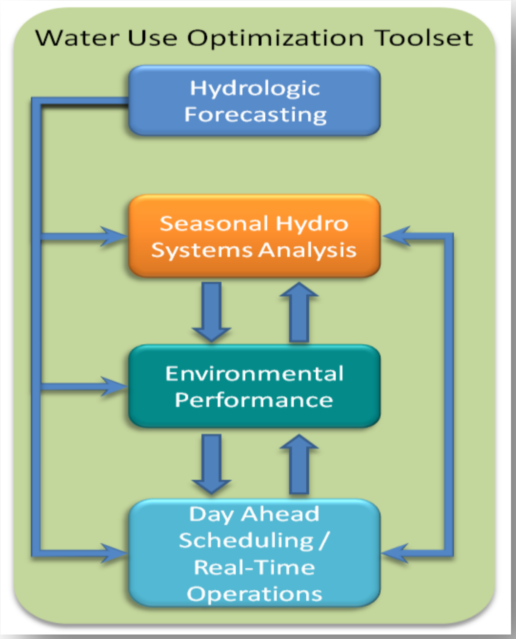
Cost of Inflow Forecast Uncertainty for Day Ahead Hydropower Production Scheduling



HEPEX 10th University Workshop

June 25th, 2014

NOAA Center for Weather and Climate

Thomas D. Veselka and Les Poch

Argonne National Laboratory

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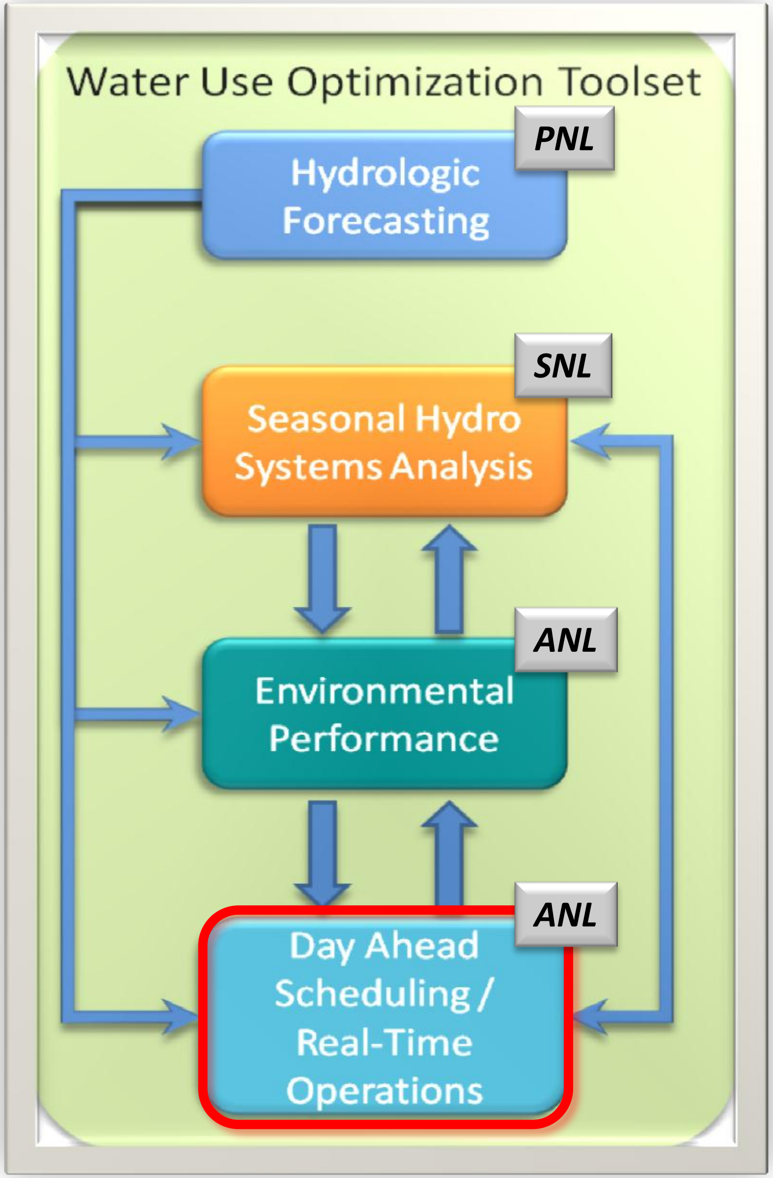
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy | Water Power Program

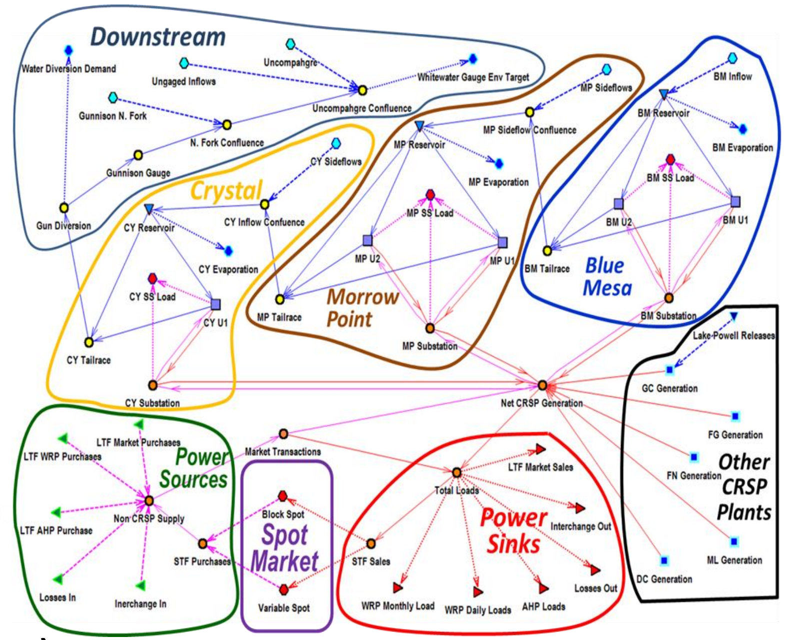
Project Background Information

- **The DOE Water Power Program is funding the development and deployment of the Water Use Optimization Toolset (WUOT)**
  - Multi-lab effort (ANL,PNL, SNL)
  - Contains several integrated components
  - Objective: Produce more power with the same amount of water
- The day-ahead scheduling and real-time operations tool is named ***C**onventional **H**ydropower **E**nergy and **E**nvironmental **S**ystems* (CHEERS)
- **CHEERS Simultaneously optimizes power and environmental objectives**
  - **Power:** Maximize the value of energy production and ancillary services
  - **Environment:** Enhance habitats and improve river functionality
  - **Granularity:** 5 minute to 1 hour time step for 1 to 7 days at the generating unit level



