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Research paper

The value of water-related amenities in an arid city: The case of the Phoenix metropolitan area

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HIGHLIGHTS

- Water-related amenities are reflected in hedonic property models for the greater Phoenix metropolitan region.
- Parcel and nearby vegetation abundance correlated positively with house prices.
- Submarkets display variable combinations of environmental attributes that are significant in relation to house prices.
- Proximity to small parks is generally not revealed as an amenity, but proximity to large parks is highly desirable.

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ABSTRACT

In the arid metropolitan area of Phoenix, AZ, water resources play a vital role in maintaining and enhancing the urban ecosystem. There are several examples of "luxury" uses of water to create amenities not common to desert ecosystems: reduced temperatures, artificial lakes, golf courses, and abundant vegetation. In this study our goal was to appraise the relative value of these water-related amenities for urban residents. We correlated spatially explicit housing sales data from the Maricopa County Assessor's Office with environmental and locational data provided by the Central Arizona – Phoenix Long Term Ecological Research project to construct hedonic models at the regional and local scales to estimate the marginal willingness to pay for amenities associated with intensive water use. Our results revealed the preferences of homeowners for lowered temperatures, and vegetation abundance, however we found proximity to small parks to be generally considered a disamenity despite their frequent landscape design of grass, trees, and artificial lakes. At the local level of analysis, our analyses found examples where one attribute (e.g., plant richness) is considered an amenity in one place, but a disamenity in another, suggesting that there may be several markets in the metropolitan region. Because climate change models predict the US Southwest to become hotter and drier, evaluation of the importance of these water-dependent luxury amenities will be vital for future planning.

1. Introduction

Urban ecosystems are highly heterogeneous, comprised of patches that are a combination of built structures and natural elements (Cadenasso, Pickett, & Schwarz, 2007). Many urban patches were created to provide specific services to urban dwellers. Some of these services are the result of ecosystem structure and functioning, and thus are called ecosystem services. Ecosystem services are seldom delivered in isolation; just as agricultural monocultures have a range of impacts aside from the production of foods, fuels or fibers, so do urban patches deliver a range of services/disservices aside from those they are designed to yield. Moreover, since different patches deliver distinct bundles of services, city dwellers typically rely on a range of patch types for the services they need (Kareiva, Watts, McDonald, & Boucher, 2007). The development and change in the structure of natural and built environment over time has altered the set of services delivered by the local environment. Indeed, in many cases the changes were specifically wrought to enhance or reduce specific environmental characteristics, as in the case of landscaping and flood irrigation. Other changes, such as the urban heat island (UHI) effect, have been unintentional side effects of urban development.

The Millennium Ecosystem Assessment (MA) popularized the notion that ecosystems are a source of multiple services to people, but it paid relatively little attention to constructed urban ecosystems. Since publication of the report of the Assessment (MA, 2005), there has been considerable interest in the identification and evaluation of the services delivered by ecosystems in the urban

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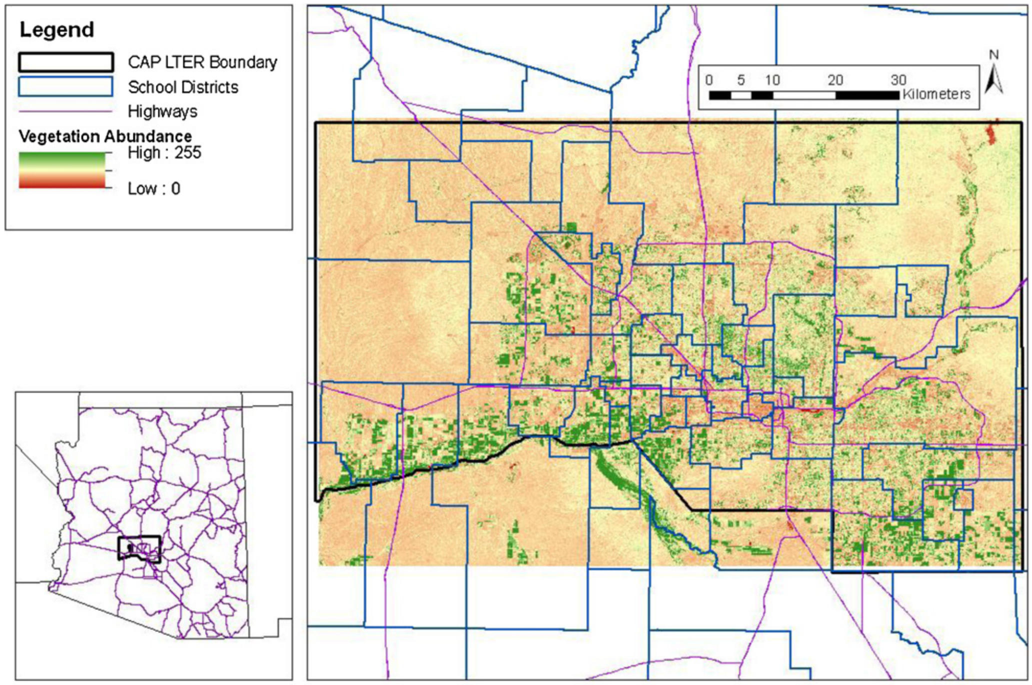

Fig. 1. Map of the Central Arizona – Phoenix Long Term Ecological Research Project area.

environment (e.g., Andersson, 2006; Andersson, Barthel, & Ahrne, 2007; Tratalos, Fuller, Warren, Davies, & Gaston, 2007). However, these assessments have generally not addressed how overall land use and land cover affect the value of the urban ecosystem to the inhabitants of cities. Our goal was to evaluate the relative value to urban residents of several environmental variables that are associated with this land cover/use and that vary widely within the Phoenix, Arizona metropolitan area.

