Uncertainty in Integrated Modeling for Decision Support: the Decision Center for a Desert City

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TOY Uncertainty Workshop
NCAR
August 13, 2012
Boulder, CO

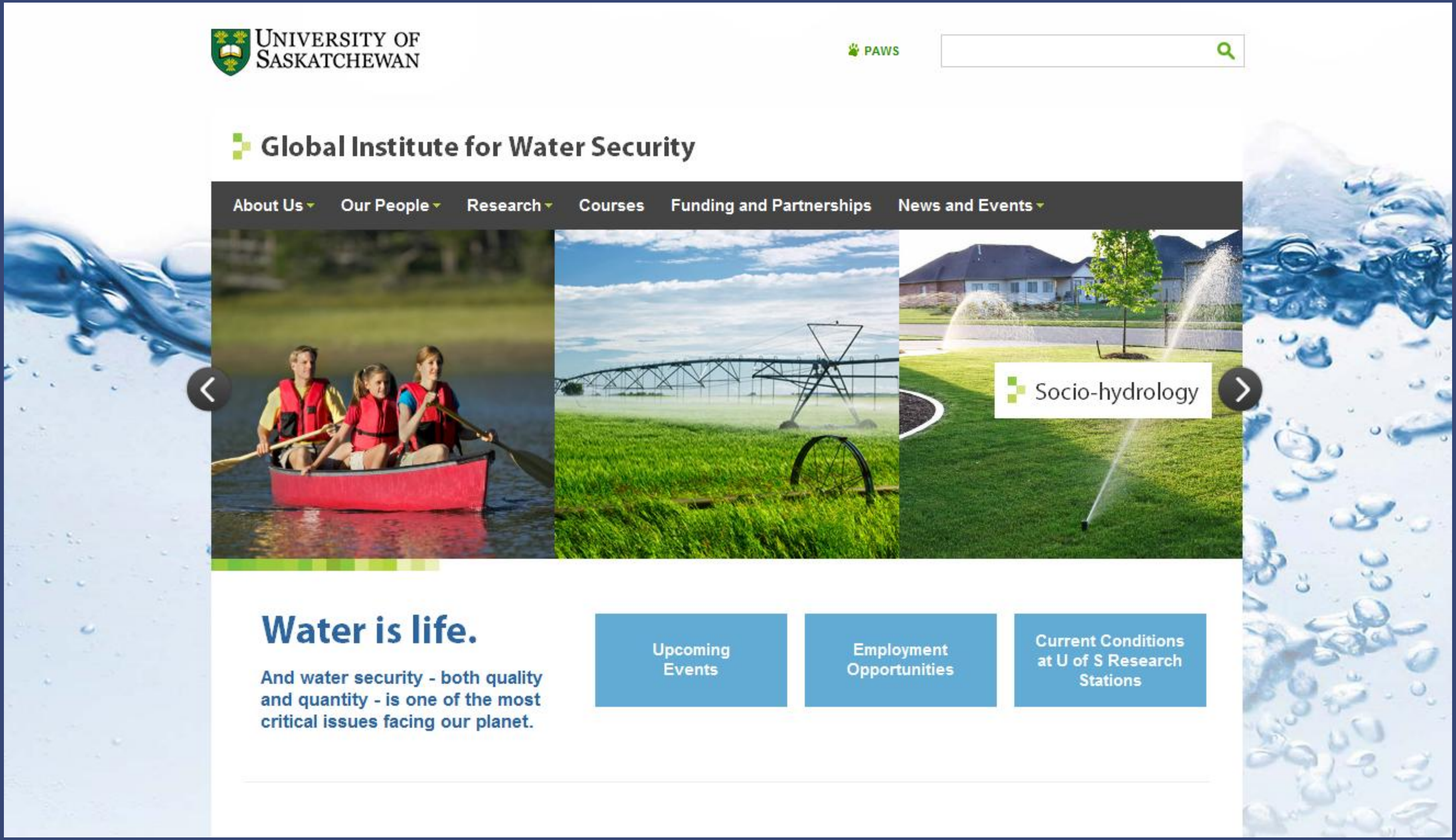
ASU GLOBAL INSTITUTE of SUSTAINABILITY
ARIZONA STATE UNIVERSITY

Decision Center for a Desert City II

Background:

- NSF’s Decision Making Under Uncertainty (DMUU) Initiative
- Reframe climate change question to focus on decision making
- Create “what if” scenarios under conditions of policy change
- Boundary organization

Global Institute for Water Security



UNIVERSITY OF SASKATCHEWAN

PAWS

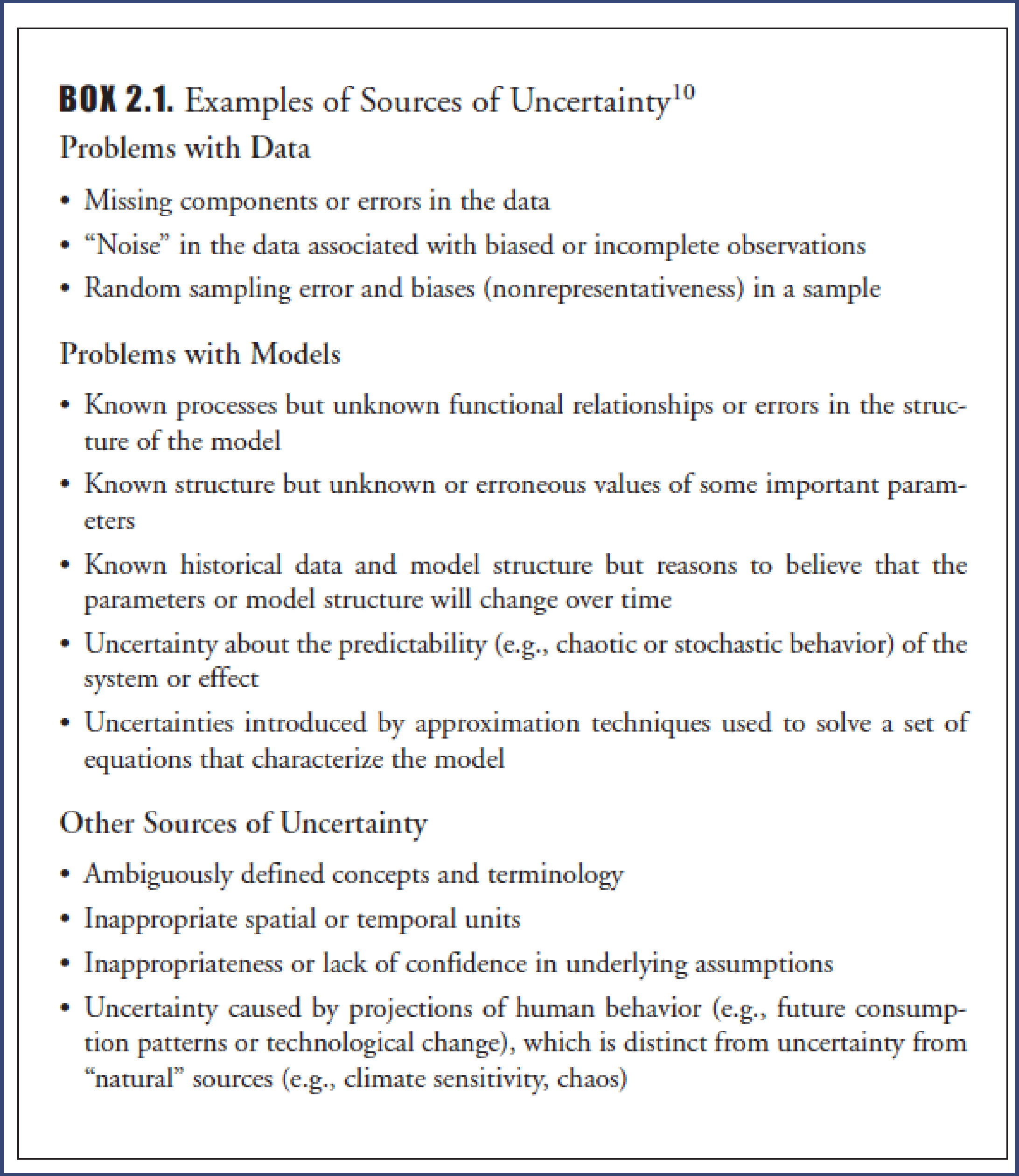
Global Institute for Water Security

Water is life.

And water security - both quality and quantity - is one of the most critical issues facing our planet.

Today’s Presentation

- Integrated modeling for decision support
  - WaterSim 1.0-5.0
  - Process more than a product
- Approaches for dealing with uncertainty—sensitivity analysis, scenario planning, consultation and deliberation
- Research outputs
- Stakeholder engagement—what we learned from decision makers



BOX 2.1. Examples of Sources of Uncertainty[10]

Problems with Data

- Missing components or errors in the data
- "Noise" in the data associated with biased or incomplete observations
- Random sampling error and biases (nonrepresentativeness) in a sample

Problems with Models

- Known processes but unknown functional relationships or errors in the structure of the model
- Known structure but unknown or erroneous values of some important parameters
- Known historical data and model structure but reasons to believe that the parameters or model structure will change over time
- Uncertainty about the predictability (e.g., chaotic or stochastic behavior) of the system or effect
- Uncertainties introduced by approximation techniques used to solve a set of equations that characterize the model

Other Sources of Uncertainty

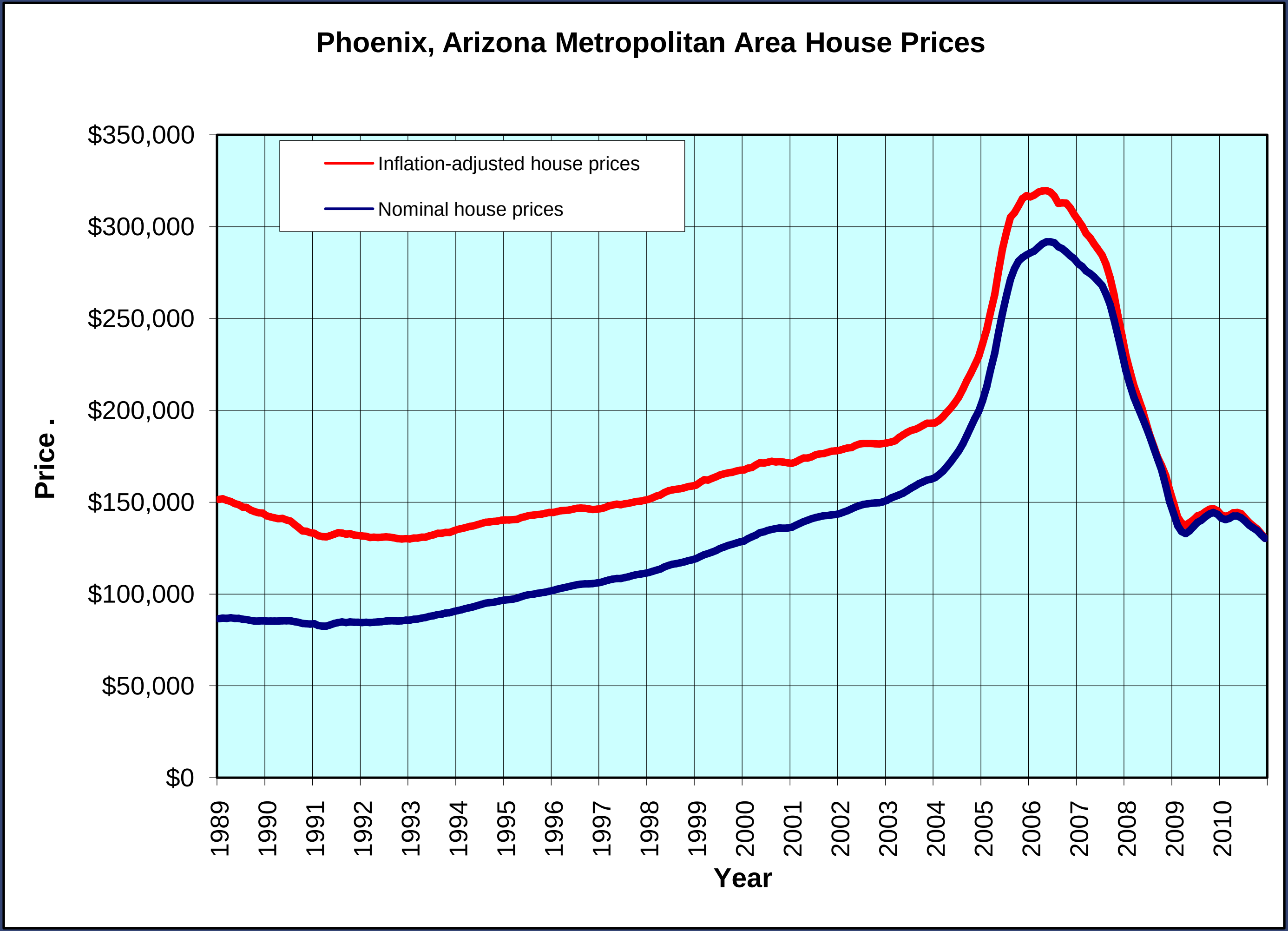
- Ambiguously defined concepts and terminology
- Inappropriate spatial or temporal units
- Inappropriateness or lack of confidence in underlying assumptions
- Uncertainty caused by projections of human behavior (e.g., future consumption patterns or technological change), which is distinct from uncertainty from "natural" sources (e.g., climate sensitivity, chaos)

S. H. Schneider and Kristin Kuntz-Duriseti. 2002. Uncertainty and climate change policy. *Climate Change Policy: A Survey*.
S. H Schneider, A. Rosencrantz, and J.O. Niles (eds). Island Press.

