Decision Center for a Desert City: Selected Highlights

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DMUU Centers Meeting
April 10, 2008
Columbia University, CRED

GLOBAL INSTITUTE of SUSTAINABILITY
ARIZONA STATE UNIVERSITY

Organization of Today's Talk

- Building a Scientific Base
  - Climate and water
  - BME—representing uncertainty
  - Water decision making and demand modeling
- Institution Building
  - LTER, IGERT, DT
  - DMUU partners
- WaterSim
  - Model
  - Stakeholder Research

Climate and Water

Balling and Goodrich. 2007. Analysis of drought determinants for the Colorado River Basin. *Climate Change* 82(1-2): 179-194.

Climatic Change (2007) 82:179–194
DOI 10.1007/s10584-006-9157-8

Analysis of drought determinants for the Colorado River Basin

Robert C. Balling Jr · Gregory B. Goodrich

Received: 7 July 2004 / Accepted: 23 May 2006 / Published online: 15 February 2007

Abstract Ongoing drought in the Colorado River Basin, unprecedented urban growth in the watershed, and numerical model simulations showing higher temperatures and lower precipitation totals in the future have all combined to heighten interest in drought in this region. In this investigation, we use principal components analysis (PCA) to independently assess the influence of various teleconnections on Basin-wide and sub-regional winter season Palmer Hydrological Drought Index (PHDI) and precipitation variations in the Basin. We find that the Pacific Decadal Oscillation (PDO) explains more variance in PHDI than El Niño-Southern Oscillation (ENSO), the Atlantic Multidecadal Oscillation (AMO), and the planetary temperature combined for the Basin as a whole. When rotated PCA is used to separate the Basin into two regions, the lower portion of the Basin is similar to the Basin as a whole while the upper portion, which contains the high-elevation locations important to hydrologic yield for the watershed, demonstrates poorly defined relationships with the teleconnections. The PHDI for the two portions of the Basin are shown to have been out of synch for much of the twentieth century. In general, teleconnection indices account for 19% of the variance in PHDI leaving large uncertainties in drought forecasting.

1 Introduction

Over the past decade, hydroclimatic variability in the western United States has emerged as a dominant environmental issue of concern among climate scientists. Since 1996, a

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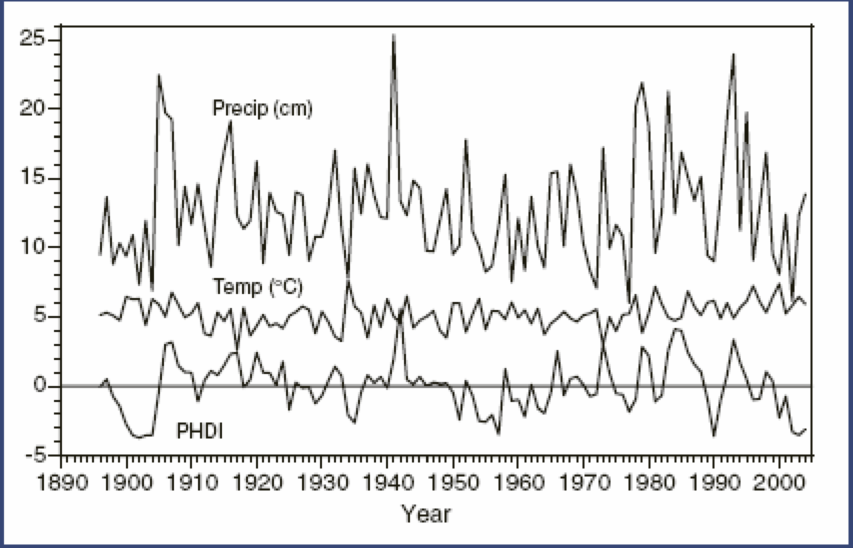

Teleconnections explain only 19% of the variation in PSDI, leaving large uncertainties for drought forecasting.

Balling and Gober. 2007. Climate variability and residential water use in the City of Phoenix, Arizona. *Journal of Applied Meteorology and Climatology* 46(7): 1130-1137

Climate Variability and Residential Water Use in the City of Phoenix, Arizona

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School of Geographical Sciences, Arizona State University, Tempe, Arizona

(Manuscript received 23 June 2006, in final form 19 October 2006)

ABSTRACT

In this investigation, how annual water use in the city of Phoenix, Arizona, was influenced by climatic variables between 1980 and 2004 is examined. Simple correlation coefficients between water use and annual mean temperature, total annual precipitation, and annual mean Palmer hydrological drought index values are +0.55, −0.69, −0.52, respectively, over the study period (annual water use increases with higher temperature, lower precipitation, and drought). Multivariate analyses using monthly climatic data indicate that annual water use is controlled most by the overall state of drought, autumn temperatures, and summer-monsoon precipitation. Model coefficients indicate that temperature, precipitation, and/or drought conditions certainly impact water use, although the magnitude of the annual water-use response to changes in climate was relatively low for an urban environment in which a sizable majority of residential water use is for outdoor purposes. People's perception of the landscape's water needs and their willingness and ability to respond to their perceptions by changing landscaping practices are probably more important than the landscape's need for water in assessing residential water demand and the variation therein.

1. Introduction

In 1980, the state of Arizona passed landmark legislation to reduce drastically the mining of its underground aquifers. The Groundwater Management Act was brokered by then Governor Bruce Babbitt in response to a threat from the federal government to withdraw support for the Central Arizona Project, a 530-km-long aqueduct designed to deliver Colorado River water to the rapidly growing desert cities of Phoenix and Tucson of central and southern Arizona. The successful legislation resulted from a delicate and complicated set of agreements from the state's water stakeholders: farmers, utilities, industry, Native American communities, and municipalities (Connall 1982; Jacobs and Holway 2004). To win concessions from farmers and other users, municipalities agreed to reduce gradually their per capita water consumption. Most communities, including the city of Phoenix, implemented water conservation policies, such as distributing water-saving devices, requiring low-flow devices for new and replacement fixtures, establishing educational programs, and creating pricing structures (Campbell 2004). Although annual water consumption has declined in a general way, sizable annual variation, presumably related in some part to climate variability, confounds efforts to evaluate systematically the effects of water conservation and behavior changes in use (Fig. 1). Climatic variability is particularly relevant in Phoenix because it is estimated that 74% of residential water use is for outdoor purposes, which are sensitive to variations in temperature and rainfall (Mayer and DeOreo 1999).

We use a time series of water use measured in terms of annual liters per capita per day that was developed by Phoenix city government to meet its reporting requirements under the Groundwater Management Act of 1980, per-household monthly water consumption for single-family homes based on the authors' calculations from Phoenix city-government metered water records, and climate records from the U.S. Historical Climatology Network (USHCN) to evaluate the effect of climate variability on water use. Results yield estimates of potential water consumption under different drought conditions and suggest the relative importance of climate versus nonclimate determinants of water demand.

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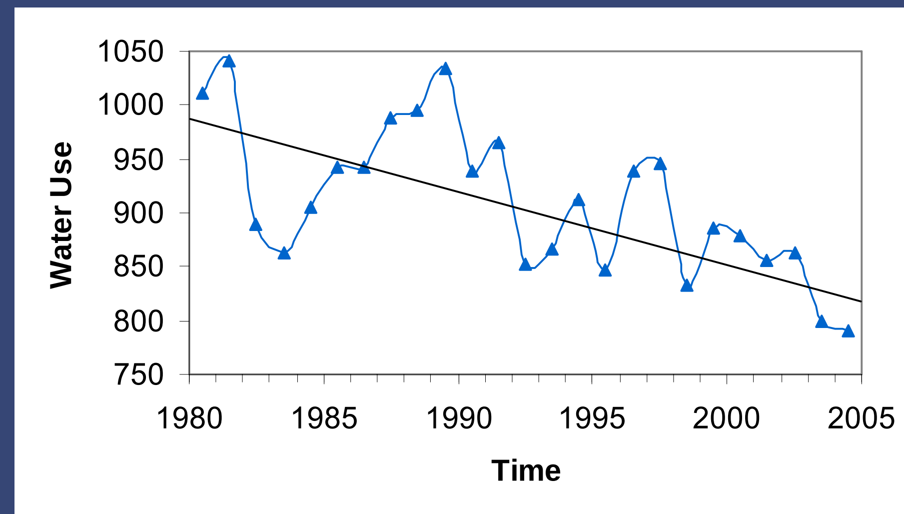


Sensitivity is 1°C → 1.5% change in water use

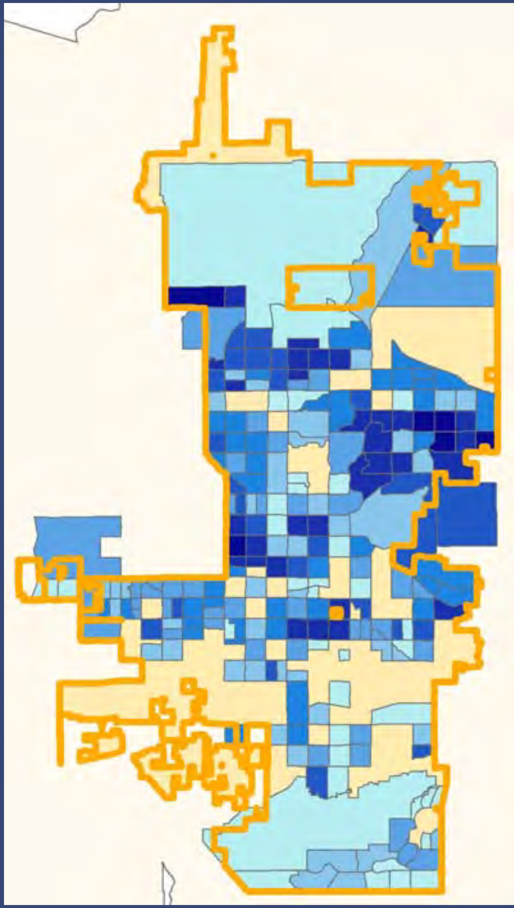
Watering habits – mechanical sensors

Balling et al. Accepted with revisions. Sensitivity of residential water consumption to variations in weather and climate: An intra-urban analysis of Phoenix, Arizona. *Water Resources Research*.

