Do open space resources shape residential outdoor water consumption?

Author: Eve B. Halper
Affiliation: Ph.D. Candidate, Department of Geography and Regional Development, University of Arizona, Tucson, Arizona

Introduction:

Like many cities in the Southwest United States, Tucson, Arizona is experiencing rapid growth in population and municipal water demand, with no corresponding expansion of water supplies. This has lead to the depletion of non-renewable groundwater supplies, the degradation of riparian areas and other undesirable consequences. By 2050, municipal demand is projected to outstrip renewable water supplies (City of Tucson, 2004). Single family residential (SFR) outdoor use, though lower than many other Southwest cities, still comprises a considerable part of municipal water demand, and is considered a natural target for water conservation efforts. In 2001, 36% of use by SFR's, approximately 20,000 acre-feet, went to outdoor use (Western Resource Advocates, 2003). Moreover, there is little opportunity to recapture and reuse this water, and it is generally considered a consumptive use.

Since the 1970's, many homeowners have converted their landscaping from lawns to desert plants (McPherson and Haip, 1989). This has been reinforced by city ordinances against wasting water and voluntary programs promoting low water use landscaping. Still, the fact that Tucson households devote more than a third of their water to outdoor use, in the presence of an increasing block rate structure, indicates that some important value is being realized through landscape irrigation. Research by this author, along with many other case studies, has shown that homes with more vegetation generally have higher property values, all else being equal (Halper, 1995, Luttik, 2000).

Survey research has shown that Phoenix area homeowners prefer an "oasis" type landscape that combines lawns and desert plants to a fully xeric landscape (Martin, 2003). Outdoor landscaping is an important "quality of life" variable and further restriction by public ordinance may not be politically feasible.

A community facing the possibility of long-term water shortages due to growth needs to minimize outdoor water use while maintaining the "quality of life" that attracted its residents in the first place. To do this, it is necessary to have a better understanding of the factors that determine outdoor water use. This study examines the influence of individual house attributes, block group level census demographic data and neighborhood characteristics on SFR level outdoor water consumption. To a greater degree than other research, this study examines the spatial relationships between SFR outdoor water use, parcel characteristics and neighboring land uses. Specifically, it investigates whether proximity to various types of open spaces (riparian areas, nature preserves, parks, golf courses) affects household behavior.

<u>Data set:</u>

SFR monthly water use records from 2000 were obtained from Tucson Water, the Tucson metropolitan area's main water provider. Annual outdoor water use was initially calculated as the difference between the minimum monthly usage and the usage during other months of the year. Records where the primary household occupants changed during the year, and those in which any month's consumption was zero, were deleted from the dataset. After this process, 100,765 records remained. Monthly outdoor water use for various portions of the distribution is shown in Figure 1. Q1-Q3 are the first to third quartile use and P5-P99 are the fifth to ninety ninth percentile use, respectively.