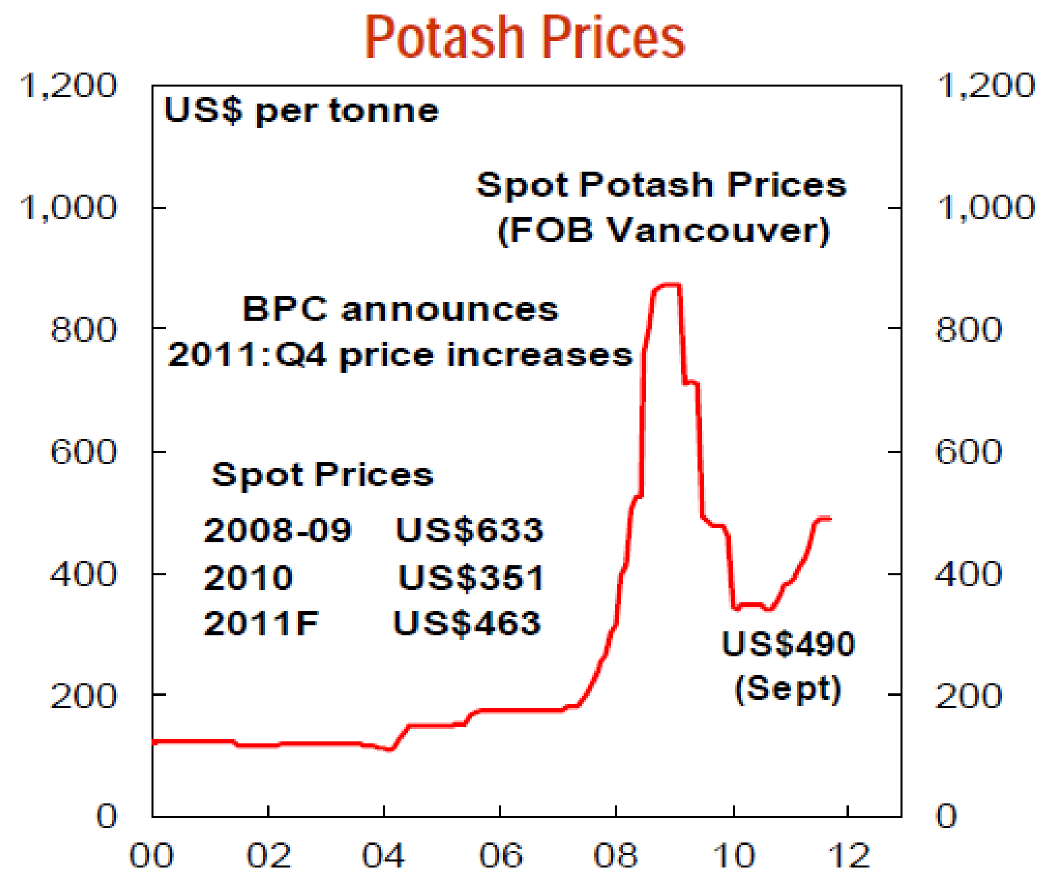
Other Sources of Uncertainty

- Designation of endangered species
- Legal designations of Native American water rights
- Political forces
- Population and economic growth
- Enforcement of AZ Groundwater Management Act
- Decisions by neighboring communities

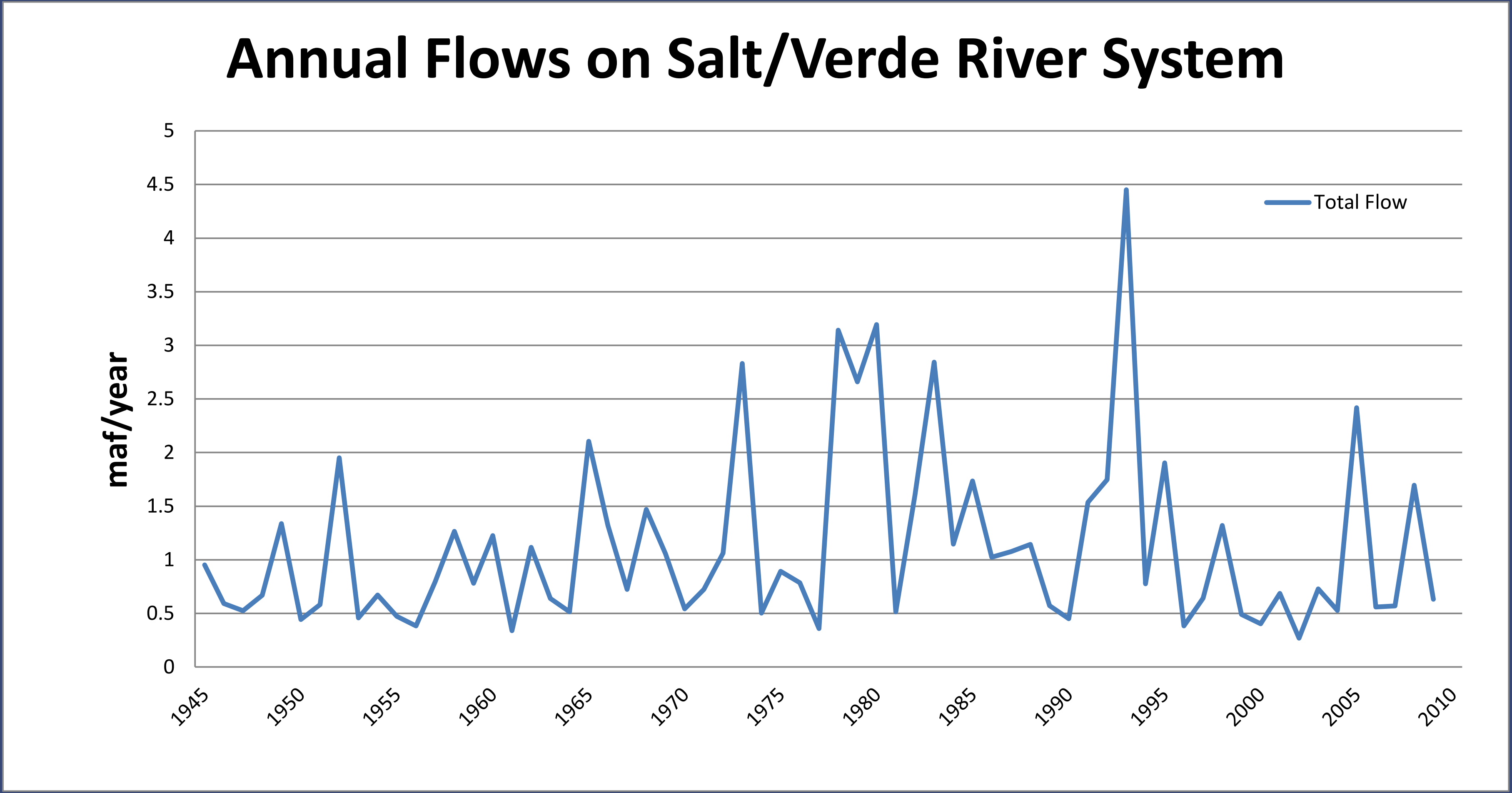
Uncertainties in human systems



Uncertainties in human systems



Stationarity Assumption

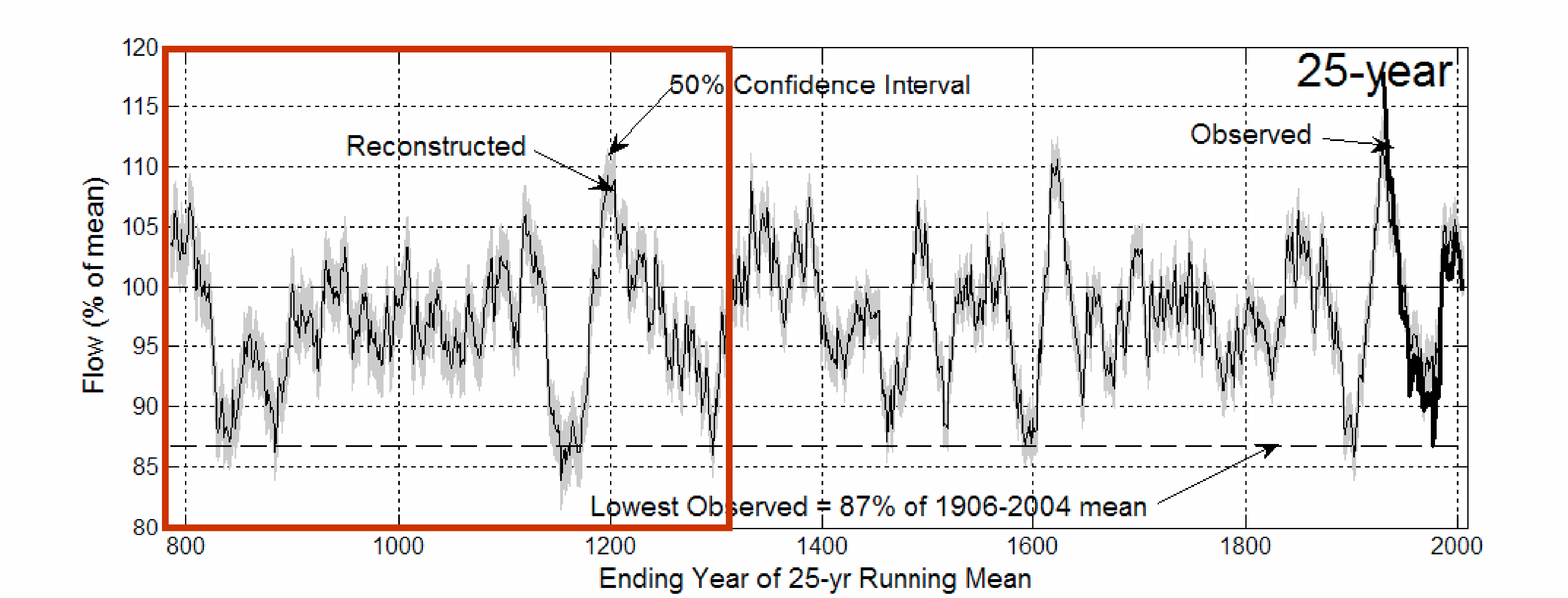


Source: USGS Stream Gages for Salt, Verde, and Tonto stations, 1946-2009

Infrastructure and Operations

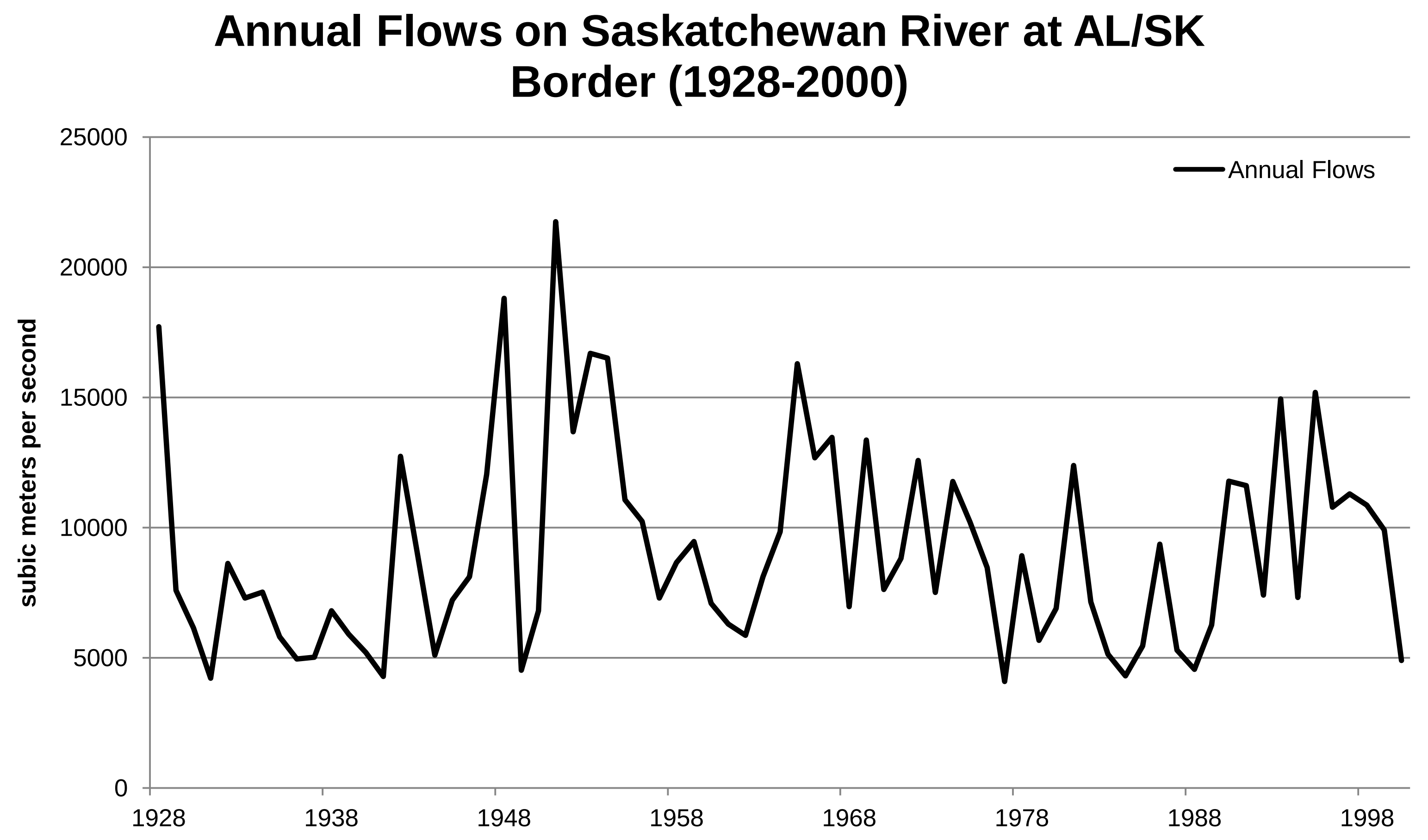
Low-frequency variability and persistent periods of low flow

Colorado River at Lees Ferry, AD 762 - 2002



25-yr running means of reconstructed and observed annual flow of the Colorado River at Lees Ferry, expressed as percentage of the 1906-2004 observed mean (Meko et al. 2007).

AL/SK FLOWS (1928-2000)



Source: Alberta Canada. Natural flow (apportionment on the SSR at the AB/SK border.

“Stationarity is Dead”

CLIMATE CHANGE

Stationarity Is Dead: Whither Water Management?

Climate change undermines a basic assumption that historically has facilitated management of water supplies, demands, and risks.

P. C. D. Milly,[1]* Julio Betancourt,[2] Malin Falkenmark,[3] Robert M. Hirsch,[4] Zbigniew W. Kundzewicz,[5] Dennis P. Lettenmaier,[6] Ronald J. Stouffer[7]

Systems for management of water throughout the developed world have been designed and operated under the assumption of stationarity. Stationarity—the idea that natural systems fluctuate within an unchanging envelope of variability—is a foundational concept that permeates training and practice in water-resource engineering. It implies that any variable (e.g., annual streamflow or annual flood peak) has a time-invariant (or 1-year–periodic) probability density function (pdf), whose properties can be estimated from the instrument record. Under stationarity, pdf estimation errors are acknowledged, but have been assumed to be reducible by additional observations, more efficient estimators, or regional or paleohydrologic data. The pdfs, in turn, are used to evaluate and manage risks to water supplies, waterworks, and floodplains; annual global investment in water infrastructure exceeds U.S.$500 billion (*1*).

