharing. Any reductions will be in the same proportion as M&I priority CAP water. The cities are allowed to re-lease this water, but only within the CAP three county area.

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<sup>68</sup> Exhibits 17.1A-D. Goodyear and Peoria have contracts to lease up to 7 KAF of CAP water each, Phoenix up to 15 KAF and Scottsdale up to 12 KAF annually.

<sup>69</sup> Pub. L. 100-512. The water price in this agreement is the result of a cost analysis of replacement CAP water capitalized over the period of the lease.

<sup>70</sup> To account for inflation the base payment of \$1,203 per AF is multiplied by a ratio. This ratio is of the CPI-U (this is the Consumer Price Index for All Items for All Urban Consumers, U.S. City Average, published by the U.S. Department of Labor, Bureau of Labor Statistics) in the month the term begins divided by this index value in December 1991. For example, for the City of Goodyear the formula for an agreement beginning in March 2006 is:  $((199.8/137.9) \times \$1,203) \times 7 \text{ KAF} = \$12,200,985$ .

<sup>71</sup> These plans range from the upfront payment of the entire lease costs within 30 days of the contract to an upfront payment of 1/15 of the total lease cost plus fourteen annual installments of 1/15 of the lease cost plus interest, where the interest is the Chase Manhattan Prime rate plus 1%.

These agreements seem to benefit both sides to the contract: the cities secure, inexpensive water that meets AWS standards, while the Community receives money upfront (a total \$71.463M)<sup>72</sup> for investment on the reservation. In addition, the U.S. Treasury benefits to the extent that lease holders must pay CAP OM&R costs, costs that would not be paid if the water remained with the Community.<sup>73</sup> To illustrate, in 2006 OM&R costs for these leases would be around \$2M.

A clearer evaluation comes from comparing the lease agreements to a likely alternative. The four cities with lease agreements have accessed low price,<sup>74</sup> secure water, at the cost of the lease price and CAP OM&R costs. However, it is possible that the cities could have made even better water deals, for example with agricultural and tribal interests along the Colorado River. The opportunity costs<sup>75</sup> of the cities' investment in 100-year leases are alternative spending priorities in the cities. However, their opportunity costs are mitigated by their ability to re-lease the water to others and their desire to hold a diversified portfolio of water. On the other hand the Community is bound by the lease pricing mechanism even if the value of water in the region rises substantially. This

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<sup>72</sup> If the cities paid the leases upfront. See footnote 69.

<sup>73</sup> Pub. L. 108-451, Title II, Sec 205(a)(6) provides that the Secretary shall pay the OM&R costs for the delivery of Community CAP water to GRIC, given adequate funds in the Lower Colorado River Basin Development Fund, but not for water leased by others. In 2006 OM&R costs are \$49/AF.

<sup>74</sup> Id. at Sec 205(a)(8) states that CAP water service capital charges are not payable for Community CAP water whether or not the water is used on-Reservation. This is reiterated in Sec 205(e).

<sup>75</sup> Opportunity cost is a term used in economics to mean the cost of an action or project in terms of the next most valuable opportunity forgone (and the net benefits that could have been received from that opportunity). (Wikipedia, accessed May 12, 2006).

designated pricing formula though accounting for inflation has little connection with forces affecting future water demand, supply and market value.

The Community has a side agreement with Phelps-Dodge Corporation resolving all outstanding water rights litigation between the parties<sup>76</sup> and incorporating provisions for lease and exchange.<sup>77</sup> The initial lease is for 12 KAFY of CAP Indian Priority<sup>78</sup> water for a 50 year term.<sup>79</sup> The lease price will be paid in full at the start of the lease term in the amount of \$4.8M.<sup>80</sup> Within two years of the end of this initial lease the parties can start negotiating for a renewal for an additional 50 years. At this stage a new lease price will be determined by negotiation of ‘fair market value’ which will be based on then-current M&I priority CAP water prices and other agreed to factors.<sup>81</sup> If no price can be agreed upon within a year of the termination of the initial lease then the Secretary will establish a fair market value using comparable lease quantities and prices for M&I priority CAP water.<sup>82</sup> This lease can either be paid in a single installment or in ten equal installments plus accrued interest of 8% per annum.<sup>83</sup> As per the city leases above, Phelps-Dodge will not pay CAP capital charges, but will pay OM&R charges.<sup>84</sup> The corporation can use the

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<sup>76</sup> Phelps-Dodge’s water rights are listed as Attachments C-1 to C-3 and its water rights priorities asserted in Attachment D to Exhibit 10.1

<sup>77</sup> Exhibit 10.1.

<sup>78</sup> This type of CAP water has high priority in the system. Exhibit 8.2, Sec 5.7 details the priority system of the CAP and the impact of shortage on the system and the appropriate formula to calculate CAP Indian and CAP M&I allocations.

<sup>79</sup> Id para 6.1.

<sup>80</sup> Id para 6.2. There are provisions to adjust this sum for inflation. The lease cost works out at \$400/AF for 50 years, this is a lower price than the lease water for cities, see footnote 69.

<sup>81</sup> Id. Para 6.3(a)

<sup>82</sup> Id. Para 6.3(b).

<sup>83</sup> Id. Paras 6.4 (a)-(b).

<sup>84</sup> Id. Para 6.5. The value of these OM&R charges is \$588,000/year.

water for direct use, recharge or exchange with GRIC or other parties within the CAWCD Service Area.<sup>85</sup> The agreement also includes terms for an option to lease an additional 10 KAFY of Indian priority CAP water within a 20-year option period.<sup>86</sup> The price and payment terms of this agreement are similar to those of the renewal lease above.<sup>87</sup>

The Community also has an exchange agreement with Phelps-Dodge Corporation whereby the corporation can divert upstream Gila River water, in accordance with environmental laws, in lieu of CAP water. This exchange provision allows for a limited decoupling of beneficial use and location of the exchange-water right. This may have implications for water management in this watershed: issues that must be resolved by the Secretary.<sup>88</sup> In addition to the lease agreement, another source of Phelps-Dodge funds for the benefit of the Community is the so-called “monetary consideration for settlement”. This \$18M compensation fund<sup>89</sup> is in return for waivers and confirmation of the company’s water rights.<sup>90</sup>

Another side agreement<sup>91</sup> authorizing exchanges with two Phoenix valley cities will give GRIC access to “exchange” and “contributed” reclaimed water supplies to up to 45.1

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<sup>85</sup> Id. Para 6.8.

<sup>86</sup> Id. Paras 7.1-7.7. Phelps-Dodge will pay the Community \$50K annually for right to have this option.