CHEERS Framework

Application: <u>Aspinall Cascade</u> of the Salt Lake City Area Integrated Projects



- **Describes a system as a network of objects**
  - Commodity (water & power) flows
  - Boundary nodes (inflows)
  - Storage nodes (reservoir)
  - Conversion nodes (turbine/generator)
  - Junction nodes (confluence)
  - Links (river, canal, power transport)
- **Creates schedules - when, where & how much**
  - Water release from storage
  - Power generation
  - Ancillary services (regulation, spin, & non-spin)

Historical → ***Real-time and pre-schedule*** → ***Forecast*** → ***Extension***

- **Describes functionality and applies rules**
  - For individual objects, groups of objects, and/or the whole system
  - For individual time steps or over specified time periods

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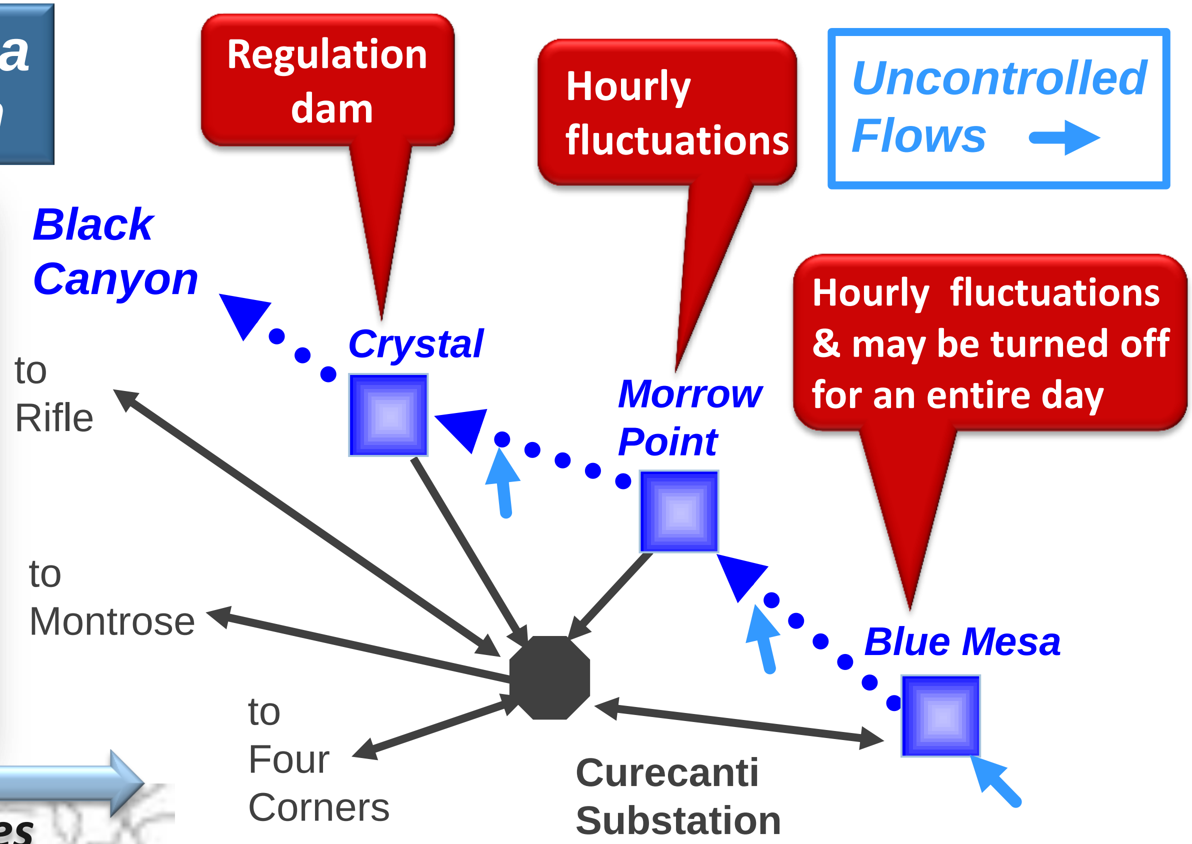
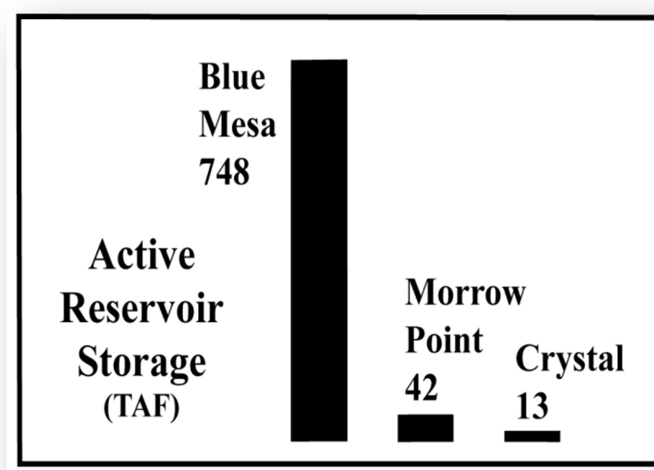
The Aspinall Cascade Is a Tightly Coupled System

