Decision Making under Uncertainty:

Climatic Variability, Stakeholders, and Modeling in the Colorado River Basin

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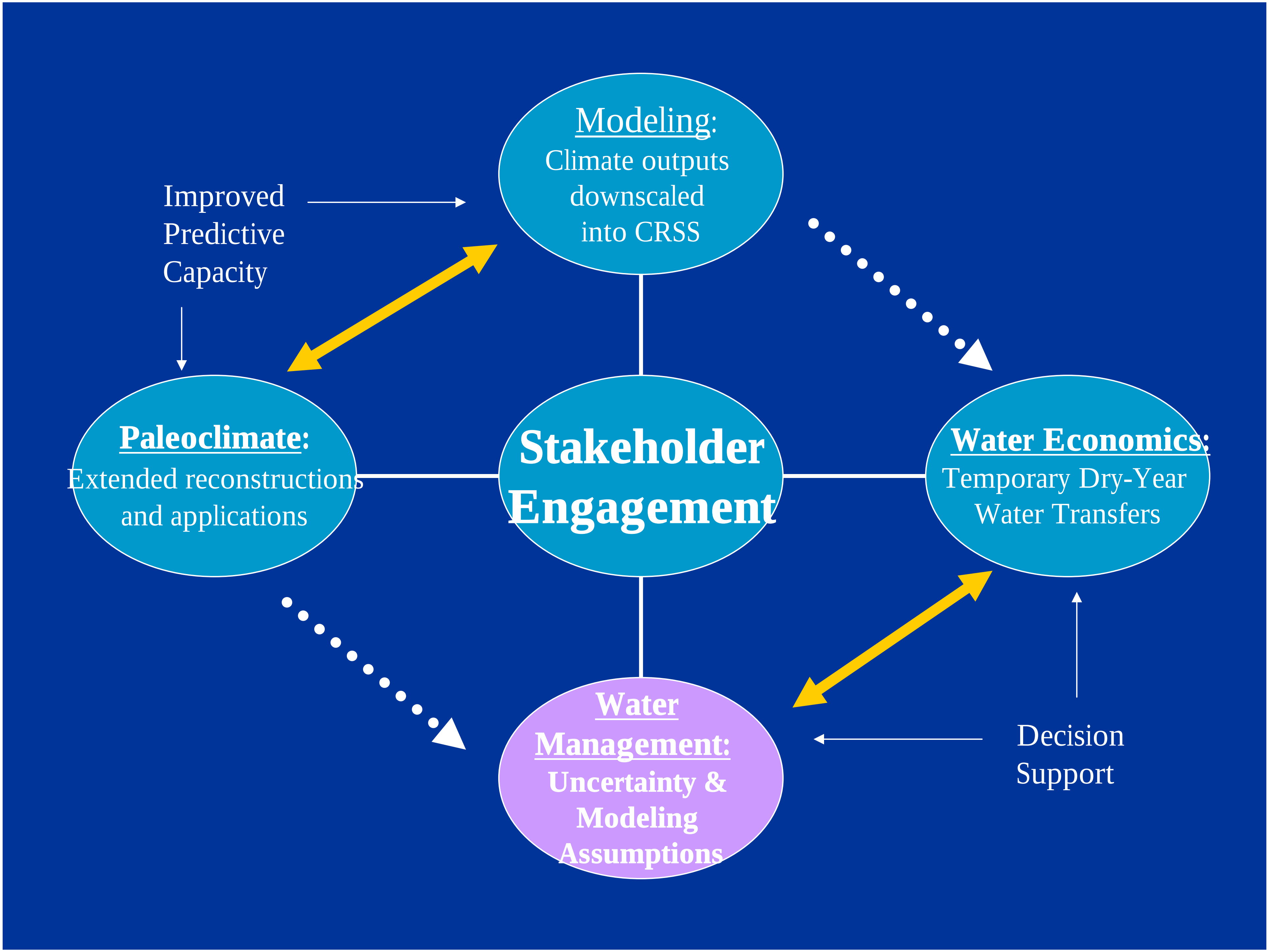
Research Overview

