Climate Change in the Colorado River Basin

Southern Nevada Water Authority
April 23, 2014
Las Vegas, NV

Heron Reservoir on April 9, 2014: Colorado River storage for Albuquerque and Santa Fe, 84 kaf here (not visible), 134 kaf last year, 288 kaf average

Outline

* Basin Overview
  * Geography, Recent News, Overallocation
* Climate Change
  * Basics, 1000-year problem, Water Connection
* Climate Change and the Colorado
  * History, Projections
* Other Applicable Science
  * Beetles, Dust, Fires, Paleoclimate
* Some Conclusions

21st Century Water Manager

One day, son, all of these perfectly good A.C. adapters, which have long outlived the products they were originally designed for, will be yours.
Colorado River Drought Forces a Painful Reckoning for States

* Unprecedented 14-Year Drought
* Low Lake Mead Levels
* First Shortages Ever Likely soon
* Climate Change
* Supply-Demand Gap
* Power Losses
* Central AZ Project Threats
* Desal as Option
* Conservation

The New York Times

The climate of the western United States could become much drier over the course of this century.

Dry Times Ahead

Science, June 25, 2010

- 2°F Warming since 1900
- Snowpack Reductions and Changes in Runoff Timing Already Present
- Most Severe Drought since records kept
- Powell and Mead at 50% of capacity now, full 2000
- Tree Mortality Rates High
- Increase in Wildfire Frequency
- Drought may be natural, but exacerbated by higher temperatures
- Snowpack Reductions and Runoff Timing attributed to climate change
- Continued drying likely as temperatures increase and storm tracks shift
- Megadroughts independent of climate change a possibility with severe consequences if combined with warming
7 States, 2 Nations
Annual Flow 16.4 MAF (20,000 GL = 20 km³)
40 M People
All of the Major Cities in Southwest
5.5m Irrigated Acres (2.2 m Ha)
250,000 mi² Basin Area (650,000 km²)
Huge Topographic and climatic Variability
90 Years of Agreements known as “Law of the River”
Basic Allocation: 50/50 Split Upper Basin Lower Basin

40+ Million Americans depend on the Colorado River

Source: City of Tucson
Contents of the Two Largest Reservoirs in the United States

Combined Volume in MAF of Lakes Mead and Powell since 1935

- Initial Filling of Lake Powell, 1963-1983
- Only Lake Mead Existed Here, 1935-1963
- We are now at a level last seen in 1968 during Powell’s initial filling
- Due to unprecedented drought since 2000, the first ever delivery shortage is likely to be experienced by 2015 or 2016

Source: Udall, using Reclamation data

Reclamation’s Guess of the Future

Source: Reclamation, 2011
How does the Colorado River drought stack up?
It’s one of the worst of the millennium.
NEWS - October 28, 2013
By Matt Jenkins

Reliable flow-gauge records for the Colorado River extend back to 1906. But specialists have used tree rings to estimate flows more than 1,100 years earlier, as far back as 762 A.D.
The current drought began in 2000, and is now entering its 14th year. When matched up against every other 14-year period since 762 A.D., it falls in the driest 2 percent of all those periods.
That means the current 14-year period is, as federal Bureau of Reclamation head Michael Connor told a Senate committee this summer, “one of the lowest in the Basin in over 1,200 years.”
That’s true, says Jeff Lukas, with the Western Water Assessment at the University of Colorado, adding that the tree rings show a half-dozen decade-or-longer droughts that were likely more severe than the current one.
But stay tuned: If the drought continues, it will likely keep climbing in the rankings.

* Lower Basin Problem
  - Lake Mead on average is overdrawn by 1.2 maf/year
  - Unused Upper Basin Water bails out Lower Basin
  - Climate Change or UB Demand Growth means LB must solve
  - Current Uses 9 maf/year US, 1.5 maf Mexico

* Upper Basin Problem
  - Colorado River Compact forces delivery requirement on Upper Basin to Lower Basin
  - Upper Basin gets ‘Hydrologic Leftovers’
  - Climate Change makes Leftovers even more uncertain
  - Current Uses about 5 maf/year