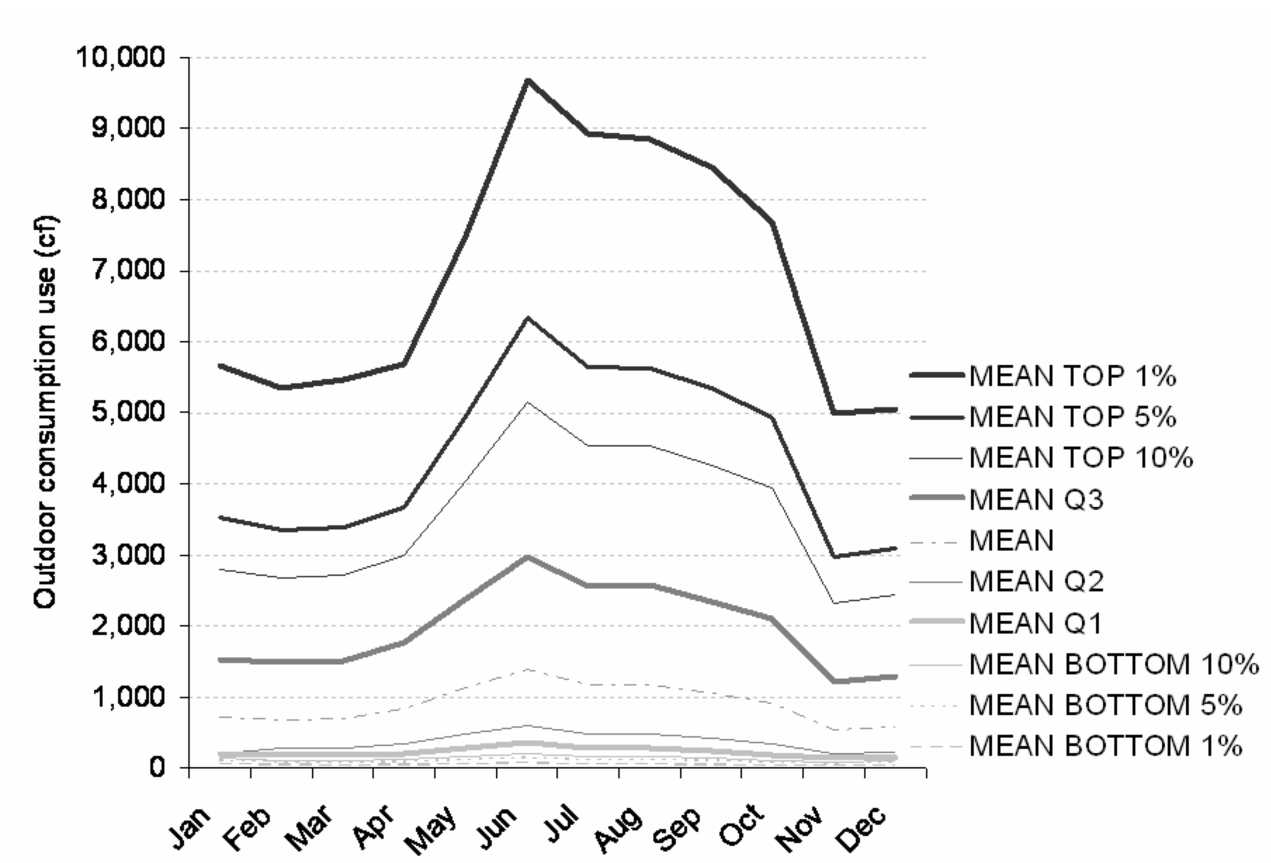

Figure 1 - Distribution of SFR Monthly Outdoor Water Use

The records were then address matched with a file of single-family residence properties for 2000 from the Pima County Assessor's office containing property attributes collected for tax purposes. Next, the records were joined to a GIS shapefile of Pima County parcel addresses for geospatial analysis. Using ESRI's ArcInfo Desktop Software version 9.2, the parcel shapefile was overlaid onto spatial data layers delineating census block groups, local associations (subdivisions, homeowners and neighborhood associations), land cover types (biomes, soil types) and several types of open space (riparian areas, preserves, city parks, golf courses).