- Project Scope & Research Question
- Decision Making Context
- Stakeholder Engagement
- Modeling and Uncertainty in CR long range planning
- Arizona Stakeholder Recommendations
- Conclusions



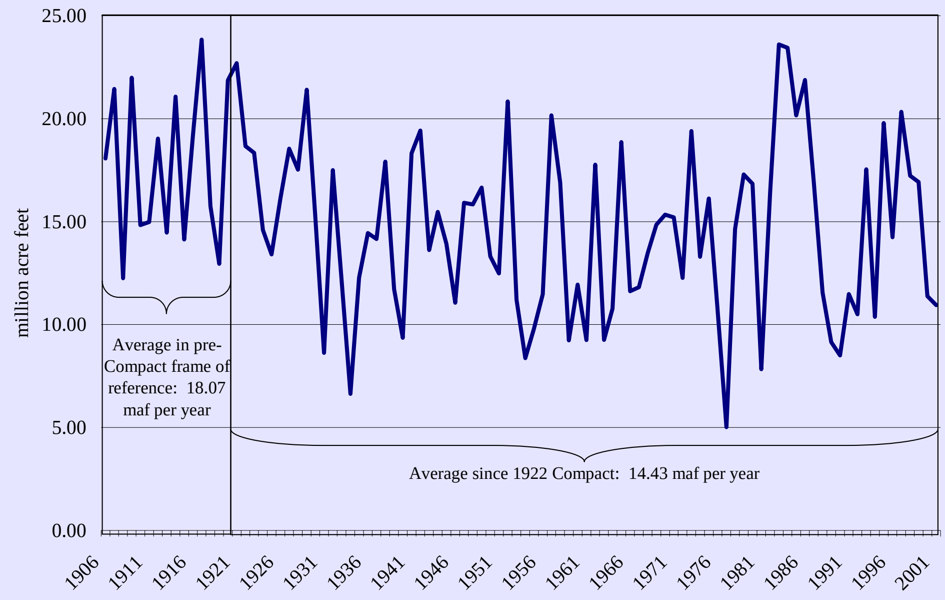
Modeling:
Climate outputs downscaled into CRSS
Improved Predictive Capacity
Paleoclimate:
Extended reconstructions and applications
Stakeholder Engagement
Water Economics:
Temporary Dry-Year Water Transfers
Water Management:
Uncertainty & Modeling Assumptions
Decision Support

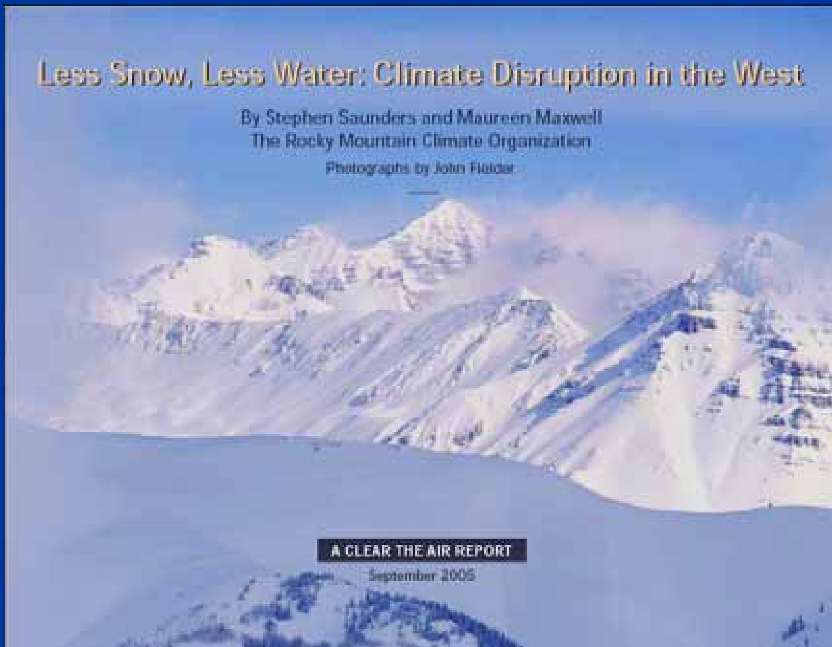
Decision Making Context:

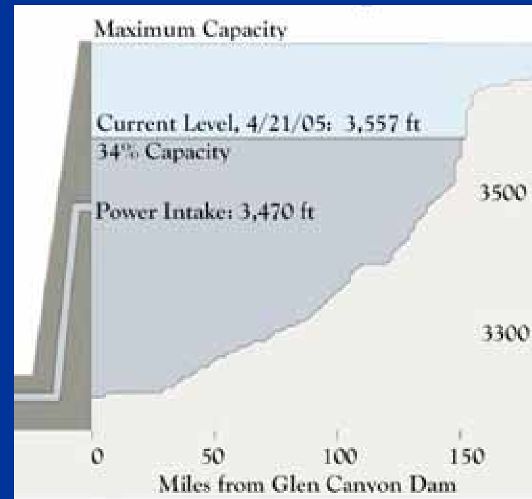
Climatic Variability & Growth in the CR Basin

- Institutionalized Over-allocation
- Shortage as the norm
  (Christensen et al 2004)
- Intensifying reliance on CRSS
- Expanding Stakeholder / Modeling Interface

Figure 1: Natural Flow at Lee Ferry, AZ: Compliance Point of the 1922 Colorado River Compact







Data Source: US Bureau of Reclamation, Lower Colorado Water Supply Report, 4/21/2005
Design Source: Adapted from USGS

Climate Disruption's Effects in the Colorado River Basin: A "Best-Case" Scenario

Projected Changes	Time Period	
	2010-2039	2040-2069
Temperature	+ 1.8°F	+ 3.6°F
Precipitation	- 3%	- 6%
Snowpack	-24%	-30%
Runoff	- 14%	- 17%
Water Storage	-36%	-40%

Source: Top Right, Enhancing Water Supply Reliability (2005);

Others, Rocky Mountain Climate Organization (2005)

Stakeholder-Driven Research Agenda

- What are the key modeling assumptions and sources of uncertainty in CRSS? What are the **long-term planning** implications of these assumptions?

- How can modeling outputs be tailored to aid decision making under uncertainty?

Who are the stakeholders?

Direct

State DWR

Central Arizona Project

Salt River Project

Municipal Water User Groups

Indirect

On-River Users

Irrigation Districts

Power Providers

Conservation Groups

Stakeholder / Modeling Nexus
Colorado River Simulation System

Table 1: Major planning processes in the Colorado River Basin according to model type.

Selected Planning Processes	Long-Range Operating Criteria (1968)	Hydrologic Determination (1988)	Interim Surplus Guidelines (2001) Multi-Species Conservation Plan (2005)	
Model Type	Hydrologic Studies Proto-CRSS Rule Curves	Fortran-encoded CRSS	CRSS in RiverWare (1996)	
Versions developed for direct stakeholder use →			CRSS-EZ (1994)	CRSS-Lite (2005)

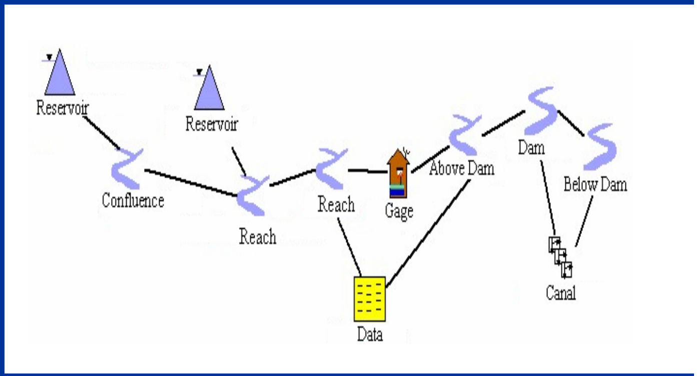
1970 1975 1980 1985 1990 1995 2000 2005

Other Simulations:

Severe Sustained Drought (1995);

Christensen et al (2004)

24-month Model



University of Colorado at Boulder **News**Center

CU-Boulder's RiverWare Modeling Tool Played Key Role In Colorado River Negotiations

Feb. 14, 2006

Across the West this month, local newspapers reported that the seven Colorado River states finally reached an agreement on a consensus recommendation for managing the river under drought conditions, as directed by Secretary of Interior Gale Norton.