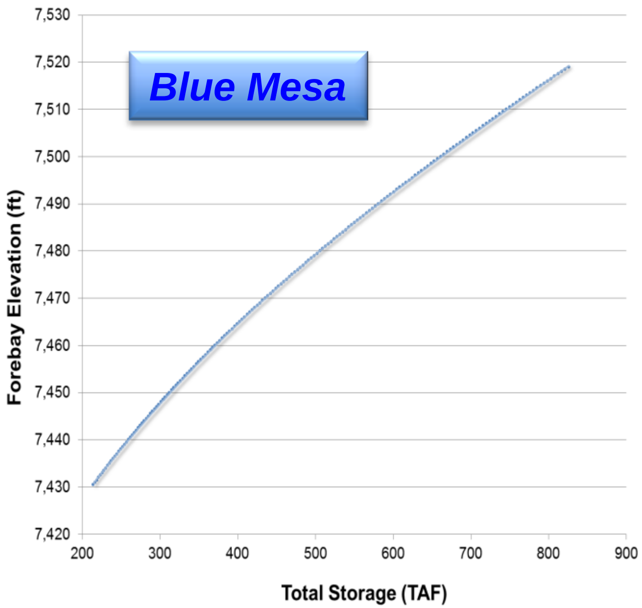


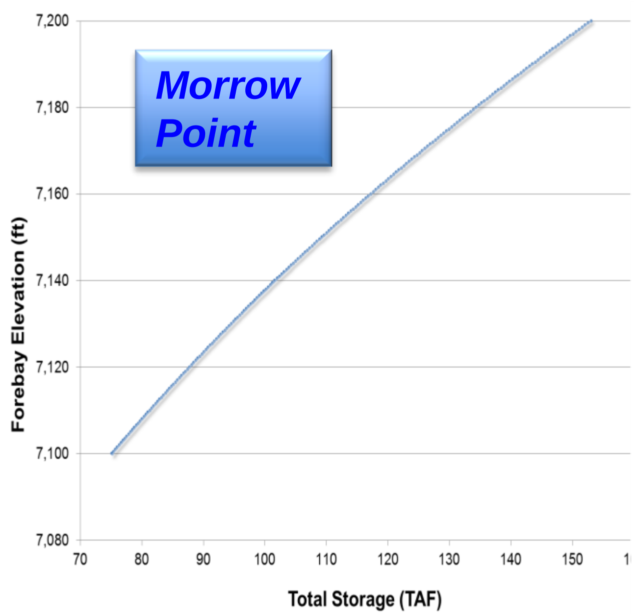


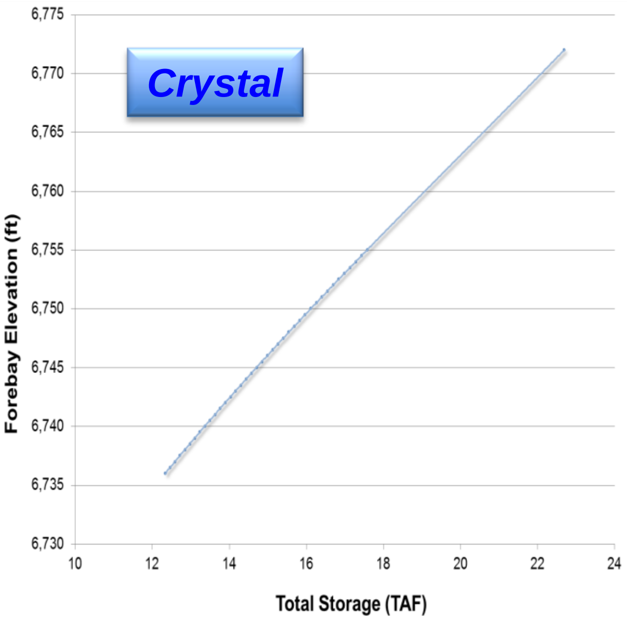
Aspinall Operating Limits Restrict Power Plant Operations

- **Blue Mesa**
  - Maximum elevation
  - Minimum elevation
- **Morrow Point**
  - Seasonal minimum elevations
  - Maximum elevation
- **Crystal**
  - Maximum elevation
  - Minimum elevation
  - Seasonal daily elevation change limit as a function reservoir state
  - Seasonal multiple day change limits

	Blue Mesa		Morrow Point		Crystal				
Month	Minimum Elevation (ft)	Maximum Elevation (ft)	Minimum Elevation (ft)	Maximum Elevation (ft)	Minimum Elevation (ft)	Maximum Elevation (ft)	Max Daily Change (ft)	Elev (ft) for 0.5 ft/Day Change	3-Day Elevation Change (ft)
Jan	7,393.0	7,519.4	7,143	7,160	6,739	6,760	10	6,733	15
Feb	7,393.0	7,519.4	7,143	7,160	6,739	6,760	10	6,733	15
Mar	7,393.0	7,519.4	7,143	7,160	6,739	6,760	4	6,748	6
Apr	7,393.0	7,519.4	7,143	7,160	6,739	6,760	4	6,748	6
May	7,393.0	7,519.4	7,143	7,160	6,739	6,760	4	6,748	6
Jun	7,393.0	7,519.4	7,151	7,160	6,739	6,760	4	6,748	6
Jul	7,393.0	7,519.4	7,151	7,160	6,739	6,760	10	6,733	15
Aug	7,393.0	7,519.4	7,151	7,160	6,739	6,760	10	6,733	15
Sep	7,393.0	7,519.4	7,151	7,160	6,739	6,760	10	6,733	15
Oct	7,393.0	7,519.4	7,143	7,160	6,739	6,760	10	6,733	15
Nov	7,393.0	7,519.4	7,143	7,160	6,739	6,760	10	6,733	15
Dec	7,393.0	7,519.4	7,143	7,160	6,739	6,760	10	6,733	15





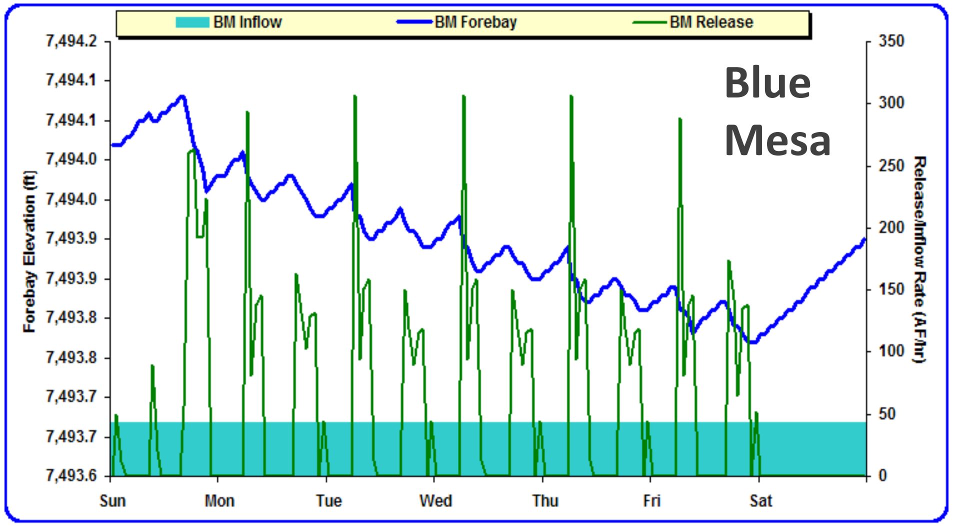


Typical Day Ahead Deterministic Result

- **Blue Mesa**
  - Capacity of 86.4 MW (2 units)
- **Morrow Point**
  - Capacity of 173.4 MW (2 units)
- **Crystal**
  - One unit with a capacity of 28 MW

