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*Managing Water in the West*

# Application of ensemble predictions in US Bureau of Reclamation water management decisions

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U.S. Department of the Interior
Bureau of Reclamation

# Bureau of Reclamation

- Manage, Develop, and Protect Water and Related Resources in and Environmentally and Economically Sound Manner
- 337 Reservoirs
  - 10 trillion gallons of water to 31 million people annually
- 53 Hydroelectric Power Plants
  - 14,723 MW Capacity
  - 40 million MWh/year
  - 240 Pumping Plants


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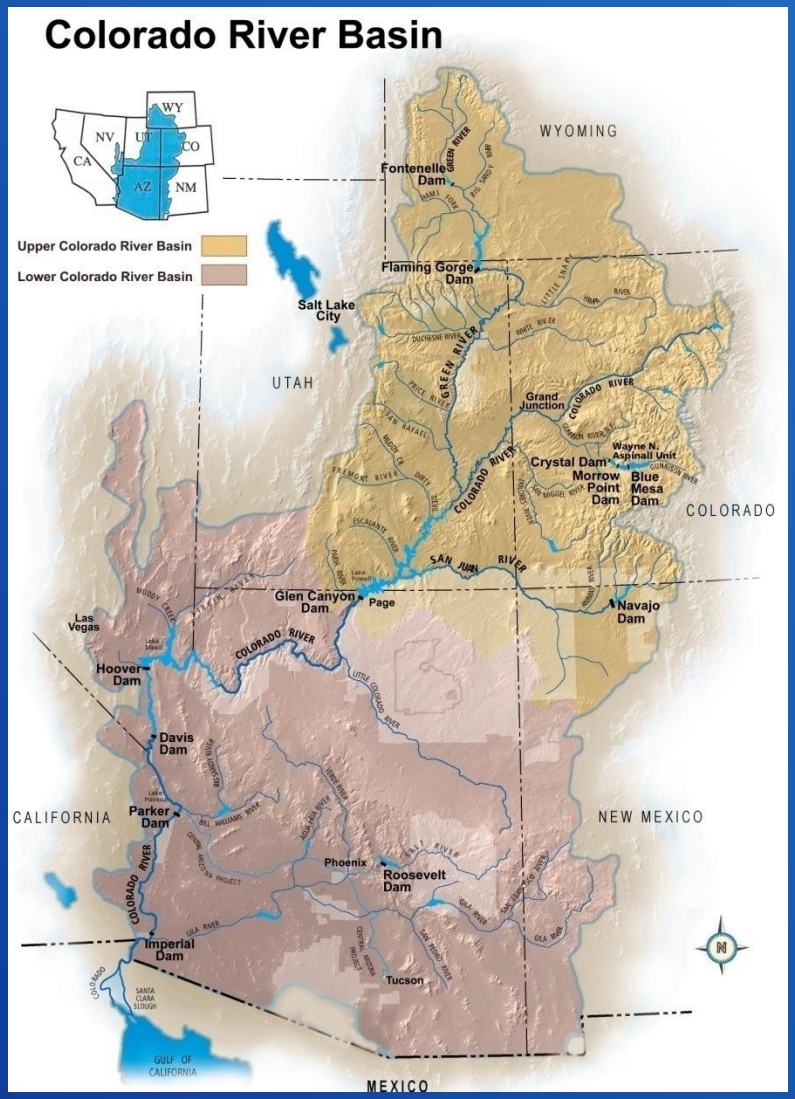
# Colorado River Basin

- Operation governed by the “Law of the River” (suite of laws and treaties)
- Water used by 7 states in US
  - Agriculture, M&I, hydropower, recreation, environmental flows
  - 16.5 maf allocated annually
  - 13 to 14.5 maf of consumptive use annually
- 60 million acre-feet of storage capacity (approximately 4 times the average annual natural inflow)
- 12 major reservoirs (Lake Powell and Lake Mead)
- Variable hydrology
- System operated on a tight margin

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# Impetus for the 2007 “Interim Guidelines”

- Five years of unprecedented drought, coupled with continuing increased water demand Basin-wide
- Operations between Lake Powell and Lake Mead were coordinated only at the higher reservoir levels via “equalization”
- No shortage guidelines for the Lower Basin
- 2007 Agreement on interim guidelines for operating Upper Basin and Lower Basin in times of drought

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# Use of Forecasts in Decisions

