Tree Rings, Gages and Climate Models: Revising reservoir planning based on vulnerability to sustained drought in the past and future

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Water Resource Operations

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Salt River Project

Salt River Valley Water Users Association

- Established 1903
- A Federal reclamation project
- A private corporation
- Delivers almost 1 million acre-feet per year

SRP Agricultural Improvement and Power District

- Established 1937 as a political subdivision of the state of Arizona
- 32,571 million kWh sold in FY10
- 942,000 customers in and around the Phoenix metro area
SRP manages 6 reservoirs on the Salt (4) and Verde (2) rivers, operates wells in the service area, and delivers nearly 1 million acre-feet of water per year.
Salt-Verde Watershed Normals

1971-2000

Inflow, Kaf

Precipitation, inches

WINTER:
Precip. (Dec-Mar): 6.3 in
Runoff (Dec-May): 665 Kaf

SUMMER:
Precip. (Jul-Sep): 6.8 in
Runoff (Jul-Sep): 120 Kaf
Salt+Tonto+Verde WINTER (Dec-May) INFLOW:
Departure from Median (651 Kaf)

1892-1904: 2 wet, 11 dry
1905-45: 28 wet, 13 dry
1946-64: 5 wet, 14 dry
1965-95: 19 wet, 12 dry
1996-2011: 4 wet, 12 dry
How Vulnerable Are We?

Key Question: What is minimum annual inflow that allows SRP to maintain carryover storage in perpetuity?

Examined:

• Historical, instrument-era record (110 years)
• Tree-ring record (600 years)
• Climate change, GCM scenarios (future decades)
Salt River Project Historic Drought Periods
(Average Runoff 1913–2010 = 1,198,536 AF)

Drought of Record

1900-1904: 35%
1942-1948: 62%
1953-1957: 47%
1974-1977: 52%
1995-2011?: ??%
Planning Assumptions
Version 1.0 (1980s and 1990s)

- 950 kaf -- full demand
- 325 kaf -- maximum pumping
- Historical “drought of record”: 1898-1904
- Use allocation and pumping to manage for “drought of record”
Salt River Project Historic Drought Periods
(Average Runoff 1913–2010 = 1,198,536 AF)

- 7 Years 1942–1948: 62%
- 5 Years 1953–1957: 47%
- 4 Years 1974–1977: 52%
- 16+ Years 1995–2011?: ??%

Longer Period Of Sustained Drought
What can tree ring analysis tell us about pre-20th century floods and droughts?
Analysis conclusions:

From 1975 to 1995, Arizona was very wet (25% more than average), and...
...Droughts lasting a decade or more are not uncommon.
The mega-drought of 1575-85.

An 11-Year drought with 70 percent of historical gaged median inflow.
2002 and 1996 have the lowest reconstructed annual flows in the entire record (28% and 30% of normal* respectively).

Maximum number of consecutive years below normal is 5 years (in 1590s and 1660s).

Longest stretch of consecutive years below normal in recent interval of 1914-2005 is 4 years (in 1950s).
Variations in Time-Averaged Flows

Plotted as % of normal*
*median of all 6-year running means

- 14 distinct prior occurrences of flow as low as 1999-2004 average
- 1-3 occurrences in each century
- Most severe conditions at ~1590 and ~1670
Length of Intervals Between Wet Years
based on reconstructed flows, 1330-2005

Longest interval = 22 years (1382-1403)
Recent interval = 12 years (1993-2004)
1950s interval = 12 years (1953-1964)
10 intervals ≥ 12 years
Median interval is 3 years

“Wet Year” = flow above 75th percentile

LTRR, UA (2008)
SRP Storage, Pumping & Water Allotment Planning

Median Inflow

3.0 af/ac
2.5 af/ac
2.0 af/ac

11-yr Tree-ring Drought with previous planning scenario
SRP Storage, Pumping & Water Allotment Planning

Median Inflow

Drought of Record

3.0 af/ac

2.0 af/ac

11-year Tree-ring Drought with new planning scenario
Version 2.0 Planning Guidelines

• 950 kaf -- full demand
• 325 kaf -- maximum pumping (start earlier)
• Tree-ring drought of record, 1575-1585
• Use allocation and pumping to manage for the 11-year tree-ring drought
Version 2.0 Planning Guidelines

SRP Storage, Pumping & Water Allotment Planning

Year

Reservoir Storage (KAF)

- 325
- 250
- 200
- 150
- 75
11-year Tree Ring Drought
Median Inflow

Ground Water Production (KAF)

2.0 AF/AC
3.0 AF/AC

- 75
- 150
- 200
- 250
- 325

Version 2.0 Planning Guidelines
Simulated Reservoir Storage for a Range of Perpetually Reduced Inflows (as a percent of historical median)

SRP Storage, Pumping & Water Allotment Planning
Simulated Reservoir Storage for a Range of Perpetually Reduced Inflows (as a percent of historical median)

<table>
<thead>
<tr>
<th>PERCENT OF MEDIAN INFLOW</th>
<th>YEARS TO RESERVOIR DRYUP</th>
</tr>
</thead>
<tbody>
<tr>
<td>64</td>
<td>INDEFINITE</td>
</tr>
<tr>
<td>63</td>
<td>50+</td>
</tr>
<tr>
<td>60</td>
<td>19.5</td>
</tr>
<tr>
<td>55</td>
<td>9.3</td>
</tr>
<tr>
<td>50</td>
<td>7.3</td>
</tr>
<tr>
<td>48</td>
<td>6.4</td>
</tr>
<tr>
<td>45</td>
<td>5.4</td>
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<tr>
<td>40</td>
<td>4.4</td>
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</tbody>
</table>
Precipitation increases very likely in high latitudes
Decreases likely in most subtropical land regions
Projections of Future Changes in Climate

Modeled changes in annual mean precipitation minus evaporation over the American Southwest…(Seager et al, 2007)
ASU sensitivity analyses (Ellis et al, 2008):

- Each 1 degree C of temperature rise yields a 6 to 7 percent reduction in streamflow.