The Phoenix Metropolitan Statistical Area (MSA) has been one of the most rapidly growing areas in the United States over the last sixty years. The population increased from approximately 300,000 in 1950 to more than 4 million inhabitants in 2008, with an estimated growth rate of 31.7% for the years 2000–2008 (US Census, 2008). This growth has been associated with extensive land use change (Gober & Burns, 2002; Jenerette & Wu, 2001), resulting in a desert city of relatively low density, heterogeneous land use/land cover patches which range from built structures and impervious paved areas, to lush residential lawns, to relatively 'natural looking' parks and undeveloped areas. These changes have fundamentally changed the patch structure within the Phoenix MSA, and in so doing have altered the array of ecosystem services derived from the ecosystems within the region. Given the climatic extremity of this desert city, these changes frequently involve the allocation and management of water. Many of the land uses require substantial water resources (e.g., artificial lakes, golf courses, flood-irrigated lawns) to provide environmental amenities to residents (Gober, 2006; Larson & Grimm, 2012; Larson et al., 2005). However, there are concerns about the impact of climate change on available water resources (Hirschboeck & Meko, 2005), and the future sustainability of water use in the area (ADWR, 1999; Gammage, 2003; Gober, 2006; Jacobs & Holway, 2004; Morehouse, Carter, & Tschakert, 2002; Phoenix Water Services Dept, 1995). Newly converted land is increasingly parsimonious in its use of water, and thus does not harness many of the ecosystem services associated with intensive water use, such as attenuation of the UHI effect, public and private spaces characterized by lush vegetation, and water-related recreation.

In this paper we pay special attention to the effect of water-related environmental attributes, such as vegetation abundance, proximity to water, and reduced UHI effect. These attributes are associated with a set of ecosystem services: microclimatic regulation, recreation and amenity, and health. If the services associated with these attributes are valuable, we would expect them to be capitalized into the price of the house. To test this we estimate a hedonic price function, the most widely used approach to measure willingness to pay for ecosystem services in built environments.

We applied the hedonic pricing method to data on residential property sales in Phoenix in order to understand the value of the shifting array of ecosystem services resulting from alterations to the natural and built environments. The study benefits from the fact that Phoenix is one of the most intensively studied urban ecosystems in the US, as it is home to the Central Arizona – Phoenix Long Term Ecological Research project (CAP LTER), one of two urban sites funded by the National Science Foundation to study urban ecosystems over long time periods. CAP LTER seeks to expand the field of urban ecology by incorporating human dynamics into the understanding of cities as complex systems. Over the past 10+ years, CAP LTER has compiled data on many environmental factors for the Phoenix metropolitan area and outlying desert (Fig. 1). Using these data together with data on residential property sales, we examined the relative contribution of water-related attributes for the whole CAP LTER region, and then segmented by school district to assess potential differences in sub-markets. As predictions of climate change for the US Southwest point to a hotter, drier climate, this will help decision-makers understand the trade-offs involved in planning decisions that alter the set of services enjoyed by residents.

2. Urban ecosystem services and their valuation

Some of the most studied environmental consequences of urban life are a set of environmental hazards or disamenities: increased levels of noise, pollution, pathogens, heat (Redman & Jones, 2005), and flooding (Walsh et al., 2005). However, urban dwellers also benefit daily from environmental amenities, some of which offset the impact of the hazards mentioned above. Ecosystem services provided by various types of urban ecosystems include microclimatic regulation, noise reduction, stormwater drainage, sewage treatment, air filtering, recreation and esthetics. These services are provided by distinct terrestrial and aquatic ecosystems found within cities (Bolund & Hunhammar, 1999; Tratalos et al., 2007), and most such systems provide multiple services. For example, urban hedgerows, parks, lakes, lawns, green roofs, and vacant lots (to name a few of these ecosystems), can simultaneously provide an array of services to urban inhabitants, some of which will be easily apparent to its recipients, but many will not be.

Researchers have used a variety of valuation methods to estimate the value of both disamenities and amenities in urban areas. Some studies have focused on single or groups of services, such as water quality improvement (Bateman, Cole, Georgiou, & Hadley, 2006), pest control (Jetter & Paine, 2004), seed dispersal (Hougner, Colding, & Soderqvist, 2006), air quality improvement (Escobedo et al., 2008), recreation and esthetics (Jim & Chen, 2006) and stormwater abatement (McPherson, 1992). Others have focused on the value of specific types of ecosystems, such as green roofs (Clark, Adriaens, & Talbot, 2008), wetlands (Tong et al., 2007), parks (Troy & Grove, 2008), green infrastructure (Vandermeulen, Verspecht, Vermeire, Van Huylenbroeck, & Gellynck, 2011), urban forests (Sander, Polasky, & Haight, 2010) and open space (Brander & Koetse, 2011).

The selection of valuation method depends both on the attribute in question and on the data available for analysis. In many cities, spatially explicit environmental data are sparse or non-existent. For this paper, we saw a unique opportunity to utilize the environmental data available from the CAP LTER in conjunction with housing sales data for the Phoenix area using hedonic valuation. We used the hedonic method to decompose assets into the individual attributes that confer value, an approach that is well suited to the analysis of constructed systems that yield an array of services or disservices. The value of the hedonic method in urban areas lies in the fact that cities are typically characterized by well-developed property-markets. These markets provide a direct measure of peoples' willingness to pay for the attributes associated with the property, whether those attributes are priced or not. So for example, the price of a residential home encapsulates not only the specific attributes of the house (e.g., living space, type of roof, etc.), but a set of environmental and locational attributes as well (e.g., the amount and type of vegetation in the neighborhood, exposure to air, soil or water pollution, proximity to amenities such as parks, schools and hospitals or disamenities such as waste-disposal sites). By analyzing the relationship between house prices and environmental conditions, it is possible to estimate people's willingness to pay for a range of both amenities and disamenities. One caution is that the resulting value estimates capture only part of the value of the identified characteristics. The hedonic pricing method is not able to ascertain the specific services that influence people's economic behavior – e.g. whether the homeowner likes living near the park because of the recreation provided, or the vegetation and plant diversity, or privacy, or some combination of these. Although we were constrained by the nature of the available environmental data, and the fact that not all urban ecosystem services are reflected in house purchases, we were able to generate estimates of the value that urban residents place on an important set of environmental amenities. In particular, we were able to estimate the value of environmental attributes that are dependent on a substantial allocation of water resources for their maintenance.

3. Data and methods

3.1. Housing sales and environmental data

Data for the study were obtained from a number of sources. The US Census data were used for demographic information of the tracts encompassing each parcel. The housing sales data came from the Maricopa County Assessor's (MCA) Office. In order to correlate sales with a time period for which we had the most environmental data, we selected sales for only the year 2000 from the total dataset, which was compiled in 2005. Because of the structure of the Assessor's database, the resale of homes overwrites prior sale data, so we were not able to capture data for homes sold in 2000 and again in a later year. However, given this restriction, there were still greater than 47,000 records of single-family residential sales. To eliminate the unduly large influence of anomalous sales (whether due to data entry errors on the Assessor's part, or unusual sale conditions), we limited our analysis to sales where the price was not greater than twice nor less than half the reported "Full Cash Value" of the parcel. This reduced our sample by only approximately 400 records. The Assessor's data include vital information about the properties that were included in our analysis: size of the house and lot, presence of a garage and pool, and the construction year.