The stationarity assumption has long been compromised by human disturbances in river basins. Flood risk, water supply, and water quality are affected by water infrastructure, channel modifications, drainage works, and land-cover and land-use change. Two other (sometimes indistinguishable) challenges to stationarity have been externally forced, natural climate changes and low-frequency, internal variability (e.g., the Atlantic multidecadal oscillation) enhanced by the slow dynamics of the oceans and ice sheets (*2*, *3*). Planners have tools to adjust their analyses for known human disturbances within river basins, and justifiably or not, they generally have considered natural change and variability to be sufficiently small to allow stationarity-based design.

An uncertain future challenges water planners.

In view of the magnitude and ubiquity of the hydroclimatic change apparently now under way, however, we assert that stationarity is dead and should no longer serve as a central, default assumption in water-resource risk assessment and planning. Finding a suitable successor is crucial for human adaptation to changing climate.

How did stationarity die? Stationarity is dead because substantial anthropogenic change of Earth’s climate is altering the means and extremes of precipitation, evapotranspiration, and rates of discharge of rivers (*4*, *5*) (see figure, above). Warming augments atmospheric humidity and water transport. This increases precipitation, and possibly flood risk, where prevailing atmospheric water-vapor fluxes converge (*6*). Rising sea level induces gradually heightened risk of contamination of coastal freshwater supplies. Glacial meltwater temporarily enhances water availability, but glacier and snow-pack losses diminish natural seasonal and interannual storage (*7*).

Anthropogenic climate warming appears to be driving a poleward expansion of the subtropical dry zone (*8*), thereby reducing runoff in some regions. Together, circulatory and thermodynamic responses largely explain the picture of regional gainers and losers of sustainable freshwater availability that has emerged from climate models (see figure, p. 574).

Why now? That anthropogenic climate change affects the water cycle (*9*) and water supply (*10*) is not a new finding. Nevertheless, sensible objections to discarding stationarity have been raised. For a time, hydroclimate had not demonstrably exited the envelope of natural variability and/or the effective range of optimally operated infrastructure (*11*, *12*). Accounting for the substantial uncertainties of climatic parameters estimated from short records (*13*) effectively hedged against small climate changes. Additionally, climate projections were not considered credible (*12*, *14*).

Recent developments have led us to the opinion that the time has come to move beyond the wait-and-see approach. Projections of runoff changes are bolstered by the recently demonstrated retrodictive skill of climate models. The global pattern of observed annual streamflow trends is unlikely to have arisen from unforced variability and is consistent with modeled response to climate forcing (*15*). Paleohydrologic studies suggest that small changes in mean climate might produce large changes in extremes (*16*), although attempts to detect a recent change in global flood frequency have been equivocal (*17*, *18*). Projected changes in runoff during the multidecade lifetime of major water infrastructure projects begun now are large enough to push hydroclimate beyond the range of historical behaviors (*19*). Some regions have little infrastructure to buffer the impacts of change.

Stationarity cannot be revived. Even with aggressive mitigation, continued warming is very likely, given the residence time of atmospheric CO_2 and the thermal inertia of the Earth system (*4*, *20*).

A successor. We need to find ways to identify nonstationary probabilistic models of relevant environmental variables and to use those models to optimize water systems. The challenge is daunting. Patterns of change are complex; uncertainties are large; and the knowledge base changes rapidly.

Under the rational planning framework advanced by the Harvard Water Program (*21*, *22*), the assumption of stationarity was

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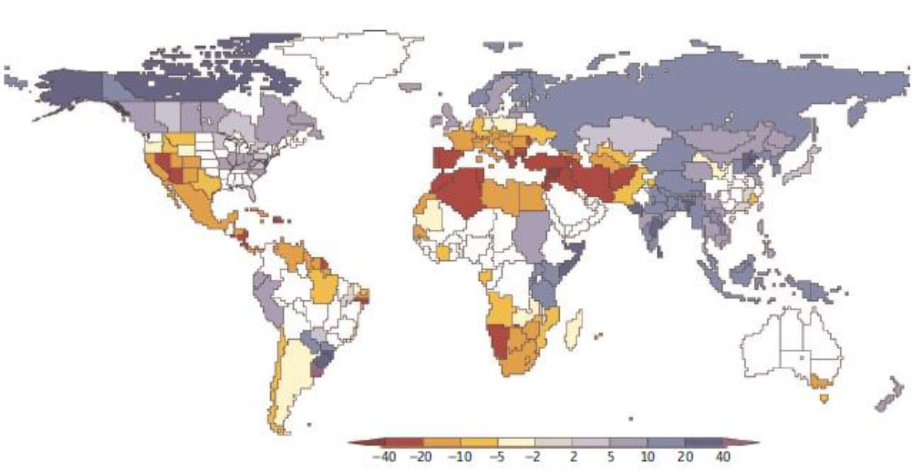
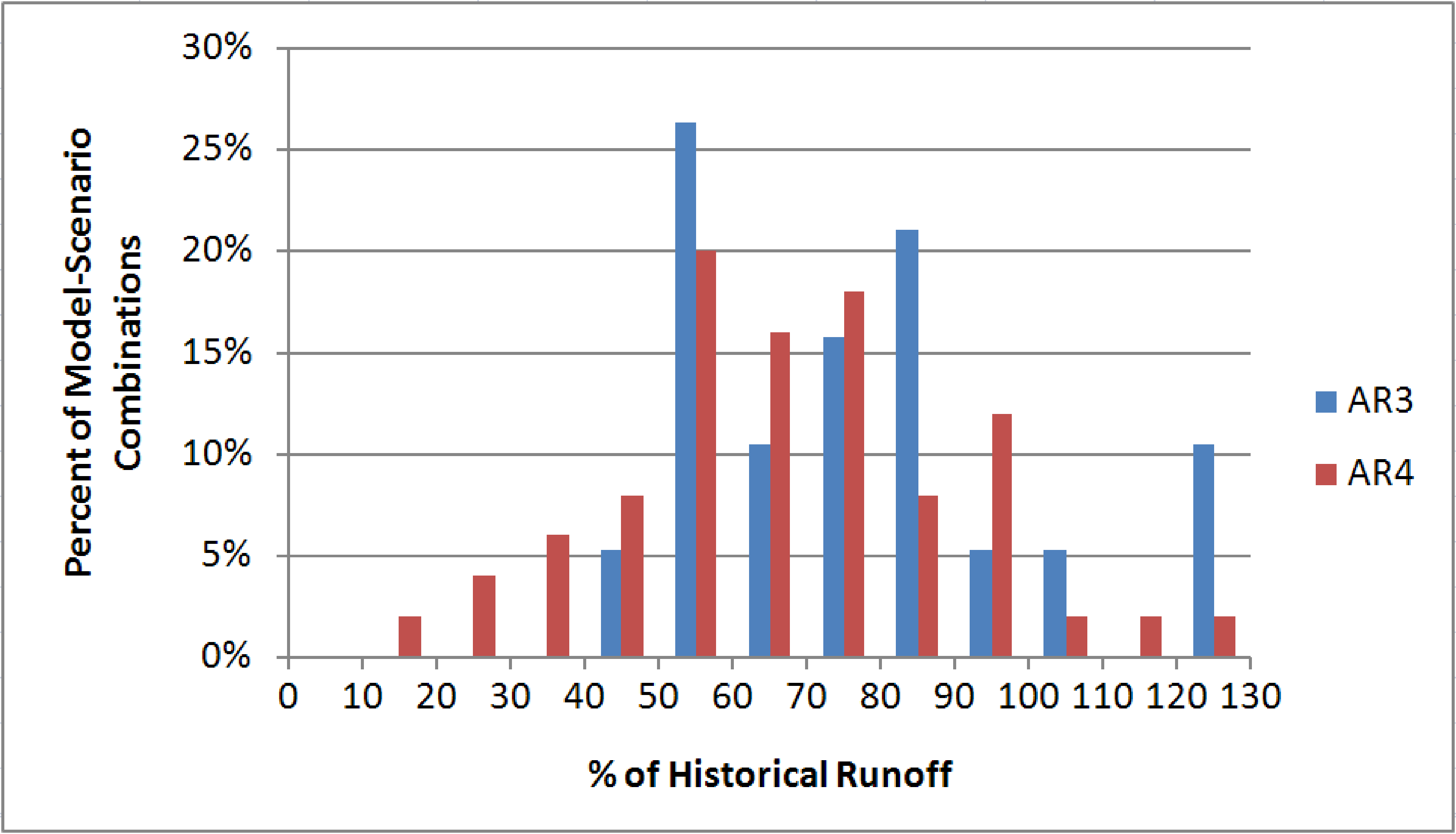
Published by AAAS

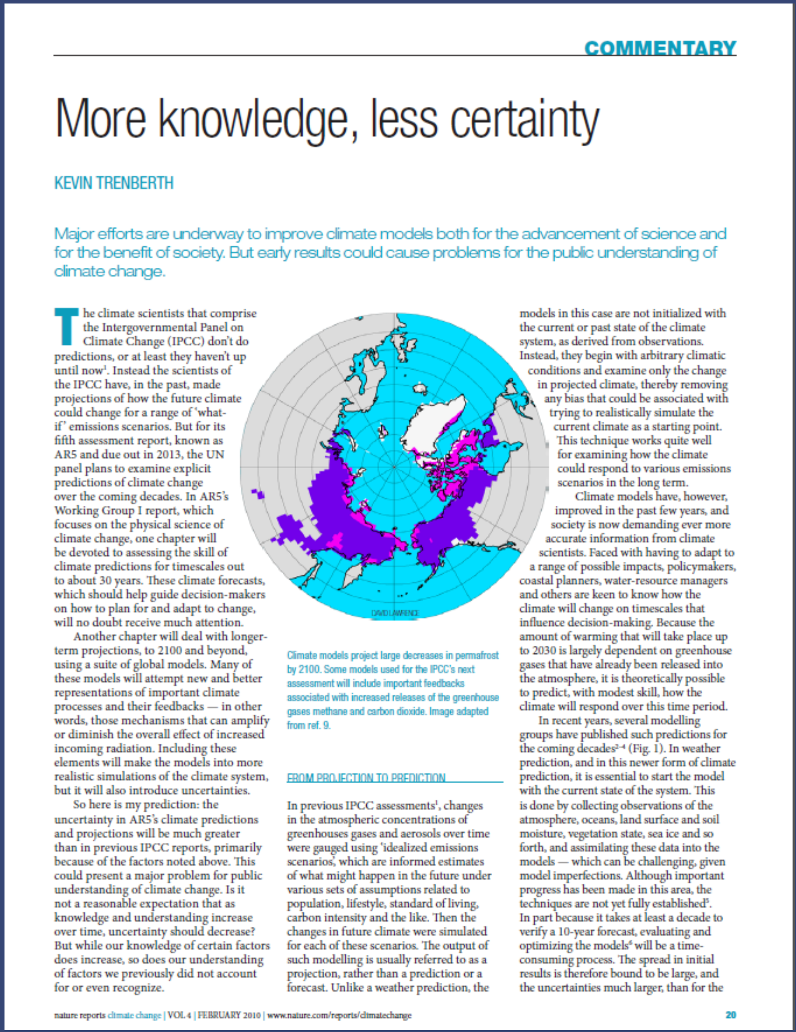


Human influences. Dramatic changes in runoff volume from ice-free land are projected in many parts of the world by the middle of the 21st century (relative to historical conditions from the 1900 to 1970 period). Color denotes percentage change (median value from 12 climate models). Where a country or smaller political unit is colored, 8 or more of 12 models agreed on the direction (increase versus decrease) of runoff change under the Intergovernmental Panel on Climate Change’s “SRES A1B” emissions scenario.

Uncertainty is growing.



"More knowledge, Less Certainty"



More knowledge, less certainty

KEVIN TRENBERTH

Major efforts are underway to improve climate models both for the advancement of science and for the benefit of society. But early results could cause problems for the public understanding of climate change.

The climate scientists that comprise the Intergovernmental Panel on Climate Change (IPCC) don't do predictions, or at least they haven't up until now[1]. Instead the scientists of the IPCC have, in the past, made projections of how the future climate could change for a range of 'what-if' emissions scenarios. But for its fifth assessment report, known as AR5 and due out in 2013, the UN panel plans to examine explicit predictions of climate change over the coming decades. In AR5's Working Group I report, which focuses on the physical science of climate change, one chapter will be devoted to assessing the skill of climate predictions for timescales out to about 30 years. These climate forecasts, which should help guide decision-makers on how to plan for and adapt to change, will no doubt receive much attention.

Another chapter will deal with longer-term projections, to 2100 and beyond, using a suite of global models. Many of these models will attempt new and better representations of important climate processes and their feedbacks — in other words, those mechanisms that can amplify or diminish the overall effect of increased incoming radiation. Including these elements will make the models into more realistic simulations of the climate system, but it will also introduce uncertainties.

So here is my prediction: the uncertainty in AR5's climate predictions and projections will be much greater than in previous IPCC reports, primarily because of the factors noted above. This could present a major problem for public understanding of climate change. Is it not a reasonable expectation that as knowledge and understanding increase over time, uncertainty should decrease? But while our knowledge of certain factors does increase, so does our understanding of factors we previously did not account for or even recognize.

DAVID LAWRENCE

Climate models project large decreases in permafrost by 2100. Some models used for the IPCC's next assessment will include important feedbacks associated with increased releases of the greenhouse gases methane and carbon dioxide. Image adapted from ref. 9.

FROM PROJECTION TO PREDICTION

In previous IPCC assessments[1], changes in the atmospheric concentrations of greenhouses gases and aerosols over time were gauged using 'idealized emissions scenarios', which are informed estimates of what might happen in the future under various sets of assumptions related to population, lifestyle, standard of living, carbon intensity and the like. Then the changes in future climate were simulated for each of these scenarios. The output of such modelling is usually referred to as a projection, rather than a prediction or a forecast. Unlike a weather prediction, the models in this case are not initialized with the current or past state of the climate system, as derived from observations. Instead, they begin with arbitrary climatic conditions and examine only the change in projected climate, thereby removing any bias that could be associated with trying to realistically simulate the current climate as a starting point. This technique works quite well for examining how the climate could respond to various emissions scenarios in the long term.

