Drivers of household water conservation in a decade of drought

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Watershed Management Group

TUCSON WATER

Thanks!

NATIONAL PARK SERVICE

PEACE CORPS

Peace Corps Fellows/USA

WSP

Water Sustainability Program

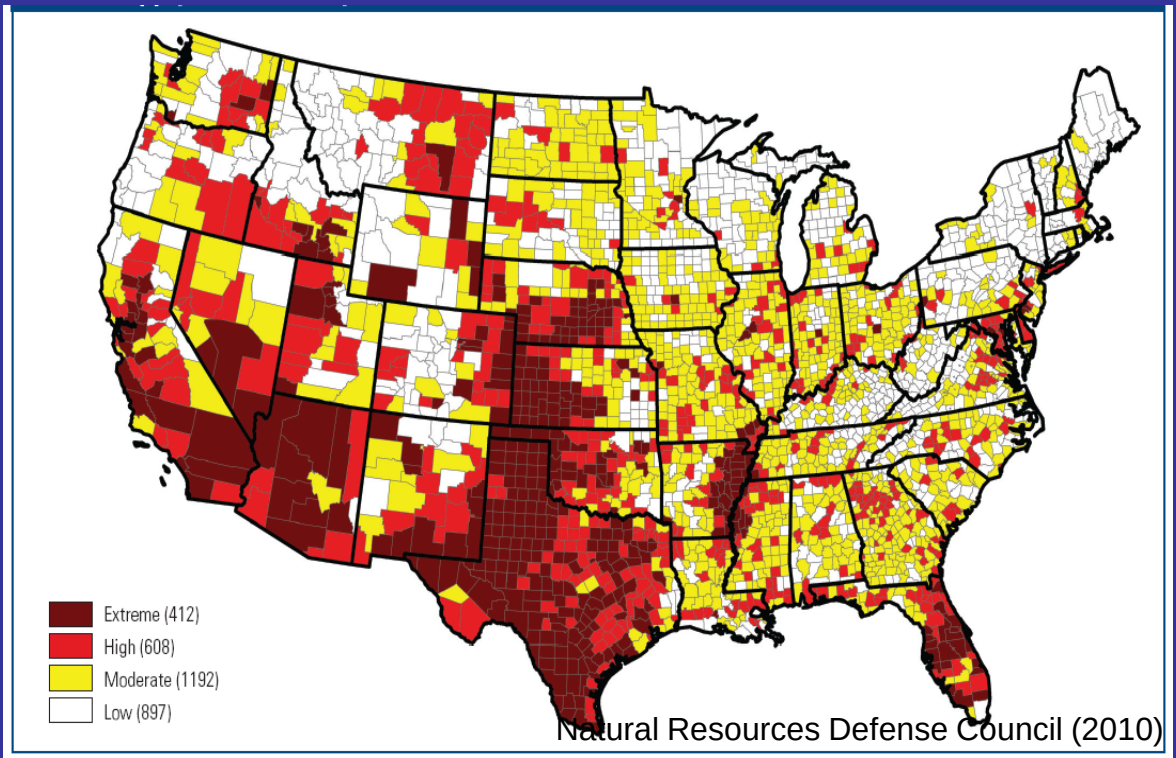
Our Water Future

Questions

- Why do people conserve water?
- How does drought impact conservation?
- Are current conservation initiatives effective?

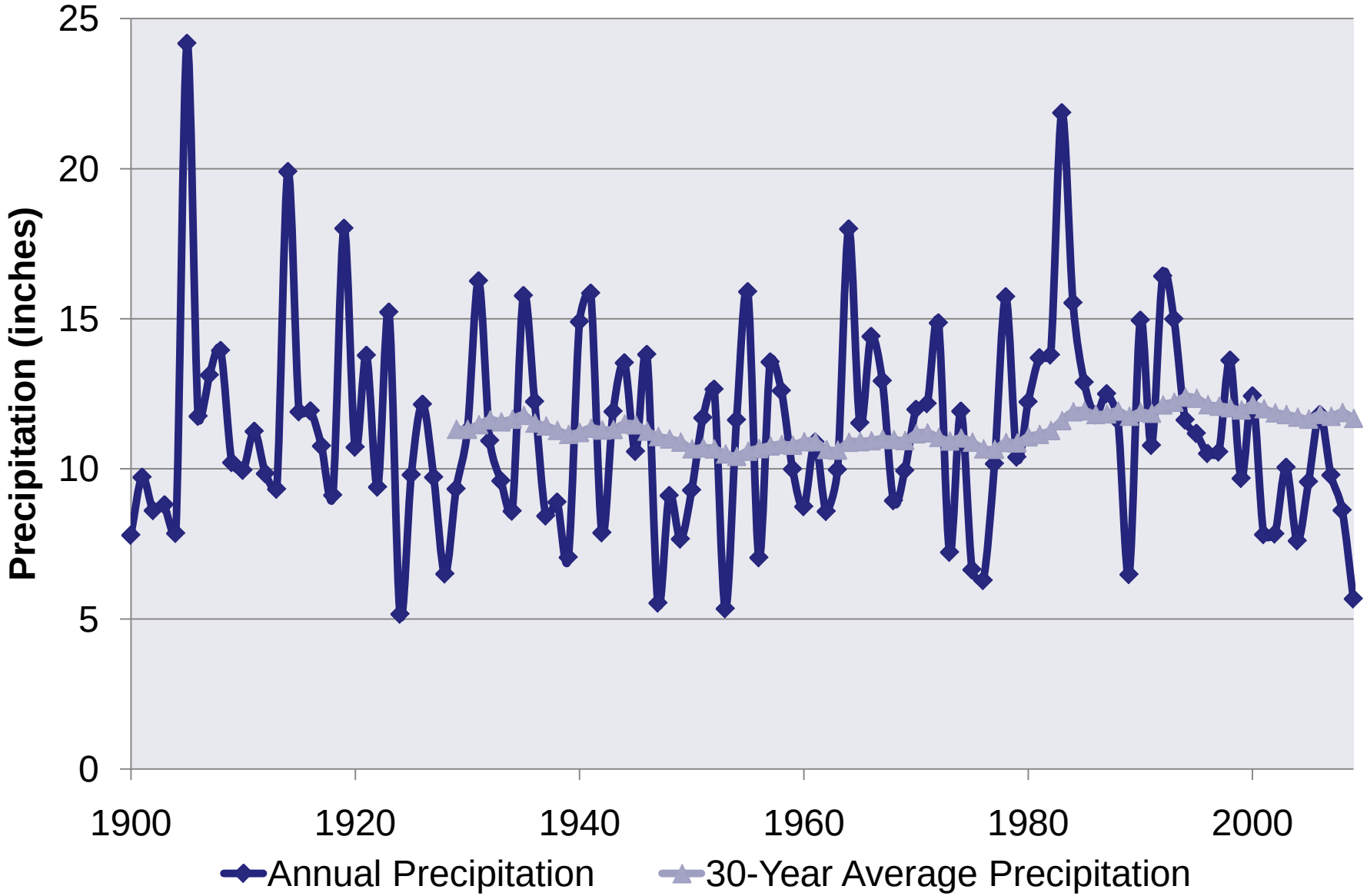
Water Security

- Climate change: temp ↑ & precip ↓
- 2010 Census:
  - West → 2nd fastest growing region
  - AZ → 2nd fastest growing state