The environmental and locational data came primarily from the CAP LTER, although additional data were gathered from the City of Phoenix, the Maricopa Association of Governments (MAG) and GIS Services at the Institute for Social Science Research (ISSR) at Arizona State University, plus individual researchers (Table 1). For our analysis, we selected attributes that would be apparent to homeowners and might be expected to influence their purchase decision.

As stated earlier, we were primarily interested in environmental attributes associated with the presence (or absence) of water that connect to specific ecosystem services. These include summer temperature, bird abundance, vegetation diversity, distance to the desert environment, and distance to recreational parks. Corresponding services include recreation and amenity a sense of place, noise abatement, microclimatic regulation, and air quality enhancement. In the Phoenix area, vegetation cover varies substantially in both private and public spaces. The vegetation on residential properties tends to be one of two main types. Some homes have green lawns with trees and shrubs (mesic vegetation), while others are landscaped with desert plants and an inorganic mulch (xeric vegetation). The ecosystem services provided by the two vegetation types differ: xeriscaped areas can enhance a sense of 'place', being more desert-like, but mesiscaped landscaping provides cooling, recreation, privacy, and/or noise reduction.

Vegetation data were derived from the Soil Adjusted Vegetation Index (SAVI), created by CAP LTER from the remotely sensed Landsat Thematic Mapper (ETM) image. SAVI is defined as:

$$\mathrm{SAVI} = [(NIR - RED)/(NIR + RED + L)/(1 + L)]$$

where NIR is Landsat band 4 (0.76–0.9 μm), RED is band 3 (0.63–0.69 μm), and L is a constant used to correct for the influence of soil color on canopy spectra (Huete, 1988). The CAP LTER has used a value of 0.5 for L in several applications (Buyantuyev, Wu, & Gries, 2007; Stefanov, Ramsey, & Christensen, 2001). We calculated two estimates of vegetation abundance: the mean SAVI for the parcel itself, and the mean SAVI for the parcel with a 100-m buffer, as studies have shown that residents capitalize on the vegetation abundance of their neighbors (Kadish & Netusil, 2012; Kestens, Thériault, & Rosiers, 2004).

In the Phoenix metropolitan area, the UHI effect is observed in the elevation of night-time temperatures as built structures re-radiate heat accumulated during daylight hours (Baker et al., 2002). Evaporation from surface waters and evapotranspiration from vegetation lower air temperatures, mitigating this effect at small local scales. Recent work has shown that vegetation can provide as much as 25 °C surface cooling when compared to bare soil (Jenerette, Harlan, Stefanov, & Martin, 2011). This microclimate regulation was estimated using CAP LTER data of the mean minimum temperature for August 2000. CAP LTER also has interpolated data from

Table 1
List of variables and their sources for the hedonic model with predicted relationship to the dependent variable, house price. MCA = Maricopa County Assessor, CAP LTER = Central Arizona – Phoenix Long Term Ecological Research Project, ISSR = Institute for Social Science Research at Arizona State University, MAG = Maricopa Association of Governments, FCDX = Flood Control District of Maricopa County.

Variable	Description	Year	Source	Expected relationship to house price
House characteristics				
Living ratio	Ratio of house size to lot size	2005[a]	MCA	Negative
Rooms	# of rooms	2005[a]	MCA	Positive
Pool	Presence/absence of a pool	2005[a]	MCA	Positive
Garage	Presence/absence of garage	2005[a]	MCA	Positive
Age^2	Squared-age	2005[a]	MCA	Negative
Neighborhood characteristics				
School district	Dummy variable for school district	2000	ISSR	–
Per capita income	Per capita income for Census tract	2000	US Census	Positive
% Bachelor's	Percent of Census tract pop. > 25 with a bachelor's degree	2000	US Census	Positive
Distance variables, all in ft and log-transformed				
ln Phoenix dist.	Distance to Phoenix Sky Harbor airport (Central Phoenix)	1999	City of Phoenix	Negative
ln Stream dist.	Distance to nearest stream	2000	CAP LTER	Negative
ln Canal dist.	Distance to nearest canal	2000	CAP LTER	Negative
ln Water dist.	Distance to nearest water	2000	CAP LTER	Negative
ln Golf dist.	Distance to nearest golf course	2000	MAG	Negative
ln Sm. park dist.[b]	Distance to nearest small park (<250 acres)	2000	MAG	Negative
ln Lg. park dist.[b]	Distance to nearest large park (>250 acres)	2000	MAG	Negative
ln Desert dist.	Distance to nearest desert area	2000	CAP LTER	Negative
Environmental variables				
Aug. Min. T	Minimum August temperature	2000	CAP LTER	Negative
Parcel Veg.	Average vegetation abundance for the parcel, determined by SAVI	2000	CAP LTER	Positive
Parcel 100 m Veg.	Average vegetation abundance for the parcel + 100 m buffer	2000	CAP LTER	Positive
Bird abundance	Average bird abundance for the parcel	2000	CAP LTER	Positive
Plant diversity	Average plant richness (diversity) for the parcel	2000	CAP LTER	Positive
Flood category	Categorical risk to 100- and 500-year floods	2000	FCDX	–

[a] Year 2000 sales were selected from the 2005 Assessor's data.
[b] Large and small park areas derived from MAG active open space category.

CAP LTER surveys which estimate plant richness (diversity) and bird abundance. Bird abundance may be viewed as an amenity, but only within certain conditions. If the species of abundant birds are considered undesirable (e.g., starlings or pigeons), or if the abundance is so high that the negative qualities of the birds (e.g., noise, excrement) outweigh the positive bird qualities, then high bird abundance may be considered a nuisance. Bird population size may be influenced by water and food subsidies found in urban areas. Plant diversity in the Phoenix metropolitan area is largely driven by human selection and maintenance of both native and non-native flora, and correlated with Census tract income and if the land was ever used for agriculture (Hope et al., 2006). While in some cases increased levels of diversity may be related to intensive water use, "desert" landscaping for SFRs in the area also frequently involves the use of a large variety of plant species, resulting in greater diversity (Walker, Grimm, Briggs, Gries, & Dugan, 2009). For more information about CAP LTER published GIS data, visit http://caplter.asu.edu/data/?GIS=1.

