Colorado Basin River Forecast Center

2017 Water Supply
Verification / Year in Review

November 14th 2017

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Sr. Hydrologist

Please mute your phone until ready to ask a question - Thank You

2017 Water Supply Review / Verification Webinar

Why Do Verification?

It's a path to improvement
Reviewing the season helps us know where to focus efforts

Primary sources of error in the forecast:

Future weather (largest uncertainty and impact)
- Hydrology model uses climatology going forward
- Extreme future weather results in largest forecast errors

Data Issues (impact model states such as snowpack)
- Bad data quality, non-functioning gages, network outages
- Data availability, network density

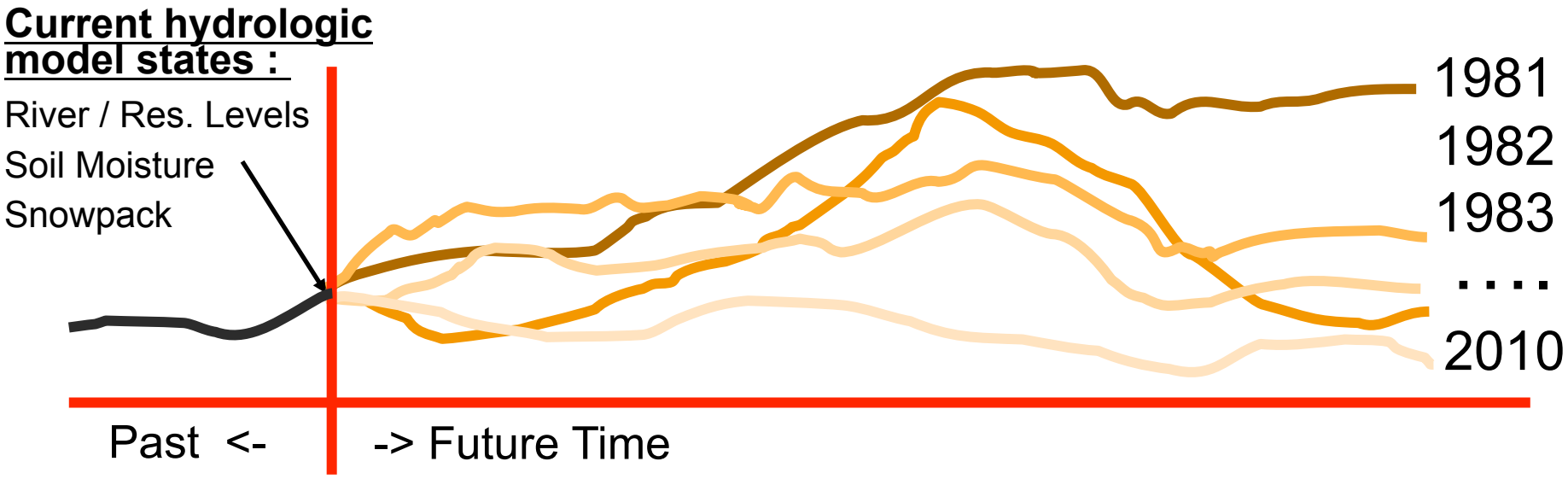
Model calibration limitations
- Quality / availability of historical data
- Unknown / Ungaged Diversions
- Changes in the river basin

2017 Water Supply Review / Verification Webinar

- Understanding the forecasts – what are we providing?
- Weather recap – primary impacts to the 2017 runoff
- Forecasts and verification for key sites – basin highlights
- Summary / Conclusion & the next steps toward improvement

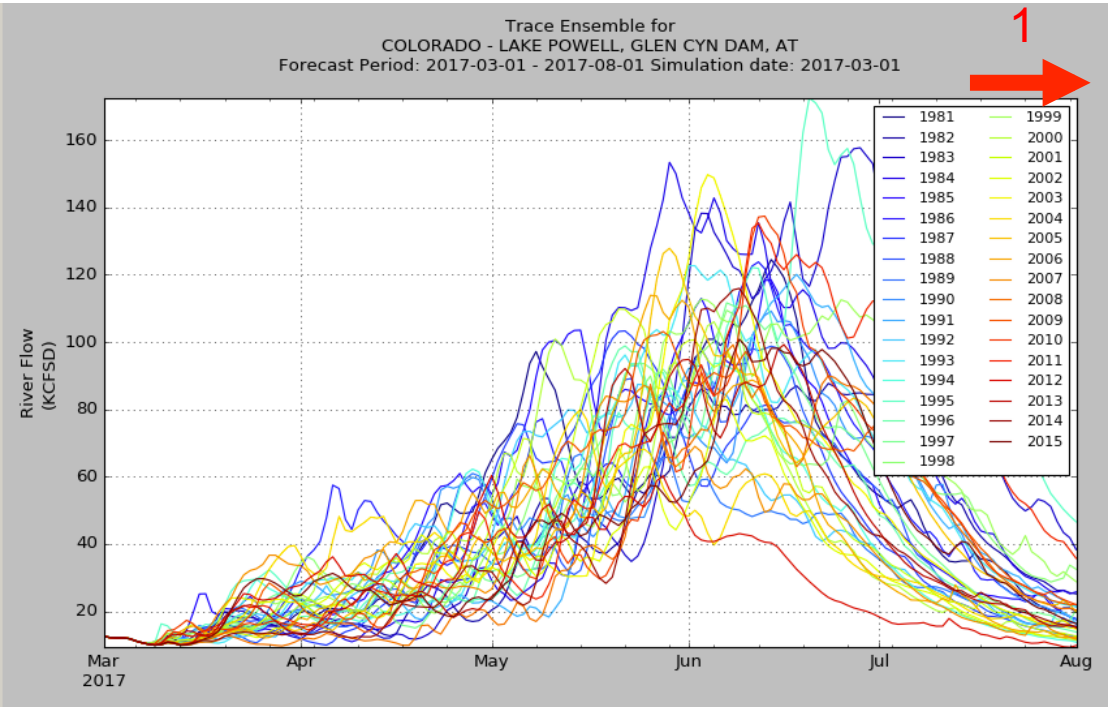
Probabilistic Forecasts

- Start with current conditions of streamflow, soil moisture, snowpack
- Apply precipitation and temperature from each historical year used in model calibration (1981-2015) from current date into the future.
- A forecast is generated for each of the years (1981-2015) *as if, going forward,* that year will happen
- This creates 35 possible future streamflow patterns. Each year is given a 1/35 chance of occurring



Ensemble Prediction System (ESP) - **Probabilistic Forecasts**

March 1st 2017 Forecast Guidance for Lake Powell



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Emperical Sample Points:
Period: 2017-04-01 - 2017-07-31

	UnReg
1981	13845.79
1982	11985.36
1983	17009.89
1984	15658.50
1985	14717.33
1986	14516.88
1987	11884.92
1988	11507.81
1989	9305.36
1990	13012.86
1991	12754.98
1992	11374.14
1993	14058.69
1994	11226.87
1995	18056.13
1996	10919.53
1997	12301.95
1998	13181.66
1999	14866.12
2000	11787.64
2001	12272.80
2002	9047.87
2003	12312.83
2004	10015.99
2005	12868.08
2006	12099.64
2007	10140.51
2008	10826.36
2009	13564.96
2010	12796.12
2011	16158.94
2012	7892.50
2013	11167.89
2014	10518.40
2015	11621.66

2

Period: 2017-04-01 - 2017-07-31

	UnReg
90%	9731.74
80%	10844.99
70%	11344.69
60%	11826.55
50%	12272.80
40%	12779.66
30%	13258.32
20%	14425.24
10%	15858.68