Climate models have, however, improved in the past few years, and society is now demanding ever more accurate information from climate scientists. Faced with having to adapt to a range of possible impacts, policymakers, coastal planners, water-resource managers and others are keen to know how the climate will change on timescales that influence decision-making. Because the amount of warming that will take place up to 2030 is largely dependent on greenhouse gases that have already been released into the atmosphere, it is theoretically possible to predict, with modest skill, how the climate will respond over this time period.

In recent years, several modelling groups have published such predictions for the coming decades[2–4] (Fig. 1). In weather prediction, and in this newer form of climate prediction, it is essential to start the model with the current state of the system. This is done by collecting observations of the atmosphere, oceans, land surface and soil moisture, vegetation state, sea ice and so forth, and assimilating these data into the models — which can be challenging, given model imperfections. Although important progress has been made in this area, the techniques are not yet fully established[5]. In part because it takes at least a decade to verify a 10-year forecast, evaluating and optimizing the models[6] will be a time-consuming process. The spread in initial results is therefore bound to be large, and the uncertainties much larger, than for the

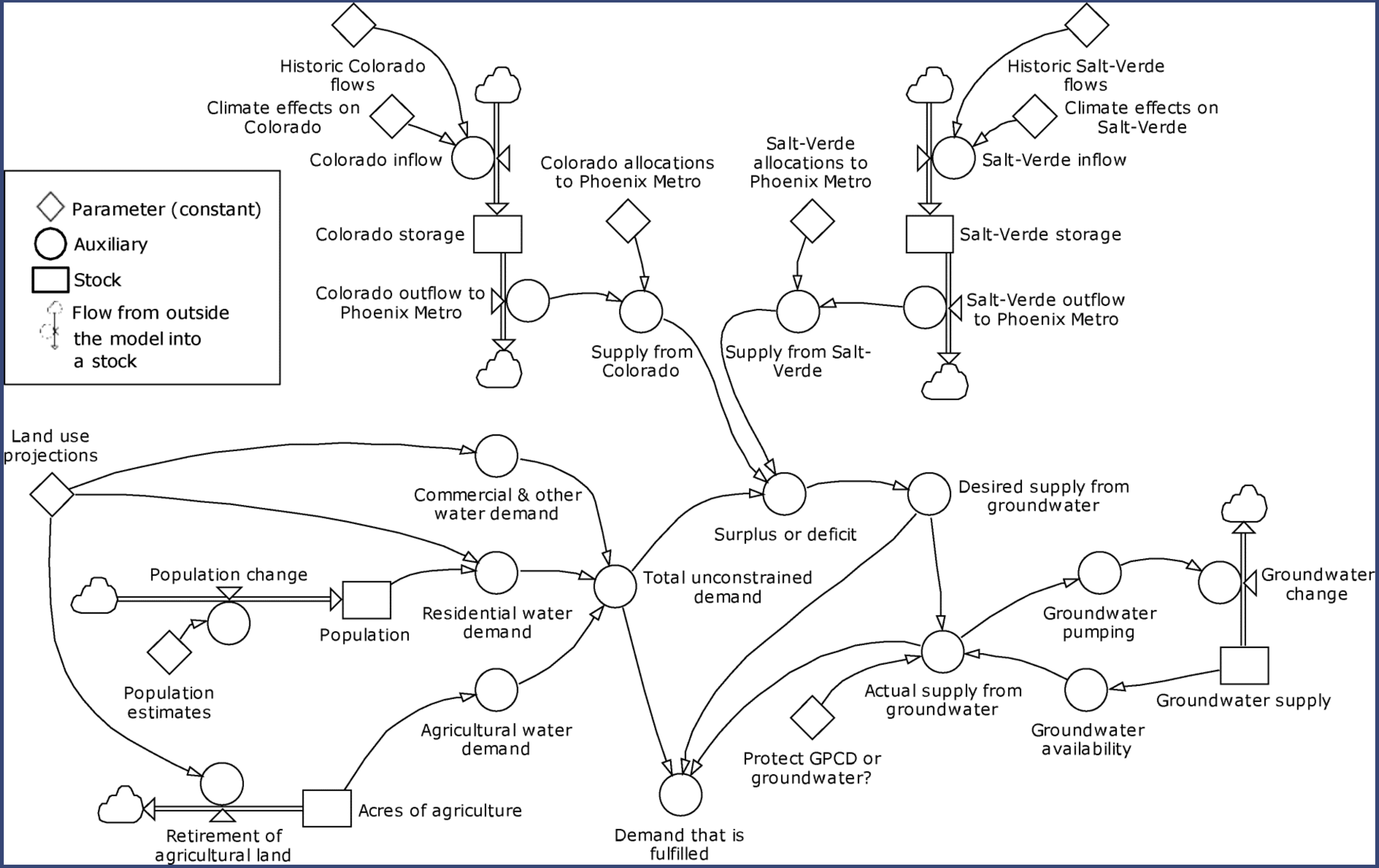
Problems of “Deep Uncertainty”

- Parties cannot agree upon:
  - The fundamental driving forces that will shape the future and/or the models that describe them
  - The probability distributions used to represent uncertainty and key variables and parameters
  - How to value alternative outcomes (gains or losses?)

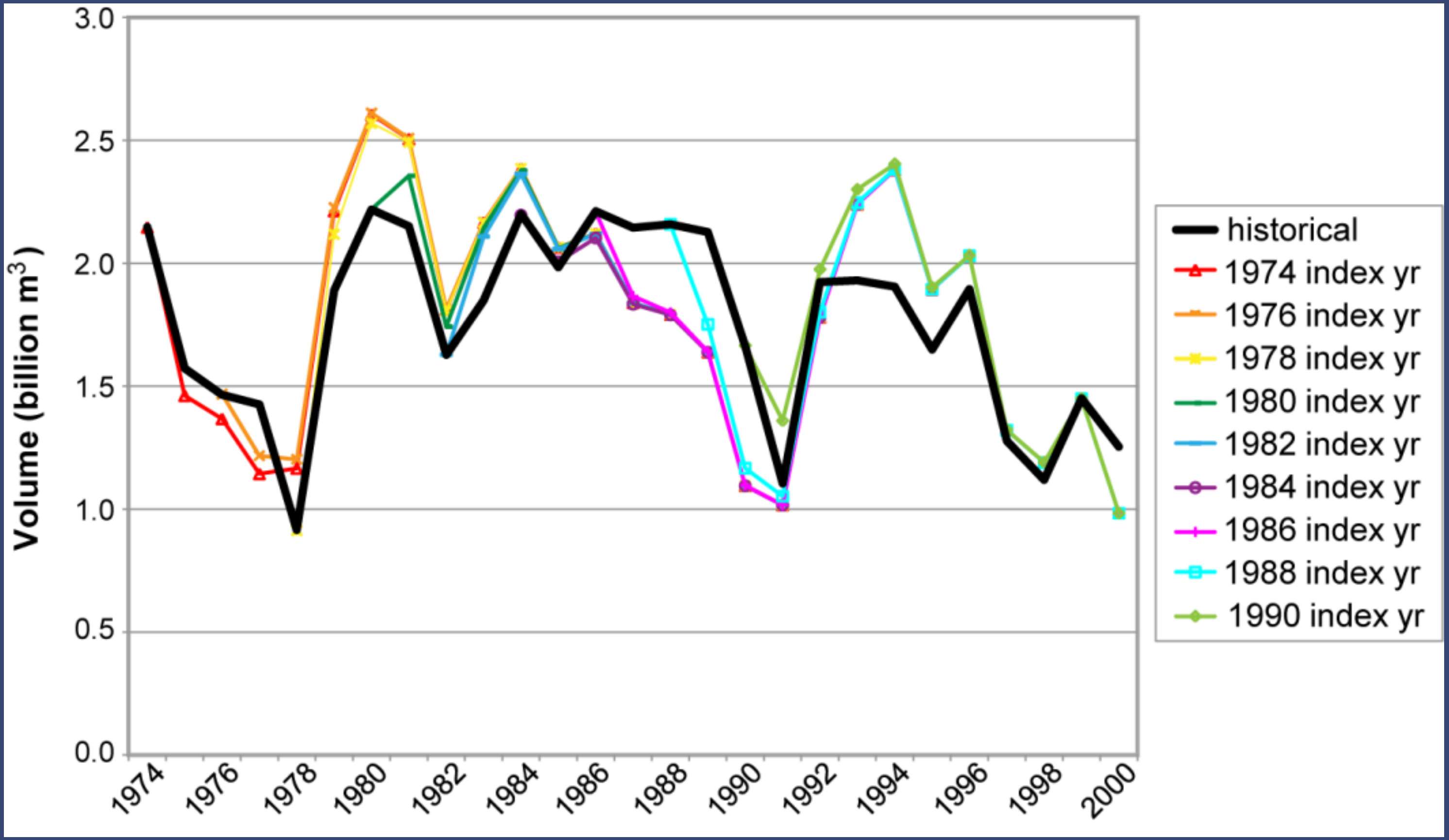
New Questions for Problems of Deep Uncertainty

- What kind of future do we want and what decisions do we need to make to get there?
- What is the range of how the future might look and how do we avoid regrettable outcomes?
- “What if-ing” What are the consequences of particular decisions in a complex system?
  - Inflection points
  - Critical feedbacks (water-energy nexus)
- What policies work best across a range of climate futures?
- What are the costs of delaying decisions?
- What are the tradeoffs between these costs and the risk of making expenditures that are not necessary?

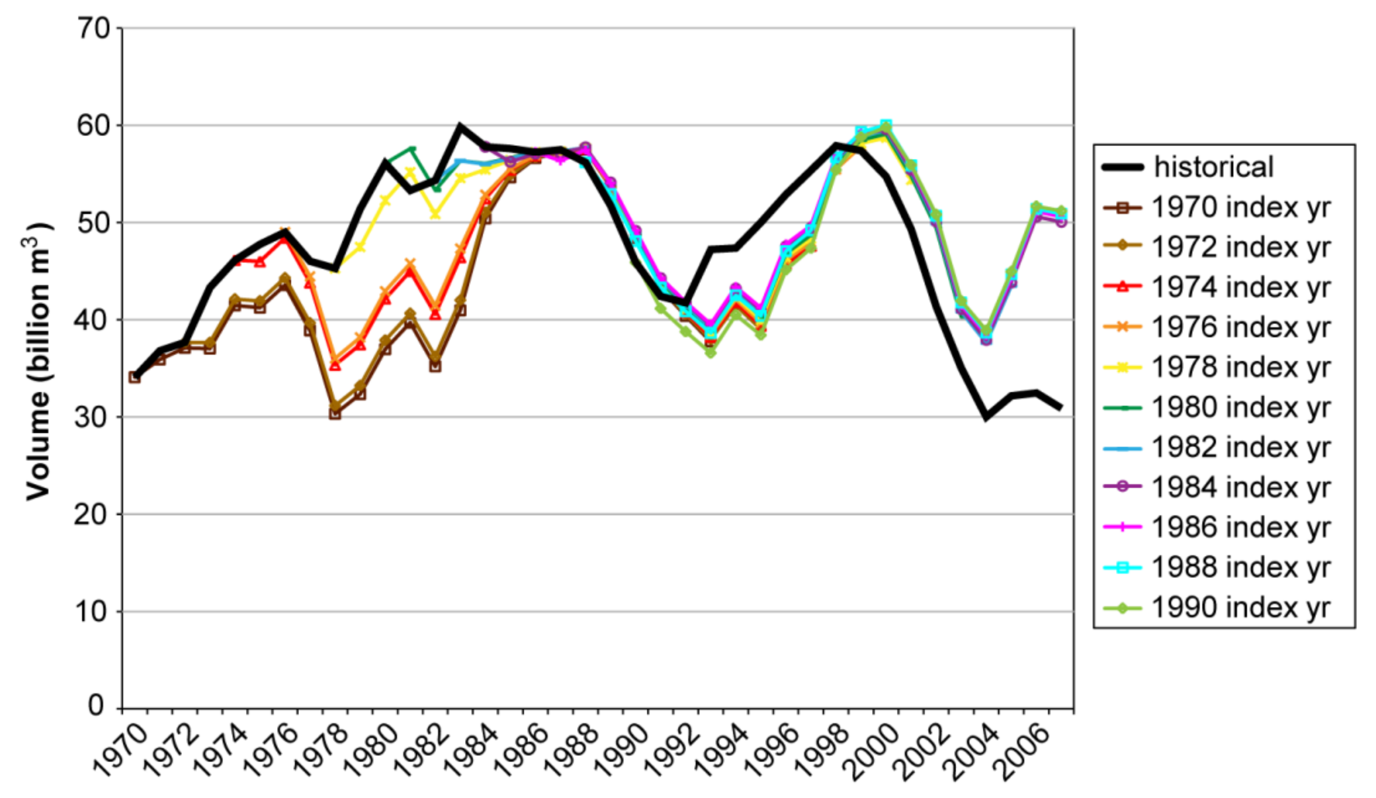
WaterSim 4.0


Historic Colorado flows
Climate effects on Colorado
Colorado inflow
Colorado storage
Colorado outflow to Phoenix Metro
Colorado allocations to Phoenix Metro
Supply from Colorado
Salt-Verde allocations to Phoenix Metro
Historic Salt-Verde flows
Climate effects on Salt-Verde
Salt-Verde inflow
Salt-Verde storage
Salt-Verde outflow to Phoenix Metro
Supply from Salt-Verde
◇ Parameter (constant)
○ Auxiliary
□ Stock
Flow from outside the model into a stock
Land use projections
Commercial & other water demand
Population change
Population
Population estimates
Residential water demand
Total unconstrained demand
Surplus or deficit
Desired supply from groundwater
Agricultural water demand
Retirement of agricultural land
Acres of agriculture
Demand that is fulfilled
Protect GPCD or groundwater?
Actual supply from groundwater
Groundwater pumping
Groundwater change
Groundwater availability
Groundwater supply