<sup>87</sup> Id. Paras 7.4-7.5.

<sup>88</sup> See footnote 114.

<sup>89</sup> Exhibit 10.1, Sec 4.1.

<sup>90</sup> Of this total, \$1M has already been paid as per the terms of the agreement and a schedule and terms for the payment of the remaining \$17M have also been agreed, including penalties for non-compliance.

<sup>91</sup> Exhibit 18.1 to the agreement.

KAFY. These exchanges were made possible by new water ‘accounting’ rules that mean any entity which receives CAP water in exchange for reclaimed water does not have to count this CAP-exchange water against its contracted CAP allocation.<sup>92</sup> GRIC will receive up to 29.4 KAFY of Mesa reclaimed water, up to 11.2 KAFY of Chandler “exchange reclaimed water”, and an additional 4.5 KAFY of Chandler “contributed reclaimed water”. The Chandler and Mesa exchanges are based on a 4:5 ratio: the cities receive 1/5 less CAP water (a total 32.5 KAFY). This exchange may seem like a poor trade, however, such exchanges can delay new investment in wastewater treatment facilities or upgrades. Cities often recharge treated wastewater (which is of poorer quality); it is subsequently mixed with groundwater and recovered. This is an expensive process that also requires large tracts of land and available aquifer space. This process is bypassed in these agreements at the cost of a fifth of the water. The exchange water (CAP water) requires no pre-treatment for storage. The cities likely incur cost savings at their wastewater treatment facilities and the Community benefits from securing reclaimed water as a drought-proof agricultural and golf course irrigation<sup>93</sup> water supply.

The sum of all of these lease and exchanges just discussed is that the GRIC will have a net 93.5 KAFY additional allocation of mostly NIA grade water for agricultural development.<sup>94</sup> We estimate that leases, exchanges and options will reduce the

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<sup>92</sup> Pub. L. 108-451, Title I, Sec 104(d)(2)(E)(i).

<sup>93</sup> The reservation has three golf courses.

<sup>94</sup> On the addition side: 102 KAF new NIA CAP + 18.6 KAF RWCD CAP + 17.8 KAF HVID CAP + 17 KAF Asarco CAP + 40.6 KAF Chandler/Mesa reclaimed = 196 KAF. On the subtraction side: 41 KAF city leases + 17 KAF Asarco lease + 12 KAF Phelps-Dodge lease + 32.5 KAF Chandler/Mesa exchange = 102.5 KAF. Net additions are 196 KAF-102.5 KAF = 93.5 KAF.

Community's combined higher priority CAP IA, CAP M&I, and CAP firmed NIA water (a total 205.1 KAFY) by 95.5 KAFY while increasing revenues by around \$78M.<sup>95</sup>

### *3.2. Water resource management*

This section details some of the water management tools incorporated into the settlement, such as conservation measures and water management plans. A water settlement process creates the opportunity to settle not only Indian water rights claims but also to address other water management issues. This is particularly true when the settlements are basin-wide. In multiple agreements the signatory tribes are required to develop on-reservation water codes,<sup>96</sup> groundwater codes,<sup>97</sup> water management plans,<sup>98</sup> and monitoring capabilities.<sup>99</sup> The reason for these requirements is that the ADWR has no jurisdiction on Indian reservations. Thus tribal water management features have been incorporated as integral elements in the settlements. The tribes remain sovereign managers of their groundwater use but are required to contribute to overall water use efficiency in the state.

One aspect of water management is efficiency, efficiency in use and in delivery. Conservation practices are incorporated into the settlement through the rehabilitation of irrigation district infrastructure. The GRIC settlement makes the GRIC the manager of

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<sup>95</sup> See footnote 165.

<sup>96</sup> The GRIC must develop a Community Water Code within 18 months of the enactment of the AWSA, 2004. The requirements of this code are detailed in Pub. L. 108-451, Title II, Sec 204(e)(A).

<sup>97</sup> The Secretary will provide \$215,000 to the San Xavier District and \$175,000 for the eastern Schuk Toak District to develop and implement a groundwater management program, Id. at Title III, Sec 311(c)(1)-(2).

<sup>98</sup> The Secretary will provide \$891,200 to the San Xavier District and \$237,200 to the Tohono O'odham to develop such plans (Id. at Sec 308(d)(2)(A)(i) and (ii)).

<sup>99</sup> The Community has a \$3.4M fund to develop a water monitoring program, GRIC WRSA, subpara 27.2.

the SCID, makes provisions for its rehabilitation, and creates a rehabilitation fund.<sup>100</sup> Investments in canal lining will conserve water, of which, GRIC will be entitled to up to 18 KAF.<sup>101</sup> The Community agreed to develop an effective water conservation program prior to the delivery of its initial allocation of CAP NIA water.<sup>102</sup> A final example of conservation as a water efficiency tool is contained in the side agreements between GRIC and four towns along the Gila River.<sup>103</sup> All the agreements have a clause requiring the town to control phreatophytes.<sup>104</sup> The conservation measures adopted in the settlement are small steps towards greater water efficiency in the State.

### *3.3. Water supply reliability*

There are a number of features in the AWSA that increase water supply reliability for the Community (and third parties). These include agreements with upstream water users, increased diversification of water supplies, and firming arrangements. Groundwater pumping protection zones are also important supply reliability mechanisms, because they reduce stressors to the reservation's aquifers.

#### 3.3.a. Upstream consumptive use forbearance

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<sup>100</sup> Pub. L. 108-451, Title II, Sec 203(d) and a \$52.396M fund Title II, Sec 214(a)(1)(A).

<sup>101</sup> Id. at Sec 203(d)(4)(B)(ii).

<sup>102</sup> Exhibit 8.1, para 14. This program must contain objectives, economically feasible water conservation measures, and time schedules for meeting the objectives. At five year intervals progress must be reported and necessary revisions made to the program.

<sup>103</sup> Exhibits 26.1 and 26.3-26.5.

<sup>104</sup> For example, in Exhibit 26.1, Para 13. Phreatophytes are water-loving plants.



