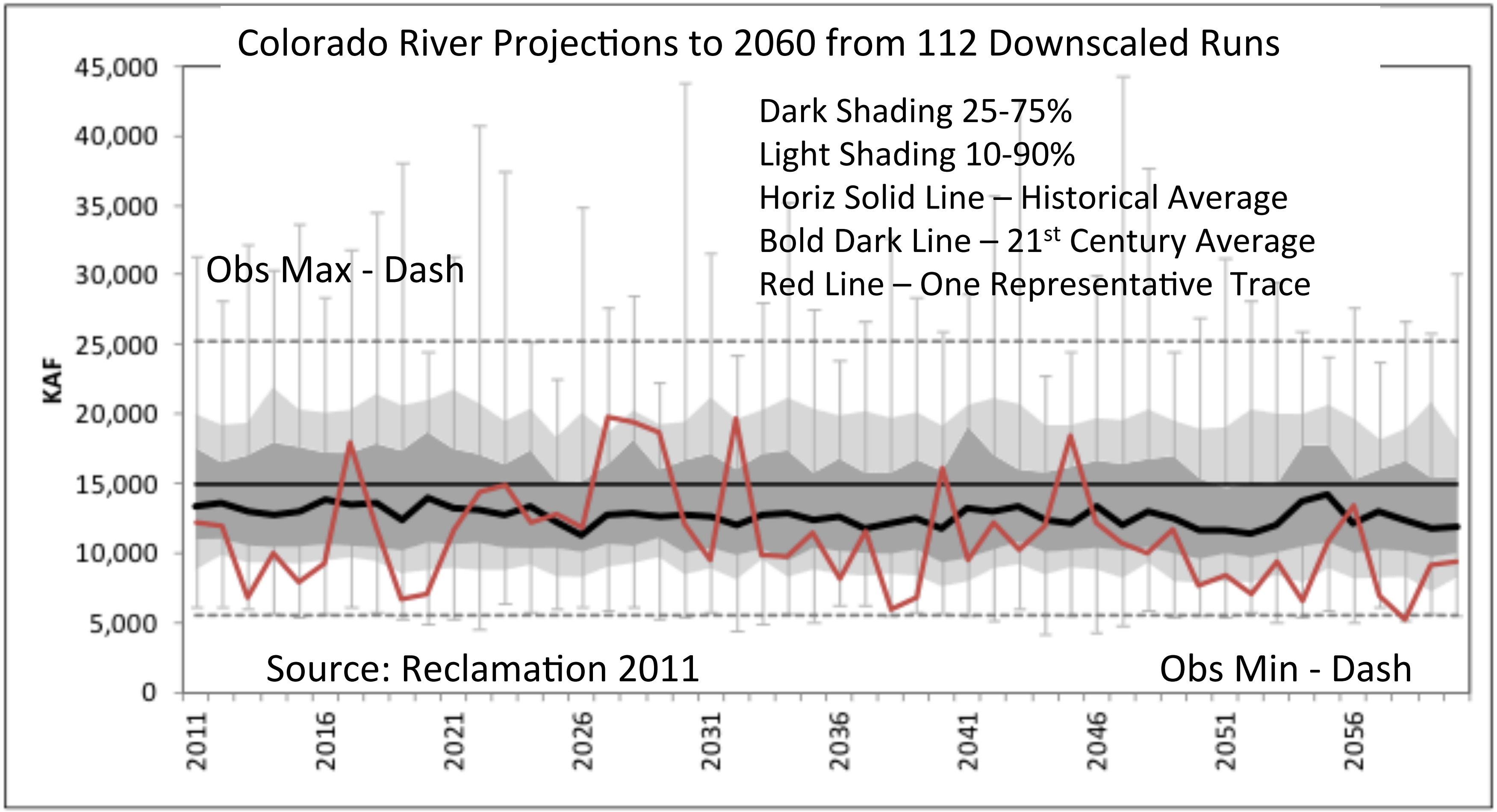
Being Honest about the Values of Models and Modeling: Why Model Outputs are the Least Valuable Part of the Process



CI-Water Symposium
Salt Lake City, UT
September 5, 2012

Brad Udall - bradley.udall@colorado.edu
Western Water Assessment
CIRES, University of Colorado

Western Water Assessment

Talk Overview

- Concepts re Uncertainty
  - On Policy Making - Smith and Stern, 2011
  - On Climate Modeling - Stainforth et al., 2007
  - Known Issues – GCMs, Downscaling, Natural Variability, etc
  - Warnings from Nature and Science
- Case Studies on Uncertainty, Projections
  - Australia via Kiem & Verdon-Kidd
  - USGCRP SAP 5.2 on Uncertainty
  - State of Colorado CRWAS Study
  - NRC Report Informing Decisions
  - Reclamation West Wide Climate Risk Assessment

"Perhaps you'd like a second opinion?"

- Conclusions and Musings
- Note: Focus is on Climate Change and Modeling, but these concepts apply to all uncertainty issues and modeling
- Advice From Churchill…Doing the Right Thing…

Western Water Assessment

Uncertainty in Science and its role in Climate Policy

- Terrific, Thought-Provoking Article Worth a Read
- Key Points
  - Science focuses on what is known or almost known but what is unlikely to be known can aid policy maker
  - Large Uncertainties do not mean small risks
    - Uncertainty can support immediate action in some cases
  - A lack of certainty provides no rational argument against action
  - Varieties of uncertainty:
    - Imprecision – can be quantified by PDF
    - Ambiguity – impacts known but can't be quantified via PDF, e.g. 100 yr impacts
    - Intractability – not solvable, e.g. no equations or lack computers
    - Indeterminacy – also not solvable, e.g., a societal value or non-physical parm.
  - "Models can increase our understanding long before they start providing realistic numbers."
  - Nice Discussion about Hydrological Uncertainties
  - These concepts not appreciated by both modeling community and user community

Uncertainty in science and its role in climate policy
Leonard Smith and Nicholas Stern
Phil. Trans. R. Soc. A (2011) **369**, 1–24 doi:10.1098/rsta.2011.0149

Western Water Assessment

Confidence, Uncertainty and Decision-Support Relevance in Climate Predictions

- Models can’t be calibrated – simulating never before seen state
  - Contrast with Weather where models interpolate
  - Climate models: no archive, run once, lead times >> model life
- PDFs can be made but meaning unclear
  - A Lower Bound on Range of Uncertainty
- 3 (5) Sources of Uncertainty
  - Forcing
    - External to Climate System
  - Initial Conditions
    - Makes a Difference to End Results
    - Does Not Make a Difference to End Results
  - Model Imperfection
    - Model Uncertainty – e.g. parameters
    - Model Inadequacy – incorrect formulation
- No rational way to weight models now