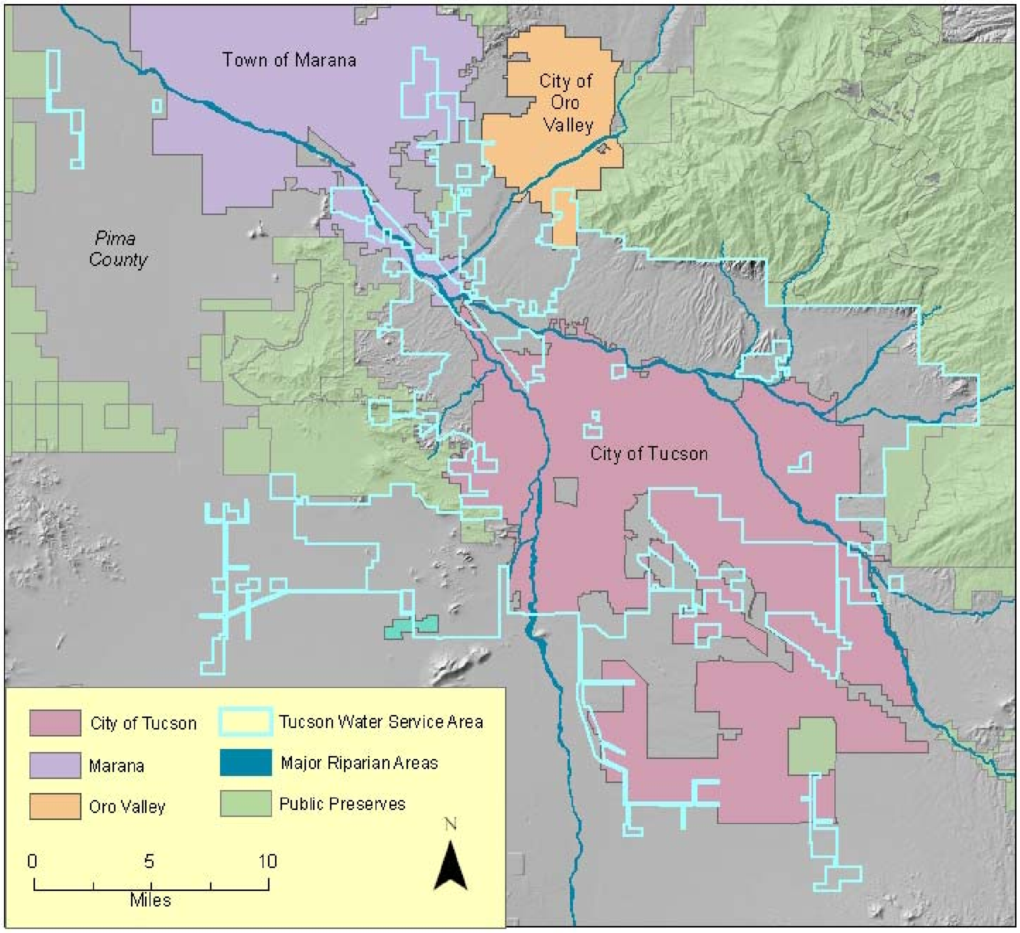

Figure 2. Overview of Study Area

Climate data was assigned to parcels by obtaining the locations of the four weather stations in Tucson with daily records for 2000, creating Thiessen polygons with respect to the Tucson Water service area, and assigning climate data within the Thiessen polygon to each parcel. The parcel layer was also overlaid on a 1m-resolution layer of Soil Adjusted Vegetation Index values, derived from orthophotography acquired by the

Pima Association of Governments in May 1998. Although this image was taken a year and half before the beginning of the water use data set, it was the only high resolution, multi-band image available of the area. Given that homeowners must invest substantial time and money to alter their outdoor landscape, the remote sensing data is believed to be representative of conditions in 2000.

Research has shown a direct relationship between housing values, house and yard size, and the presence of a pool on outdoor water use (Dandy 1997, Nieswiadomy 1988, Renwick, 1998**).** The detailed assessor database provided the opportunity to examine other housing attributes, such as the age of the home, its quality, the number of rooms, the number of bathroom fixtures and the presence of an evaporative cooler. Since recent construction has begun to incorporate water conservation measures, a dummy variable was added for houses built after 1990. The assessor's office also grades the quality of a home's construction as minimum, fair, good or excellent. Dummy variables are used to represent the first three conditions. The parcels were also joined with 2000 census data at the block group level, as very little data is available at the higher "census block" resolution. Home ownership, household size, education and ethnic variables were hypothesized to have an influence on residential outdoor water use.

