

Communicating Climate Change Scenarios to Decision Makers

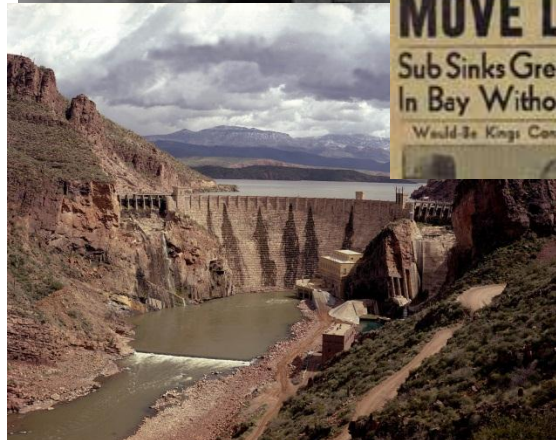
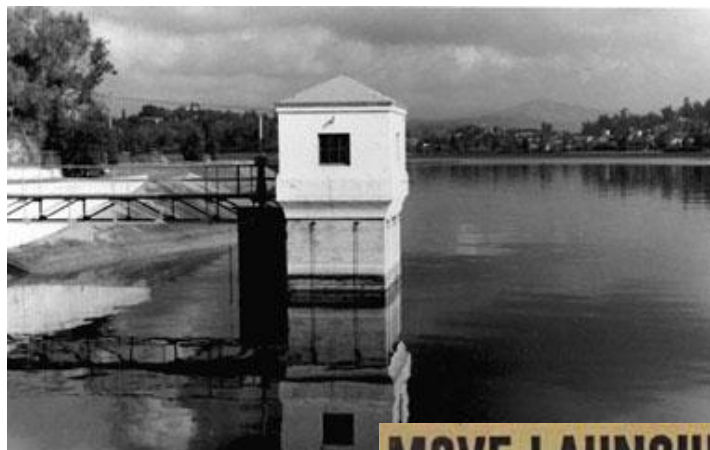


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Water Management Has Long Used Climate Information

Reservoirs, levees, irrigation systems, groundwater development, water allocation & transfer agreements are all designed to mitigate climate variability – across many time/space scales.



“Stationarity is Dead” – Our fundamental assumption!

Stationarity

- Time invariant statistics
- Different parts of historic record equally likely
- Statistical definition of probability distribution faithfully represents expectations for the future

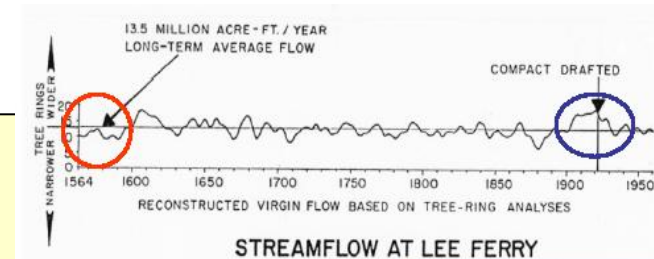
Stationarity Is Dead: Whither Water Management?

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. Stouffer⁷

Science 2008

Meaning for Water Management

- Risks are stationary/stable over time
- Observed flow records are the best estimate of future variability
- Systems that are robust to past variability are robust to future variability



Woodhouse, UA

Decision Makers Must Confront Two Realities

Intractable Uncertainty, Irreducible Uncertainty

- trends, regimes
- paleoclimatological evidence of extended or regional drought
- other human impacts on hydrologic systems, ecosystems
- global warming impacts – beyond past experience?

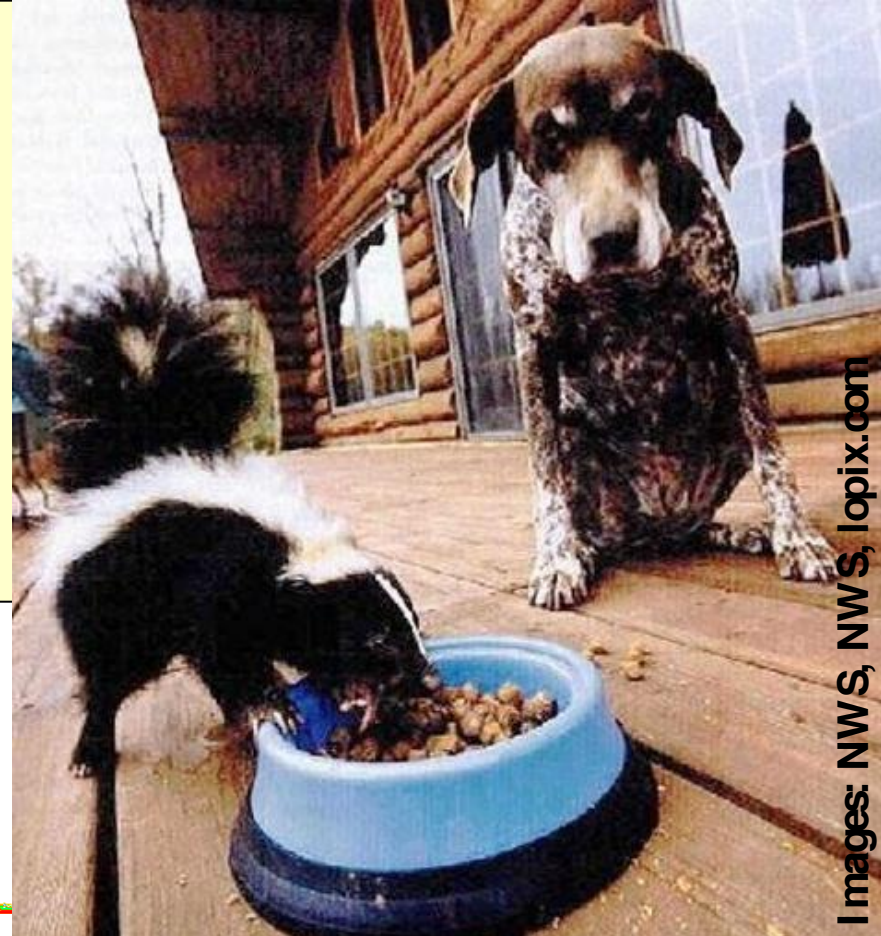
Non-stationarity: the past doesn't represent the future

- no 'standard approach' for handling non-stationarity
- models more informative than historical statistics alone
- temperature is a hydrologic variable

Supporting Adaptation: Effectively, Efficiently

What is decision support ?

Climate change decision support refers to **organized efforts to produce, disseminate, and facilitate the use of data and information in order to improve the quality and efficacy of climate-related decisions** (NRC 2009, Informing Decisions in a Changing Climate).

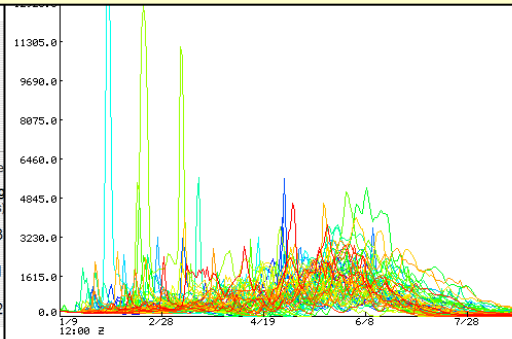


Images: NWS, NWS, lopix.com

Weather Conditions for:
Eugene, Mahlon Sweet Field, OR (KEUG)
Elev: 364 ft; Latitude: 44.13333; Longitude: -123.21444

Current time: Fri, 10 Dec 7:27 am (PST)
Most Recent Observation: Fri, 10 Dec 6:54 am (PST)

Time (PST)	Temp (F)	Dew (F)	Relative (%)	Wind Direction	Wind Speed (mph)	Visibility (miles)	WX	Clouds	Sea Level Pressure (mb)	Altimeter Setting (inches)
10 Dec 6:54 am	47	44	90	S	15	10.00		SCT028 BKN044 OVC060	1016.9	30.03
10 Dec 5:54 am	46	43	89	SSE	7	7.00	RA	FEW027 BKN036 OVC050	1016.4	30.01
10 Dec 4:54 am	46	43	89	SSE	8	10.00	-RA	FEW033 BKN040 OVC060	1016.6	30.02



VUCA is the “New Normal”

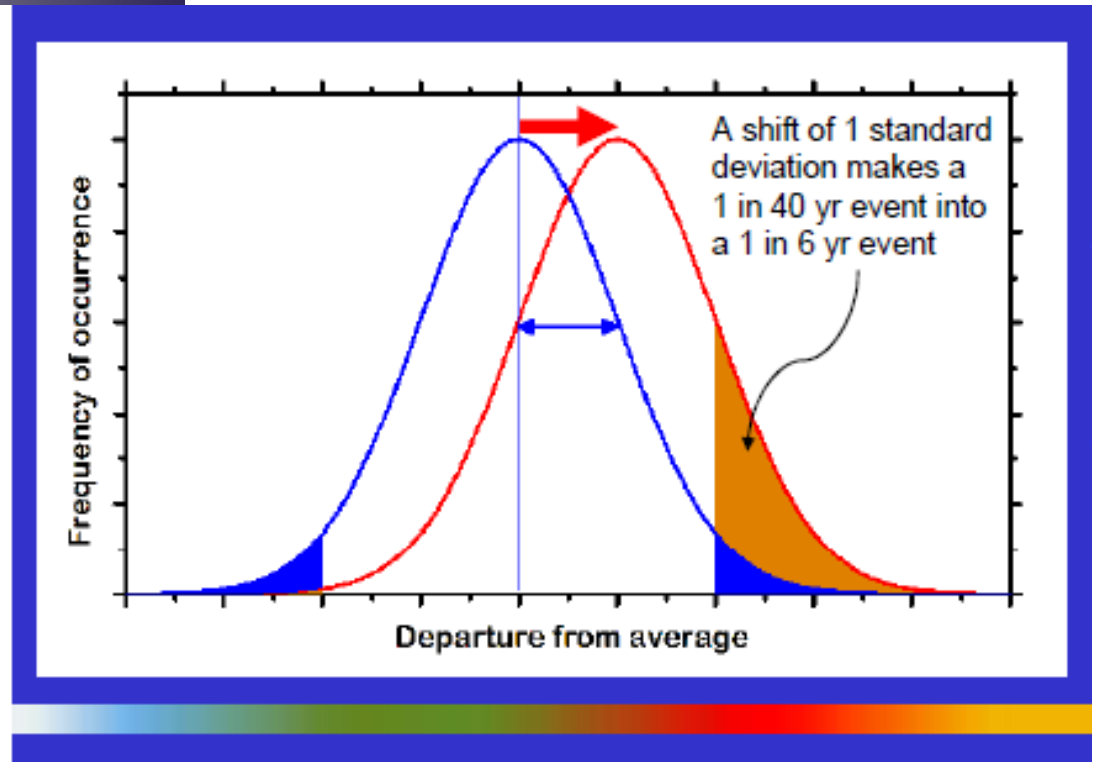
Volatility

Uncertainty

Complexity

Ambiguity

Institute for the Future



IPCC WG1

VUCA is not new but scale and intensity are increasing.

Policy/management dilemma: committing too soon vs. deciding too late.

R.K. Craig: “Accept – really accept – that climate change will often be painful.”



The ADAPTATION BOTTLENECK

... shifting from awareness to adaptation

Adaptation: Deliberate Change in System Behavior, Function, or Design

1. **Resistance:** defend against change (Homeland Security)
2. **Resilience:** 'bounce back' after disturbance (Health Care)
3. **Response:** facilitate change (Beginners Mind), e.g., regional approaches, interconnections, diversity
4. **Realignment:** accept different systems, focus on function (Auto Mechanics)
5. **Reduce:** *mitigation* of GHG (Good Samaritan)
6. **Triage:** let go (Pragmatic)

Adapted from Millar et al, 2007. Ecological Applications. 2008, Forest Guild presentation



Decision Support Approaches for Water Management

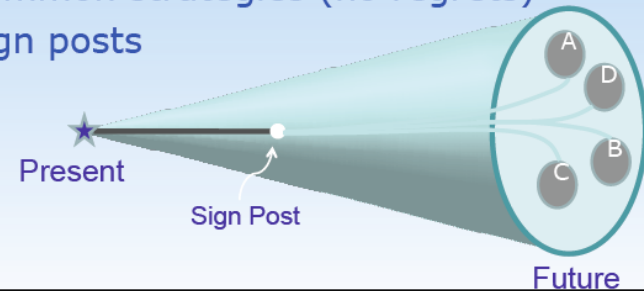
Decision Analysis

- Decision trees, probabilities and costs
- Minimize expected costs



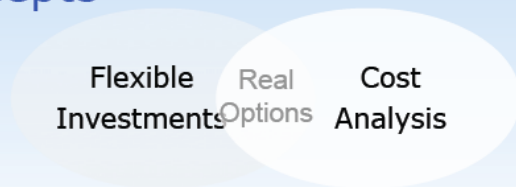
Scenario Planning

- Small number of equally likely scenarios [A, B, C, D]
- Common strategies (no regrets)
- Sign posts



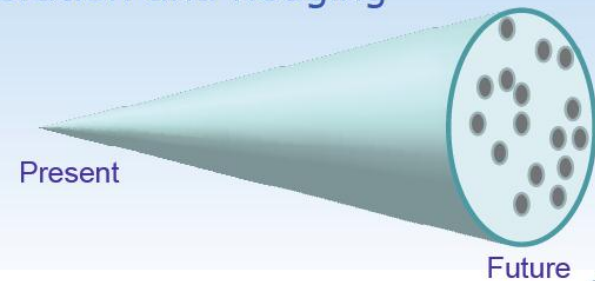
Real Options

- Combines decision analysis and financial theory
- Decision tree and financial hedging concepts