3

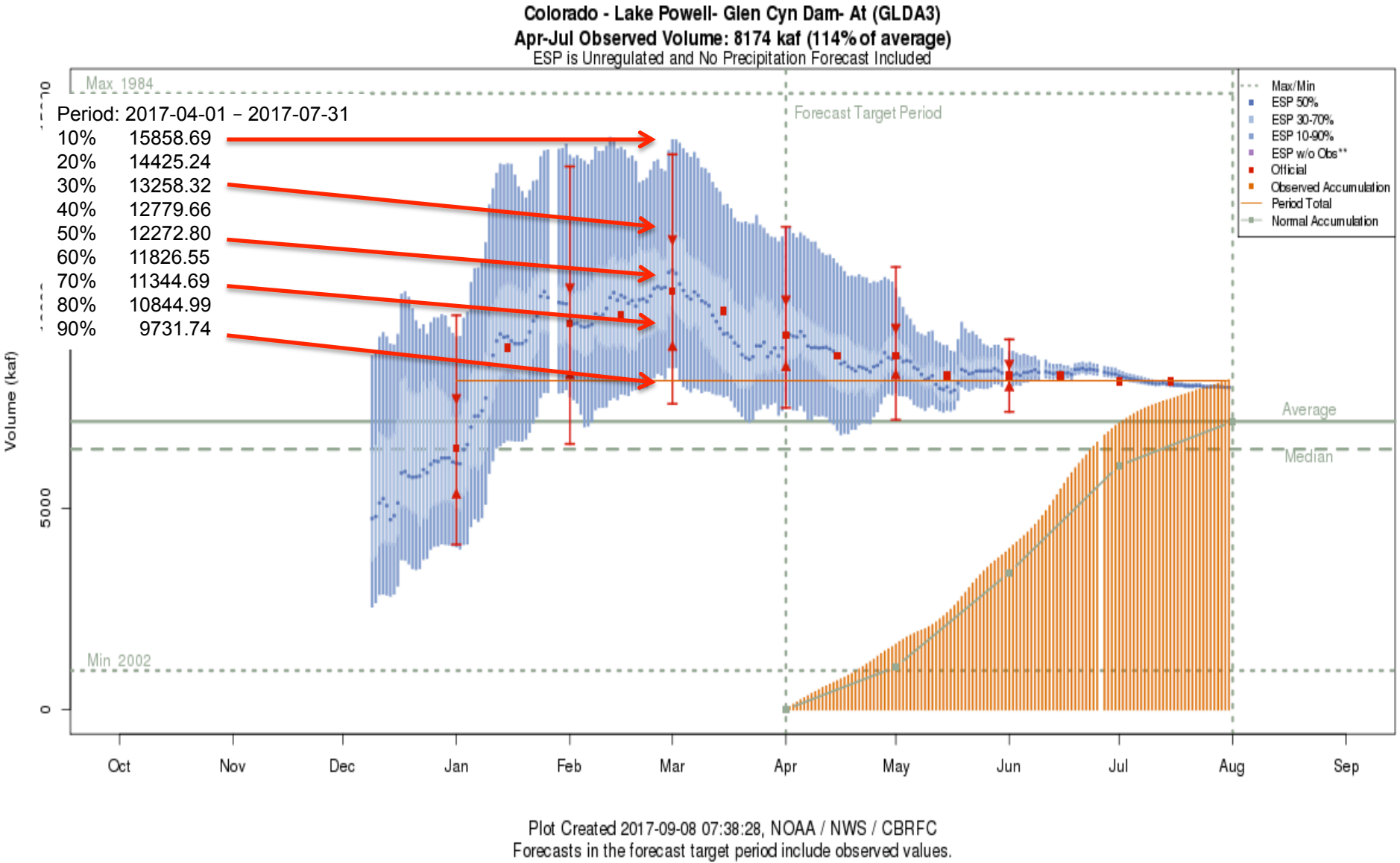
1. The flows are summed into volumes for the period of interest(typically April 1 – July 31)

2. The statistics are simplified

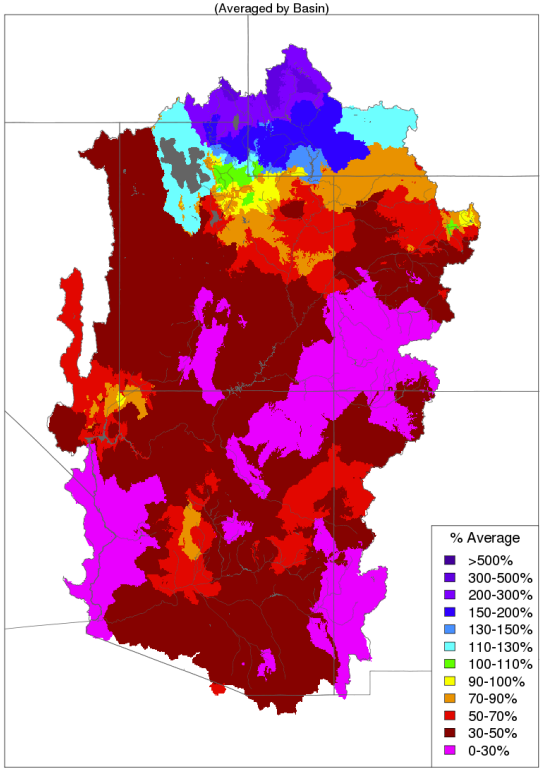
3. 50% exceedance value approximates the most probable forecast. A range of probable outcomes is also provided.

The range of probable outcomes are summarized graphically.

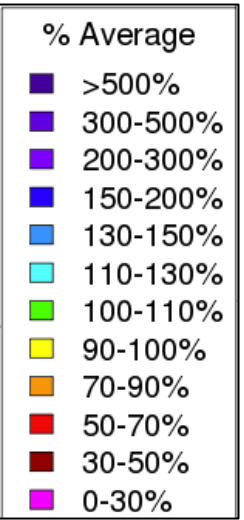
These “forecast evolution plots” are updated daily throughout the season

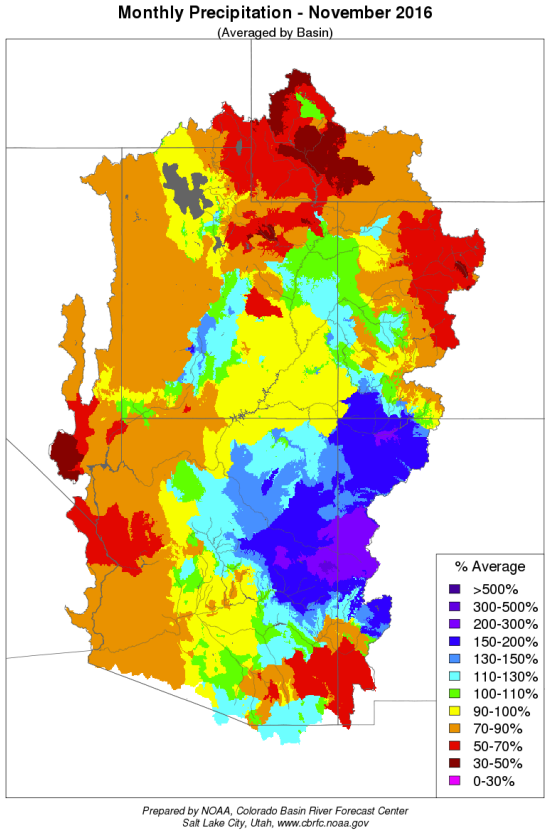


Precipitation: Fall was dry but winter was wet



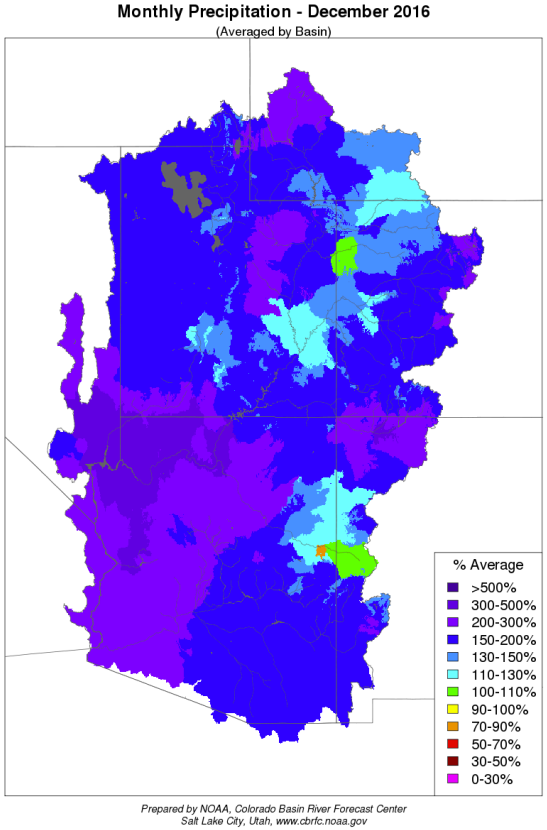
Very Dry October





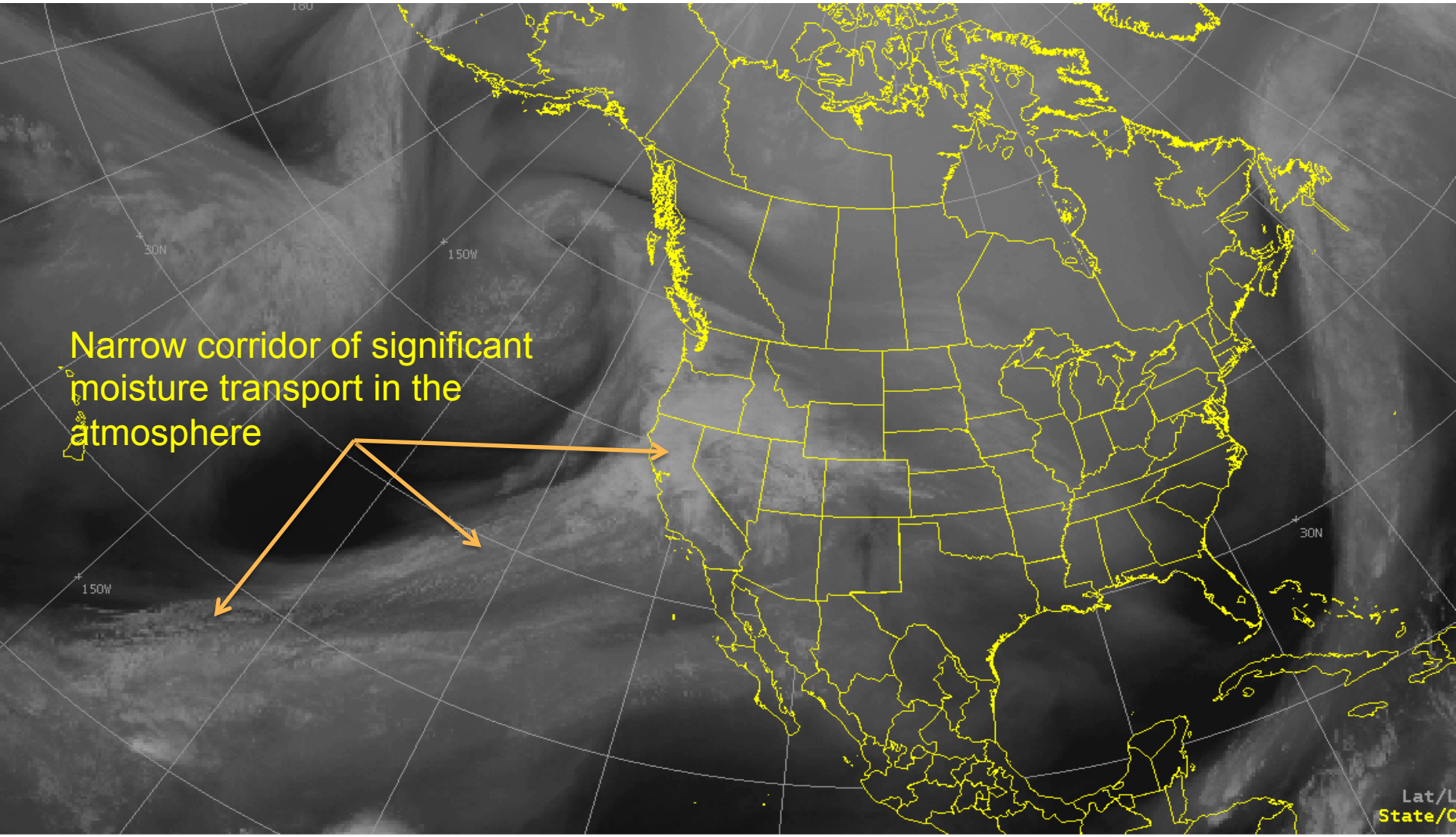
Dry in much of the Upper Colorado & Great Basins. A mix in the Lower Colorado Basin