Confidence, uncertainty and decision-support relevance in climate predictions
D.A Stainforth, M.R Allen, E.R Tredger and L.A Smith
Phil. Trans. R. Soc. A 2007 **365**, 2145-2161 doi: 10.1098/rsta.2007.2074

Western Water Assessment

Some Known GCM - LSM Uncertainties

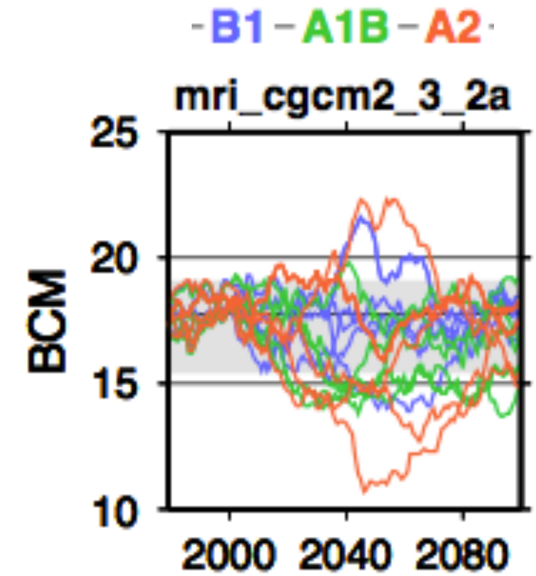
- Emissions Scenarios
- Models show consistent errors (biases)
- El Nino, Monsoons, Mountains, Blocking, Extremes
- Natural Variability Critical
- Models Constantly Changing
- Can't Verify Model Output
- Won't get any better for at least 10 years – See WUCA -- and maybe not even then…
- How much hydro cycle enhanced?
- Downscaling Issues
- Land Surface Models

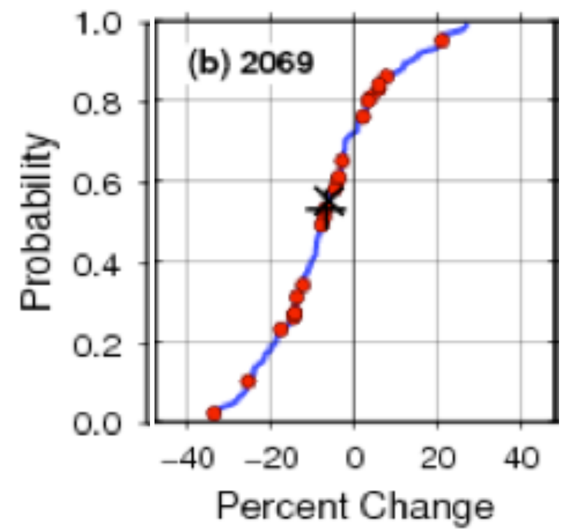
"The First Principle is you must not fool yourself and you are the easiest person to fool." ~ Feynman

		temperature BIAS					% precipitation BIAS				
REGION	SEASON	MIN	25	50	75	MAX	MIN	25	50	75	MAX
North America											
ALA	DJF	-9.8	-2.4	-0.8	1.9	8.2	3	33	51	89	179
	MAM	-7.4	-1.4	0.2	1.0	3.8	25	58	86	108	197
	JJA	-4.9	-1.6	-0.4	0.4	3.1	8	18	40	54	113
	SON	-5.7	-1.6	-0.6	1.4	4.8	14	33	52	65	113
	ANN	-5.2	-1.8	-0.4	0.6	3.7	14	41	53	59	106
CGI	DJF	-12.5	-4.5	-2.4	-0.5	4.8	-14	5	14	29	98
	MAM	-6.3	-2.6	-1.1	1.0	5.5	-4	19	29	45	97
	JJA	-4.4	-2.7	-0.9	0.9	4.7	4	13	16	30	47
	SON	-7.5	-3.8	-1.9	-0.4	6.6	0	10	15	21	72
	ANN	-7.	-3.2	-2.0	0.3	5.3	0	12	21	29	69
WNA	DJF	-4.7	-2.7	-0.9	-0.5	0.9	32	66	93	103	192
	MAM	-4.6	-2.9	-2.0	-1.0	0.1	37	62	71	93	158
	JJA	-2.5	-1.3	-0.4	0.9	2.2	-9	22	28	45	98
	SON	-4.4	-1.8	-1.2	-0.3	1.1	10	45	61	75	110
	ANN	-3.8	-1.8	-1.3	-0.5	0.7	29	53	65	74	130
CNA	DJF	-4.0	-2.4	-0.8	0.8	3.0	-37	-6	7	20	84
	MAM	-4.1	-1.3	-1.1	0.6	2.8	-17	-3	8	25	41
	JJA	-1.8	-0.3	0.4	1.6	3.5	-34	-21	-12	15	39
	SON	-3.8	-1.3	-0.6	0.4	2.3	-37	-24	-16	0	24
	ANN	-3.2	-1.0	-0.5	0.6	2.6	-18	-8	2	5	21
ENA	DJF	-4.6	-2.8	-1.6	-0.6	3.4	-18	-2	17	25	55
	MAM	-4.5	-2.1	-1.3	-0.7	2.4	-5	13	21	27	38
	JJA	-3.7	-1.4	-0.9	-0.5	2.3	-10	-2	13	18	45
	SON	-4.2	-2.0	-1.2	-0.6	2.0	-30	-17	-4	6	25
	ANN	-4.2	-2.1	-1.2	-0.6	2.2	-7	1	9	17	27

Deser et al, Uncertainty in Backyard

- “While there is undoubtedly much room for model improvement, we show that natural climate variability poses inherent limits to climate predictability and the related goal of adaptation guidance at many places in North America.”
- “On the other hand, low natural variability in some locations leads to a more predictable future in which anthropogenic forcing can be much more readily identified, even on small scales.”
- “We call for a more focused dialogue between scientists, policymakers, and the public to improve communication, avoid raising expectations for accurate regional predictions everywhere, and recognize that in some locations more useful predictability can be expected.”
- Harding et al on CRB Projections: at Mid-century one GCM with 4 runs shows -30% and +30%





“Uncertainty in the Backyard: Communicating the Role of Natural Variability in Future North American Climate

Clara Deser, Reto Knutti, Susan Solomon and Adam S. Phillips

January 17, 2012, Perspective submitted to Nature Climate Change

Western Water Assessment

Hydrologic Cycle Intensification

Ocean Salinities Reveal Strong Global Water Cycle Intensification During 1950 to 2000

Paul J. Durack,[1,2,3,4]* Susan E. Wijffels,[1,3] Richard J. Matear[1,3]

Fundamental thermodynamics and climate models suggest that dry regions will become drier and wet regions will become wetter in response to warming. Efforts to detect this long-term response in sparse surface observations of rainfall and evaporation remain ambiguous. We show that ocean salinity patterns express an identifiable fingerprint of an intensifying water cycle. Our 50-year observed global surface salinity changes, combined with changes from global climate models, present robust evidence of an intensified global water cycle at a rate of 8 ± 5% per degree of surface warming. This rate is double the response projected by current-generation climate models and suggests that a substantial (16 to 24%) intensification of the global water cycle will occur in a future 2° to 3° warmer world.