Robust Decision Making

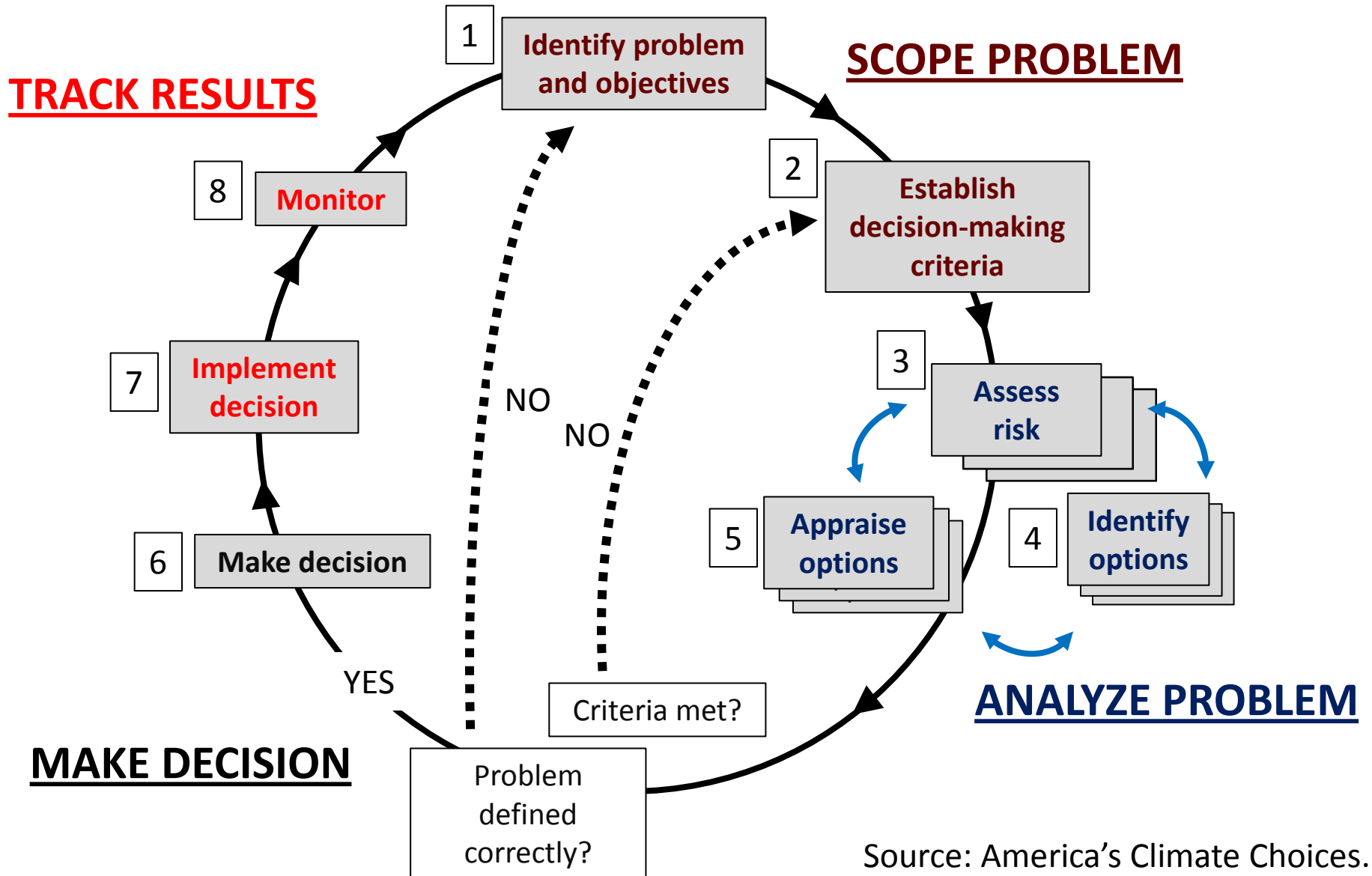
- Computer analysis of many plausible likely scenarios
- Iteration and hedging



Overall Approach: Iterative Risk Management

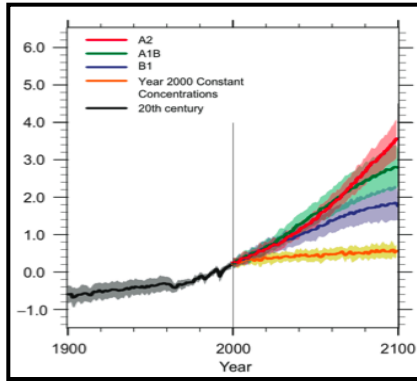


Iterative Risk Management Framework

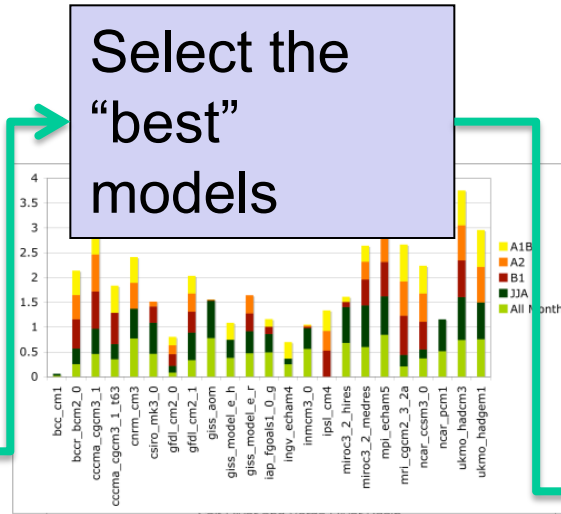


Source: America's Climate Choices.
National Research Council, 2010.

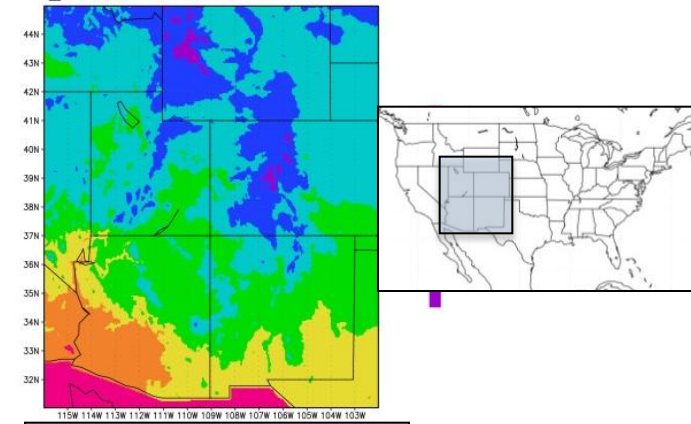
Model Chain: Rapidly Increasing Output!



IPCC AR4 GCM projections



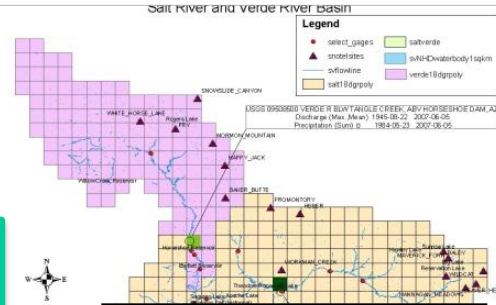
MPI_ECHAM5 SRESA1B Winter 2075-2098



Spatial Downscaling

From approx. 200 km to 4 km.

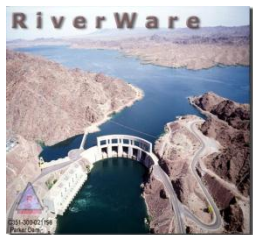
Hydrologic projections at watershed scale.



Hydrologic models

Temporal Downscaling

From Seasonal to Daily



Water Management Models

Evaluate Management Options

Irreducible Uncertainty of Climate Change

A1: Rapid economic growth, population 9B in 2050 then decline, quick spread of efficient technologies, convergent world

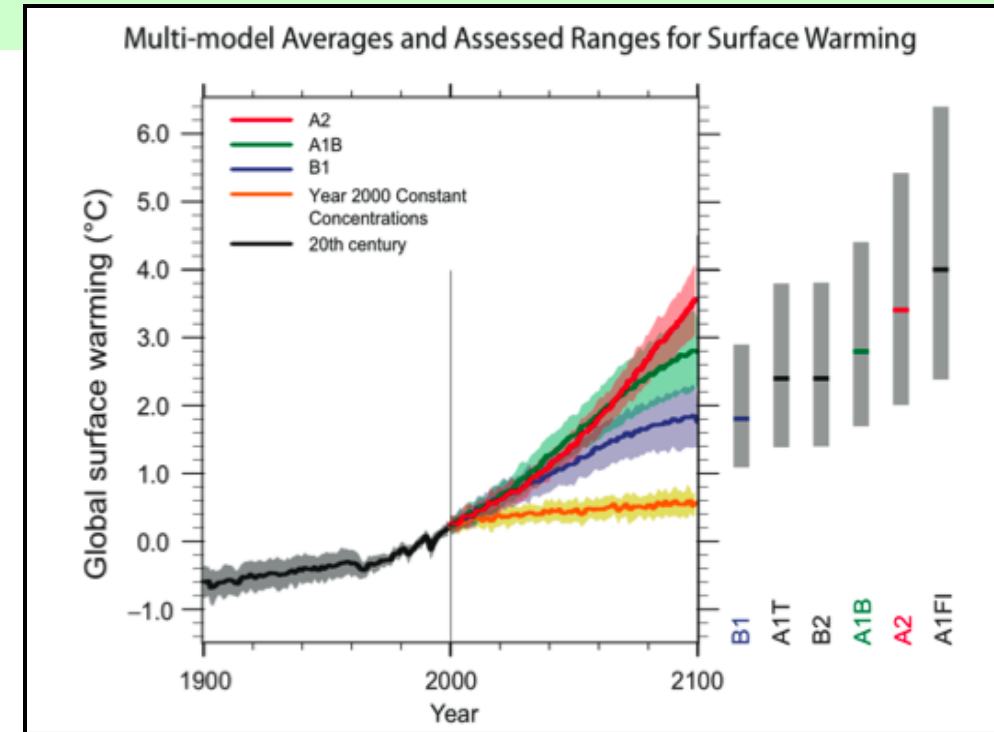
A1F: fossil fuels

A1B: mix of fuels

A1T: non-fossil fuels

A2: more divided/diverse world, continual population increases, regional economic development, slower and fragmented technological and economic gains

B1: Same as A1, but change toward service and information economies, reductions in material intensity

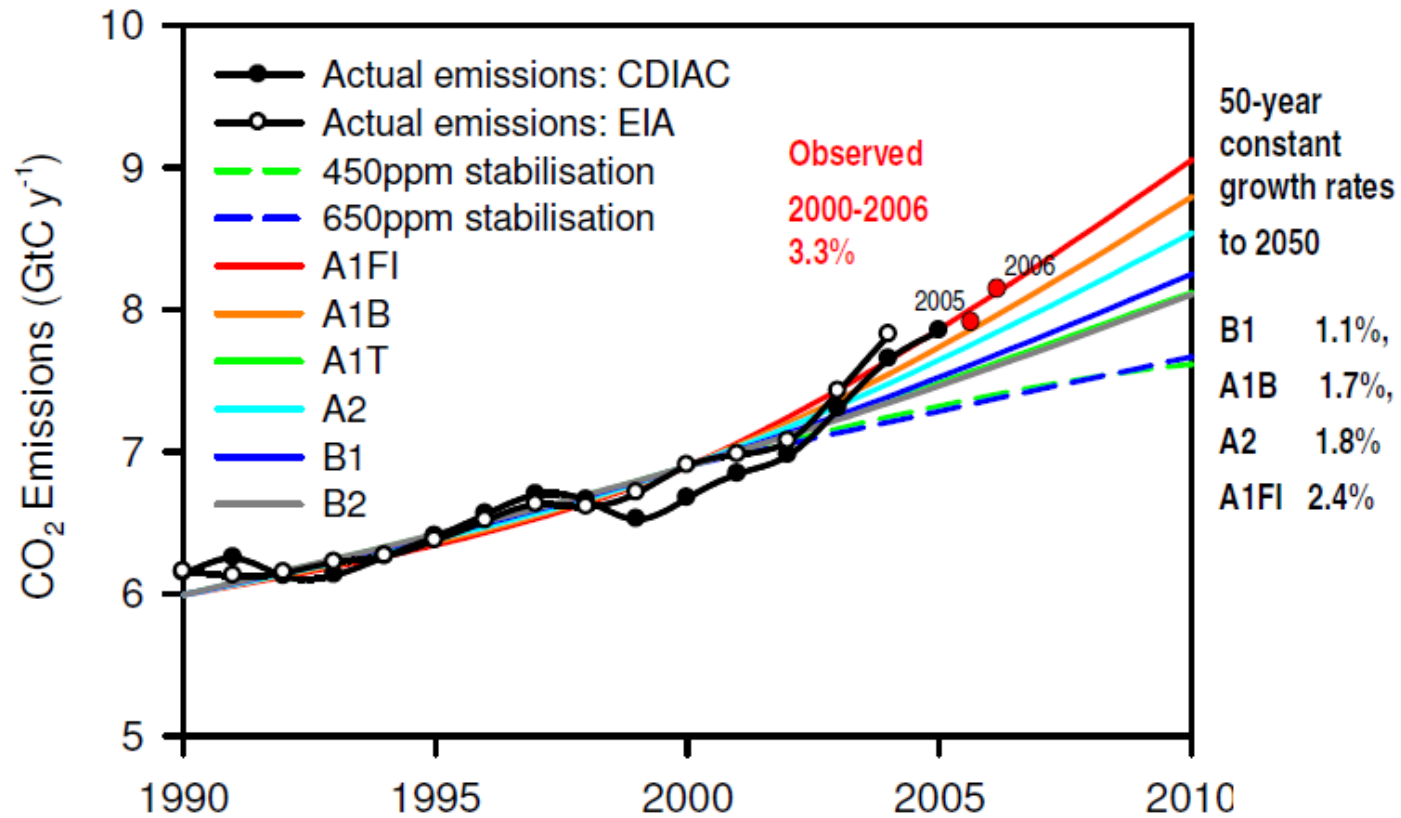


IPCC Fourth Assessment Report May 2007

B2: More divided world but ecologically friendly, slower population growth than A2, intermediate economic development, less rapid technological change, more fragmented change at more local level