December – Big Change



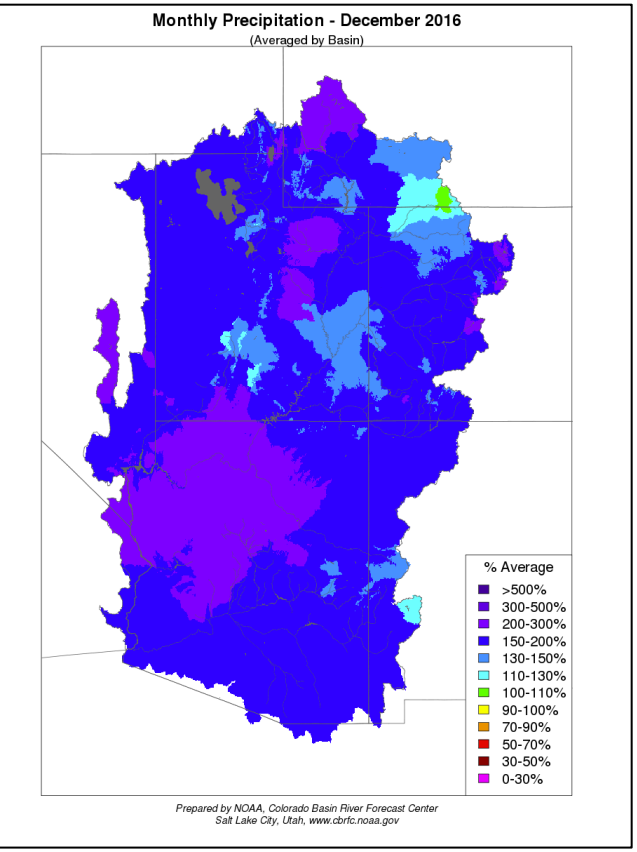
In fact winter was Very Wet !

Mid December through January: significant moisture impacted the western U.S.

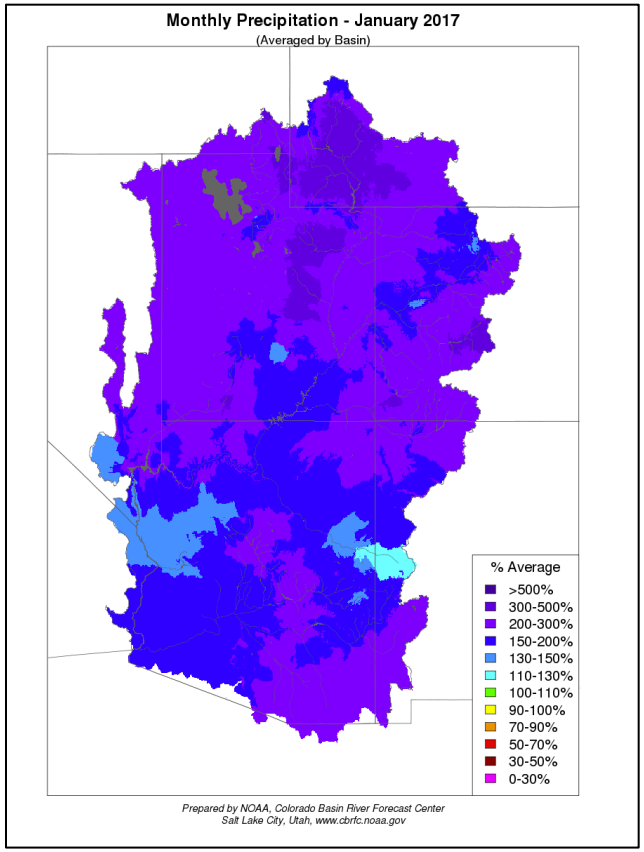


December-January: Very Wet
February: Continued wet in Green, Great, part of Lower Colorado Basins

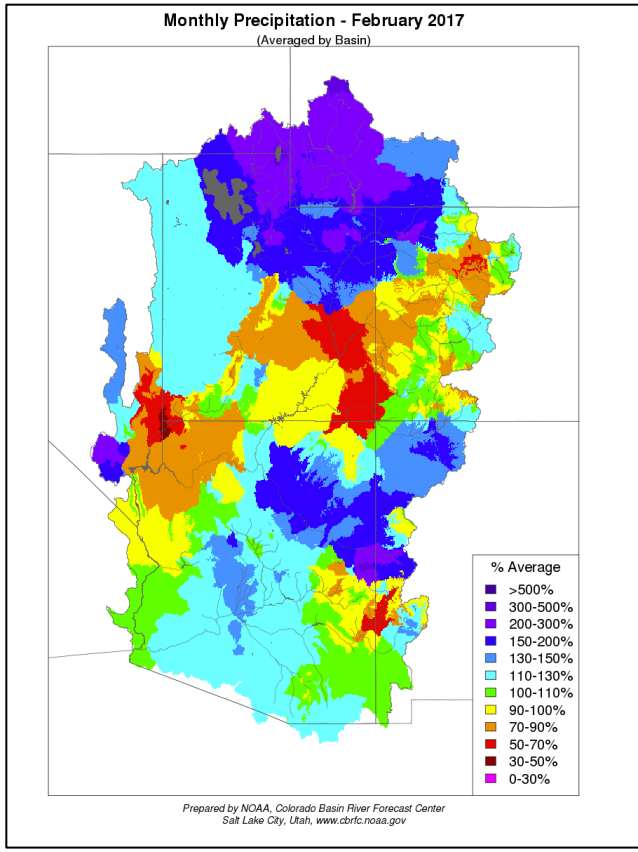
December 2016



January 2017



February 2017



United States Department of Agriculture
NRCS Natural Resources Conservation Service
National Water and Climate Center