Data for flood zone characterization were obtained from the Flood Control District of Maricopa County. These data delineate the Federal Emergency Management Agency (FEMA) flood hazard zone areas. The categories indicate whether the parcel is outside of a flooding zone, or within the 100-y or 500-y flooding zones, or in areas of undetermined flood hazard.

Aside from ambient environmental characteristics of the parcel and its immediate neighbors, proximity to specific ecosystems may influence the amenities (and disamenities) realized by the resident. We included several locational variables of potentially important ecosystems that are notable for the presence or absence of water: small parks (grassy with trees and therefore irrigated), large parks (desert vegetation), streams (usually dry desert washes, but potentially wet during the rainy seasons), canals, lakes (all human-made in this desert environment, Larson & Grimm 2012), golf courses (heavily irrigated and frequently having water hazards), agricultural fields (also heavily irrigated), and desert areas (only receiving water as natural precipitation). Public open spaces potentially provide recreational opportunities, as well as shaded areas for cooling. In the Phoenix MSA, parks tend to fall into two categories: small municipal parks that usually have grass and trees, and larger parks that have natural desert vegetation and are not irrigated. The Maricopa Association of Governments (MAG) county land use data do not distinguish between these two types of park, lumping them together as "active open space." To divide the group, we designated all polygons <250 acres in size to be small parks, with those >250 acres labeled large parks. We also included a distance measure to the Phoenix Sky Harbor International Airport, which is near the central business district.

ArcGIS was used to calculate both ambient (e.g. vegetation amount) and distance characteristics for each parcel sold. Distances were measured as the Euclidian distance in feet from the centroid of the parcel to the centroid of the feature of interest. Ambient conditions were calculated as the average of conditions within the parcel. A wide range of values for each variable were found across the region (Table 2).

3.2. The hedonic property model

Hedonic property models are widely used for assessing environmental impacts on property values. The basic approach has already been described. Property values are decomposed to reflect the attributes of those properties, some of which may be environmental. These values may be more or less specific to the location in which the attributes occur. We estimated a hedonic price function for the Phoenix area of the following general form:

$$p_i = f(h_i, a_i, s_i) \quad (1)$$

where p_i is the price of the ith property sold during the reference period, $\mathbf{h}_i$ is a vector of house characteristics, $\mathbf{a}_i$ is a vector of

Table 2
Descriptive statistics of the variables.

Variable	Mean	Std. Dev.	Min	Max
House characteristics				
House price	179,136	145,741	19,000	4,100,000
Living ratio	0.232	0.089	0.004	0.963
Rooms	6.5	1.6	1	21
Age^2	454	807	1	10,201
Distance variables, all in ft				
Phoenix	64,047	29,970	2.0	206,872
Stream	1996	1804	0.1	12,950
Canal	9712	9149	1.6	78,016
Water	9471	6401	6.1	50,485
Golf	7958	6559	2.6	110,390
Agriculture	8367	6329	103.7	47,657
Small park	2692	2689	0.1	61,045
Large park	24,300	16,892	0.4	82,840
Desert	9929	9253	0.1	40,245
Environmental variables				
Aug. Min. Temp. (°C)	22.08	0.65	19	23
Parcel vegetation	0.48	0.06	0	0.88
Neighbor vegetation	0.45	0.15	0	0.97
Bird abundance	124	61	0	194
Plant diversity	0.39	0.19	0	0.94
Census Data, all by tract				
Per capita income	24,961	11,743	0	97,295
% Bachelor's degree	0.19	0.10	0	0.43

environmental or ambient conditions, and $\mathbf{s}_i$ is a vector of location-specific ecosystem services.

There are a number of options for the specification of (1), depending on the assumptions made about interactions in the environmental attributes associated with distinct residential properties. If the characteristics of individual properties impose significant external effects on neighboring properties, a spatial autoregressive specification would be appropriate (Anselin, 2001; Can, 1992). We elected to use two regression equations, one considering spatial auto-correlation and one without. The non-spatial equation has the form:

$$\ln \mathbf{P} = f(\mathbf{h}, \mathbf{a}, \mathbf{s}, \mathbf{y}, \boldsymbol{\beta}, \boldsymbol{\mu}, \boldsymbol{\lambda}, \boldsymbol{\gamma}) + \boldsymbol{\varepsilon} \tag{2}$$

where $\mathbf{P}$ is a vector of observed market prices of housing, $\mathbf{h}$, $\mathbf{a}$ and $\mathbf{s}$ are vectors of housing, ambient and locational environmental attributes, $\mathbf{y}$ is a vector of household characteristics, $\boldsymbol{\beta}$, $\boldsymbol{\mu}$, $\boldsymbol{\lambda}$ and $\boldsymbol{\gamma}$ are the associated parameter vectors, and $\boldsymbol{\varepsilon}$ is a vector of random error terms. Diagnostic tests revealed that the data are not normally distributed and exhibit high heteroskedasticity, which is expected with data of this type. To address the former, we used the logarithm of the price. This transformation is reasonable, given that small changes in price are unlikely to represent demonstrable differences in house, environmental, or locational attributes. We also log-transformed all distance variables, as the effect of these variables likely declines as values increase. Housing characteristics and ambient environmental variables (e.g. vegetation abundance) were not log-transformed. Use of the semi-log regression for hedonic models is common (e.g., Anderson & West, 2006; Jim & Chen, 2006; Lee & Li, 2009; Sander et al., 2010).

The MCA data for the year 2000 were limited regarding the housing stock characteristics – we did not have data on number of bathrooms or fireplaces, for example. We did use information about the presence/absence of a pool and garage, the ratio of the living area to parcel size, number of rooms, age (calculated as 2000 – construction year + 1), and age^2. We also included Census tract data of per capita income and percent of the population over 25 with a bachelor's degree. Regression statistics for the non-spatial model were done using Systat (SYSTAT, 2009), with $\alpha = 0.05$.