Moving Beyond IPCC 4 Scenarios

Trajectory of Global Fossil Fuel Emissions



Raupach et al. 2007, PNAS

Liverman et al., 2009: planning should consider 4 deg C rise by 2060

Moving Beyond IPCC 4 Scenarios

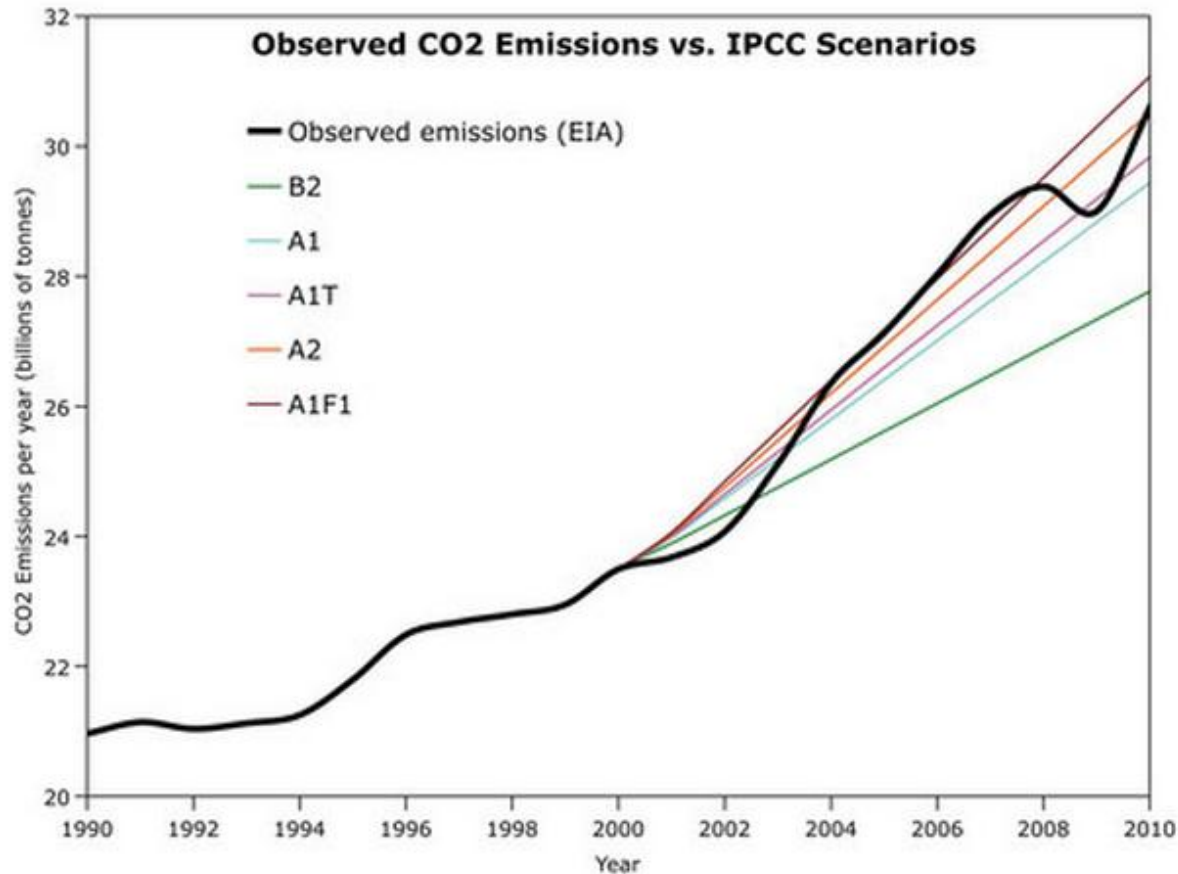
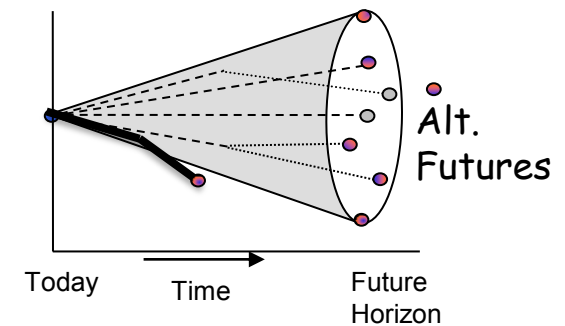


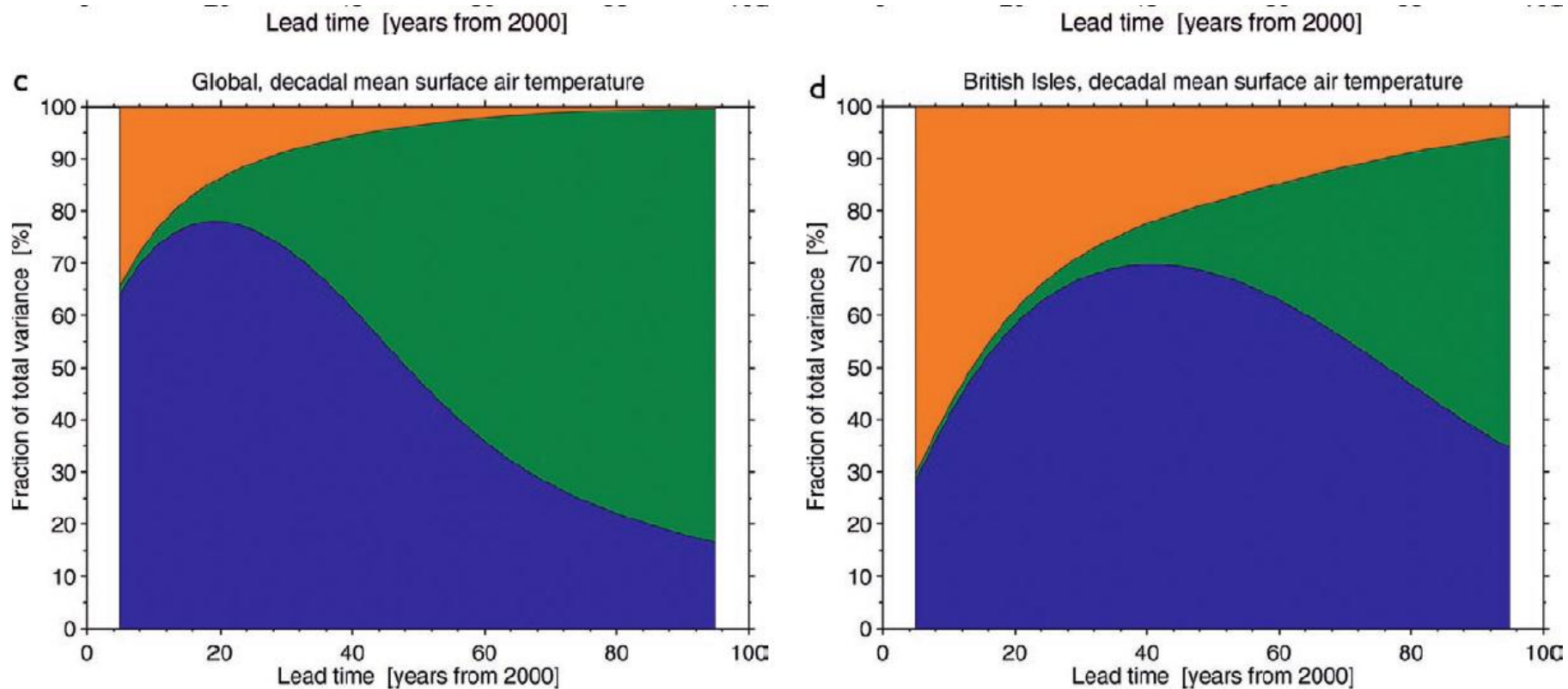
Figure 1: US Energy Information Administration (EIA) global human CO₂ annual emissions from fossil fuels estimates vs. IPCC SRES scenario projections. The IPCC Scenarios are based on observed CO₂ emissions until 2000, at which point the projections take effect.



Abraham, 2012, <http://theconversation.edu.au>

Liverman et al., 2009: planning should consider 4 deg C rise by 2060

Relative Importance of Sources of Uncertainty on Decadal Surface Temperature



Climate internal variability

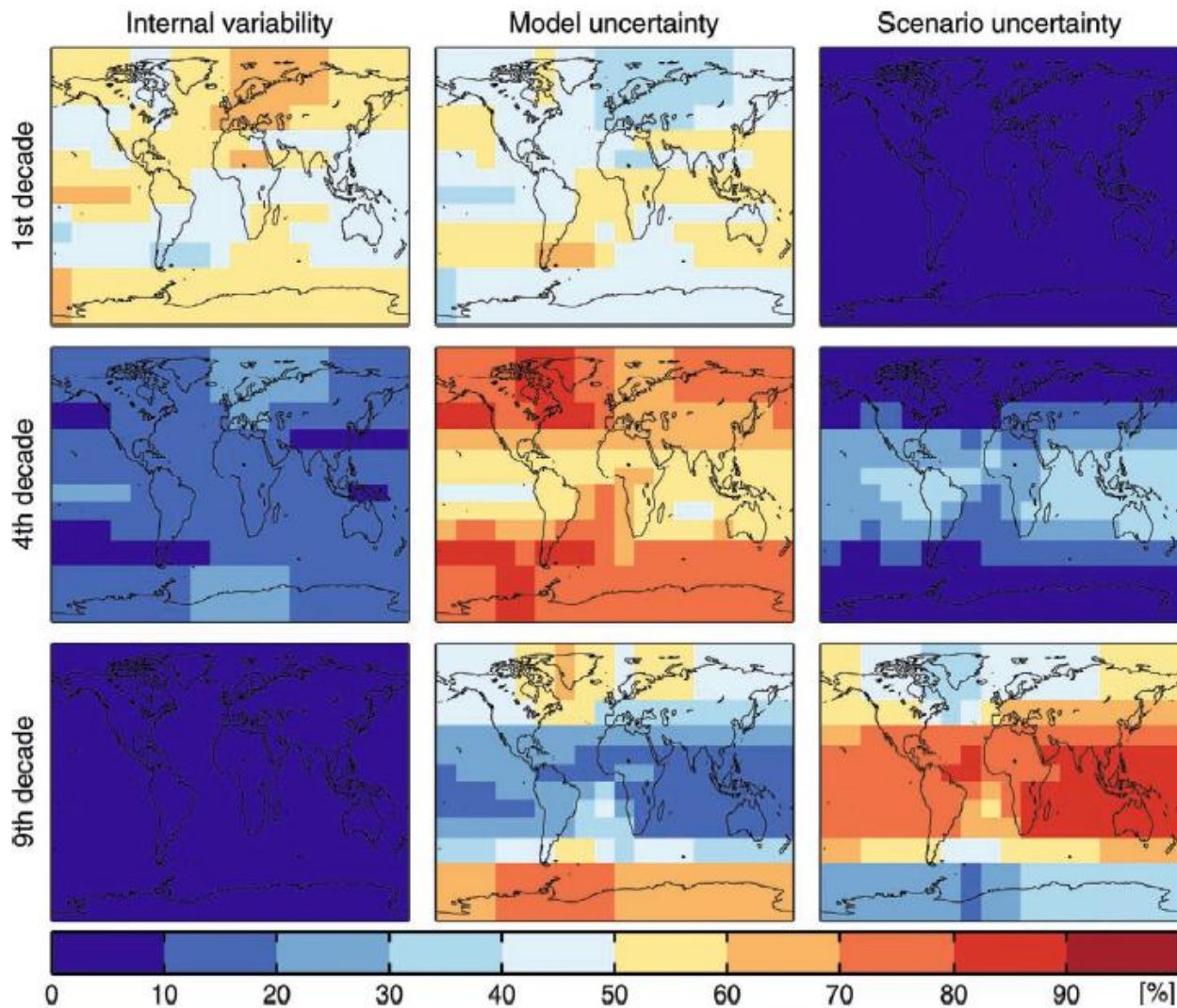


Climate models



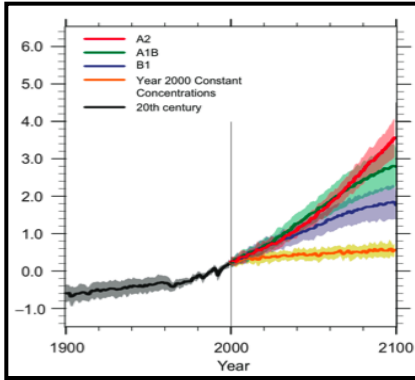
Emissions scenarios

Relative Importance of Sources of Uncertainty on Decadal Surface Temperature



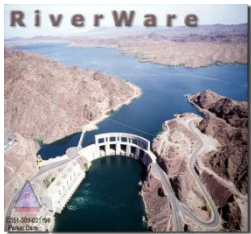
Variance explained vs. time

Model Chain: More Isn't Always More Certain

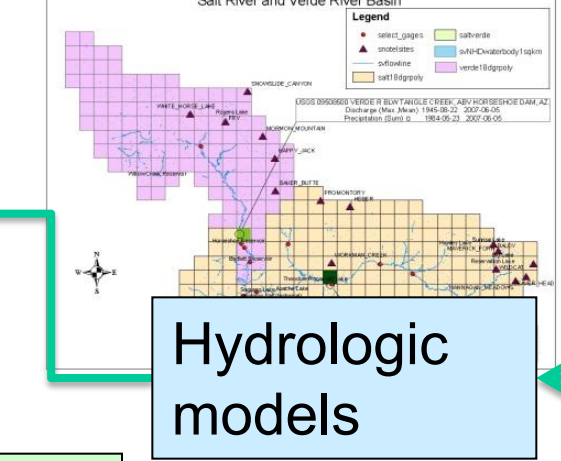
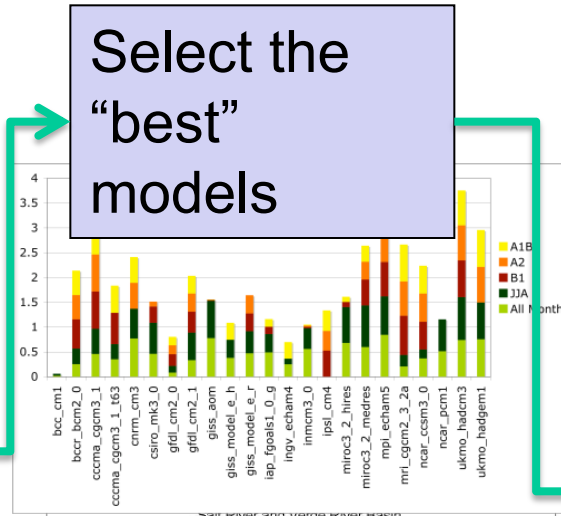


IPCC AR4 GCM projections

Hydrologic projections at watershed scale.