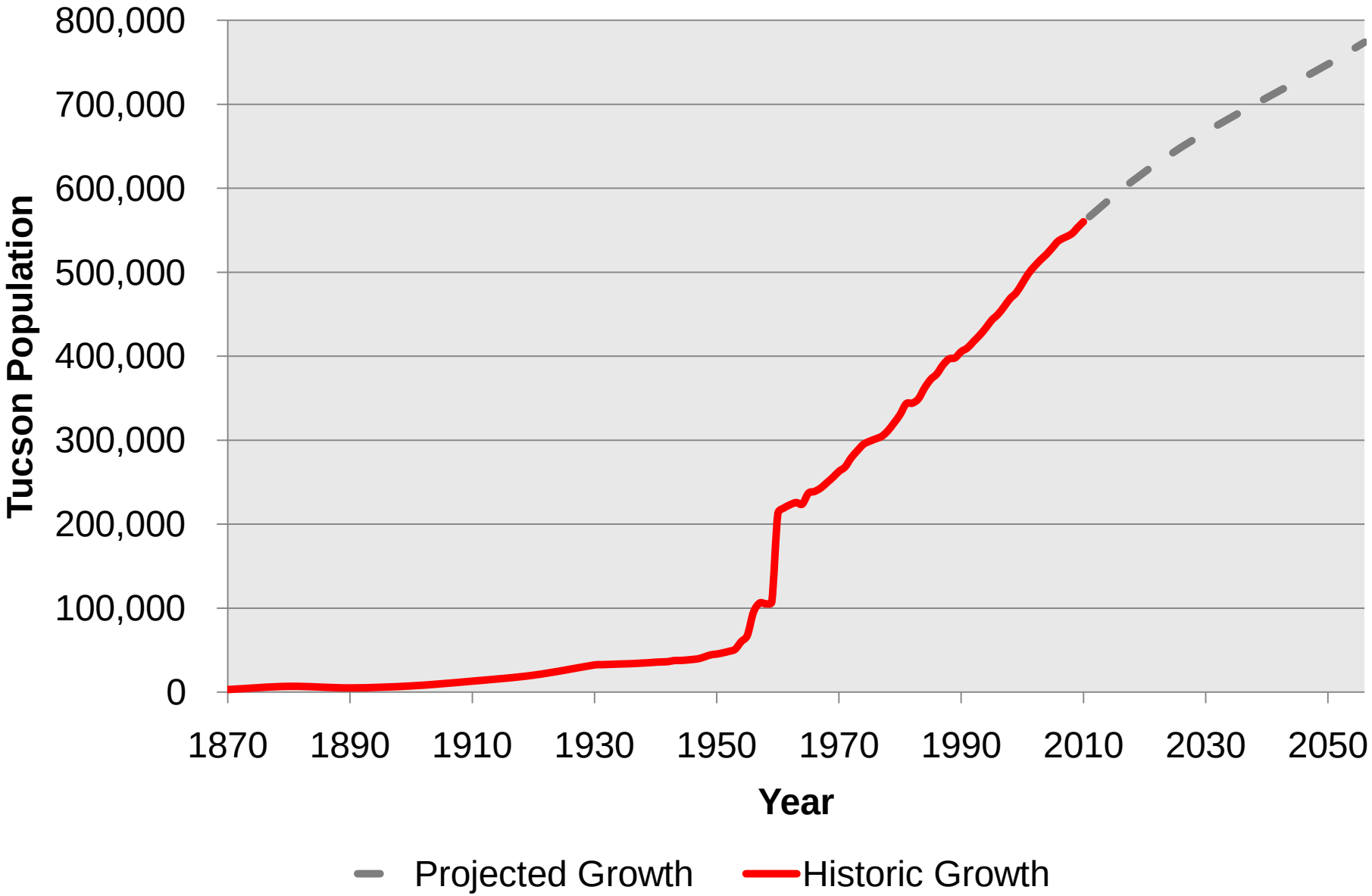


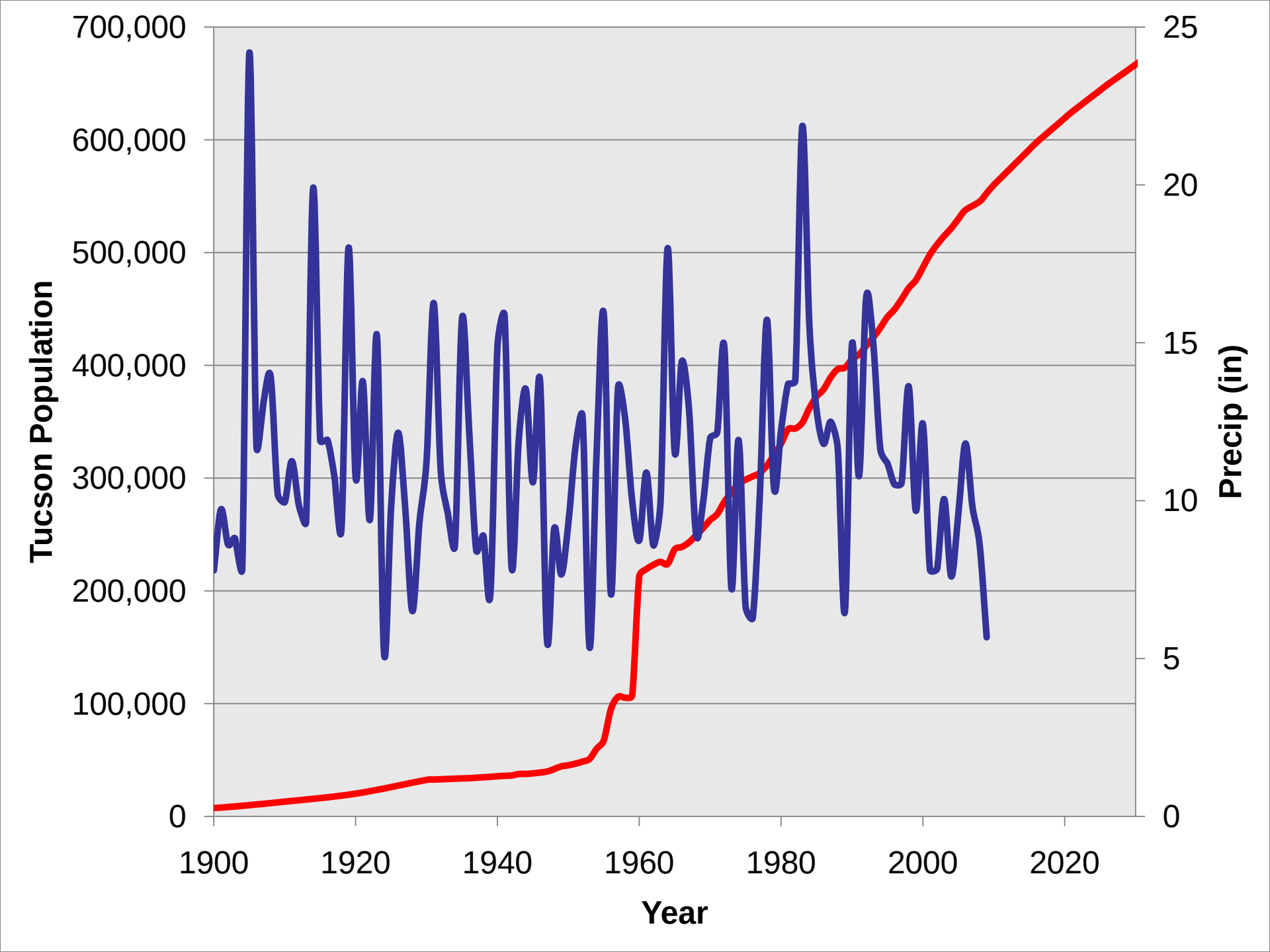
Natural Resources Defense Council (2010)

Tucson Precip Record

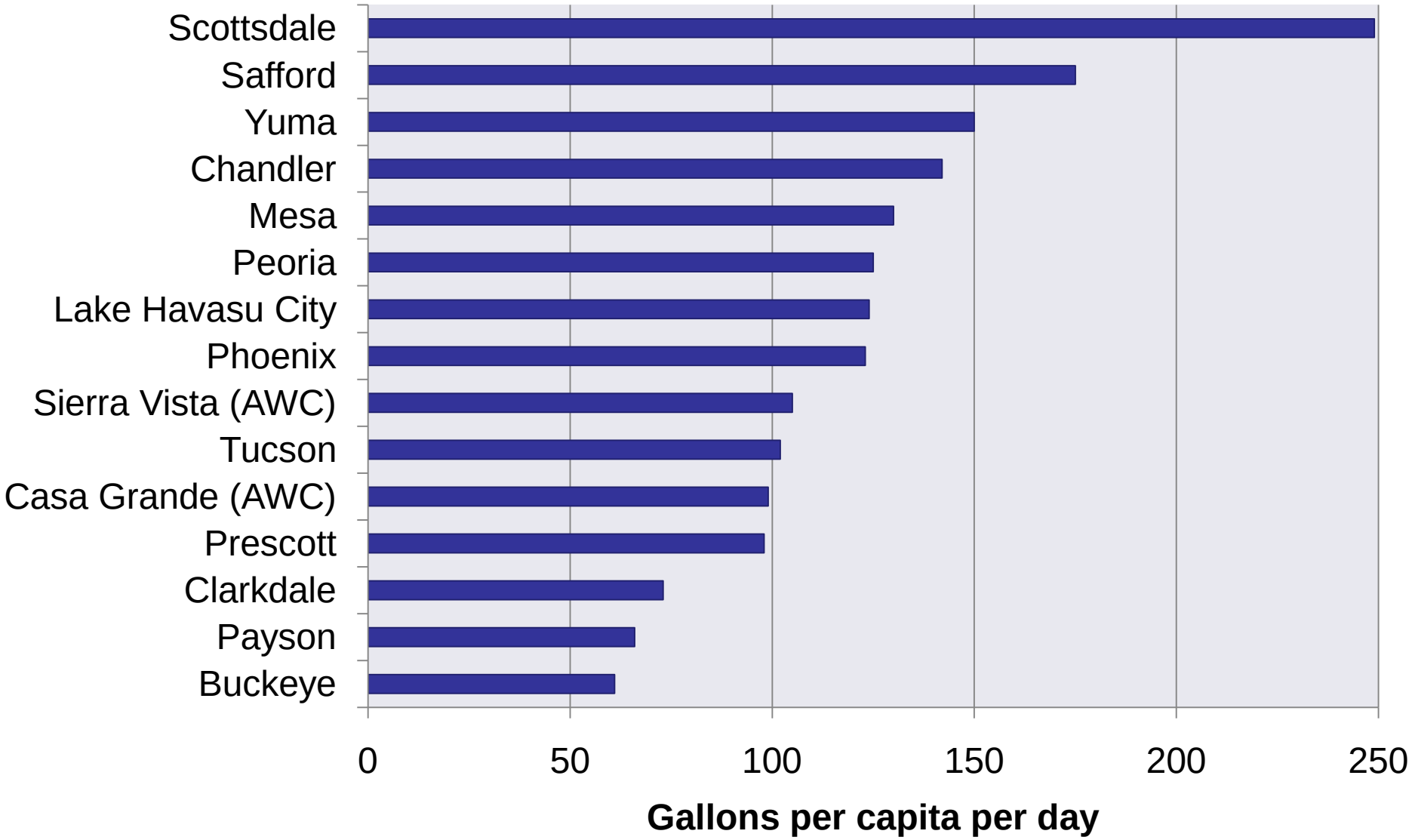


Historic & Projected Population




700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
Tucson Population
25
20
15
10
5
0
Precip (in)
1900
1920
1940
1960
1980
2000
2020
Year

Single family residential consumption (2008)



Data from Western Resource Advocates. 2010. Arizona Water Meter.

Household Water Conservation Milestones

- 1976—Beat the Peak
- 1984—Water wasting ordinance
- 1989—Plumbing ordinance for higher efficiency
- 1991—Xeriscaping ordinance for new construction
- 2004—Zanjero water auditing program
- 2007—Rainwater harvesting & graywater tax credit from AZ ($1,000)
- 2008—High-efficiency toilet rebate from Tucson Water ($200)
- 2010—Residential graywater ordinance requiring stub-outs
- 2010—Commercial rainwater harvesting ordinance for 50% of landscape irrigation
- 2011—Graywater rebate from Tucson Water ($200)
- 2011—Conserve to Enhance

Previous Research

- Why do people conserve water?
  - “Water conservation is one of the least investigated pro-environmental behaviors.” (Corral-Verdugo et al., 2002)
- Are current conservation initiatives effective?
  - “There are surprisingly few readily available formal evaluations of the effects of water conservation campaigns on domestic consumption.” (Syme et al., 2000)
- How does drought impact conservation?
  - The spatial and cumulative nature of drought has not been adequately explored with regards to household consumption.

Relevant Literature

- General environmental behavioral research
  - Education, income, sense of place, political affiliation
  - Attitudes do not equal behavior
- Water consumption studies
  - Water meter studies from 1967, meta-analyses
  - Income, household size, seasonality
- Water conservation studies
  - Pro-environmental attitude
  - Is water viewed as a resource to be used or conserved?
  - Water bill influences outdoor use, but indoor use inelastic
  - Regulation vs voluntary action
- No studies of individual water conservation behaviors?