Previous work also suggests that proximity to riparian areas influences housing prices within short distances (Bark-Hodgins et al., 2006). This study hypothesized that proximity to common vegetated areas, especially those of high quality, would be associated with decreased outdoor water use. Theoretically, as cities grow and land use becomes more intensive, residents become further removed from undeveloped areas, and the need to re-create "green space" is expressed by outdoor irrigation. In other words, the private outdoors may be a substitute for access to common open space. However, the spatial dimensions of this effect were not known. Tests of 0.1, 0.2 and 0.3 mile buffers of each type of open space indicated that effects decay significantly over short distances, and the 0.1 mile buffer was selected as most appropriate. Membership in a neighborhood or homeowner's association was also theorized to reduce outdoor water use, as these groups have been a focus of the city government in the campaign to reduce outdoor water use. A summary of the geographic data is shown in Figure 3.

Besides housing, demographic and neighborhood influences, the influence of the natural environment, such as the vegetation biome, soils and climate were postulated to influence outdoor water use. A home located in an area with greater natural vegetation should tend to use less water outdoors. However, the available classification divided the vast majority of the Tucson metropolitan area into two groups: Sonoran desertscrub and "developed". The impact of soil type, using a classification by the Natural Resource Conservation Service, was also tested. The default soil type was Mohave-Sahuarita-Cave.

Climate variables have been shown to strongly influence residential outdoor water use, though earlier studies have focused on regional-level spatial variation or temporal variation **(**Wong 1972**,** Gutzler, 2005**).** In this study we attempt to control for climatic variation within the Tucson metropolitan area, since residential areas vary widely in their elevation. Besides the expected temperature variations, summer monsoon storms can be extremely localized, resulting in spatial variation of precipitation. However, the ability to