Dec-Feb Precipitation Ranking

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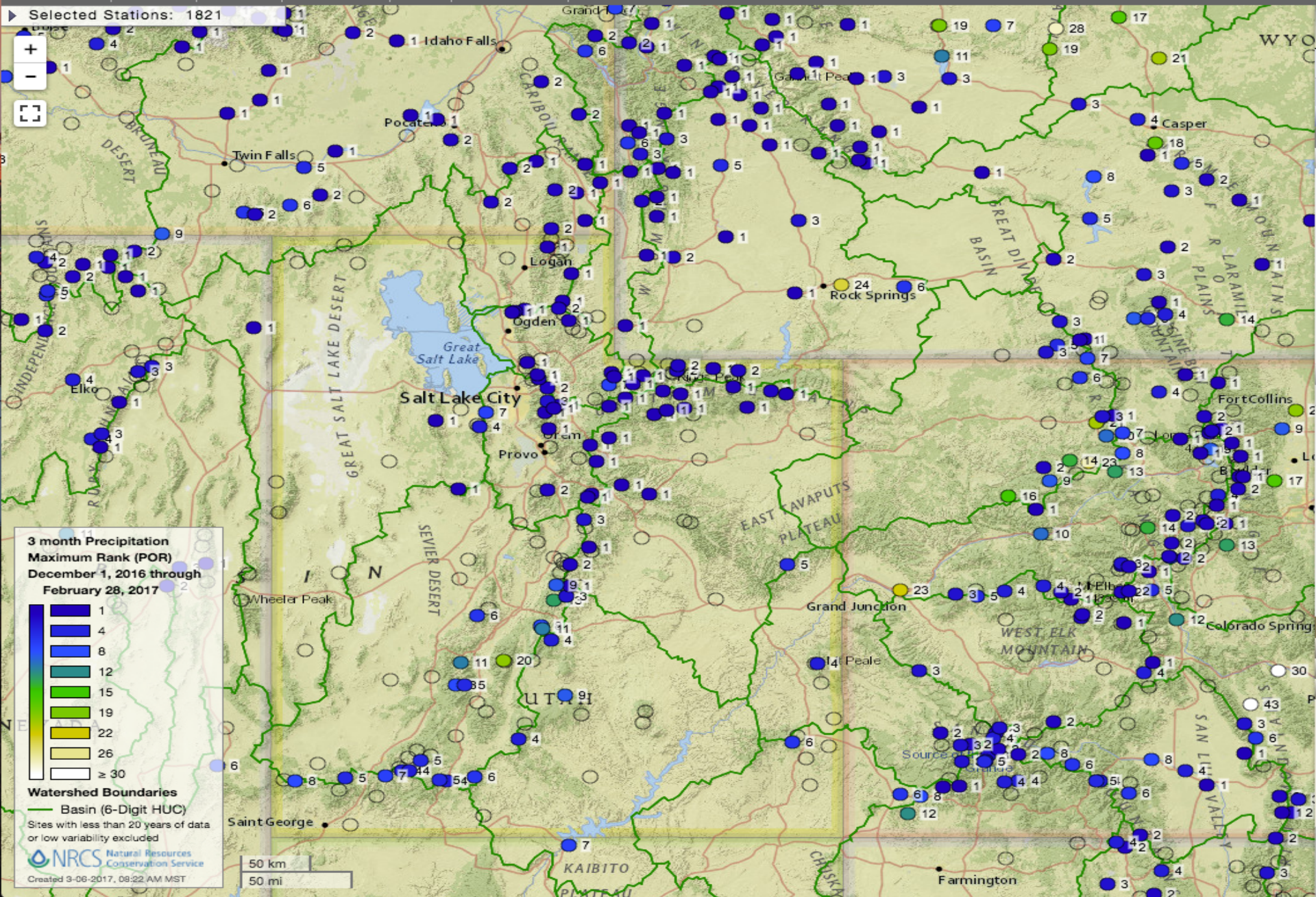
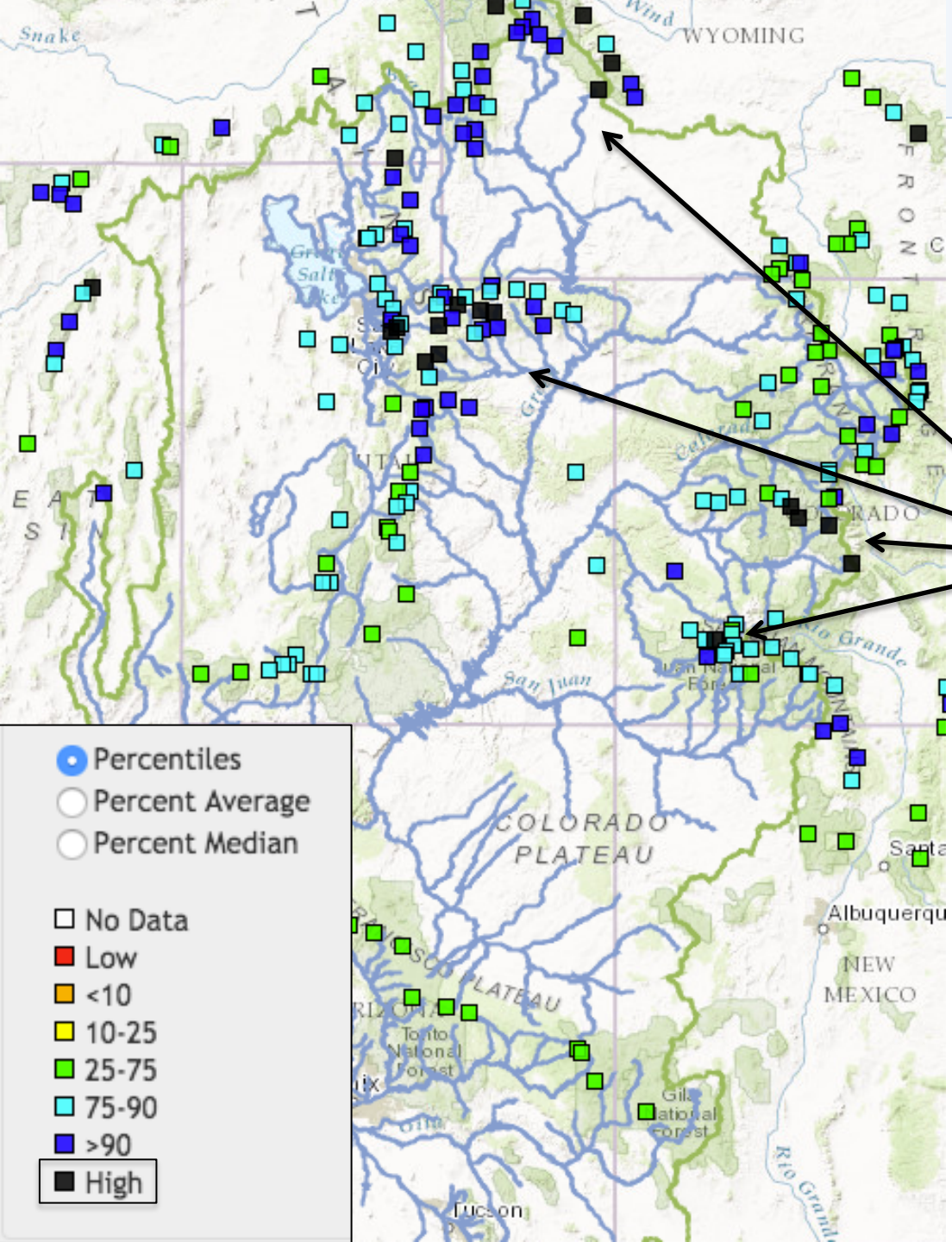


Snow Conditions

SNOTEL ranking for March 6th 2017

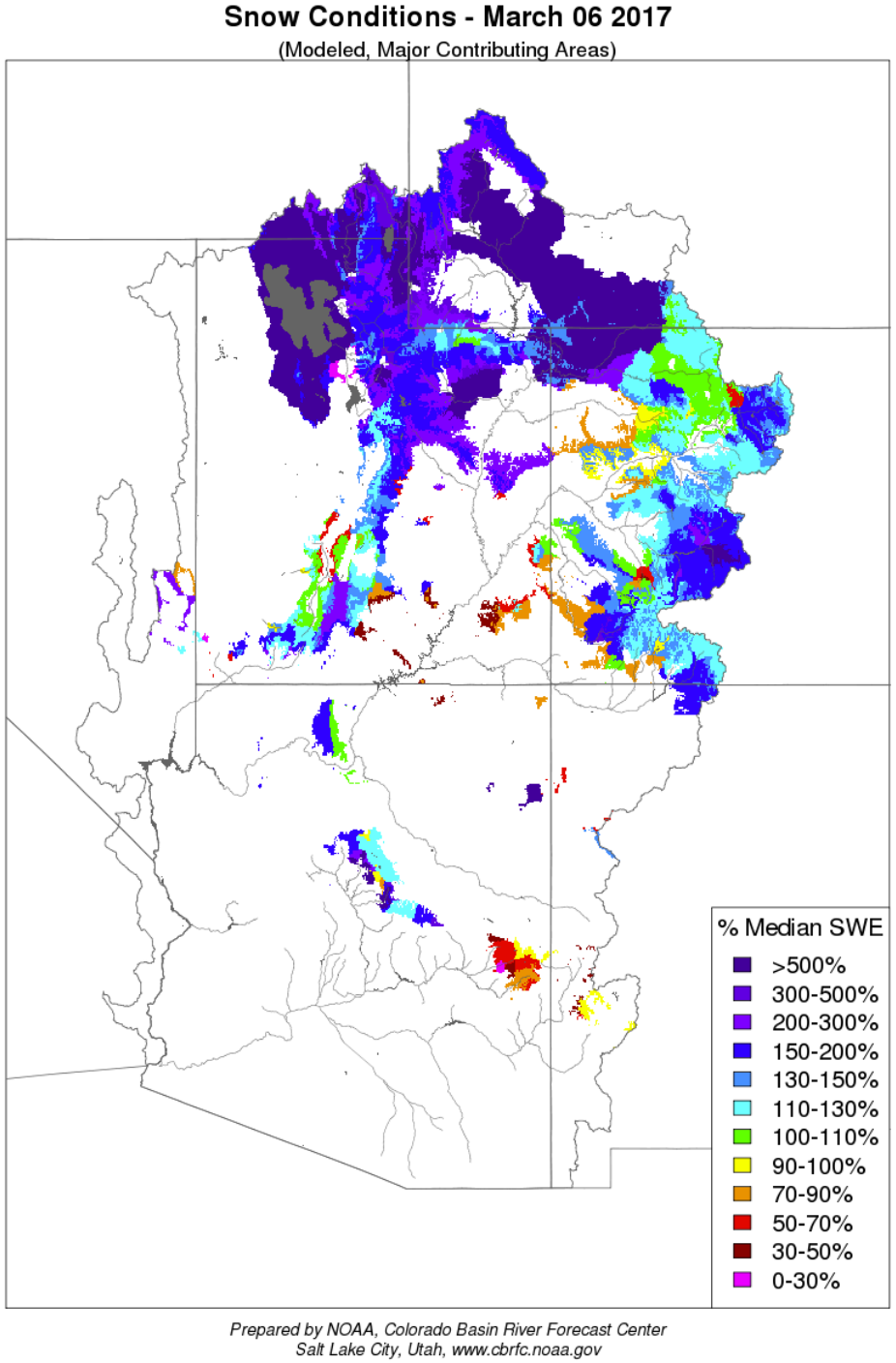


Black – Highest on record (upper Gunnison, Dolores, Duchesne, Great Basin, Green above Fontenelle)