This was especially exciting news to researchers at the University of Colorado at Boulder's Center for Advanced Decision Support for Water and Environmental Systems or CADSWES, who developed and support RiverWare, the modeling tool that played a key role in this long and difficult negotiation.

"RiverWare empowers stakeholders such as the Colorado Basin states to develop and evaluate operational plans that previously could only be modeled by the water management agencies"

simulation model of the Colorado River. The model can be used to evaluate the effects of various operational strategies on the water supply to the seven states and Mexico during a range of hydrologic scenarios, including extreme droughts.

The Bureau of Reclamation used RiverWare to provide technical modeling support to the Basin States Technical Modeling Work Group Committee over the past 18 months. RiverWare, which also is used by individual states and water districts, is provided by CADSWES through the CU Office of Technology Transfer.

Carly Jerla, while a graduate student at CADSWES, developed a special version of the Bureau of Reclamation's RiverWare model of the Colorado River as part of her research on new drought management strategies for the basin. Both the model and her research results have proven to be useful to the states in reaching a mutually agreeable proposal. Now a bureau employee, Jerla maintains an office at CADSWES where she continues to provide technical modeling support to interested stakeholders while maintaining close ties with the developers and support staff.

"The Basin States discussions over the past 18 months were truly informed discussions all the way up through the final hours of negotiation," Jerla said. "Our ability to quickly produce various model runs to inform their discussions kept the process moving forward on the technical front."

The Basin States committee's proposal was sent to Norton on Feb. 3 and will be considered in the development of alternatives to be studied by the Bureau of Reclamation as provided by the National Environmental Policy Act. A draft

Data & Research Approach

- Ongoing Stakeholder Engagement
- Two Basin-wide planning processes

1. Surplus (1996 - 2001)
2. Shortage (2004 -?)
3. AZ Shortage Sharing

- CRSS modeling assumptions and outputs

f (inflow, depletion, physical process, operating criteria)

1. Inflow: Index Sequential Method
2. Depletion: Upper Basin
3. Operating Criteria: Surplus Guidelines & 602 (a) criteria
4. Initial Reservoir Conditions

Modeling Assumptions

Inflow: Index Sequential Method

Table 2: 97-year Traces in Index Sequential Method (Wrap-Around Concept)