Daily Inflow

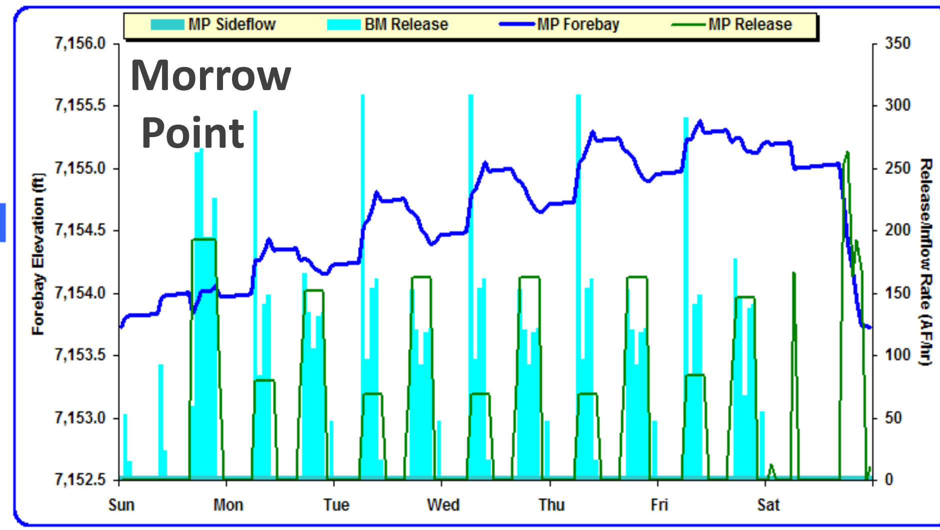
7,233



8,167

467

Daily Side Flows

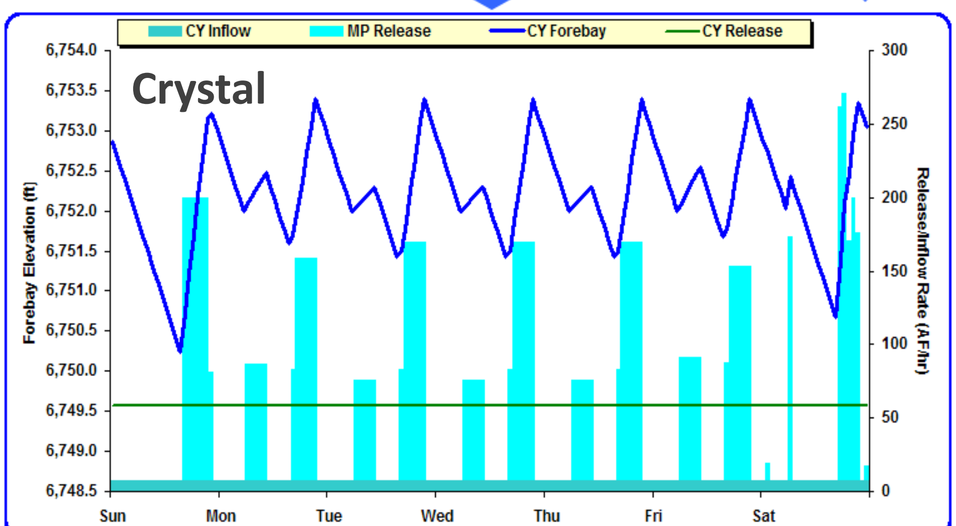


Morrow Point	
In (AF)	8,633
Out (AF)	8,633
Elev Diff (ft)	0.0000

8,633

1,167

Daily Side Flows

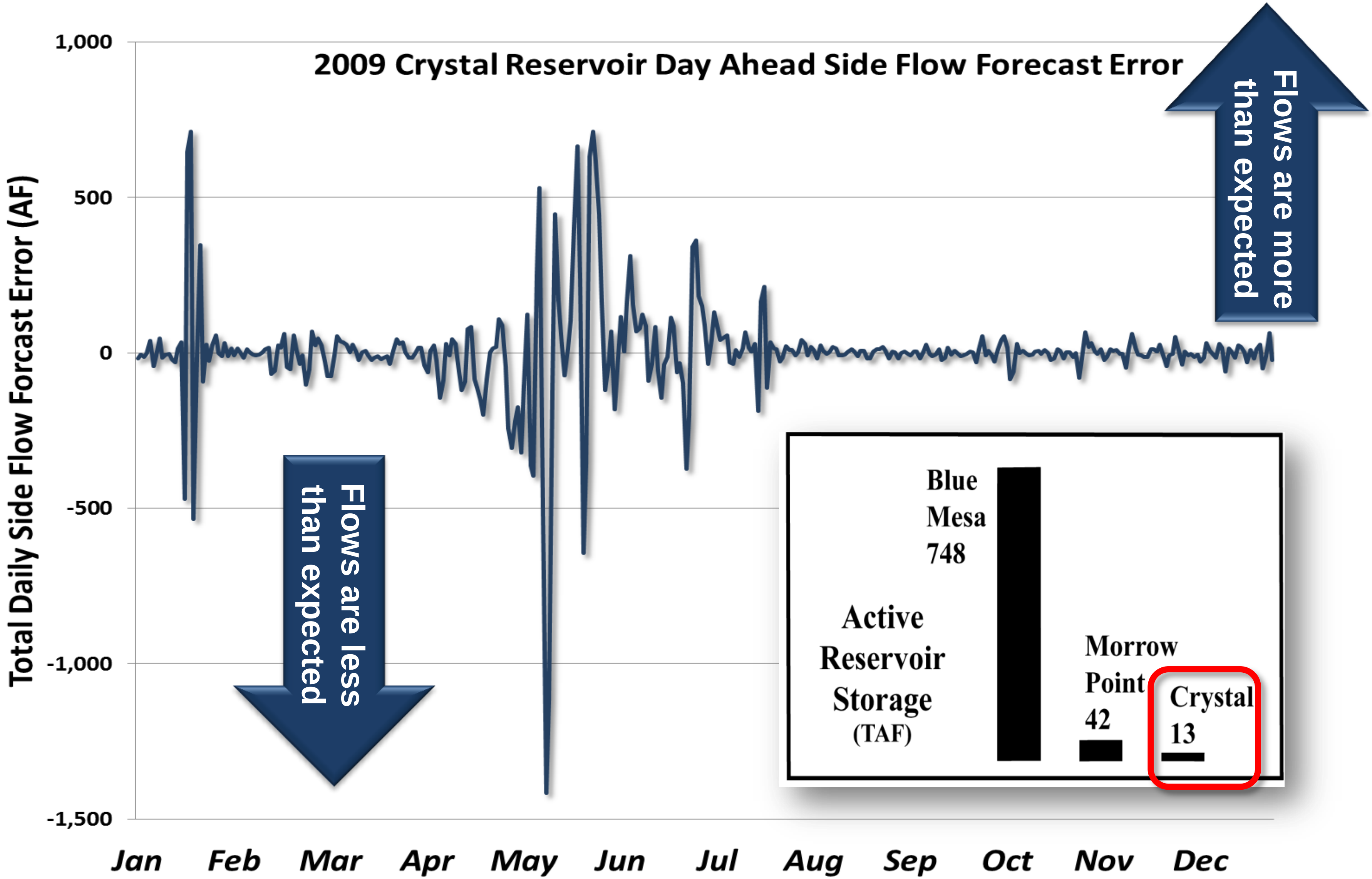


Crystal	
In (AF)	9,800
Out (AF)	9,800
Elev Diff (ft)	0.1800

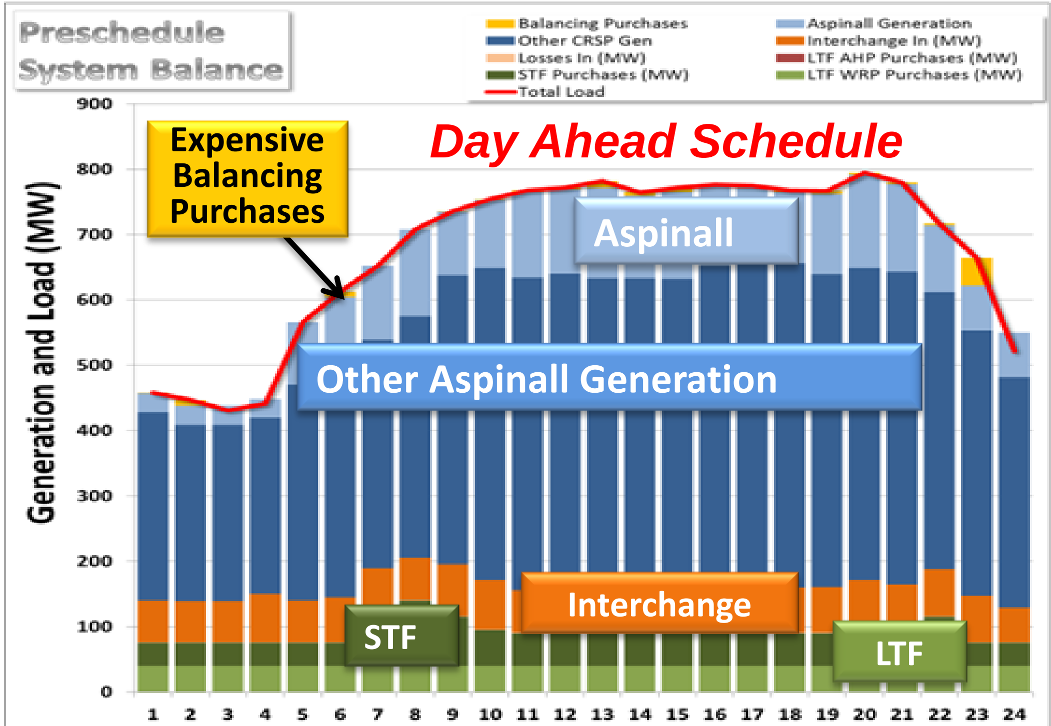
9,800