A key provision in the agreement to improve basin-wide water management is upstream forbearance. There are a number of provisions incorporating outright water right extinguishment and fallowing arrangements. The Secretary will provide funds to the Gila Valley Irrigation District and the Franklin Irrigation District (the so-called Upper Valley Defendants, UVD) for the acquisition of specified decreed water rights. The water rights appurtenant to 2,000 acres of land<sup>105</sup> will either be extinguished to reduce diversions from the Gila River or will be transferred to the SCIP for the benefit of the GRIC and SCIDD.<sup>106</sup> The agreement incorporates a timetable for the acquisition of these rights and a formula for compensation.<sup>107</sup>

An interesting feature of the AWSA is the number of clauses that consider future Indian water rights settlements. The motivation for including such clauses in this agreement is to encourage and provide resources for future settlements and also in recognition of the failed attempt to incorporate a comprehensive agreement with the San Carlos Apache Tribe (SCAT, Title IV) in the AWSA. For example, provisions are made for the purchase and transfer of water rights appurtenant to between 500 and 3,000 additional acres from

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<sup>105</sup> Pub. L. 108-451, Title II, Sect 211(a)(2)(A)-(B). Water rights will be acquired in two 1,000 acre phases.

<sup>106</sup> Id. at Sec 211(a)(5)(a)(i). Of the decreed water rights associated with 2,000 acres above, the water rights associated with 900 acres will be transferred to the SCIP.

<sup>107</sup> Id at Sec 211(a)(2)(A)-(D). The value of a water right appurtenant to 1,000 acres of land will be determined and the Secretary will pay districts 125% of this value, Id. at Sec 211(a)(2)(D)(3). Such monetary compensation is one method for keeping non-Indian water rights holders 'whole'. In addition the UV irrigation districts will receive a \$15M fund to comply with the NM CUFA, Id. at Sec 213(g)(1).

the Upper Valley Irrigation Districts (UVID) if a water rights settlement with the SCAT is reached.<sup>108</sup>

Fallowing arrangements can be used with, or in lieu of, the water rights extinguishment and transfer arrangements above. Irrigation districts can enter into fallowing arrangements which essentially reduce irrigation acreage thereby reducing demands on the Gila River.<sup>109</sup> Another provision incorporates environmental goals. A cooperative program would allow for the purchase and extinguishment of water rights appurtenant to agricultural lands that have not recently been irrigated in the upper valley for the benefit or riparian habitat. Essentially this provision would prevent riparian parcels from being reclaimed for agriculture. The irrigation districts have also agreed to limits on river diversions and groundwater pumping for the benefit of the river and GRIC's water rights.<sup>110</sup>

There is also a consumptive use and forbearance agreement with the upstream State of New Mexico as part of the "New Mexico Unit" (NMU).<sup>111</sup> New Mexico has an authorized apportionment of Gila River basin water as provided by article IV of the decree of *Arizona v. California* (376 U.S. 340). At the time of the decree an

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<sup>108</sup> Id. at Sec 211(a)(2)(C). The division of benefits from such a transfer and elucidated in Sec 211(a)(5)(B)(i)-(iii) whereby GRIC will receive the water rights to 200 acres, the water rights appurtenant to 300 acres will be extinguished and the balance will be transferred to SCAT.

<sup>109</sup> Id. at Sec 211(a)(4)(B).

<sup>110</sup> Id. at Sec 211(b)(1)-(3).

<sup>111</sup> This side agreement is an exhibit to the main law. It is not numbered but goes by the short title "Consumptive Use and Forbearance Agreement" (CUFA). The main provisions are under Id. at Sec 212. Phelps-Dodge Corp is also a signatory to this agreement.

apportionment for future uses was not specified. This NMU refers to supplemental consumptive use water that will be made available to water users of an amount not to exceed 18 KAFY, of which 4 KAFY can be diverted from the San Francisco River and the rest from the Gila River.<sup>112</sup> This use is conditional on there being adequate Colorado River (exchange) water for delivery to downstream Gila River users in Arizona and adequate reservoir storage.<sup>113</sup> Funds to construct this project are detailed in Title II, Sections 212 (i) and (j) and Section 213(g)(1). The NMU must pay its share of the OM&R CAP costs but is exempt from capital costs. A fund has been created to pay for the construction of the Unit.<sup>114</sup> Crucially, the Secretary is instructed not to approve any new Gila River water for CAP water exchanges that would conflict with this more senior exchange.<sup>115</sup> In this basin the Secretary will have the responsibility to ensure that all the decree, exchange, and other water rights are kept “whole”,<sup>116</sup> and that each new exchange proposal is strictly reviewed.

There are significant provisions for managing water resources in other areas of the Gila River and its tributaries. These sections of the settlement combine a number of water

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<sup>112</sup> CUFA paras 4.4 and 4.3 (Pub. L. 108-451, Title I, Sec 107(a)). The cost of installing water gauges on the rivers will be borne by the U.S. up to \$0.5M (Pub. L. 108-451, Title I, Sec 107(a)). The agreement provides for \$53M to be deposited in the GRIC Water OM&R Trust Fund (Sec 107(a) which amends Section 403 (f)(2)(D)(vii) of the Colorado River Basin Project Act (43 U.S.C. 1543(f)).

<sup>113</sup> CUFA paras 4.5 and 4.7. Water banking provisions are allowed (paras 4.6, 5.4-6.6) and the terms of the water diversions, including dates and volumes are specified Exhibit 2.47 Sec (B) (1.1)-(1.1.2.3.).

<sup>114</sup> These provide for a \$66M (adjusted) NMU Fund for the construction of the NMU. The Secretary may provide additional construction funds from \$34M to a maximum \$62M (Pub. L. 108-451, Title I, Sec 107(a) which amends Section 403(f)(2)(D)(i) and (ii) of the Colorado River Basin Project Act (43 U.S.C. 1543(f)).

<sup>115</sup> Pub. L. 108-451, Title II, Sec 212 (m). New Mexico has senior exchange priority as per the 1968 Act.

<sup>116</sup> In an over-allocated watershed where no ‘new’ water supplies are available for settlement, non-Indian water users might be financially compensated or made whole, for relinquished water rights.

management tools, for instance municipal water budgets, groundwater pumping forbearance zones, and restrictions on new dam building. A comprehensive assessment of current and future water needs and of various water resource management strategies has underpinned the design these measures. GRIC has forbearance agreements with municipalities in the middle Gila valley<sup>117</sup> and with agricultural, industrial, M&I, and domestic water users in the San Pedro River and Aravaipa Creek watersheds<sup>118</sup> and those inside the Gila River Impact Zone<sup>119</sup> who are parties to the *Globe Equity* Decree. These agreements require the establishment of the Gila River Watershed Maintenance Program<sup>120</sup> in State law to limit groundwater pumping in these areas. Another section of the proposed program is the establishment of “Safe Harbor” provisions<sup>121</sup> to protect existing non-irrigation water users water rights in these watersheds from legal challenge. The Safe Harbor provisions permit new domestic and large industrial uses in these impact zones under specific terms and as long as the new use does not exceed the adjudicated water entitlement. These provisions allow for growth but place limits on groundwater pumping for the benefit of the rivers and the downstream Community.