* Basin Overview
  - Geography, Recent News, Overallocation

* Climate Change
  - Basics, 1000-year problem, Water Connection
  - Climate Change and the Colorado
    - History, Projections
  - Other Applicable Science
    - Beetles, Dust, Fires, Paleoclimate

* Some Conclusions

**Outline**
• Earth is about 60°F warmer than it should be
• Very Small Concentrations of Greenhouse Gasses (GHGs) are the cause
  • Almost every gas other than Oxygen (O₂) and Nitrogen (N₂) are GHGs. CO₂ is most important one.
• Earth’s Temperatures have fluctuated widely over its 4.5B year history
  • But NOT during human’s very short time
• Humans are adding enormous amounts of GHGs to the atmosphere every day and it is increasing over time
• Total Warming will be related to GHG concentrations, not emissions
  • If you stop tomorrow, you still have a 1000-year problem
• Humans are also modifying the planet in many other ways
  • ‘The Anthropocene’

*Climate Change Basics*

IPCC: All Kinds of Observations are Consistent with Climate Change Expectations

- Up by 5%, Consistent with 7%/C Max Rate
- Up by ~0.5°F since 1950
- Up by 1.4°F Since 1950, May exceed 7°F by 2100
- Up by 53% decline in June in NH
- Up by 8” since 1900, may reach 1m by 2100
- 90% of energy from warming here
Why this problem is not going away anytime soon….GHG emissions continue to increase.

*Note the pattern: 30 Degrees North and South are where they exist. Deserts expect to move poleward under climate change.*
**George Hadley, 1700s**

*Simple Theory Explains*

* N-S movement of air near equator
* Trade winds blow from NE/SE
* Deserts at 30 N/S Latitude
* Areas of heavy rain at Equator
* Location of “Subtropical Jet”

* Under climate change, Hadley Cells expand poleward, moving deserts poleward

*Note: major UK Modeling Center named after Hadley*

---

**Climate Change is Water Change**

Spruce Beetle Kill, San Juan Mountains, 2012

Heat Drives the Water Cycle - 1000 km3 evaporates daily from the oceans

The Water Cycle mixes heat from areas of too much to too little

As the Atmosphere Warms it Holds More Moisture: -5F warming is 20% increase

Heating Up the Earth (and uneven heating) results in Water Cycle changes

  * More Evaporation, More Precipitation, More Moisture
  * Changes in weather patterns
  * Wet Wetter, Dry Drier Standard Rule
  * More Intense Floods and Droughts

All Kinds of Water Changes Already Noted

  * More rain/less snow, Earlier Runoff, Higher Water Temps, More Intense Rain

Many of the most critical impacts of climate change will arise through water cycle changes driven by higher temps, not simply rising temperatures
Water and Climate Change Connection:
Then...

The Effects of Doubling the CO₂ Concentration on the Climate of a General Circulation Model

SYUKURO MANARE 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 CO₂ 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 CO₂ concentration may affect the distribution of temperature in the atmosphere. It is shown that the CO₂ increase raises the temperature of the model stratosphere, 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.

Water and Climate Change Connection:
Now

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

Paul J. Durack,1,2,3,4, Susan E. Wijffels,1,2 Richard J. Matear1,2

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 8–55% 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
* Baseline Overview
  * Geography, Recent News, Overallocation
* Climate Change
  * Basics, 1000-year problem, Water Connection
* Climate Change and the Colorado
  * History, Projections
* Other Applicable Science
  * Beetles, Dust, Fires, Paleoclimate
* Extreme Events, Uncertainty, Conclusions

*Outline*
Source: Reclamation, 2012
At Least 15 Colorado River Climate Change Studies Since 2004...

Runoff Declines Range from -6% to -45% by 2050

...Best guess now -10% to -20% by 2050

*Regional to global-scale projections of soil moisture and drought remain relatively uncertain compared to other aspects of the water cycle. Nonetheless, drying in the Mediterranean, southwestern U.S. and south African regions are consistent with projected changes in Hadley circulation, so drying in these regions as global temperatures increase is likely for several degrees of warming under the RCP8.5 scenario.*

Source: Water Cycle Box in IPCC 2013 WG1 Technical Summary, also Summary for Policy Makers
Why huge range (-5% to -50%) in predictions of future runoff declines?