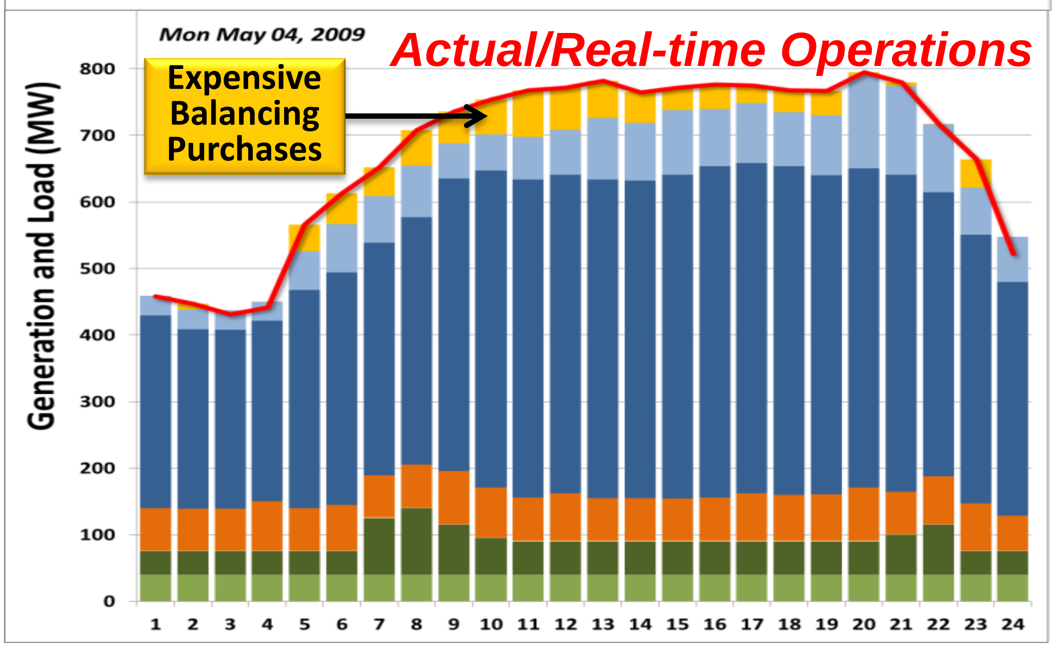
	Crystal				
	Max Elevation (ft)	Min Elevation (ft)	Daily Elevation Change (ft)	3-Day Change (ft)	
Sun	6,753.2	6,750.2	3.0		1
Mon	6,753.4	6,751.6	1.8		2
Tue	6,753.4	6,751.4	2.0	3.2	3
Wed	6,753.4	6,751.4	2.0	2.0	4
Thu	6,753.4	6,751.4	2.0	2.0	5
Fri	6,753.4	6,751.7	1.7	2.0	6
Sat	6,753.4	6,750.7	2.7	2.7	7
Week	*6,753.4*	*6,750.2*	*3.0*	*3.15*	
Change	*3.2*		*Max Daily*	*Max 3-Day*	