Trace effects on WaterSim results



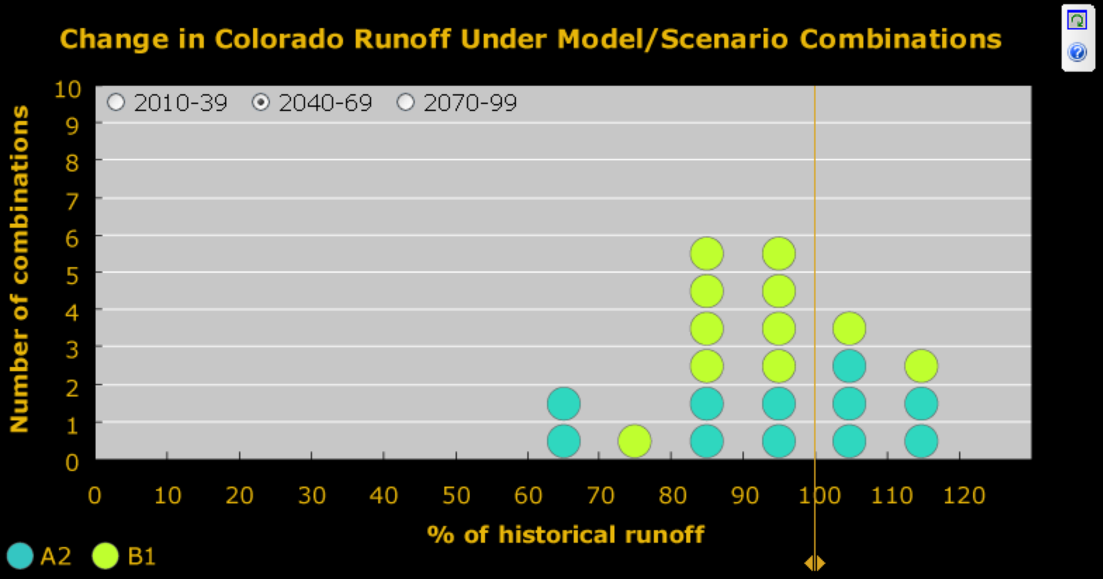
Trace Analysis--Colorado



WaterSim in Decision Theater

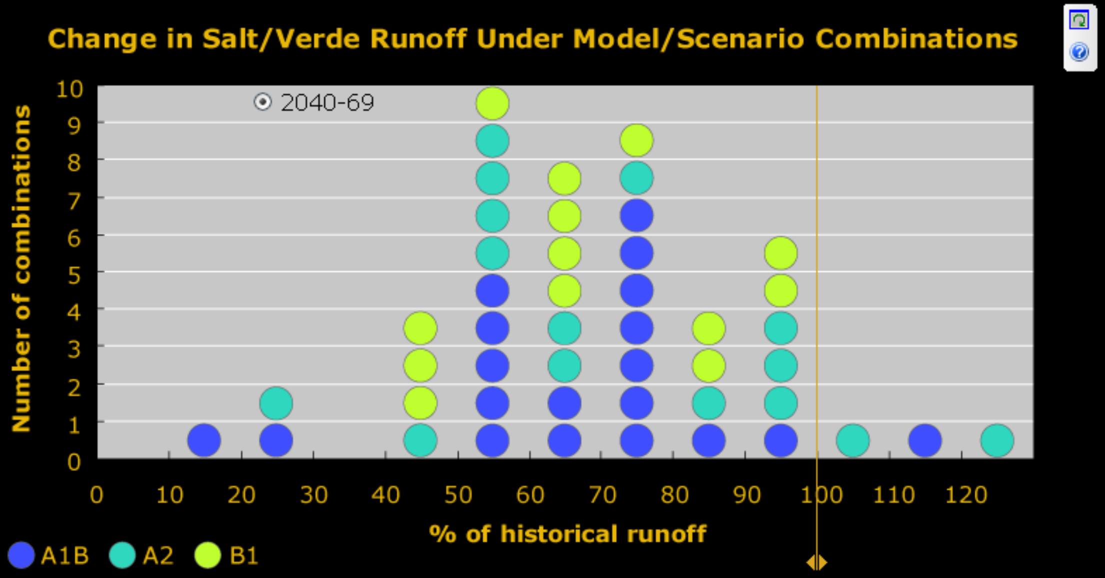
Implications of Climate on Watershed

2007 IPCC Fourth Assessment Report Results Applied to the Colorado Basin

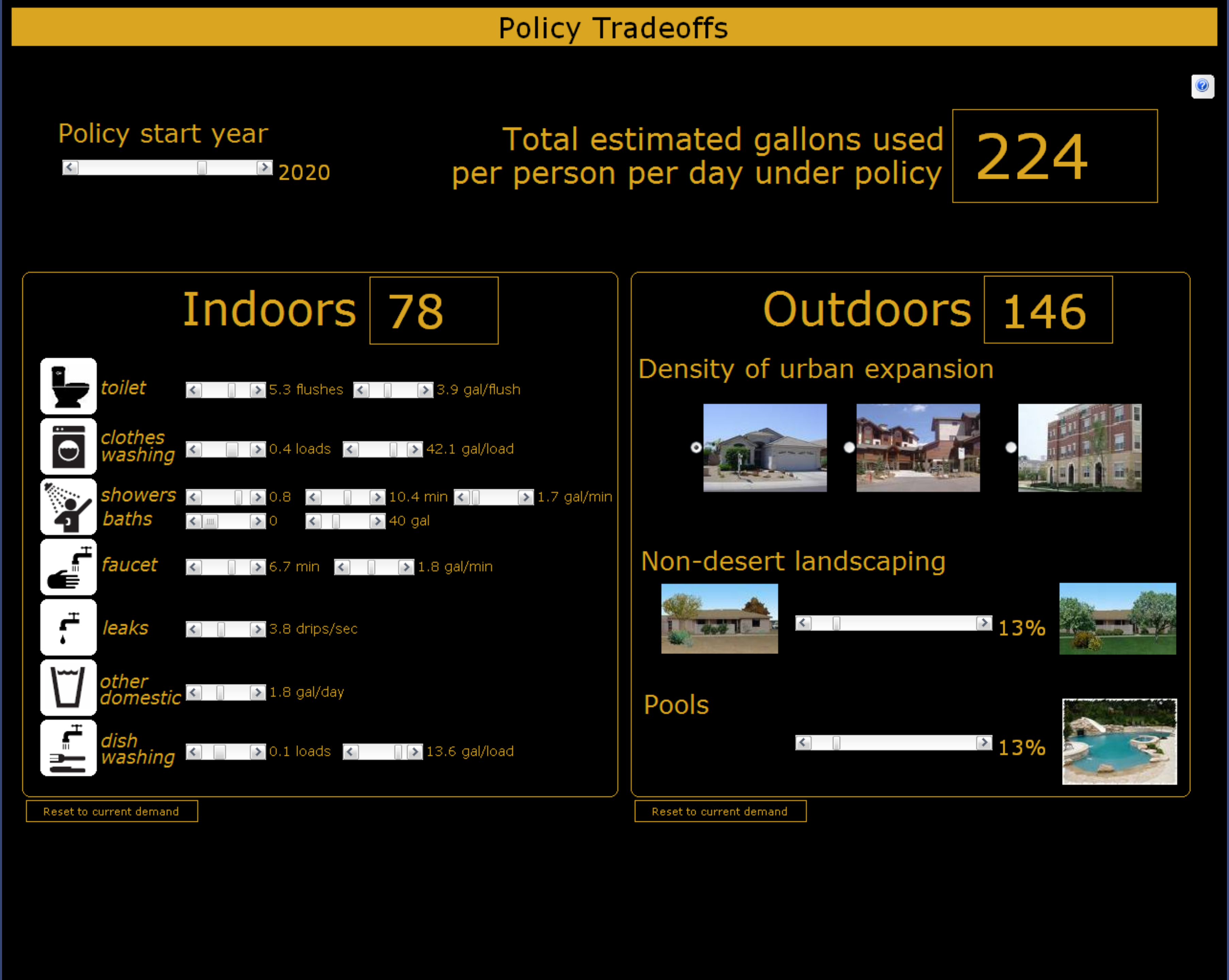


Change in Colorado Runoff Under Model/Scenario Combinations

2007 IPCC Fourth Assessment Report Results Applied to the Salt/Verde Basin



Change in Salt/Verde Runoff Under Model/Scenario Combinations



Policy Tradeoffs

Policy start year 2020

Total estimated gallons used per person per day under policy **224**

Indoors 78

toilet 5.3 flushes 3.9 gal/flush

clothes washing 0.4 loads 42.1 gal/load

showers 0.8 10.4 min 1.7 gal/min

baths 0 40 gal

faucet 6.7 min 1.8 gal/min

leaks 3.8 drips/sec

other domestic 1.8 gal/day

dish washing 0.1 loads 13.6 gal/load

Reset to current demand

Outdoors 146

Density of urban expansion

● ○ ○

Non-desert landscaping 13%

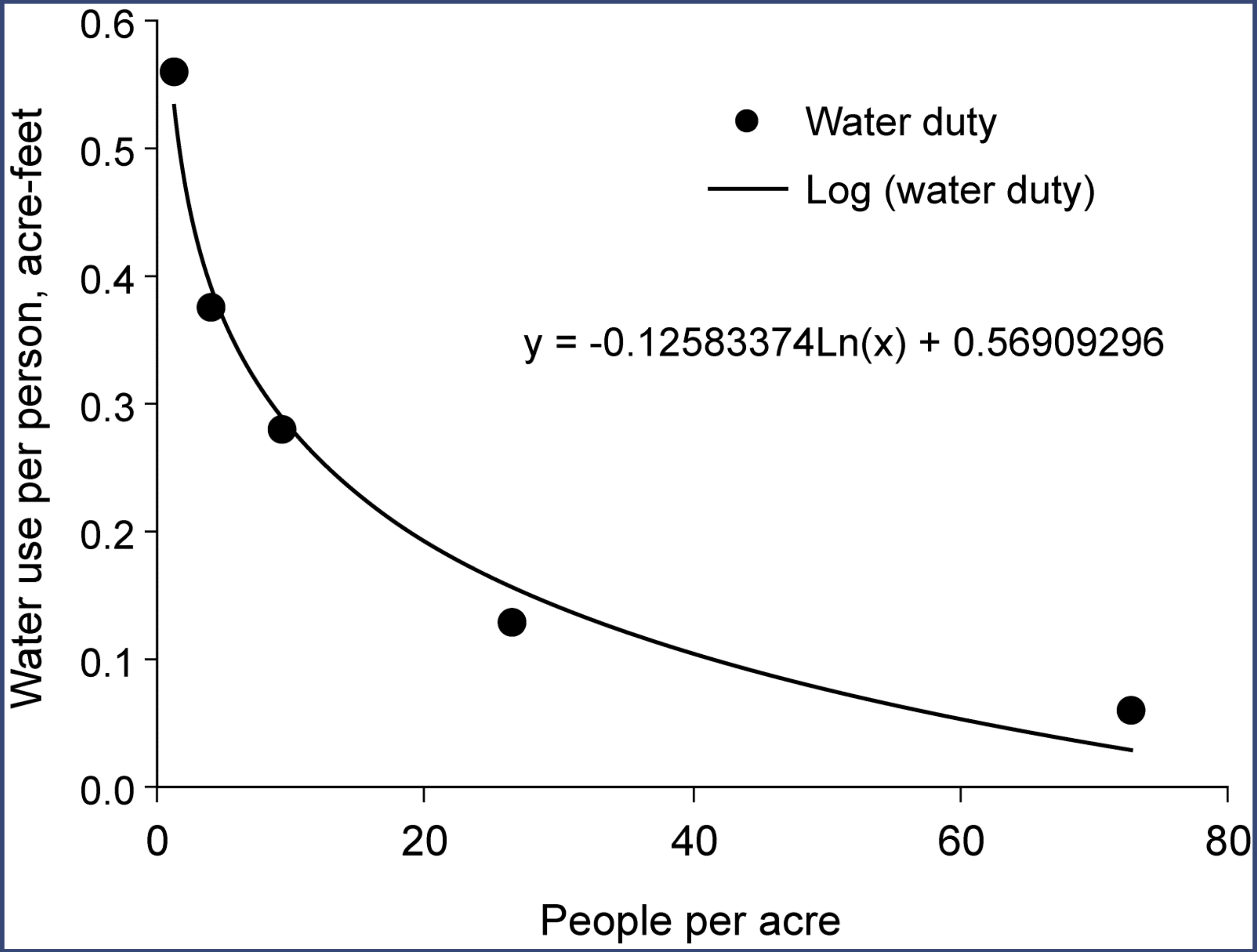
Pools 13%

Reset to current demand

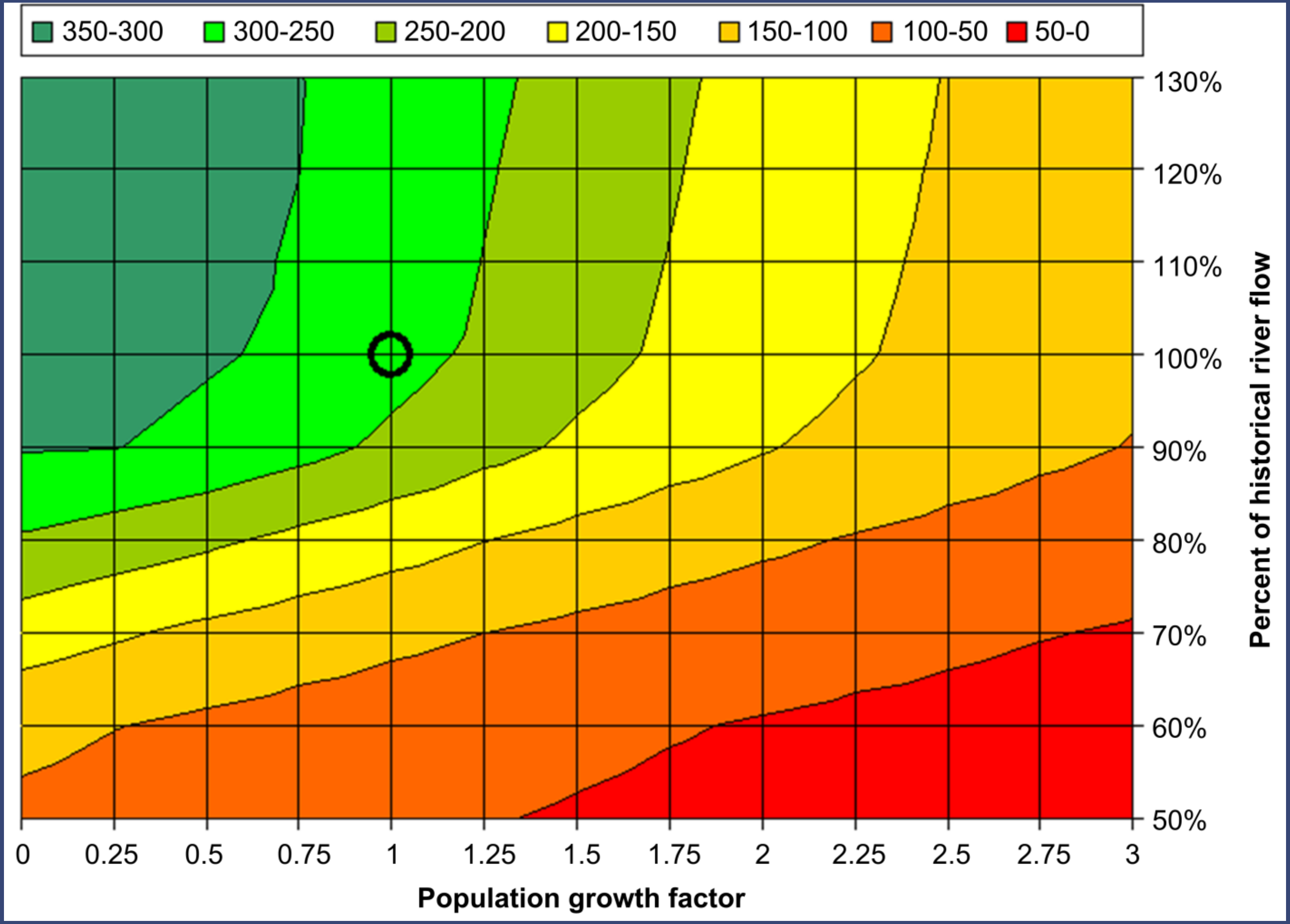
Critical Trade-off: Lifestyle and Sustainability

50% for outdoor use

Water use increases with urban densities.