Period of record 34-39 years most sites

Snow Conditions

CBRFC Model Snow for March 6th 2017



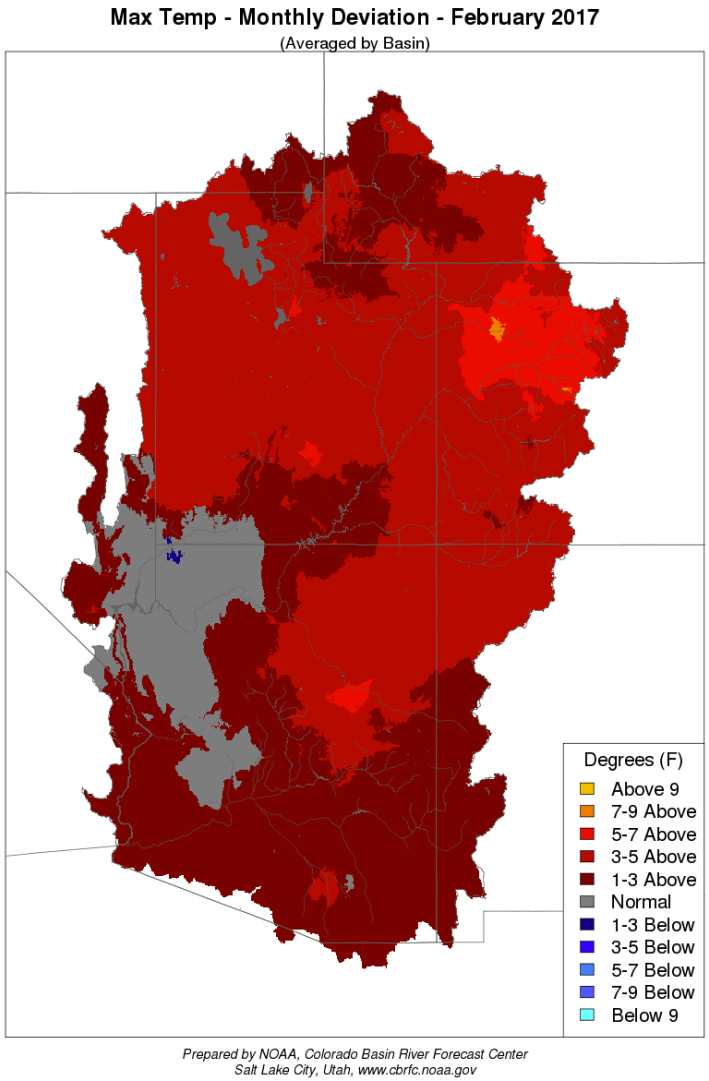
Significant Snowpack: Green River Basin, Great Basin, Gunnison River Basin.

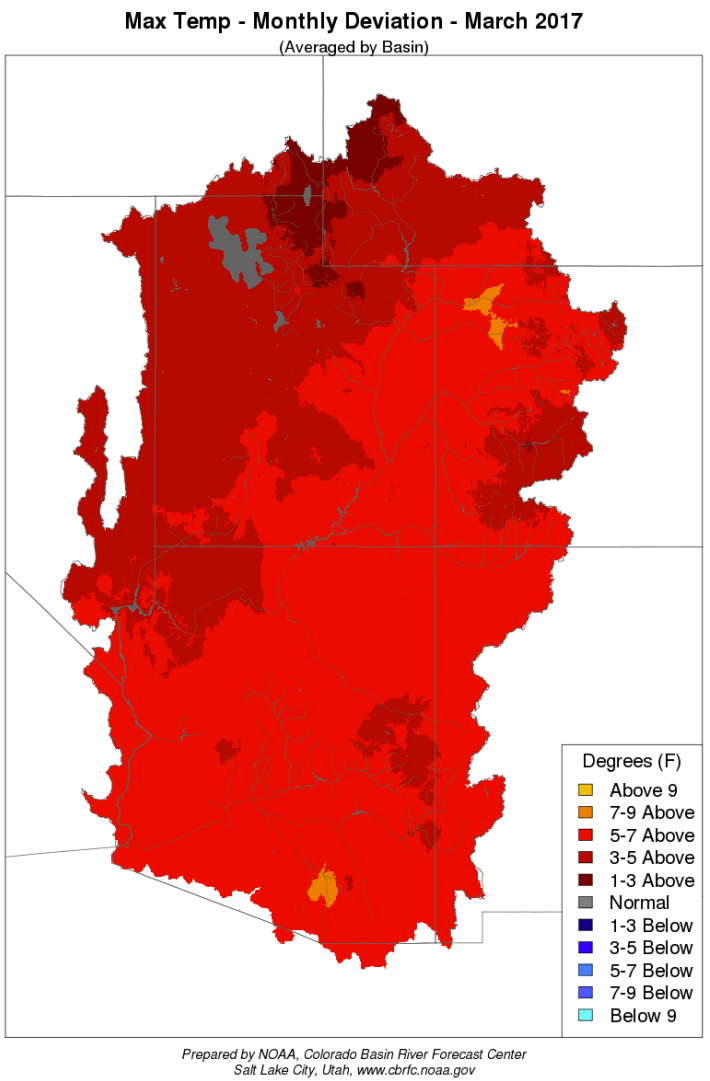
Above average snow many other areas.

Significant lower elevation snow in Green River Basin, Gunnison River Basin, Great Basin

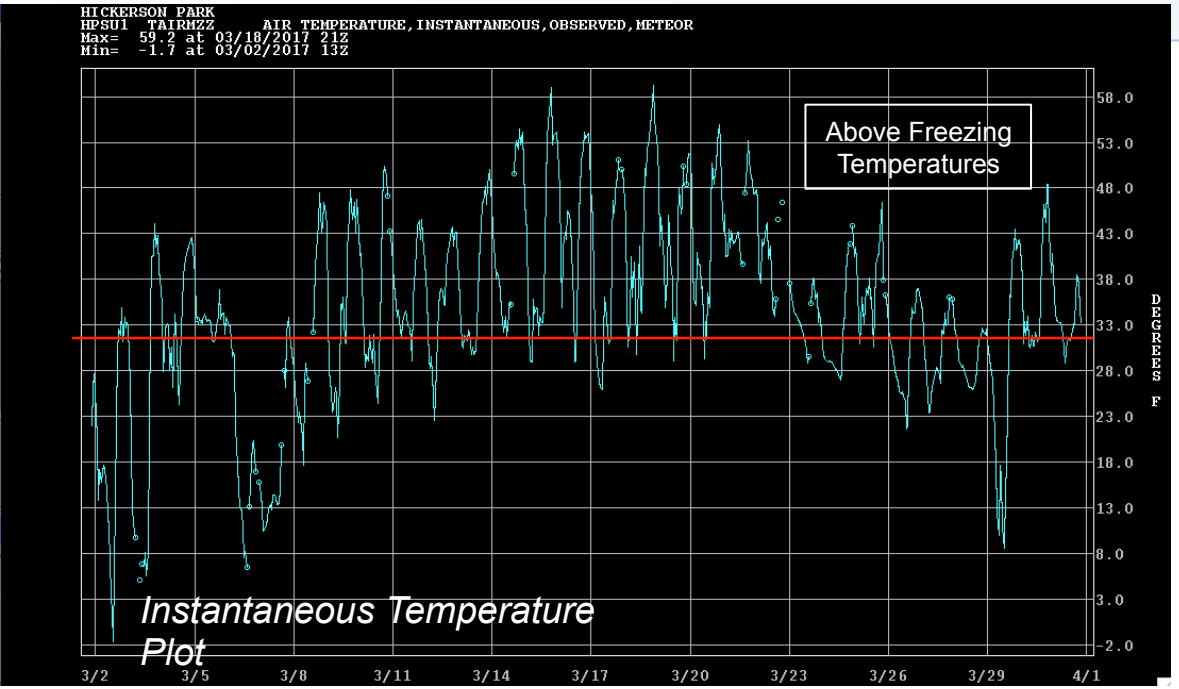
Temperature Impacts: Warm later winter / spring temperatures