SCIENCE VOL 336 27 APRIL 2012

Western Water Assessment

Regional Climate Change Assessments

nature

Vol 463 | Issue no. 7283 | 18 February 2010

Validation required

Transparency and quality control are essential in the highly uncertain business of assessing the impact of climate change on a regional scale.

Climate scientists are engaged in a lively debate about how — or whether — the Intergovernmental Panel on Climate Change (IPCC) should reform itself (see *Nature* **463**, 730–732; 2010). At a minimum, the panel needs to hold itself to the highest possible standards of quality control in future assessments.

But so do climate scientists themselves — especially those who study the links between global climate change and its potential regional effects on factors such as weather patterns, ecosystems and agriculture. Governments faced with the need to make difficult, disruptive and politically fraught decisions about when and how to respond to climate change are understandably eager for certainty. But certainty is what current-generation regional studies cannot yet provide. Researchers need to resist the pressures to overstate the robustness of their conclusions, and to be as open as possible about where the uncertainties lie.

As an example of the scientific challenges involved, imagine a regional authority wanting to plan for water resources in a river basin over the next four decades. An applicable study might be probabilistic in approach. It could take into account a range of global greenhouse-gas-emission trajectories, and involve multiple runs of global climate models using different values for a number of parameters. However, such models cannot reproduce some important atmospheric phenomena such as circulation trapping, and cannot be validated against real climate behaviour over decadal timescales. The multiple runs will produce a probability distribution of precipitation which itself will contain intrinsic uncertainties. These outcomes then need to be fed into a catchment model with its own range of parameters and limitations of knowledge, and which in turn needs to be coupled to models of water demand as local housing and populations change over the period (M. New *et al. Phil. Trans. R. Soc. A* **365**, 2117–2131; 2007, and other papers in that issue).

Climate projections at the national level are crucial for such efforts. One such study was published last year, when the UK Met Office produced its climate projections of the next eight decades, including analysis down to a resolution of 25-kilometre squares (http://ukclimateprojections.defra.gov.uk). The British government is now conducting a national climate-change risk assessment, due for completion in early 2012, that uses the projections. But such an application could well be problematic: it is likely that the projections reflect the limitations of the models and analyses as much as probabilities intrinsic to the real world. Yet regional planners and others might easily miss the detailed discussions of uncertainties, and misguidedly seize on these projections as a solid basis for investment decisions. And depressingly for decision-makers, the more the uncertainties are explored, the greater the ranges in the projected possible outcomes are likely to become.

> **"Grey-literature studies should be transparently peer reviewed as a part of their commission."**

This combination of projections and risk analysis is one way in which an over-reliance by decision-makers on modelling may be setting up the scientific community for a loss of trust. What is more, like regional-impact studies, such analyses often appear not in peer-reviewed journals but in 'the grey literature' — in reports, or on websites. Yet they are no less important in representing the outputs of climate science, and need to be included in the IPCC assessment. For these reasons, such grey studies should be transparently peer reviewed as a part of their commission.

Uncertainties about future climate effects do not undermine the case for action to reduce greenhouse-gas emissions. But there is a long way to go in the science before regional-impact studies provide a suitable basis for detailed planning. Whatever the pressures, statements by scientists and government agencies about such studies need to be well qualified, and policies based on them need to be kept as flexible as possible. It is intrinsic to this research, after all, that scientists' best judgements will be subject to change. ■

nt

Don't Overstate What we Know

nature
Vol 463 | Issue no. 7283 | 18 February 2010

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Western Water Assessment

Warning Shot to UKCIP….

nature
Vol 463 | Issue no. 7283 | 18 February 2010

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Avoid Loss of Trust

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Grey-literature studies should be transparently peer reviewed as a part of their commission."

Recent Science Articles on Similar Themes

PREDICTING CLIMATE CHANGE

Vital Details of Global Warming Are Eluding Forecasters

Decision-makers need to know how to prepare for inevitable climate change, but climate researchers are still struggling to sharpen their fuzzy picture of what the future holds

SCIENCE VOL 334 14 OCTOBER 2011

ADAPTATION TO CLIMATE CHANGE

Time to Adapt to a Warming World, But Where's the Science?

With dangerous global warming seemingly inevitable, users of climate information—from water utilities to international aid workers—are turning to climate scientists for guidance. But usable knowledge is in short supply

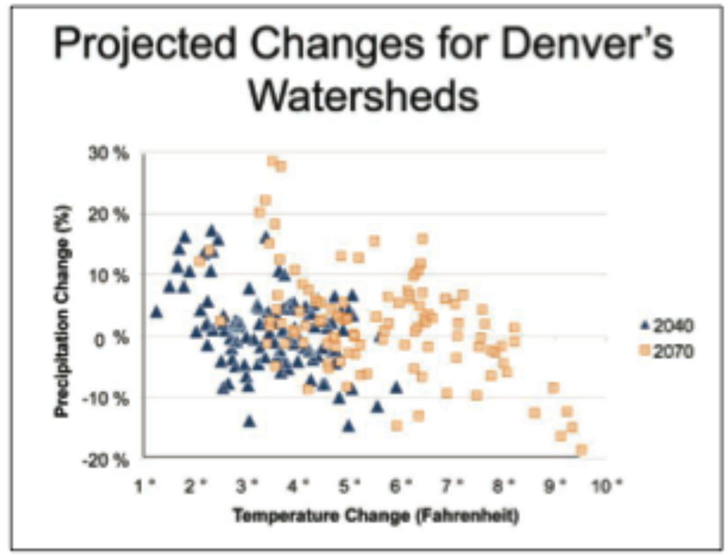
25 NOVEMBER 2011 VOL 334 SCIENCE

"Many regional modelers don't do an adequate job of quantifying issues of uncertainty."

"We are not confident predicting the things people are most interested in being predicted."

"The problem is that precision is often mistaken for accuracy."

~ Christopher Bretherton
University of Washington



A fuzzy future. Sixteen climate models run under three greenhouse gas emission scenarios consistently showed warmings (horizontal spread), but some projected more precipitation and others less (vertical spread).