Howe and Linaweaver (1967)

Water Conservation Methods

- Rainwater harvesting system
- Graywater system
- High-efficiency devices
- Xeriscaping
- Volunteerism for water conservation projects

Rainwater Harvesting

- Passive: depressions, basins
- Active: cisterns, tanks, rain barrels

Photos from WMG

Graywater

- Re-use of water from:
  - Washing machine
  - Sink
  - Shower/tub
  - Air conditioner condensate
- 32% of household wastewater can be utilized as graywater

Tucson Water (2011)

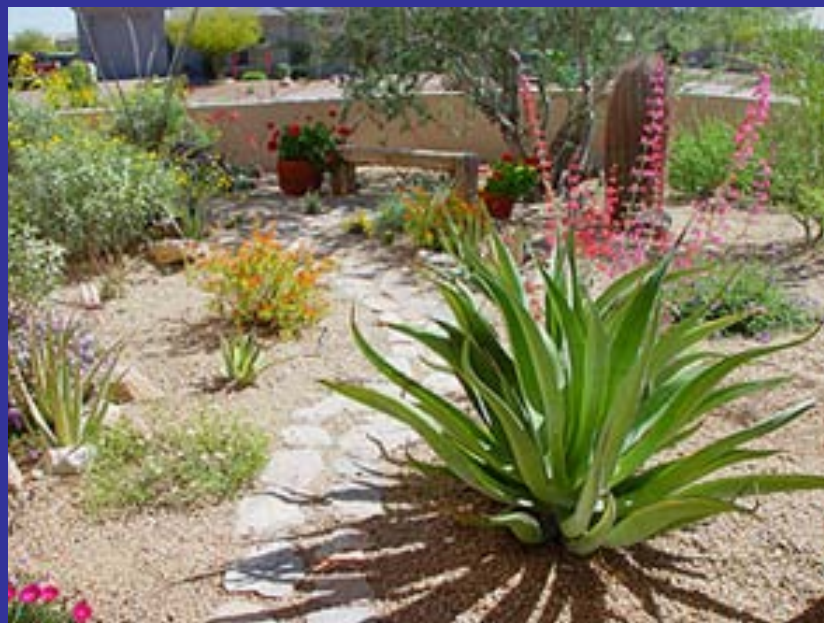
High-efficiency devices

- Toilets
- Washing machines
- Dishwashing machines
- Faucets
- Showerheads

EPA WaterSense

Xeriscaping

- Converting high-water use landscape to desert-adapted plants



Volunteerism

Photos from WMG

Mixed Methods Study Design

1. Survey designed with:
   - Tucson Water, Watershed Management Group, Ward 2 & 3 offices, Neighborhood Presidents, UA faculty, Tucson residents
   - Dept of Neighborhood Resources→NA president contact
   - 93 of 134 neighborhoods (69%)
   - 656 surveys returned
2. Summarize findings
3. Interviews
   - 24 interviews from 22 neighborhoods

Statistical Analysis

$$
\begin{aligned}
&logit\left\{\Pr\left(y_{ijk}=1\middle|x_{ijk},\zeta_{jk}^{(2)}+\zeta_{k}^{(3)}\right)\right\}\\
&\quad=\gamma_{111}+\beta_{2}x_{2ijk}+\pi_{11k}+\pi_{12}year_{2jk}+\pi_{13}educ_{3jk}+\pi_{14}income_{4jk}\\
&\quad+\pi_{15}own_{5jk}+\pi_{16}hshld\_size_{6jk}+\pi_{17}age_{7jk}+\pi_{18}involve_{8jk}\\
&\quad+\pi_{19}tucson\_yrs_{9jk}+\pi_{110}residence\_yrs_{10jk}+\pi_{111}star_{11jk}\\
&\quad+\pi_{112}citizen_{12jk}+\pi_{113}weekly_{13jk}+\pi_{114}zanjero_{14jk}\\
&\quad+\pi_{115}train_{15jk}+\pi_{116}backyard\_drought_{16jk}+\gamma_{117}\\
&\quad+\gamma_{118}water\_bill_{18k}+\gamma_{119}tucson\_drought_{19k}\\
&\quad+\gamma_{120}pima\_drought_{120k}+\gamma_{121}az\_drought_{21k}\\
&\quad+\gamma_{122}west\_drought_{22k}+\zeta_{jk}^{(2)}+\zeta_{k}^{(3)}
\end{aligned}
$$

- 5 simultaneous regression models
  - Longitudinal, multilevel, logistic
    - Level 1: Annual household observation
    - Level 2: Household variables
    - Level 3: Neighborhood variables
    - Level 4: City variables
    - Upper level models calculated 1st
- 1 combined model
  - Longitudinal, multilevel, ordinal logistic regression

Levels 1 & 2

Data Source: Household Survey

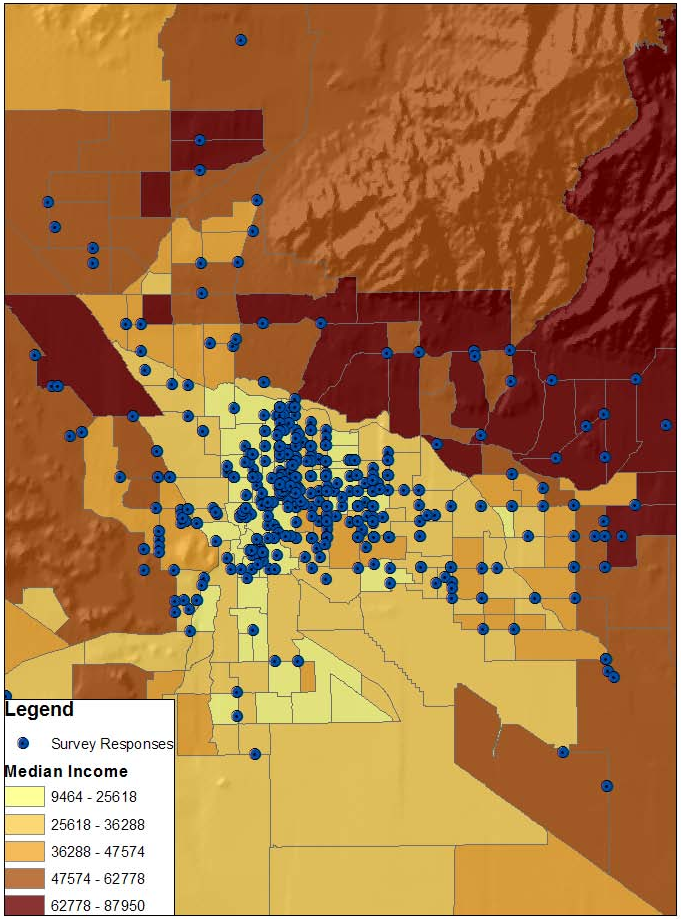
- Level 1: Annual household observation
- Level 2: Household characteristics
  - Own/rent
  - Income
  - Education
  - # in household
  - Age
  - Years in Tucson
  - Years at residence
  - Exposure to media
  - Community involvement
  - Utilization of education opportunities (Zanjero, UA trainings, WMG workshops, etc.)
  - Rebates and incentives (toilet and water harvesting/graywater)

Level 3 (Neighborhood Variables)

Data Source: US Census Bureau

- Geolocate households
- Extract data to hshlds for:
  - Income, educ, age, hshld size

Median Income

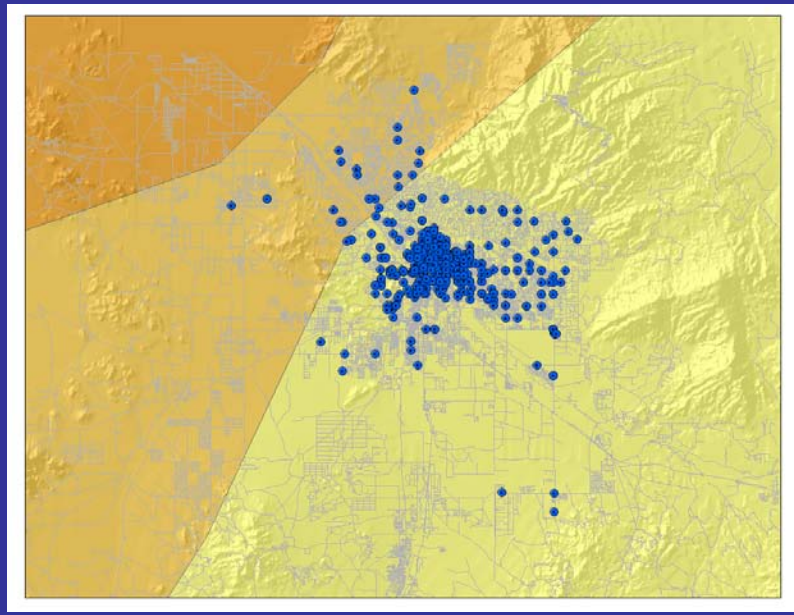


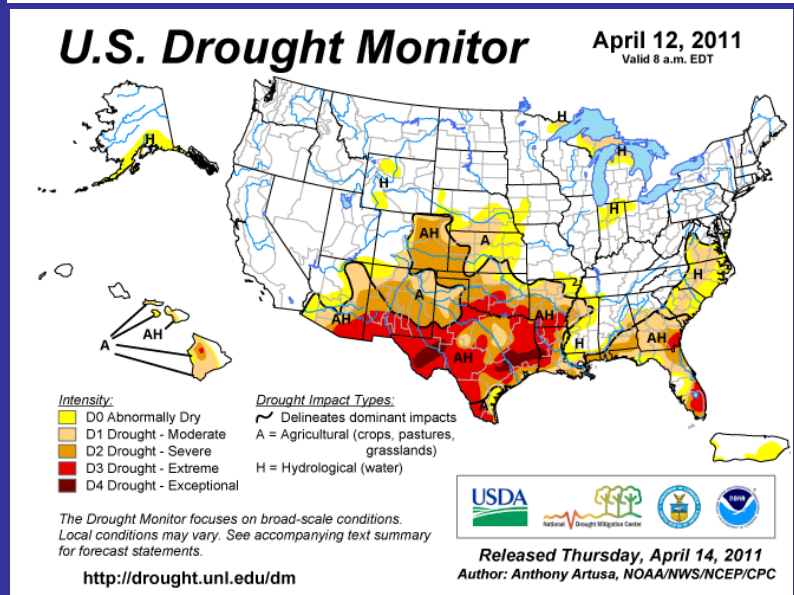
Level 4: Drought

Category	Description	Possible Impacts	Palmer Drought Index	CPC Soil Moisture Model (%)	USGS Weekly Streamflow (%)	Standardized Precip Index	Satellite Vegetation Health Index
D0	Abnormally Dry	Going into drought: short-term dryness slowing planting, growth of crops or pastures; fire risk above average. Coming out of drought: some lingering water deficits; pastures or crops not fully recovered.	-1.0 to -1.9	21-30	21-30	-0.5 to -0.7	36-45
D1	Moderate Drought	Some damage to crops, pastures; fire risk high; streams, reservoirs, or wells low, some water shortages developing or imminent, voluntary water use restrictions requested	-2.0 to -2.9	11-20	11-20	-0.8 to -1.2	26-35
D2	Severe Drought	Crop or pasture losses likely; fire risk very high; water shortages common; water restrictions imposed	-3.0 to -3.9	6-10	6-10	-1.3 to -1.5	16-25
D3	Extreme Drought	Major crop/pasture losses; extreme fire danger; widespread water shortages or restrictions	-4.0 to -4.9	3-5	3-5	-1.6 to -1.9	6-15
D4	Exceptional Drought	Exceptional and widespread crop/pasture losses; exceptional fire risk; shortages of water in reservoirs, streams, and wells, creating water emergencies	-5.0 or less	0-2	0-2	-2.0 or less	1-5