Some daily temperatures 10-25 degrees above average in February and March

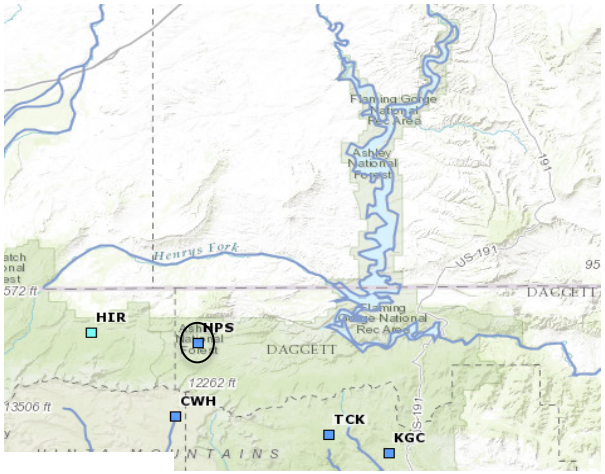


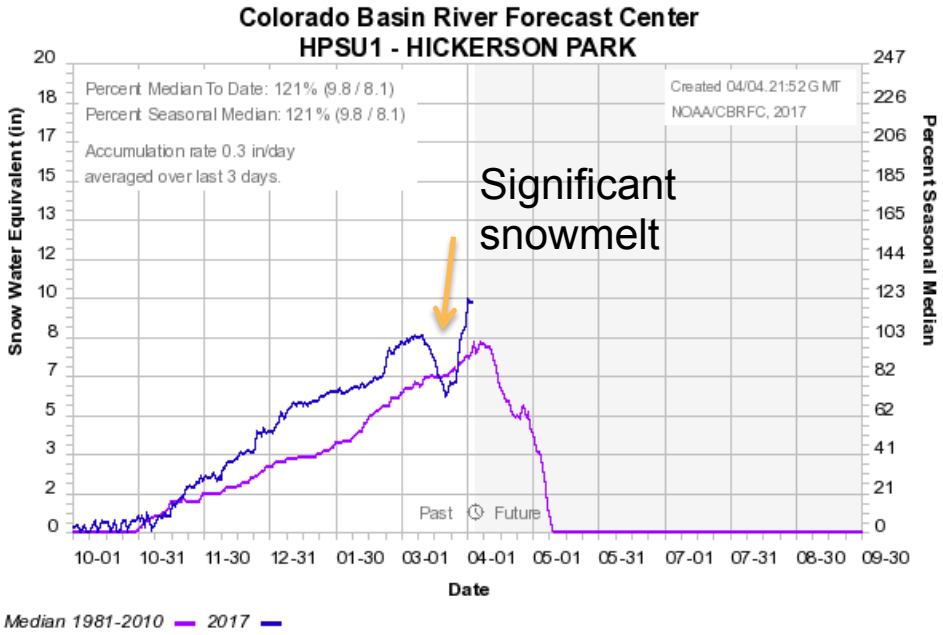


March Weather – Temperature Impacts

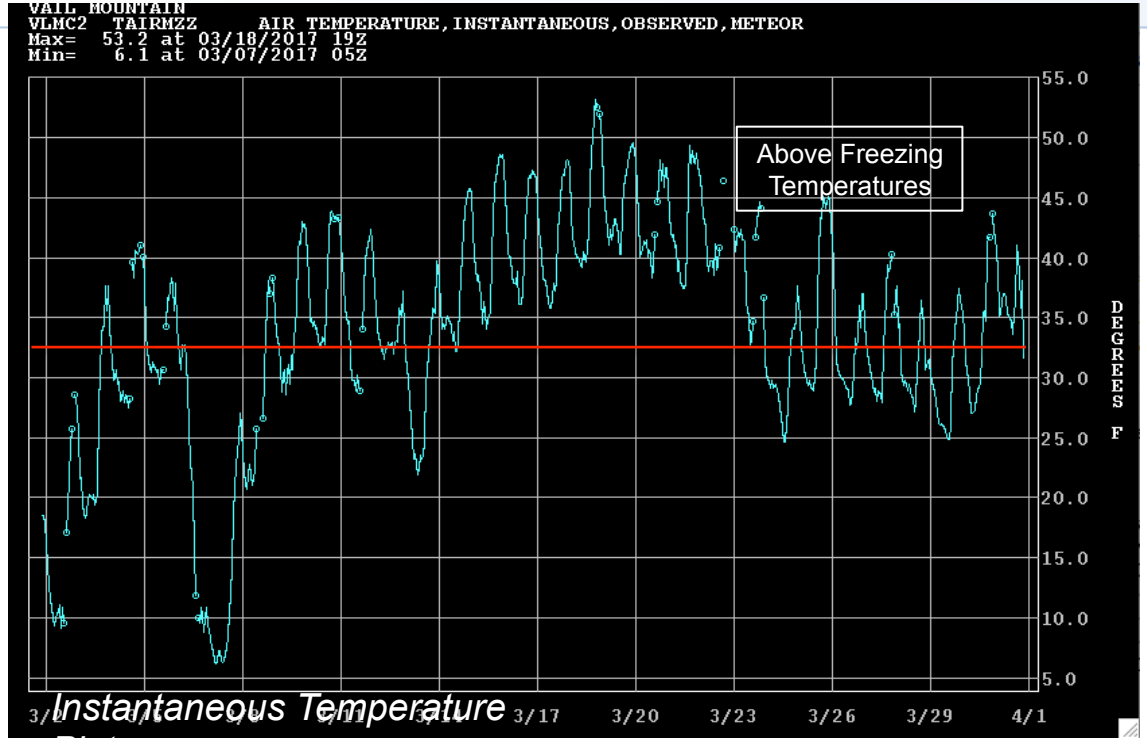


Hickerson Park SNOTEL
Elevation: 9,145 Feet
Upper Green River Basin



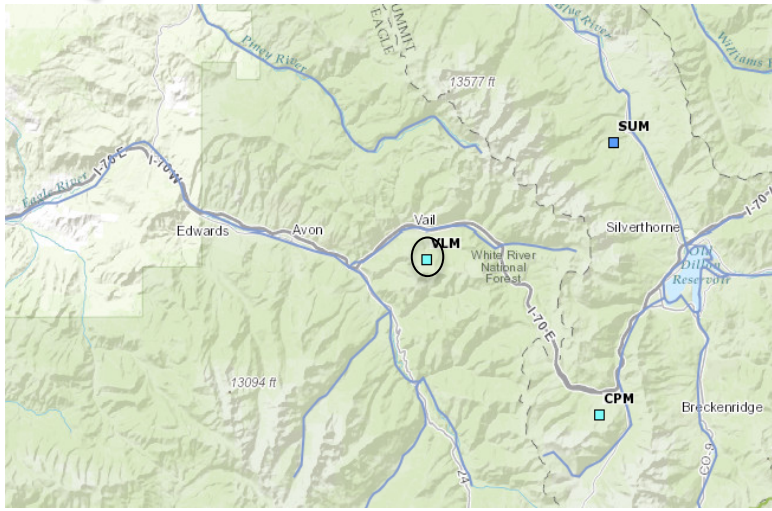


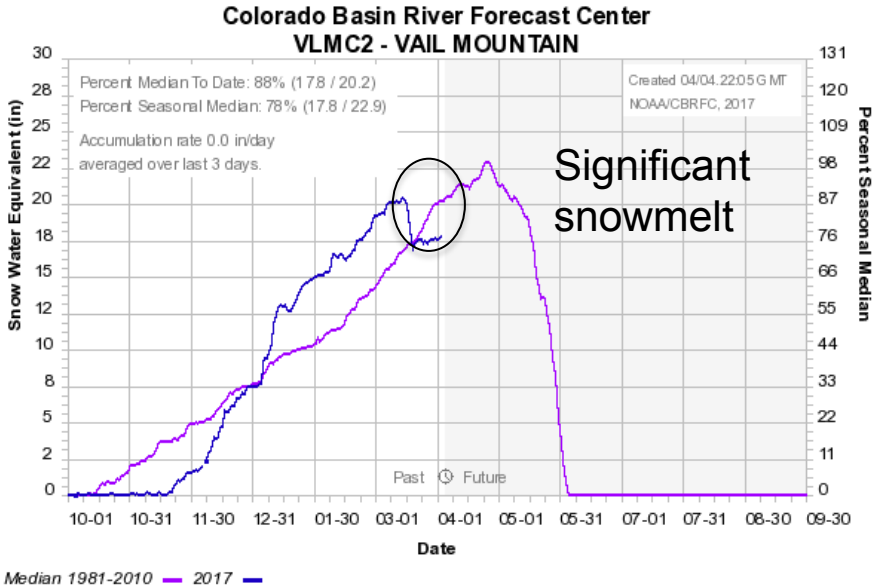
March Weather – Temperature Impacts



Instantaneous Temperature

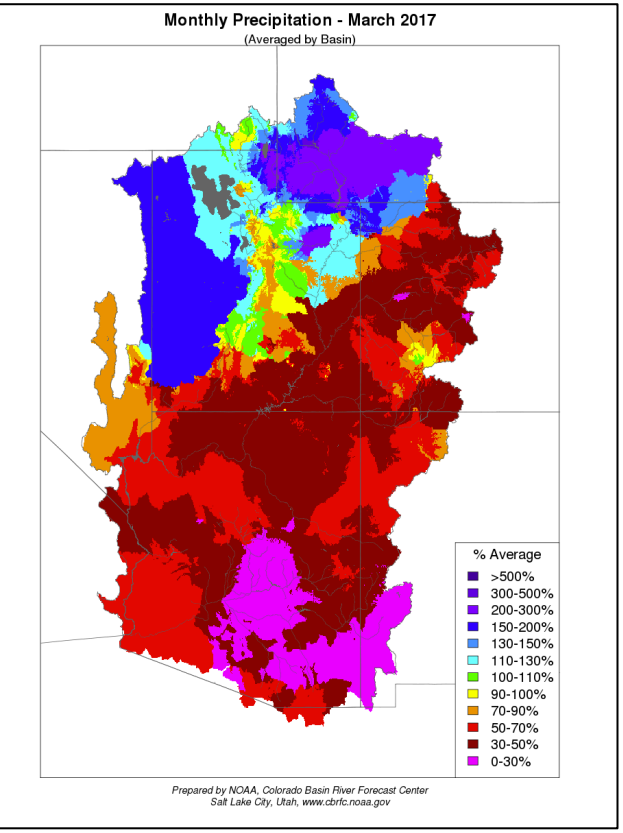
Vail Mountain SNOTEL
Elevation: 10,300 Feet
Colorado River Headwaters