## Lake Powell & Lake Mead Operational Table
## Operational Tier Determinations for Water Year/Calendar Year 2014

| Lake Powell | | | Lake Mead | | |
|---|---|---|---|---|---|
| **Elevation (feet)** | **Operation According to the Interim Guidelines** | **Live Storage (maf)[1]** | **Elevation (feet)** | **Operation According to the Interim Guidelines** | **Live Storage (maf)[1]** |
| 3,700 | **Equalization Tier**<br>Equalize, avoid spills or release 8.23 maf | 24.3 | 1,220 | **Flood Control Surplus or Quantified Surplus Condition**<br>Deliver > 7.5 maf | 25.9 |
| 3,636 - 3,666 (2008-2026) | **Upper Elevation Balancing Tier**[3]<br>Release 8.23 maf; if Lake Mead < 1,075 feet, balance contents with a min/max release of 7.0 and 9.0 maf | 15.5 - 19.3 (2008-2026) | 1,200 (approx.)[2] | **Domestic Surplus or ICS Surplus Condition**<br>Deliver > 7.5 maf | 22.9 (approx.)[2] |
| | | | 1,145 | | 15.9 |
| | | | 1,105 | **Normal or ICS Surplus Condition**<br>Deliver ≥ 7.5 maf | 11.9 |
| 3,575 | **3,573.69** | 9.5 | **1,103.08** | | |
| | **1/1/14 Projection[1]** **Mid-Elevation Release Tier**<br>Release 7.48 maf; if Lake Mead < 1,025 feet, release 8.23 maf | | 1,075 | **1/1/14 Projection** **Shortage Condition**<br>Deliver 7.167[4] maf | 9.4 |
| 3,525 | | 5.9 | 1,050 | **Shortage Condition**<br>Deliver 7.083[5] maf | 7.5 |
| | | | 1,025 | | 5.8 |
| 3,490 | **Lower Elevation Balancing Tier**<br>Balance contents with a min/max release of 7.0 and 9.5 maf | 4.0 | 1,000 | **Shortage Condition**<br>Deliver 7.0[6] maf<br>Further measures may be undertaken[7] | 4.3 |
| 3,370 | | 0 | 895 | | 0 |

**Diagram not to scale**

[1] Acronym for million acre-feet

[2] This elevation is shown as approximate as it is determined each year by considering several factors including Lake Powell and Lake Mead storage, projected Upper Basin and Lower Basin demands, and an assumed inflow.

[3] Subject to April adjustments which may result in a release according to the Equalization Tier

[4] Of which 2.48 maf is apportioned to Arizona, 4.4 maf to California, and 0.287 maf to Nevada

[5] Of which 2.40 maf is apportioned to Arizona, 4.4 maf to California, and 0.283 maf to Nevada

[6] Of which 2.32 maf is apportioned to Arizona, 4.4 maf to California, and 0.280 maf to Nevada

[7] Whenever Lake Mead is below elevation 1,025 feet, the Secretary shall consider whether hydrologic conditions together with anticipated deliveries to the Lower Division States and Mexico is likely to cause the elevation at Lake Mead to fall below 1,000 feet. Such consideration, in consultation with the Basin States, may result in the undertaking of further measures, consistent with applicable Federal law.

[1] Lake Powell's projected elevation is based on an 8.23 maf annual release pattern from in water year 2014.

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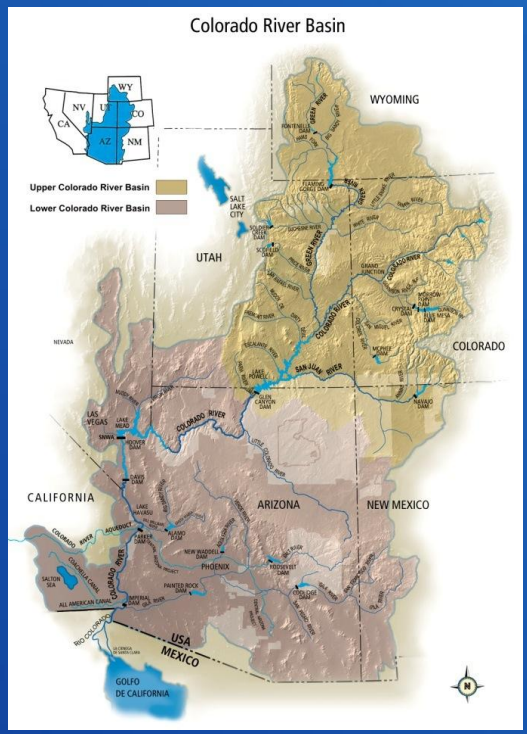
# Reclamation Operational Modeling Overview

- "Mid-Term" operations for the Colorado River
  - Operations of major reservoirs in the monthly to 2-year and beyond timeframe
- 2 operational models
  - 24-Month Study (deterministic, official)
  - Mid-Term Ops Model (probabilistic, additional analysis)

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# Mid-Term Operations Model

- Jan 2012 inaugural month of “production” modeling
- Based on 24-Month Study model
- Accommodates ensemble forecast rather than most probable inflow forecast
- Uses “rules” (prioritized logic) to set reservoir releases rather than manually set by operators