* GCM Differences
* GHG Emission Trajectories
* Scale (Elevation, especially, also grid size)
* Hydrology Model Sensitivities to Temp and Precip
* Downscaling of Climate Data

My Take Home Message...

* Trust the direction of changes, and rough magnitudes, but don’t think we have a crystal ball
* Uncertainty should cause action, not inaction
* “The proper response to uncertainty is insurance, not denial”

Understanding Uncertainties in Future Colorado Streamflow
Vano, et al., 2013

Runoff is Generated From VERY Small Area

April 1 SWE

Runoff

Source: Reclamation, 2012
**Earlier Peaks, Less Flow Later**

**Figure B-49**
Comparison of Observed and Future Simulated Mean Monthly Flows at Colorado River at Lees Ferry, Arizona

- 1990-1999
- 2011-2040
- 2041-2070
- 2066-2099

Source: Reclamation, 2012

---

**Increased Demands Due to Climate Change**

**Bottom Line:** A Variety of Demand Increases Possible by Mid-Century, Average is 4%

**Figure 11**
Current Projected (All) Scenario Demands Adjusted for Possible Future Climate Change

4% More Annually Basin Wide

Source: Reclamation, 2012
Lee Ferry Projected Flows from Basin Study

Bottom Line: 75% Models Show Declines, Median Decline -9% at Mid-Century

At 45 maf/year flood control may be an issue

Source: Reclamation, 2012
**Myth: Upper Basin Bears Entire Climate Risk**

Water Availability as a Function of Lee Ferry Flow

- **Blue Line:** Decreasing Lee Ferry Supply Over Time
- **Red Line:** Increasing UB Demands Over Time

*Source: Doug Kenney*  
*Figure 1. Water Availability (by sub-basin) as a Function of Long-Term Average Flows*  

Myth: Compact Section III (d) forces Upper Basin to take on entire climate change risk. 85% of flows originate in Upper Basin.
* Basin Overview
  * Geography, Recent News, Overallocation
* Climate Change
  * Basics, 1000-year problem, Water Connection
  * Climate Change and the Colorado
  * History, Projections
* Other Applicable Science
  * Beetles, Dust, Fires, Paleoclimate
* Some Conclusions

Outline

**Wild Cards: Pine Beetles**
Raffa et al, 2008

Figure 1. Recent mortality of major western conifer biomes to bark beetles. (a) Map of western North America showing regions of major eruptions by three species. (b) Sizes of conifer biome area affected by these three species over time. Data are from the Canadian Forest Service, the British Columbia Ministry of Forests and Range, and the US Forest Service.
Dust on Snow Reduces Runoff

**Dust-on-snow** — modern dust loading is causing earlier snowmelt and runoff, and may be reducing UCRB flow by ~5% compared to pre-1850 conditions and causing runoff to occur 3 weeks earlier (Painter et al. 2010)

Why: dark surface absorbs more energy

Dust Source: NE Arizona, S. Utah

*“Warming and Earlier Spring Increases Western US Forest Wildfire Activity”*

Westerling et al., Science 2006

* Large fires increased dramatically in the mid 1980s - Compared to 1970-86 average
  * More Total Number of Fires - 4x
  * Total Area Burned - 6x
  * Longer Lasting Fires: from 7.5 days to 37 days
  * Longer Fire Seasons - 76 days, half of increase at begin, half at end
  * Fires strongly tied to spring and summer temperatures
* Note: Hayman and Buffalo Creek Fires have cost Denver Water Millions of $ to remove and prevent sediment in reservoirs

Western US Forest Wildfires and Spring–Summer Temperature
Megadroughts at 15% Flow for 60 Years

Medieval drought in the upper Colorado River Basin

David M. Meko, 1 Connie A. Woodhouse, 2 Christopher A. Baisan, 1 Troy Knight, 1 Jeffrey J. Lukas, 3 Malcolm K. Hughes, 1 and Matthew W. Salzer 1

[Graph showing flow percentage over time with a peak at 87% of 1906-2004 mean at the end of the graph.]