The spatial model is the same as (2), except that an additional term is added to account for the weighted average of each variable in the neighborhood, or spatial lag. Thus the regression equation becomes:

$$\ln \mathbf{P} = \boldsymbol{\chi\beta} + \lambda \boldsymbol{Wu} + \boldsymbol{\varepsilon} \tag{3}$$

where $\mathbf{P}$ is a vector of the sale prices for $i = 1, 2, \ldots, n$, $\boldsymbol{\chi}$ is the matrix of structural, neighborhood, environmental, and locational variables for the n properties as described in (2), $\boldsymbol{\beta}$ is a vector of the associated parameters, $\boldsymbol{\lambda}$ represents the spatial autoregression coefficient, $\boldsymbol{W}$ is an $n \times n$ spatial weights matrix used to estimate the model, $\boldsymbol{u}$ is the spatially dependent error term, and $\boldsymbol{\varepsilon}$ is the vector independent, identically distributed error terms (Anselin, 2001). For our study, we used GeoDa™ (Anselin, Syabri, & Kho, 2005) to calculate $\boldsymbol{W}$ using queen contiguity based on Theissen polygons of the parcel data, and then conducted a spatial-lag regression. GeoDa™ also calculates Moran's I to determine if spatial autocorrelation exists, and then a Lagrange Multiplier (LM) and a robust Lagrange Multiplier (Robust – LM) to evaluate the presence of spatial lag. When statistically significant, they indicate that a spatial lag regression is appropriate. By incorporating spatial effects, the spatial lag model takes into account that the value of $\mathbf{P}_i$ is a function not just of the explanatory variables and the error term, but also of nearby $\mathbf{P}_n$.

We expected that ambient effects would be associated with differences in attribute 'prices', implying the existence of distinct submarkets. This implies spatial heterogeneity in the parameters of the hedonic price function, and so heterogeneity in the marginal willingness to pay for common attributes across the city. To address this we estimated the hedonic price function initially for the whole Phoenix MSA and then separately for several submarkets. Lacking GIS data for delineated neighborhoods within cities, we use the school district to define the submarket. School district was included in the overall regression as an explanatory variable, and then used to estimate hedonic price function for the N submarkets in the form:

$$\mathbf{p}_n = f_n(\mathbf{h}, \mathbf{s}, \mathbf{y}, \boldsymbol{\beta}, \boldsymbol{\lambda}, \boldsymbol{\gamma}) + \boldsymbol{\varepsilon}_n, \quad n = 1, \ldots, N \tag{4}$$

Some school district had very few sales, resulting in poor model fit. Here we report only the school districts with >500 sales for the year 2000. There are 47 school districts in the area, 21 of which have >500 sales, representing 91% of the entire data set.

In addition to exploring the results of the hedonic regressions, we also used ArcGIS to create a map of the spatial configuration of the relative economic value of water-related environmental amenities. To accomplish this, we first selected the subset of parcels included in the 21 school districts mentioned above. Using the district-specific coefficients calculated in (4), we estimated the marginal willingness to pay (MWTP) for each housing sale using the equation:

$$\mathbf{MWTP}_{\boldsymbol{ij}} = \frac{(\boldsymbol{\beta_j} * \boldsymbol{P_i})}{\chi_{\boldsymbol{i}}} \tag{5}$$

where $\boldsymbol{\beta_j}$ is the submarket-specific coefficient for the variable of interest $\boldsymbol{j}$, $\boldsymbol{P_i}$ is the price of parcel $\boldsymbol{i}$, and $\boldsymbol{x_i}$ is the measure of variable $\boldsymbol{j}$. We then calculated a total value for water-intensive environmental amenities, adding up the MTWPs for vegetation abundance and distances to water, golf, agriculture, and small parks. We also created a similar metric for positive value associated with more desert-like attributes by adding the MTWPs for streams, desert, and large parks. To create a visual representation of the range of these totals, the values were interpolated based on these results for the nearby area by ordinary spherical kriging with a search radius of 500 m.

Table 3
Results of the regressions for the Phoenix metropolitan area (N = 47,586).

Effect	Non-spatial model R^2 = 0.769, AIC = 479.66			Spatial lag model Pseudo-R^2 = 0.875, AIC = −24981.20		
	Coeff.	Std. error	t	Coeff.	Std. error	z
Constant	11.504	0.0476	241.79*	4.231	0.0529	80.02*
Living ratio	−0.861	0.0151	−57.12*	−0.303	0.0113	−26.81*
Rooms	0.136	0.0009	151.70*	0.083	0.0073	112.72*
Pool	0.125	0.0027	46.39*	0.077	0.0020	38.77*
Garage	0.072	0.0041	17.75*	0.047	0.0030	15.70*
Age	−0.013	0.0003	−52.33*	−0.005	0.0002	−26.12*
Age^2	<0.001	<0.0001	29.62*	<0.001	<0.0001	12.35*
School district	<0.001	<0.0001	5.45*	<−0.001	<0.0001	−3.65*
Per capita income	<0.001	<0.0001	95.97*	<0.001	<0.0001	44.96*
% Bachelor's	0.202	0.0219	9.22*	−0.191	0.0161	−11.87*
ln Phoenix dist.	−0.068	0.0029	−23.48*	−0.049	0.0021	−23.11*
ln Stream dist.	−0.002	0.0008	−2.15*	<0.001	0.0006	0.51
ln Canal dist.	−0.008	0.0011	−7.81*	−0.002	0.0008	−2.41*
ln Water dist.	−0.008	0.0015	−5.22*	−0.006	0.0011	−5.34*
ln Golf dist.	−0.034	0.0014	−23.97*	−0.016	0.0010	−14.98*
ln Agric. dist.	0.029	0.0016	17.86*	0.019	0.0012	15.46*
ln Sm. park dist.	0.012	0.0009	12.87*	0.005	0.0007	8.13*
ln Lg. park dist	−0.010	0.0013	−8.21*	−0.004	0.0009	−3.27*
ln Desert dist.	−0.006	0.0009	−6.94*	−0.003	0.0007	−4.21*
Aug. Min T	−0.002	0.0007	−2.83*	<−0.001	0.0005	−1.25
Parcel Veg.	0.488	0.0214	22.85*	0.281	0.0158	17.78*
Parcel 100 m Veg.	0.048	0.0077	6.24*	0.024	0.0056	4.32*
Bird Abund.	<−0.001	<0.0001	−12.51*	<−0.001	<0.0001	−7.55*
Plant diversity	0.143	0.0075	19.01*	0.027	0.0056	4.89*
Flood category	0.024	0.0023	10.49*	0.004	0.0017	2.78

* = significant at alpha < 0.05.

4. Results

4.1. Entire Phoenix MSA

For the total metropolitan area data set (N = 47,586) both the non-spatial and spatial hedonic property models had relatively strong fit (Table 3). The Moran's I test statistic was 175.15, showing statistically significant spatial-autocorrelation. The Lagrange and Robust Lagrange Multiplier tests were also significant, suggesting that a spatial lag model would be more appropriate for interpreting these results. The pseudo-R^2 value higher, indicating a better fit of the spatial lag model to the data.