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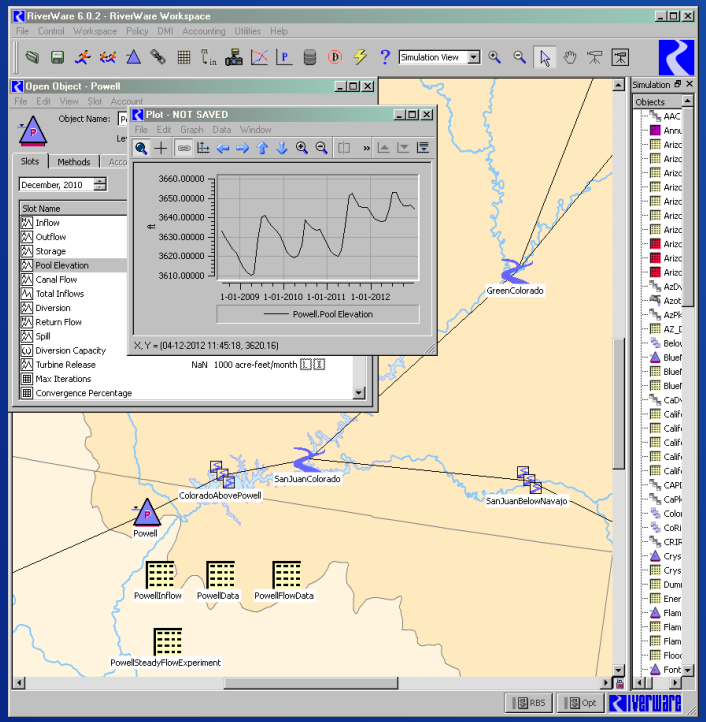
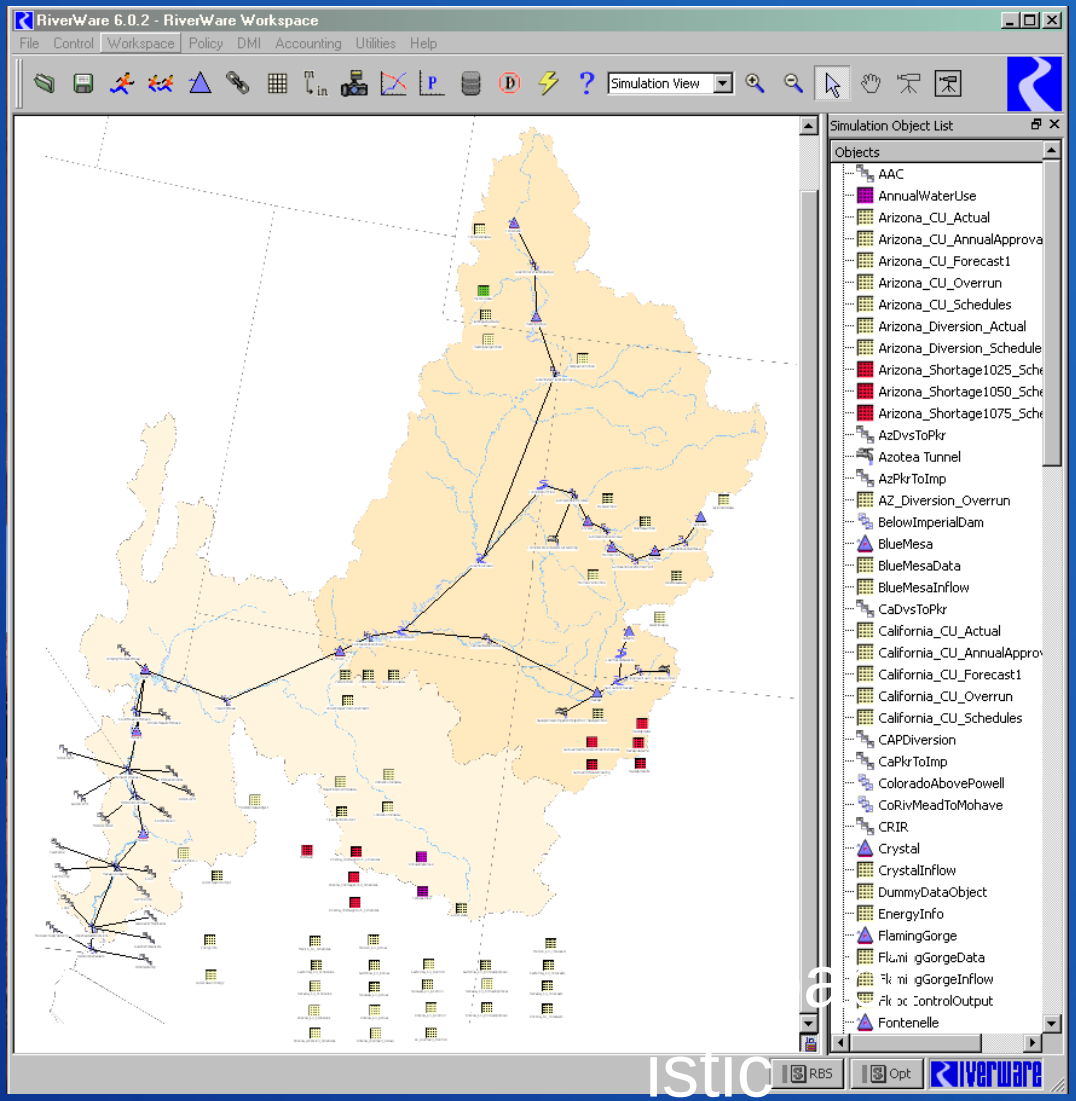
# Comparing 24-month Study approaches: Official versus MTOM

| Feature | Official | MTOM |
|---|---|---|
| Operational Model | simulates states given constraints + input hydrology forecast + input targets for reservoir water levels and releases | same, except that targets for reservoir water levels and releases are now simulated (emulating operators' sense) |
| Forecast Use | Applied using single or three trace members, limited by time to manually identify targets and also communication objectives | Applied using all ESP members, motivated by desire to better translate hydrologic forecast uncertainty into ops uncertainty |
| Outlook Information | Scenario-based by single trace member, transparent output, target setting is less transparent but best captures operators' sense | Probabilistic, aggregated across all members, more complex output, target setting is model-based and more transparent but captures limited set (hopefully most) of operators' sense |