Meko, et al, 2007 GRL

Outline

* Basin Overview
  * Geography, Recent News, Overallocation
  * Climate Change
    * Basics, 1000-year problem, Water Connection
    * Climate Change and the Colorado
      * History, Projections
    * Other Applicable Science
      * Beetles, Dust, Fires, Paleoclimate
    * Extreme Events, Uncertainty, Conclusions
1. Is this (drought/flood/etc) caused by climate change?
   - Natural Variability makes it hard to discern climate change ‘signal’ from natural variability ‘noise’
   - Usually the answer will be ‘No’ due to statistical hurdles. Gives mistaken impression that climate change is not happening or is not affecting events
   - Scientists prefer to err on side of ‘Trojan Horse’ than ‘Cry Wolf’
2. Is climate change affecting this event?
   - Generally, Yes.
   - More atmospheric moisture for sure
   - Higher temps and more drying
   - Other factors may be at work, too
   - Lots of possible climate change effects: intensity, duration, frequency
3. How will climate change affect future droughts/floods/etc ?
   - All the usual answers apply
   - More extremes: bigger droughts and bigger floods

The 2 Kinds of Errors we make with Predictions

<table>
<thead>
<tr>
<th>Scientific Prediction</th>
<th>Truth</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Climate Change</td>
<td>Good Prediction</td>
</tr>
<tr>
<td>Yes Climate Change</td>
<td>Cry Wolf Error</td>
</tr>
</tbody>
</table>

Wandering Jet Stream and Extremes

Is it or Isn’t it Climate Change?

Uncertainty in Science and its role in Climate Policy

Terrific, Thought-Provoking Article Worth a Read

Key Points
- 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.”
- These concepts not appreciated by both modeling community and user community
- Key Point: we need to move away from scientific uncertainty to managing risk

Uncertainty in science and its role in climate policy
Leonard Smith and Nicholas Stern
Take Home Points

- Climate change is real, here now, not stopping, 1000-year commitment
- Climate Change is Water Change
- Colorado River is Overallocated AND Overused
- Colorado River Flows Very Likely to Decline By 2050 (-9%??)
- Drought of Last 13 Years is Unprecedented at shows about a ~15% reduction relative to 15 maf
- Colorado River Demands Likely to Increase but by how much?
- Extreme Events are being impacted by climate change
- Expect to See Lakes Powell and Mead Continue to Fluctuate Significantly
- Climate Change will impact LB and UB in very different ways
- Science will never be certain; but we already know much
- Science unlikely to provide more accuracy beyond what we already have, at least in next decade and maybe longer
- Smart solutions should be robust to range of uncertainty so as to manage risk

“The First Principle is to not fool yourself, and you are the easiest person to fool” ~ Richard Feynman

The Basin States

“I don’t mind getting married for better or for worse as long as it’s not a whole lot worse.”
CMIP 5 Models said to be a little wetter (less dry?) than CMIP3 in Colorado River

IPCC FAR Results: RCP 8.5 Precipitation at 2081-2100
IPCC FAR Results RCP 8.5 at 2081 to 2100

* Emissions Scenarios
* Models show consistent errors (biases)
* Known Problems: El Nino, Monsoons, Mountains, Blocking, Extremes
* Natural Variability Critical - inherent limits to predictability exist
* 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
* CRB Flows can change by > 10%
* Land Surface Models
* Sensitivity to T & P Varies

“The First Principle is you must not fool yourself and you are the easiest person to fool.” - Feynman

[Image of world map showing soil moisture]
Main Point:

150,000 AF of water going to China in Alfalfa Bales...

Increased Demands Due to Climate Change

Basin Study Did Incorporate SOME Aspects of Changing Demands

Did Include Changes in Demand Due to Increased ET

- Agricultural
- Reservoir Evaporation
- M&I Demands
- Phreatophyte Losses

Mean Change is +4% due to increased ET: ~ 500 kaf/year by 2060

Did Not Include changes in Demand due to...

- Changes in Energy Demand
- Changes in Environmental Flow Needs due to warmer waters
- Changes in Crop Types
Can we model events like this or Front Range Floods?

Even if we can model an event that lies outside natural variability, can we accurately portray new frequencies?

Note that these frequencies will continue to change throughout 21st Century.