Socio-economic Determinants of Climate Sensitivity

Predictor	Total Variance	Temp	Prec	PHDI
Income / Household	0.23			-0.53
Percent Mesic	0.18			-0.26
Number in Household				0.22
Lot Size	0.2		-0.15	-0.29
Pool Percent	0.32	0.16		-0.62
Percent Hispanic	-0.27			0.49
Component #1	0.3	0.17		-0.63

Non-parametric Spearman rank-order correlation coefficients between socio-economic predictors for 230 census tracts and (a) the total temporal variance in water consumption explained by all three climate variables, and the sensitivity of water consumption to changes in (b) temperature, (c) precipitation, and (d) PHDI (values significant at the 0.05 level are in plain text and those significant at the 0.01 level are in bold text)

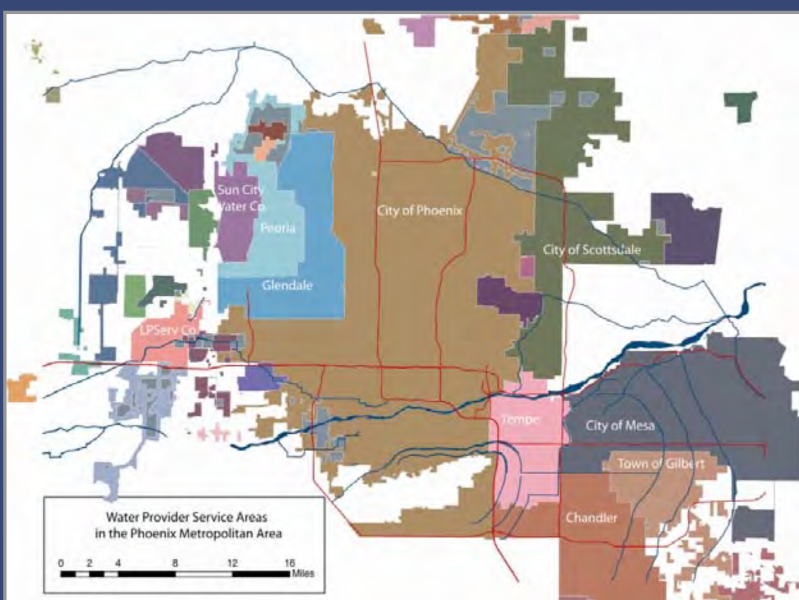


High sensitivity to drought conditions occurs in high-income, small, Anglo households
living on large lots with swimming pools and irrigated mesic landscaping.

NOAA SARP Proposal with Portland State

Project Title: Integrating land use planning into water resource decision-making as a potential adaptation to climate-induced water stresses in the Portland and Phoenix metropolitan areas

Institutions: Portland State University, Arizona State University



Ellis, et al. 2008. Estimating future runoff levels for a semi-arid fluvial system in Central Arizona. *Climate Research* 33: 171-182.

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CLIMATE RESEARCH
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Estimating future runoff levels for a semi-arid fluvial system in central Arizona, USA

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ABSTRACT: We developed a water budget runoff model for the Salt and Verde River basins of central Arizona and used the outputs of 6 global climate models (GCMs) to estimate runoff in the future under assorted emissions scenarios developed by the Intergovernmental Panel on Climate Change (IPCC). We used a statistical downscaling routine to refine the GCM outputs for the 2 basins, and we found that all model–scenario combinations simulate a mean temperature rise in the study area of between 2.4 and 5.6°C, using year 2050 greenhouse gas concentrations. Mean changes in precipitation vary substantially among the models and scenarios, and, as a result, changes in runoff vary from 50 to 127 % of historical levels. Assuming equal probabilities associated with each scenario and model run, the overall results suggest that runoff from the Salt and Verde will have an approximately 85 % chance of being less strong, the certainty of which is related to consensus on warming in the study area. The large variability among predictions of precipitation trends introduces substantial uncertainty.

KEY WORDS: Dryland runoff · Climate change · Water budget

1. INTRODUCTION

Global climate change may reveal itself in a number of ways across local and regional scales. As an example, global climate models (GCMs) generally predict that precipitation levels will increase at hemispheric and global scales, but the same models predict that some areas of the earth will receive less precipitation in the future (IPCC 2007). However, from model to model, the results vary considerably in their simulations of future conditions at local and regional scales, and policymakers must cope with substantial uncertainty as they plan for the future.

Uncertainty in the local impacts of global climate change raises concern about continued population growth and the economic development of central Arizona. The rapidly growing desert city of Phoenix depends heavily upon faraway sources of water from the Colorado River Basin through the Central Arizona Project and from the upland watersheds of the Salt and Verde Rivers (Gammage 1999, Gober 2005). To account for the extreme variability of their desert climate, Phoenix's early leaders constructed one of the world's largest and most sophisticated water storage and delivery systems on the planet, and developed a set of regulations and agreements to allocate water. These water agreements and the physical infrastructure have assured an adequate water supply for the region's current population of 4 million, and they are the basis for projections of some 8 million residents by 2040 (Jacobs & Holway 2004, Arizona Department of Economic Security 2006).

Uncertainties associated with climate change create several challenges for water managers, planners, and decision makers in Phoenix. First, changes in climatic conditions on the watersheds can alter runoff regimes, affect water supply, and jeopardize growth in a city whose economy is heavily dependent upon land development and housing construction. Second, the sheer magnitude of growth (>100 000 new residents are added annually), in conjunction with natural climate variability, and anthropogenic climate change raises the stakes that the region will overshoot its sustainable population before the regional impacts of climate

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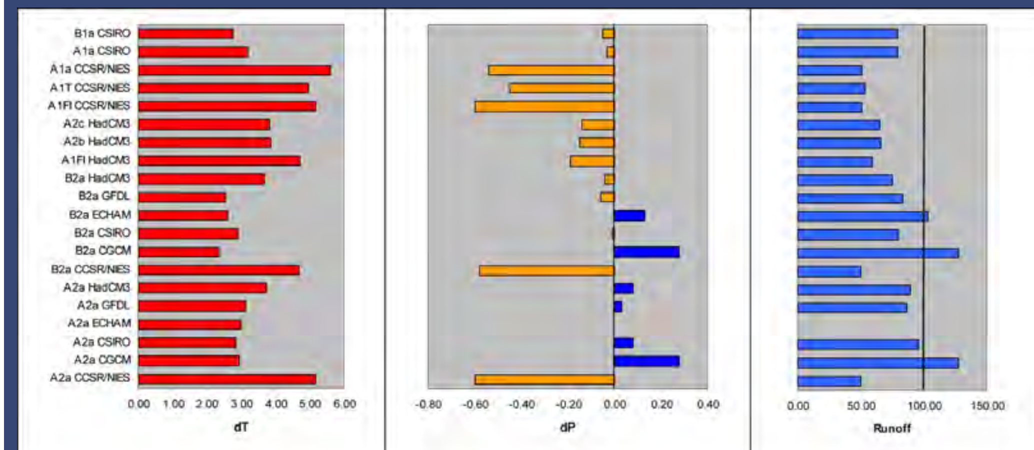
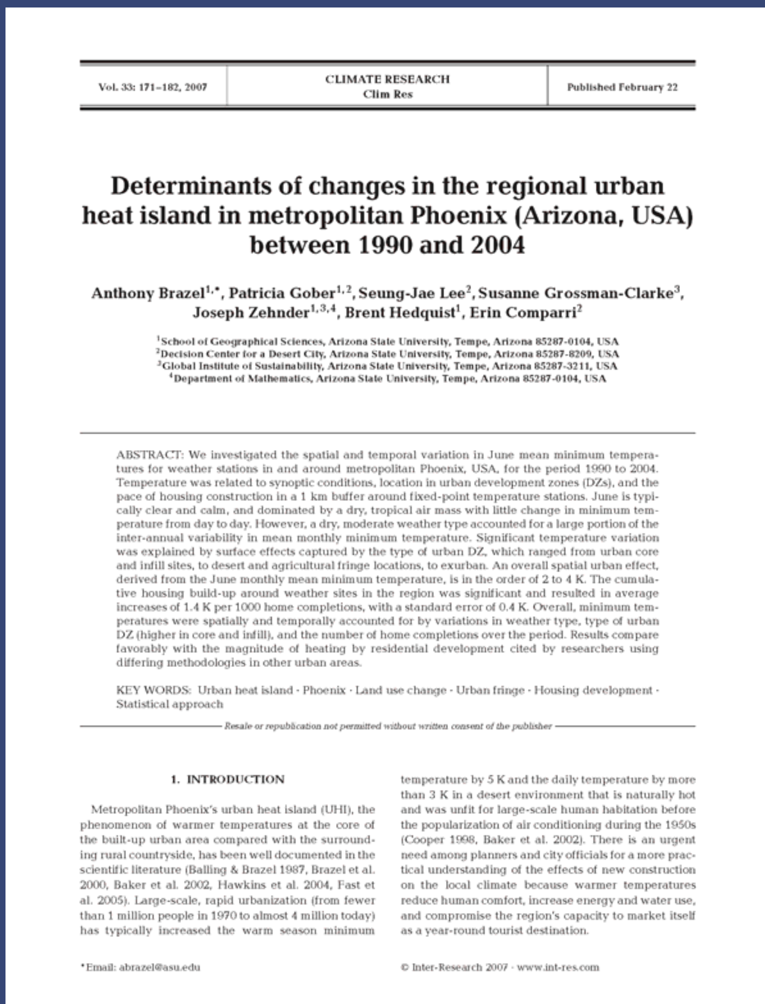


~2050 change in temperature, dT (°C), change in precipitation, dP (mm day-1), and change in runoff (% of historical levels) according to the 20 model – scenario combinations.

Brazel, et al. 2007. Determinants of changes in the regional urban heat island in metropolitan Phoenix (Arizona, USA) between 1990 and 1994. *Climate Research* 33(2):171-182.



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Determinants of changes in the regional urban heat island in metropolitan Phoenix (Arizona, USA) between 1990 and 2004

Anthony Brazel[1,*], Patricia Gober[1,2], Seung-Jae Lee[2], Susanne Grossman-Clarke[3], Joseph Zehnder[1,3,4], Brent Hedquist[1], Erin Comparri[2]

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ABSTRACT: We investigated the spatial and temporal variation in June mean minimum temperatures for weather stations in and around metropolitan Phoenix, USA, for the period 1990 to 2004. Temperature was related to synoptic conditions, location in urban development zones (DZs), and the pace of housing construction in a 1 km buffer around fixed-point temperature stations. June is typically clear and calm, and dominated by a dry, tropical air mass with little change in minimum temperature from day to day. However, a dry, moderate weather type accounted for a large portion of the inter-annual variability in mean monthly minimum temperature. Significant temperature variation was explained by surface effects captured by the type of urban DZ, which ranged from urban core and infill sites, to desert and agricultural fringe locations, to exurban. An overall spatial urban effect, derived from the June monthly mean minimum temperature, is in the order of 2 to 4 K. The cumulative housing build-up around weather sites in the region was significant and resulted in average increases of 1.4 K per 1000 home completions, with a standard error of 0.4 K. Overall, minimum temperatures were spatially and temporally accounted for by variations in weather type, type of urban DZ (higher in core and infill), and the number of home completions over the period. Results compare favorably with the magnitude of heating by residential development cited by researchers using differing methodologies in other urban areas.