- 10 percent less precipitation yields 15 to 20 percent less streamflow.

- +3 degrees C with 10 percent less precipitation yields 37 to 42 percent less streamflow.
Bottom Line for the Southwest:

- Continued warming.
- 20 to 50 percent decrease in runoff over the next several decades.
Response To Decreasing Supply:

-- augment supply to the “63 percent” line.

When storage drops below the target “63 percent” line, activate augmentation efforts to raise storage back to the 63 percent line.
Severe Droughts Capable of Depleting Surface Water Supply
(with the noted reduction in flow)

<table>
<thead>
<tr>
<th>Period</th>
<th>Source</th>
<th>Duration (yrs)</th>
<th>“What If” Flow Reduction</th>
<th>Average Annual % of Median</th>
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<tbody>
<tr>
<td>1214-1217</td>
<td>Tree-ring</td>
<td>4</td>
<td>20%</td>
<td>40%</td>
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<tr>
<td>1579-1585</td>
<td>Tree-ring</td>
<td>7</td>
<td>15%</td>
<td>50%</td>
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<tr>
<td>1666-1670</td>
<td>Tree-ring</td>
<td>5</td>
<td>20%</td>
<td>45%</td>
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<tr>
<td>1817-1823</td>
<td>Tree-ring</td>
<td>6</td>
<td>20%</td>
<td>48%</td>
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<tr>
<td>1898-1904</td>
<td>Historical</td>
<td>7</td>
<td>20%</td>
<td>48%</td>
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<tr>
<td>1999-2002</td>
<td>Historical</td>
<td>4</td>
<td>20%</td>
<td>40%</td>
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</tbody>
</table>
SRP Storage, Pumping & Water Allotment Planning

Year 1 Year 2 Year 3 Year 4 Year 5 Year 6 Year 7 Year 8 Year 9 Year 10
Reservoir Storage (KAF)
- 325
Median Inflow
- 250
- 175
- 125
- 75
Groundwater Pumping (KAF)
2.0 AF/AC
63% Median
SRP Storage, Pumping & Water Allotment Planning

Reservoir Storage (KAF)
- 325
Median Inflow
- 250
- 175
- 125
- 75
Groundwater Pumping (KAF) 2.0 AF/AC 63% Median
SRP Storage, Pumping & Water Allotment Planning

Reservoir Storage (KAF)
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Median Inflow
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Groundwater Pumping (KAF)
2.0 AF/AC
63% Median

63% Median
SRP Storage, Pumping & Water Allotment Planning

Reservoir Storage (KAF)

Median Inflow

Groundwater Pumping (KAF)

63% Median

2.0 AF/AC

Year 1
Year 2
Year 3
Year 4
Year 5
Year 6
Year 7
Year 8
Year 9
Year 10
SRP Storage, Pumping & Water Allotment Planning

Reservoir Storage (KAF)
- Median Inflow
- Groundwater Pumping (KAF)
- 2.0 AF/AC
- 63% Median
Augmented Storage Necessary to Recover to the Target 63 percent Line

<table>
<thead>
<tr>
<th>Historical Drought</th>
<th>Recovery Water (KAF)</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Year 5</th>
<th>Year 6</th>
<th>Year 7</th>
<th>Year 8</th>
<th>Year 9</th>
<th>Year 10</th>
<th>Year 11</th>
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<td></td>
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<td>1576-1586</td>
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<td>316</td>
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<td>29</td>
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<td>40</td>
<td>256</td>
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<td>1817-1824</td>
<td>20%</td>
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<td>337</td>
<td>140</td>
<td>261</td>
<td>19</td>
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<td>1895-1905</td>
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<td>298</td>
<td>180</td>
<td>38</td>
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<td>1998-2004</td>
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<td></td>
<td>19</td>
<td>242</td>
<td>283</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>544</td>
</tr>
</tbody>
</table>
Menu Of Options:

- Increase groundwater pumping (well restoration program)
- Reduce allocation of water
- Purchase Central Arizona Project (CAP) water
- Exercise lease options—Indian and non-Indian agriculture
- Recover long-term underground storage credits
- Increased conservation efforts
- Watershed management
- Weather modification
- Increase water-use efficiency
- Other…
Discussing Water Rights, A Western Pastime
DH Phillips; Reinink, Y; Skarupa, T; Ester C; and Skindlov, J. (2009). Water resources planning and management at the Salt River Project, Arizona, USA. *Irrigation and Drainage Systems* 23 (2-3), 109-124.


LTRR/SRP [Phase 1]: A Tree-Ring Based Assessment of Synchronous Extreme Streamflow Episodes in the Upper Colorado & Salt-Verde-Tonto River Basins (2005): [http://fp.arizona.edu/kkh/srp.htm](http://fp.arizona.edu/kkh/srp.htm)

Questions?
Short papers and panel discussions on these themes:

-- Effects of drought, climate variability and long-term climate change in the upper and lower Colorado Basin.

-- Use and utility of the NOAA (and other) drought and outlook products.

-- Climate Services – A look at NOAA’s new Climate Service and the current climate services.

-- Water resources monitoring, management, supply, demand and conservation.

-- Severe weather in arid climates. Forecasts and warnings: needs, production, dissemination and use. Vulnerability of communities to extreme weather.

Organized by the ASU Office of Climatology and NWS Phoenix.
“Call for papers” due out shortly (http://www.wrh.noaa.gov/psr/).