Source: TX Climatologist John Neilsen-Gammon

Note: Wx Models performed horribly during Boulder storm

---

Some Observations on Extreme Events

* Many Climate Scientists are tying themselves into knots trying to explain extreme events as Yes/No which is a mistake.

* “Is it caused by climate change” is a poorly framed question

* No events are caused by climate change, but all have a contribution

* All weather events are affected by climate change because the atmosphere is warmer (~1F Land Temps, ~0.5 F Ocean SSTs) and moister (~5%) than it used to be.

* Small shift in the mean can cause very large changes in the extremes

* There are many different aspects to extremes including intensity, duration, frequency of occurrence. Science is unlikely to provide useful answers for decision makers in many cases, e.g., new flood frequencies. In all cases these numbers are moving targets through 21st century.

Trenberth, 2012: Framing the Way to Relate Climate Extremes to Climate Change
Total Ag Demand Increases by 150 to 500 kaf at 2040.
Average Increase ~ 20%.
18 Days Longer Growing Season

<table>
<thead>
<tr>
<th>Study Basin</th>
<th>Historical Period</th>
<th>Minimum Projection</th>
<th>Maximum Projection</th>
<th>Average of Projections</th>
<th>% Increase From Historical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yampa River</td>
<td>214,271</td>
<td>225,440</td>
<td>263,438</td>
<td>245,964</td>
<td>15%</td>
</tr>
<tr>
<td>White River</td>
<td>45,937</td>
<td>50,123</td>
<td>62,182</td>
<td>53,713</td>
<td>23%</td>
</tr>
<tr>
<td>Upper Colorado River</td>
<td>577,043</td>
<td>618,704</td>
<td>736,863</td>
<td>688,314</td>
<td>19%</td>
</tr>
<tr>
<td>Gunnison River</td>
<td>618,070</td>
<td>680,364</td>
<td>769,496</td>
<td>724,335</td>
<td>17%</td>
</tr>
<tr>
<td>San Juan/Dolores Rivers</td>
<td>554,821</td>
<td>591,795</td>
<td>685,620</td>
<td>647,506</td>
<td>17%</td>
</tr>
<tr>
<td>Total</td>
<td>2,010,142</td>
<td>2,146,426</td>
<td>2,516,889</td>
<td>2,360,832</td>
<td>17%</td>
</tr>
</tbody>
</table>
Projected Future Colorado River System Conditions

SNWA's Integrated Resource Planning Advisory Committee
April 23, 2014
Las Vegas, NV

U.S. Department of the Interior
Bureau of Reclamation

Presentation Outline

• Overview of the Colorado River Basin
• The Colorado River Basin Water Supply & Demand Study
  – Water Supply and Demand Scenarios
  – Options & Strategies
  – Projected Future System Reliability
• Current Projections

Projected Future Colorado River System Conditions
Colorado River Basin

- 16.5 MAF allocated annually
- 13 to 14.5 MAF of consumptive use annually
- 15.0 MAF average annual "natural" inflow into Lake Powell over the past 100 years
- Inflows are highly variable year to year
- 60 MAF of storage capacity
- Operation governed by the "Law of the River"

Emerging Water Challenges in the Colorado River Basin

- Natural Flow
Colorado River at Lees Ferry Gaging Station, Arizona
Water Year 1906 to 2014

Chart showing natural flow of the Colorado River at Lees Ferry, AZ, from 1906 to 2014 with average and 10-year average lines.
Historical Colorado River Water Supply & Use (10-year Running Average)

Colorado River Basin Water Supply and Demand Study

- Study Objective
  - Assess future water supply and demand imbalances over the next 50 years
  - Develop and evaluate opportunities for resolving imbalances
- Conducted through the WaterSMART Basin Study Program
- Conducted by Reclamation and the Basin States, in collaboration with stakeholders throughout the Basin
- Began in January 2010 and completed in December 2012
- A planning study – does not result in any decisions, but provides the technical foundation for future activities
### Final Study Reports

- The final Study is a collection of reports available at: [http://www.usbr.gov/lc/region/programs/crbstudy.html](http://www.usbr.gov/lc/region/programs/crbstudy.html)