KEY WORDS: Urban heat island · Phoenix · Land use change · Urban fringe · Housing development · Statistical approach

1. INTRODUCTION

Metropolitan Phoenix's urban heat island (UHI), the phenomenon of warmer temperatures at the core of the built-up urban area compared with the surrounding rural countryside, has been well documented in the scientific literature (Balling & Brazel 1987, Brazel et al. 2000, Baker et al. 2002, Hawkins et al. 2004, Fast et al. 2005). Large-scale, rapid urbanization (from fewer than 1 million people in 1970 to almost 4 million today) has typically increased the warm season minimum temperature by 5 K and the daily temperature by more than 3 K in a desert environment that is naturally hot and was unfit for large-scale human habitation before the popularization of air conditioning during the 1950s (Cooper 1998, Baker et al. 2002). There is an urgent need among planners and city officials for a more practical understanding of the effects of new construction on the local climate because warmer temperatures reduce human comfort, increase energy and water use, and compromise the region's capacity to market itself as a year-round tourist destination.

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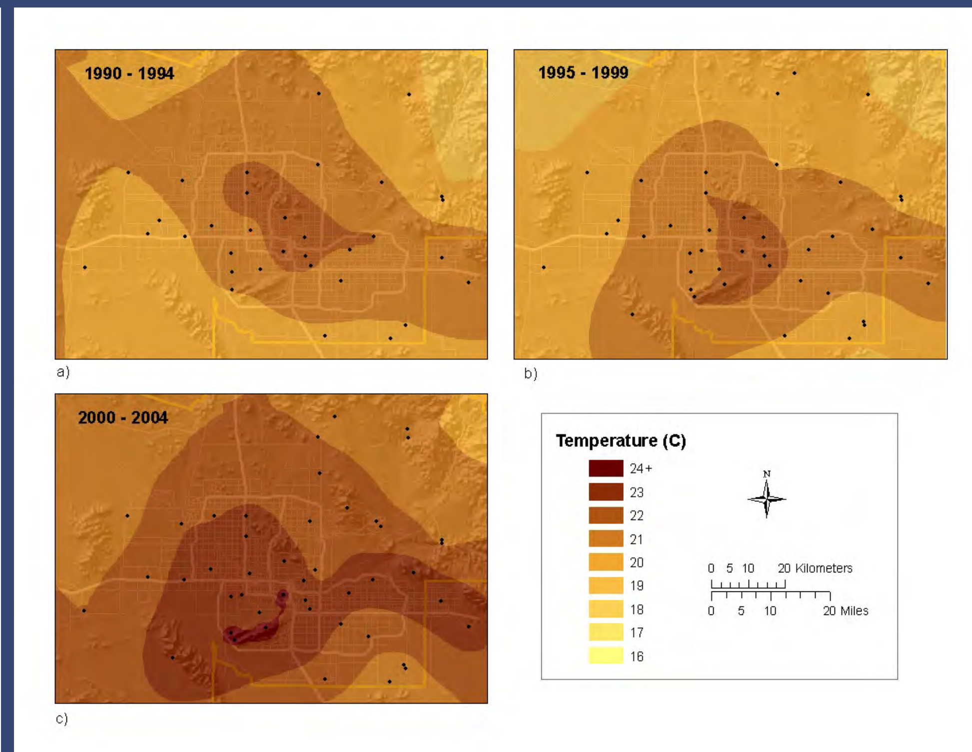
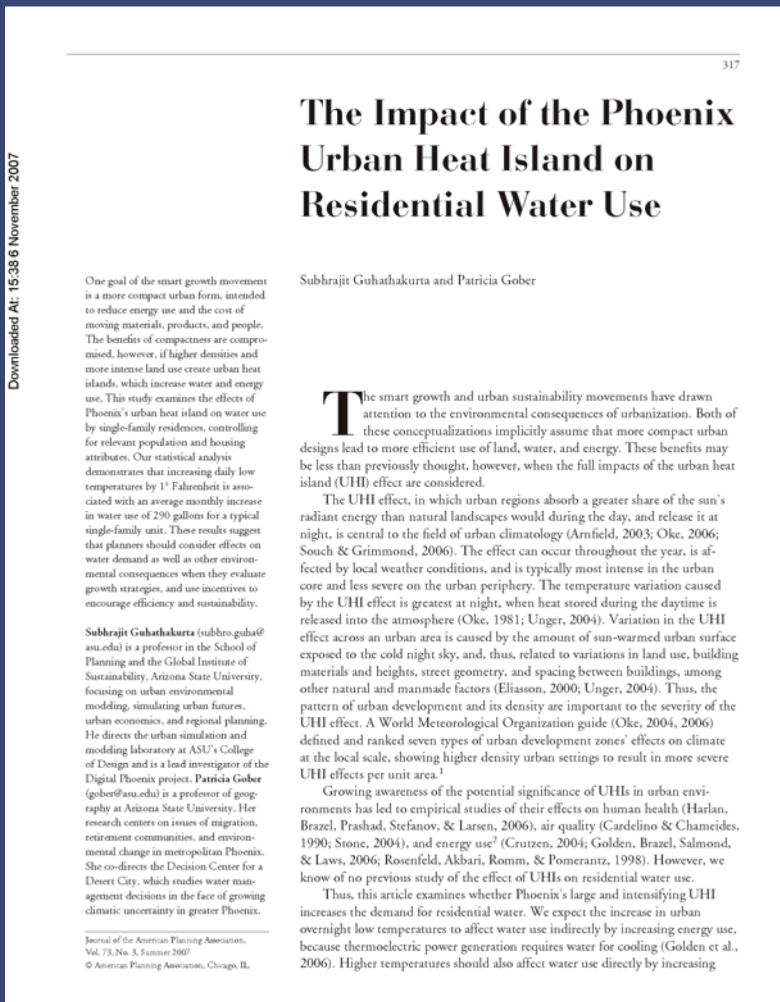


Temp = f [development zone (core, infill, agricultural fringe, desert fringe), weather type, home completions]
Urban effect is 2° to 5°C
1.4°C per 1,000 home completions

Guhathakurta and Gober. 2007. The Impact of the Urban Heat Island on Residential Water Use: The Case of Phoenix Metropolitan Area. *Journal of the American Planning Association* 73(3): 317-329.



The Impact of the Phoenix Urban Heat Island on Residential Water Use

Subhrajit Guhathakurta and Patricia Gober

One goal of the smart growth movement is a more compact urban form, intended to reduce energy use and the cost of moving materials, products, and people. The benefits of compactness are compromised, however, if higher densities and more intense land use create urban heat islands, which increase water and energy use. This study examines the effects of Phoenix's urban heat island on water use by single-family residences, controlling for relevant population and housing attributes. Our statistical analysis demonstrates that increasing daily low temperatures by 1° Fahrenheit is associated with an average monthly increase in water use of 290 gallons for a typical single-family unit. These results suggest that planners should consider effects on water demand as well as other environmental consequences when they evaluate growth strategies, and use incentives to encourage efficiency and sustainability.

Subhrajit Guhathakurta (subhro.guha@asu.edu) is a professor in the School of Planning and the Global Institute of Sustainability, Arizona State University, focusing on urban environmental modeling, simulating urban futures, urban economics, and regional planning. He directs the urban simulation and modeling laboratory at ASU's College of Design and is a lead investigator of the Digital Phoenix project. **Patricia Gober** (gober@asu.edu) is a professor of geography at Arizona State University. Her research centers on issues of migration, retirement communities, and environmental change in metropolitan Phoenix. She co-directs the Decision Center for a Desert City, which studies water management decisions in the face of growing climatic uncertainty in greater Phoenix.

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The smart growth and urban sustainability movements have drawn attention to the environmental consequences of urbanization. Both of these conceptualizations implicitly assume that more compact urban designs lead to more efficient use of land, water, and energy. These benefits may be less than previously thought, however, when the full impacts of the urban heat island (UHI) effect are considered.

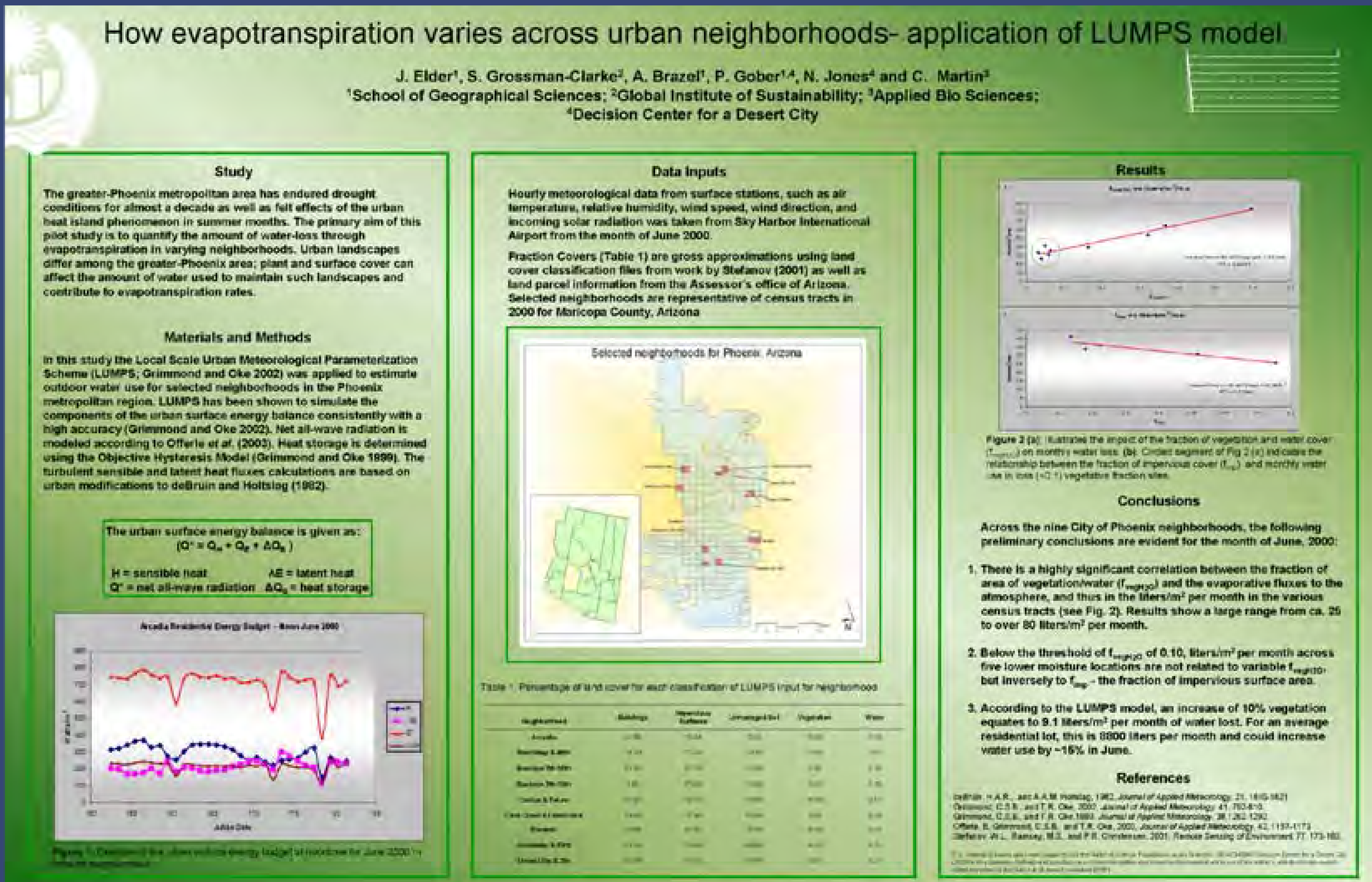
The UHI effect, in which urban regions absorb a greater share of the sun's radiant energy than natural landscapes would during the day, and release it at night, is central to the field of urban climatology (Arnfield, 2003; Oke, 2006; Souch & Grimmond, 2006). The effect can occur throughout the year, is affected by local weather conditions, and is typically most intense in the urban core and less severe on the urban periphery. The temperature variation caused by the UHI effect is greatest at night, when heat stored during the daytime is released into the atmosphere (Oke, 1981; Unger, 2004). Variation in the UHI effect across an urban area is caused by the amount of sun-warmed urban surface exposed to the cold night sky, and, thus, related to variations in land use, building materials and heights, street geometry, and spacing between buildings, among other natural and manmade factors (Eliasson, 2000; Unger, 2004). Thus, the pattern of urban development and its density are important to the severity of the UHI effect. A World Meteorological Organization guide (Oke, 2004, 2006) defined and ranked seven types of urban development zones' effects on climate at the local scale, showing higher density urban settings to result in more severe UHI effects per unit area.[1]