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<sup>117</sup> Agreements with Safford, Duncan, Kearney, and Mammoth are attached as exhibits (Exhibits 26.1, 26.3, 26.4 and 26.5, respectively).

<sup>118</sup> Two Impact Zones (IZ) are specified on maps they are: the San Pedro River and Aravaipa Creek IZs, as shown in Exhibit 2.146B. These zones extend to the incorporate the fluvial depositional systems of these rivers. Areas included in this forbearance are San Manuel, Winkelman, Cochise County, and BHP company (subparas 26.8.2.7.1-26.8.2.8.).

<sup>119</sup> Exhibit 2.84A.

<sup>120</sup> State legislation creating this GRWMP must be enacted by the enforceability date to secure all these side agreements (Title II, Sec 207(c)(1)(I)(iii).

<sup>121</sup> These provisions are detailed in the GRIC WRSA, para 26.8.2

The state has passed new legislation establishing a Gila River Maintenance Area (GRMA) and a GRMA Impact Zone.<sup>122</sup> There are prohibitions on the construction of new or enlarged dams within the GRMA, with some exceptions for example for flood control, and provisions to prohibit the irrigation of new lands within the GRMAIZ.<sup>123</sup> These provisions will be enforced by the ADWR. This legislation will not only benefit the downstream GRIC Reservation by limiting groundwater pumping in the alluvial zones of the main rivers and tributaries and limiting new storage on the river, but also benefit the SRP, the other large downstream water right holder.

To illustrate the complexity of the municipal forbearance arrangements, the side agreement with the City of Safford (Exhibit 26.1) is examined. The city has an initial water budget of 9.74 KAFY for M&I uses: this budget allocates water for growth as projected water use on the enforceability date is just 7.5KAFY.<sup>124</sup> Any consumptive water use above this budget must be matched with an identified water source. Furthermore, any exceedances must be mitigated according to set rules.<sup>125</sup> The impact of potential new groundwater pumping (in and outside the protection zones) has to be modeled. If and only if, it is found to have no impact on the upper Gila River, is it exempted from counting as a new diversion against water budget, but if not, it will count

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<sup>122</sup> As per HB 2728 which added A.R.S. §45-2603.

<sup>123</sup> Id. §45-2631 and §45-2641. Lands irrigated between January 1, 2000 and the effective date of this Section are exempt. This new prohibition may be redundant if new irrigated agriculture in this region is not profitable.

<sup>124</sup> Exhibit 26.1, budget as per subpara 2.15 and current use as per subpara 4.2.

<sup>125</sup> Id. Para 10.

against the city's water budget.<sup>126</sup> In return for compliance with these terms, the city will receive debt relief of up to \$13.9M.<sup>127</sup> This seems a particularly good deal for Safford that has not gone unnoticed by others in the agreement: the city is allowed to grow and receives debt relief for participation in the AWSA. The agreement incorporates provisions for accounting, reporting, and dispute resolution; hallmarks of a durable agreement.<sup>128</sup> There are similar restrictions and provisions in the other metropolitan side agreements.<sup>129</sup> These side agreements demonstrate the benefits of a negotiated settlement in achieving improved water management in effected watersheds.

### 3.3.b. Reservation groundwater protection zones

The settlement requires new state legislation to protect on-Reservation groundwater for the GRIC.<sup>130</sup> Titles II (and III) contain provisions that create a buffer zone around reservations, within which groundwater pumping by non-Indians is limited. This is a regulatory innovation: a specific settlement provision analogous to State groundwater law is being used to protect groundwater levels beneath the reservations of sovereign tribes. A precursor to these protection zones are limits to on-reservation groundwater pumping. The GRIC are allowed to pump 156.2 KAFY. For the tribes to accept such limits on their groundwater use there had to be concurrent groundwater pumping restrictions on non-

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<sup>126</sup> Id. Subpara 9.3 and subpara 9.2.

<sup>127</sup> Pub. L. 108-451, Title II, Sec 214(a)(5)(A).

<sup>128</sup> Exhibit 26.1, paras 12, 14, and 17.

<sup>129</sup> Initial water budgets for the other towns are: Kearny 600 AF, Mammoth 300 AF, both within the Gila River, Middle Gila River and San Pedro River impact zones, and the Town of Duncan 470AF, of which 400AF within the UV impact zone.

<sup>130</sup> Title II, Sec 207(c)(1)(i). This is the so-called Southside Replenishment Program.

Indians near reservation boundaries. Significantly, the GRIC's groundwater protection zone and replenishment requirements are stricter than State well spacing rules and the Central Arizona Groundwater Replenishment District (CAGR),<sup>131</sup> in terms of the actual measurement of the cone of depression and the spatial connectivity of replenishment and pumping.

The Southside Replenishment Program establishes five protection zones<sup>132</sup> along the southern border of the GRIC Reservation in which water conveyance outside the Eastern or Western Protection Zones is prohibited for non-irrigation use, with certain exemptions,<sup>133</sup> and where the State has obligations to replenish groundwater pumped in excess of set limits. For example, in the Eastern Protection Zone replenishment obligations are triggered when pumping is in excess of 2.33AF/acre.<sup>134</sup> The replenishment obligations are spatially connected to the groundwater pumping so that the spatial integrity of the aquifer is respected and incidentally subsidence risk is reduced. This spatial aspect of the replenishment was a sticking point with the Community which was concerned about existing impacts on their groundwater by non-Indian users. To resolve this issue the state agreed to an additional replenishment volume to recompense for historic pumping. The State is required to establish a Southside Replenishment Bank

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<sup>131</sup> "The purpose of the CAGR is to provide a mechanism for landowners and water providers to demonstrate an assured water supply under the new AWS Rules". "The CAGR must replenish (or recharge) in each AMA the amount of groundwater pumped by or delivered to its members which exceeds the pumping limitations imposed by the AWS Rules." There is no requirement to replenish the same localized area where groundwater was pumped.

[http://www.cagr.com/Gen\\_Info/index.cfm?action=execSum](http://www.cagr.com/Gen_Info/index.cfm?action=execSum). Accessed May 11, 2006.

<sup>132</sup> A.R.S. §45-2602 (A) as amended by HB 2728.

<sup>133</sup> Id. §45-2611(A-B).

<sup>134</sup> Id. §45-2602(3)(d).

and deliver at least 1 KAFY up to a total 15 KAF and to ensure that credits never fall below 5 KAF.<sup>135</sup> This block of water will be delivered at no charge to the Community and will be paid for by withdrawal fees from Pinal County. The AWBA, the firming agent for the State, has fulfilled this obligation in one direct delivery of CAP water during 2006 using low cost available excess CAP water thereby reducing the cost of this program to the state.

