Investigating the Effects of Population, Policy, and Economic Change on Water Use in Tucson and Phoenix, 1990-2013

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Background

- Urbanization and climate change represent significant sustainability challenges in the 21st Century and nowhere is this a greater concern than for arid cities, such as Tucson and Phoenix.
- Yet, to understand how future conditions may alter water use in desert cities, we must begin with a clear understanding of how past episodes of change have shaped the current state.
- To do so, researchers must engage with the contemporary history of water use in arid settings and, specifically, address the roles of population, regulation, and the market as drivers of demand.

Research Questions

- Have water use patterns changed significantly for Phoenix and Tucson in recent decades?
- If so, what social and climatic factors may have contributed to such transitions?

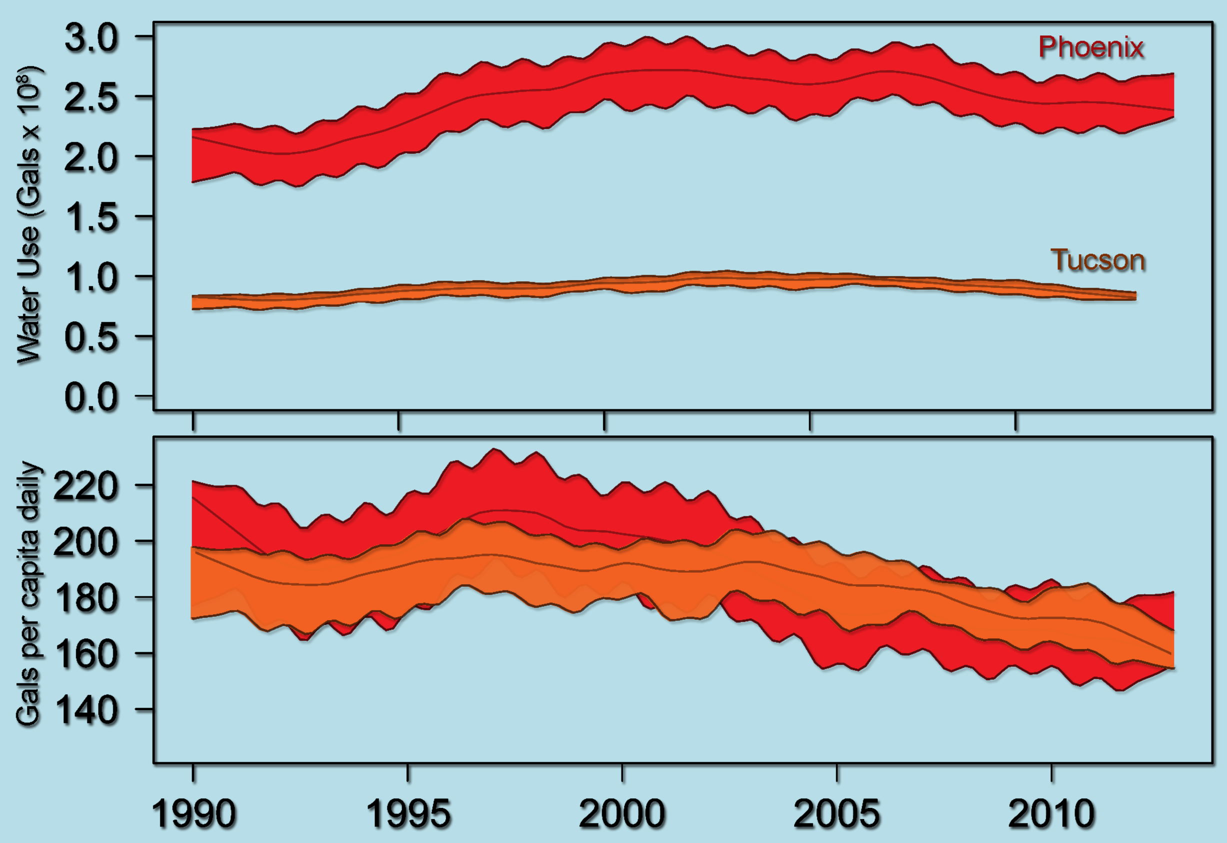

Fig 1. Trends in water use for Phoenix and Tucson, 1990 – 2013. Solid lines mark inter-annual trends and shaded areas delineate seasonal and episodic variability.

Data Collection

4 key data sources were employed:

1) Annual water use data were estimated from data provided by the utilities servicing Phoenix and Tucson
2) Palmer Drought Severity Indices were collected from NOAA for each county.
3) Population, Median Household Income, and Average Home Lot Size were gathered from the US Census
4) Home Appliance data came from the Penn State Extension.

