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Research Paper

Effects of irrigated parks on outdoor residential water use in a semi-arid city

Eve B. Halper[a,*], Sandy Dall'erba[b], Rosalind H. Bark[c,1], Christopher A. Scott[d], Stephen R. Yool[e]

[a] U.S. Bureau of Reclamation, 300 W. Congress Street, FB-37, Tucson, AZ 85701, USA
[b] Regional Economics and Spatial Modeling Laboratory and School of Geography and Development, University of Arizona, P.O. Box 210076, Tucson, AZ 85721, USA
[c] CSIRO, Land and Water Flagship, P.O. Box 2583, Brisbane, QLD 4001, Australia
[d] School of Geography and Development and Udall Center for the Study of Public Policy, University of Arizona, P.O. Box 210483, Tucson, AZ 85721, USA
[e] School of Geography and Development, University of Arizona, P.O. Box 210076, Tucson, AZ 85721, USA

HIGHLIGHTS

- Do irrigated parks and public pools affect residential outdoor water use?
- We investigate this question in semi-arid Tucson, AZ, USA.
- Outdoor water use is influenced by park conditions within 8 km (5 miles).
- Park proximity, greenness (NDVI) and public pools affect residential outdoor water use.
- Responses varied between households with and without home pools.

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ABSTRACT

We investigate whether public park amenities act as a substitute for outdoor water use by single-family residential (SFR) households in semi-arid Tucson, AZ, USA. Specifically we account for the effects of a park's proximity, size, and greenness (measured by NDVI), as well as the presence of a public swimming pool. SFR households with and without home pools are analyzed separately. We control for SFR property attributes, including house size, age, yard size and property NDVI. Results suggest that SFR outdoor water use is influenced by the conditions of all parks within an 8 km (5 mile) street distance. We also find significant differences between the "with" and "without" home pool groups. Households with pools used more outdoor water per square meter of house, per year of house age and per unit of NDVI. Households without pools appeared to reduce outdoor use in response to nearby small parks and increased park NDVI. "With pool" households had the opposite response: they appeared to increase outdoor water use in response to these variables. However, "with pool" households did reduce their outdoor water use in response to nearby public pools. Medium and large parks were associated with increased outdoor water use for both groups. We conclude that public green space and pools can substitute for private versions of these amenities, and if well designed, can contribute to water demand management and urban sustainability. This may be an avenue for addressing water supply shortages in semi-arid cities and other areas where populations are growing but water supplies are finite.

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1. Introduction

Compact cities have gained recognition as resource-efficient forms of human settlement (Glaeser, 2011; Glaeser & Kahn, 2010). Even so, there are many aspects of density that are stressful and discourage city living, including noise, over-crowding and poor air quality (Robin, Matheau-Police, & Couty, 2007). Urban green spaces have been shown to mitigate these stresses, promote human health

* Corresponding author. Tel.: +1 520 670 4809; fax: +1 520 670 4745.
E-mail addresses: ehalper@usbr.gov (E.B. Halper), dallerba@arizona.edu (S. Dall'erba), rh.bark@gmail.com (R.H. Bark), cascott@arizona.edu (C.A. Scott), yools@arizona.edu (S.R. Yool).
[1] Currently Visiting Researcher, CCEP, University of Leeds, Leeds, LS2 9JT, UK.

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and make city living attractive. A wide range of studies has linked the viewing of, or physical presence in, green spaces with reduced stress (Grahn & Stigsdotter, 2003; Kaplan, 1984; Parsons, Tassinary, Ulrich, Hebl, & Grossman-Alexander, 1998; Ulrich, 1986; Ulrich et al., 1991; Ward Thompson et al., 2012), improved cognitive abilities (Berman, Jonides, & Kaplan, 2008; Hartig, Evans, Jamner, Davis, & Garling, 2003) and overall health (Stigsdottir et al., 2010). Lee and Maheswaran's (2010) review paper reports the effects of urban green space on physical and mental health.

Most studies of green space have been conducted in humid climates, generally the eastern U.S. and northern Europe. The few studies conducted in arid and semi-arid climates show that green spaces, especially those that are green year-round, are highly valued (Bark, Osgood, Colby, Katz, & Stromberg, 2009; Bark, Osgood, Colby, & Halper, 2011; Hatton-MacDonald et al., 2010; Sengupta & Osgood, 2003). Naturally green spaces tend to be rare within arid cities because near-surface groundwater has frequently been depleted (Zektser, Loaiciga, & Wolf, 2004). Urban vegetation in these areas must survive on highly intermittent precipitation and stormwater, or supplemental irrigation. For these cities, providing public green space involves not only setting aside land, but devoting scarce and often costly water resources. In Tucson, AZ, for instance, water is imported for long distances at considerable cost (Westerhoff & Crittenden, 2009).

Low density suburbs provide households with the opportunity to enjoy private green space. When this lifestyle is adopted by a large population, especially in a semi-arid climate, a substantial consumptive water demand is generated. In the southwest United States, outdoor water use comprises a major portion of municipal water budgets (Pataki et al., 2011). With municipal supplies in the Southwest under pressure due to population growth, drought, climate warming and the need to preserve environmental resources (MacDonald, 2010), outdoor residential uses are a common target of demand management programs.