As one would expect, the dominant characteristics were those associated with the structural features of the house; however, certain ambient environmental characteristics were also found to be important. In the non-spatial model, all of the ambient environmental coefficients are significant. In the spatial lag model minimum August temperature and flood category are not significant. The bird abundance coefficient is negative, indicating this variable is perceived as a disamenity. For parcel vegetation, the sign of the coefficient is positive, meaning that greater levels of vegetation correlate with high house prices. For the locational features, all of the distance variables are significant in the non-spatial model, while distance to stream is not significant in the spatial lag model (Table 3). Between the two models, the signs of the coefficients are the same for the variables of interest. Golf and desert areas are revealed to be amenities (the negative sign of the coefficient indicates that increasing distance decreases house price), while agriculture and small parks are not. Note that proximity to desert and Phoenix are both beneficial. While most of the area defined as desert is located on the outskirts of the MSA, there are some areas that are closer in Fig. 2.

4.2. School district submarkets

The model fit for the school district submarkets varies substantially, with an R^2 of 0.34 for district 148 (Cartwright), to 0.87 for district 146 (Creighton) (Table 4). The Creighton district has the best model fit despite the lack of significance of any of the distance variables. It is worth noting that the two school districts with the lowest average house price also have the poorest model fit. For locational variables, proximity to golf courses and large parks is almost always considered an amenity, while small parks and agriculture is almost always a disamenity.

For environmental attributes, parcel vegetation is mostly significant and positive, with relatively large coefficients (Table 5). The August minimum temperature does not vary for many of the school districts, and thus was eliminated from the regression analysis. Average plant diversity is significant and positive for the majority of the school districts. Bird abundance has mixed results, sometimes considered an amenity, sometimes not. Flood hazard category is significant for several of the school districts. Some school districts (e.g., Sun City, Cave Creek, and Higley) have no or only one significant environmental attributes, with the rest of the significant model variables consisting of distance variables. Other school districts' models have few significant distance variables (e.g., Glendale, Alhambra, and Creighton).

The mapped total value of water-related amenities reveals a clear pattern (Fig. 2), concentrated in school districts in the north and eastern areas of the MSA. These are not necessarily the areas where vegetation abundance is the most scarce, nor most abundant (Fig. 1). Areas of low to moderate levels of water-amenity value overlapped substantially with areas of moderate to high desert value (data now shown), especially in the southeast.

5. Discussion

The results of the overall non-spatial and spatial lag hedonic models reveal homeowner preferences for several important environmental and locational characteristics for the Phoenix metropolitan area that require substantial water resources, although other environmental and locational attributes contribute to or detract from house prices. The assessed spatial statistics indicate that the spatial lag model is more appropriate for evaluating

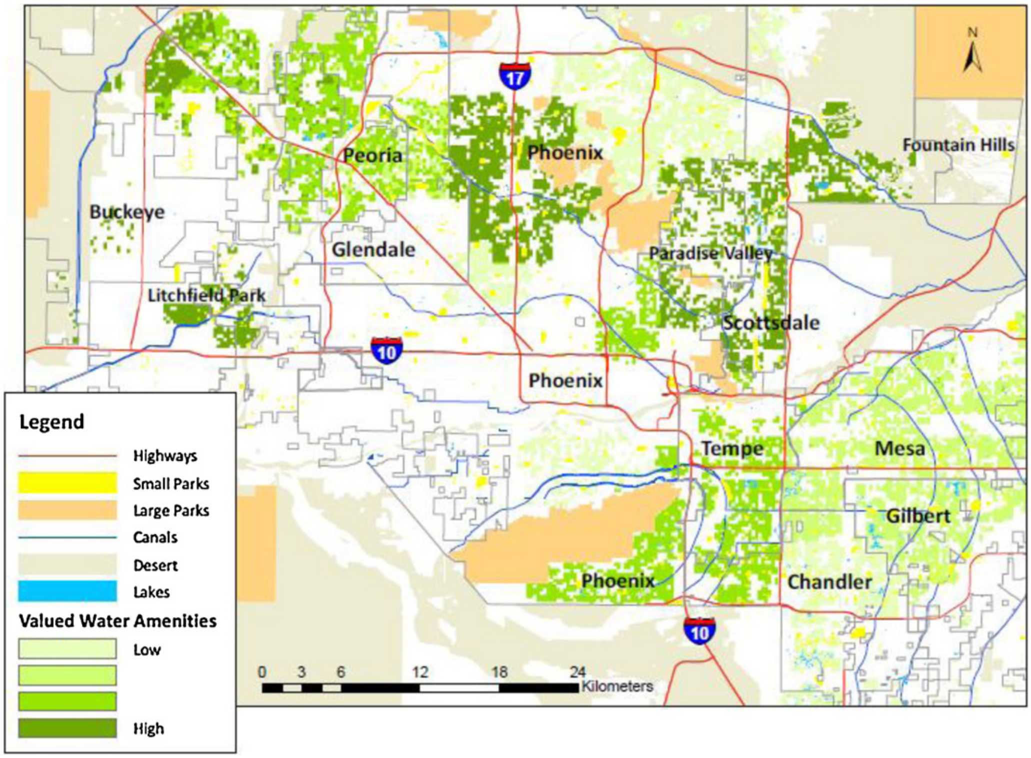

Fig. 2. Map of the total value of water-intensive environmental and locational amenities.

the data for the region. The non-spatial and spatial lag models generally agree with each other, although fewer of the distance and environmental variables are significant in the latter, which is to be expected.

Prior CAP LTER research has shown that the level of vegetation is higher in areas that have been developed for longer times (Jenerette et al., 2007). We re-ran the non-spatial regression and included an interaction term for *age*^{2} × *parcel vegetation*, which is positive

Table 4
Statistically significant regression coefficients. Regression coefficients by school district for distance variables. Shaded boxes indicate when being closer to the location is considered an amenity.