Growing awareness of the potential significance of UHIs in urban environments has led to empirical studies of their effects on human health (Harlan, Brazel, Prashad, Stefanov, & Larsen, 2006), air quality (Cardelino & Chameides, 1990; Stone, 2004), and energy use[2] (Crutzen, 2004; Golden, Brazel, Salmond, & Laws, 2006; Rosenfeld, Akbari, Romm, & Pomerantz, 1998). However, we know of no previous study of the effect of UHIs on residential water use.

Thus, this article examines whether Phoenix's large and intensifying UHI increases the demand for residential water. We expect the increase in urban overnight low temperatures to affect water use indirectly by increasing energy use, because thermoelectric power generation requires water for cooling (Golden et al., 2006). Higher temperatures should also affect water use directly by increasing

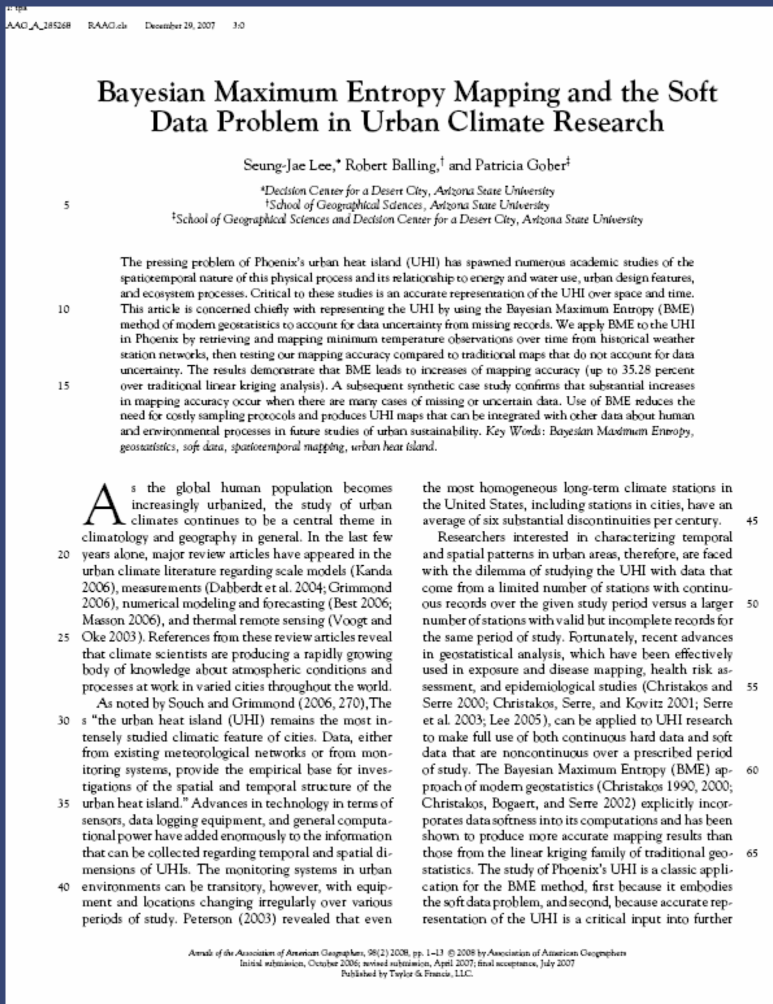
Urban heat island affects residential water use.
A 1° F increase in a tract's low temperature increases average water use in single-family units by 1.7%, or 290 gallons for the typical single family unit for the month, holding all else constant.

City of Phoenix Project with LUMPS Model



Bayesian Maximum Entropy

Lee, et al. 2008. Bayesian maximum entropy mapping and the soft data problem in urban climate research. *Annals of the AAG* 98(2): 1-13.



Bayesian Maximum Entropy Mapping and the Soft Data Problem in Urban Climate Research

Seung-Jae Lee,* Robert Balling,† and Patricia Gober‡

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The pressing problem of Phoenix's urban heat island (UHI) has spawned numerous academic studies of the spatiotemporal nature of this physical process and its relationship to energy and water use, urban design features, and ecosystem processes. Critical to these studies is an accurate representation of the UHI over space and time. This article is concerned chiefly with representing the UHI by using the Bayesian Maximum Entropy (BME) method of modern geostatistics to account for data uncertainty from missing records. We apply BME to the UHI in Phoenix by retrieving and mapping minimum temperature observations over time from historical weather station networks, then testing our mapping accuracy compared to traditional maps that do not account for data uncertainty. The results demonstrate that BME leads to increases of mapping accuracy (up to 35.28 percent over traditional linear kriging analysis). A subsequent synthetic case study confirms that substantial increases in mapping accuracy occur when there are many cases of missing or uncertain data. Use of BME reduces the need for costly sampling protocols and produces UHI maps that can be integrated with other data about human and environmental processes in future studies of urban sustainability. *Key Words: Bayesian Maximum Entropy, geostatistics, soft data, spatiotemporal mapping, urban heat island.*

As the global human population becomes increasingly urbanized, the study of urban climates continues to be a central theme in climatology and geography in general. In the last few years alone, major review articles have appeared in the urban climate literature regarding scale models (Kanda 2006), measurements (Dabberdt et al. 2004; Grimmond 2006), numerical modeling and forecasting (Best 2006; Masson 2006), and thermal remote sensing (Voogt and Oke 2003). References from these review articles reveal that climate scientists are producing a rapidly growing body of knowledge about atmospheric conditions and processes at work in varied cities throughout the world.

As noted by Souch and Grimmond (2006, 270),The s "the urban heat island (UHI) remains the most intensely studied climatic feature of cities. Data, either from existing meteorological networks or from monitoring systems, provide the empirical base for investigations of the spatial and temporal structure of the urban heat island." Advances in technology in terms of sensors, data logging equipment, and general computational power have added enormously to the information that can be collected regarding temporal and spatial dimensions of UHIs. The monitoring systems in urban environments can be transitory, however, with equipment and locations changing irregularly over various periods of study. Peterson (2003) revealed that even the most homogeneous long-term climate stations in the United States, including stations in cities, have an average of six substantial discontinuities per century.

Researchers interested in characterizing temporal and spatial patterns in urban areas, therefore, are faced with the dilemma of studying the UHI with data that come from a limited number of stations with continuous records over the given study period versus a larger number of stations with valid but incomplete records for the same period of study. Fortunately, recent advances in geostatistical analysis, which have been effectively used in exposure and disease mapping, health risk assessment, and epidemiological studies (Christakos and Serre 2000; Christakos, Serre, and Kovitz 2001; Serre et al. 2003; Lee 2005), can be applied to UHI research to make full use of both continuous hard data and soft data that are noncontinuous over a prescribed period of study. The Bayesian Maximum Entropy (BME) approach of modern geostatistics (Christakos 1990, 2000; Christakos, Bogaert, and Serre 2002) explicitly incorporates data softness into its computations and has been shown to produce more accurate mapping results than those from the linear kriging family of traditional geostatistics. The study of Phoenix's UHI is a classic application for the BME method, first because it embodies the soft data problem, and second, because accurate representation of the UHI is a critical input into further

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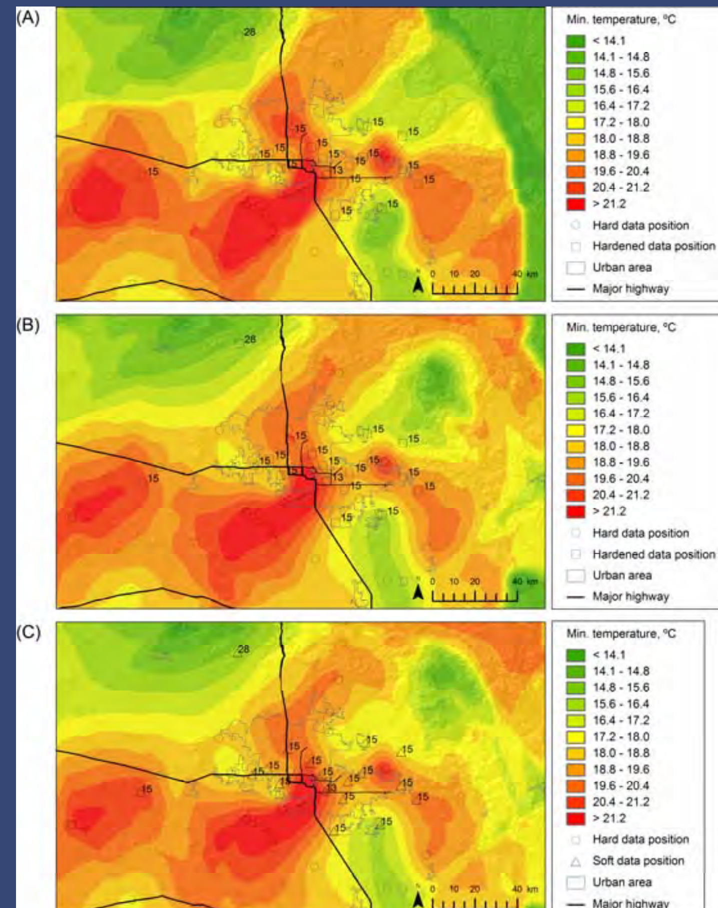

BME provides a more accurate representation of the UHI than simple kriging or spatiotemporal kriging..