Meanwhile, hedonic house price studies provide evidence that homeowners willingly substitute outdoor public space for smaller residential lots (Cho, Lambert, Roberts, & Kim, 2010; Henderson & Song, 2008; Kopits, McConnell, & Walls, 2007; Mansfield, Pattanayak, McDow, McDonald, & Halpin, 2005). Mansfield et al. (2005) extend these investigations to "greenness" as measured by the Normalized Difference Vegetation Index (NDVI). In this paper, we hypothesize that the substitution of common for private land extends to irrigated green spaces within semi-arid cities, and that evidence for this substitution can be found in patterns of outdoor water consumption by single-family residential (SFR) households. Further, we extend this inquiry to community-provided swimming pools. Like green spaces, swimming pools are highly valued in semi-arid climates (Bark et al., 2011; Sirmans, MacDonald, Macpherson, & Zeitz, 2006), consume large volumes of municipal water supplies (Mayer & DeOreo, 1999), and are a target of water conservation campaigns.

To address our substitution hypothesis, we first need to account for the major factors that influence household water use. There is no universally agreed upon statistical model for estimating residential water demand. Non-spatial studies have employed least-squares methods (ordinary, two-stage, three-stage and general), as well as logit and instrumental variable techniques (Worthington & Hoffman, 2008). Independent variables commonly include property and socio-demographic information, such as assessed home value (a proxy for income), home age, size of the structure and lot, and the number of residents (Danielson, 1979; Morgan, 1973). The need to estimate peak demands motivated studies that disaggregate indoor and outdoor use (Agthe & Billings, 1987; Aitken, 1991; Lyman, 1992; Nieswiadomy & Molina, 1989).

Most of these studies were completed before the advent of citywide geographic information systems (GIS) and could not easily analyze the spatial characteristics of their data. More recently, spatially explicit studies of residential water use have taken advantage of GIS data (Balling, Gober, & Jones, 2008; Chang, Parandvash, & Shandas, 2010; Halper, Scott, & Yool, 2012; House-Peters, Pratt, & Chang, 2010; Shandas & Parandvash, 2010; Wentz & Gober, 2007). For instance, Chang et al. (2010), House-Peters et al. (2010) and Wentz and Gober (2007) found evidence of spatial autocorrelation in SFR water use data at the census tract and block group levels. These studies are empirical: a well-developed theory to explain these findings has yet to be developed, but results could indicate that the local environment, including the presence of public amenities, influences residential water use.

The degree to which residents of semi-arid cities substitute public green spaces and pools for private versions of these amenities, raises intriguing public policy options. It might be possible, for instance, to reduce SFR outdoor water use by improving access to public amenities, increasing the number of facilities, or improving their quality. Rather than being viewed as an expense, public green spaces and pools could be seen as water conservation strategies that reduce overall water demand while maintaining a city's quality of life.

The paper proceeds with detail on our data sources and statistical methods. Four model specifications are run which allow us to investigate whether differences in outdoor water use by SFR households with and without home pools are statistically significant. For each model, we report the effects of a park's size, its facilities (public pool), and its vegetation (NDVI), for SFR households with and without pools. We also test if SFR outdoor water use is influenced by multiple parks within two distance bounds. The paper concludes with some observations for Tucson, AZ, recommendations to city planners and some transferrable lessons to semi-arid urban areas worldwide.

2. Methods

2.1. Study area

Our study area is metropolitan Tucson, AZ, located in Pima County, in the U.S. Tucson is a semi-arid city with 295 mm (12 in.) annual precipitation that is distinctly bimodal, with intense summer monsoon storms and winter frontal systems. Winter precipitation varies substantially from year to year (Fig. 1). Irrigation demand is concentrated in the April–May–June pre-monsoon period, when potential evapotranspiration is highest and precipitation is lowest. Tucson Water, the area's largest water provider, supplied SFR household-level water use data for their service area for 2006 and 2007. The spring of 2007 was much drier than average, which aided our study purposes (Fig. 1). We limit our analysis to those parts of Tucson Water's service area contiguous with the metropolitan area, as shown in Fig. 2.

Despite metropolitan Tucson's relatively low per capita water use (Western Resource Advocates, 2006), supplies available through regulatory processes are fixed, while total demand is increasing with population growth (Tucson Water, 2008). Scenarios project that demand will exceed supplies between 2017 and 2035 (Tucson Water, 2008). Outdoor uses, such as irrigated landscapes and pools, represent an estimated 45% of all water supplied to SFR households (City of Tucson & Pima County, 2009, chap. 2). Using this estimate, 2007 SFR outdoor water use was 38.7×10^6 m^3 (31,374 acre-feet), or about a quarter of Tucson Water's annual potable water deliveries. Reducing outdoor water use by SFR households is an important strategy to extend available resources.

Around 21% (25,921) of the homes in our dataset have in-ground pools. To visualize the geographic distribution of home pools (and other variables), we aggregate our data by "quarter-section", a square unit of land with an area of 64.7 ha (160 acres). The left-hand

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