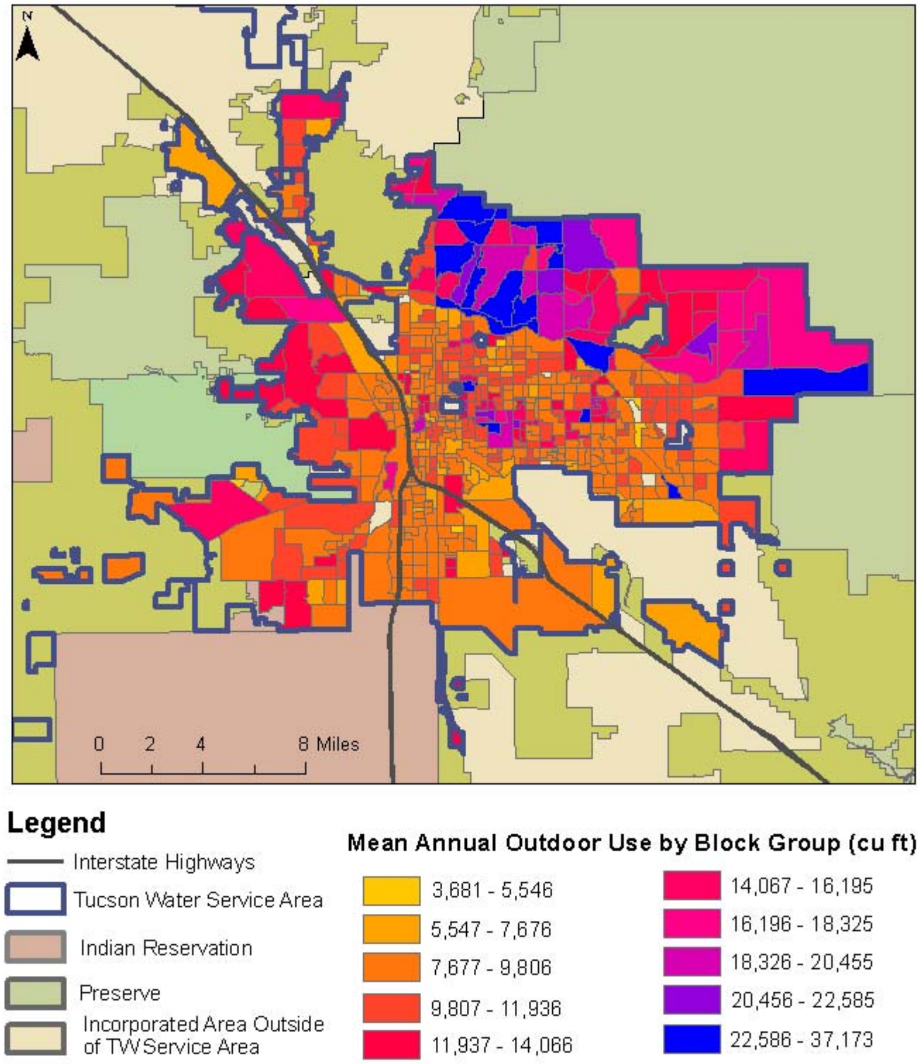

Figure 3 – Census Block Group Annual Outdoor Water Use Data GIS Display

analyze spatial variation in climate was limited due to the small number of weather stations. Through experimentation, variables representing the number of days where precipitation was greater than or equal to 0.1 inches during April-October and the total monthly heating degree-days for the period April-October were developed. (Heating degree days are calculated as the difference between daily mean temperatures and 65 F.

It is a proxy used to measure cooling energy needs, and in this study serves as a proxy for outdoor water needs.)

A vegetation index is derived from reflectance measurements in the red (600 - 700 nm) and near-infrared (800 – 1100 nm) bands of the electromagnetic spectrum. These bands take advantage of the unique spectral characteristics of vegetation: its absorption of wavelengths between 630 and 690 nm by chlorophyll and its scattering of wavelengths between 740 and 1200 nm. A high vegetation index value indicates a greater amount of green leaf area and green biomass (Tucker 1974). The Soil Adjusted Vegetation Index, or SAVI, was developed by Huete to reduce the effect of soil brightness variations in areas with incomplete vegetation cover (Huete 1988), such as semi-arid climates. The SAVI was calculated using the red and near infrared bands of the four-band 1m resolution orthophotograph. The "zonal statistics as table" function in ArcInfo was used to calculate statistics for each parcel associated with a water use record. The mean and the sum of the SAVI values were tested for their relationship to outdoor water use. To better quantify the influence of neighborhood "greenness", the average SAVI of all the parcels within a subdivision was also computed. A close-up of the SAVI image is shown in Figure 4.

The final variable tested in this study was price. Much literature exists on the method for calculating marginal price under a block rate system (Arbues, 2003). The Taylor-Nordin method (Nordin, 1976), was used to calculate the "difference" variable, the additional cost to the consumer if all water had been purchased at the marginal price. Under an increasing block rate structure, the difference variable is positive, and is expected to be inversely correlated with water use. Two different rate structures applied during 2000, shown in Tables 1 and 2. Only the December block rate difference variable was calculated, as the steeper rate was more likely to have a significant effect, especially since it added a new block for monthly use greater than 4500 cubic feet.