# Mid-Term Operations Model

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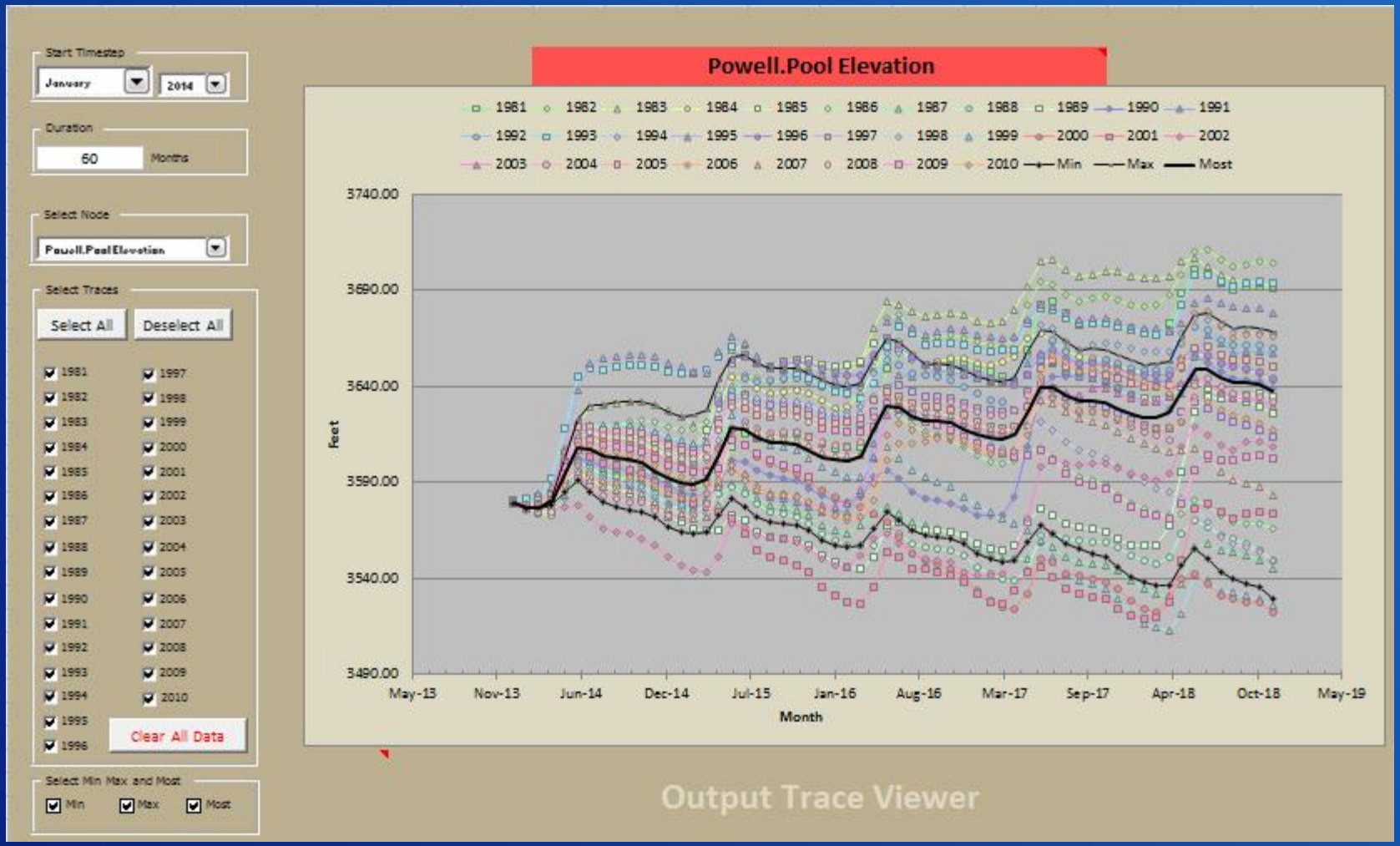
# Mid-Term Ops Model: Output Example

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# Percent of Traces Showing Occurrence of Event or System Condition