<table>
<thead>
<tr>
<th>Executive Summary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Study Report</td>
</tr>
<tr>
<td>Technical Report A  – Scenario Development</td>
</tr>
<tr>
<td>Technical Report B – Water Supply Assessment</td>
</tr>
<tr>
<td>Technical Report C – Water Demand Assessment</td>
</tr>
<tr>
<td>Technical Report D – System Reliability Metrics</td>
</tr>
<tr>
<td>Technical Report E – Approach to Develop and Evaluate Opportunities to Balance Supply</td>
</tr>
<tr>
<td>Technical Report F – Development of Options and Strategies</td>
</tr>
</tbody>
</table>

### Scenario Planning: Addressing an Uncertain Future

- The path of major influences on the Colorado River system is uncertain and can not be represented by a single view

- An infinite number of plausible futures exist

- A manageable and informative number of scenarios are being developed to explore the broad range of futures

(adapted from Timpe and Scheepers, 2003)
Quantification of Water Supply Scenarios
Projections of 2011-2060 Average Natural Flow at Lees Ferry

1994 – 2013 average = 13.5 MAF*

*Natural flows for 2011-2013 are provisional

Quantification of Water Demand Scenarios
Projections of Colorado River Water Demand

- Key water demand drivers and change from 2015 to 2060:
  - Population increase from about 40 million people by 23% (49 million) to 91% (77 million)
  - Per capita water use decrease by 7% to 19%
  - Irrigated acreage decrease from about 5.5 million acres by 6% (5.2 million) to 15% (4.6 million)
Projected Future Colorado River Basin Water Supply and Demand

- Average supply-demand imbalances by 2060 are approximately 3.2 million acre-feet
- This imbalance may be more or less depending on the nature of the particular supply and demand scenario
- Imbalances have occurred in the past and deliveries have been met due to reservoir storage

System Reliability Analysis

- Simulate the state of the system over the next 50 years for each scenario, with and without options and strategies
- Use metrics and vulnerabilities to quantify impacts to Basin resources
- Resource Categories
  - Water Deliveries
  - Electrical Power Resources
  - Water Quality
  - Flood Control
  - Recreational Resources
  - Ecological Resources
Lower Basin Water Deliveries - Baseline
Percent of All Plausible Futures that Result in Vulnerability

<table>
<thead>
<tr>
<th>Time Period</th>
<th>2012-2026</th>
<th>2027-2040</th>
<th>2041-2060</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lake Mead Pool Elevation &lt; 1,000 feet in any one month</td>
<td>13%</td>
<td>25%</td>
<td>40%</td>
</tr>
<tr>
<td>Lower Basin Shortage (exceeds 1 maf over any two year window)</td>
<td>22%</td>
<td>59%</td>
<td>80%</td>
</tr>
<tr>
<td>Lower Basin Shortage (exceeds 1.5 maf over any five year window)</td>
<td>30%</td>
<td>64%</td>
<td>87%</td>
</tr>
</tbody>
</table>

Options to Resolve Water Supply/Demand Imbalances

<table>
<thead>
<tr>
<th>Volumes in Million Acre-Feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reuse</td>
</tr>
<tr>
<td>Local Supply</td>
</tr>
<tr>
<td>Importation</td>
</tr>
<tr>
<td>Desalination</td>
</tr>
<tr>
<td>Energy Water Use Efficiency</td>
</tr>
<tr>
<td>M&amp;I Conservation</td>
</tr>
<tr>
<td>Agricultural Conservation</td>
</tr>
<tr>
<td>Watershed Management</td>
</tr>
</tbody>
</table>

Portfolio B (5.608)  Portfolio C (4.735)
### Lower Basin Water Deliveries - Portfolios