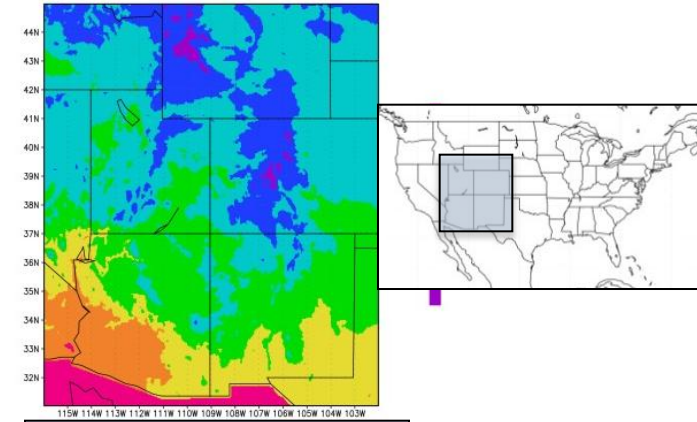


Water Management Models



Hydrologic models

MPI_ECHAM5 SRESA1B Winter 2075-2098



Spatial Downscaling

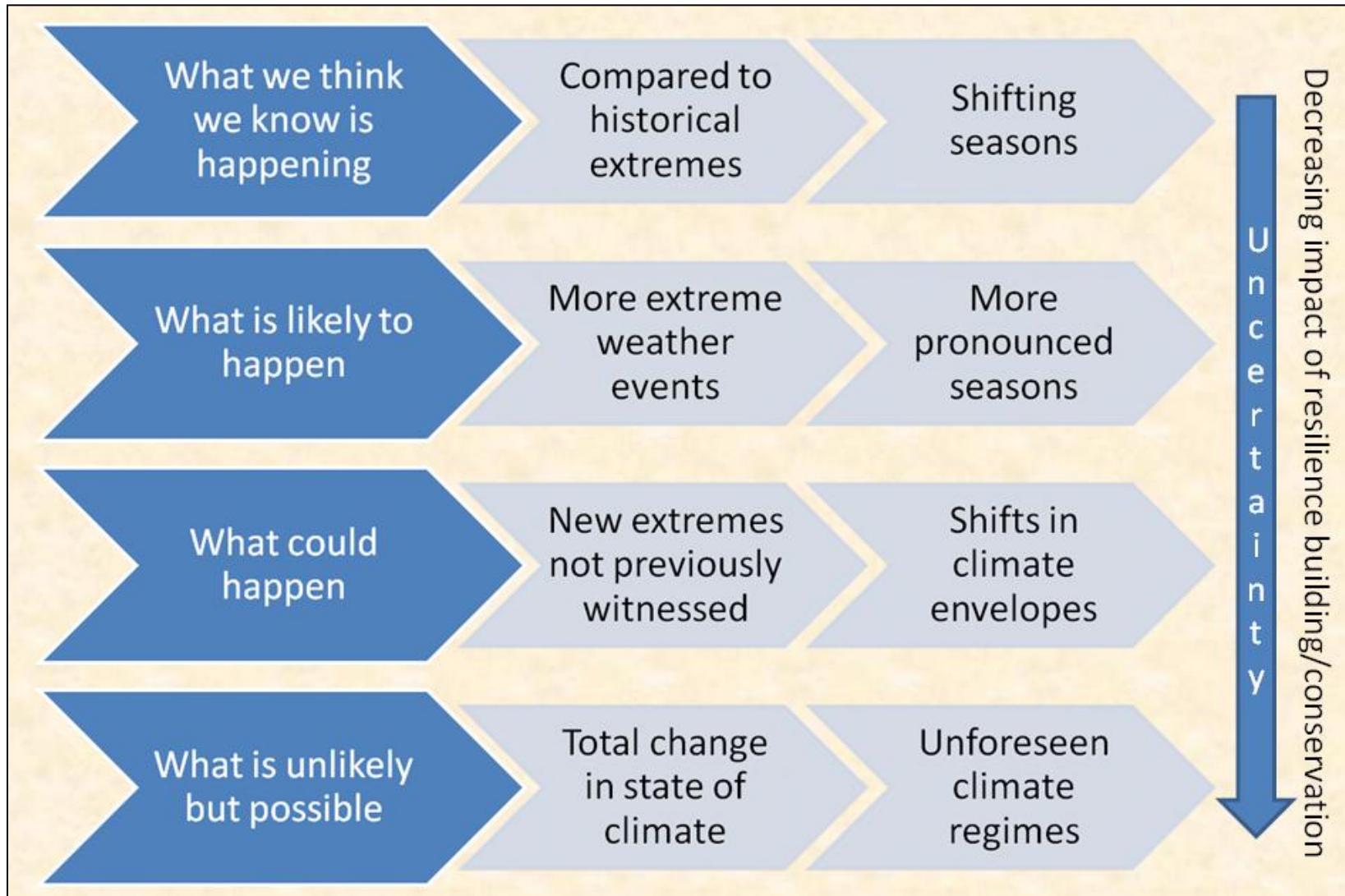
From approx. 200 km to 4 km.

Temporal Downscaling

From Seasonal to Daily

Evaluate Management Options

The Adaptation Challenge

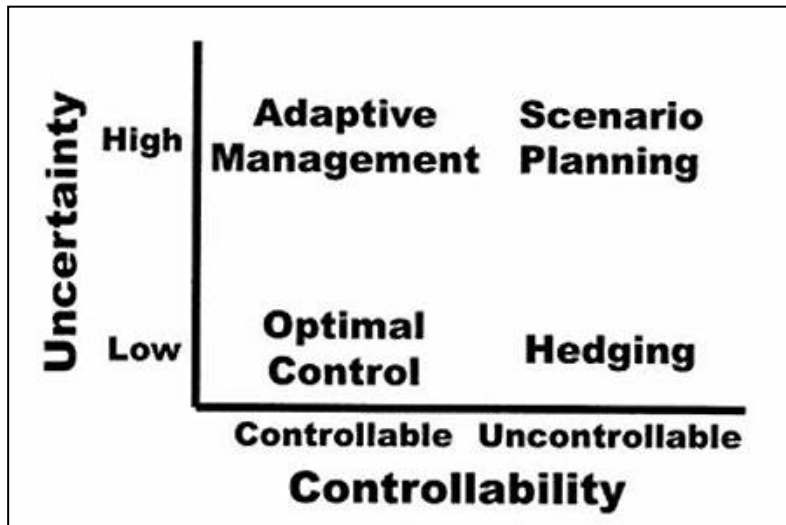


From Wickel et al, 2009

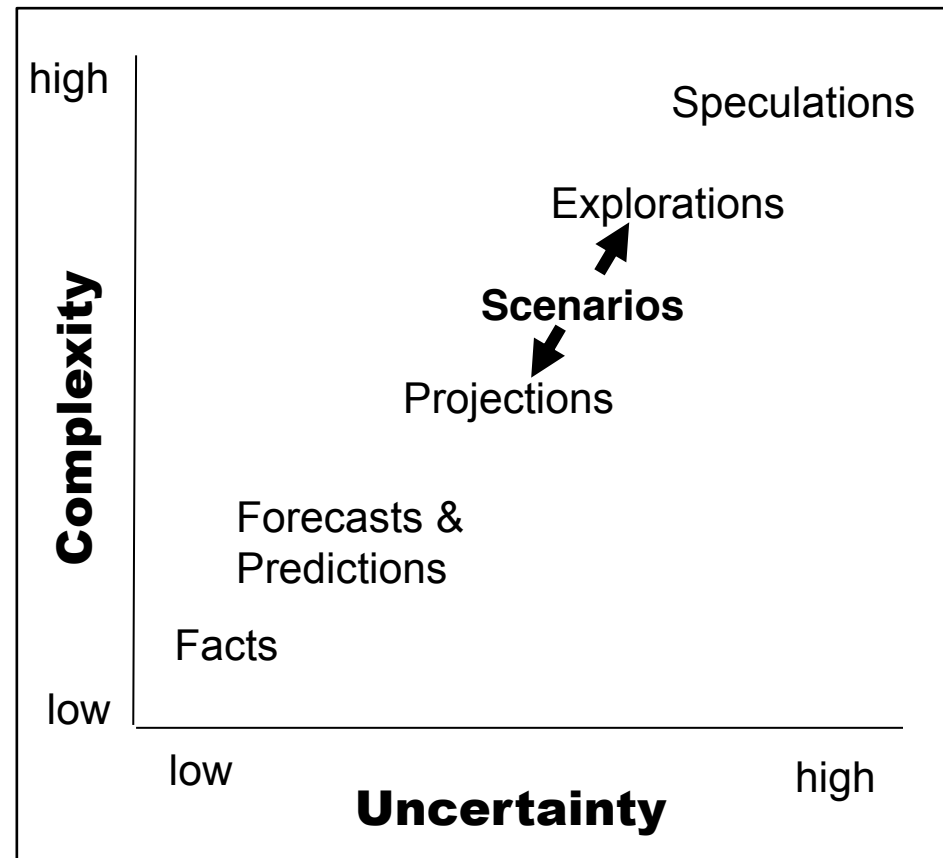


Projections: Lower Bound on Uncertainty!

Goal: Challenge thinking about the future; foster strategic thinking about responses to different possibilities. “Worst case” is beyond the projections.



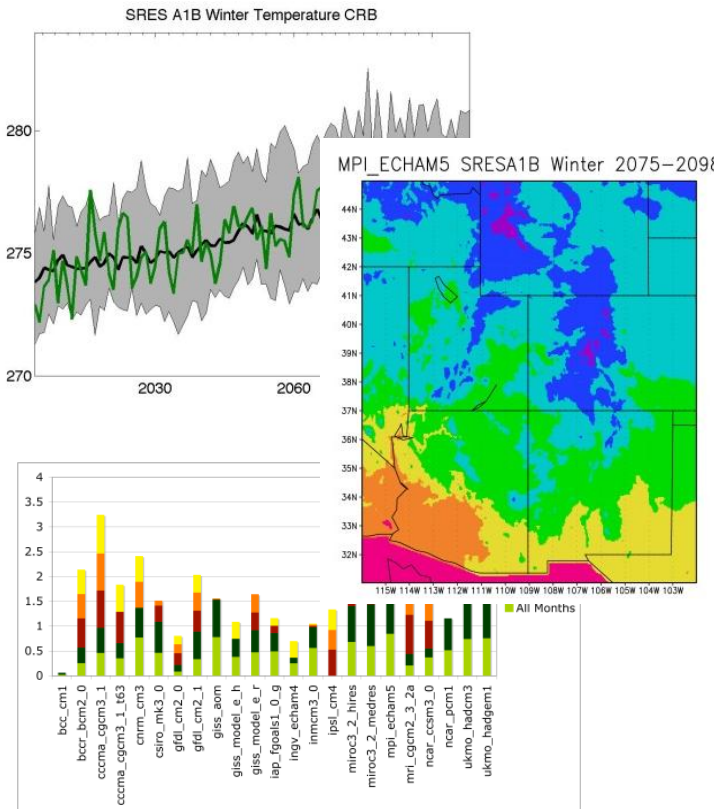
Peterson et al., 2003.
Conservation Biology