**Results from June 2014 MTOM Run (Values in percent)**

| | Event or System Condition | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|
| Upper Basin - Lake Powell | **Equalization Tier** | **0** | **27** | **37** | **37** | **37** | **37** |
| | *Equalization - annual release > 8.23 maf* | *0* | *27* | *37* | *37* | *37* | *37* |
| | *Equalization - annual release = 8.23 maf* | *0* | *0* | *0* | *0* | *0* | *0* |
| | **Upper Elevation Balancing Tier** | **0** | **73** | **60** | **40** | **40** | **43** |
| | *Upper Elevation Balancing - annual release > 8.23 maf* | *0* | *63* | *50* | *27* | *27* | *30* |
| | *Upper Elevation Balancing - annual release = 8.23 maf* | *0* | *10* | *10* | *13* | *13* | *13* |
| | *Upper Elevation Balancing - annual release < 8.23 maf* | *0* | *0* | *0* | *0* | *0* | *0* |
| | **Mid-Elevation Release Tier** | **100** | **0** | **3** | **23** | **20** | **17** |
| | *Mid-Elevation Balancing - annual release = 8.23 maf* | *0* | *0* | *0* | *0* | *3* | *7* |
| | *Mid-Elevation Balancing - annual release = 7.48 maf* | *100* | *0* | *3* | *23* | *17* | *10* |
| | **Lower Elevation Balancing Tier** | **0** | **0** | **0** | **0** | **3** | **3** |
| Lower Basin - Lake Mead | **Shortage Condition - any amount (Mead <= 1,075 ft)** | **0** | **0** | **23** | **40** | **40** | **33** |
| | *Shortage - 1st level (Mead<= 1,075 and >= 1,050)* | *0* | *0* | *23* | *37* | *30* | *10* |
| | *Shortage - 2nd level (Mead<1,050 and >= 1,025)* | *0* | *0* | *0* | *3* | *7* | *13* |
| | *Shortage - 3rd level (Mead< 1,025)* | *0* | *0* | *0* | *0* | *3* | *10* |
| | **Surplus Condition - any amount (Mead >= 1,145 ft)** | **0** | **0** | **0** | **10** | **20** | **33** |
| | *Surplus - Flood Control* | *0* | *0* | *0* | *0* | *3* | *3* |
| | **Normal or ICS Surplus Condition** | **100** | **100** | **77** | **50** | **40** | **33** |

Short-term Water Management Context:

Interconnected Decisions that (1) address different objectives, (2) occur at different time-resolutions, (3) are updated on different cycles.

**Fine Resolution**
(Duration: hours to days)

- Objectives addressed at this Resolution: emergency response, flood risk management, hydropower, navigation

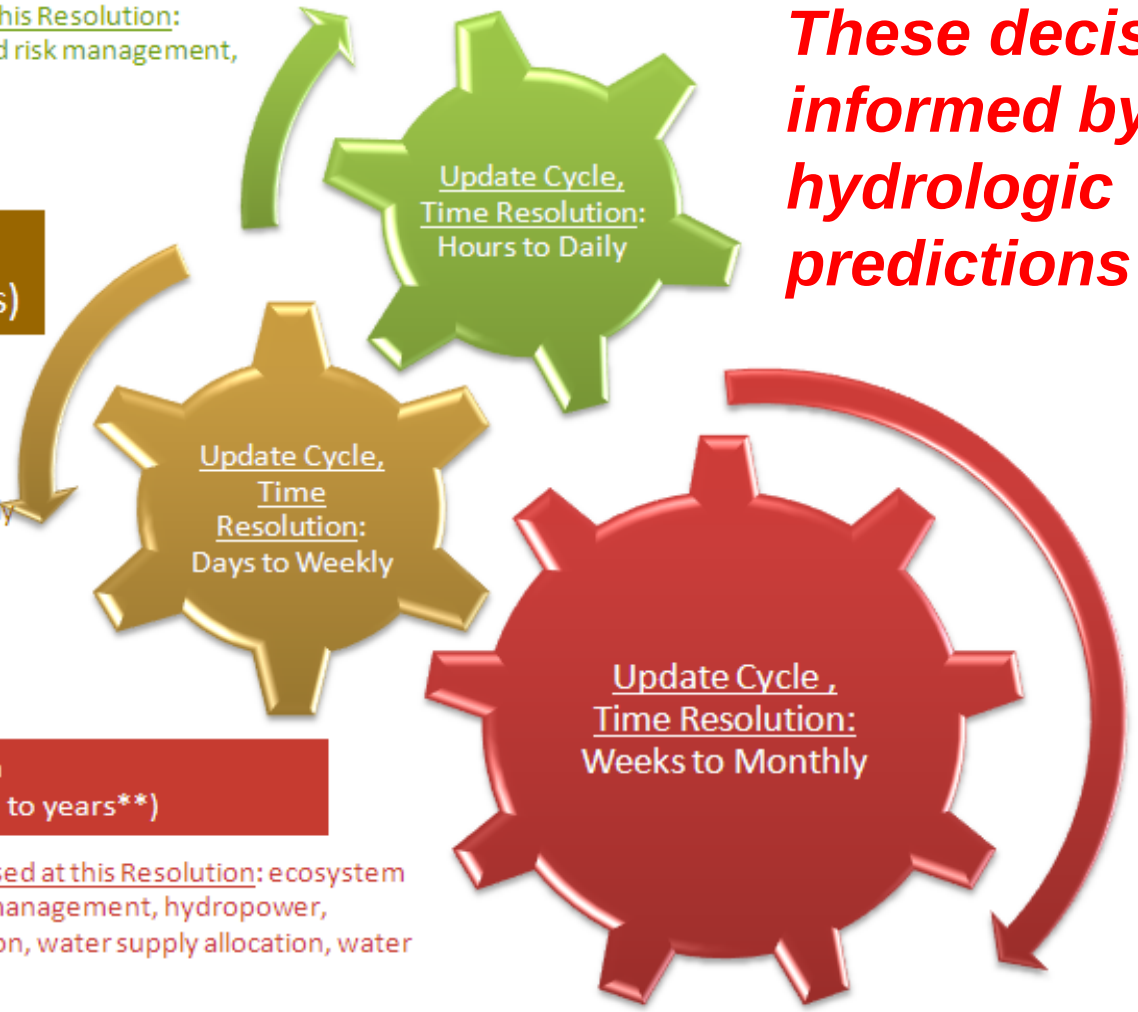
**Medium Resolution**
(Duration: days to weeks)