**Percent of All Plausible Futures that Result in Vulnerability**

#### Current Projections

<table>
<thead>
<tr>
<th>Time Period</th>
<th>Baseline</th>
<th>Portfolio A</th>
<th>Portfolio B</th>
<th>Portfolio C</th>
<th>Portfolio D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lower Basin Water Delivery</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lake Mead Pool Elevation &lt; 1000 feet (below 1000 feet in any one month)</td>
<td>2012-2026</td>
<td>13%</td>
<td>12%</td>
<td>11%</td>
<td>12%</td>
</tr>
<tr>
<td></td>
<td>2027-2040</td>
<td>25%</td>
<td>17%</td>
<td>15%</td>
<td>18%</td>
</tr>
<tr>
<td></td>
<td>2041-2060</td>
<td>40%</td>
<td>10%</td>
<td>10%</td>
<td>14%</td>
</tr>
<tr>
<td>Lower Basin Shortage (exceeds 1 maf over any two year window)</td>
<td>2012-2026</td>
<td>22%</td>
<td>16%</td>
<td>15%</td>
<td>16%</td>
</tr>
<tr>
<td></td>
<td>2027-2040</td>
<td>59%</td>
<td>48%</td>
<td>43%</td>
<td>48%</td>
</tr>
<tr>
<td></td>
<td>2041-2060</td>
<td>80%</td>
<td>35%</td>
<td>34%</td>
<td>38%</td>
</tr>
<tr>
<td>Lower Basin Shortage (exceeds 1 maf over any five year window)</td>
<td>2012-2026</td>
<td>30%</td>
<td>29%</td>
<td>27%</td>
<td>28%</td>
</tr>
<tr>
<td></td>
<td>2027-2040</td>
<td>64%</td>
<td>61%</td>
<td>54%</td>
<td>61%</td>
</tr>
<tr>
<td></td>
<td>2041-2060</td>
<td>7%</td>
<td>61%</td>
<td>56%</td>
<td>62%</td>
</tr>
</tbody>
</table>
Natural Flow
Colorado River at Lees Ferry Gaging Station, Arizona
Water Year 1906 to 2014

Shortage Condition – 1,025 ft
Shortage Condition – 1,050 ft
Shortage Condition – 1,075 ft
Normal or ICS Surplus Condition – 1,145 ft
Domestic Surplus or ICS Surplus Condition – 1,200 ft
Flood Control Surplus or Quantified Surplus Condition – 1,220 ft

Dead Pool – 895 ft

Lake Mead Projected* Elevations

Historical Elevation
Projected Min, Mean, Max Elevations using Historical Hydrology
Projected Min, Mean, Max Elevations using GCM-Driven Hydrology
Current Projections

Historical Hydrology

* Projected using January 2014 CRSS

Current Projections

GCM (Global Climate Model)-Driven Hydrology

* Projected using January 2014 CRSS
Protection Volume Analysis

Volumes needed to “absolutely protect” Lake Mead elevations 1,000 ft and 1,025 ft through 2026

<table>
<thead>
<tr>
<th>Hydrology</th>
<th>Lake Mead Elevation 1,025 ft</th>
<th>Lake Mead Elevation 1,000 ft</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Maximum in any year (MAF)</td>
<td>First Year that Maximum Occurs</td>
</tr>
<tr>
<td>Historical</td>
<td>2.1</td>
<td>2017</td>
</tr>
<tr>
<td>GCM-Driven</td>
<td>5.0</td>
<td>2018</td>
</tr>
</tbody>
</table>

1Volumes are in addition to Shortages per the 2007 Interim Guidelines

Lake Powell Conditions when Lake Mead < 1,000 ft and Recovery Times

- **When Lake Mead is < 1,000 ft**
  - Lake Powell is < 3,490 ft about 75% of the time
  - Lake Powell is < 3,525 ft about 84% of the time

- **Recovery**
  - Average number of years until Lake Mead is > 1,025 ft: 9.5
  - Average number of years until Lake Mead is > 1,050 ft: 12.1
  - Average number of years until Lake Mead is > 1,075 ft: 13.5

Note: Analysis done using Historical Hydrology only
Projected Future Colorado River System Conditions

Questions?