Western Water Assessment

Talk Overview

- Concepts re Uncertainty
  - On Policy Making - Smith and Stern, 2011
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  - Warnings from Nature and Science
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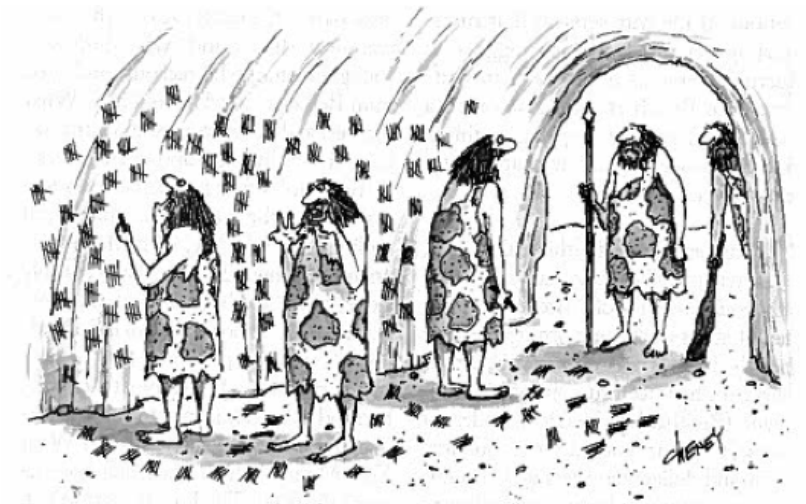
  - Reclamation West Wide Climate Risk Assessment



"It will take longer than we thought to go digital."

- Conclusions and Musings
- Note: Focus is on Climate Change and Modeling, but these concepts apply to all uncertainty issues and modeling
- Advice From Churchill…Doing the Right Thing…

Western Water Assessment

An Australian Example – Kiem and Verdon-Kidd

Steps toward "useful" hydroclimatic scenarios for water resource management in the Murray-Darling Basin

Anthony S. Kiem[1] and Danielle C. Verdon-Kidd[1]

Received 29 July 2010; revised 8 February 2011; accepted 21 March 2011; published 16 June 2011.

[1] There is currently a distinct gap between what climate science can provide and information that is practically useful for (and needed by) natural resource managers. Improved understanding, and model representations, of interactions between the various climate drivers (both regional and global scale), combined with increased knowledge about the interactions between climate processes and hydrological processes at the regional scale, is necessary for improved attribution of climate change impacts, forecasting at a range of temporal scales and extreme event risk profiling (e.g., flood, drought, and bushfire). It is clear that the science has a long way to go in closing these research gaps; however, in the meantime water resource managers in the Murray-Darling Basin, and elsewhere, require hydroclimatic projections (i.e., seasonal to multidecadal future scenarios) that are regionally specific and, importantly, take into account the impacts, and associated uncertainties, of both natural climate variability and anthropogenic change. The strengths and weaknesses of various approaches for supplying this information are discussed in this paper.

Citation: Kiem, A. S., and D. C. Verdon-Kidd (2011), Steps toward "useful" hydroclimatic scenarios for water resource management in the Murray-Darling Basin, *Water Resour. Res.*, *47*, W00G06, doi:10.1029/2010WR009803.

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KVK - Identified Shortcomings with Current Approach

- Failure to simulate synoptic patterns that drive rainfall, especially extremes
- Large Scale Processes not well simulated: ENSO, IOD, Others
  - Not understood, either
- Of 39 GCM runs, 22 show increases, 17 show decreases in precipitation
- None of the models could reproduce the drying trend since mid 1990s
- GCMs couldn't distinguish between wet coastal strip and dry interior 300 km away
- Climate model outputs at monthly and submonthly scale do not reproduce historical climate and show significant biases
  - Downscaling (Bias Correction and Change Factor) introduce 'false precision' and introduce an additional layer of uncertainty
  - Bias Corrections assumed to be stationary over time
- Climate to Hydrology Connection is Poorly Understood
  - Current Hydrology models calibrated to current conditions, not future
    - When does such calibration cease to be useful?

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KVK - “A 5-Step Way Forward”

- Step 1: Communication Between Climate Scientists, Hydrologists, and Water Resource Managers
  - Define what is ‘practically useful’
  - Disconnects about what can be expected and How to act in face of uncertainty
- Step 2: Quantify Baseline Risk Associated with Natural Climate Variability
  - Need to understand paleoclimate better
    - How dry can it get and for how long?
  - Need to understand drivers of variability
  - Stochastic Framework needed to integrate both
- Step 3: Incorporate the Projected Impacts of Anthropogenic Change
  - Identify physical processes driving hydroclimate
  - Identify or Develop models that simulate these processes
  - Determine how processes will change in the future and apply changes in stochastic framework
- Step 4: Develop Appropriate Adaptation Strategies
  - Need Reliable Probabilities of Uncertainties
  - Robust Quantification of Uncertainties Needed
  - Identify Win-win Adaptation Strategies
- Step 5: Ongoing Communication
  - Address Intensity, Time Span, Frequency

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KVK - Key Quote re Projections of Extremes

- "Until climate models can be shown to satisfactorily simulate the physical mechanisms we know are important for regional scale hydrology, their outputs should be used with caution as there is the danger that the "worst-case scenario" projected by current climate models may not actually be the worst case possible for water resource managers in terms of extreme events, particularly if the baseline is inappropriately assessed [e.g., Verdon-Kidd and Kiem, 2010].
- This has been recently demonstrated in eastern Australia with the December 2010 and January 2011 flooding and prior to that with the Big Dry drought, which lasted more than a decade; both of these events were far more severe than anything projected by any climate models under even the worst emissions scenarios and out to at least 2070."

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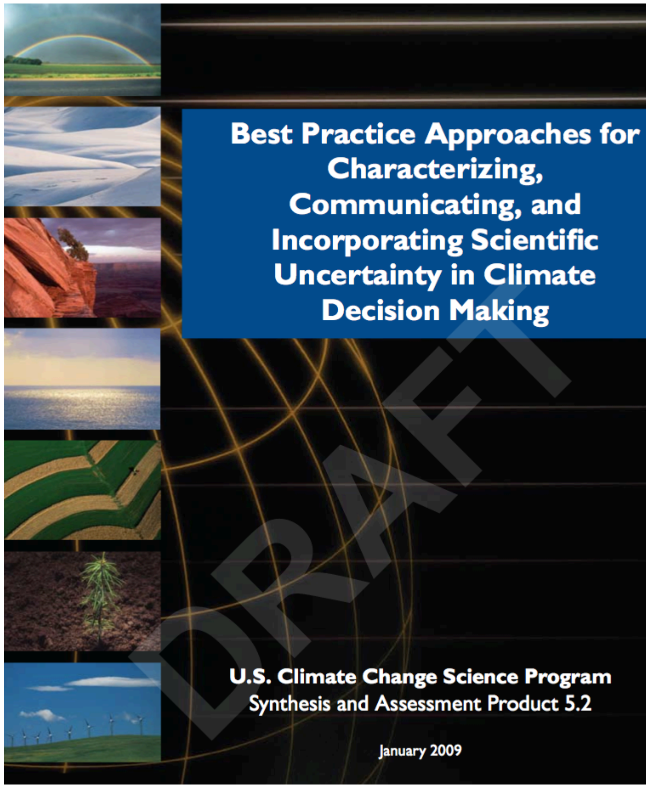
Lessons from SAP 5.2 – Uncertainty Guidance for Researchers

- Does what we are doing make sense?
- Are there other important factors that are equally or more important than the factors we are considering?
- Are there key correlation structures in the problem that are being ignored?
- Are there standard assumptions and judgments about which we are not being explicit?
- Is information about the uncertainties related to research results and potential policies being communicated clearly and consistently?