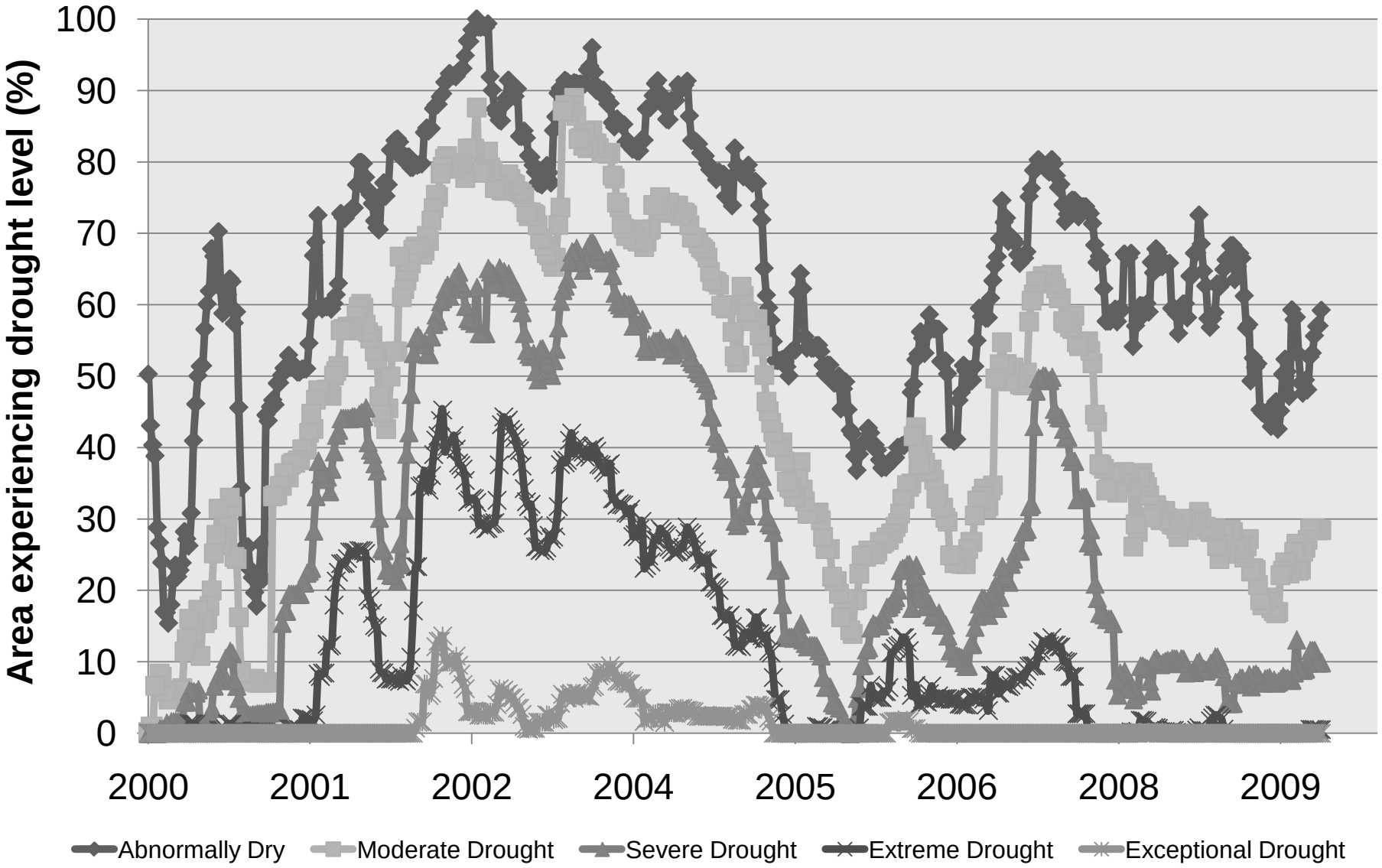
Spatial Extent & Severity

- U.S. Drought Monitor Data (10 yrs x 52 wks)
  - Backyard (Level 2)
  - Tucson
  - Pima Co.
  - Arizona
  - West





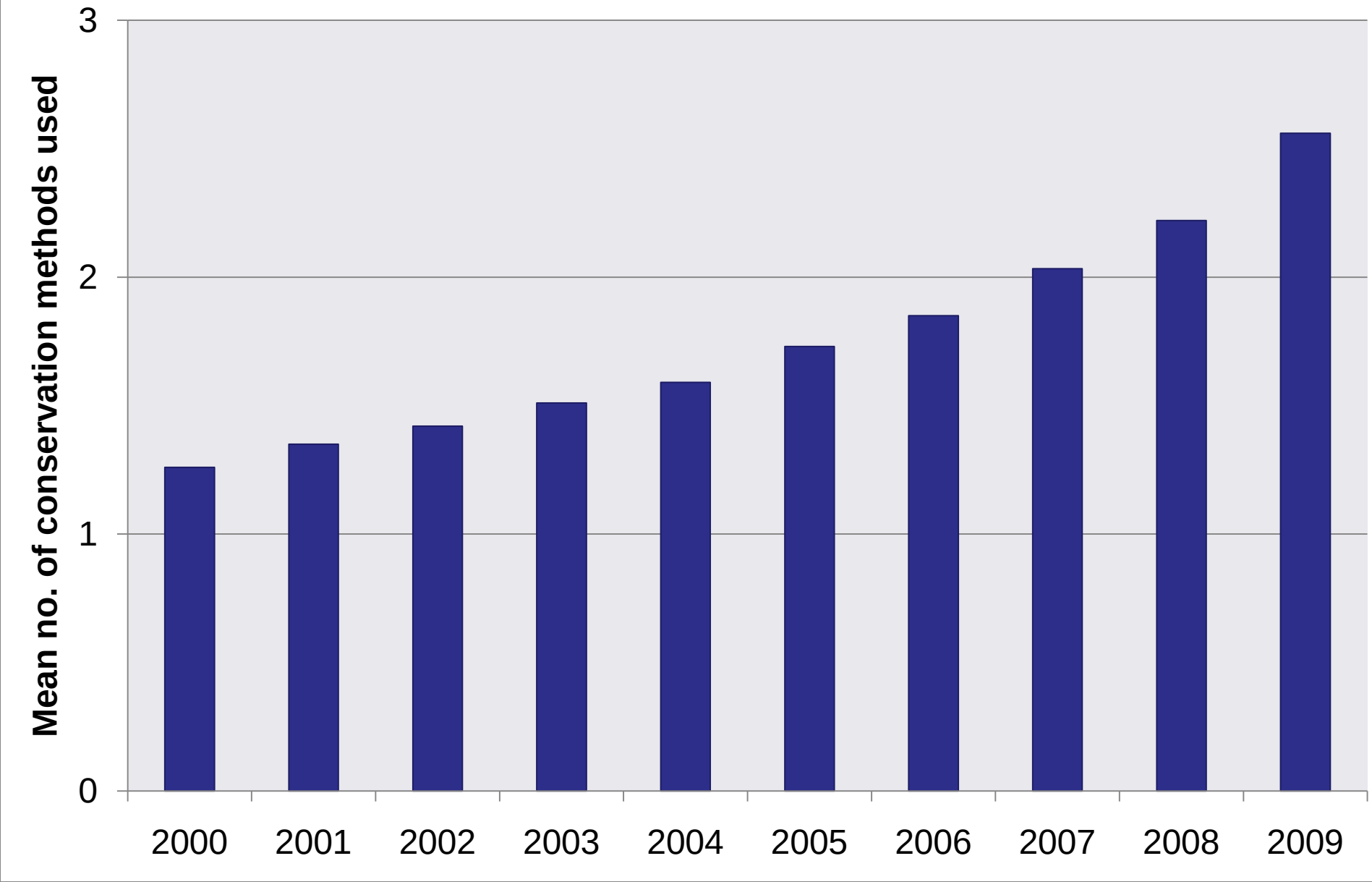
Drought in the West (2000-2009)