- Objectives addressed at this Resolution: ecosystem support, emergency response, flood risk management, hydropower, navigation, recreation, water supply conservation (e.g., snowmelt management), water delivery

**Coarse Resolution**
(Duration: seasons to years**)

- Objectives addressed at this Resolution: ecosystem support, flood risk management, hydropower, navigation, recreation, water supply allocation, water delivery

** Most systems prepare outlooks having a duration of one-year or less.




***These decisions are informed by a suite of hydrologic predictions***

http://www.ccawwg.us/docs/Short-Term_Water_Management_Decisions_Final_3_Jan_2013.pdf

# (FY 13-15 Project) “The Predictability of Streamflow across the contiguous United States”

Partners: NCAR Research Applications Laboratory, USACE Institute of Water Resources, Reclamation Science and Technology Program, http://www.usbr.gov/research/docs/updates/2013-20-streamflow-predictions.pdf

Study Components

1. Establish nationwide assessment platform of calibrated watershed models
2. Assess and understand streamflow predictability and uncertainty at weather to climate time scales
3. Evaluate state of the science for modeling and prediction techniques that can improve streamflow prediction (e.g., multi-model, data assimilation, forecast bias-correction)
4. Relate research to case studies for a range of water resources applications

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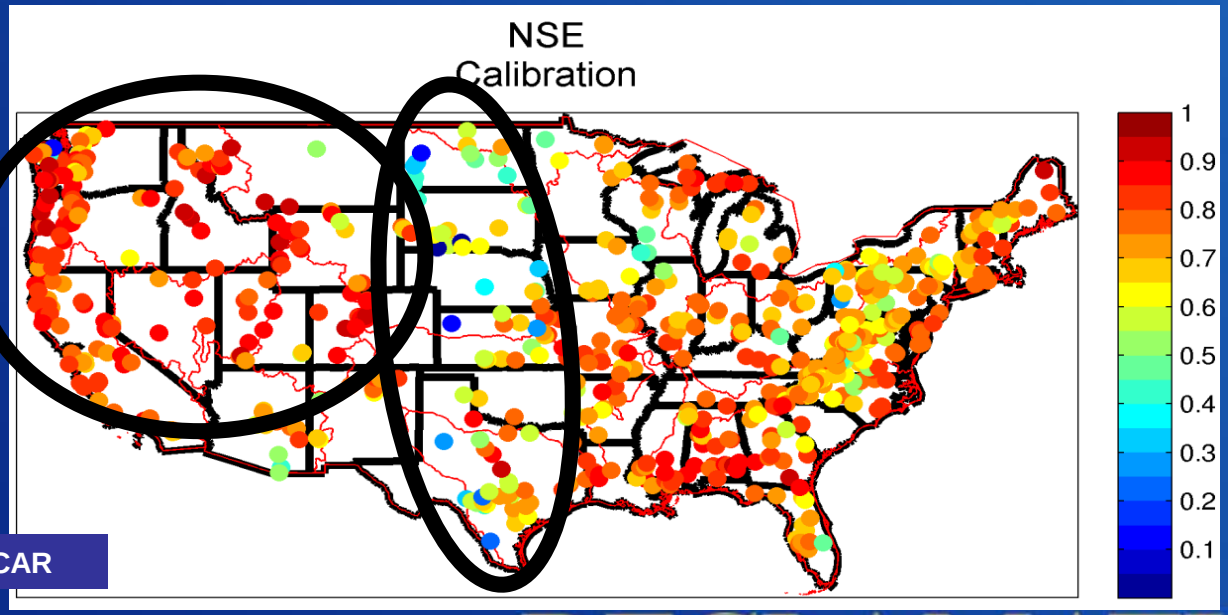
# Building a Nationwide Assessment Platform

- Initial Platform: single model, single parameterization … Highlights
  - 670 basins, SacSMA/Snow17 applications, late 20th century calibration
  - Areas with seasonal snow, frequent precipitation perform best in terms of NSE; High plains and desert SW perform worse
- Future Plans: multi-model, multi-parameterization, support evaluation of forecast improvement strategies
- More information:
  - Newman et al. 2014 (http://www.hydrol-earth-syst-sci-discuss.net/11/5599/2014/hessd-11-5599-2014.html)