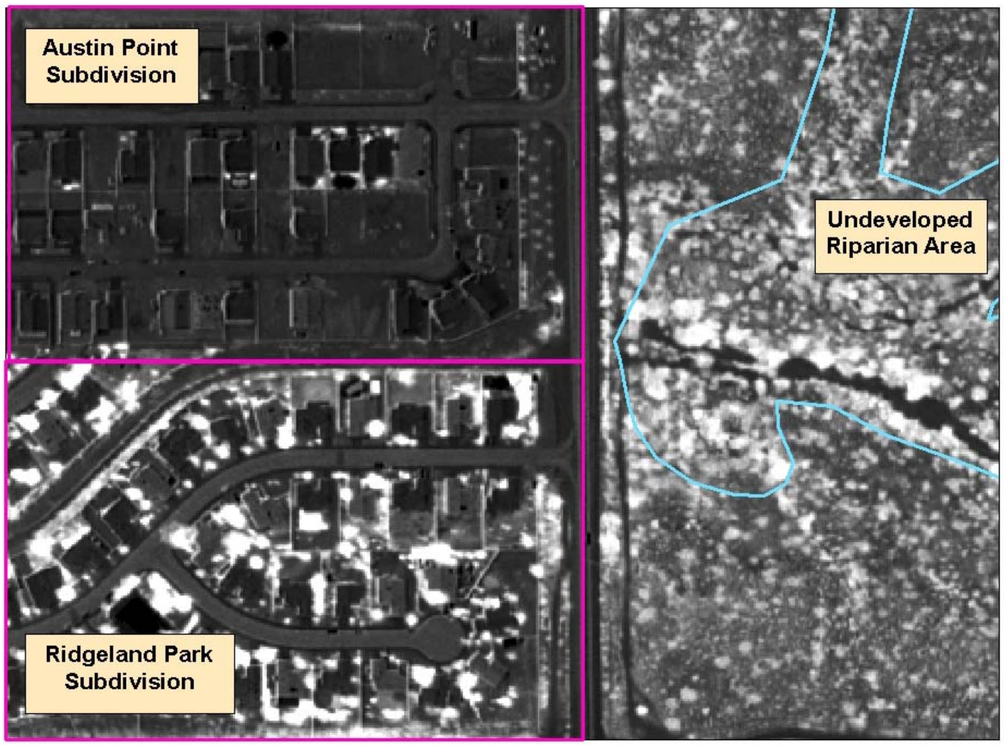

Figure 4. Close-up View of 1 m resolution SAVI image

The initial model uses ordinary least squares (OLS) estimation and linear specification. Annual outdoor water consumption (OUTDOOR) is modeled as a function of home (H), socio-economic (S), demographic (D), price (P), neighborhood (N), meteorological (M), and lot-based vegetation (V) variables, see Equation 1.

$$OUTDOOR_i = [H_i, S_i, N_i, D_i, P_i, M_i, V_i]'\beta + \varepsilon_i \quad [1]$$

Initial model results showed these variables, most of which were significant at the 0.05 level, accounted for about 25% of the variance in the data set. However, closer examination of the data showed that the method for calculating the dependent variable to be a source of error. Like many other studies, this investigation used the difference between winter and summer usage to estimate outdoor water consumption. However, a portion of the records showed high water usage year-round, far greater than what would be expected given the average household size and Tucson gallons per capita per day (gpcd). It was assumed that these households continually irrigate their landscape, regardless of the season. Therefore, an adjusted method was needed to estimate outdoor water usage for these users. In the adjusted method, an indoor use of 200 cubic feet per person per month was assumed, based on the first rate block. This was multiplied the census block group estimate of average household size. If the minimum monthly water use did not exceed this amount, the actual minimum was used to calculate outdoor water use (low water users). If the minimum monthly usage exceeded this amount, the lower estimate of indoor water use was used in the calculation (higher water users). This redefinition of the dependent variable raised the adjusted R^2 of the model to 0.34.

Table 1. January – November 2000 Residential Block Rates

*Volume (ft^3 * 100)*	*Rate, Jan. – Nov. 2000*
1 - 3	$0.00 (included in service charge)
4 - 15	$1.62
16 - 30	$2.61
31 and up	$3.29

Table 2. December 2000 Residential Block Rates

*Volume (ft^3 * 100)*	*Rate, December 2000*
1 - 2	$0.00 (included in service charge)
3 - 15	$1.33
16 - 30	$2.99
31 - 45	$3.87
45 and up	$5.85