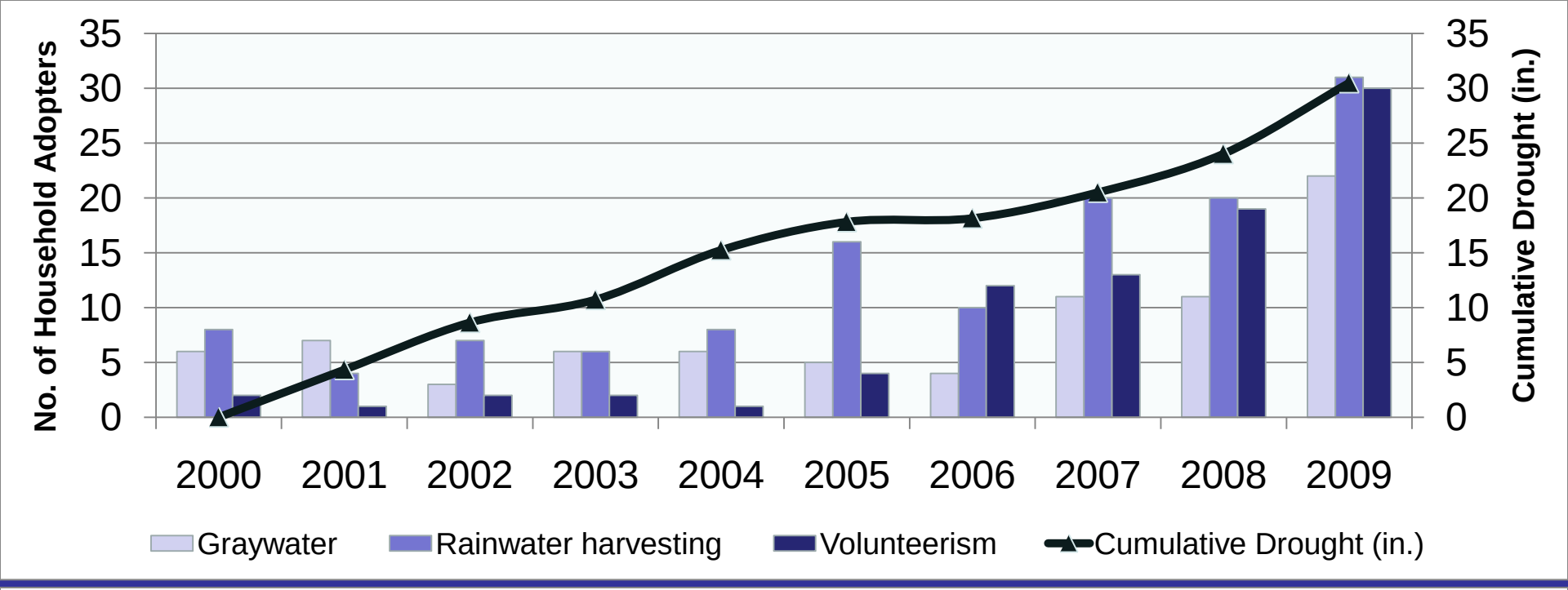


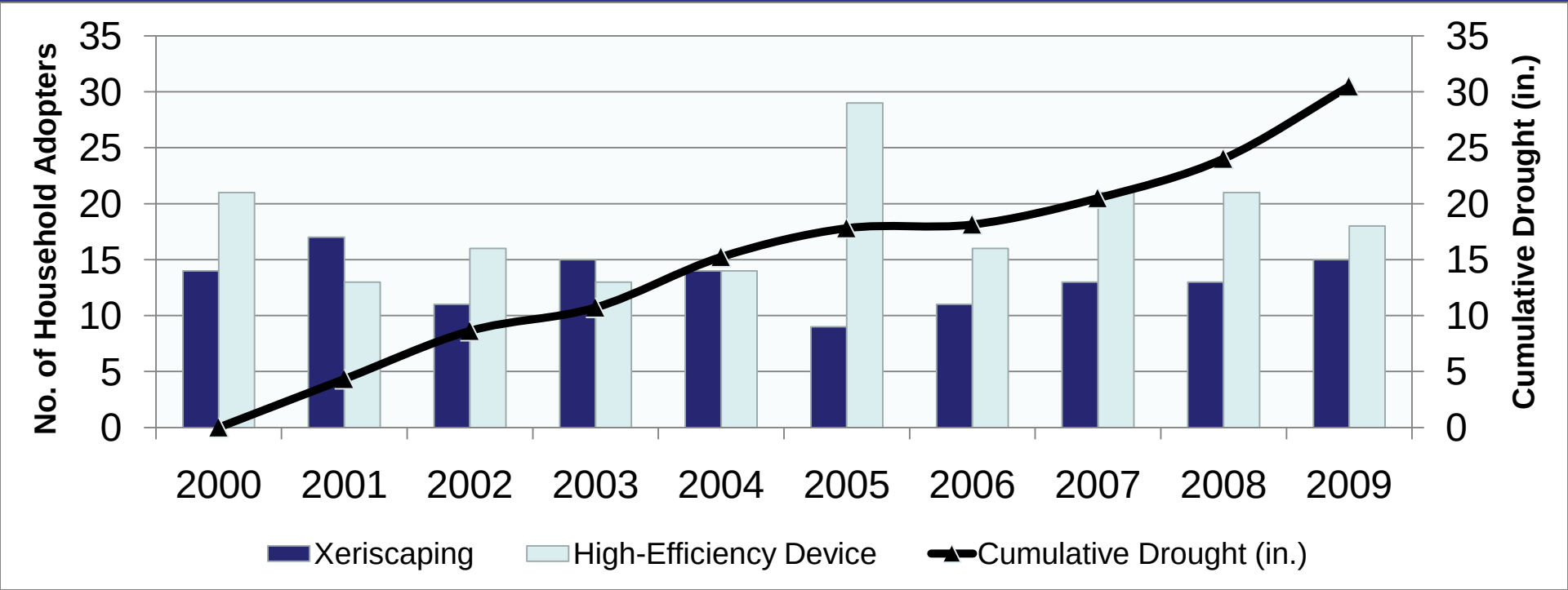
Semi-structured interviews

1. Interpretation of results
2. Utility of ordinances, financial incentives, education programs, water rates, drought awareness, other factors
3. Household response to drought—spatial & severity
4. Life experiences that shaped water conservation behavior
5. Fluctuations in conservation effort

Results: Conservation Method Adoption




No. of Household Adopters
Cumulative Drought (in.)
0
5
10
15
20
25
30
35
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Graywater
Rainwater harvesting
Volunteerism
Cumulative Drought (in.)


No. of Household Adopters
Cumulative Drought (in.)
0
5
10
15
20
25
30
35
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
Xeriscaping
High-Efficiency Device
Cumulative Drought (in.)

How important have the following factors been to your household's water conservation efforts?

Factor	Households reporting factor as “Important” or “Very Important”
1. Improve or protect the environment	414
2. Desire to improve your community	330
3. Save money on water bill	312
4. Use of water conservation methods by other people in your community	196
5. Information received from family or friends	135
6. Information received from a water conservation education event or workshop	129
7. Information received from television, radio or print media	100
8. Tax rebates or financial incentives available from the city or state	89
9. Information received from Tucson Water’s Zanjero water-auditing program	35

Full Model

- Use likelihood ratio tests for model-building

Variable	Gray	Harvest	Volunt	Xeri	Devices	All
year	0 .9772***	1.3981***	1.7613***	1.3073***	1.5610***	0.1349***
	(0.0976)	(0.1552)	(0.3913)	(0.1323)	(0.2134)	(0.0147)
harvest_graywater_credit	11.3515***	5.8389**				0.6634***
	(2.7798)	(1.8316)				(0.1413)
toilet rebate					1.6527	0.6342***
					(1.9088)	(0.1196)
zanjero	7.5871*	2.0139	0.0567	1.3224	1.6276	0.3908**
	(2.9467)	(2.7012)	(2.3477)	(1.4772)	(2.6467)	(0.1395)
own_home	0.6881	9.6679***	-0.6696	9.2980***	9.2430***	1.2628***
	(1.0541)	(1.6095)	(1.6986)	(1.3635)	(2.3106)	(0.1355)
hshld_size	-0.1172	-0.8834	1.4326**	-0.1789	0.5220	0.0428
	(0.3014)	(0.6056)	(0.5326)	(0.4507)	(0.5634)	(0.0314)
age	0.0073	0.0235	-0.0924*	0.0017	0.0666	0.0029
	(0.0296)	(0.0534)	(0.0425)	(0.0451)	(0.0484)	(0.0029)
tucsonyrs	-0.0318	0.0728	-0.0539	-0.0090	0.0373	0.0015
	(0.0310)	(0.0473)	(0.0506)	(0.0473)	(0.0474)	(0.0028)
residenceyrs	0.1486**	-0.0158	0.0165	0.2368**	0.2559***	0.0003
	(0.0440)	(0.0698)	(0.0743)	(0.0685)	(0.0563)	(0.0038)
star	0.1077	-0.8481	-0.6691	0.3483	1.6032	0.0151
	(0.6809)	(0.9233)	(1.1069)	(0.8417)	(0.8368)	(0.0723)
citizen	0.2469	0.0987	-0.7795	-0.1714	-0.4208	-0.0203
	(0.7809)	(1.3041)	(1.2794)	(1.2218)	(1.0299)	(0.0801)
weekly	-0.3311	3.5434*	4.1782**	4.5631***	1.7085*	0.5279***
	(0.7247)	(1.3831)	(1.5309)	(1.2379)	(0.8647)	(0.0715)
training	0.1229	0.3254**	1.7198***	0.4253	0.2221	0.1144***
	(0.1619)	(0.1012)	(0.1913)	(0.2169)	(0.1621)	(0.0198)
involve	0.6628***	1.1778***	1.1199***	1.1073***	0.2989	0.1918***
	(0.1645)	(0.2151)	(0.2796)	(0.2579)	(0.2054)	(0.0179)
educ	-0.1237	0.1699	-0.5097	0.8516**	0.1283	0.0052
	(0.1632)	(0.3137)	(0.2813)	(0.2574)	(0.2165)	(0.0175)
income	-0.4113	-0.4014	-0.8083	0.3781	0.3991	-0.1317***
	(0.2691)	(0.3222)	(0.4789)	(0.3111)	(0.3279)	(0.0278)
water_bill	0.3675*	0.2424	1.1764***	0.0975	0.0411	0.0398
	(0.1809)	(0.1694)	(0.3337)	(0.1806)	(0.1723)	(0.0317)
backyard_DM2	-0.0599	0.0379	0.0008	0.0071	-0.0479	-0.0433**
	(0.0805)	(0.0789)	(0.1294)	(0.1168)	(0.0769)	(0.0159)
tucson_DM2	0.0502	0.0399	-0.0326	0.0055	0.0571	0.0276**
	(0.0472)	(0.0449)	(0.0770)	(0.0641)	(0.0453)	(0.0092)
pima_DM2	-0.0066	-0.0236	0.0189	-0.0125	-0.0126	-0.0007
	(0.0141)	(0.0131)	(0.0277)	(0.0139)	(0.0125)	(0.0028)
az_DM2	-0.0063	0.0046	0.0012	0.0136	0.0063	-0.0004
	(0.0156)	(0.0145)	(0.0306)	(0.0145)	(0.0134)	(0.0031)
west_DM2	0.0200	-0.0411	0.0238	-0.007	-0.0436	-0.0012
	(0.0286)	(0.0265)	(0.0576)	(0.0259)	(0.0251)	(0.0056)

- Logistic regression
  - Coefficients
  - Odds ratio
  - Predicted probabilities

Variable	harvest	gray	volunt	xeri	devices	all
year	1.6788*** (5.4)	1.1499*** (3.2)	1.7668*** (5.9)	1.2825*** (3.6)	1.7310*** (5.6)	0.1769*** (1.2)
educ				0.5909* (1.8)		
hshld size			1.4305 (4.2)			
income	-0.5498* (0.6)		-0.7752 (0.5)			-0.0439 (0.9)
age			-0.1176* (0.9)		0.1055* (1.1)	
own home	7.4287*** (1683.6)			7.3816*** (1606.2)	8.9684*** (7850.6)	1.2488*** (3.5)
residence yrs		0.1205 (1.1)		0.2261*** (1.3)		
tucson yrs	0.0492* (1.1)					
involve	0.8979*** (2.5)	1.1648** (3.2)	0.9826** (2.7)	1.1889*** (3.3)		0.2007*** (1.2)
star					1.3829 (3.9)	
weekly	1.7469* (5.7)		2.2109* (9.1)	2.3266* (10.2)		0.2759*** (1.3)
toilet rebate						0.5048*** (1.7)
training	0.4278** (1.5)		1.7325*** (5.75)	0.3717* (1.5)		0.1351*** (1.1)
zanjero		2.5638 (12.9)				0.3342* (1.4)
water bill	0.5613*** (1.8)	0.6476*** (1.9)	0.6421*** (1.9)		0.2721* (1.3)	
factor environ	2.0365*** (7.7)	2.1772*** (8.8)	1.7651* (5.8)	1.7266*** (5.6)	1.2442*** (3.5)	0.4073*** (1.5)
Tucson DM2	0.0159 (1.0)					
West DM1		0.02467* (1.0)				
Odds ratios in parentheses; ***p<0.001, **p<0.01, *p<0.05						