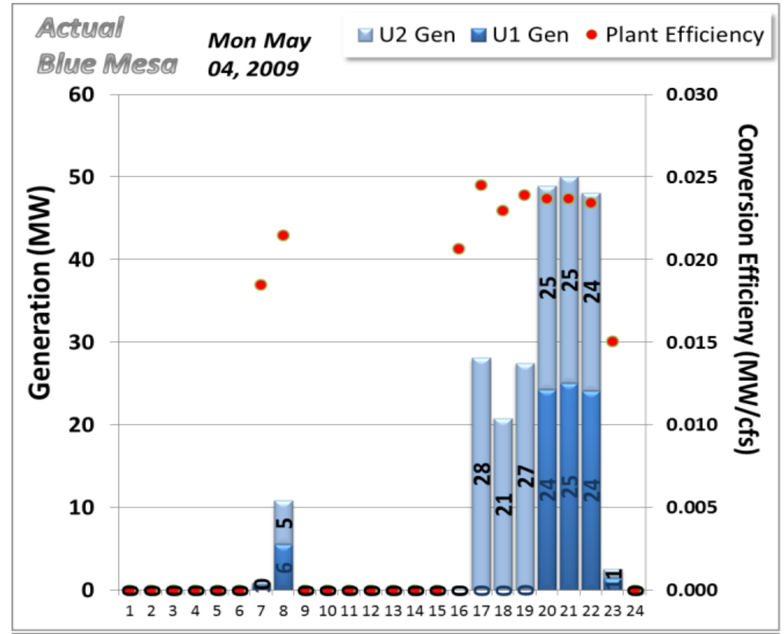
Power Schedulers Currently Use Persistence to Forecast Short-term Aspinall Side Flows

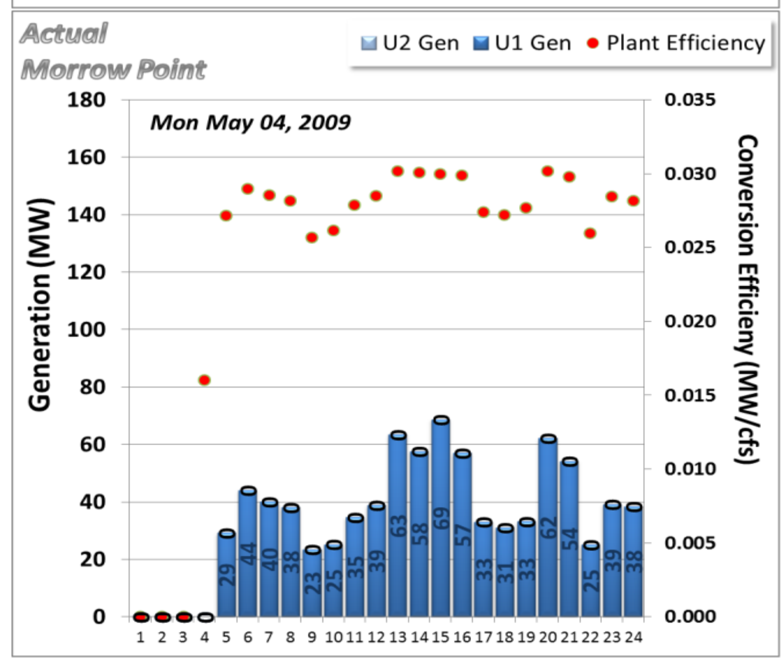


Inaccurate May 4th Forecast









Inflow and Side Flow Forecast Error Computations

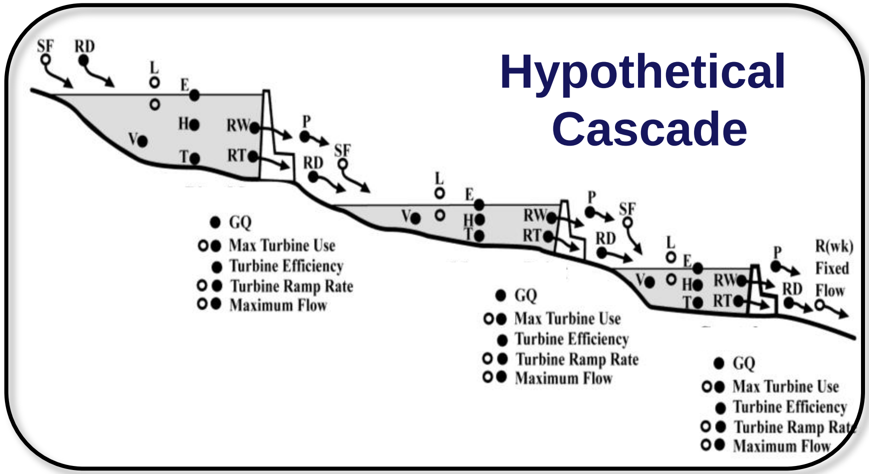
Assume persistence forecasting

- Flows tomorrow and thereafter will be identical to yesterday

Use historical data

- Hourly data for the years 1999 through 2010
- Cascade reservoir elevations
- Power and non-power water releases and reservoir elevations

Uncontrolled inflows into the top reservoir and side flows between reservoirs are based on a water mass balance equation and water storage volume-to-elevation curves