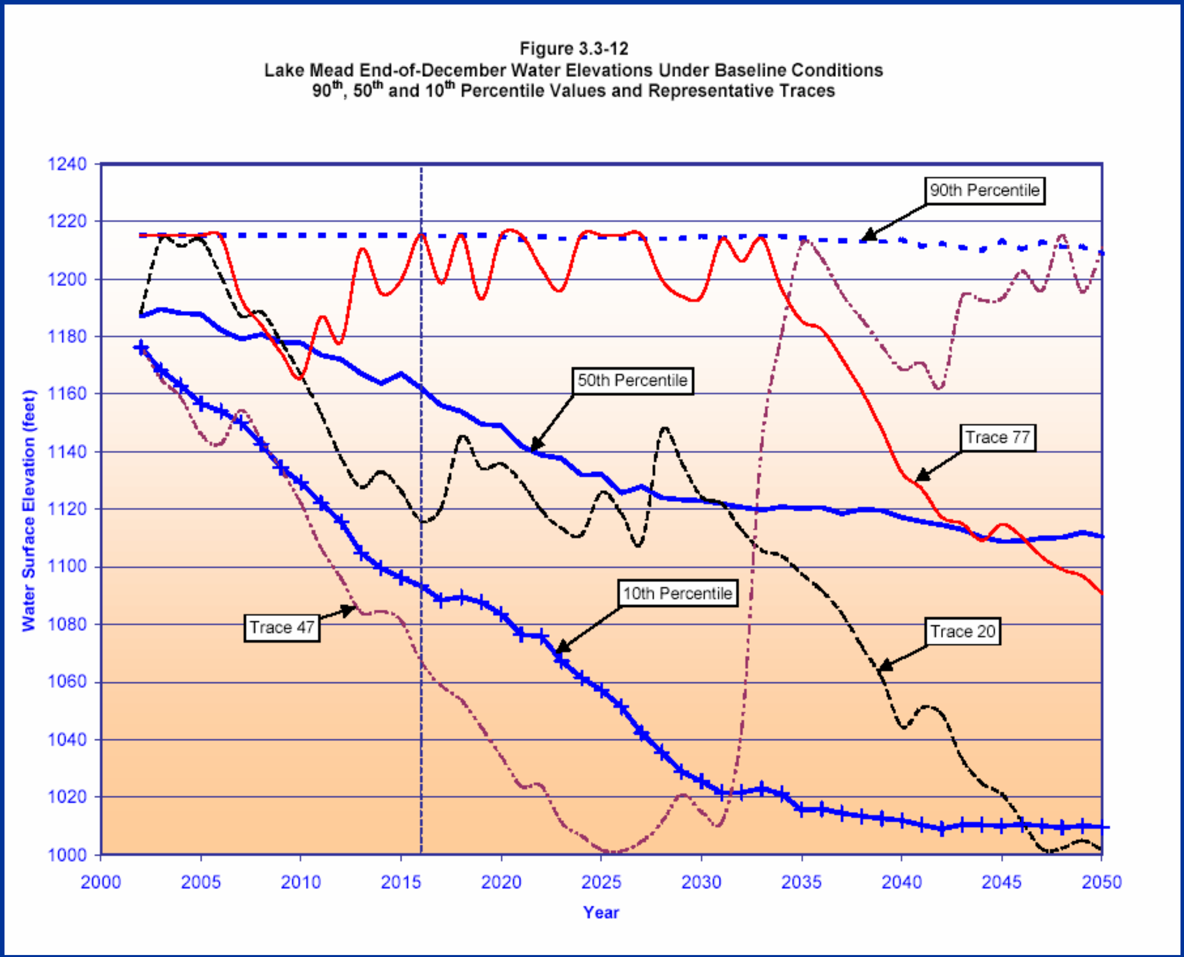
Trace	Initial Year (year 1)	Second Year (year 2)	Second to Last **(year 96)**	Last Year (year 97)
1	1906	1907	**2002**	2003
2	1907	1908	2003	1906
…	…		…	…
97	2003	1906	2001	2002

Adapted from USBR 1988

Historical Record: 1906 to 2003*

Implication: future flows will vary within the range of variability experienced during the historical record; 1999-2004 was novel