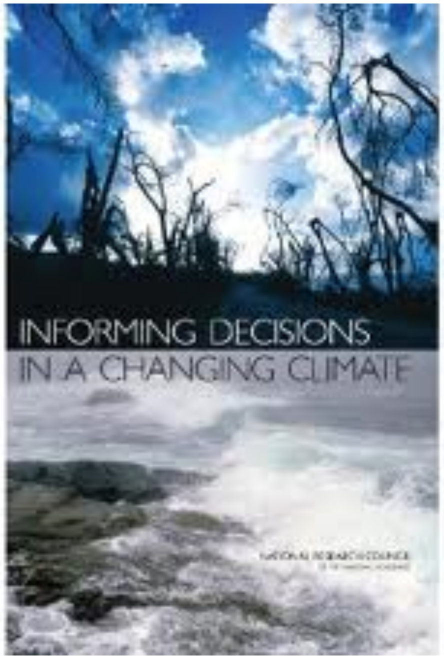
M. Granger Morgan, Hadi Dowlatabadi, Max Henrion, David Keith, Robert Lempert, Sandra McBride, Mitchell Small, and Thomas Wilbanks

Western Water Assessment

Informing Decisions in a Changing Climate, NRC 2009

- EPA and NOAA asked NRC to study informing decisions
    - Stationary Climate Assumption No Longer Tenable

- 6 Key Principles
    - Begin with Users Needs
    - Give Priority to Process over Products
    - Link Information Users and Providers
    - Build Connections Across Disciplines
    - Seek Institutional Support
    - Design Process for Learning



- Other Ideas
    - Use "Deliberation with Analysis"
    - Broadly Scan for New Information, Including Overseas
    - USGCRP Should support Research on Decisions, not just climate
    - Maintain and Expand Observing Systems
    - Support Students with Specialized Decision Support Knowledge
    - Undertake National Initiative for Decision Support

- Note: Almost nothing on forecasts, projections

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State of Colorado Lessons
Colorado River Water Availability Study

- Attempted to discover how much water ‘left to develop’ in the state under Colorado River Compact entitlement
- Strong North to South Water Availability Gradient made some think no problem
- Identified Inadequacy of Current Compact Allocation Models
- Climate Science is not yet Engineering
- Overall Frustration with Results

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Lessons from State of Colorado

Source: State of Colorado "CRWAS" Study

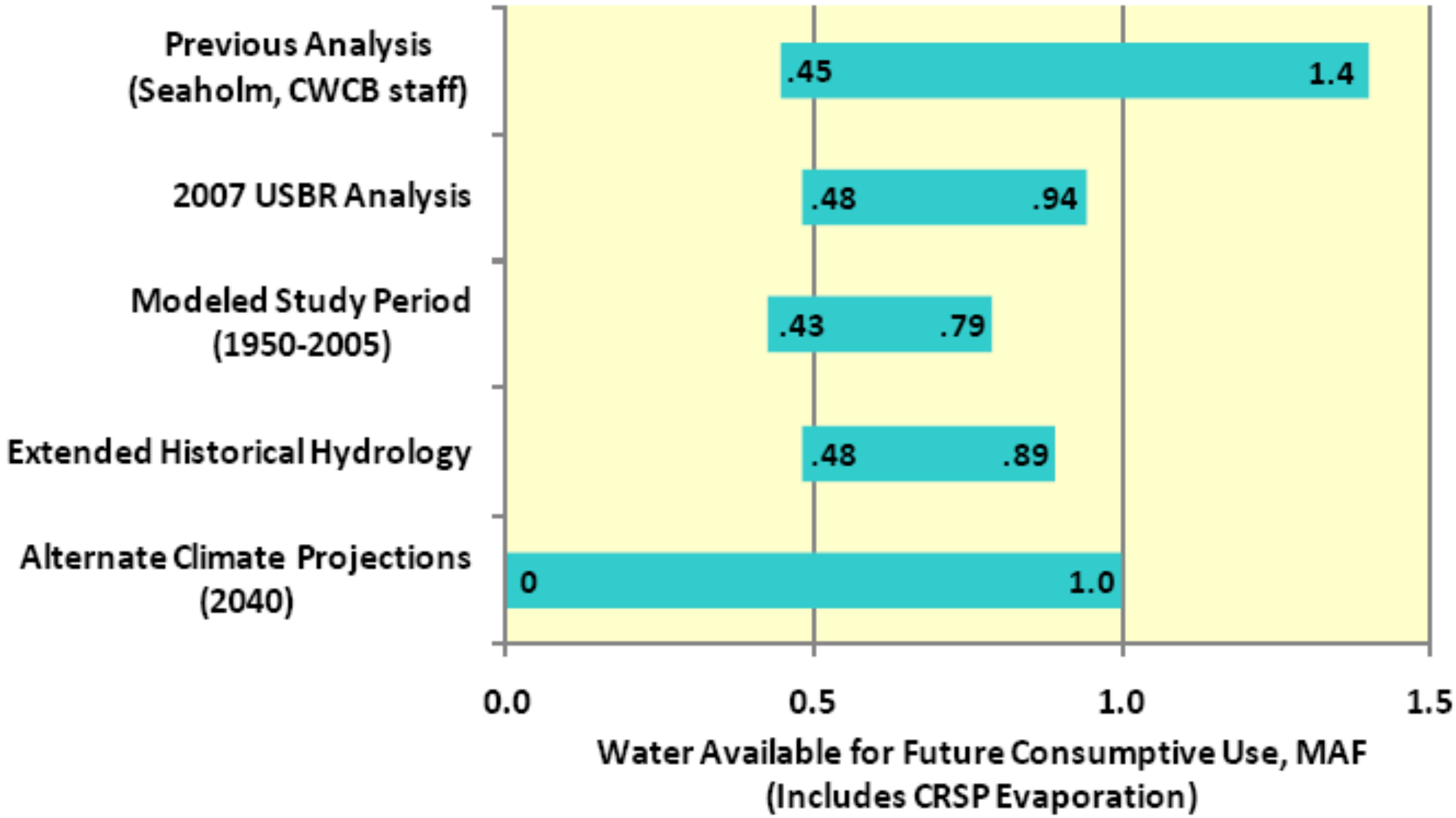


Figure 3-37 –Water Available for Future Consumptive Use by Colorado (MAF)
Revised from preliminary charts presented from January through March 2010 to CWCB, IBCC, Joint Agriculture Committee, and Colorado Water Congress