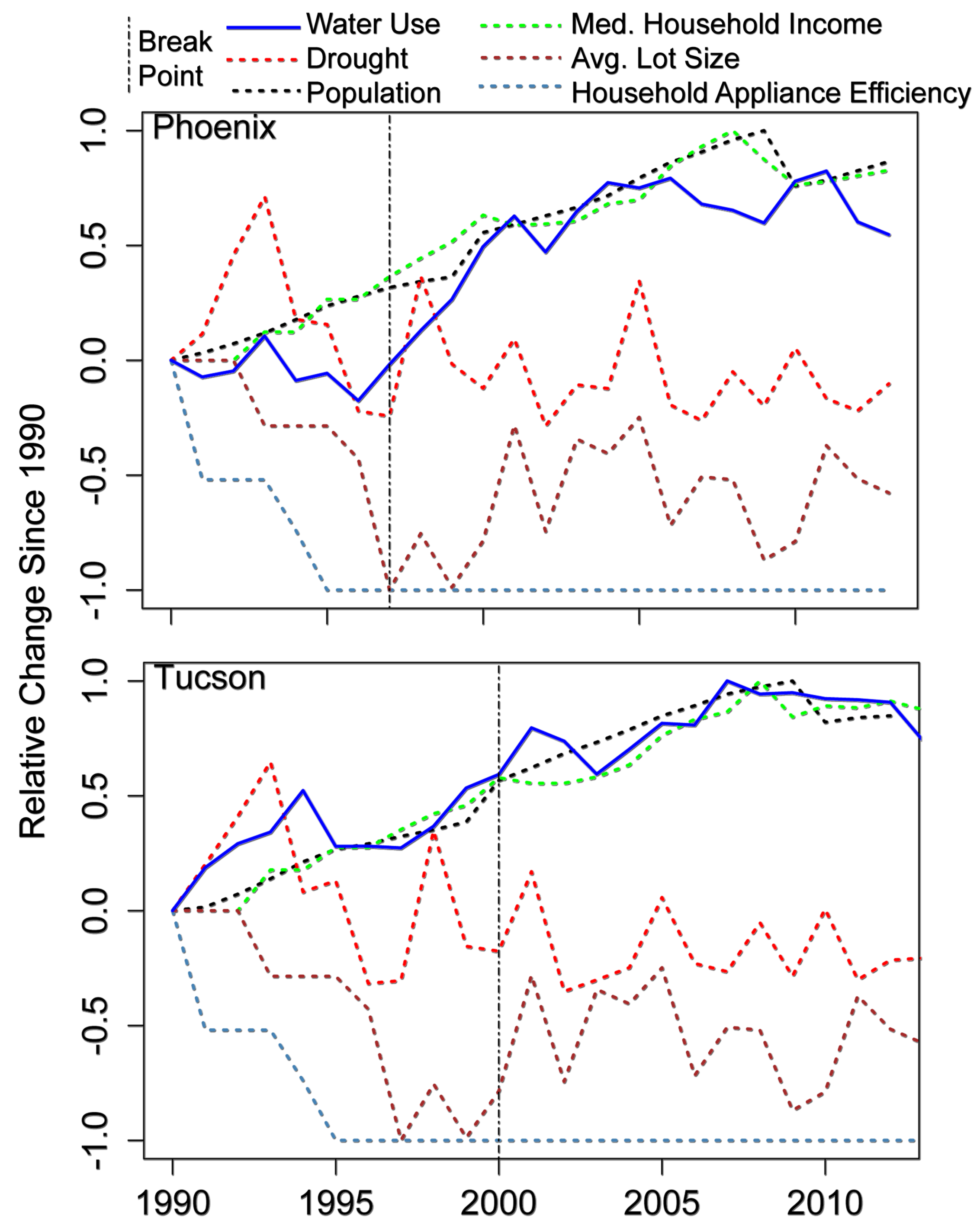

Fig 2. Deviation of normalized variables from their initial values in 1990 (t=0) for Phoenix and Tucson. Vertical lines denote significant periods of change in urban water use.

Detection Change

- Breakpoint techniques enable researchers to identify endogenous periods of change in a univariate statistic, such as water use.
- In such cases, total municipal water use (Y) takes the form:

$$Y_t = \alpha_j + \beta_j t + \sum_{i=1}^{s-1} \delta_{i,j} D_{i,t} + \varepsilon_t \qquad t = t_{j-1}^* + 1, \ldots, t_j^*$$

Where, intercept (α) and slope (β) are constant within each j regime, which are bounded by break points. The remainder of the variables represent seasonal and residual components that are not emphasized here.