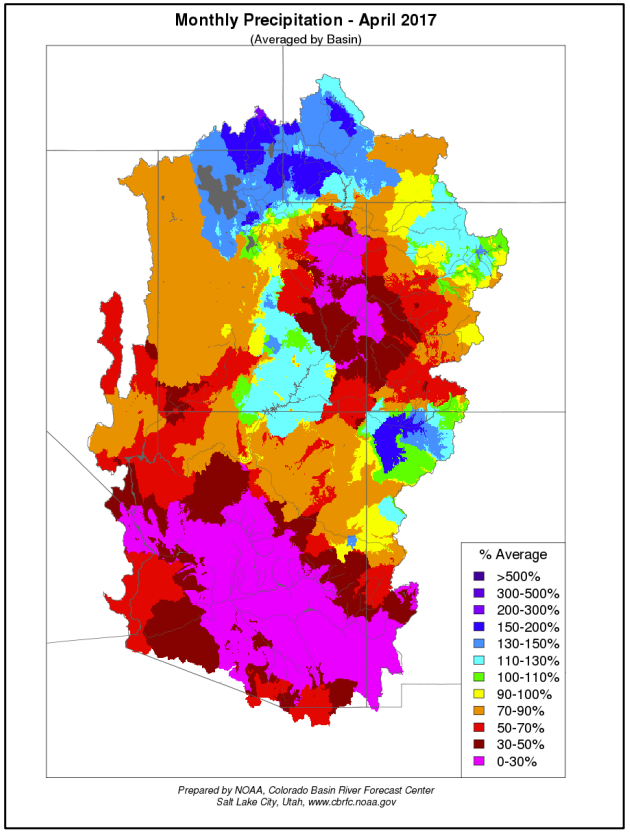


March-May: Generally wetter in northern areas and drier to the south

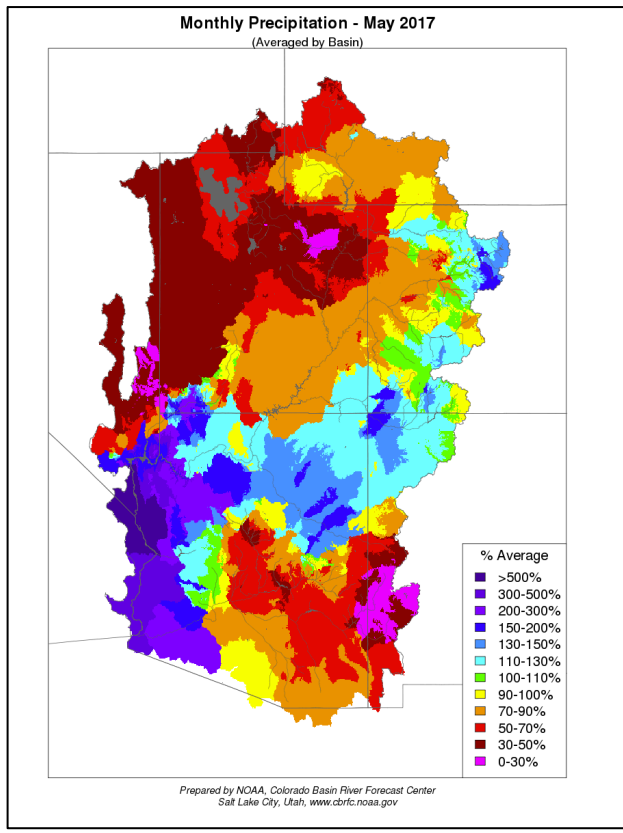
March 2017



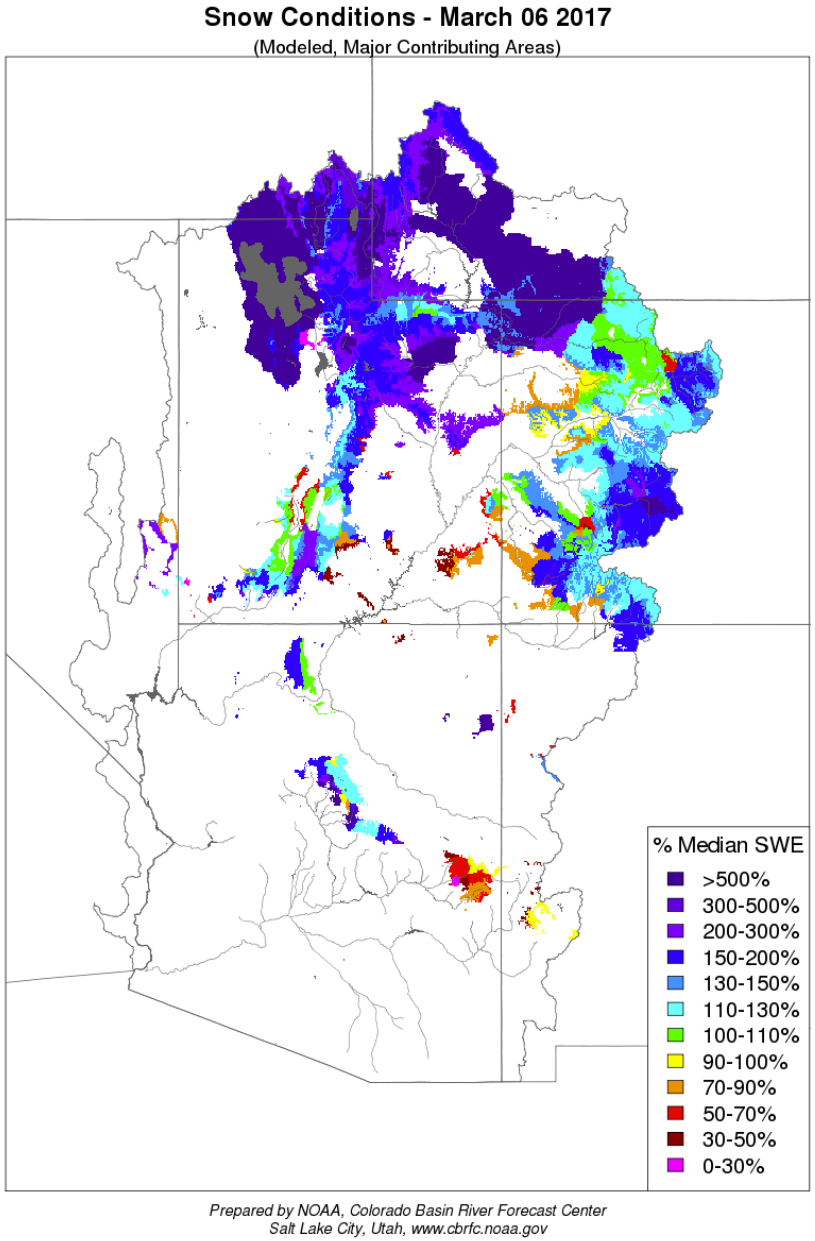
April 2017

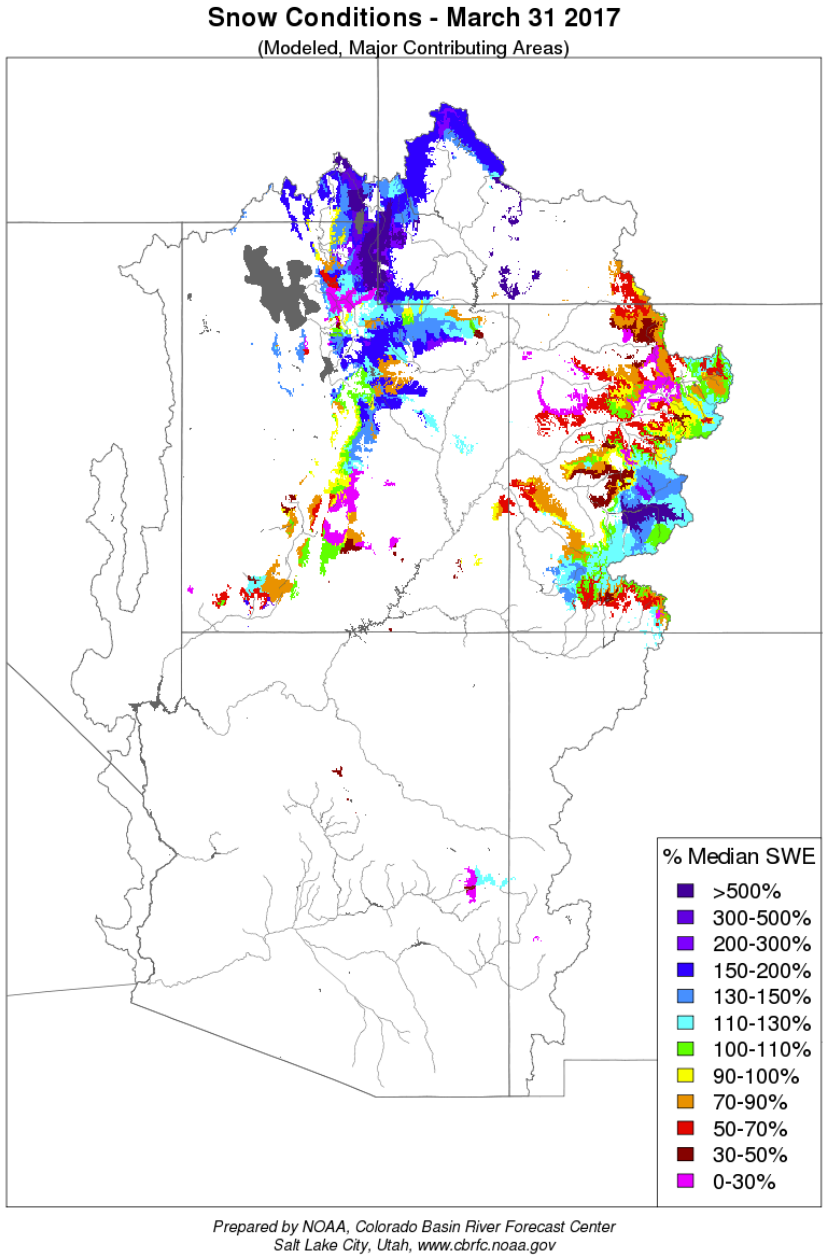


May 2017



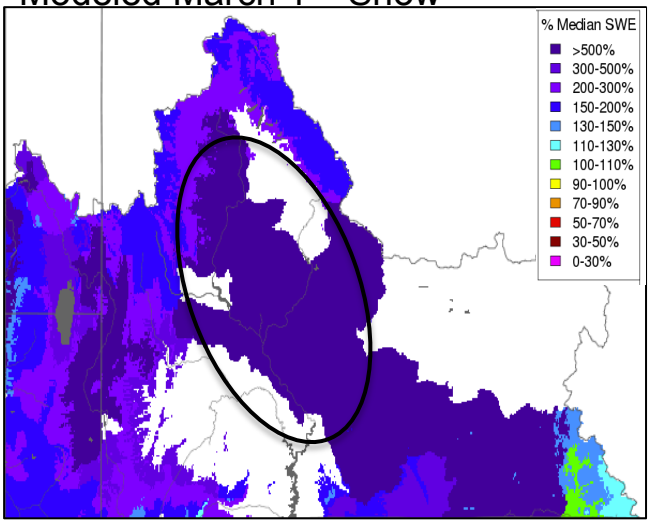
March Weather – Impacts to the snowpack



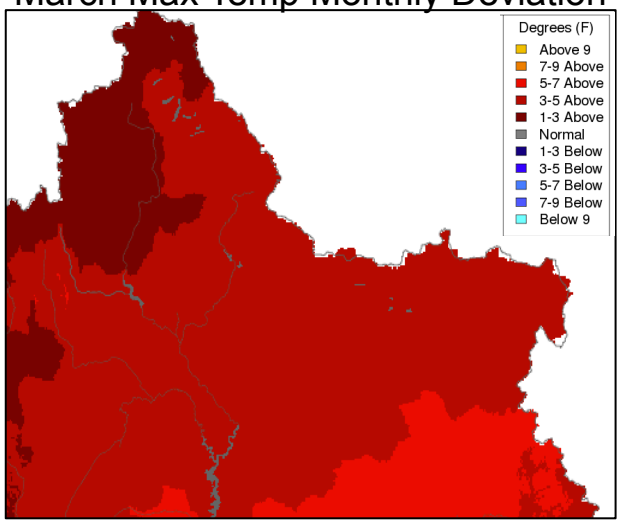


Low Elevation Snowmelt in March/April

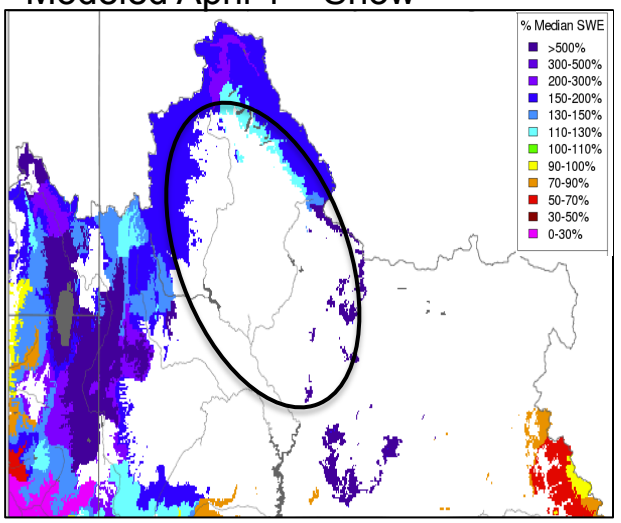
Modeled March 1st Snow