Table 3. Linear OLS Regression Results

Variable	*Coefficient*	*Robust Std. Err.*	*t-value*	*P>|t|*
Constant	-7125.83	984.0757	-7.24	0.000
Assessed Value	**0.025108**	**0.0015968**	**15.72**	**0.000**
Yard Size (without pool, square feet)	0.006188	0.0036733	1.68	0.092
Age of House	**30.17071**	**5.047359**	**5.98**	**0.000**
Built 1990 or later	**-1574.71**	**133.1169**	**-11.83**	**0.000**
Living Area (square feet)	**3.362096**	**0.1731849**	**19.41**	**0.000**
Pool Area (square feet)	**4.956016**	**0.2056087**	**24.1**	**0.000**
House quality = minimum	-1384.56	940.5032	-1.47	0.141
House quality = fair	-1696.15	930.2002	-1.82	0.068
House quality = good	-1753.09	928.8045	-1.89	0.059
Evaporative Cooler	**1286.026**	**114.0288**	**11.28**	**0.000**
Number of Rooms	**539.2288**	**39.46556**	**13.66**	**0.000**
Number of Bath Fixtures (e.g toilet, sink, etc.)	**1544.59**	**294.3212**	**5.25**	**0.000**
% of houses rented	**7.012547**	**1.904141**	**3.68**	**0.000**
% residents w/less than high school diploma	**29.54089**	**4.096089**	**7.21**	**0.000**
% of residents with bachelor's degree or higher	**-14.4411**	**3.716894**	**-3.89**	**0.000**
% Hispanic (all races)	**6.571586**	**2.316077**	**2.84**	**0.005**
% One person households	**13.8457**	**3.62011**	**3.82**	**0.000**
Residents per square mile	**-0.03061**	**0.0142921**	**-2.14**	**0.032**
Golf course w/in 528 feet	**-1750.02**	**238.1438**	**-7.35**	**0.000**
City, county or private park w/in 528 feet	**446.9133**	**81.49518**	**5.48**	**0.000**
Undeveloped preserve w/in 528 feet	**-667.067**	**320.6888**	**-2.08**	**0.038**
Riparian area w/in 528 feet	**-270.449**	**79.67218**	**-3.39**	**0.001**
Desert scrub biome	**339.4743**	**110.4615**	**3.07**	**0.002**
Days with >= 0.1 precip from April – Oct.	**-146.179**	**11.67609**	**-12.52**	**0.000**
Heating degree days from April - Oct.	**37.69158**	**3.819721**	**9.87**	**0.000**
Located within homeowners association	-143.202	155.6963	-0.92	0.358
Located within neighborhood association	-245.869	136.3517	-1.8	0.071
Continental-Tubac soil type	214.9407	176.9581	1.21	0.225
Pinalenos–Nickel–Palos Verdes soil type	161.2107	95.11601	1.69	0.090
Whitehouse – Caralampi soil type	-100.662	1518.584	-0.07	0.947
Anklam–Pantano–Chiminea soil type	**-967.782**	**180.1562**	**-5.37**	**0.000**
Tanque–River Road–Arizo–Riggs soil type	18.49088	87.70836	0.21	0.833
Hayhook – Sonoita soil type	16.06056	179.9148	0.09	0.929
Mean Parcel SAVI	**38.45134**	**0.6931019**	**55.48**	**0.000**
Average Subdivison SAVI	**-15.309**	**1.285711**	**-11.91**	**0.000**
Difference variable – December block rate	**-51.0278**	**7.21542**	**-7.07**	**0.000**

Adjusted R-Square = 0.3434

(Bolded variables are significant at the $\propto = 0.05$ level.)

OLS Results:

The results of the OLS regression appear in Table 3. Overall, the model explained a third of the variation in outdoor water use in the Tucson Water service area. This result is comparable to other residential water use studies (Dandy 1997, Renwick, 1998, Jones, 1984, Nieswiadomy, 1988). The significant coefficients are mostly of the expected sign, with a few exceptions. For instance, the coefficient for % Houses Rented, was expected to be negative. However, on reflection, it is common practice in Tucson for landlords to pay for water bills, because landlords cannot trust tenants will water vegetation in the hot dry months if they have to pay for the water bills. (This is another indication that landscaping is a valued asset for a homeowner.)

Housing attributes correlated with increased outdoor water use include variables that proxy household size and income, such as Living Area, Number of Rooms and Number of Bath Fixtures. The regression results confirm that other outdoor and summer-based water uses (Pool Size, Evaporative Cooler) are significant in explaining the variation in outdoor water use. The coefficient for the binary variable Built 1990 or Later, is negative and significant, and suggests that local efforts to reduce water use via promotion of low-water use fixtures is effective.