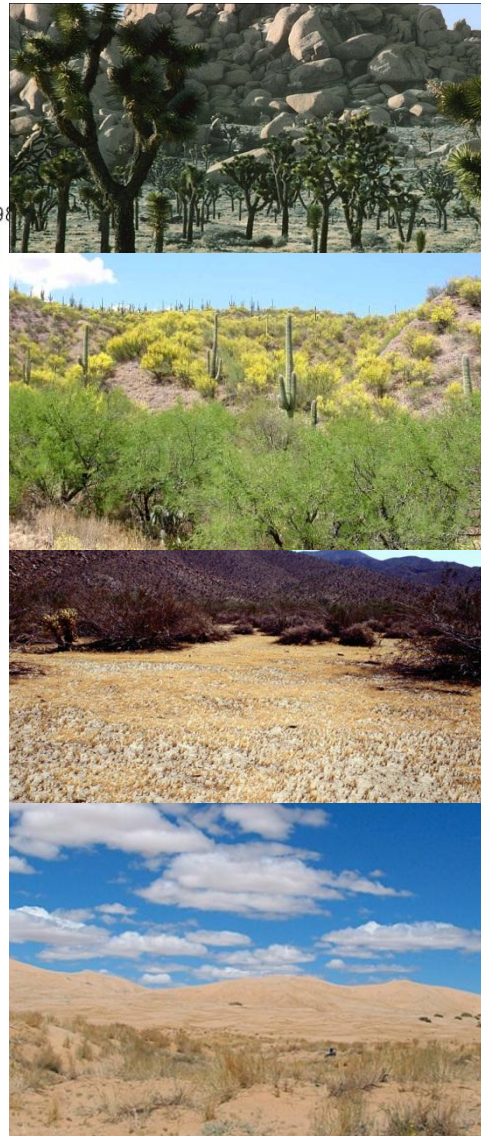
Adapted from Zurek and Henrichs, 2007

Use of Scenarios and Scenario Thinking

Characterizing Uncertainty



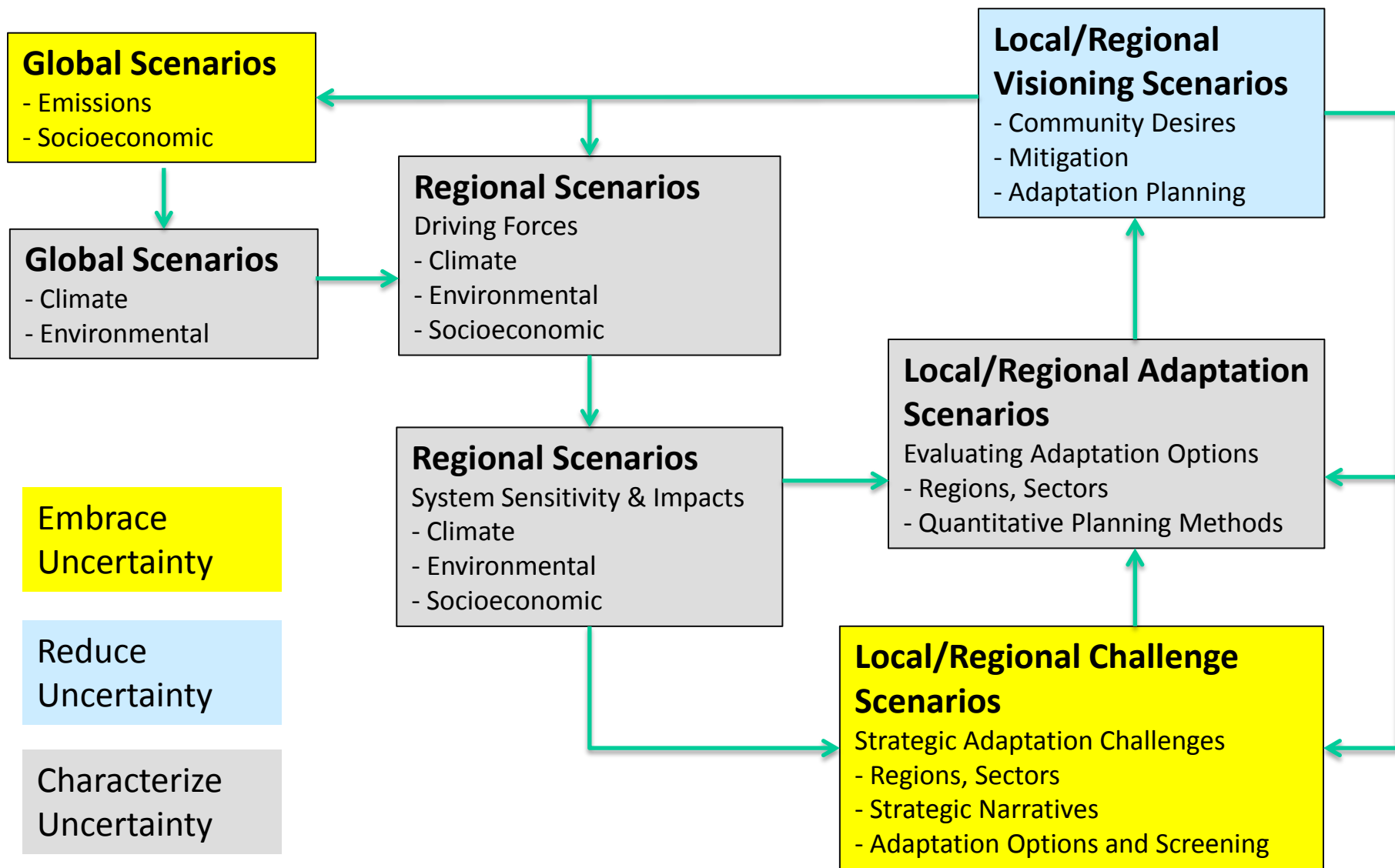
Embracing Uncertainty



Reducing Uncertainty

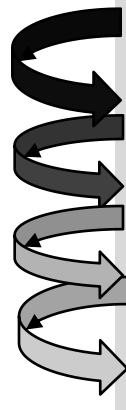


Ecology of Scenarios



Typical Planning: Are Targets /Goals Achievable?

Planning for a Desired Future

- 
- Defining goals
 - Taking stock
 - Examining trends
 - Setting targets, thresholds
 - Directing management

Choosing Among Alternatives

Outcomes

A

B

C

D

Decision Making: Priority Setting

No Regrets: benefits regardless of climate change

Low Regrets: important benefits with little additional cost or risk

Win-Win: reduce climate change impacts and provide other benefits

Adapted from Luers and Moser, 2006

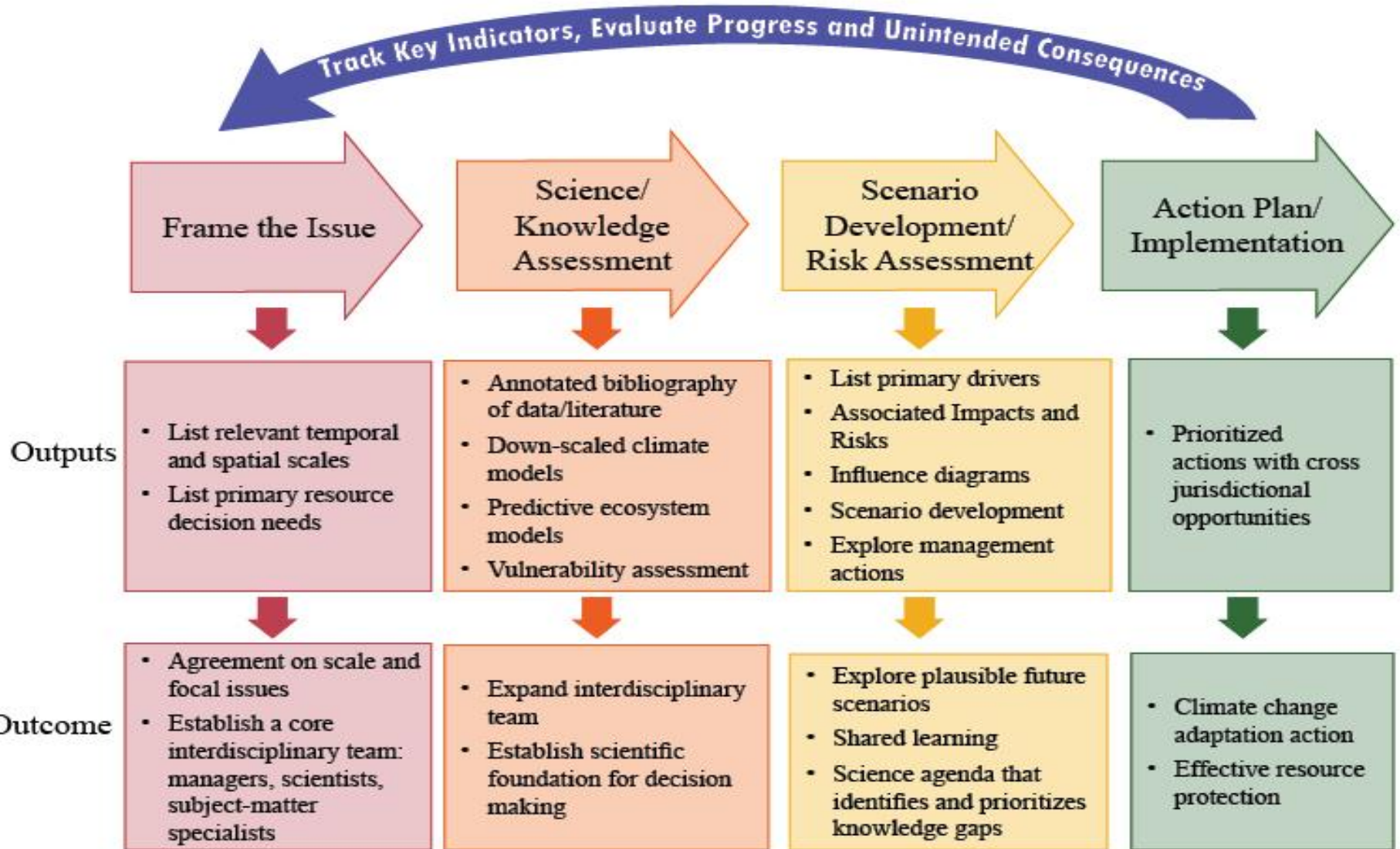
Limitations: Especially at long term/emissions driven

- Uncertainty incompletely specified
- Difficult choices not addressed

Challenge:

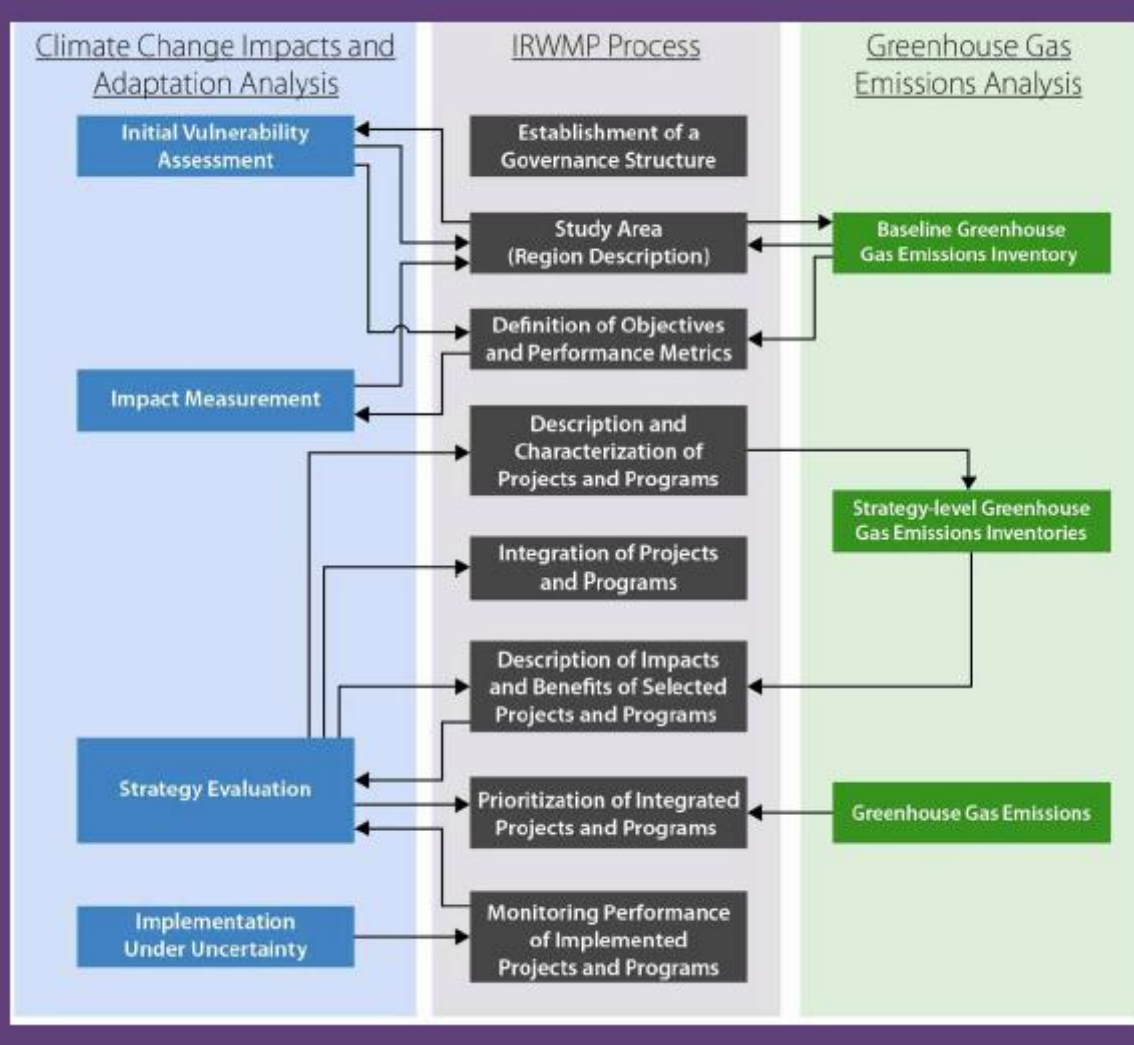
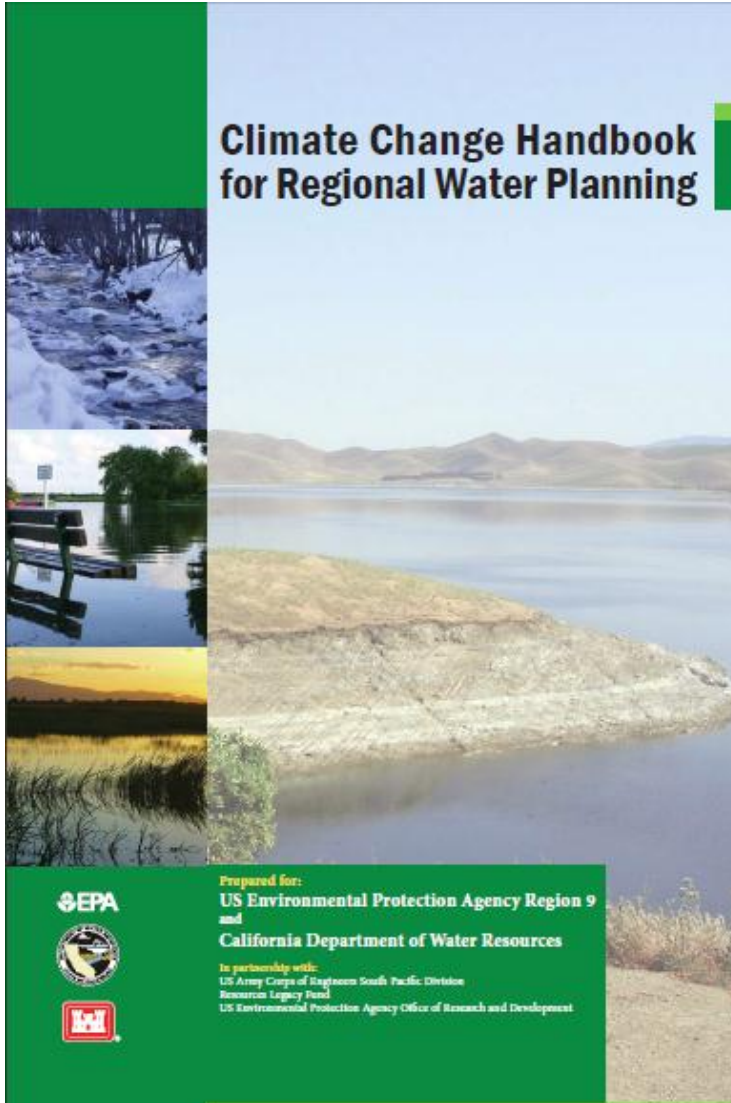
- Acting too soon vs. too late
- Surprise vs. false alarms