School district (#)	Mean sale price	N	R^2	Distance variables							
				Stream	Canal	Water	Golf	Agric.	Small park	Large park	Desert
Peoria (16)	$153,328	3454	0.73	−0.02	−0.04	0.09	0.03			−0.16	
Dysart (17)	$143,421	2957	0.68	0.01	0.05		−0.04		0.01		0.04
Paradise Valley (18)	$205,319	3402	0.77	−0.02	0.06	−0.03	−0.11			−0.05	
Sun City (19)	$119,263	1430	0.69	−0.01	−0.15		−0.09				0.03
Washington (20)	$127,690	2118	0.69	0.03	−0.02		−0.09	0.04	0.01	−0.04	
Glendale (21)	$117,148	1097	0.75	−0.01						−0.29	
Litchfield (22)	$184,761	1096	0.70	−0.02	0.02		−0.15	0.06			
Deer Valley (119)	$171,791	2880	0.75	0.01	−0.10	−0.07	−0.07	0.05			−0.04
Cave Creek (127)	$324,915	1302	0.62		2.14	−0.17	−0.07	0.12	−0.09	0.18	
Scottsdale (137)	$386,754	2532	0.79		−0.02	−0.04	−0.43	0.12	0.04	−0.04	−0.04
Mesa (143)	$153,930	5332	0.75	−0.01	0.02	0.01	−0.17	−0.02	0.01	−0.02	−0.05
Alhambra (144)	$89,734	621	0.50				−0.27				
Pendergast (145)	$117,939	902	0.74		−0.03	0.05		0.04	−0.02		−0.04
Creighton (146)	$155,848	507	0.87								
Cartwright (148)	$86,600	1231	0.34								
Tempe (160)	$131,303	854	0.64			−0.06		−0.07			0.15
Balsz (162)	$121,879	814	0.78			−0.21	−0.05		0.04		0.03
Gilbert (165)	$175,886	4186	0.64	0.09	−0.02	−0.11	−0.04	−0.06	0.01		−0.22
Kyrene (167)	$215,520	2571	0.68	0.09			−0.03	0.04	−0.01	<−0.01	
Chandler (168)	$182,419	3496	0.69	0.02		−0.04		−0.03	0.03	−0.28	−0.08
Higley (169)	$163,468	747	0.57	0.02	0.12	0.17	−0.19				−0.41

Table 5
Statistically significant regression coefficients. Regression coefficients by school district for selected environmental variables. Shaded boxed indicate when higher levels of the variable are associated with higher house prices. For Aug. Min. and Flood, n/a indicates that the value did not vary within the school district.

School district #	Mean sale price	*N*	R^2	Aug. Min.	Parcel Veg.	Neighbor Veg.	Bird Abund.	Plant Divers.	Flood
Peoria (16)	$153,328	3454	0.73		0.42			0.34	−0.03
Dysart (17)	$143,421	2957	0.68		1.12		−0.01	−0.13	−0.04
Paradise Valley (18)	$205,319	3402	0.77				−0.02	0.17	
Sun City (19)	$119,263	1430	0.69		1.12				
Washington (20)	$127,690	2118	0.69		1.42	0.30	−0.01	−0.38	
Glendale (21)	$117,148	1097	0.75		−0.43	−0.06			
Litchfield (22)	$184,761	1096	0.70	−0.01	1.60		0.01	0.46	−0.04
Deer Valley (119)	$171,791	2880	0.75		−0.81		<−0.01	−0.08	
Cave Creek (127)	$324,915	1302	0.62						
Scottsdale (137)	$386,754	2532	0.79	−0.01	1.48			0.27	
Mesa (143)	$153,930	5332	0.75		0.39	−0.04	<−0.01	0.38	−0.04
Alhambra (144)	$89,734	621	0.50				−0.02		0.09
Pendergast (145)	$117,939	902	0.74	n/a				0.55	n/a
Creighton (146)	$155,848	507	0.87	n/a	0.53		−0.06	1.17	
Cartwright (148)	$86,600	1231	0.34	n/a			0.01		
Tempe (160)	$131,303	854	0.64	n/a	0.94		0.01		
Balsz (162)	$121,879	814	0.78	n/a			0.02	0.95	
Gilbert (165)	$175,886	4186	0.64	0.24	0.25		<−0.01	−0.19	
Kyrene (167)	$215,520	2571	0.68		0.56			−0.19	0.08
Chandler (168)	$182,419	3496	0.69		0.15		<0.01	0.30	−0.04
Higley (169)	$163,468	747	0.57				<−0.01		n/a

(0.001) and significant ($p < 0.0001$). There are potentially two factors at work here. One is that because the older areas are more likely to be flood irrigated and have more mature vegetation. The other is that older areas are more likely to have mature vegetation. Conversely, the value of plant richness is clearly higher in the newer areas of the MSA. The coefficient in the interaction between plant richness and age^2 was significant ($p < 0.0001$) and negative (−0.0003). These areas are more likely to be xeriscaped, and to have previously been a desert rather than agriculture land cover. Residents in the region have been found to prefer an "oasis" style of xeriscaping, which has a greater variety of plants than desert landscapes (Martin et al., 2003). Older urban areas were previously likely to be agriculture, and then converted to mesic residential land use (Buyantuyev, Wu, & Gries, 2010), which tends to have less plant diversity (Walker et al., 2009).

One would expect that proximity to parks would be a benefit, as they provide many ecosystem services such as recreation, greenery, access to biodiversity, and esthetics. But while living close to parks may provide easier access to these services, it may also increase the exposure to potential disamenities associated with parks, such as crime and noise. We separated parks into two size categories, with the expectation that people might derive different benefits from large vs. small parks. Small parks are more likely to have playgrounds and fields, while large parks are less congestible and may offer opportunities for hiking and access to desert flora and fauna. Thus, while we found a negative coefficient for proximity to small parks in most cases, large parks are considered an amenity for the metropolitan Phoenix area. Our results are consistent with other studies. In their 2005 review, McConnell and Walls found examples of both negative and positive relationships between house price and park proximity. Troy and Grove (2008) demonstrated that consideration of neighborhood crime rates altered homeowners' willingness to live close to parks. Unfortunately, we did not have access to crime data at a fine enough resolution to evaluate its influence on property values.