### 3.3.c. Access to stored water

A key benefit of the GRIC settlement is new access to reservoirs and thus stored water. It is with stored water that one of the SRP roles in the settlement becomes clear. SRP was one of the drivers of the settlement and is one of the main beneficiaries.<sup>136</sup> The 1.8 MAFY GRIC claim could have severely impacted SRP's ability to reliably supply water. The agreements between GRIC and SRP are detailed in the GRIC Water Rights Settlement Agreement. SRP offered a combination of access to water and access to water delivery infrastructure to settle outstanding disputes with the Community. GRIC is entitled to an initial 2 KAFY rising to 35 KAFY of stored SRP water in any year that net storage levels are above 100 KAF on May 1st.<sup>137</sup> Furthermore, the Community can accrue credits up to 45 KAF: this facility is another hedge against supply variability.<sup>138</sup>

This stored water will be delivered through SRP drainage ditches that GRIC is permitted

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<sup>135</sup> Id. §45-2624(A)-(C).

<sup>136</sup> SRP delivers 1 MAFY to a central Arizona service area and also provides electricity to nearly 860,000 retail customers in the Phoenix area. <http://www.srpnet.com/about/facts.aspx> accessed May 5, 2006.

<sup>137</sup> GRIC WRSA, Sec 12.1. Volumes available will ratchet up over a five year period to the maximum entitled as per para 12.2.

<sup>138</sup> Id. at subpara. 12.3.1.



to use,<sup>139</sup> and the water will be managed and monitored by the Community.<sup>140</sup> The price of stored water is determined annually and in 2005 was \$11.25/AF.<sup>141</sup> Up to 836 AFY of additional stored water from the Blue Ridge Dam may be made available to the Community.<sup>142</sup> The parties have an option for a SRP stored water-CAP water exchange.<sup>143</sup> As with the other stored water, the Community can receive water credits.<sup>144</sup> This agreement entitles the Community to yet another source of water and access to storage at a low cost.<sup>145</sup>

### 3.3.d. Diversification of water sources

A key benefit of the GRIC settlement is the diversification of the tribe's water supplies and new access to reservoirs, discussed above (see Figure 2). Prior to the agreement, the tribe was reliant on a drought-prone and over-allocated Gila River watershed and received only a third of its *Globe Equity* allocation. The settlement shifts the Community's water allocation from the Gila River to the Colorado River, via the CAP. In essence, 185 KAF of Gila water has been replaced by CAP water. There are advantages

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<sup>139</sup> SRP will also pay GRIC \$0.5M towards cost of easements, construction, rehabilitation, operation and maintenance of these drain ditches on the reservation, Id at subpara 16.9.

<sup>140</sup> Id. at subparas 12.5.1 and 12.5.4.

<sup>141</sup> Id. at para 12.7. Prices are determined by the Board of Governors of the Salt River Valley Water Users' Association.

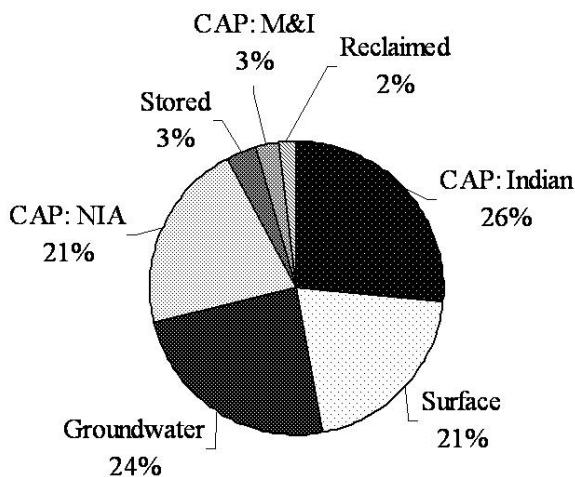
<sup>142</sup> Id. at subpara 12.13.1. Unlike the SRP stored water this will not be subject to transportation or evaporation losses, or spills (Id. at subpara 12.13.3.). The cost of this water is 10% of the OM&R costs (Pub. L. 108-451, Title II, Sec 12.12.4 and Exhibit 12.13.4). In addition up to 3.5 KAFY will be made available for M&I purposes in Northern Gila County (Id. at Sec 213 (i)(3)(B)).

<sup>143</sup> GRIC WRSA, para 13.1. The Community will pay for all associated pumping charges (Id. at subpara 13.1.1)

<sup>144</sup> Id. at para 13.2.

<sup>145</sup> Id. at subpara 13.5.5. Water costs in 2005 were \$10.06/AF plus transportation charges of \$12.14/AF. A flat administrative fee of approximately \$4,254 in each year the option is exercised would also be levied.

to this substitution. The Colorado River has more storage, and is highly managed with drought reliability a foremost objective. One drawback from this substitution is that CAP water is more expensive to provide for the Community than Gila River water.



**Figure 2: GRIC Water Budget Water Sources**

GRIC's water portfolio is dissimilar to that of the State as a whole (see Table 1). GRIC is more heavily reliant on surface water (Colorado River and in-state rivers) than the State. The Community has a lower reliance on groundwater than Arizona as a whole. Groundwater supplies, if well managed, can be a buffer against long-term drought and improve long term sustainability of reservation activities that depend on water. The settlement introduced groundwater management rules akin to those in Active Management Areas (AMAs), to the reservation. Additionally, the Community benefits from stricter-than-State's rules governing the pumping and sinking of new wells within the newly created groundwater protection zone. The Community now has access to above-ground stored water through agreements with SRP. The settlement also opened a

new source of water to the Community; highly supply reliable reclaimed water. The Community itself has a small population and therefore limited opportunities to generate reclaimed water supplies. However, through side agreements with the nearby cities of Chandler and Mesa it takes Grade A+ reclaimed water in exchange for CAP water on a 5:4 ratio. This reliable water source has another benefit, in that it can replace higher quality groundwater for agricultural and golf course irrigation. Overall the settlement has diversified the Community's water supplies and increased protection from current and future water users upstream, bordering the reservation, and on the reservation.