Modeling Assumptions
Inflow: Index Sequential Method



Source: Department of Interior, 2001

Modeling Assumptions

Demand: Upper Basin Depletion

Figure 2: Historical and Projected Upper Basin Consumptive Use

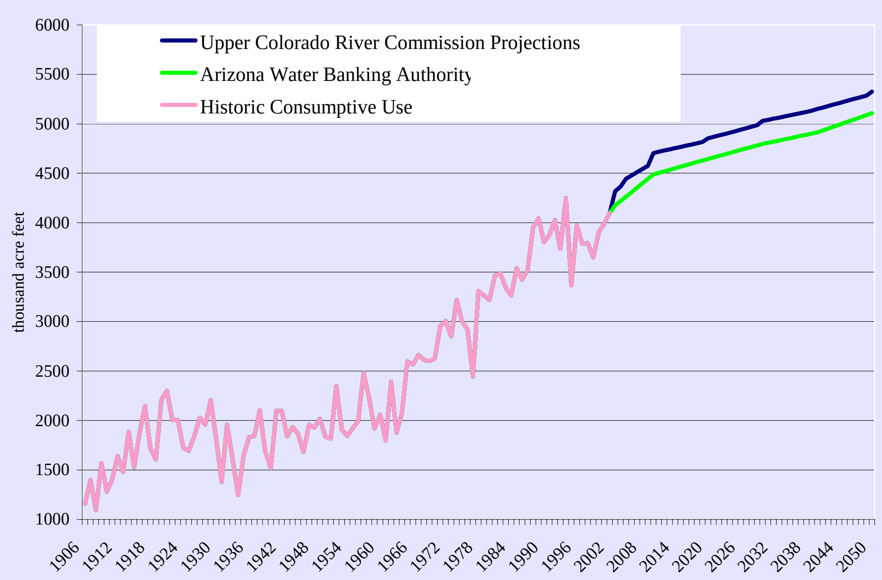
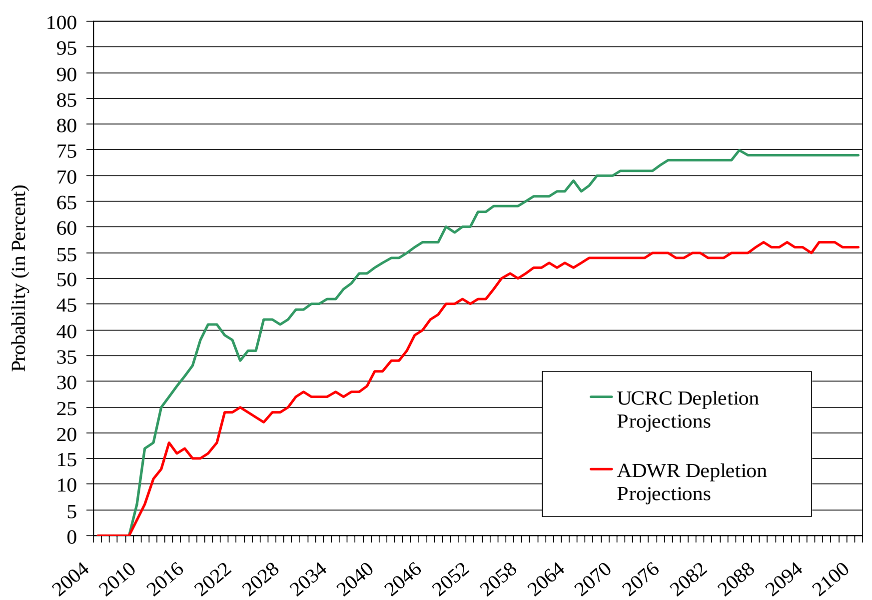


Figure 3: Shortage Probability and Upper Basin Depletion Projections



Lower Basin & Upper Basin differ in projections of growth rate; limit

Operational Assumptions: 602 (a) Storage

Table 3: Key parameters of the 602 (a) storage calculation		
602 (a) parameter	**Description**	**Current model input assumption**
UB Depletion	Average of next 12 years of projected demand	NA
UB Evaporation	Average annual evaporation	560,000 acre feet
% Shortage	Percent shortage applied to UB	0%
Minimum Objective Release	Annual minimum release from Lake Powell to Mead	8.23 million acre feet
Critical Period Inflow	Average annual natural inflow into the Upper Basin from 1953 to 1964, which is considered the critical low inflow period.	12.18 million acre feet
Minimum Power Pool	Amount preserved for power pool in Upper Basin	5.19 million acre feet
Source: Final Environmental Assessment (March 2004) – Adoption of Interim 602 (a) Storage Guideline		

Initial Conditions:
The three- to five-year blinders

Table 4: Impact of Starting Reservoir Conditions

Initial Conditions Option	Option 1: January 2002 (Projected by April 2001 model forecast)	Option 2: Jan 2003 (Projected in August 2002 model forecast)	Option 3: Jan 2003 (Actual end-of-December 2002 levels)
System Storage (maf)	52.33	36.24	36.76
Lake Mead (Elevation; % capacity)	1182 ft / 70.6 %	1151.5 ft / 58.3%	1152 ft / 58.6%
Lake Powell (Elevation; % capacity)	3669.9 ft / 89.9 %	3617.76 ft / 50.1 %	3620.1 ft / 51%

Source: US Bureau of Reclamation, Colorado River Modeling Group Meeting (2003)