The disaggregation of the greater metro area into component school districts gives further insight into the relative importance of the environmental and locational variables. The consistency of the coefficient signs for vegetation abundance and proximity to golf and large parks highlight their importance across the entire metropolitan area. The existence of cases where the sign changes depending on district, such as bird abundance, plant richness and proximity to desert and water reinforces the notion that there are separate markets at play. Tiebout (1956) suggested that municipalities may offer unique packages of public goods. In the Phoenix MSA, cities also differ in their access to (inexpensive) surface water

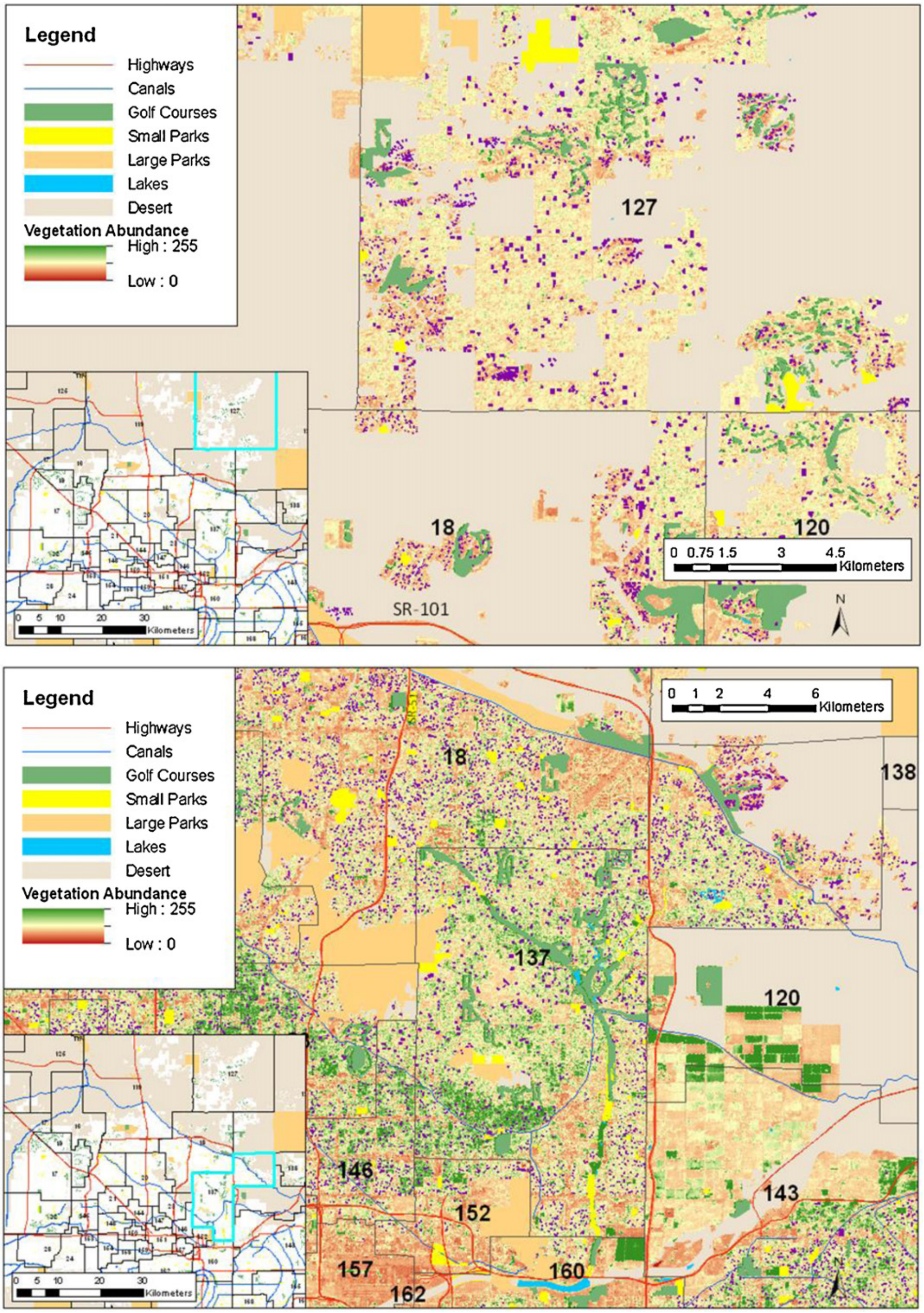

Fig. 3. Maps of school districts 127 (Cave Creek) and 137 (Scottsdale).

(Larson et al., 2005), creating variation in the ability of homeowners to capitalize on both the private (parcel vegetation) and (semi-)public (golf courses, lakes) benefits requiring substantial water resources. The homeowners in this study may be sorting into school districts that best provide their desired environmental and locational amenities, depending on their needs. For example, in comparing the two school districts with the highest average house prices (Cave Creek and Scottsdale), it is apparent that the residents are purchasing very different suites of environmental and locational amenities (Fig. 3). In the Cave Creek district, none of the ambient environmental variables are significant, but the proximity to water-intensive locations such as lakes, golf courses, and small parks positively influences house prices (Tables 4 and 5). As is apparent in Fig. 3, aside from the golf courses, the vegetation abundance in this area is quite low. The Cave Creek district encompasses parts of northern Phoenix, Scottsdale, and the town of Carefree, which were never used for agricultural production and likely appeal to potential homeowners for their "authentic" desert character. Homes in the Scottsdale district also derive benefits from locational amenities, but a premium is also found for high parcel vegetation and plant diversity. The Scottsdale district is within the cities of Phoenix and Scottsdale that are wealthy, older areas with historically access to more water, as is apparent in the comparatively high levels of vegetation abundance.

6. Conclusion

Our findings confirm the importance of water-related environmental amenities in a desert environment. Vegetation abundance and proximity to water-intensive land uses such as golf and lakes are all amenities, reflecting the influence of the hot desert climate on homeowner choice. Since climate models indicate that the region may become hotter and drier due to global climate change (Karl, Melillo, & Peterson, 2009; Parry, Canziani, Palutikof, van der Linden, & Hanson, 2007), and since Arizona may have to reduce its allotment under new rules for the Colorado River Compact signed in 2007 (Archibold, 2007), these factors are likely to increase in importance. If water resources become scarcer, the amenity value of water-related ecosystem services in areas that continue to enjoy the benefits of historic water access rights may increase significantly.

In the future, there may not be enough water to sustain lush vegetation, golf courses and recreational lakes, especially in newer developments which tend to occur in areas without access to surface water. Urban planners and municipal water managers may have to restrict 'luxury' water uses in favor of more 'basic' uses, although increased technological efficiencies and use of gray water or treated effluent may buffer some of these impacts. Our research also suggests the possibility of substitution of (semi) public water amenities for those on private properties, which may result in more economical use, depending on management practices. However, homeowners who find submarkets like the Cave Creek district appealing may be distinct from those preferring districts like Scottsdale. Furthermore, some locational attributes that appeal to those seeking 'authentic' desert homes, such as proximity to large parks or desert areas, may not be easily recreated in other parts of the metropolitan area. Additional research may reveal whether residents' preferences are flexible enough to embrace urban desert landscapes without water-intensive land uses.

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