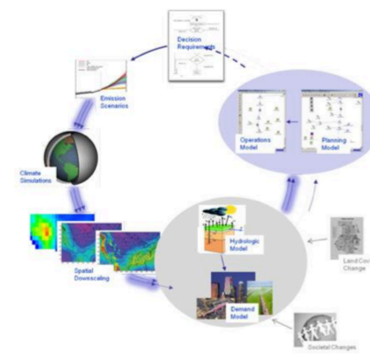
West-Wide Climate Risk Assessments

- Mandated by SECURE Water Act
- 7 Basins Modeled
- Chapter 6 on Uncertainties
  - GCM Forcing, Simulation, Bias, Downscaling
  - Hydrologic Issues: Natural Flows, Bias, Calibration, Spatial and Temporal Resolution

RECLAMATION
Managing Water in the West

Technical Memorandum No. 86-68210-2011-01

West-Wide Climate Risk Assessments: Bias-Corrected and Spatially Downscaled Surface Water Projections



Caveats on Model Output….

"lack of calibration of the hydrologic models is a real issue that needs to be addressed and should be addressed before these models are used in future assessments. Reclamation will (a) refine the VIC application and/or (b) introduce more appropriate hydrologic models. However, before implementing west-wide calibration efforts, it also is important to assess the fitness of the chosen model structure for some geographic situations."

Western Water Assessment

Some Musings and Conclusions - 1

- Churchill's Advice – Need to Think!
- Water Users have gotten smarter, not so sure about some researchers
  - WUCA a case in point
  - No one, far as I know, is using hydrologic outputs to make decisions
  - 1 km downscaling by ecological researchers
- Need to Have Better, Much Better Communication with Users
  - Push Back on What we Can and Cannot Do with Decision Makers
  - We must show full range of futures and explain different risks with each – credibility!
  - Uncertainty can in fact be a cause for action
- Need to Have Better Language around Uncertainty
  - Not all uncertainty the same
  - Like Smith & Stern Language: Imprecision, Ambiguity, Intractable, Irreducible
  - Need to discuss Emissions, Variability, El Nino etc in these terms in addition to other knowledge about these effects
  - Can we create a food label for these projects showing uncertainty?
  - Avoid being overly deterministic and precise when there is no basis

Some Musings and Conclusions - 2

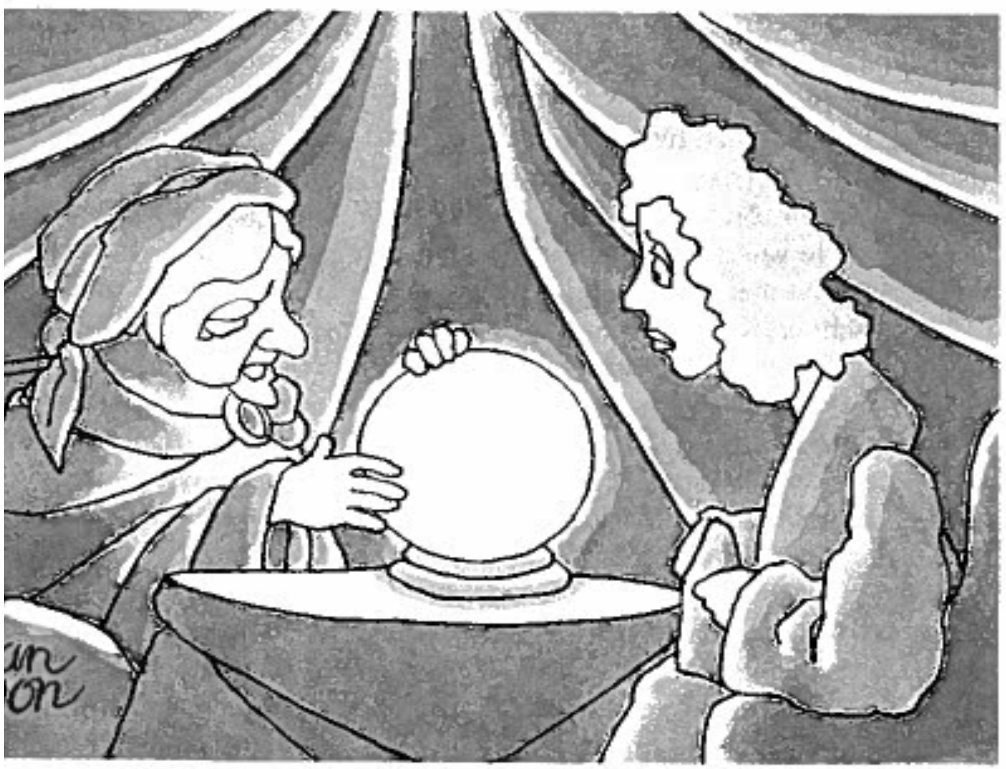
- Projections least valuable part of modeling
  - "We Model for Insights not Answers"
  - "Plans are Nothing, Planning is Everything"
  - Physical Mechanisms, Counter-intuitive findings, Data Issues, Learning ALL trump projections
- Modeling as thinking…
  - Writing is thinking with words, modeling is thinking with numbers
  - Writing generates multiple insights, so should modeling
  - Turning the crank to blindly produce outputs is not thinking
  - Simple Models are ok, too
- Should we stop doing 100 year projections?
  - The greater the warming, the less our ability to model
  - Just because we can do this doesn't make it a good idea
  - Probability(Big Surprises) is Large at > 30 Years
- Specialization leads to blindness
  - Are Really Smart People doing collectively dumb things?
  - We need to bring other disciplines into this discussion
  - The less you want to read Smith and Stern, Stainforth et al, the more you need to read them!
- Easy to Dump on Models, not so easy to define a healthy relationship
  - This is our challenge

Western Water Assessment

Final Thoughts…

We are headed towards a very different and disturbing world with respect to our water supplies and our inability to precisely define these changes should not take away from this critical message.

Modeling, properly done, can inform and guide our actions in a way that no other scientific tool can.



"You will make the same foolish mistakes you have made before, not only once but many, many times again."