Lee and Wentz. 2008. Applying Bayesian Maximum Entropy to extrap0olating local-scale water consumption in Maricopa County, Arizona. *Water Resources Research* 44: 1-13.

WATER RESOURCES RESEARCH, VOL. 44, W01401, doi:10.1029/2007WR006101, 2008

Click Here for Full Article

Applying Bayesian Maximum Entropy to extrapolating local-scale water consumption in Maricopa County, Arizona

Seung-Jae Lee[1] and Elizabeth A. Wentz[2]

Received 10 April 2007; revised 23 July 2007; accepted 14 August 2007; published 1 January 2008.

[1] Understanding water use in the context of urban growth and climate variability requires an accurate representation of regional water use. It is challenging, however, because water use data are often unavailable, and when they are available, they are geographically aggregated to protect the identity of individuals. The present paper aims to map local-scale estimates of water use in Maricopa County, Arizona, on the basis of data aggregated to census tracts and measured only in the City of Phoenix. To complete our research goals we describe two types of data uncertainty sources (i.e., extrapolation and downscaling processes) and then generate data that account for the uncertainty sources (i.e., soft data). Our results ascertain that the Bayesian Maximum Entropy (BME) mapping method of modern geostatistics is a theoretically sound approach for assimilating the soft data into mapping processes. Our results lead to increased mapping accuracy over classical geostatistics, which does not account for the soft data. The confirmed BME maps therefore provide useful knowledge on local water use variability in the whole county that is further applied to the understanding of causal factors of urban water demand.

Citation: Lee, S. J., and E. A. Wentz (2008), Applying Bayesian Maximum Entropy to extrapolating local-scale water consumption in Maricopa County, Arizona, *Water Resour. Res.*, *44*, W01401, doi:10.1029/2007WR006101.

1. Introduction

[2] Water usage is not constant across all users in a geographic region. In fact, studies have shown that variations in residential water use exist owing to differences in landscaping, pools, lot size, and number of residents per household [*Mayer and DeOreo*, 1999; *Jacobs and Haarhoff*, 2004; *Troy and Holloway*, 2004]. To potentially impact and change water usage, policy makers need to quantify and visualize water usage across a geographic region. Maps showing water usage can be used to answer water questions related to urban growth and climate variability.

[3] There are numerous challenges to quantifying and visualizing regional water usage. In some regions, separate governing municipalities record water usage and may not make those data available to the public. Even when data are available, they may be recorded at different geographic scales (e.g., individual water usages or aggregated to a common geographic boundary) or at different temporal scales (e.g., monthly versus annually). As a result, regional water usage data remain incomplete because of (1) lack of accessible data and (2) mixing of data with multiple observation scales.

[4] To address these problems, we introduce the Bayesian Maximum Entropy (BME) of modern geostatistics that assimilates data uncertainty into the mapping processes [*Christakos*, 1990, 2000; *Christakos et al.*, 2002]. The BME approach has proven effective in several application contexts such as environmental exposure [*Christakos and Serre*, 2000; *Christakos et al.*, 2001; *Lee*, 2005], health [*Lee*, 2005], disease [*Law et al.*, 2004], and urban climate [*Brazel et al.*, 2007; *Lee et al.*, 2008] by producing nonlinear estimates at unsampled locations while overcoming various limitations inherent in classical geostatistics (i.e., no incorporation of soft data and Gaussian assumption) [*Christakos and Serre*, 2000; *Christakos et al.*, 2001; *Lee*, 2005; *Lee et al.*, 2008; *Serre et al.*, 2003].

[5] We apply the BME approach to map water usage in Maricopa County, Arizona, home to the City of Phoenix. The City of Phoenix and the surrounding metropolitan area is one of the fastest growing urban areas in the United States, with numerous pressures for water. Managing population growth, particularly in the context of climatic uncertainty, requires a reliable long-term supply of water. Data to map countywide water usage were unavailable. Rather, we were able to acquire water consumption data for the City of Phoenix aggregated to census tracts. The BME produces countywide estimates of water consumption in areas smaller than the observation scales of the data by processing the data uncertainty sources.

[6] Using countywide estimates of water consumption, we are able to describe regional water use variability. We contribute to the body of knowledge on water consumption by (1) accurately describing countywide water usage as a case study in Maricopa County, Arizona, overcoming lack of data, and (2) accurately representing local-scale water usage regardless of varying observation scales of the available data.

[7] Our research is part of a larger project mandated to study water management and decision-making in the context of climatic uncertainty in central Arizona. Understanding the spatial pattern of water consumption contributes significantly to this project because it helps to articulate the factors that determine urban water demand. These provide

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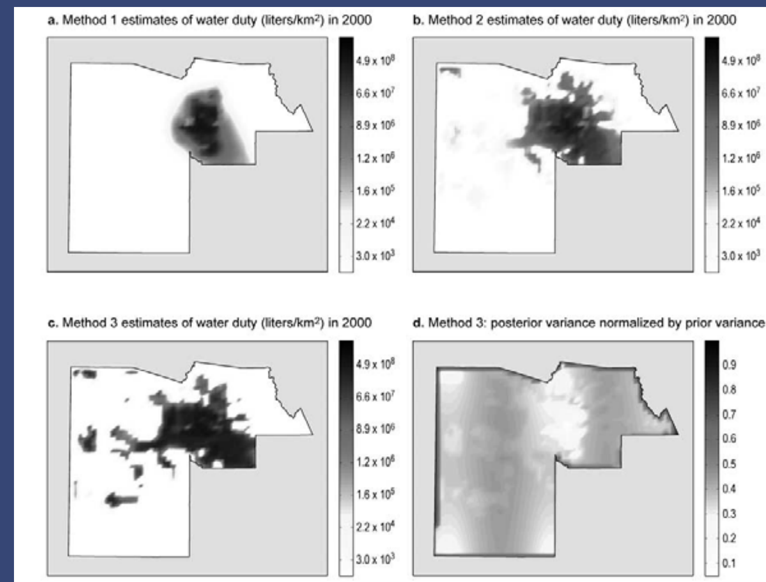
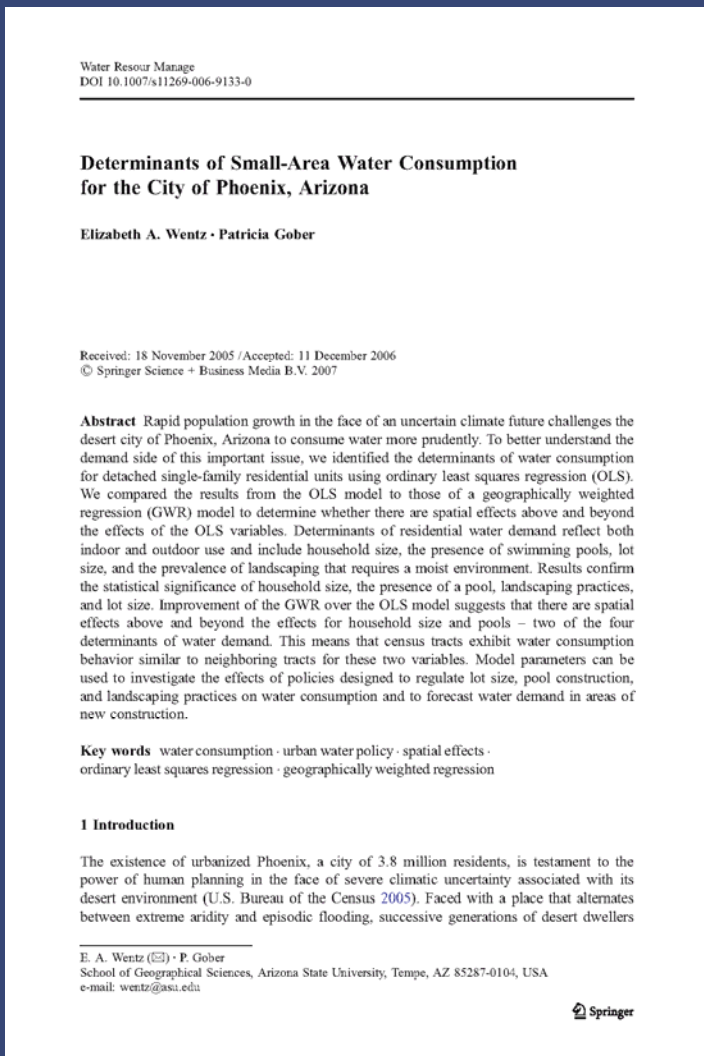


BME can be used to extrapolate local-scale water consumption using a secondary variable—land use.

Water demand modeling and decision making

Wentz and Gober. 2007. Determinants of Small-Area Water Consumption for the City of Phoenix, Arizona. *Water Resources Management* 21(4): 1849-1863.



Water Resour Manage
DOI 10.1007/s11269-006-9133-0

Determinants of Small-Area Water Consumption for the City of Phoenix, Arizona

Elizabeth A. Wentz · Patricia Gober

Received: 18 November 2005 / Accepted: 11 December 2006

Abstract Rapid population growth in the face of an uncertain climate future challenges the desert city of Phoenix, Arizona to consume water more prudently. To better understand the demand side of this important issue, we identified the determinants of water consumption for detached single-family residential units using ordinary least squares regression (OLS). We compared the results from the OLS model to those of a geographically weighted regression (GWR) model to determine whether there are spatial effects above and beyond the effects of the OLS variables. Determinants of residential water demand reflect both indoor and outdoor use and include household size, the presence of swimming pools, lot size, and the prevalence of landscaping that requires a moist environment. Results confirm the statistical significance of household size, the presence of a pool, landscaping practices, and lot size. Improvement of the GWR over the OLS model suggests that there are spatial effects above and beyond the effects for household size and pools – two of the four determinants of water demand. This means that census tracts exhibit water consumption behavior similar to neighboring tracts for these two variables. Model parameters can be used to investigate the effects of policies designed to regulate lot size, pool construction, and landscaping practices on water consumption and to forecast water demand in areas of new construction.