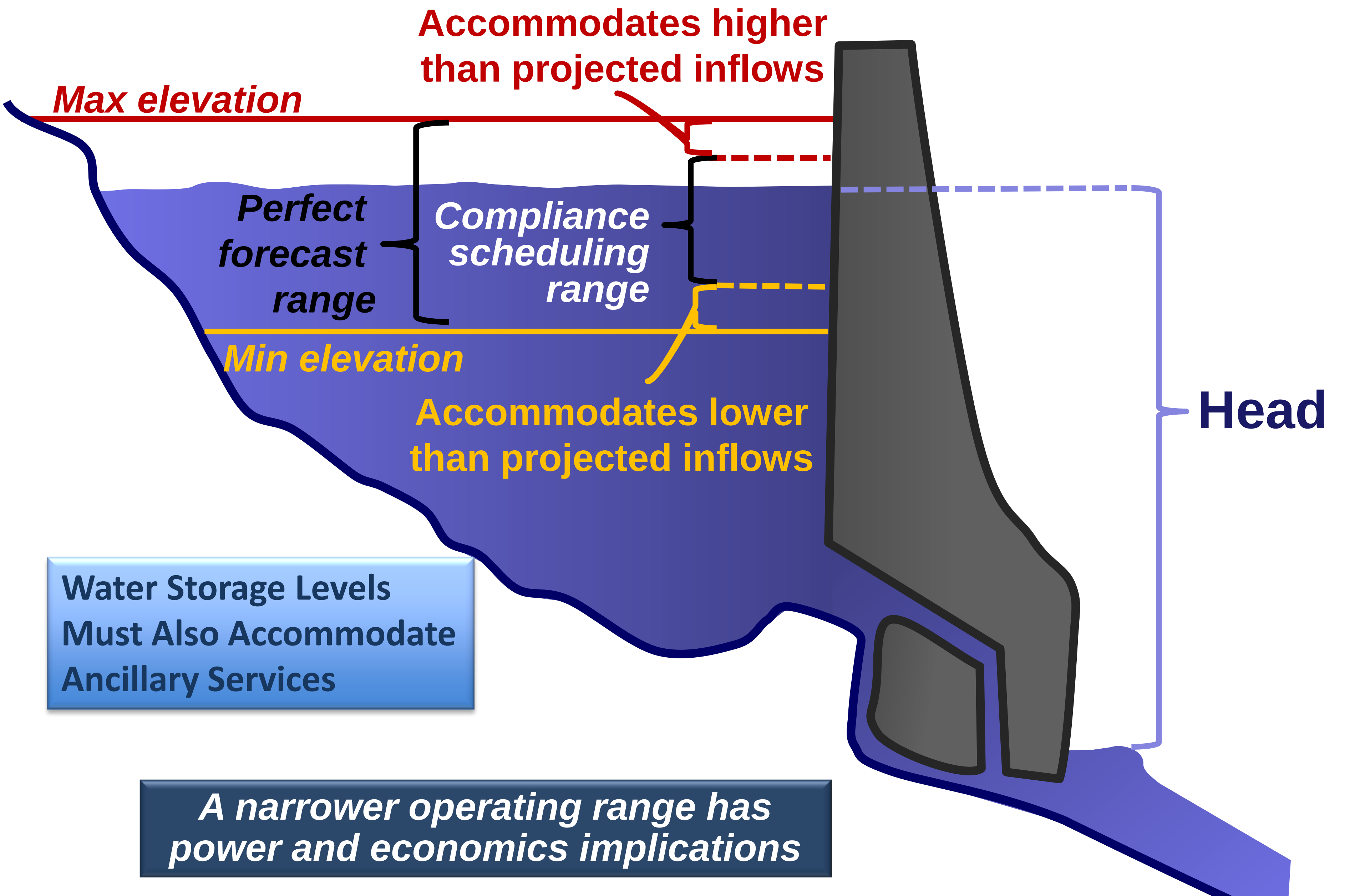
Challenges

- Water release rate measurement error
- Reservoir elevation measurement error
- Accuracy of volume-to-elevation curves

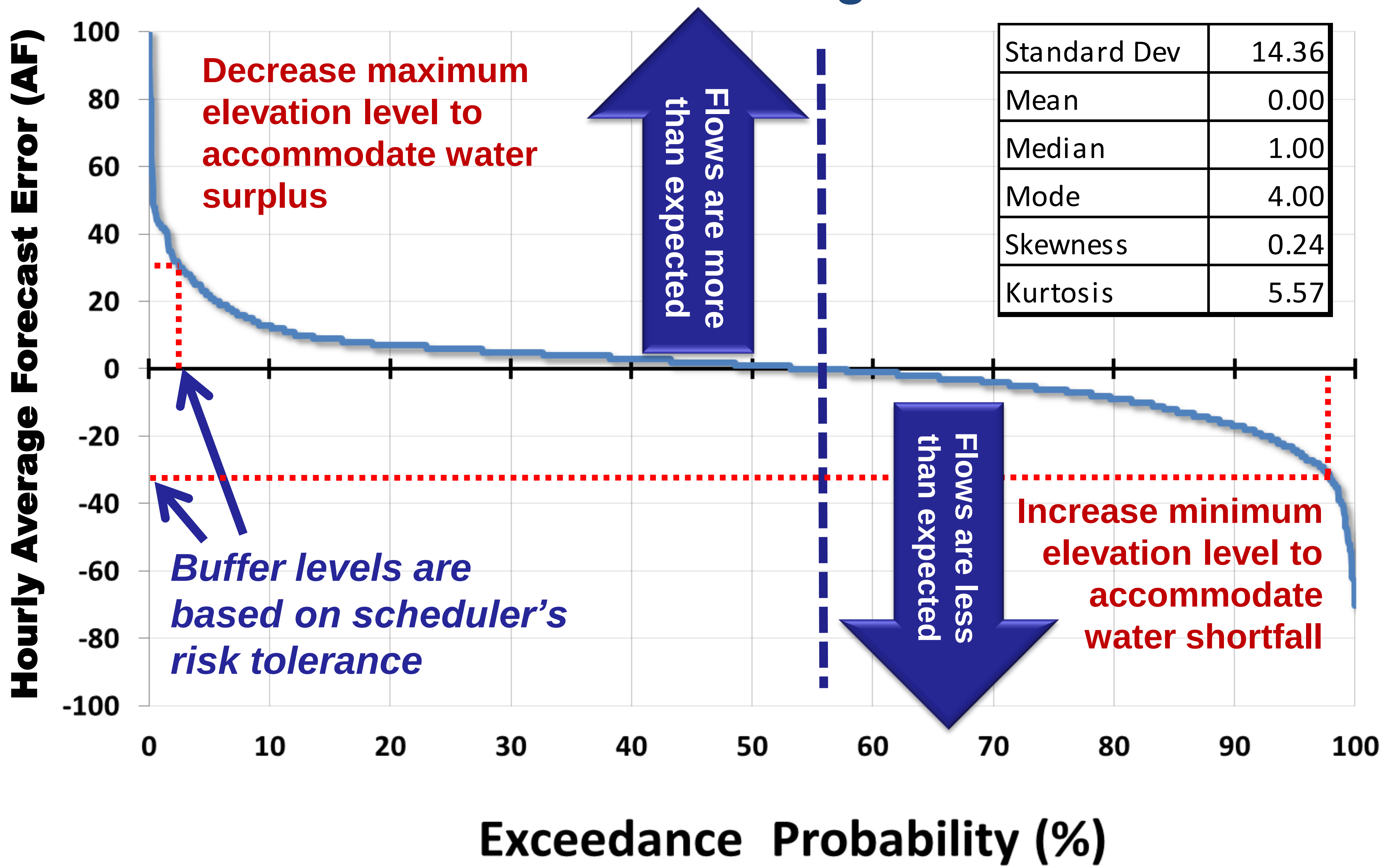
Eventually switch to the WUOT Hydrologic Forecasting tool

- Shows promise to reduce daily forecast error

CHEERS Uses Buffers to Reduce Reservoir Violations Associated with Inflow Forecast Error



Crystal Water Side Flow Forecast Errors Are Used to Estimate Water Storage Buffer



One Statistical Distribution *DOES NOT* Fit all Situations

Seasonal differences: monthly distributions

- Forecast errors in Spring tend to be the highest
- Winter has the most reliable forecast

Time of day during Spring: night versus day

- Forecast errors in mid to late afternoon are relatively high
- Nighttime forecasts are more reliable