Western Water Assessment

The Effects of Doubling the CO_2 Concentration on the Climate of a General Circulation Model[1]

SYUKURO MANABE AND RICHARD T. WETHERALD

Geophysical Fluid Dynamics Laboratory/NOAA, Princeton University, Princeton, N.J. 08540

(Manuscript received 6 June 1974, in revised form 8 August 1974)

ABSTRACT

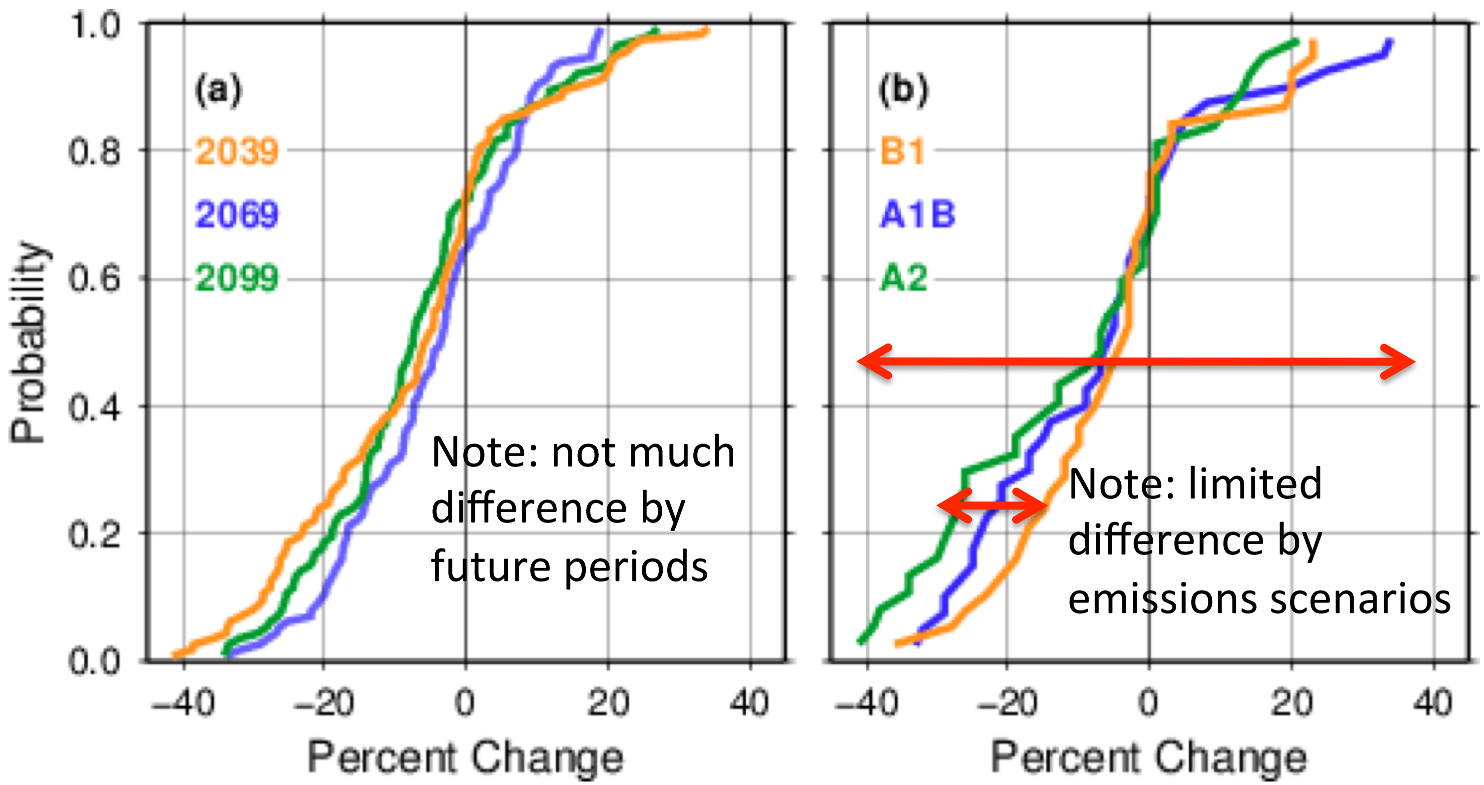
An attempt is made to estimate the temperature changes resulting from doubling the present CO_2 concentration by the use of a simplified three-dimensional general circulation model. This model contains the following simplifications: a limited computational domain, an idealized topography, no heat transport by ocean currents, and fixed cloudiness. Despite these limitations, the results from this computation yield some indication of how the increase of CO_2 concentration may affect the distribution of temperature in the atmosphere. It is shown that the CO_2 increase raises the temperature of the model troposphere, whereas it lowers that of the model stratosphere. The tropospheric warming is somewhat larger than that expected from a radiative-convective equilibrium model. In particular, the increase of surface temperature in higher latitudes is magnified due to the recession of the snow boundary and the thermal stability of the lower troposphere which limits convective heating to the lowest layer. It is also shown that the doubling of carbon dioxide significantly increases the intensity of the hydrologic cycle of the model.

A Wetter Colorado River?

Rasmussen et al., 2011: increased Precip due to better topography
Harding et al., 2012: Don't forget 30% of runs which show greater precip

- **Unforced internal model variability and model choice dominate**

empirical CDFs of streamflow change projections



At 3 Future Periods

At 2070-2099

Slide from Andy Wood

Western Water Assessment

Mysteries vs. Puzzles

Two Kinds of Problems

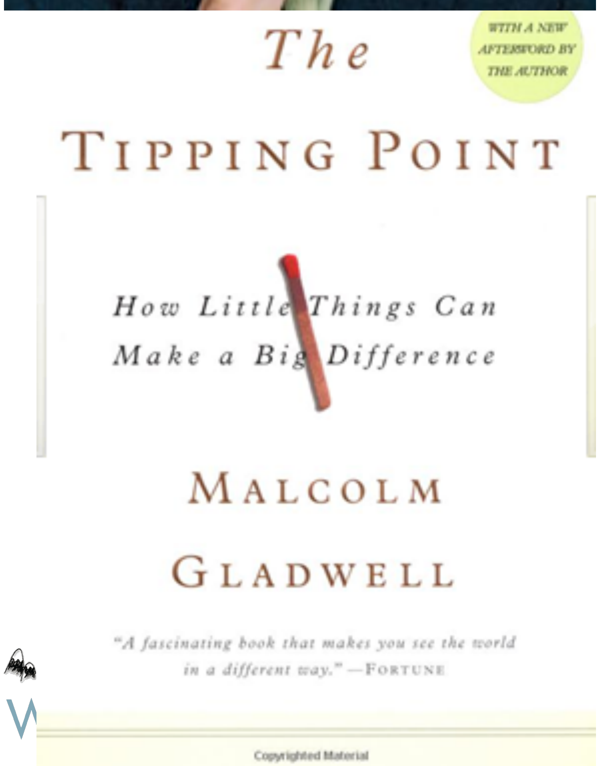
Malcolm Gladwell on Enron Collapse

Mystery: problem where the answer is obscured by lots of details. The answer is there but most of us can’t see it.