Key words water consumption · urban water policy · spatial effects · ordinary least squares regression · geographically weighted regression

1 Introduction

The existence of urbanized Phoenix, a city of 3.8 million residents, is testament to the power of human planning in the face of severe climatic uncertainty associated with its desert environment (U.S. Bureau of the Census 2005). Faced with a place that alternates between extreme aridity and episodic flooding, successive generations of desert dwellers

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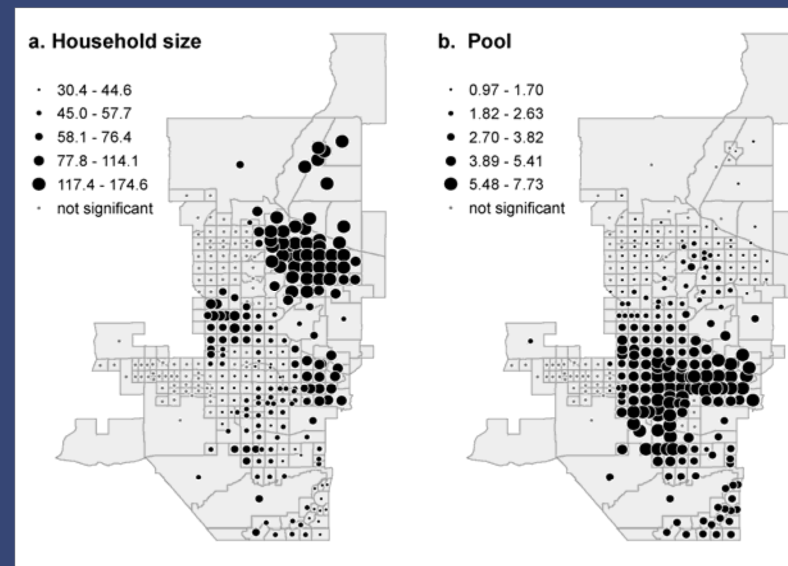
Springer



There are spatial effects in the way household size, presence of a pool, landscaping practices and lot size affect water.

Reconsidering the economics of residential water demand (Kerry Smith)

- Long Term
  - Develop an economic framework that is capable of describing household responses to changes in the terms of water availability
  - Design new price structures
  - Evaluate non-price and mixed policies
- Short Term
  - Provide measures of responsiveness of residential water demand by location and household attributes.

White, et al. 2008. Water managers' perceptions of the science-policy interface in Phoenix, Arizona USA. *Society and Natural Resources* 21(3): 1-14.

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Date and Time : 10/1/08 and 17:07

Society and Natural Resources, 21:1–14

ISSN: 0894-1920 print/1521-0723 online
DOI: 10.1080/08941920701329678

Routledge
Taylor & Francis Group

Water Managers' Perceptions of the Science–Policy Interface in Phoenix, Arizona: Implications for an Emerging Boundary Organization

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A potential water supply crisis has sparked concern among policymakers, water managers, and academic scientists in Phoenix, AZ. The availability of water resources is linked to population growth, increasing demand, static supply, land use change, and uncertainty. This article examines the perceptions of water managers working at the science–policy interface in Phoenix and discusses the implications of their experiences for the development of an emerging boundary organization: the Decision Center for a Desert City. Qualitative analysis of data generated through in-depth interviews with water managers uncovers two understandings of the intersection of science and policy: One perspective is a traditional, linear model with sharp conceptual distinctions between the two spheres, and the other is a recursive model recognizing fluid boundaries. Managers describe uncertainty as inescapable, but manageable. A prescriptive model for the science–policy interface for Phoenix water management is presented.

Keywords climate change, drought, environmental policy, uncertainty, urban water resources, Western water management

According to the U.S. Bureau of Reclamation (2003), Arizona is at the center of a geographic region facing a potential water supply crisis by 2025: Existing water supplies may not be adequate to meet future demands for society or the environment. This potential crisis is tied to a convergence of factors including explosive population

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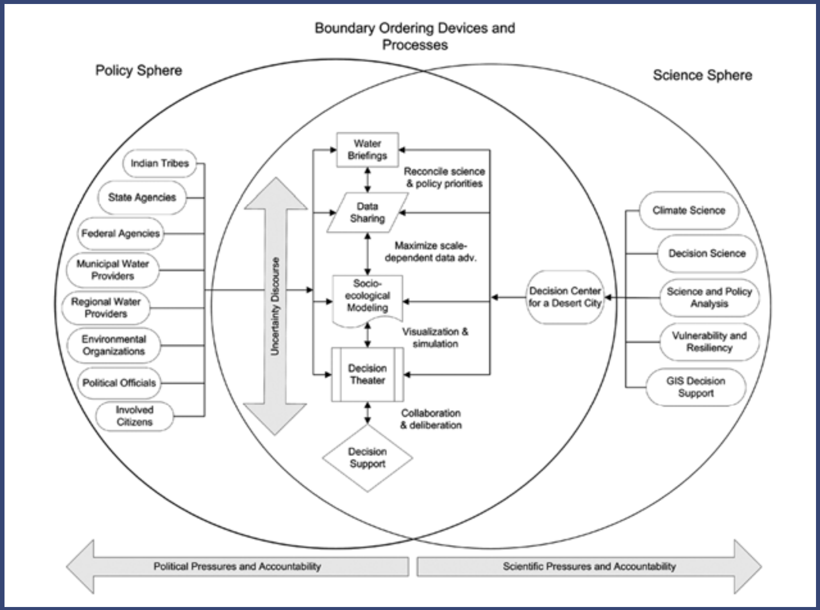
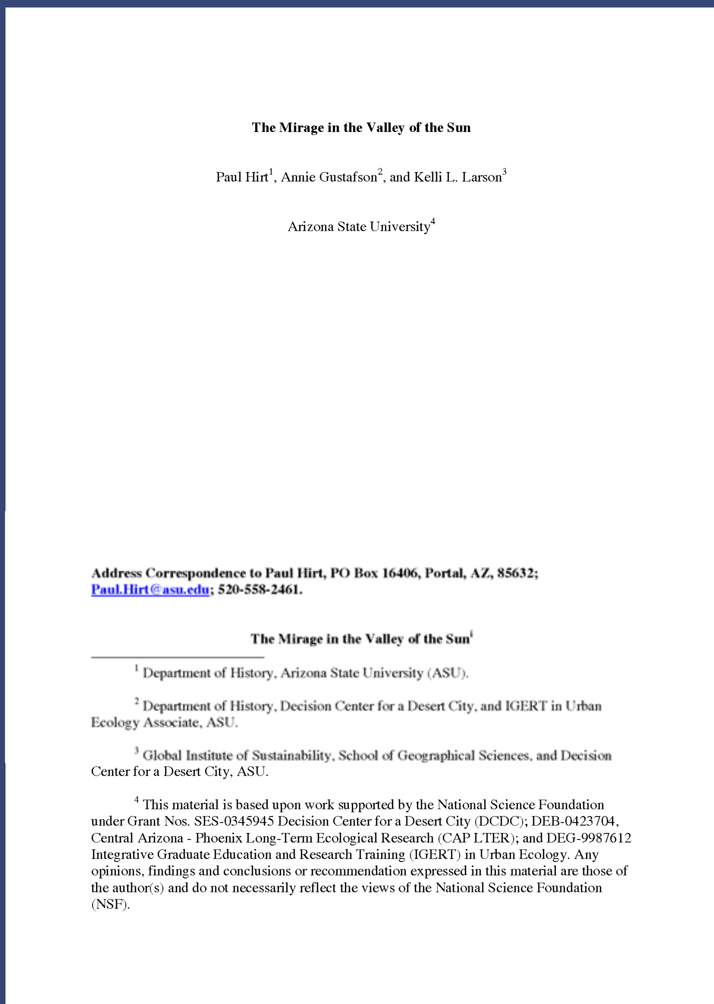
This material is based upon work supported by the National Science Foundation (NSF) under grant SES-0345945, Decision Center for a Desert City (DCDC). Any opinions, findings and conclusions, or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the NSF. The authors thank Patricia Gober, Charles Redman, Bill Edwards, Nancy Jones, Arianne Peterson, Peter Howe, and Michelle Malonzo.
Address correspondence to Dave D. White, ASU School of Community Resources and Development, 411 N. Central Avenue, Ste. 550, Phoenix, AZ 85004-0690, USA. E-mail: dave.white@asu.edu



Uncertainty discourse serves as a bridge between the science and policy worlds.

Hirt, et al. In Press. The mirage in the Valley of the Sun. *Environmental History* 13(3). Forthcoming.



The Mirage in the Valley of the Sun

Paul Hirt[1], Annie Gustafson[2], and Kelli L. Larson[3]

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The Mirage in the Valley of the Sun[1]

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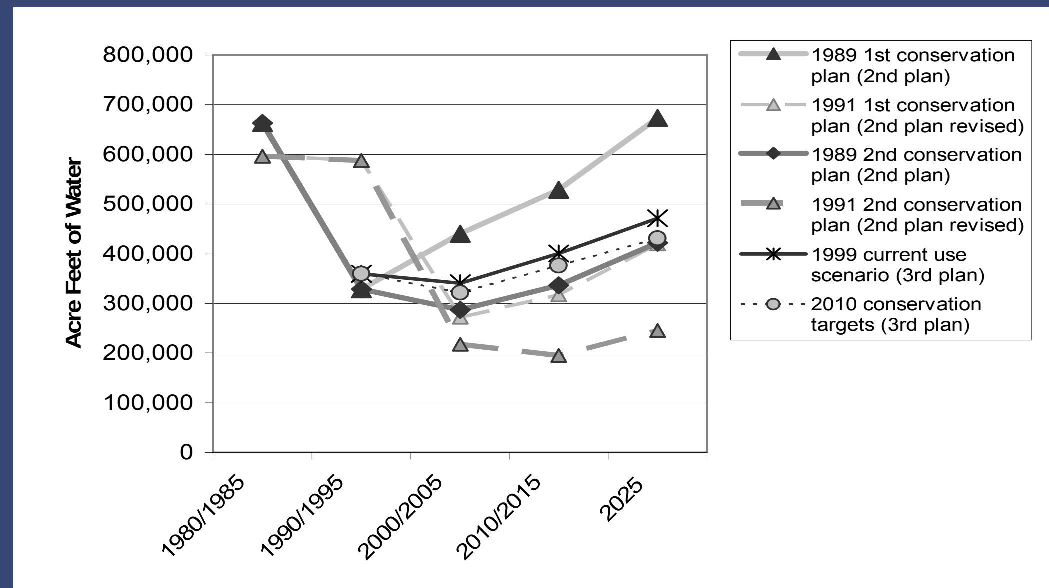
[4] This material is based upon work supported by the National Science Foundation under Grant Nos. SES-0345945 Decision Center for a Desert City (DCDC); DEB-0423704, Central Arizona - Phoenix Long-Term Ecological Research (CAP LTER); and DEG-9987612 Integrative Graduate Education and Research Training (IGERT) in Urban Ecology. Any opinions, findings and conclusions or recommendation expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Science Foundation (NSF).