An important aspect of water diversification is water supply reliability. The priority of the Community's CAP water allocations is fundamental to any assessment of the reliability of the Community's (agricultural water) supplies. The Community currently plans to develop up to 120,000 acres of irrigable land on the reservation. The PIA standard has focused near-term economic development on the reservation on agriculture. For a period of 100 years, just 15 KAFY or 14.7% of the Community's new 102 KAFY NIA CAP allocation will have at least the same priority as M&I water via State firming commitments. Delivery of the residual 87 KAFY is at risk in a future drought because it has the lowest priority in the CAP system: in a severe drought these contracts would be cut first. If one uses the State's forecast of drought probability, which they use in determining firming volumes, the Colorado River is expected to be in drought one quarter of the time, that is one year in four the Community might receive none of this

allocation.<sup>146</sup> One hundred years after the settlement, the Community will be reliant on low priority rights for a fifth of its total water budget.

Other water sources included in GRIC budget are also subject to shortage risk. For example, the RCWD 4.5 KAFY relinquishment water, surface water from the Salt and Verde Rivers, has lower priority than RCWD water allocated to the Salt River Pima Maricopa Indian Community and the Fort McDowell Indian Community settlement agreements.<sup>147</sup> Mitigating this risk are firmer alternative Community agricultural water supplies, namely 173.1 KAFY of IA water and 45.1 KAFY of reclaimed water. These water sources are more drought-proof for planning agricultural investments, but also are appealing to potential lessees. The Community could minimize its exposure to NIA junior status by managing groundwater as a backup drought supply. This however would require the Community to establish a groundwater recharge, recovery and delivery system capable of delivering groundwater to reservation locations normally reliant on surface water. An alternative strategy for reducing drought-induced risks to agricultural investments is to limit the amount of irrigable land developed (developing least profitable lands last).

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<sup>146</sup> The modeling assumptions used by the State can be found in Appendix II of the Indian Farming Study Commission, Interim Report, Draft 10-06-05. Available from [http://www.awba.state.az.us/annc/Indian\\_Farming\\_Study\\_Comm/default.htm](http://www.awba.state.az.us/annc/Indian_Farming_Study_Comm/default.htm), accessed May 6, 2006.

<sup>147</sup> Exhibit 9.1, Sec 5.1.3. Sec 5.2 sets the terms of the delivery of this water at \$18.5/AF, of which \$13.5/AF is for transportation of the water, this charge will be adjusted for inflation and a \$5/AF charge for pumping, which will be adjusted with power and energy rates.

However, it is important to compare this situation with the situation prior to the settlement for the Community. The GRIC likely has much more reliable supplies with this arrangement than its previous reliance on Gila River and groundwater supplies.<sup>148</sup> Nevertheless, GRIC needs to plan for drought to ensure that cutbacks in the activities relying on its 102 KAFY NIA CAP allocation can readily be accommodated. Possible uses for this water include annual crops (that could be fallowed in dry years), or leasing to the Arizona Water Banking Authority or other entities that recharge excess water for firming obligations. Other Community surface water deliveries are more assured, as per the *Globe Equity* and *Haggard* Decrees. The settlement side agreements increase the surety of the GRIC's senior surface water rights further through the Upper Gila River Maintenance Area and the CUFA.

### 3.3.e. FIRMING

The outcome of reallocating M&I water to M&I uses rather than to tribal settlements resulted in a compromise to firm equivalent volumes for such settlements so that tribal water can be delivered during shortages as if it were M&I priority water (see Section 2ic above). This was an innovative solution to what had become a vexing and contentious issue between the State and the Federal negotiators. The firming volumes and division of responsibilities are detailed in Title I, Sec 105. A consequence of dividing firming responsibilities by water quantity (rather than dividing up costs of a single firming program) is that federal and state agencies may compete for excess water and aquifer

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<sup>148</sup> Pre-settlement the GRIC were subject to an 185 KAFY shortfall in its *Globe Equity* decreed water.

space. This is perhaps somewhat more problematic for the federal side as the State has got a head start on the process because of the necessity to pass new legislation<sup>149</sup> to address several components of the federal legislation.<sup>150</sup> This new legislation created a Firming Program Study Commission<sup>151</sup> which modeled shortages on the Colorado River to estimate the firming volume required,<sup>152</sup> estimated the costs of various options, and made recommendations including changes to law. This firming legislation was adopted by the Arizona legislature in March 2006.<sup>153</sup> The outcome is that new authorities and duties have been identified for the AWBA and these have been codified into the AWBA statutes.<sup>154</sup> An interesting outcome of the State firming program is the creation of a groundwater savings facility (GSF)<sup>155</sup> on the GRIC reservation.<sup>156</sup> This GSF has permitted the direct delivery of CAP water in lieu of a portion of the State's firming

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<sup>149</sup> Pub. L. 108-451, Title II, Sec 207(c)(1)(I)(ii).

<sup>150</sup> HB 2728.

<sup>151</sup> The Study Commission was established per Appendix III, HB 2728, Section 12, to investigate firming volumes, options to meet the obligation including costs and funding sources, and identifying necessary changes to Arizona Revised Statutes.

<sup>152</sup> The firming volume used by the Study Commission was 548,770 AF. [Reclamation, the lead Federal agency in charge of the firming for Title III estimates that firming the 28.2 KAFY will require a firming obligation of 846 KAF. Using Reclamation's calculations the State's firming requirement is much higher at 711.7KAF. The difference is based on assumptions about water development in the Upper Basin States: ADWR the lead agency for the State expects 4.8 MAFY compared to the much higher 5.4 MAFY water demand projected by the Upper Colorado River Commission and used by the BOR ]. See also footnote 149.

<sup>153</sup> HB 2835.

<sup>154</sup> These changes make the AWBA the State's agent for firming. The Statutes also identifies State general funds and a portion of groundwater withdrawal fees in the Phoenix, Pinal and Tucson Active Management Areas (AMAs) to pay for the program A.R.S. §45-611(C)(1)-(3). Other duties include developing accounting mechanisms for tracking firming. The Statutes also identify water sources that can be used for Indian firming, these include effluent, which is not permissible for other types of firming, however, the legislation still prioritizes the use of CAP excess water, to comply with priorities to fully utilize the CAP. Finally the AWBA is permitted to direct deliver firming water to the GRIC. See next footnote.

<sup>155</sup> A GSF works by conserving groundwater through the direct delivery of an alternative water source as a replacement for groundwater pumping.

<sup>156</sup> Agreement between the Arizona Water Banking Authority, and Gila River Indian community for Storage of Central Arizona Project Water at a Groundwater Savings Facility, April 2006. The facility has been permitted for up to 56 KAFY.

obligation.<sup>157</sup> This facility reduces the cost of water banking for the State and makes water available for the tribe earlier, water that will be used for agricultural purposes. Incidentally, it has also increased recharge capacity in the State.