For more information:
• Basin Study: http://www.usbr.gov/lc/region/programs/crbstudy.html
• Next Steps: http://www.usbr.gov/lc/region/programs/crbstudy/MovingForward/index.html
• River Operations: http://www.usbr.gov/lc/riverops.html
Drought Update

Seasonal Drought Outlook

(April 15, 2014)

Source: National Oceanic Atmospheric Administration and the U.S. Department of Commerce
Drought Update

- March inflow to Lake Powell: 76% of average
- Snow Pack: 107% of average
- Water Year 2014 Precipitation: 99% of average
- Forecasted Water Year 2014 Inflow to Lake Powell: 103% of average

Upper Colorado River Basin Snow Accumulation

As of 04/15/2014 with 73 of 116 sites reporting, the basin wide SWE is 114 percent of median.
### Drought Update

#### Lake Powell Precipitation and Inflow Forecast

<table>
<thead>
<tr>
<th>Month</th>
<th>2013 Water Year</th>
<th></th>
<th>2014 Water Year</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Actual Precipitation</td>
<td>Inflows Forecast</td>
<td>Actual Precipitation</td>
<td>Inflows Forecast</td>
</tr>
<tr>
<td>Jan</td>
<td>72%</td>
<td>61%</td>
<td>96%</td>
<td>93%</td>
</tr>
<tr>
<td>Feb</td>
<td>78%</td>
<td>54%</td>
<td>102%</td>
<td>96%</td>
</tr>
<tr>
<td>Mar</td>
<td>76%</td>
<td>49%</td>
<td>103%</td>
<td>105%</td>
</tr>
<tr>
<td>Apr</td>
<td>78%</td>
<td>42%</td>
<td>99%</td>
<td>103%</td>
</tr>
<tr>
<td>May</td>
<td>80%</td>
<td>45%</td>
<td>97%</td>
<td>105%</td>
</tr>
<tr>
<td>Jun</td>
<td>77%</td>
<td>44%</td>
<td>100%</td>
<td>105%</td>
</tr>
<tr>
<td>Jul</td>
<td>80%</td>
<td>41%</td>
<td>102%</td>
<td>105%</td>
</tr>
<tr>
<td>Aug</td>
<td>81%</td>
<td>40%</td>
<td>103%</td>
<td>103%</td>
</tr>
<tr>
<td>Sept</td>
<td>90%</td>
<td>46%</td>
<td>104%</td>
<td>105%</td>
</tr>
<tr>
<td>Actual</td>
<td>91%</td>
<td>47%</td>
<td>105%</td>
<td>105%</td>
</tr>
</tbody>
</table>

#### Lake Mead Capacity - Current

- Current elevation: 1,097 ft.
- 1,220 ft.: 100% of capacity
- 1,000 ft.: 44% of capacity
- 1,000 ft. [Intakes 2 & 3]: 17% of capacity
- Hoover Dam: 100% of capacity
Drought Update

Lake Mead Capacity – Projected (Dec. 31, 2014)

- 100% of capacity
- 40% of capacity
- Projected Dec. 31, 2014
- 17% of capacity
- 1,220 ft.
- 1,085 ft.
- 1,000 ft.
- Intakes 2 & 3

Hoover Dam

Lake Mead Capacity – Projected (Dec. 31, 2014)
Analysis of Alternatives Using Attributes

Importance of Attributes

- Help to establish criteria that alternatives can be compared against
- Must be easy to understand
- Are non-redundant
- Can be measured
- Concise in number
Attributes and Performance Measures

Performance measures indicate how well attributes are being met.

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Performance Measures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost Effective</td>
<td>Water rates</td>
</tr>
<tr>
<td>Vulnerability to Climate Change</td>
<td>Frequency of water shortages</td>
</tr>
<tr>
<td></td>
<td>Amount of climate change influence on a given water resource</td>
</tr>
</tbody>
</table>

Attributes vs. Solutions

- Attributes help define the **what** we are trying to achieve
- Solutions represent **how** we could get there

<table>
<thead>
<tr>
<th>Attributes</th>
<th>Solutions (can serve multiple attributes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water Efficiency</td>
<td>Convert lawns to desert landscaping</td>
</tr>
<tr>
<td>Maintain Existing Supplies</td>
<td>Incentives for water-efficient equipment</td>
</tr>
<tr>
<td>Drought Resilience</td>
<td>Construct deferred facilities</td>
</tr>
<tr>
<td></td>
<td>New water treatment processes</td>
</tr>
<tr>
<td></td>
<td>Develop “out of basin” resources</td>
</tr>
<tr>
<td></td>
<td>Pursue storage agreements</td>
</tr>
</tbody>
</table>