KEY ELEMENTS OF AN ADAPTATION PLANNING FRAMEWORK



National Park Service, 2010. Climate Change Response Plan

CA Integrated Regional Water Management Planning



Schwarz, 2011 California Department of Water Resources, Division of Statewide Integrated Water Management

Assess Vulnerability – Supplies and Beyond

Thresholds, cascades, surprising results!

- Assessment of infrastructure, policies, procedures
- Linkages: water supply infrastructure, land management, fire management, energy, communities



Photos: R. Meade,
J. Moody: USGS,
Mike McHugh,
Aurora Water

Colorado River Basin Climate

Paleo • Present • Future



Special Publication for Association of California Water Agencies and Colorado River Water Users Association Conference

November 2005

The Effects of Climate Change on Agriculture, Land Resources, Water Resources, and Biodiversity in the United States

U.S. Climate Change Science Program
Synthesis and Assessment Product 4.3

Global Climate Change Impacts in the United States

U.S. GLOBAL CHANGE RESEARCH PROGRAM



RECLAMATION

Managing Water in the West

Colorado River Basin Water Supply and Demand Study

Technical Report G – System Reliability Analysis and Evaluation of Options and Strategies



CLIMATE CHANGE AND WATER

IPCC Technical Paper VI



Climate Change in Colorado

A Synthesis to Support Water Resources Management and Adaptation

A REPORT FOR THE COLORADO WATER CONSERVATION BOARD



Colorado
University of Colorado at Boulder

COLORADO CLIMATE PREPAREDNESS PROJECT FINAL REPORT

Prepared by
the Western Water Assessment
for the State of Colorado



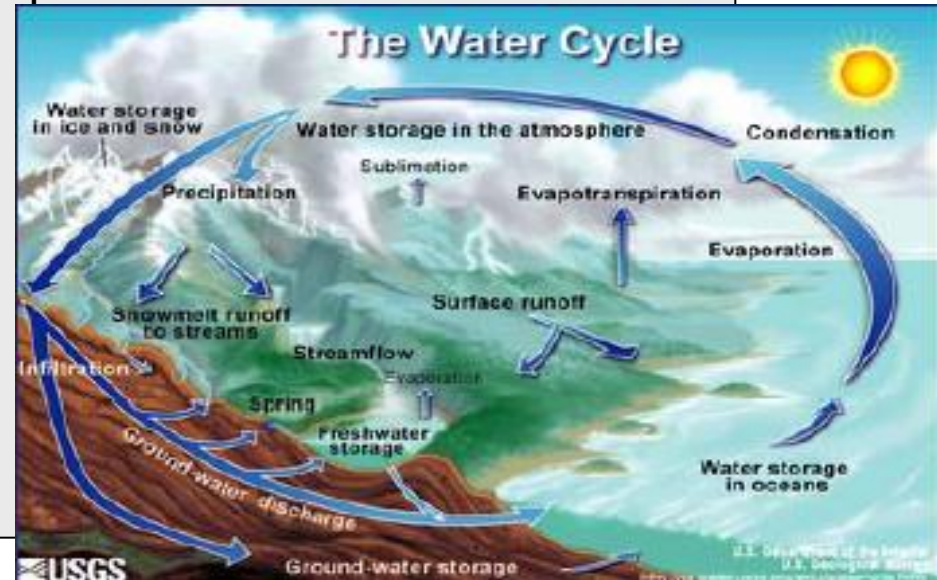
Intergovernmental Panel on Climate Change



Focus on 'Actionable Information' (Hydrology)

Extra Energy: Enhanced Hydrologic Cycle

- Higher temps increase atmosphere moisture holding capacity
- Higher temps imply globally increased evaporation
- Precipitation must increase globally (but not necessarily regionally)
- More intense precipitation - Floods
- More intense drying - Drought
 - Mid-continental summertime drying
 - Increased evaporation increases water demand
- More rain, less snow
- Earlier spring runoff



IPCC 2007 Southwest North America Regional Findings

- Annual mean warming likely to exceed global mean
- Western NA warming likely between 2C and 7C at 2100
- In Southwest greatest warming in summer
- Precipitation likely to decrease in Southwest
- Snow season length and depth very likely to decrease

Can decision makers act on these levels of information?
-- Some, YES! --

Past Reports Provide a Foundation

Water cycle has already been altered by climate change. The past century is no longer a guide to the future for water management.

- 2009 *Global Climate Change Impacts in the United States*

Modest declines for Colorado's high-elevation snowpack. Shifts in timing, intensity of streamflows and runoff.

Decreases in runoff.

Reductions in late-summer flows.

Increases in drought.

-- 2010 *Climate Change Preparedness Project*

Multi-model average reductions for the Colorado River runoff range from -6 to -20 percent by 2050.

- 2008 *Climate Change in Colorado*

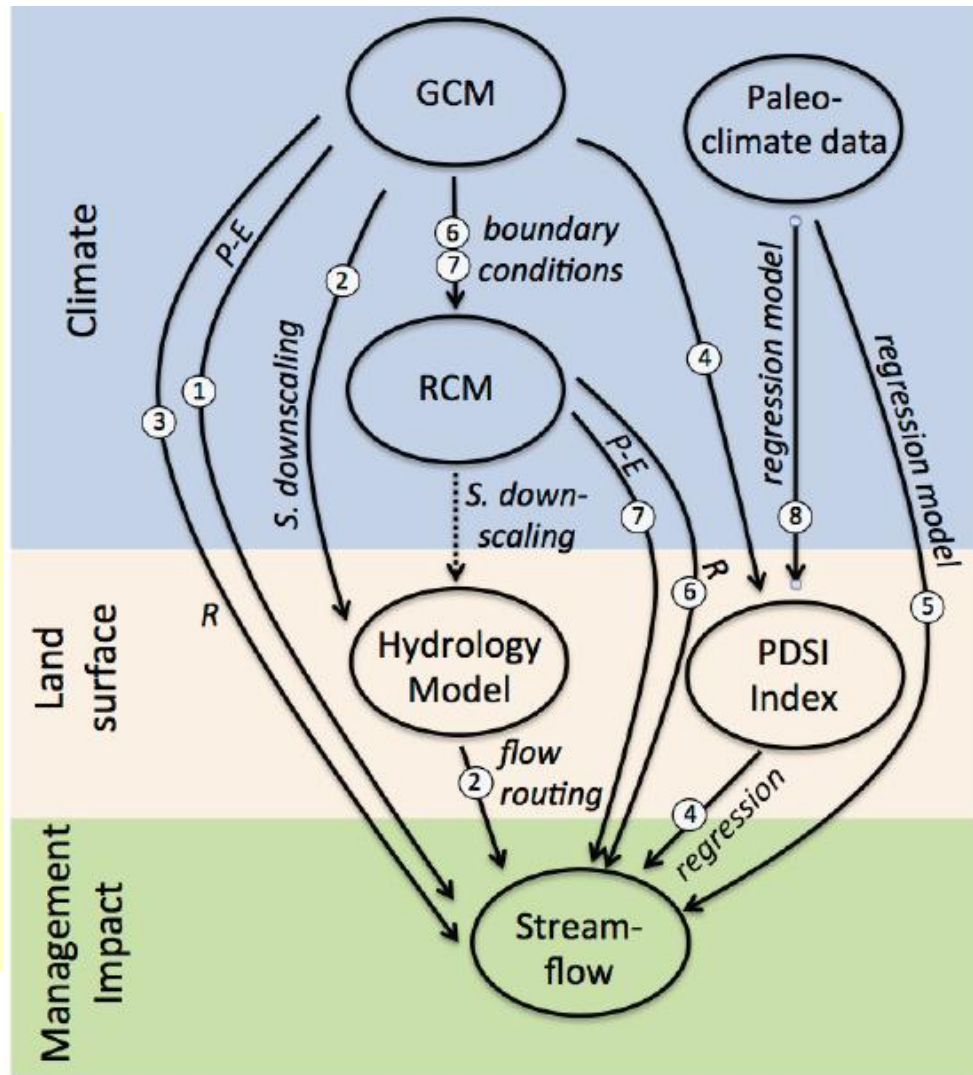
Check Interpretation, Communicate Uncertainty

Recent Studies of Mid-century Climate Change Impacts on Colorado River flows (Lee's Ferry)

<u>Recent Studies</u>	<u>Projected Annual Flow Reductions</u>
Christensen et al., 2004	~18%
Christensen and Lettenmaier, 2007	~6%
Milly et al., 2005	10 to 25%
Hoerling and Eischeid, 2007	~45%
Seager et al., 2007	“an imminent transition to a more arid climate”
McCabe and Wolock, 2008	~17%
Barnett and Pierce, 2008	assumed 10-30%

Genealogy and 'MetaData' of Studies

- Dates
- Scales
- Base data
- Models and versions
- Methods of bias adjustment & downscaling
- Which GCM projections
- Underlying assumptions



Studies using various approaches:

1. [Seager et al. 2007](#)
2. [Christensen et al. 2004](#); [Christensen and Lettenmaier, 2007](#); [USBR 2011](#)
3. [Milly et al. 2005](#)
4. [Hoerling and Eischeid, 2007](#)
5. [Woodhouse et al. 2006](#); [McCabe and Wolock 2008](#); [USBR 2011](#)
6. [Gao et al. 2011](#); [Rasmussen et al. 2011](#)
7. [Gao et al. 2012](#)
8. [Cook et al. 2004](#)

Abbreviations:

- GCM – Global Climate Model
- RCM – Regional Climate Model
- PDSI – Palmer Drought Severity Index
- P – Precipitation
- T – Temperature
- R – Runoff
- E – Evaporation
- S. Downscaling – statistical downscaling (studies above use BCSD)

Check Interpretation, Communicate Uncertainty

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Response One: These are so different, we can't trust any of them...

Response Two: We need to resolve these differences! Are the differences due to climate uncertainty or different models and methods?

Response Three: None of these studies show increasing flows. Any decrease is a source of concern.

Follow Good Examples in Reporting



Climate Change in Colorado

A Synthesis to Support Water Resources Management and Adaptation

A REPORT FOR THE COLORADO WATER CONSERVATION BOARD



Colorado
University of Colorado at Boulder

Climate Change in Colorado

A Synthesis to Support Water Resources Management and Adaptation

A REPORT FOR THE COLORADO WATER CONSERVATION BOARD

The scientific evidence is clear: the Earth's climate is warming. Multiple independent measurements confirm widespread warming in the western United States.

In Colorado, temperatures have increased by approximately 2°F between 1977 and 2006. Increasing temperatures are affecting the state's water resources.

The Colorado Climate Report is a synthesis of climate change science important for Colorado's water supply. It focuses on observed trends, modeling, and projections of temperature, precipitation, snowmelt, and runoff. The report summarizes Colorado-specific findings from peer-reviewed regional studies, and presents new graphics derived from existing datasets. The state is home to many experts in climate and hydrology, and this report also draws from ongoing work by these scientists.

Colorado Annual Mean Temperature (1959-2007)

Changes in the water cycle will be the delivery mechanism for many impacts of climate change.

July Annual Average Temperature (1950-99) vs. 2050 projection. Climate models project Colorado will warm by 2.9°F by 2025 and 4°F by 2050, relative to the 1950-99 baseline.

Summer are projected to warm more than winters. Projections suggest that typical summer monthly temperatures will be as warm or warmer than the hottest 10% of summers that occurred between 1950 and 1999.

Monthly Temperature near Grand Junction, CO

Monthly Precipitation near Grand Junction, CO

Changes in the quantity and quality of water may occur due to warming even in the absence of precipitation changes.

Annual Average Precipitation: Fort Collins

In all parts of Colorado, no consistent long-term trends in annual precipitation have been detected. Variability is high, which means consistent increases or decreases are unlikely.

Climate model projections do not agree whether annual mean precipitation will increase or decrease by 2050.

A synthesis of findings in this report suggests a reduction in total water supply by the mid-21st century.