**Courtesy: Andy Newman, NCAR**

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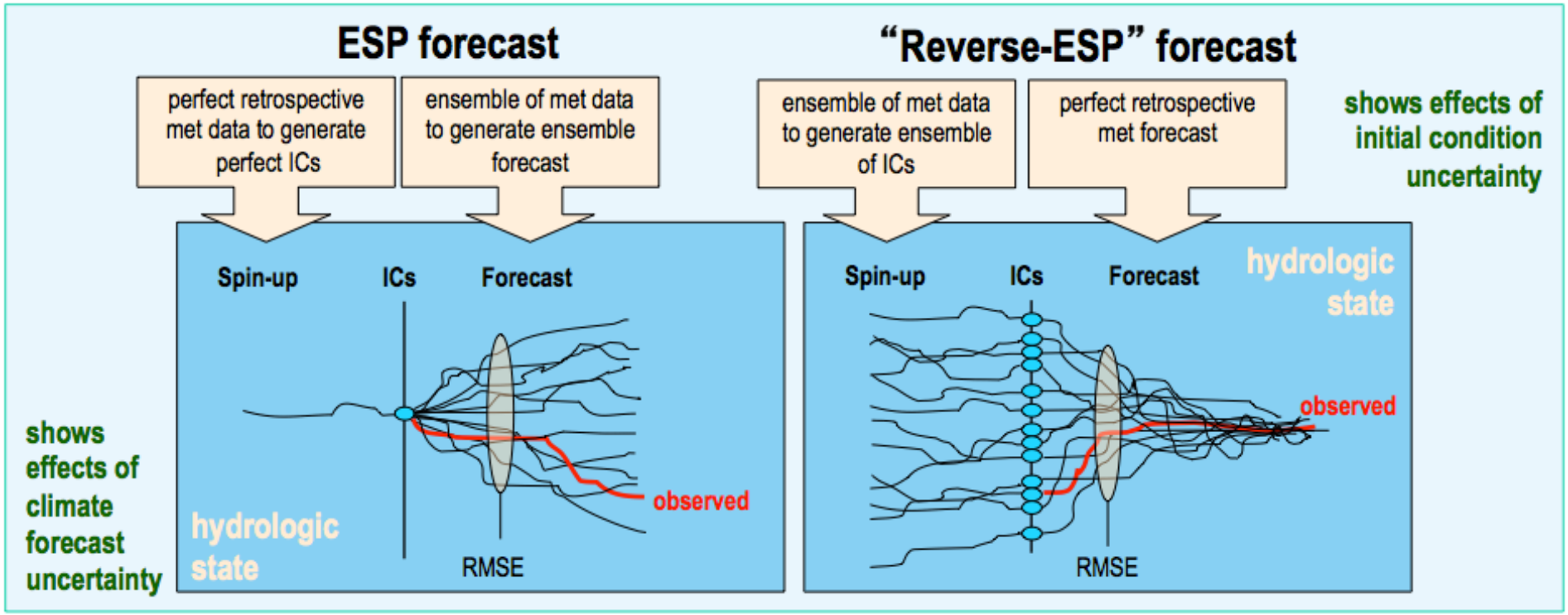
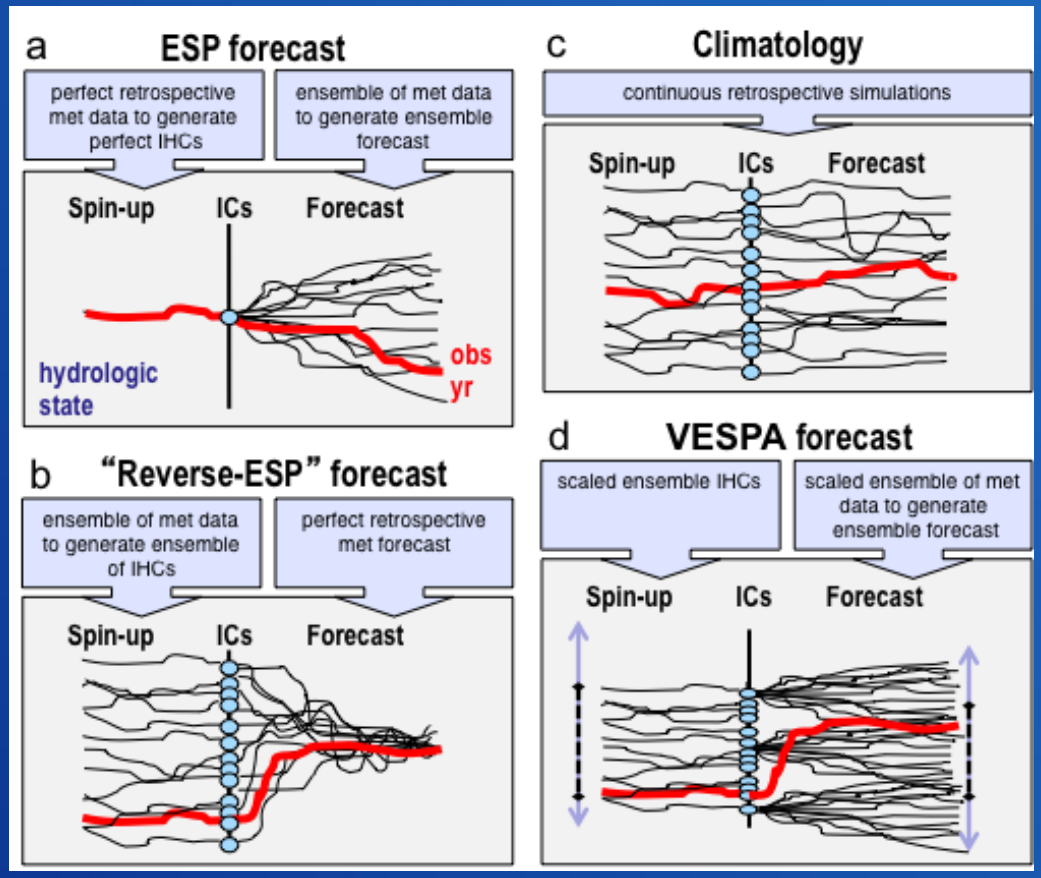
# Applying platform to assess predictability…