### ***3.4. Access to water infrastructure***

A key benefit for the Community and the Federal government in this settlement is access to water conveyance and storage infrastructure: infrastructure that in many cases was built by the federal government. This access does three things: it allows the Community to quickly ramp up its water use, it reduces the costs of the agreement to the Federal government, and it is an in-kind contribution to the settlement from state parties. For example, GRIC can use the RWCD system to transport water to the northern boundary of the reservation subject to 30 cubic feet per second (CFS) capacity restrictions.<sup>158</sup> This capacity is equivalent to 21,719 AFY, making it significantly greater than the RWCD surface water reallocation to the Community. Furthermore, RWCD will pay all the capital and OM&R costs of making the capacity available to the Community.<sup>159</sup> Additionally, the RWCD will undertake to increase the capacity of the system to 200 CFS (equivalent to 144,794 AFY) to provide for future additional deliveries to the Reservation. All costs, including OM&R costs, associated with the expanded system will be borne by the U.S..<sup>160</sup> The Community also has agreements with SRP for the direct delivery of CAP

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<sup>157</sup> The entire 15 KAFY required to satisfy the State's obligations under the Southside Replenishment District agreement was predelivered in 2006.

<sup>158</sup> Exhibit 9.1, paras 5.3 and 6.1. This option is for all water sources not just the RWCD portion of the water budget.

<sup>159</sup> Id. at para 6.1.

<sup>160</sup> Id at para 6.3 and subparas 6.3 (c) and (d).

water to the Reservation using SRP infrastructure.<sup>161</sup> The benefits accruing to the Community from these arrangements are hard to quantify. Clearly they are significant in terms of delivering wet water across the Reservation and also in reducing the cost of implementing the overall agreement by using existing infrastructure.

#### 4. CONCLUDING OBSERVATIONS

The AWSA brought together the dominant water stakeholders in central Arizona across tribal, state, federal, municipal and agricultural interests. This negotiation process itself is as significant, involving years of dialogue among hundreds of individuals and legal representatives. Important regional water management measures were incorporated into the agreement, a commendable outcome of complex negotiations. It is conceivable that similar water management goals could have been achieved more cheaply or efficiently in other ways, for example through new measures to control private wells or to improve agricultural water efficiency. The proliferation of side agreements makes it challenging to track the flows of water and money among parties and to clearly identify consequences of the AWSA. However this is critical in understanding the distribution of costs and benefits. Given the pre-existing challenges of rapid growth, variable surface supplies and spatially dis-connected pumping and replenishment activities it is remarkable that the AWSA achieved so much. The effort and expense that went into the AWSA is, of course, in large part due to the location of the GRIC Reservation and the size of the settlement.

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<sup>161</sup> GRIC WRSA, para 14.1, for delivery of up to 4 KAF per month or 20 KAFY (subpara 14.3.2.) for which the Community will pay the same charges as in footnote 143. SRP ditches are also available to the Community as per subpara 16.9.



Improvements in water supply reliability are shared with other water rights holders who are reliant on the same watersheds.

Total costs of the settlement comprise monies expended in negotiation, money pledged for various funds and administrative activities, in-kind water costs, and opportunity costs. Settlements have proven expensive to negotiate and implement. However, they defuse litigation, bind parties to make durable solutions, and deliver wet water to tribes. CAP and agricultural debt forgiveness incorporated into the AWSA will cost the federal government \$2.073B. The Congressional Budget Office further estimates that the AWSA will increase federal discretionary spending by \$6M in the years 2005-2009 and increase direct spending by \$445M in the years 2005-2014.<sup>162</sup> Meanwhile, the State has, and will continue to, provide resources for studies, legislative amendments, oversight and monitoring, and enforcement. The State must also contribute \$3M for Federal firming, in cash or in-kind. State firming obligations using a traditional AWBA approach are estimated to cost between \$25.35M and \$53.48M.<sup>163</sup> The Southside Replenishment District costs are estimated at \$0.3M.<sup>164</sup> The AWBA also expects to hire one full-time staff person to assist in these program activities.<sup>165</sup> Other costs are to the Settling Parties,

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<sup>162</sup> *Supra* note 25, p1.

<sup>163</sup> Indian Firming Study Commission, Interim Report, November 1, 2005. Appendix VII. The lower bound estimate is for a groundwater savings facility (GSF) and the higher bound for underground storage facility (USF). A USF facility (A.R.S. § 45-811.01) allows the permit holder to operate a facility that stores water in the aquifer. A GSF facility (A.R.S. § 45-812.01) allows the permit holder to deliver a renewable water supply, called "in-lieu" water, to a recipient who agrees to replace groundwater pumping with in lieu water, thus creating a groundwater savings. Other solutions were estimated to be more costly, such as dry year fallowing, at \$88.16M.

<sup>164</sup> The direct delivery of CAP water to fulfill this obligation reduces the cost of this program. Using current AWBA rates of \$20/AF the total cost of this program is around \$300,000.

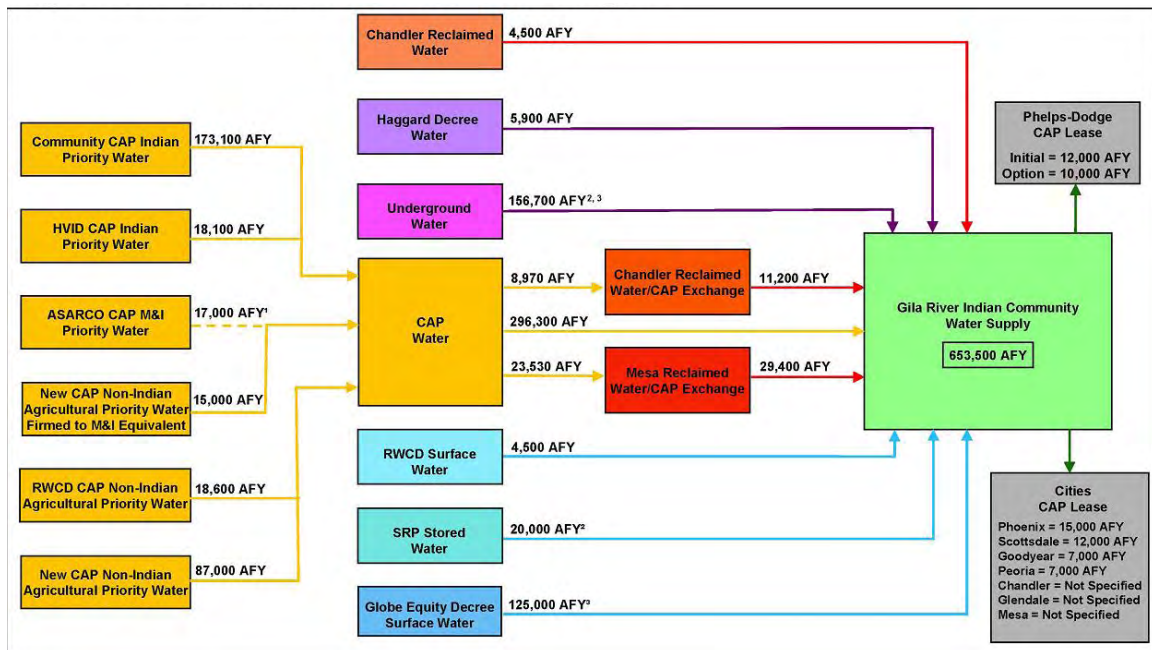
<sup>165</sup> As per discussion with AWBA staff on November, 15, 2005.