- H=Harvest
- G=Graywater
- V=Volunteerism
- X=Xeriscaping
- D=Devices

Variable	5 Discrete Methods	Cumulative Methods
Year	(H,G,V,X,D): 4.7	1.2
Education	(X): 1.8	
Income	(H,V): -0.5	-0.04
Household size	(V): 4.2	
Home ownership	(H,X,D): 3713.5	3.5
Involve	(H,G,V,X): 2.9	1.2
Environmentally-motivated	(H,G,V,X,D): 6.3	1.5
Media	(H,V,X,D): 7.3	1.3
Toilet rebate		1.7
Training	(H,V,X): 2.9	1.2
Zanjero Program	(G): 12.9	1.4
Water bill	(H,G,V,D): 1.7	
Drought	(H,G): 1.02	

- Time effect highly significant

Variable	5 Discrete Methods	Cumulative Methods
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- Educ & income→ expected effect
- Household size increases consumption in previous studies→here it increases odds of volunt

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- Home ownership—not sig for G&V
- Social & environmental altruism

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- Weekly sig to H,V,X,& cumulative
- Star sig to D
- Citizen insig to all

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Drought	(H,G): 1.02	

- Toilet rebate insig to D
- $1,000 tax credit insig

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Year	(H,G,V,X,D): 4.7	1.2
Education	(X): 1.8	
Income	(H,V): -0.5	-0.04
Household size	(V): 4.2	
Home ownership	(H,X,D): 3713.5	3.5
Involve	(H,G,V,X): 2.9	1.2
Environmentally-motivated	(H,G,V,X,D): 6.3	1.5
Media	(H,V,X,D): 7.3	1.3
Toilet rebate		1.7
Training	(H,V,X): 2.9	1.2
Zanjero Program	(G): 12.9	1.4
Water bill	(H,G,V,D): 1.7	
Drought	(H,G): 1.02	

- Water bill—broadly sig
- Tucson_DM2 sig to H
- West_DM1 sig to G

Variable	5 Discrete Methods	Cumulative Methods
Year	(H,G,V,X,D): 4.7	1.2
Education	(X): 1.8	
Income	(H,V): -0.5	-0.04
Household size	(V): 4.2	
Home ownership	(H,X,D): 3713.5	3.5
Involve	(H,G,V,X): 2.9	1.2
Environmentally-motivated	(H,G,V,X,D): 6.3	1.5
Media	(H,V,X,D): 7.3	1.3
Toilet rebate		1.7
Training	(H,V,X): 2.9	1.2
Zanjero Program	(G): 12.9	1.4
Water bill	(H,G,V,D): 1.7	
Drought	(H,G): 1.02	

- Cumulative methods have much smaller magnitude

Variable	5 Discrete Methods	Cumulative Methods
Year	(H,G,V,X,D): 4.7	1.2
Education	(X): 1.8	
Income	(H,V): -0.5	-0.04
Household size	(V): 4.2	
Home ownership	(H,X,D): 3713.5	3.5
Involve	(H,G,V,X): 2.9	1.2
Environmentally-motivated	(H,G,V,X,D): 6.3	1.5
Media	(H,V,X,D): 7.3	1.3
Toilet rebate		1.7
Training	(H,V,X): 2.9	1.2
Zanjero Program	(G): 12.9	1.4
Water bill	(H,G,V,D): 1.7	
Drought	(H,G): 1.02	

Interview Results
(24 households from 22 neighborhoods)

1. Water bill→most influential factor but need personalized info

   "[The] water bill is a big factor. Water bill includes, trash and sewer now. So it's confusing when people talk about their water bill. Mine averages between 50 and 65 dollars, but the water is only about 1/3 of that."

2. Drought not doing much directly

   "This is a desert. Drought doesn't change behavior. It's always dry here"

3. Life experiences in other places most common for forming water conservation behavior

   "I've spent some time in Spain and Mexico. In those countries people want lush plants around, but they put them in pots and planters. So the landscape is xeriscaped on the outside of the house, but inside the house and the courtyard there are some high-water use plants. This is what I try to do in my home."

How is this information useful?

- We can’t change home ownership, educ, income
- But, we can change:
  - More informative water bills: drought messages & personalized water use info
  - 2007 survey of Tucson residents: 87% of people think they use below avg
  - Training, conservation education, financial incentives are effective
- Results shared with community stakeholders

Glennon, 2009; Barrett, 2004; Tucson Water, 2009

Future Research

- Does adoption lead to conservation?
  - Examine water volume used pre- and post-adoption
  - Harvest and graywater→more landscaping?
- Social pressure & norming
- Quantify water volume saved relative to cost of implementation & cost of initiatives

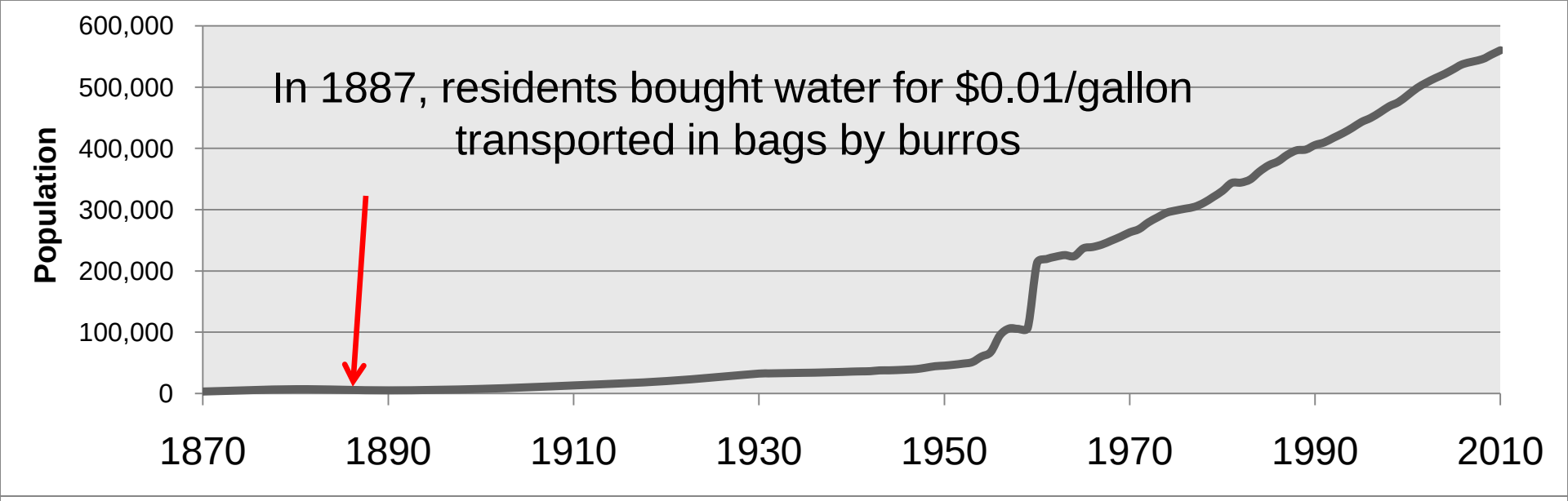
Conclusions

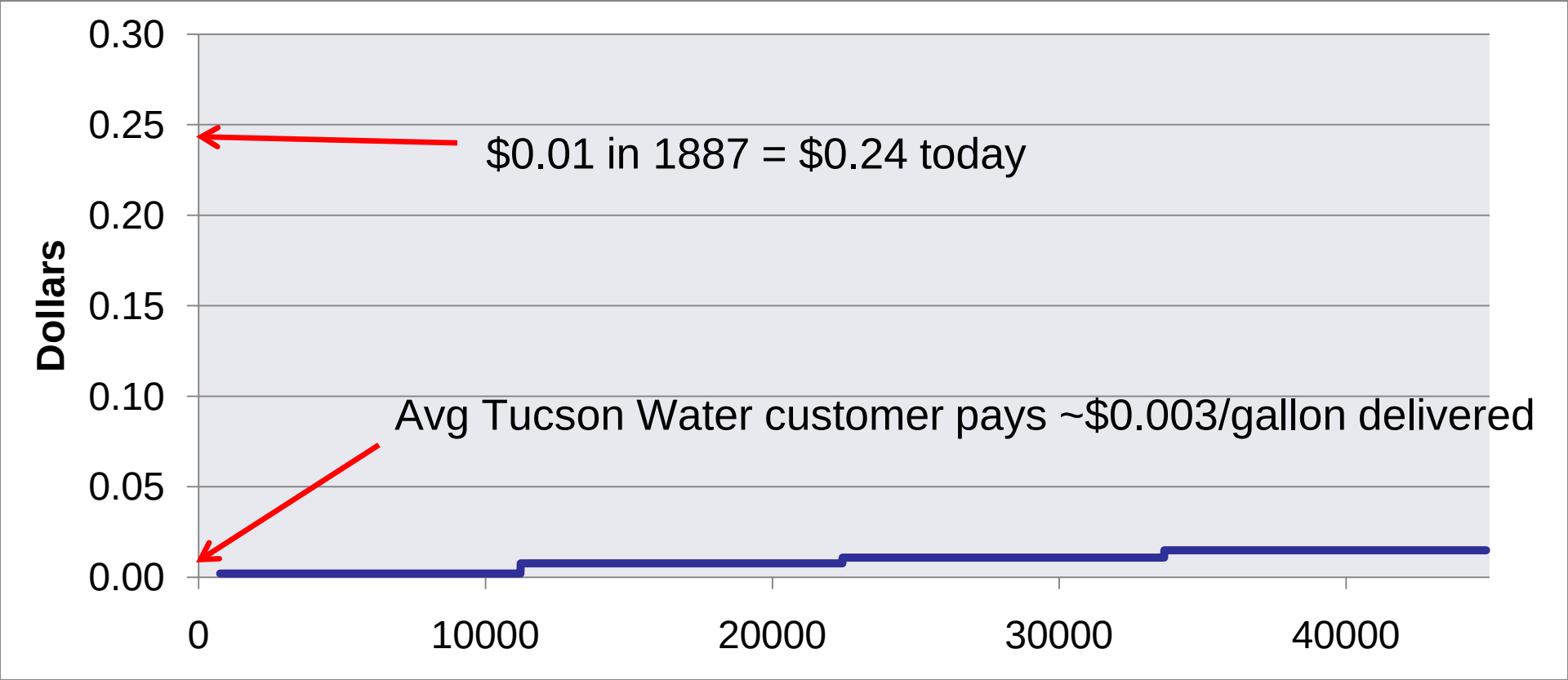
- Rainwater harvesting, graywater, volunteerism increased across the decade
- Xeriscaping & high-efficiency device adoption were flat
- Variables have more impact on individual methods than cumulative methods
- Water bill is significant, but can be improved
- Drought had little direct impact, but messaging can improve