Colorado Water Conservation Board logo and University of Colorado at Boulder logo.

To download the full report: www.colorado.edu/CO_Climate_Report/index.html

Projected Change in Colorado River Basin Snowpack

SNOWPACK

Most of the reduction in snowpack in the West has occurred below about 8200 ft. However, most of Colorado's snowpack is above this elevation, where winter temperatures remain well below freezing.

Projections show a precipitation decline in lower-elevation (below 8200 ft) snowpack across the West by the mid-21st century. However, declines are projected (10-20%) for Colorado's high-elevation (above 8200 ft) snowpack.

Climate change will affect Colorado's use and distribution of water. Water managers and planners currently face specific challenges that may be further exacerbated by projected climate change.

DROUGHT

Reconstructed Streamflow for the Colorado River at Lees Ferry

Throughout the West, less frequent and less severe drought conditions have occurred during the 20th century than recorded in the paleoclimate records over the last 1000 years.

Precipitation variations are the main driver of drought in Colorado since snow at Lees Ferry is a reflection of snowmelt in 2000-07, and these variations are comparable with the natural variability observed in long-term and paleoclimate records.

However, warming temperatures may have increased the severity of drought and exacerbated drought impacts.

Range of Forest Projections for the Upper Colorado River Basin

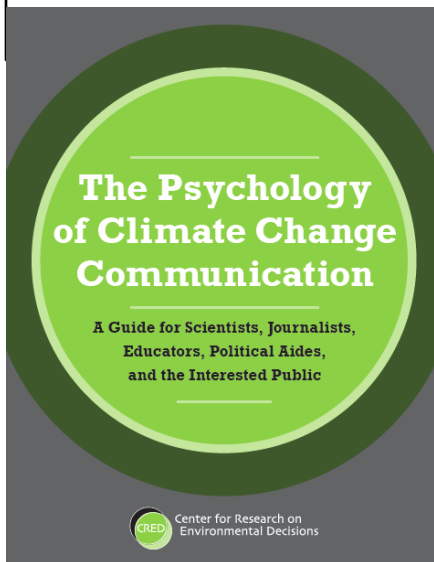
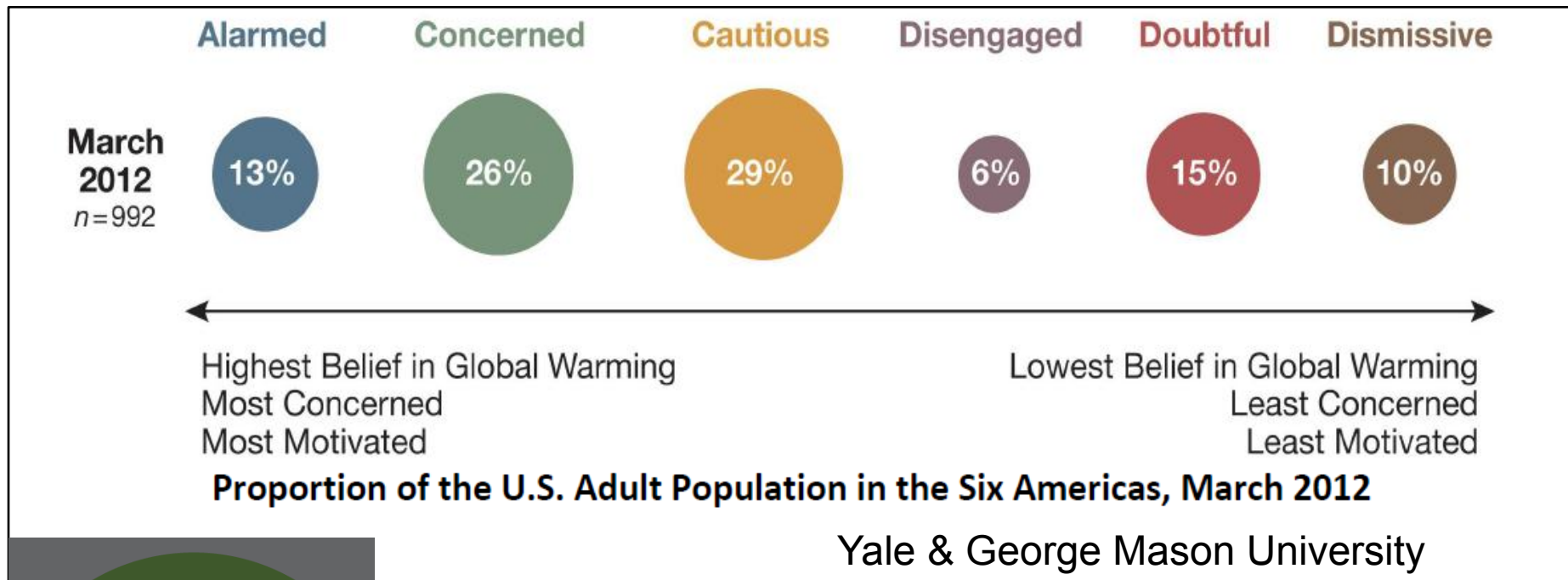
Technical Report, Summary Version

Links past, present, future

IMPLICATIONS

Issue	Observed or Projected Change
Water demands for agriculture and outdoor activity	Warming temperatures increase evapotranspiration by plants, trees, soil evaporation, and from reservoir water demand.
Water supply infrastructure	Changes in snowpack, on runoff to basins, and hydrograph seasonality may affect reservoir operation scheduling based on storage changes in the timing and magnitude of runoff may affect hydrograph seasonality, storage, and temperature regimes.
Legal water systems	Earlier runoff may complicate the operation of systems with fixed water capacity, affecting which rights holders receive water and specific plans for reservoirs.
Water quality	Although other factors have a large impact, water quality is sensitive to both temperature and changes in patterns of precipitation (CCSP 2007, p. 148). For example, changes in the timing and hydrograph may affect sediment load and pollution, impacting human health.
Energy, fish, and riparian systems	Warmer air temperatures may place higher demands on hydroelectric reservoirs for peaking power. Warmer lake and stream temperatures may affect water use by cooling power plants and fisheries.
Mountain habitats	Warming temperatures and soil moisture changes may affect mountain habitats, such as higher elevation forests.
Water use among forests, high alpine, alpine, and parks	Changes in water and soil moisture may affect the relationships between forests, tundra and groundcover, wildlife, and riparian plants. Riparian stands may, for example, rely on winter alpine runoff.
Riparian habitats and fisheries	Changes in stream are expected to include an increase in water with a shift in the timing and magnitude of runoff. Changes in streamflow may affect riparian systems and streams in higher elevations, and the potential for non-point runoff may increase in some riparian areas. Changes in streamflow may affect riparian systems and streams.
Water withdrawal from the region	Changes in streamflow may affect the availability of water for withdrawal from streams and rivers. Changes in streamflow may affect riparian systems and streams.
Groundwater resources	Changes in streamflow may affect groundwater recharge. Changes in streamflow may affect riparian systems and streams.

Match Audience, Message, Messenger



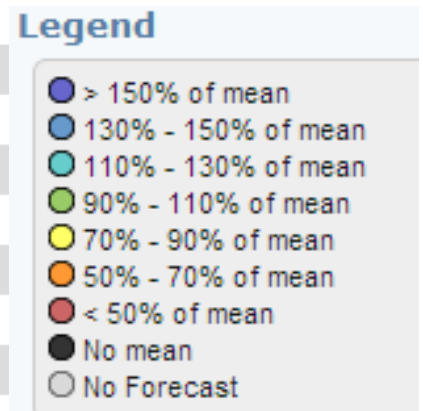
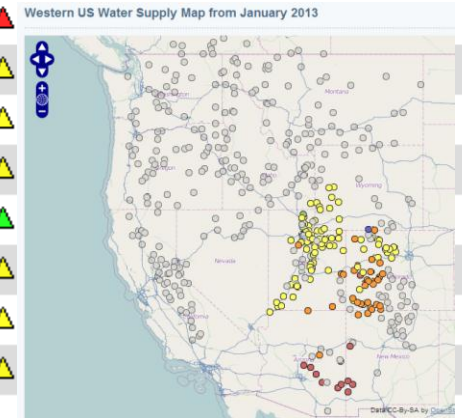
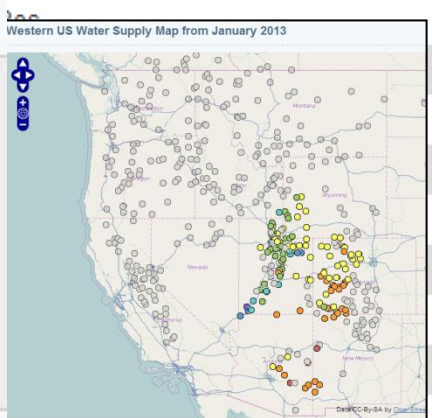
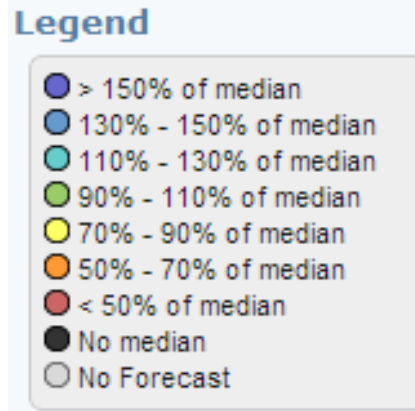
Connect with values: security, family
Connect with impacts and implications
General public: offer path of positive action

Language Matters

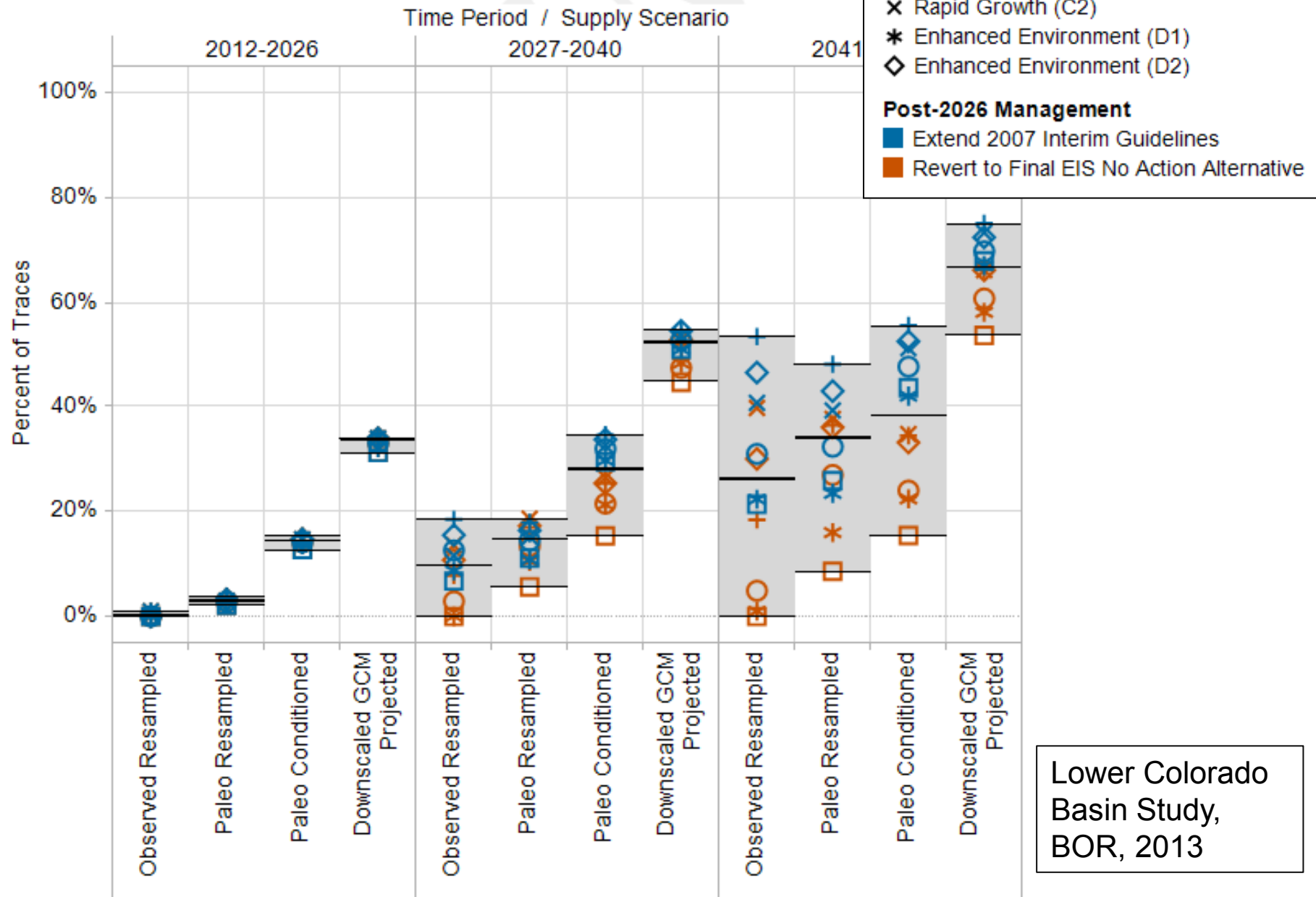
Scientific Jargon	Common Translation	Better Language
Bias	Unfair distortion	Offset from the observed value
Positive trend	A good trend	Upward trend
Error	Wrong, incorrect	Uncertainty associated with a model or measuring device
Spatial, Temporal		Space, Time
Anthropogenic		Human
Positive feedback		Amplifying effect
Uncertainty	We don't know	Range