The Worst-Case:
Aligning Assumptions

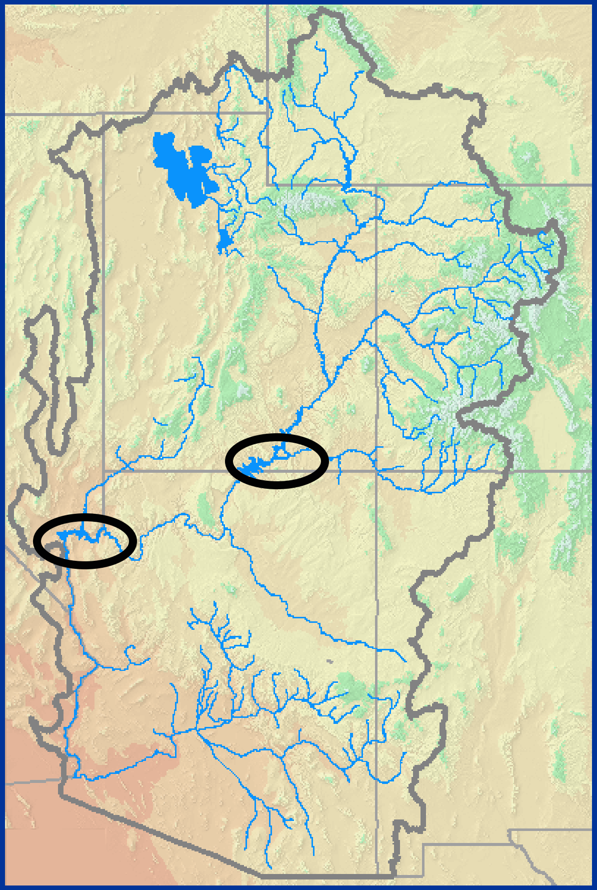
Table 5: Combining Assumptions to Form Best- and Worst-Case Scenarios		
Key Assumptions	**Shortage Probability**	
	HIGHER	**LOWER**
Inflow	Prolonged drought (e.g. 1999-2004)	Extended high flows (e.g. 1983-1986)
Demand – UB	Limit: 5.4 maf Rate: UCRC	Limit: 4.8 maf Rate: AWBA
Operating Policy: Surplus Criteria	Interim Surplus Guidelines	70R Strategy
Initial Conditions	Jan. 2005 (i.e. 50% capacity)	Jan. 2000 (i.e. nearly full)

Arizona Stakeholder Recommendations (2005)

- ✓ Articulate and document the assumptions in model runs
- ✓ Isolate the drivers of variability through sensitivity analyses and consistent constants
- ✓ Establish bounds on uncertainty by defining best and worst case scenarios
- ✓ Evaluate river system in terms of water user impacts instead of reservoir levels or other indirect measures
- ✓ Distinguish between sources of uncertainty over different time scales
- ✓ Foster trust, patience to deal with stakeholder groups with diverse levels of understanding and experience

Decision Making under Uncertainty
Colorado River Shortage

- Shortage EIS using CRSS lite to compare alternatives
- Coordinated management of Lakes Powell and Mead
- Resolution at different scales
- Augment water supplies
- Flexibility; Interim Accord
- Key: Operational Uncertainty and Legal Framework constrain Basin adaptation



Thank you

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Enhancing Water Supply Reliability