Social Movements: Structural-strain framework

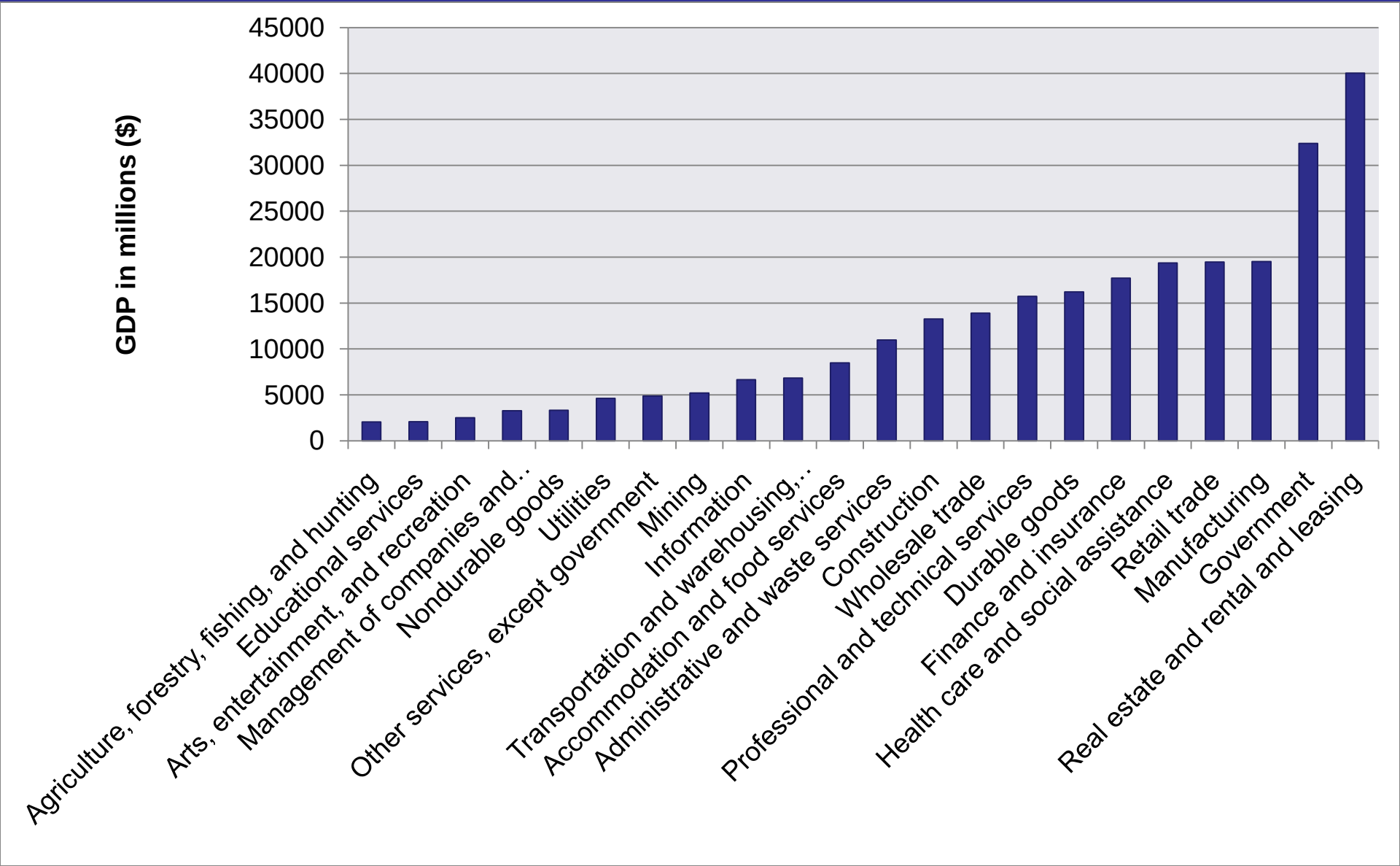
1. *Problem recognition*—water insecurity; started in 1970s
2. *Structural strain*—people deprived of something (e.g. secure water supply); solution proposed & spreads
3. *Precipitating factors*—adds urgency to the cause; transforms awareness to social movement (e.g. drought).
4. *Spread without control*—establishment of social norms (e.g. ordinances)
5. *Full mobilization*

Smelser, 1962

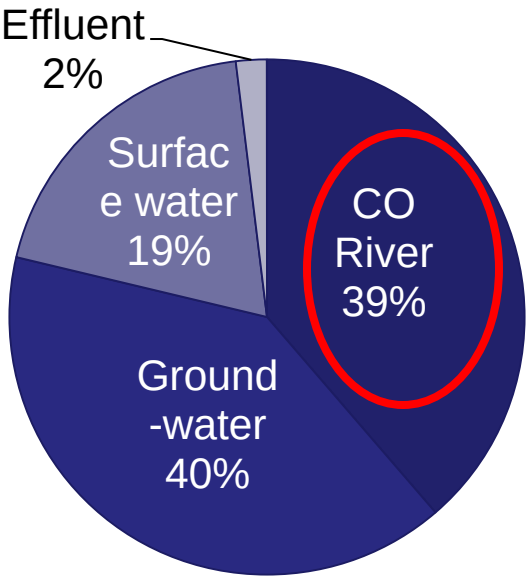

600,000
500,000
400,000
300,000
200,000
100,000
0
Population
In 1887, residents bought water for $0.01/gallon
transported in bags by burros
1870
1890
1910
1930
1950
1970
1990
2010

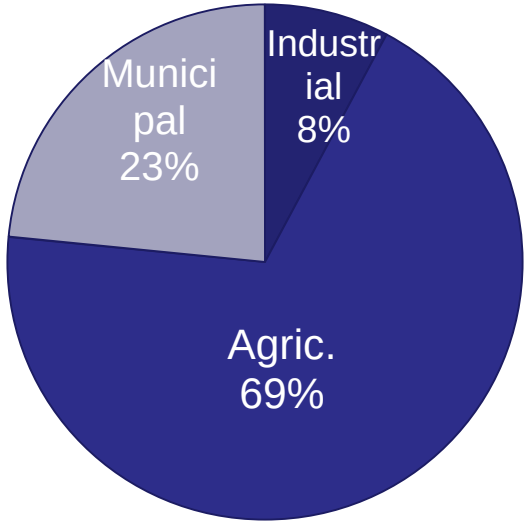

0.30
0.25
0.20
0.15
0.10
0.05
0.00
Dollars
$0.01 in 1887 = $0.24 today
Avg Tucson Water customer pays ~$0.003/gallon delivered
0
10000
20000
30000
40000