The history of water management in Phoenix shows that problem-solving reforms often require a crisis in order to overcome inertia, vested interests, false hope, and a libertine culture fixated on consumption… Real reform may have to wait for the next crisis. And the wait will not be long.

Institution Building

LTER Symposium 2008

LTER 2008 Symposium

- An ethnohydrologic evaluation of water quality in Phoenix, AZ. (Avent, Wutich, Crona, Gober, Seetharam, Westerhoff)
- Sensitivity of residential water consumption to variations in weather and climate: An intra-urban analysis of Phoenix, Arizona. (Balling, Gober, Jones)
- Is it who you know or what you know? A first examination of water information distribution across organizational networks. (Cutts, Knox, Moore)
- Estimates of outdoor water use in Phoenix using LUMPS. (Elder, Grossman-Clarke, Brazel, Butler, Martin)
- A Scenario Based Assessment of Future Groundwater Resources in the Phoenix Active Management Area. (Escobar)
- Focusing on higher quality focus groups. (Gartin, Wutich, Lant, White, Larson, Ledlow, Gober)
- The use of GIS as a decision-support tool by water managers in Phoenix, Arizona. (Howard, Larson, White, Wentz)
- Spatial extrapolation mapping based on aggregated data: Countywide extrapolation of Phoenix water use data. (Lee, Wentz)
- Temporal Geographic Information System (TGIS) to forecast future water consumption in Phoenix, Arizona. (Lee, Wentz, Gober)
- Water resources, climate change and institutional vulnerability: A case study of Phoenix, Arizona. (Seetharam, Bolin, Pompeii, Gober)
- WaterSim as an education tool. (Tschudi)
- Public good or commodity? Institutional differences in water management strategies and conservation outcomes in Tucson and Phoenix. (Turner)
- Water vulnerability on the urban periphery: The case of metropolitan Phoenix, Arizona. (Zautner, Larson, Bolin)

2008 COURS Symposium

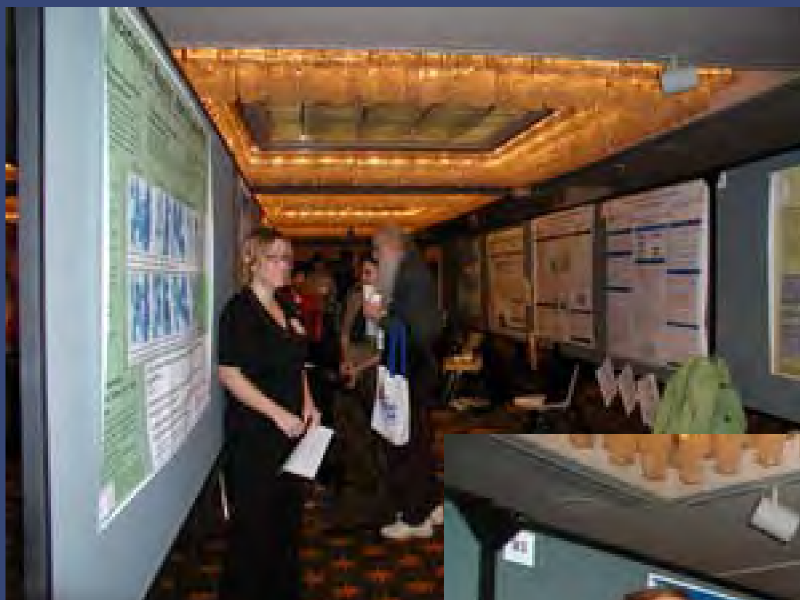
Undergraduate Students

- Genetic Variation between Urban and Desert Black Widow Spiders, *Latrodectus hesperus* — Michelle A. Gohr
- Peer Influence on Student Water Values — Allyn Knox
- Feeling the Heat: Urban Heat Island Effects in Southwest Deserts — Hannah Mensing
- Prehistoric Activity Organization Across Perry Mesa, Central AZ — JoAnn Wallace
- Performance and Perception at a Science and Policy Boundary — Eva M. Wingren

Graduate Students

- Water Privatization and Socially Constructed Scarcities: A Case Study in Phoenix, Arizona — Brian J. Pompeii
- Water Vulnerability on the Urban Periphery: The Case of Metropolitan Phoenix, Arizona — Lilah Zautner
- Risk and Exposure to Heat Stress in Microclimates of Phoenix, AZ — Darren M. Ruddell
- Does truth flow like water?: The role of social networks in the flow of scientific understandings in a water management controversy — Mark Neff
- Do Variation in Heat Islands in Space and Time Influence Household Water Use? A Longitudinal Study of Single Family Residences in Phoenix — Vasudha Lathey
- How evapotranspiration varies across urban neighborhoods- application of LUMPS model — Jillian Elder
- An Ethnohydrologic Evaluation of Water Quality in Phoenix, AZ — Zeenat Hasan
- Participatory GIS for Boundary Research? The Case of the Phoenix Area Water Education Community — Bethany Cutts

2007 AAAS Photos



2007 DMUU Session at AAAS Meetings

- **Bethany Cutts**
  "Uncertainty in Mapping: Water Education Effort"
- **Meredith Gartin and Tim Lant**
  "Examining the Interface between Policy Makers and Scientists"
- **Annie Gustafson, Kelli Larson, Paul Hirt, and Jagadeesh B. Chirumamilla**
  "Water Conservation Policy in an Arid Metropolitan Region: A Historical and Geographical Assessment of Phoenix, Arizona"
- **Ryan Meyer**
  "Arbitrary Impacts and Unknown Futures: The Shortcomings of Climate Impact Model"
- **Mark Neff, Netra Chhetri, Dan Sarewitz, Lori Hidinger, Megan O'Shea, Aliya Buttar, Uven Chong**
  "Will Phoenix Have Sufficient Water? A Workshop to Assess Stressors to an Urban Water System"
- **Jamie Patterson, Subhrajit Guhathakurta, and Patricia Gober**
  "The Impact of Housing Characteristics and Surface Heat Islands on Water Use in Single Family Residences: The Case of the Phoenix Metropolitan Area"
- **Darren Ruddell and Sharon Harlan**
  "Phoenix as a Human Habitat in Summer: Exposure and Resources to Cope with Extreme Heat"
- **Claire Smith, Lilah Zautner, Kelli Larson, and Bob Bolin**
  "Water Vulnerability on the Urban Periphery: The Case of Metropolitan Phoenix, Arizona"

Theses and Dissertations

2008

Howard, J., 2008. Water Managers' Strategies for Addressing Uncertainty in Their Use of GIS for Decision-Making. Master's Thesis, defended April 9, 2008. Committee was Elizabeth Wentz, Kelli Larson, and David White.

Patterson, J., 2008. Spatial Forecasting: A Case Study in Single Family Residential Water Consumption For Phoenix and Paradise Valley, Arizona". Master's Thesis defended April 7, 2008. Committee was Elizabeth Wentz, Patricia Gober, and Subhrajit Guhathakurta.

2006

Graham, C.J., 2006. Hydroclimatic Indexing Method for Drought Monitoring. Fulbright Award-winning Honors Thesis, School of Geographical Sciences, Arizona State University, Tempe, AZ.

Tschudi, M., 2006. Spatial Allocation of Projected Population in Maricopa County via an Automated Workflow. Thesis for Master's of Advanced Studies in Geographic Information Systems (MAS-GIS) from the School of Geographical Sciences. Arizona State University.

2005

Collins, T., 2005. The production of hazard vulnerability: The case of people, forests and fire in Arizona's White Mountains. School of Geographical Sciences, Arizona State University. Unpublished Ph.D. Dissertation. Winner of Gilbert F. White Award of the Hazards Specialty Group of the AAG.