Sensitivity Analysis



Gober, P. and Kirkwood, C. W. 2010. Vulnerability assessment of climate-induced water shortage in Phoenix, *PNAS*, 107(50).

SPECIAL FEATURE

Vulnerability assessment of climate-induced water shortage in Phoenix

Patricia Gober[a,b,c,1] **and Craig W. Kirkwood**[d]

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Edited by Glen M. MacDonald, University of California, Los Angeles, CA, and accepted by the Editorial Board April 29, 2010 (received for review September 30, 2009)

Global warming has profound consequences for the climate of the American Southwest and its overallocated water supplies. This paper uses simulation modeling and the principles of decision making under uncertainty to translate climate information into tools for vulnerability assessment and urban climate adaptation. A dynamic simulation model, WaterSim, is used to explore future water-shortage conditions in Phoenix. Results indicate that policy action will be needed to attain water sustainability in 2030, even without reductions in river flows caused by climate change. Challenging but feasible changes in lifestyle and slower rates of population growth would allow the region to avoid shortage conditions and achieve groundwater sustainability under all but the most dire climate scenarios. Changes in lifestyle involve more native desert landscaping and fewer pools in addition to slower growth and higher urban densities. There is not a single most likely or optimal future for Phoenix. Urban climate adaptation involves using science-based models to anticipate water shortage and manage climate risk.

water sustainability | climate change | decision making under uncertainty | simulation modeling

Global warming has profound implications for the future climate of the American Southwest and the region's already overallocated water supplies (1–5). Results from 15 coupled climate models from the Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report (AR4) (6) predict drier conditions for the region in this century and little prospect for return to the moister climate that prevailed before the 1997/1998 El Niño (7). Using tree-ring records, Woodhouse et al. (8) argue that the mid–12th-century drought, whose severity and duration exceeded anything in the historical record, can be used to exemplify the severe droughts that may occur in the future. Given the likelihood that climate change will diminish the Southwest's water supplies, we need to know how vulnerable people are to that risk and how best they can adapt.

The study of human vulnerability to environmental risks grew out of natural-hazards research (9, 10). Harm to human populations stems not only from physical exposure but also from a population's sensitivity to a hazardous event and capacity to cope with shocks and stresses (11–13). The concept of sustainability enlarges and redirects vulnerability analysis to consider interacting stressors functioning at varying scales in a complex system (11, 14). It infuses vulnerability research with a longer-term perspective and awareness of the importance of system resilience—the ability to bounce back after disturbance. In the process, the focus moves beyond any particular hazardous event to the preparedness of systems to cope with a range of long-term environment risks, one of which is climate change. With respect to preparedness, Guston (15) makes a useful distinction between precaution and anticipation. Precaution is a way of acting to avoid predicted but uncertain risks; anticipation implies building capacity to respond to unpredictable and uncertain risks.

Our research uses a water-balance simulation model, WaterSim, to assess the vulnerability of Phoenix, Arizona to long-term water shortage induced by global climate change. In this paper, we (*i*) summarize key human stressors on water supplies—why the Southwest would be at risk even without climate change, (*ii*) discuss the capacities of water-management systems to anticipate and cope with climate uncertainties, and (*iii*) apply principles of decision making under uncertainty to the risk of long-term water shortage. The Phoenix study offers lessons in how climate information and models can be integrated into water decisions and tradeoffs faced by decision makers in adapting to climate change.

Human Stressors on Water Supply in the American Southwest

Twentieth-century development of the Southwest was based first on irrigated agriculture and later, on large-scale urban development. The Southwest's arid and semiarid climate is highly variable in runoff from infrequent, but often heavy, rainfall events. Historically, this variability was managed by building dams, reservoirs, and canals for flood control and water supply and by transporting water over long distances to the points of human settlement and economic development (16, 17). Rapid growth adds pressure to this system of water provision, because augmenting supply through infrastructure is increasingly difficult (4, 18–21). The seven states of the Colorado River Basin (Arizona, California, Colorado, Nevada, New Mexico, Utah, and Wyoming) will add 23 million new residents between 2000 and 2030, and this accounts for 29% of the nation's total population growth (22). Growth will occur at a time when the nation's major dam-building era is over and the downstream environmental costs of dam construction are more fully understood (4, 23, 24). Population growth will intensify competition for scarce water resources, particularly between municipal and agricultural users. That competition is already reflected in a decrease in irrigated farmlands of more than 809,000 ha in the seven states of the Colorado River Basin between 1997 and 2007 (25). The amount of water used by the agricultural sector in the Greater Phoenix Area declined from 1.3 billion m^3 in 1990 to 1.2 billion in 2000 and 0.9 billion in 2006, because farmland was retired and municipal water use rapidly increased (Fig. 1). Transfers from agricultural to urban water use raise questions about the use of potable water to grow urban lawns, the potential for agriculture to buffer cities from shortage in the case of long-term drought, and the viability of exporting water through water-intensive crops such as hay, rice, and cotton from a rapidly urbanizing arid region (26).

Almost 92% of the Southwest's population lived in urban areas in 2000 compared with 79% for the nation as a whole (27).

SUSTAINABILITY SCIENCE

Author contributions: P.G. designed research; P.G. and C.W.K. performed research; P.G. contributed new reagents/analytic tools; P.G. and C.W.K. analyzed data; and P.G. and C.W.K. wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission. G.M.M. is a guest editor invited by the Editorial Board.

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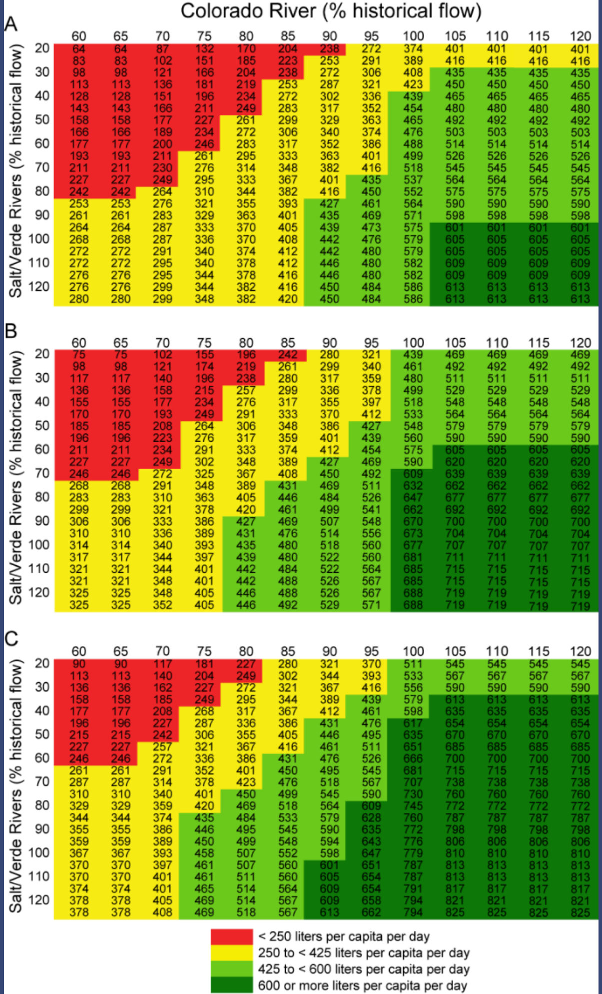
www.pnas.org/cgi/doi/10.1073/pnas.0911113107



Colorado River (% historical flow)

Salt/Verde Rivers (% historical flow)

A

	60	65	70	75	80	85	90	95	100	105	110	115	120
20	64	64	87	132	170	204	238	272	374	401	401	401	401
	83	83	102	151	185	223	253	291	389	416	416	416	416
30	98	98	121	166	204	238	272	306	408	435	435	435	435
	113	113	136	181	219	253	287	321	423	450	450	450	450
40	128	128	151	196	234	272	302	336	439	465	465	465	465
	143	143	166	211	249	283	317	352	454	480	480	480	480
50	158	158	177	227	261	299	329	363	465	492	492	492	492
	166	166	189	234	272	306	340	374	476	503	503	503	503
60	177	177	200	246	283	317	352	386	488	514	514	514	514
	193	193	211	261	295	333	363	401	499	526	526	526	526
70	211	211	230	276	314	348	382	416	518	545	545	545	545
	227	227	249	295	333	367	401	435	537	564	564	564	564
80	242	242	264	310	344	382	416	450	552	575	575	575	575
	253	253	276	321	355	393	427	461	564	590	590	590	590
90	261	261	283	329	363	401	435	469	571	598	598	598	598
	264	264	287	333	370	405	439	473	575	601	601	601	601
100	268	268	287	336	370	408	442	476	579	605	605	605	605
	272	272	291	340	374	412	442	480	579	605	605	605	605
110	272	272	295	340	378	412	446	480	582	609	609	609	609
	276	276	295	344	378	416	446	480	582	609	609	609	609
120	276	276	299	344	382	416	450	484	586	613	613	613	613
	280	280	299	348	382	420	450	484	586	613	613	613	613

B

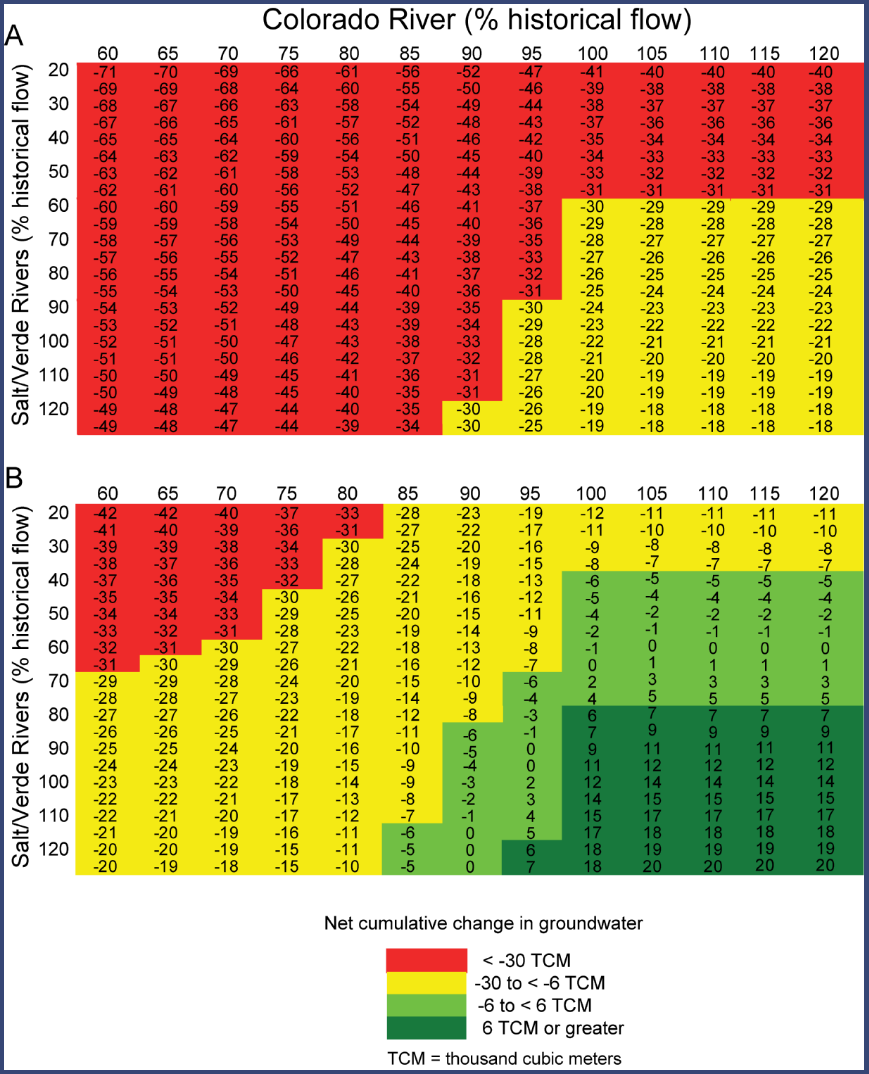
	60	65	70	75	80	85	90	95	100	105	110	115	120
20	75	75	102	155	196	242	280	321	439	469	469	469	469
	98	98	121	174	219	261	299	340	461	492	492	492	492
30	117	117	140	196	238	280	317	359	480	511	511	511	511
	136	136	158	215	257	299	336	378	499	529	529	529	529
40	155	155	177	234	276	317	355	397	518	548	548	548	548
	170	170	193	249	291	333	370	412	533	564	564	564	564
50	185	185	208	264	306	348	386	427	548	579	579	579	579
	196	196	223	276	317	359	401	439	560	590	590	590	590
60	211	211	234	291	333	374	412	454	575	605	605	605	605
	227	227	249	302	348	389	427	469	590	620	620	620	620
70	246	246	272	325	367	408	450	492	609	639	639	639	639
	268	268	291	348	389	431	469	511	632	662	662	662	662
80	283	283	310	363	405	446	484	526	647	677	677	677	677
	299	299	321	378	420	461	499	541	662	692	692	692	692
90	306	306	333	386	427	469	507	548	670	700	700	700	700
	310	310	336	389	431	476	514	556	673	704	704	704	704
100	314	314	340	393	435	480	518	560	677	707	707	707	707
	317	317	344	397	439	480	522	560	681	711	711	711	711
110	321	321	344	401	442	484	522	564	685	715	715	715	715
	321	321	348	401	442	488	526	567	685	715	715	715	715
120	325	325	348	405	446	488	526	567	688	719	719	719	719
	325	325	352	405	446	492	529	571	688	719	719	719	719