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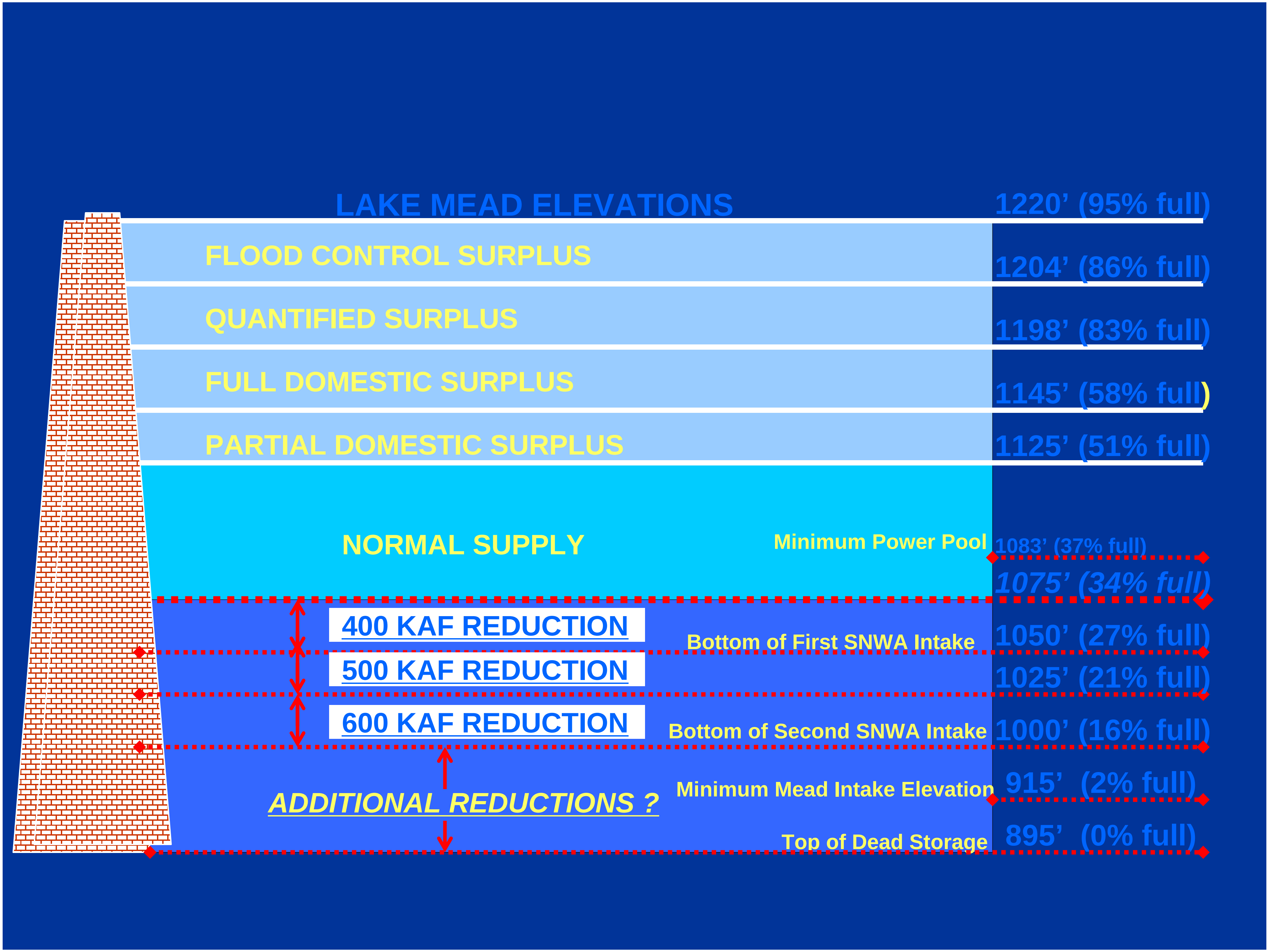
LAKE MEAD ELEVATIONS
1220' (95% full)
FLOOD CONTROL SURPLUS
1204' (86% full)
QUANTIFIED SURPLUS
1198' (83% full)
FULL DOMESTIC SURPLUS
1145' (58% full)
PARTIAL DOMESTIC SURPLUS
1125' (51% full)
NORMAL SUPPLY
Minimum Power Pool
1083' (37% full)
1075' (34% full)
400 KAF REDUCTION
Bottom of First SNWA Intake
1050' (27% full)
500 KAF REDUCTION
1025' (21% full)
600 KAF REDUCTION
Bottom of Second SNWA Intake
1000' (16% full)
ADDITIONAL REDUCTIONS ?
Minimum Mead Intake Elevation
915' (2% full)
Top of Dead Storage
895' (0% full)

Coordinated Management

Powell Elevation (feet)	Powell Operation	Powell Live Storage (maf)
3700		24.32
	Equalize or 8.23 maf	
3636 - 3664 (see table below)		15.54- 19.02 (2008 - 2025)
	8.23 maf; if Mead < 1075 feet, balance contents with a min/max release of 7.0 and 9.0 maf	
3575		9.52
	7.48 maf 8.23 maf if Mead < 1025 fee	
3525		5.93
	Balance contents with a min/max release of 7.0 and 9.5 maf	
3370		0