estimated at around \$78.06M.<sup>166</sup> There are of course other costs, such as costs to enforce the new legislation and the opportunity costs of new water, after the large reallocation to the GRIC; however, this cost could be negative, if Indian water leases are less expensive than the next alternative water source.

The sources of water for the agreement are almost evenly split between federal and (state) Settling Parties. This is a notable change in settlement history that conforms with the Federal Criteria. The federal portion includes the 102 KAFY CAP NIA water, 18 KAFY conserved in the upper Gila Valley, and an unspecified volume of water from CUFA. On the state side, SRP contributed 20.5 KAFY stored water and 5.9 KAFY in lieu of *Haggard* Decree water, RWCD and HVID contributed 36.7 KAFY CAP NIA water, RWCD also contributed 4.5 KAFY of surface water, Asarco 17 KAFY of CAP M&I priority water, and the cities of Mesa and Chandler a total 12.6 KAFY treated effluent, for a total 97.2 KAFY (see Figure 3). The contributions from the Settling Parties reduced the overall cost of the settlement for the federal government in line with Federal criteria.

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<sup>166</sup> This is not a complete list. The \$78.06M includes city lease costs (for which the lessors receive water). This upfront money has an opportunity cost. The \$78.06M also includes Phelps-Dodge's compensation money, lease cost and 20-year option, SRP payments for easements, and Tucson Water's \$300K subsidence fund.



**Figure 3: Water Flows: the GRIC Settlement**

Opportunity costs are harder to quantify. These are the costs associated with reallocating water to GRIC that could have been allocated to current and future competing uses. There may also be opportunity costs in terms of future settlements. To the extent that water settlements are a zero-sum game the GRIC settlement was the recipient of significant federal indirect and direct funds and within Arizona a large fraction of outstanding excess water has been reallocated to the GRIC.

Undeniably all parties to the settlement (and many non-signatories) benefit from the settlement. However, it is hard to quantify some of these benefits. The main benefit is the removal of risk and uncertainty associated with the GRIC water claim. Twenty cities also gained access to new allocations of AWS water and four cities to inexpensive lease

water. The benefits to individual signatories vary. Signatories and non-signatories also benefit from third-party effects, for example from upstream water forbearance agreements. The Community meanwhile benefits from the delivery of ‘wet’ water and the economic development, cultural, and environmental opportunities afforded by water resources. The Federal government benefits by fulfilling its trust obligation and both the federal and state governments benefit by resolving contentious CAP issues and introducing water management improvements. This agreement may also benefit other Indian tribes: 67 KAFY and \$250M was set aside to facilitate other settlements. It is difficult to monetize these combined benefits or allocate them between various participants, however, the OMB’s reluctance to endorse the agreement suggests that the costs to the federal government might exceed estimated “calculable legal exposure”. This contention paradoxically is one of the reasons why the agreement may prove to be durable.

Many settlements incorporate penalty provisions in the event the federal government does not meet its obligations in a timely manner. The GRIC settlement does not: this is attributable to the source of implementation funding, the LCRBD fund, and not more discretionary annual federal appropriations. However, even without such penalties, the Settling Parties have enormous incentives to ensure the durability of the settlement, particularly as this settlement includes money and water and also lease provisions for the reallocation of this water from the Community to the Settling Parties. It is unclear whether the AWSA will be a precedent for future settlements as it is the largest

settlement in the United State's history and therefore costly. There is a provision in the AWSA to keep Congress informed about the status of settlement implementation, negotiations for future settlements,<sup>167</sup> and identification of critical on-Reservation water needs.<sup>168</sup> This creates a window (some are saying the last window) for other Arizona tribes to negotiate settlements. It is likely that any new settlement in Arizona will have to follow the AWSA model with significant local contributions of water and money and access to existing infrastructure, including storage. Furthermore it is likely that future settlements will deliver subsidized but not free water and that management codes and other regulatory instruments will be incorporated into settlements to concurrently resolve vexing water management issues.

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<sup>167</sup> The San Carlos Apaches, Navajos and Hopis are all currently negotiating.

<sup>168</sup> Pub. L. 108-451, Title I Sec 104(a)(1)(C).

## APPENDIX G: COPYRIGHT PERMISSIONS

Date: Fri, 20 Oct 2006 11:57:23 +0100

From: vrose@ashgatepublishing.com

Reply-To: vrose@ashgatepublishing.com

Subject: RE: copyright

To: rbark@email.arizona.edu

Dear Rosalind Bark,

Many thanks for your email below and apologies for the delay in responding: I have been out of the office at a conference and then on a couple of visits and am only now catching up.

That's absolutely fine about using your chapter in your PhD thesis – you have permission to do so. Please let me know if you require anything more formal, but we do not.

With kind regards,

Valerie Rose

Senior Commissioning Editor

Ashgate Publishing

Date: Tue, 10 Oct 2006 08:01:31 -0600

From: "Tackman, Susan" <TACKMAN@law.unm.edu>

Reply-To: "Tackman, Susan" <TACKMAN@law.unm.edu>

Subject: RE: Article Submitted to the Natural Resources Journal

To: rbark@email.arizona.edu

Dear Rosalind,

With this email message, the Natural Resources Journal grants permission to you to include the article "An Economic Assessment of the Sonoran Desert Conservation Plan" in your PhD dissertation. We would ask that you include a brief acknowledgement of publication in the NRJ.

As you may have guessed, we have experienced delays with issues leading up to the one in which your article is to be published that have put our third issue for 2006 on a back burner for a bit. We now expect to have the issue in which your article is included printed and out to our subscribers in January. Our sincere apologies for the delay.

Best regards,

Susan Tackman

Managing Editor

Natural Resources Journal

UNM School of Law

505-277-4910

505-277-8342 (fax)

[nrj@law.unm.edu](mailto:nrj@law.unm.edu)