Puzzle: problem where we are missing a crucial piece of information. We need to search for the information.

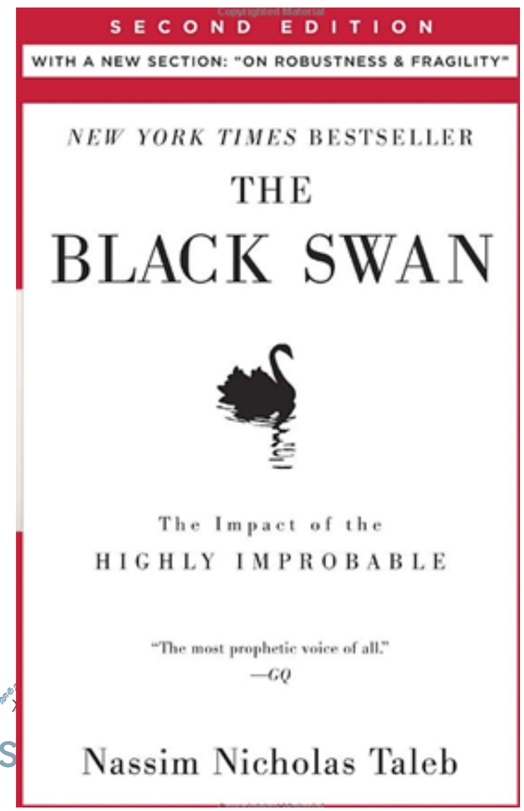
The solutions required are very different.

View climate as a mystery, not as a puzzle.

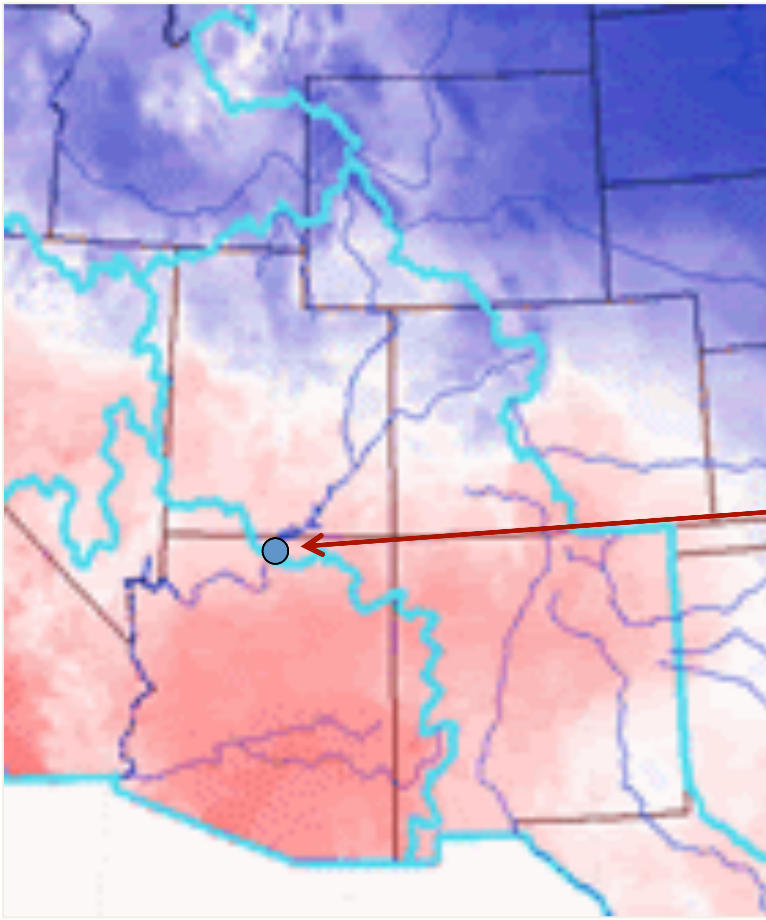


Black Swans

- Society Changing Event – Outlier and Extreme
  - 2008 Market Crash
  - Gulf Oil Spill
  - 9/11
  - 2005 Tsunami
- Happen all the time and change history
- We fool ourselves into thinking that we can predict these
- Instead of predicting, need to adjust to existence
- We fixate on what we know, rather than what we don't know
  - Knowledge makes us more confident than we should we
- Will occur more frequently in 21st century
- Taleb loathes normal distribution
  - Poorly describes risk profile for many vulnerabilities
  - 'Fat Tails' Exist in many phenomenon
- Name comes from Australia and first sightings of Black Swans

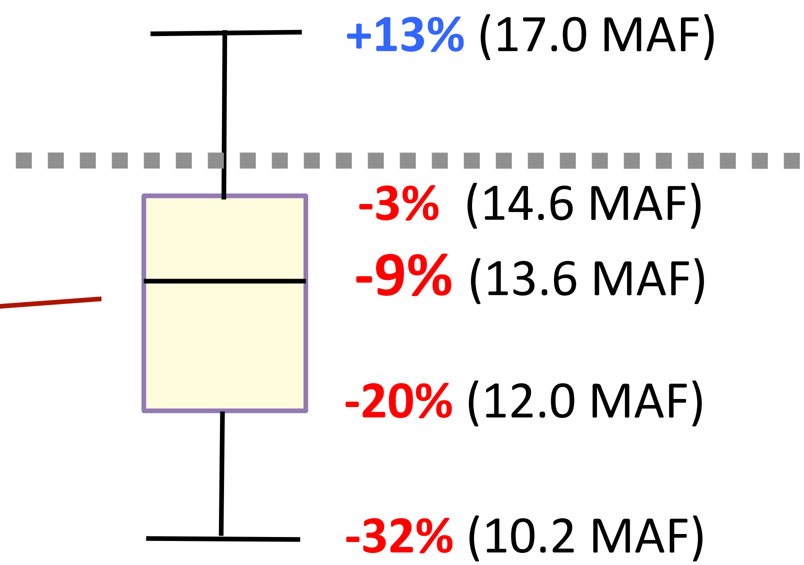


Reclamation WWCRA – *range* of projected change in annual runoff by ~2050 from all 112 projections



Map: Projected *median* change in annual precipitation by late 21st century: red = decrease; blue = increase

Colorado River at Lees Ferry, AZ



Source: Bureau of Reclamation Colorado Basin Study, Technical Report B (2011)

Western Water Assessment