Normal, Mean, Average vs. Median: Implications for Risk Perception

NWS ID	Location	Percent Avg/Med	Official Forecast Date	Official Min 90%	Official MP 50%	Official Max 10%	Official Percent Average	Official Percent Median	Average	Median
121	SMPC2 San Miguel - Placerville Nr	▲	2013-01-01	50	90	150	70%	74%	128	122
122	SOMC2 Nf Gunnison - Somerset Nr	▲	2013-01-01	27	60	110	61%	146%	99	41
123	SRKU1 Ef Sevier - Kingston Nr	▲	2013-01-01	19	31	40	89%	89%	35	35
124	SRYU1 Sevier - Gunnison Nr	▲	2013-01-01	37	60	110	61%	146%	99	41
125	STAU1 Strawberry - Starvation Res Duchesne Nr	▲	2013-01-01	27	92	142	82%	116%	112	79
126	STCO1 Santa Clara - Pine Valley Nr	▲	2013-01-01	27	92	142	82%	116%	112	79
127	STDM1 Santa Monica - Montezuma Nr	▲	2013-01-01	27	92	142	82%	116%	112	79

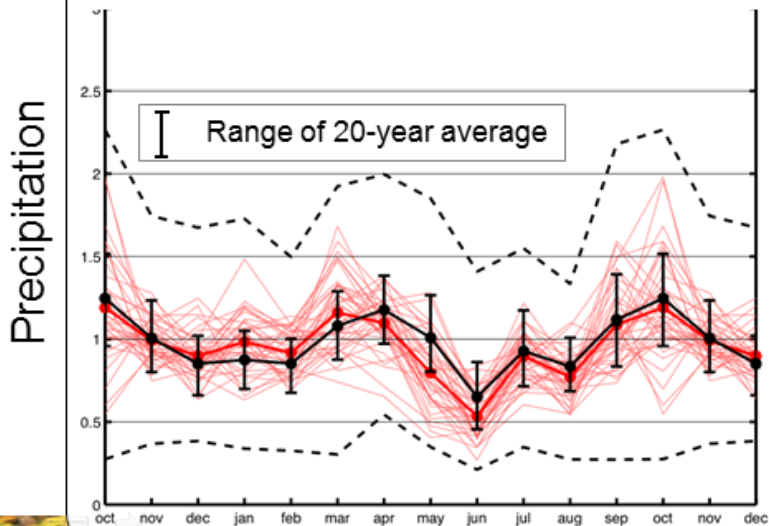
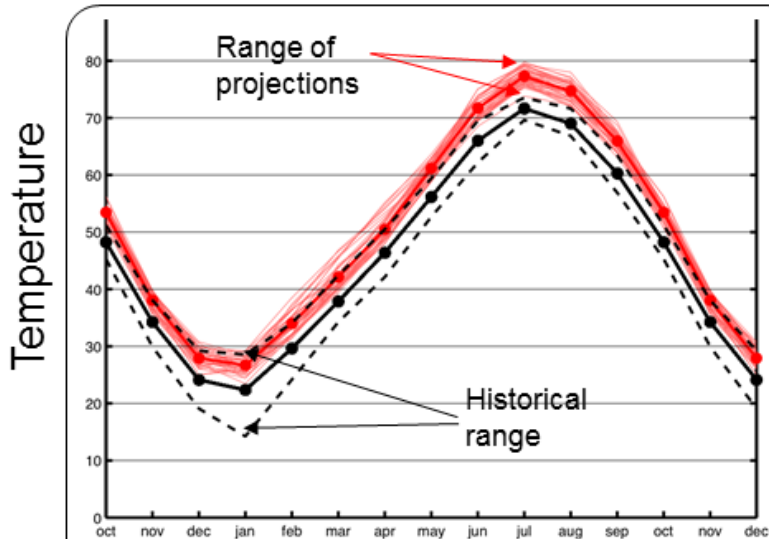


Frequency – not Probability!

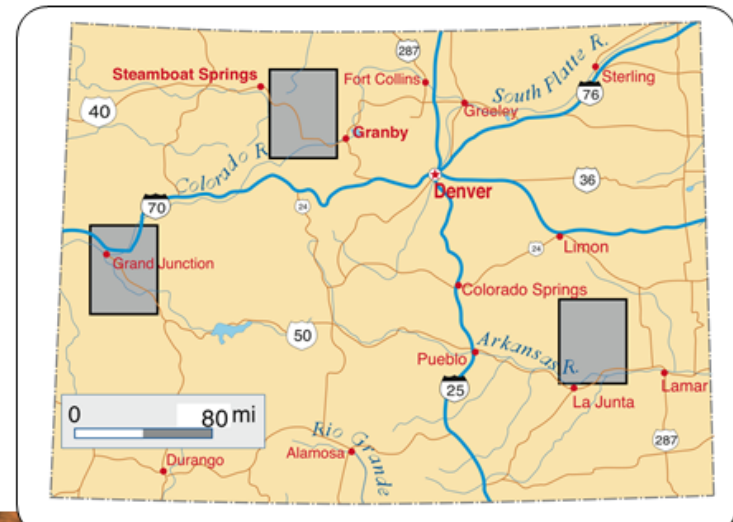


Period-Change Results

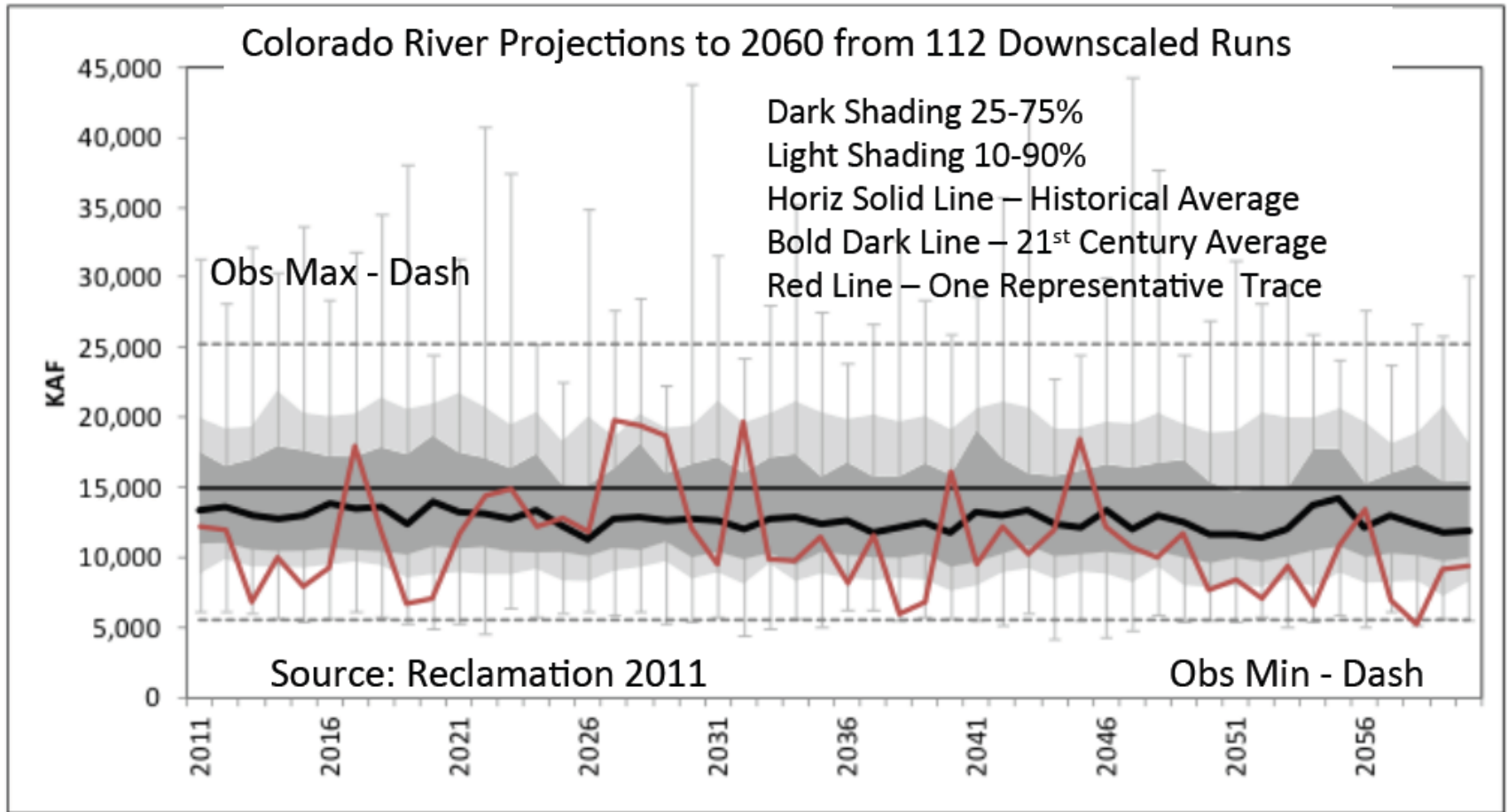
Grand Junction



- Summers warm more than winters
- Average summer temperatures similar to the hottest months in the past fifty years.
- Heat waves; fewer cold winters
- Projected precipitation trends small compared to the variability.



Time-Developing Results



From Udall, 2012, CI Water Symposium

Diagnostics Approach to Results

All Models Are Wrong – Some Are Useful

Ability to compute is not accuracy or precision

Specific numerical results - temporary, evolving, “loosely held”



Learning your system

Sensitivities

Thresholds, cascading impacts

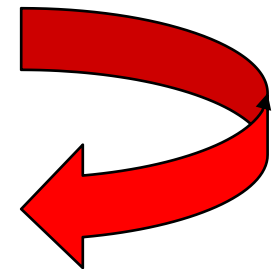
Surprising Results

Consistent Messages

Counter-Intuitive Messages

Unresolvable Uncertainties

A prepared team is essential





Academy and Tools Update!

With Dr. Holly Hartmann
Director of the Carpe Diem West Academy; and

What's New

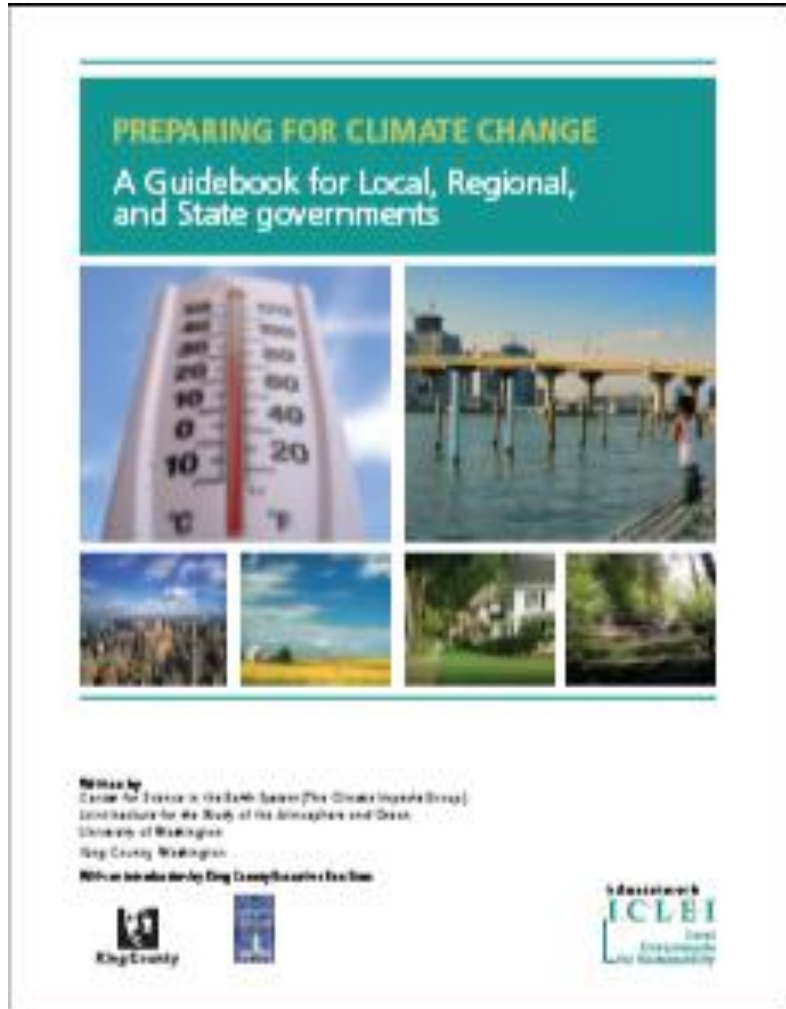
Check out the [Tool of the month](#)

Webinar on Use of Models and Scenario Studies

- “Downscaling, upscaling, and a few things in between”
- 8 Nov 2011
- Brad Udall: Western Water Assessment
- Laura Briefer: Salt Lake City Public Utilities

Carpediemwestacademy.org

Steps Toward Climate Action Plans



1. Listen to the Science
2. Build support and a team
3. Assess – risk, vulnerability, adaptive capacity
4. Set goals and develop a plan
5. Implement your plan
6. Measure progress

Practical Decision Support Activities

1. What adaptation planning/implementation is in your region?

- how does climate information fit in?**
- provide a menu for new stakeholders**
- share learning across users/sectors**
- Use common information**

2. Develop base information for your region

- driver and impact tables (CIG/ICLEI guidebook)**
- update with new science**

Practical Decision Support Activities

3. Honest broker for 'best practices', common pitfalls

- **there's not a new normal**
- **projections alone are important but insufficient**
- **non-climatic factors are changing, too**
- **lessons from other sessions!**

4. Local climate studies

- **local variables**
- **extremes**
- **trends**
- **relationships among variables, sectors**

Practical Decision Support Activities

5. Monitoring

- track trends
- evaluation of adaptation effects

6. Help decision makers practice dealing with uncertainty

- use seasonal-to-interannual forecasts to gain experience with iterative risk management

7. Stay up-to-date

- with science (IPCC, National Assessments, NRC)
- with tools: a challenge!

Enjoy the Journey...

Friends and Humor are Important