Arizona GDP by Sector

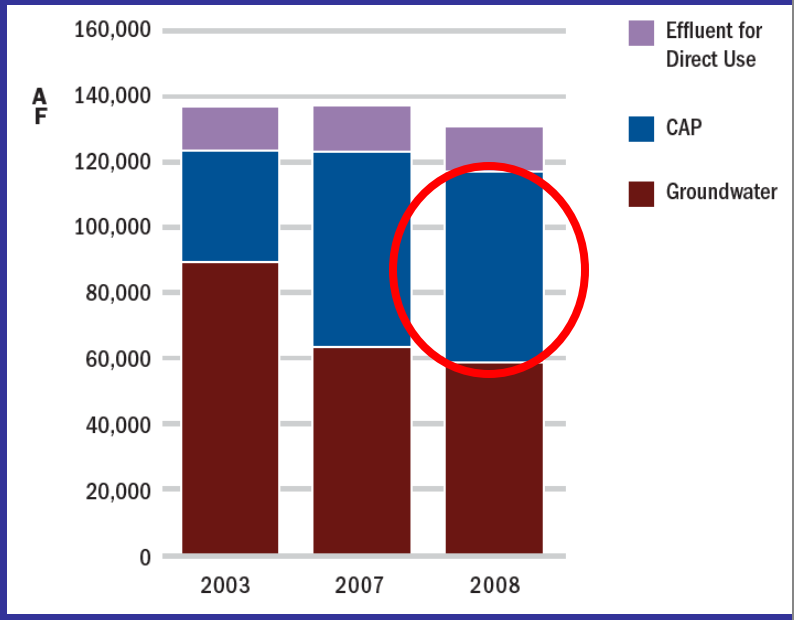


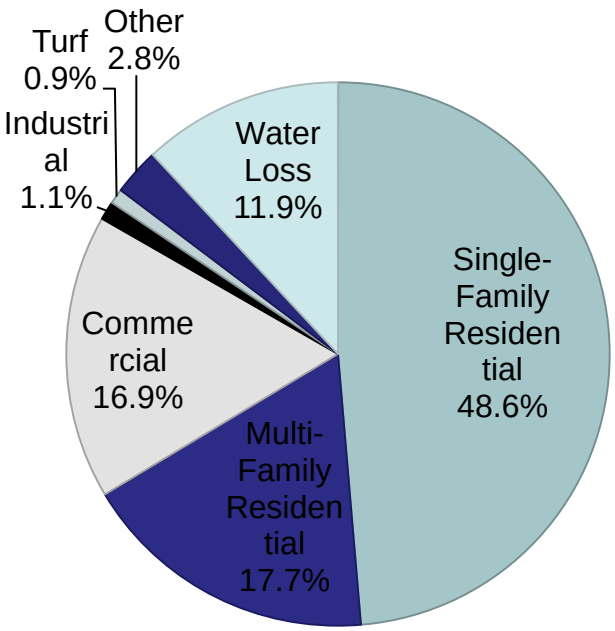
AZ





Tucson



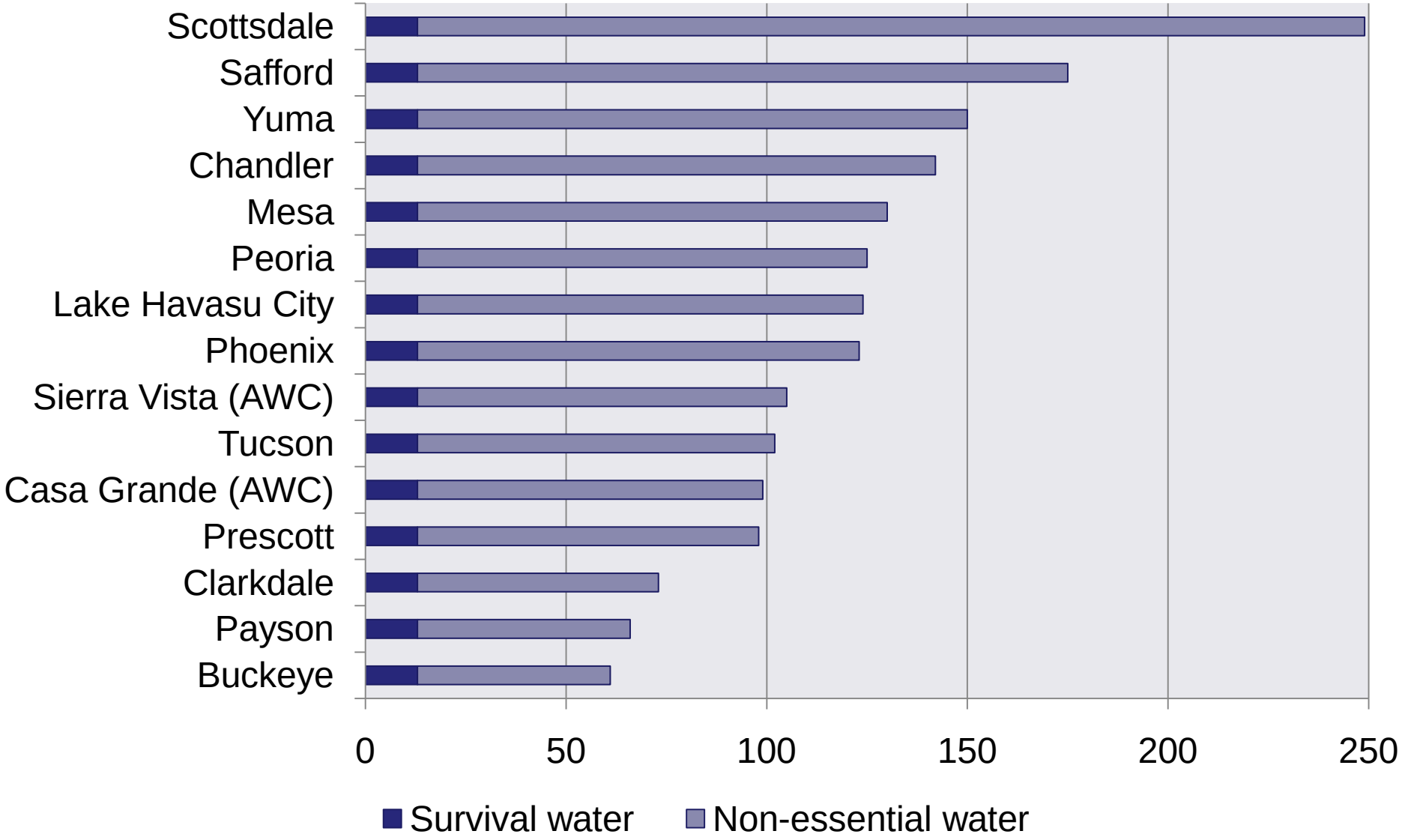


Western Resource Advocates (2010); Tucson Water (2008)

Water Lifeline

- 6.5 gallons—basic needs
- 6.5 gallons—cleaning

AZ Water Use


Scottsdale
Safford
Yuma
Chandler
Mesa
Peoria
Lake Havasu City
Phoenix
Sierra Vista (AWC)
Tucson
Casa Grande (AWC)
Prescott
Clarkdale
Payson
Buckeye
0
50
100
150
200
250
Survival water
Non-essential water

WATER RESOURCES RESEARCH, VOL. 44, W03201, doi:10.1029/2007WR006704,

Click Here for Full Article

When will Lake Mead go dry?

Tim P. Barnett[1] and David W. Pierce[1]

Received 27 November 2007; revised 22 January 2008; accepted 5 February 2008; published 29 March 2008.

[1] A water budget analysis shows that under current conditions there is a 10% chance that live storage in Lakes Mead and Powell will be gone by about 2013 and a 50% chance that it will be gone by 2021 if no changes in water allocation from the Colorado River system are made. This startling result is driven by climate change associated with global warming, the effects of natural climate variability, and the current operating status of the reservoir system. Minimum power pool levels in both Lake Mead and Lake Powell will be reached under current conditions by 2017 with 50% probability. While these dates are subject to some uncertainty, they all point to a major and immediate water supply problem on the Colorado system. The solutions to this water shortage problem must be time-dependent to match the time-varying, human-induced decreases in future river flow.

Model Projections of an Imminent Transition to a More Arid Climate in Southwestern North America

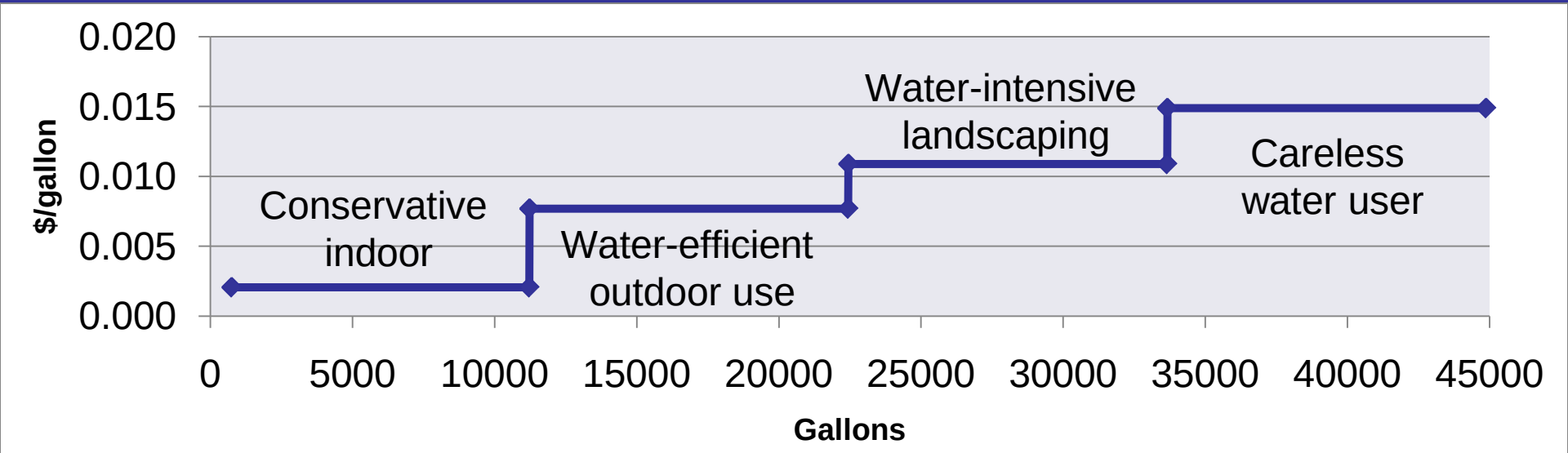
Richard Seager,[1]* Mingfang Ting,[1] Isaac Held,[2,3] Yochanan Kushnir,[1] Jian Lu,[4] Gabriel Vecchi,[2] Huei-Ping Huang,[1] Nili Harnik,[5] Ants Leetmaa,[2] Ngar-Cheung Lau,[2,3] Cuihua Li,[1] Jennifer Velez,[1] Naomi Naik[1]

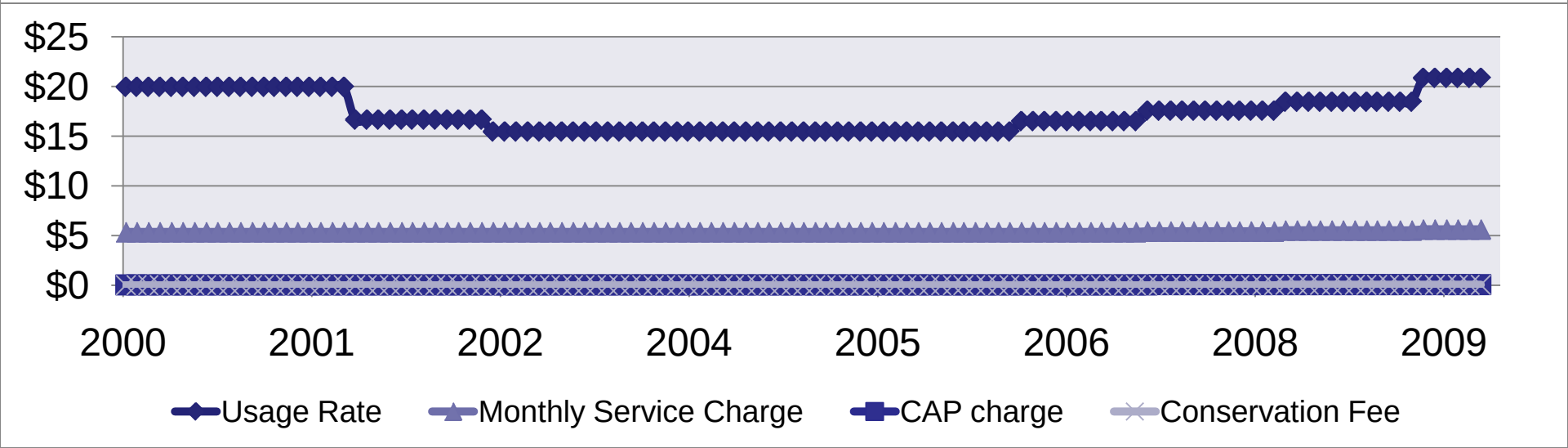
How anthropogenic climate change will affect hydroclimate in the arid regions of southwestern North America has implications for the allocation of water resources and the course of regional development. Here we show that there is a broad consensus among climate models that this region will dry in the 21st century and that the transition to a more arid climate should already be under way. If these models are correct, the levels of aridity of the recent multiyear drought or the Dust Bowl and the 1950s droughts will become the new climatology of the American Southwest within a time frame of years to decades.

Barnett and Pierce, 2008;
Seager et al., 2007

Level 4 (City Variables)

Data source: Tucson Water





Mixed Methods: Convergence of Results

- Social & environmental altruism significant
- Drought not directly significant
- Water bill moderately effective, along with Zanjero program, training, and toilet rebate

Water Conservation Initiatives

	# utilized	# eligible	%
Rainwater/Graywater $1,000 tax credit (began in 2007)	47	165	28%
Toilet $200 rebate (began in 2008)	51	65	78%
Zanjero Water-Auditing Program (began in 2004)	34	613	5%

Limitations of the design

- Sample came from neighborhood associations
  - Likely more civically involved individuals
  - Mean age=50; U.S. Census Bureau=33
- Data was collected retroactively