C

	60	65	70	75	80	85	90	95	100	105	110	115	120
20	90	90	117	181	227	280	321	370	511	545	545	545	545
	113	113	140	204	249	302	344	393	533	567	567	567	567
30	136	136	162	227	272	321	367	416	556	590	590	590	590
	158	158	185	249	295	344	389	439	579	613	613	613	613
40	177	177	208	268	317	367	412	461	598	635	635	635	635
	196	196	227	287	336	386	431	476	617	654	654	654	654
50	215	215	242	306	355	405	446	495	635	670	670	670	670
	227	227	257	321	367	416	461	511	651	685	685	685	685
60	246	246	272	336	386	431	476	526	666	700	700	700	700
	261	261	291	352	401	450	495	545	681	715	715	715	715
70	287	287	314	378	423	476	518	567	707	738	738	738	738
	310	310	340	401	450	499	545	590	730	760	760	760	760
80	329	329	359	420	469	518	564	609	745	772	772	772	772
	344	344	374	435	484	533	579	628	760	787	787	787	787
90	355	355	386	446	495	545	590	635	772	798	798	798	798
	359	359	389	450	499	548	594	643	776	806	806	806	806
100	367	367	393	458	507	552	598	647	779	810	810	810	810
	370	370	397	461	507	560	601	651	787	813	813	813	813
110	370	370	401	461	511	560	605	654	787	813	813	813	813
	374	374	401	465	514	564	609	654	791	817	817	817	817
120	378	378	405	469	514	567	609	658	794	821	821	821	821
	378	378	408	469	518	567	613	662	794	825	825	825	825

🟥 < 250 liters per capita per day
🟨 250 to < 425 liters per capita per day
🟩 425 to < 600 liters per capita per day
■ 600 or more liters per capita per day

Business as usual vs. slow growth, high density, desert landscaping, and no pools.



Colorado River (% historical flow)

A

Salt/Verde Rivers (% historical flow)

	60	65	70	75	80	85	90	95	100	105	110	115	120
20	-71	-70	-69	-66	-61	-56	-52	-47	-41	-40	-40	-40	-40
	-69	-69	-68	-64	-60	-55	-50	-46	-39	-38	-38	-38	-38
30	-68	-67	-66	-63	-58	-54	-49	-44	-38	-37	-37	-37	-37
	-67	-66	-65	-61	-57	-52	-48	-43	-37	-36	-36	-36	-36
40	-65	-65	-64	-60	-56	-51	-46	-42	-35	-34	-34	-34	-34
	-64	-63	-62	-59	-54	-50	-45	-40	-34	-33	-33	-33	-33
50	-63	-62	-61	-58	-53	-48	-44	-39	-33	-32	-32	-32	-32
	-62	-61	-60	-56	-52	-47	-43	-38	-31	-31	-31	-31	-31
60	-60	-60	-59	-55	-51	-46	-41	-37	-30	-29	-29	-29	-29
	-59	-59	-58	-54	-50	-45	-40	-36	-29	-28	-28	-28	-28
70	-58	-57	-56	-53	-49	-44	-39	-35	-28	-27	-27	-27	-27
	-57	-56	-55	-52	-47	-43	-38	-33	-27	-26	-26	-26	-26
80	-56	-55	-54	-51	-46	-41	-37	-32	-26	-25	-25	-25	-25
	-55	-54	-53	-50	-45	-40	-36	-31	-25	-24	-24	-24	-24
90	-54	-53	-52	-49	-44	-39	-35	-30	-24	-23	-23	-23	-23
	-53	-52	-51	-48	-43	-39	-34	-29	-23	-22	-22	-22	-22
100	-52	-51	-50	-47	-43	-38	-33	-28	-22	-21	-21	-21	-21
	-51	-51	-50	-46	-42	-37	-32	-28	-21	-20	-20	-20	-20
110	-50	-50	-49	-45	-41	-36	-31	-27	-20	-19	-19	-19	-19
	-50	-49	-48	-45	-40	-35	-31	-26	-20	-19	-19	-19	-19
120	-49	-48	-47	-44	-40	-35	-30	-26	-19	-18	-18	-18	-18
	-49	-48	-47	-44	-39	-34	-30	-25	-19	-18	-18	-18	-18

B

Salt/Verde Rivers (% historical flow)

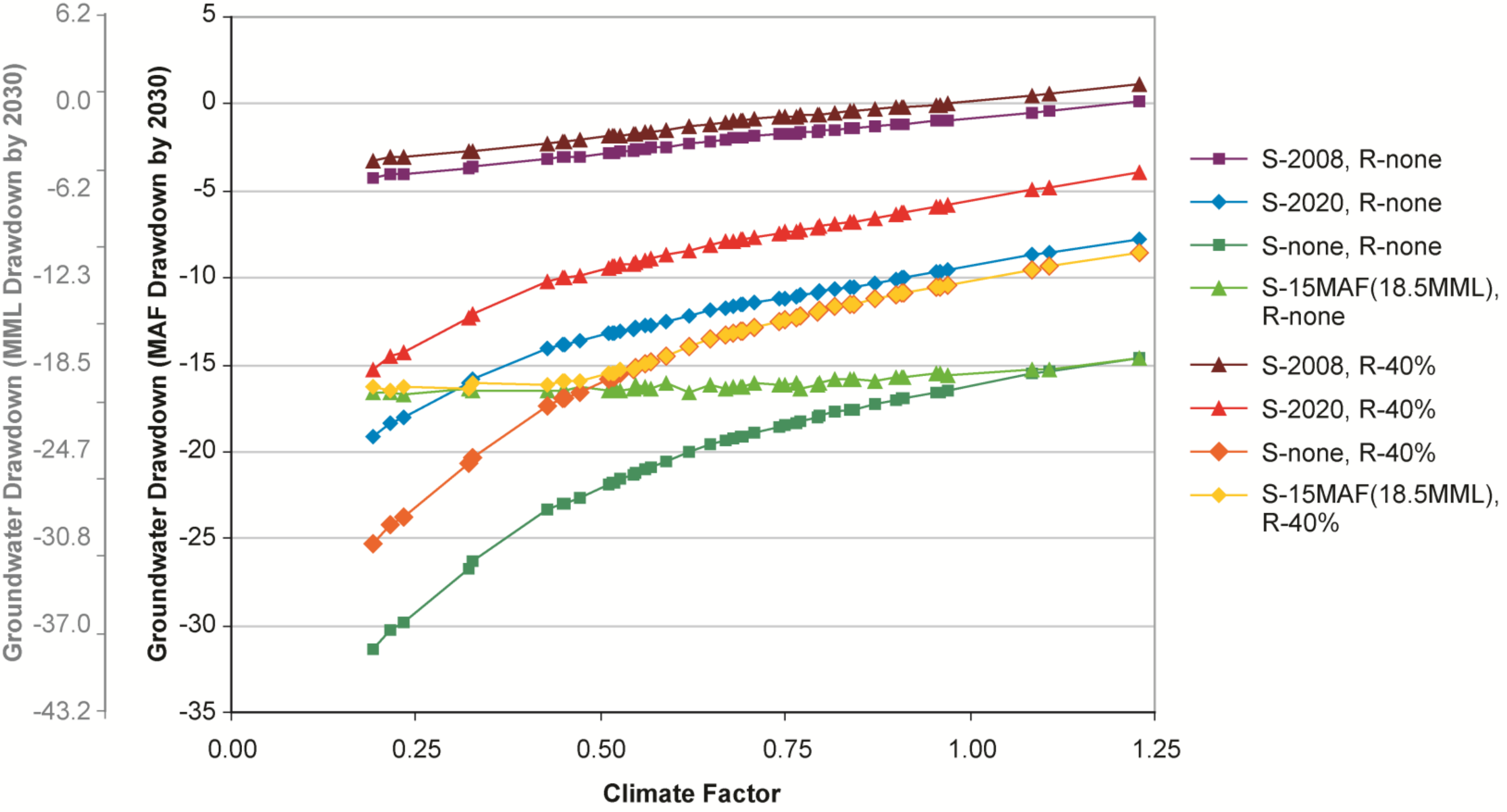
	60	65	70	75	80	85	90	95	100	105	110	115	120
20	-42	-42	-40	-37	-33	-28	-23	-19	-12	-11	-11	-11	-11
	-41	-40	-39	-36	-31	-27	-22	-17	-11	-10	-10	-10	-10
30	-39	-39	-38	-34	-30	-25	-20	-16	-9	-8	-8	-8	-8
	-38	-37	-36	-33	-28	-24	-19	-15	-8	-7	-7	-7	-7
40	-37	-36	-35	-32	-27	-22	-18	-13	-6	-5	-5	-5	-5
	-35	-35	-34	-30	-26	-21	-16	-12	-5	-4	-4	-4	-4
50	-34	-34	-33	-29	-25	-20	-15	-11	-4	-2	-2	-2	-2
	-33	-32	-31	-28	-23	-19	-14	-9	-2	-1	-1	-1	-1
60	-32	-31	-30	-27	-22	-18	-13	-8	-1	0	0	0	0
	-31	-30	-29	-26	-21	-16	-12	-7	0	1	1	1	1
70	-29	-29	-28	-24	-20	-15	-10	-6	2	3	3	3	3
	-28	-28	-27	-23	-19	-14	-9	-4	4	5	5	5	5
80	-27	-27	-26	-22	-18	-12	-8	-3	6	7	7	7	7
	-26	-26	-25	-21	-17	-11	-6	-1	7	9	9	9	9
90	-25	-25	-24	-20	-16	-10	-5	0	9	11	11	11	11
	-24	-24	-23	-19	-15	-9	-4	0	11	12	12	12	12
100	-23	-23	-22	-18	-14	-9	-3	2	12	14	14	14	14
	-22	-22	-21	-17	-13	-8	-2	3	14	15	15	15	15
110	-22	-21	-20	-17	-12	-7	-1	4	15	17	17	17	17
	-21	-20	-19	-16	-11	-6	0	5	17	18	18	18	18
120	-20	-20	-19	-15	-11	-5	0	6	18	19	19	19	19
	-20	-19	-18	-15	-10	-5	0	7	18	20	20	20	20

Net cumulative change in groundwater

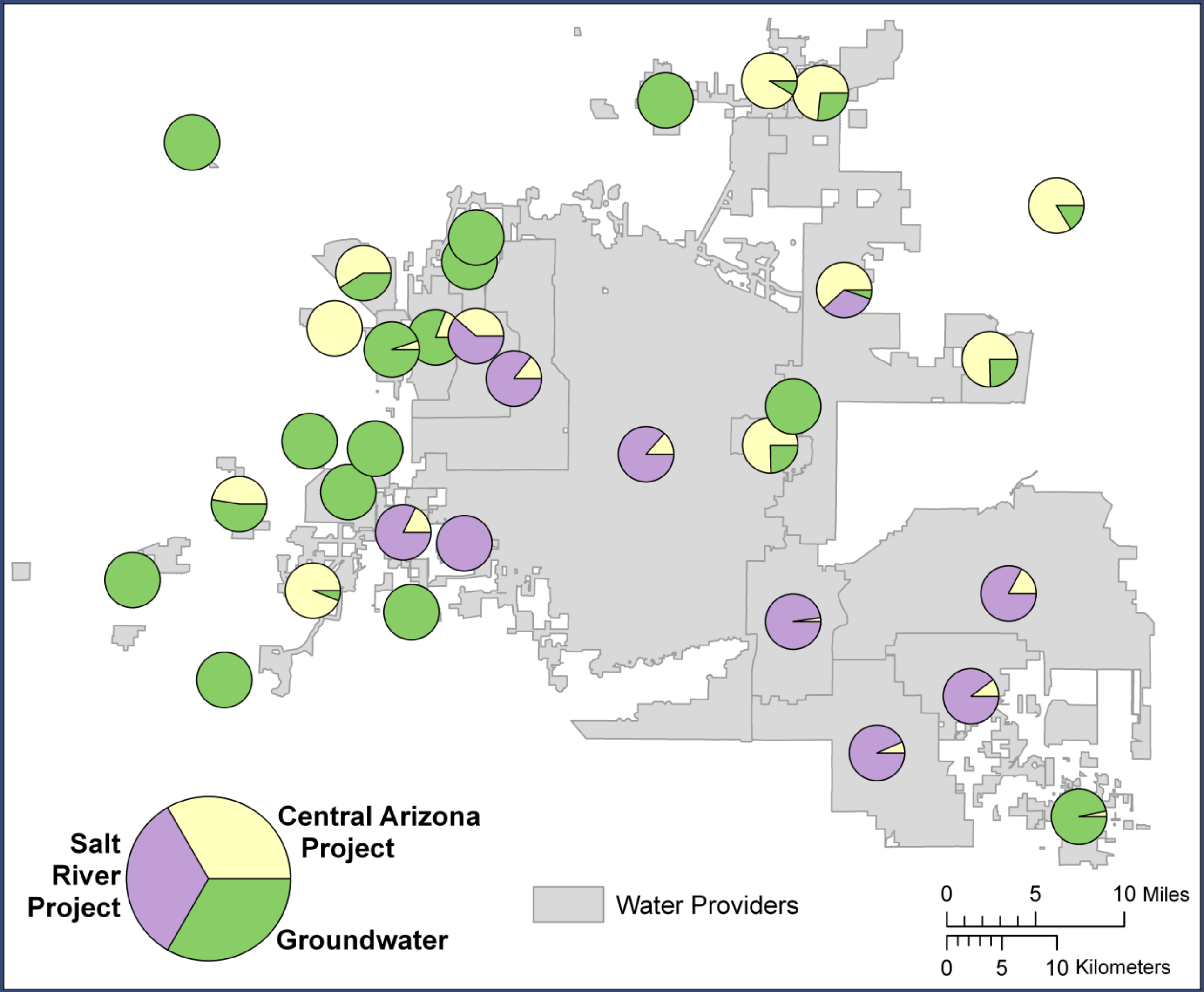
🟥 < -30 TCM
🟨 -30 to < -6 TCM
🟩 -6 to < 6 TCM
🟩 6 TCM or greater