Results show that outdoor water use is correlated with many indicators of income, especially the home's assessed value. However, higher education levels at the block group level are correlated with lower water use. This appears to be contradictory, since income is usually highly correlated with education level. A possible interpretation may be that due to boom in housing values in the Tucson market, even residents with lower education levels and incomes may see the value of their homes substantially increased from when they purchased them. In addition, the presence of the University of Arizona in Tucson accounts for a large population of graduate students, who are highly educated and generally environmentally conscious, but have low incomes. It would be interesting to perform this analysis in a city without a large population of university students and compare results.

As expected, close proximity to golf courses, natural preserves and riparian areas were correlated with lower household outdoor water use. (As the buffer size around these areas was increased from 0.1 mile to 0.2 miles and 0.3 miles, these effects disappeared.) However, proximity to a park was associated with higher outdoor water use. This implies that a nearby park may not be considered an amenity by residents, and may even be a disamenity that induces residents to compensate for its presence. This may seem counterintuitive, but many parks in Tucson tend to be fairly unattractive, with poorly kept landscaping and aging facilities. Location within a homeowner's association had no influence on water use, while location in a city neighborhood association was associated with lower water use, but only at the 10% level of significance. The mean parcel level SAVI variable was extremely significant and positively correlated with outdoor water use. The significant negative coefficient for the average subdivision SAVI further supports the hypothesis that the "greenness" of one's neighborhood can serve as a substitute for private landscaping.

Outdoor water use also varied according to local climate, vegetation biome and soil type. Rainier areas used less outdoor water and hotter areas used more. The vegetation biome and soil type classifications are somewhat more difficult to interpret, since the desertscrub biome generally corresponds to the outer perimeter of the Tucson metropolitan area, which is also a newer and more affluent area. In contrast, the Anklam–Pantano–Chiminea soil type occurs mostly in the older, less affluent center of metropolitan area. Further analysis is needed to distinguish whether the natural environment, demographic variation, or both factors have effects. Finally, the negative, significant result for the “difference” variable shows that (most) households are sensitive to increasing block rates, and tend to consume less water than they would have if a lower marginal cost were applied.

Reasons for the low adjusted R-squared probably include the lack of information on the actual number of people in the household. This variable was shown, not surprisingly, to be very significant in previous studies. However, this data is not easily available and must be collected through household surveys. This limits the size of the data set, and was not possible in a study with this many records. A lack of information on hot-tubs, another important outdoor water use, and on emergency leaks, may have contributed to underspecification of the model. The use of block group household size to estimate outdoor water use for a portion of the data set eliminates the natural variation between households that existed in the original data. However, the trade-off for a better approximation of outdoor water use appears to be a productive one.

Another explanation may be that many households in the Tucson area have automatic irrigation timers and do not vary unless the householder actively adjusts it according to the weather. Other homes may have set irrigation use incorporated in the indoor use. In this case, outdoor water use will mainly be determined by the nature and regime of the irrigation system.

Concluding remarks:

The study results identify some of the major socio-economic and environmental drivers of outdoor water demand. The results suggest positive externalities, in terms of reduced SFR outdoor water use, are associated with land use policies that preserve natural vegetation amenities. The finding that proximity to a golf course lowers outdoor water use, while proximity to a park increases it, demonstrates that homeowners also respond to artificially irrigated vegetation. However, the direction of the effect depends on the quality and "greenness" of the vegetation. The small distance over which the effect is seen implies that the visual characteristics of the area, rather than its recreational opportunities, are the drivers.

The next step in the study will involve the detection of collinearity among the independent variables and the construction of a more parsimonious data set. Principal components analysis will be used to detect the most significant variables or to construct composite variables. Future work will also include the application of image processing techniques, including feature recognition and texture analysis, to discriminate between naturally occurring and artificially irrigated vegetation.

Inspection of the spatial distribution of the residuals indicates that areas where very high outdoor water use is observed also tend to exhibit greater variability. It appears that outdoor water use tends to be homogeneous in smaller parcels with older, lower value housing, but extremely variable in more affluent areas with larger lot sizes. Spatial analysis may help to reveal the factors contributing to this variability in particular geographic areas.

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