Error distributions are dependent on current conditions

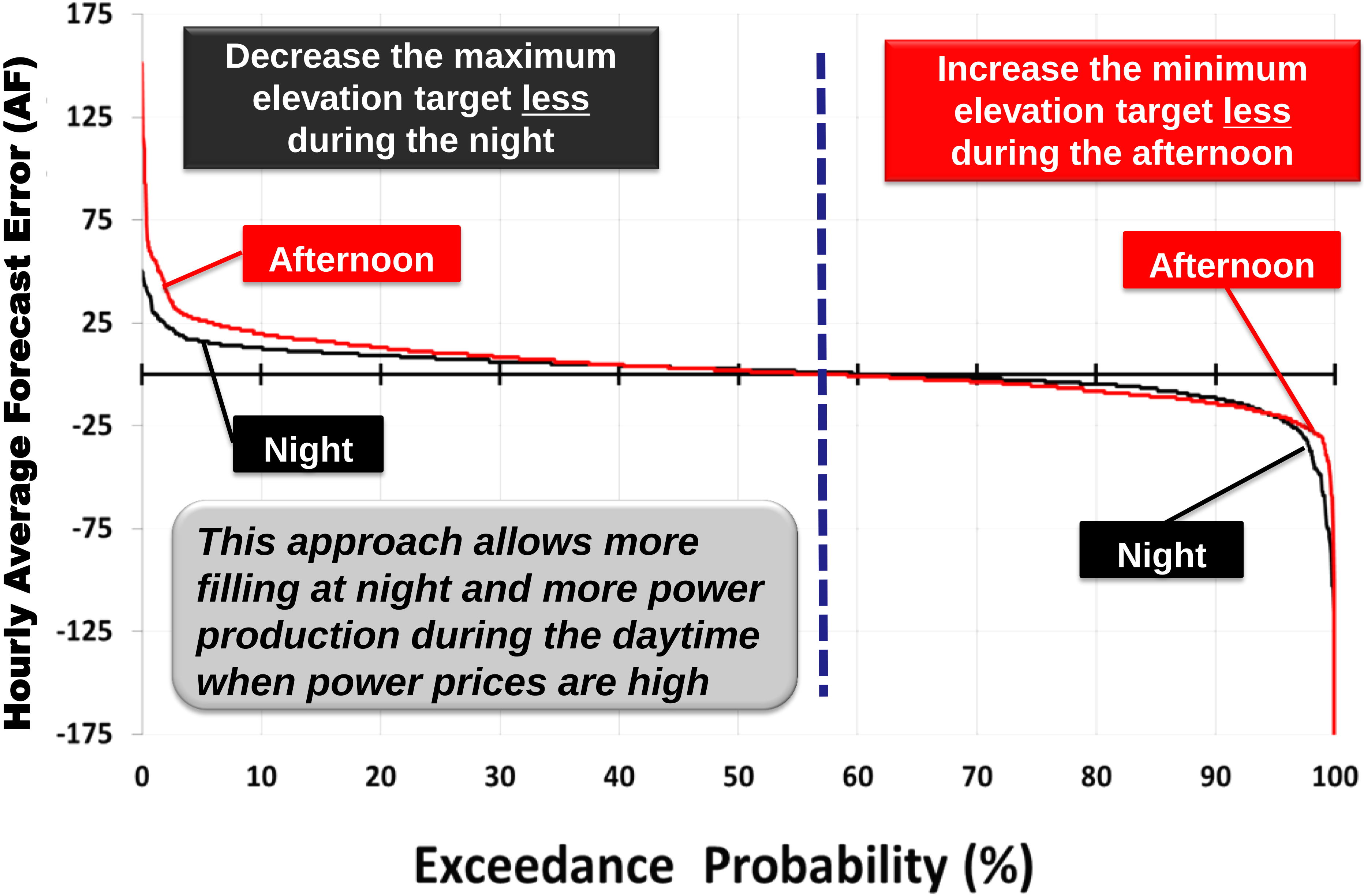
- Low inflow conditions tend to have positively skewed distribution
- High inflow conditions tend to have negatively skewed distribution

Errors increase with longer projection time

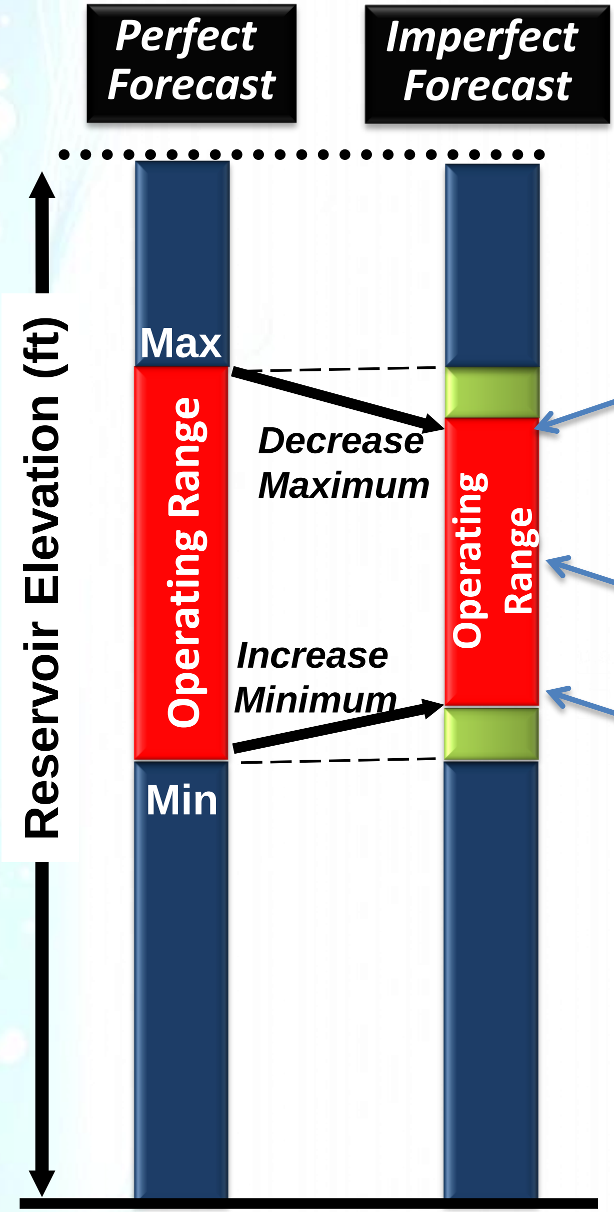
- Day-ahead scheduling may be up to 4 days or more in advance

Summer thunderstorms occasionally result in large inflow under predictions

Separating Data into Different Classes Yields Better Schedules



Summary of Economic Impacts on Power



High Reservoir Condition

- Higher power production during low priced hours results in lower on-peak generation
- Sales of regulation down are reduced or eliminated
- Down-side generation potential is reduced, limiting responses to increases in variable resource (i.e., wind and solar) output

Middle Reservoir Condition

- Forecast error has relatively little or no impact

Low Reservoir Condition

- Lower maximum power production
- Less power may be produced during the most valuable periods
- Potential sales of regulation up and contingency reserve services are reduced
- Up-side generation potential is reduced limiting responses to reductions in variable resource output

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