TCM = thousand cubic meters

Robust Policy Decisions



Problems of Aggregation



Scenario 1: Stationary climate conditions	Status Quo		Regional Cooperation (Optimization model)		
Period Range (Aggregate of 5 years)	Providers in Deficit	Total Deficit	Providers in Deficit	Total Deficit	Relative Water Savings
2006-10	2	79,944	0	0	100%
2011-15	4	107,733	0	0	100%
2016-20	4	116,046	0	0	100%
2021-25	5	138,693	0	0	100%
2026-30	7	165,685	0	0	100%

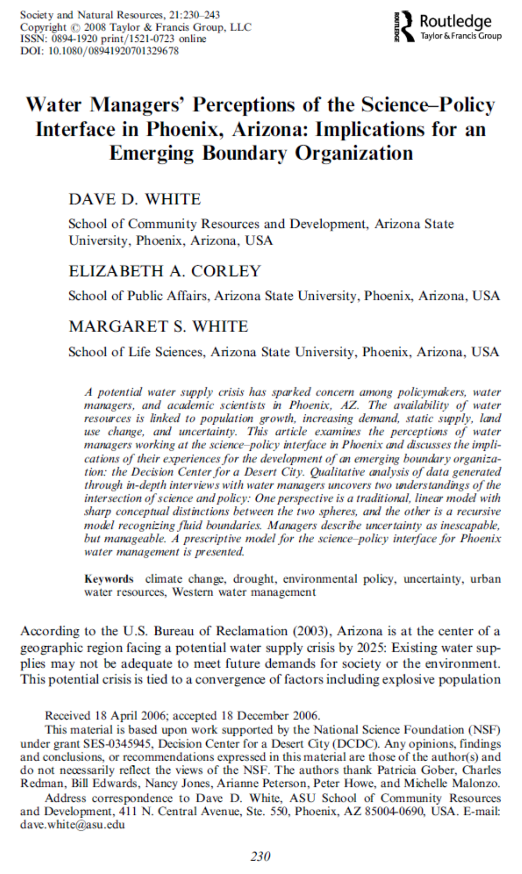
Scenario 2: Moderate reductions in current flows	Status Quo		Regional Cooperation (Optimization model)		
Period Range (Aggregate of 5 years)	Providers in Deficit	Total Deficit	Providers in Deficit	Total Deficit	Relative Water Savings
2006-10	3	91,926	0	0	100%
2011-15	4	129,854	0	0	100%
2016-20	4	303,257	0	0	100%
2021-25	6	170,274	0	0	100%
2026-30	7	231,815	0	0	100%

Scenario 3: Severe reductions in current flows	Status Quo		Regional Cooperation (Optimization model)		
Period Range (Aggregate of 5 years)	Providers in Deficit	Total Deficit	Providers in Deficit	Total Deficit	Relative Water Savings
2006-10	3	226,240	2	157,198	30.52%
2011-15	6	424,859	2	382,320	10.01%
2016-20	6	427,438	2	394,932	7.60%
2021-25	7	447,827	2	415,464	7.23%
2026-30	8	493,701	2	439,938	10.89%

Can we manipulate growth and consumption to reduce risk?

- Steer growth in favor of surplus districts
  - Who are the winners and losers?
  - What is the redistributed pattern of growth?
  - How many people need to be redistributed?
- Reduce consumption to retain growth pattern
  - Where? How severe?
- Trigger outmigration at low GPCD (<120 GPCD)
  - How much growth is redistributed under varying climate change conditions?
  - How soon do districts transition from growth to no-growth futures?

D. D. White, E. A. Corley, and M. S. White (2008) Water managers' perceptions of the science-policy interface in Phoenix, Arizona. Society and Natural Resources 21:230-245.



Society and Natural Resources, 21:230–243
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ISSN: 0894-1920 print/1521-0723 online
DOI: 10.1080/08941920701329678

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

Received 18 April 2006; accepted 18 December 2006.

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.

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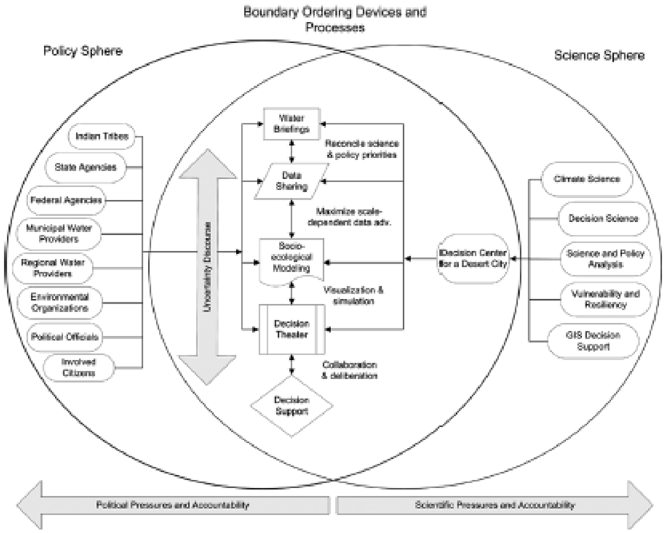
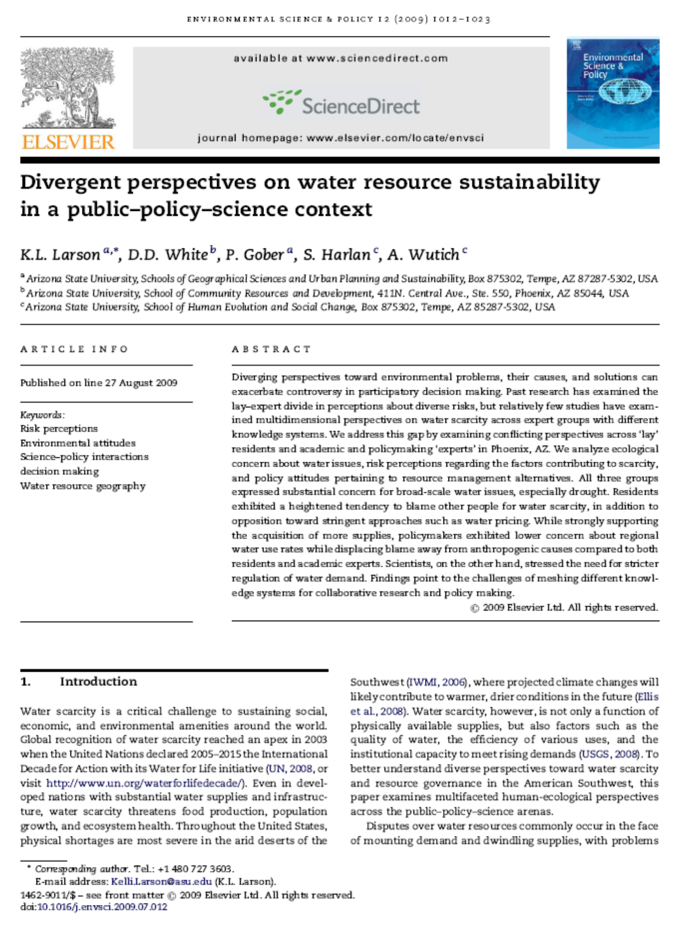


Figure 1. Prescriptive model of science–policy interface for water management in Phoenix. The Decision Center for a Desert City operates as a boundary organization to facilitate boundary-ordering devices and processes to stabilize negotiations between scientific and policy spheres. Uncertainty discourse pervades the boundary space and is embraced as a framework to order discourse.

Uncertainty was described as' 'the nature of the beast," "always present," and "the whole reason we exist."

Larson et al. 2009. Divergent perspectives on water resource sustainability in a public-policy-science context. *Environmental Science & Policy 12*(7):1012-1023.



ENVIRONMENTAL SCIENCE & POLICY 12 (2009) 1012–1023

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Divergent perspectives on water resource sustainability in a public–policy–science context

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ARTICLE INFO

Published on line 27 August 2009

Keywords:
Risk perceptions
Environmental attitudes
Science–policy interactions
decision making
Water resource geography

ABSTRACT

Diverging perspectives toward environmental problems, their causes, and solutions can exacerbate controversy in participatory decision making. Past research has examined the lay–expert divide in perceptions about diverse risks, but relatively few studies have examined multidimensional perspectives on water scarcity across expert groups with different knowledge systems. We address this gap by examining conflicting perspectives across 'lay' residents and academic and policymaking 'experts' in Phoenix, AZ. We analyze ecological concern about water issues, risk perceptions regarding the factors contributing to scarcity, and policy attitudes pertaining to resource management alternatives. All three groups expressed substantial concern for broad-scale water issues, especially drought. Residents exhibited a heightened tendency to blame other people for water scarcity, in addition to opposition toward stringent approaches such as water pricing. While strongly supporting the acquisition of more supplies, policymakers exhibited lower concern about regional water use rates while displacing blame away from anthropogenic causes compared to both residents and academic experts. Scientists, on the other hand, stressed the need for stricter regulation of water demand. Findings point to the challenges of meshing different knowledge systems for collaborative research and policy making.

1. Introduction

Water scarcity is a critical challenge to sustaining social, economic, and environmental amenities around the world. Global recognition of water scarcity reached an apex in 2003 when the United Nations declared 2005–2015 the International Decade for Action with its Water for Life initiative (UN, 2008, or visit http://www.un.org/waterforlifedecade/). Even in developed nations with substantial water supplies and infrastructure, water scarcity threatens food production, population growth, and ecosystem health. Throughout the United States, physical shortages are most severe in the arid deserts of the Southwest (IWMI, 2006), where projected climate changes will likely contribute to warmer, drier conditions in the future (Ellis et al., 2008). Water scarcity, however, is not only a function of physically available supplies, but also factors such as the quality of water, the efficiency of various uses, and the institutional capacity to meet rising demands (USGS, 2008). To better understand diverse perspectives toward water scarcity and resource governance in the American Southwest, this paper examines multifaceted human-ecological perspectives across the public–policy–science arenas.

Disputes over water resources commonly occur in the face of mounting demand and dwindling supplies, with problems

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doi:10.1016/j.envsci.2009.07.012

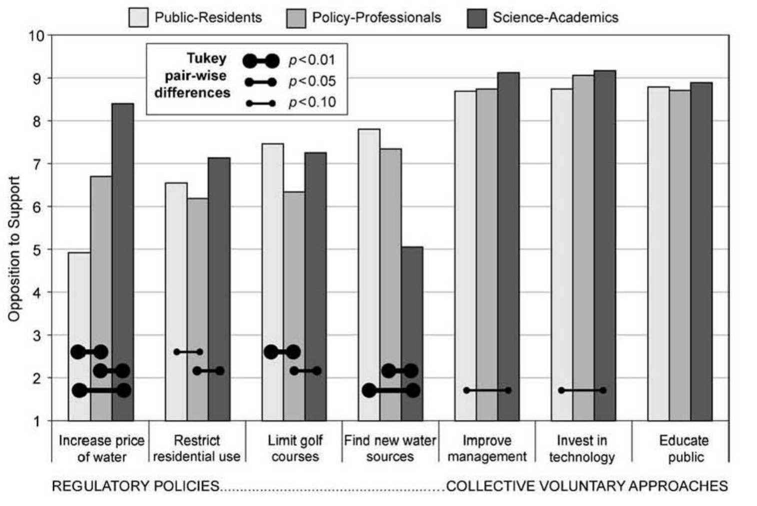


Fig. 3 – Differences in policy support for water scarcity mitigation alternatives.

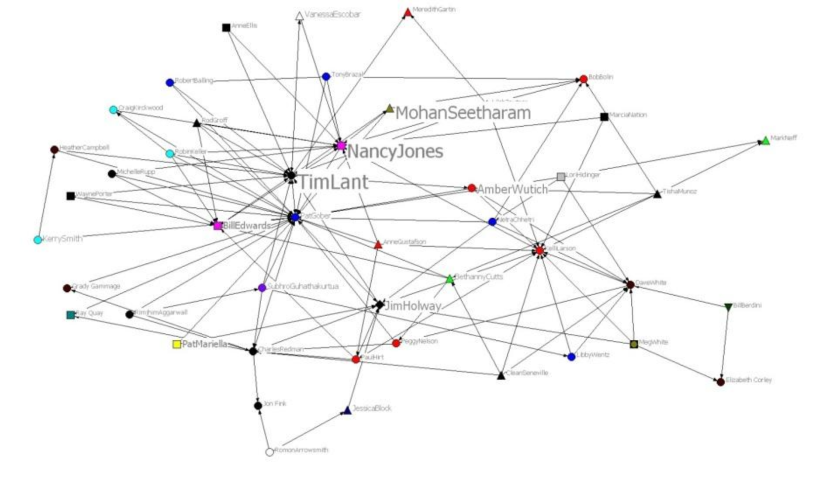
Findings point to the challenges of meshing different knowledge systems for collaborative research and policy making.


22
DAN DAVIES

Stakeholder Priorities for SRB

Major Concerns	Priority
Water Quality	3.41
Water Governance	3.62
Water Quantity	3.96
Land-use Management	4.07
Competing Demands	4.62
Drought	4.72
Long-term climate change	5.24
Flooding	6.26

Crona, B.I. and Parker, J.N. 2011. Network determinants of knowledge utilization: Preliminary lessons from a boundary organization. Science Communication published online on 11 October 2011: DOI: 10.1177/1075547011408116.



Policy makers with more direct contacts with researchers are more likely to utilize research. Policy makers interacting more with other policy makers regarding research are also more likely to utilize it. This indicates the importance of policy makers' in social networks and the importance of external reputation of boundary organizations for successful knowledge transfer.

Questions?