WaterSim

- Scientific integration
- Boundary object
- Research environment

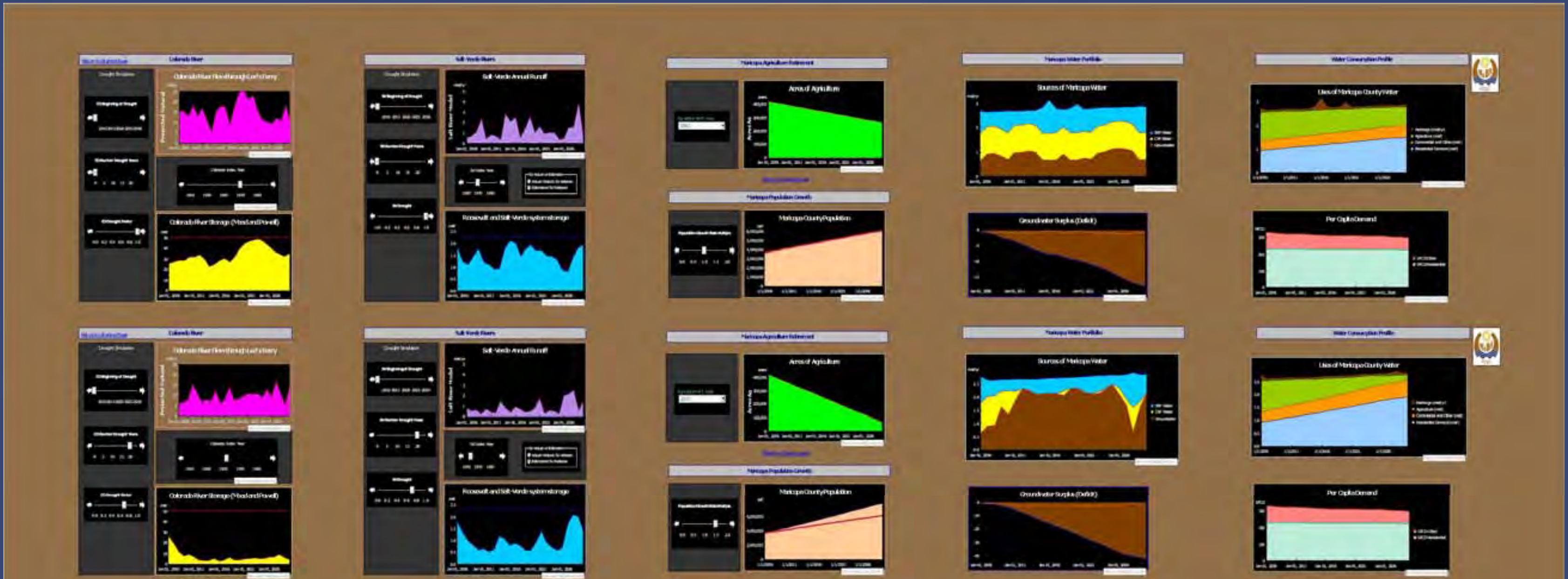


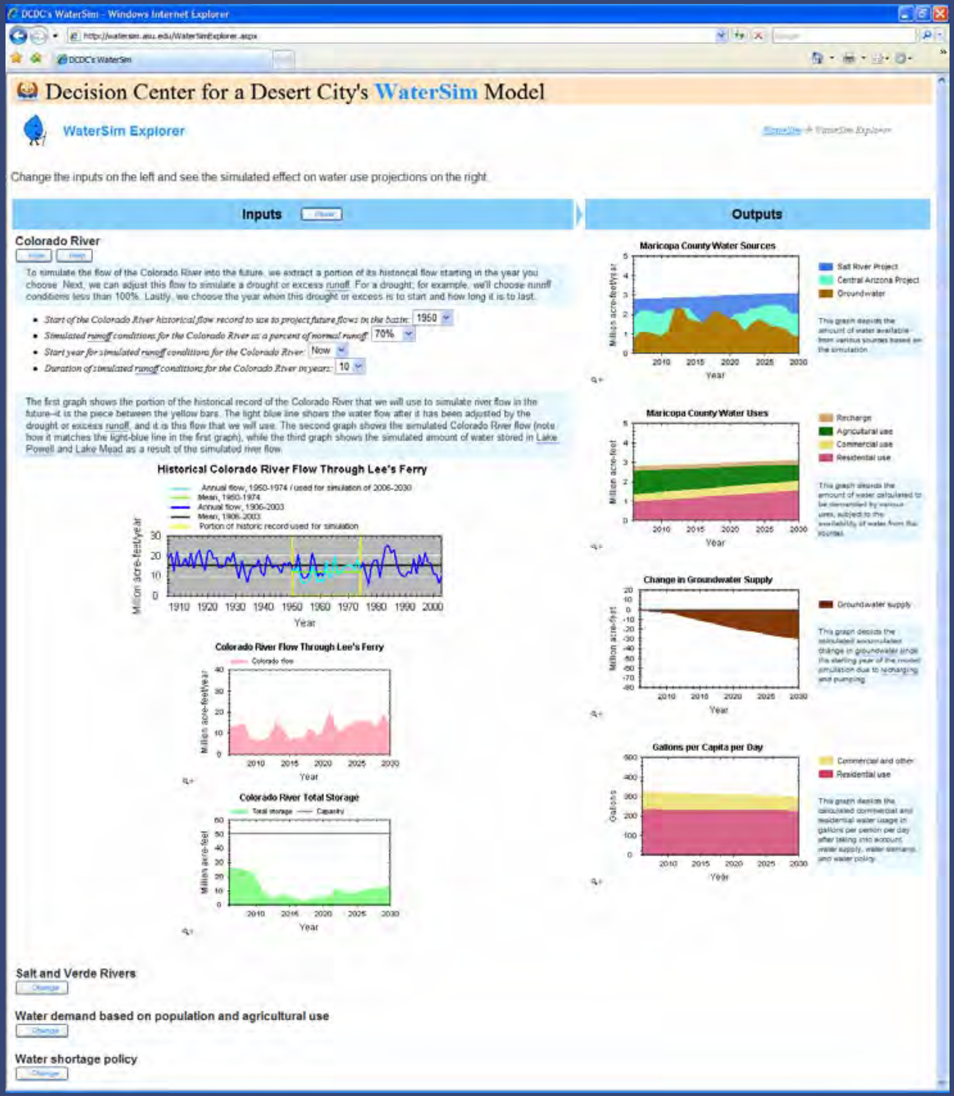
Figure 1. WaterSim Model
Top: Scenario without a drought
Bottom: Scenario with drought and change in population demands

WaterSim in the Decision Theater

Decision Theater: Focus Groups are held in the theater.

Each participant sits at the table facing the screens with a laptop

WaterSim on the Web



WaterSim Public Outreach

FROM THE FRONT PAGE

THE ARIZONA REPUBLIC

azcentral.com

Choosing a future for Arizona

IT'S 2030. We're in the 10th year of a sustained drought. Climate change shrinks rivers. We face a groundwater deficit of 8 trillion gallons, enough to create sinkholes and dry up aquifers. That's a scenario built by ASU's new WaterSim program. It's a grim picture, but the program offers choices ...

THE SCENARIOS		WHAT WE CAN DO
A sustained drought drains reservoirs and pushes the Colorado River system near collapse as millions of new people compete for the same short water supply.	**DROUGHT** 	**Adding water is the key** for Colorado River states, which propose lining canals and desalting runoff. Others say conservation is more sustainable, even in drought conditions.
Higher temperatures reduce runoff on the Salt and Verde rivers. Hotter weather increases demand by people and plants, further eroding supplies.	**CLIMATE CHANGE** 	**Arizona has proposed** plans to cut greenhouse gases with tougher rules on power plants and auto emissions. Changes would come slowly, leaving time to prepare.
Projected population in Maricopa County by 2030: 6.2 million, up from 3.8 million now. Conversion of farmland continues, shifting water supplies as demand climbs.	**GROWTH** 	**With tight supplies,** cities can adopt temporary drought restrictions or impose long-term rules that encourage fewer lawns and backyard pools.
Cities continue to meet all demands, tapping groundwater reserves as reservoirs drain. Sufficient water exists, but groundwater deficit grows.	**WATER POLICY** 	**Residents would have to** cut use by one-quarter or more to avoid serious aquifer damage. Some limits would need to be permanent to sustain supplies.

Public encouraged to play a role, one mouse click at a time

By Shaun McKinnon | The Arizona Republic

Twelve years into one of the worst droughts on record, life remains pretty good in our little central Arizona oasis. No one has forced us to give up anything so far, not grass, not swimming pools, not the fake lakes that shimmer with real water.

We even managed to steal the "fastest growing" title from Nevada in the middle of this dry streak.

But what if we had to do it again? What if the same drought strikes Phoenix 15 years from now? Same dry years, same emptying reservoirs, plus 3 million more thirsty people and the runoff-sapping effects of climate change.

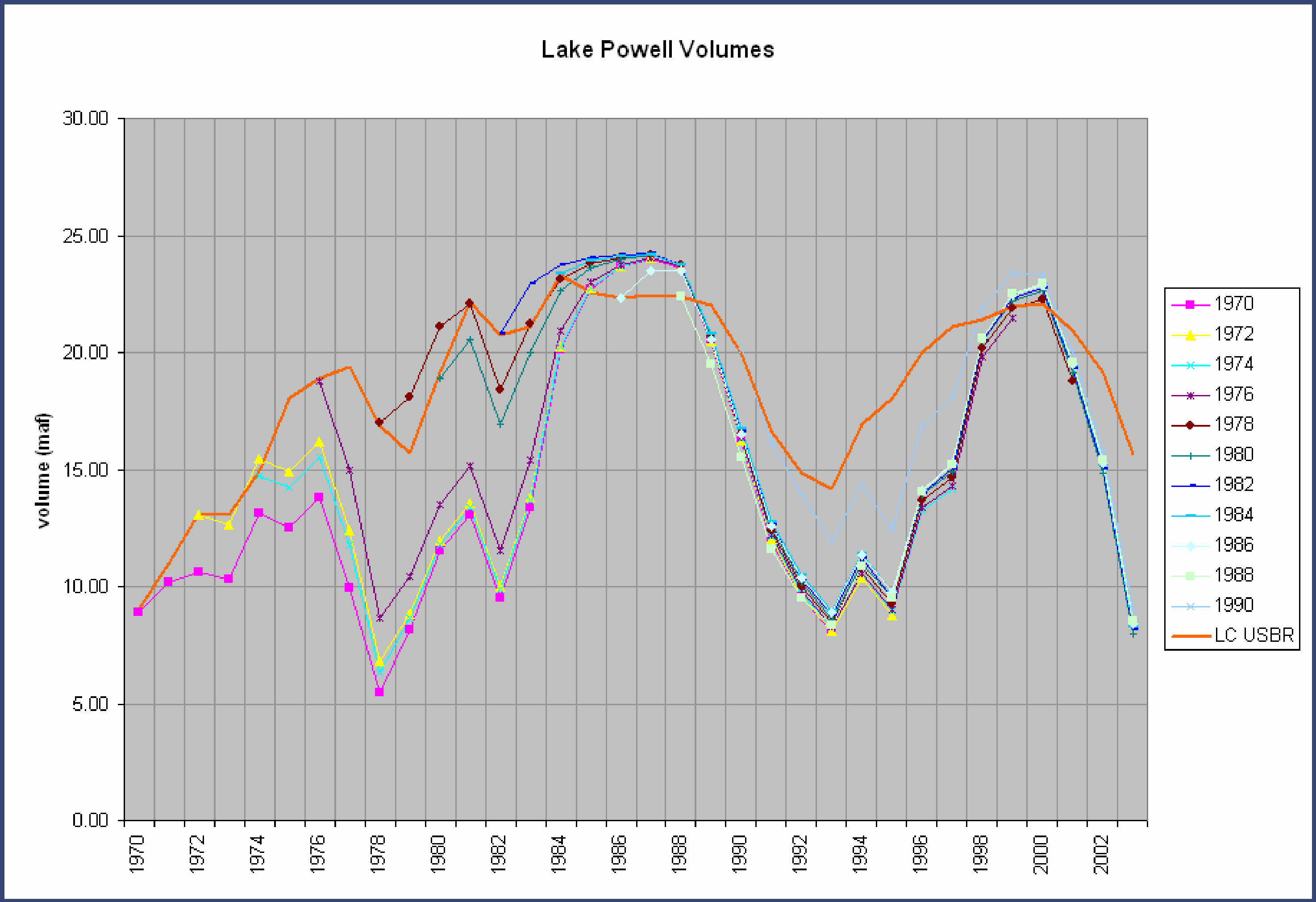
Could we still survive?

Arizona State University researchers asked that question, among scores of others like it, and built a sophisticated computer program called WaterSim to search for answers. The program uses existing models and data to produce water-use scenarios for urban Maricopa County.

The designers acknowledge that they're not trying to predict the future. Instead, they hope the program will stimulate discussion about water-resource management and help end what they describe as paralysis in the debate over emerging issues such as climate change and sustainability.

See **WATERSIM** Page A8

WaterSim Model Evaluation



WaterSim Stakeholder Research

- Study participants are Arizona water experts—technical, policy, and service professionals
- 16 controlled focus groups
- 69 respondents
- Individual (content analysis) and group responses (interaction and discourse analysis)
- Baseline for longitudinal study

Questions?