- Motive:  Where can we get most bang for the buck? Invest in better met forecasts or better basin monitoring to improve initial condition estimates?
- ESP used to explore two sources of uncertainy (Wood et al. 2008):
  - Met forcing uncertainty assuming known initial conditions (ICs) (*traditional*)
  - IC uncertainty assuming known forcing (“Reverse-ESP”)



# …considering range of potential skills

- Knowing IC or Met Forcing during forecast period is unrealistic
- VESPA approach
  - *Wood et al. 2014, in prep*
  - Scale IC and Met Forecast variance (uncertainty) between
    - 0 = perfect knowledge
    - 1 = climatology (no current knowledge for IC, no future knowledge for Met)
  - Assess flow forecast skill for all combinations (81) of scalings:
    - 0, 0.05, 0.10, 0.25, 0.50, 0.75, 0.90, 0.95, 1.00

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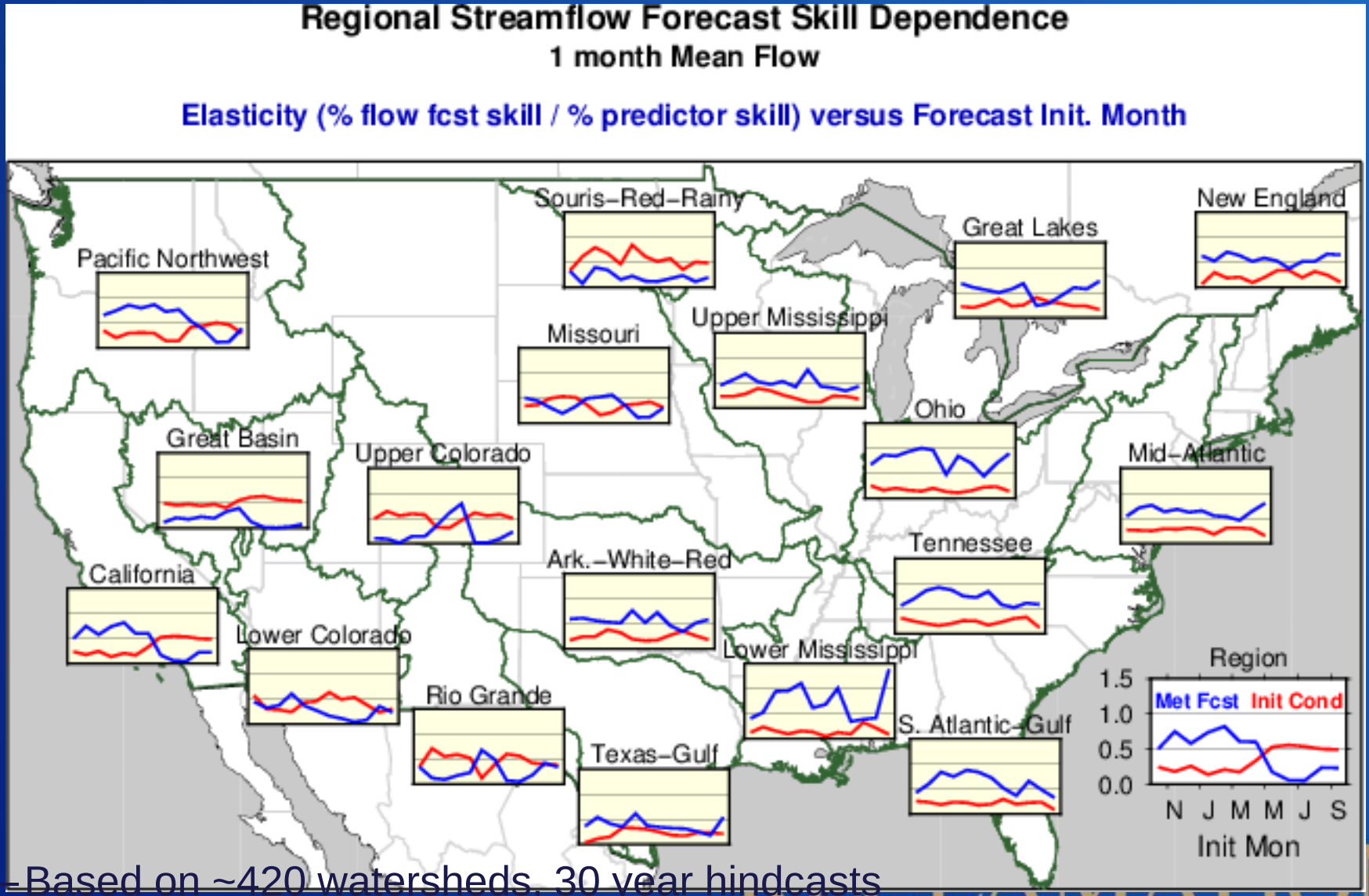
# Regional variations, 1-month forecasts




- Based on ~420 watersheds, 30 year hindcasts

# Regional variations, 6-month forecasts