- We detected and estimated the timing of break points using the BFAST01 procedure in R.

Explaining Change

- In order to understand the nature of the changes implied by the breakpoints, we plotted the relative change in water use and contributing variables (Fig. 2).
  - This suggested that further analyses remove the role of household income and lot size due to their correlation with other variables (i.e. population and drought, respectively).
- We also attempted a piecewise regression, wherein the regimes before and after the breakpoints were assumed to be separate and the drivers may vary in their influence (Table 1 and 2).

Table 1. Results of linear (all years) and piecewise regressions (pre- and post-) of water use in Phoenix, 1990-2013.

	All Years			Pre-1997			Post-1997		
	Est. (±s.e.)	***t***	***p***	**Est. (±s.e.)**	***t***	***p***	**Est. (±s.e.)**	***t***	***p***
Intercept	-3.1e7(±6.9e7)	-0.44	0.662	-3.2e7(±1.3e8)	-0.25	0.819	1.1e8(±3.9e7)	2.89	0.014
Population	8.5e7(±6.4e7)	1.33	0.199	1.2e2(±7.3e1)	1.68	0.131	1.0e2(±2.8e1)	3.59	0.003
Drought	1.6e2(±1.9e1)	8.30	<0.000	1.4e6(±6.1e5)	2.36	0.078	2.1e5(±1.5e6)	0.14	0.895
Appliance Efficiency	1.3e6(±1.0e6)	1.26	0.224	1.2e8(±6.5e7)	1.90	0.131	—	—	—
Model:	Adj. R^2 = 0.82, $F_{3,20}$ = 35.98, p = 2.98e-08			Adj. R^2 = 0.45, $F_{3,4}$ = 2.916, p = 0.164			Adj. R^2 = 0.49, $F_{2,12}$ = 7.79, p = 0.006		

Table 2. Results of linear (all years) and piecewise regressions (pre- and post-) of water use in Tucson, 1990-2012.

	All Years			Pre-2000			Post-2000		
	Est. (±s.e.)	***t***	***p***	**Est. (±s.e.)**	***t***	***p***	**Est. (±s.e.)**	***t***	***p***
Intercept	-5.6e6(±1.9e7)	-0.30	0.771	1.3e7(±6.8e7)	0.20	0.846	9.8e7(±5.4e7)	1.83	0.101
Population	-2.0e2(±1.9e1)	10.03	<0.000	150.6(±102.3)	1.47	0.184	-5.62(.01)	-0.06	0.958
Drought	5.4e5(±2.6e5)	2.06	0.054	-6.9e5(±4.4e5)	-1.55	0.165	3.2e5(9.1e5)	0.36	0.729
Appliance Efficiency	-2.7e5(1.4e7)	-0.19	0.852	6.5e6(±2.9e7)	0.22	0.832	—	—	—
Model:	Adj. R^2 = 0.90, $F_{3,19}$ = 64.75, p = 3.66e-10			Adj. R^2 = 0.52, $F_{3,7}$ = 4.62, p = 0.044			Adj. R^2 = -0.2, $F_{2,9}$ = 0.07, p = 0.9303		

Summary

- Breakpoint analysis suggests that key transition periods occurred for Phoenix water use c.a. 1997 and for Tucson c.a. 2000.
- While the overall models perform rather well (i.e., R^2 = 0.82 – 0.90), explaining the key transition periods is more challenging.
- Interestingly, population levels have a positive influence in Phoenix after the 1997 breakpoint, but a negative influence overall in Tucson.
- Drought indices are also related to water use overall for both cities and in each case they appear to use less water during drought.
- The parallel trends seen in household income, population growth, and water use (Fig. 2) strongly suggest a linkage between the economic and demographic drivers of demand.
- In both cities, federal efficiency initiatives have no demonstrable effect, at least at this scale.

Discussion

- In total, Phoenix uses more water and is more variable than Tucson, presumably due to their very different growth rates. But, this is also likely related to the water management strategies employed (e.g., Tucson's 'Beat the Peak' and xeriscaping initiatives). Scale and variability remain significant challenges for water supply planning and provisioning.
- As both cities respond to drought by using less water, demand management efforts appear to have been, at least partially, successful. That the effect is more significant in Phoenix may be a result of the larger city having more conservation potential early in the record.
- Despite increasingly efficient appliances and smaller lot sizes, population remains a powerful driver of urban water use. Arid mega-cities will need to address this through a combination of supply and demand management if they are to persist in an era of socionatural change.

Future Research

- Investigate the feedbacks connecting the economy, population, and water governance; especially as they effect water demand.
- Consider the implications of different economic, climatic, and demographic projections for future demand scenarios using multivariate forecasting methods.

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