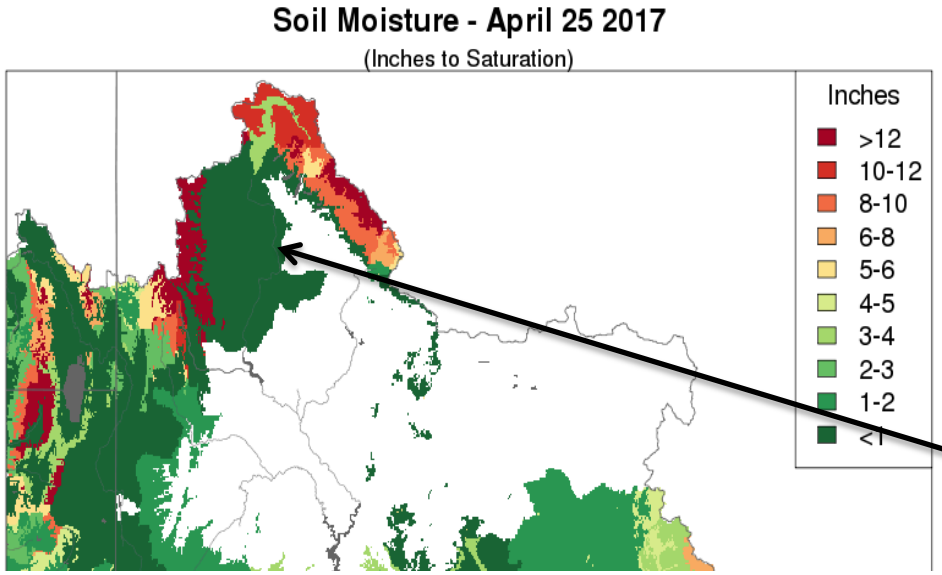
March Max Temp Monthly Deviation



Modeled April 1st Snow

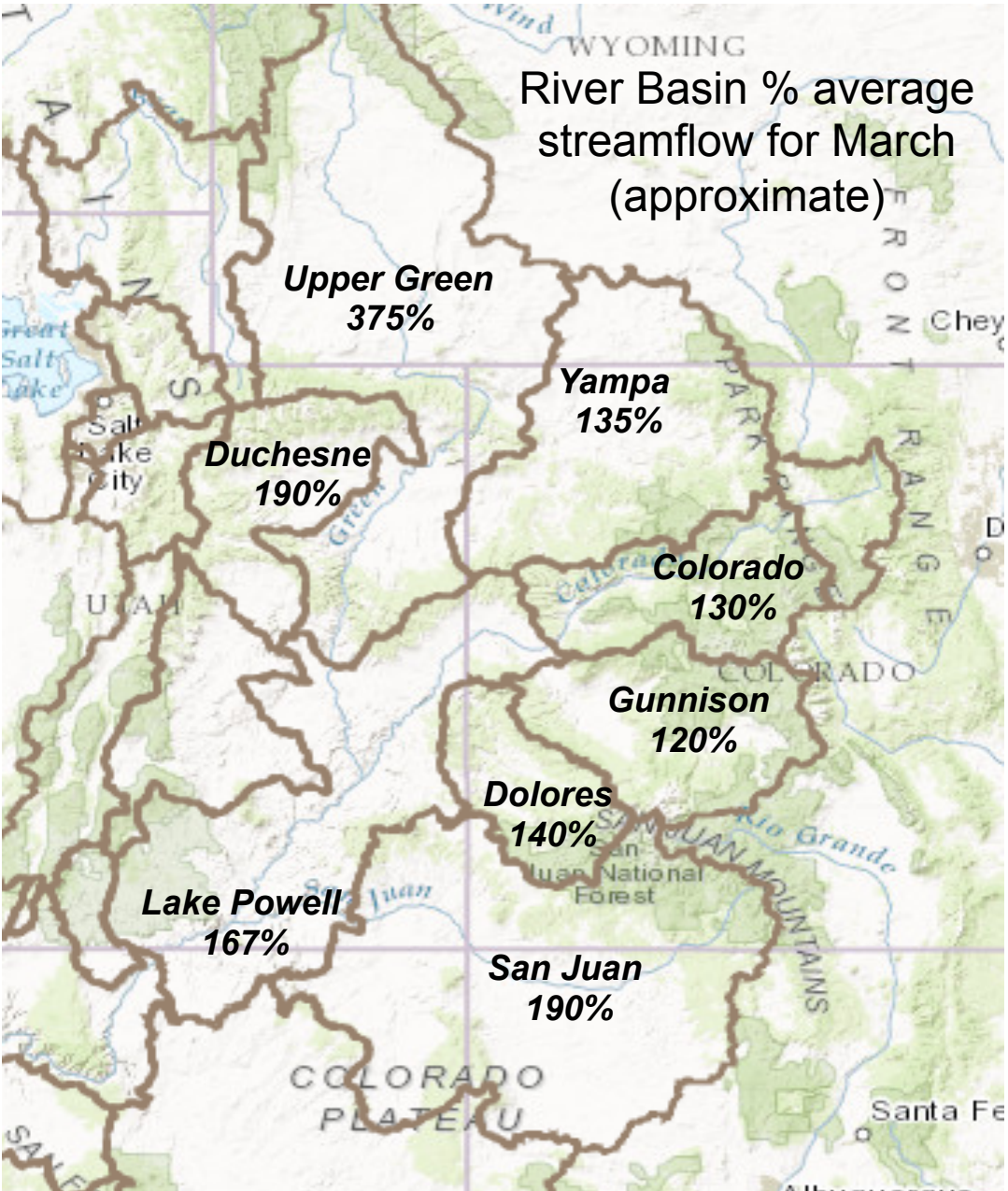


Significant low elevation snowpack melted with above normal temperatures in March. Resulted in record streamflows for the month of March and saturated soil conditions.



Lower elevation areas were saturated prior to runoff due to the melt of a significant low elevation snowpack and rain.

March Weather Impacts: Record March Runoff



Notable March Volumes

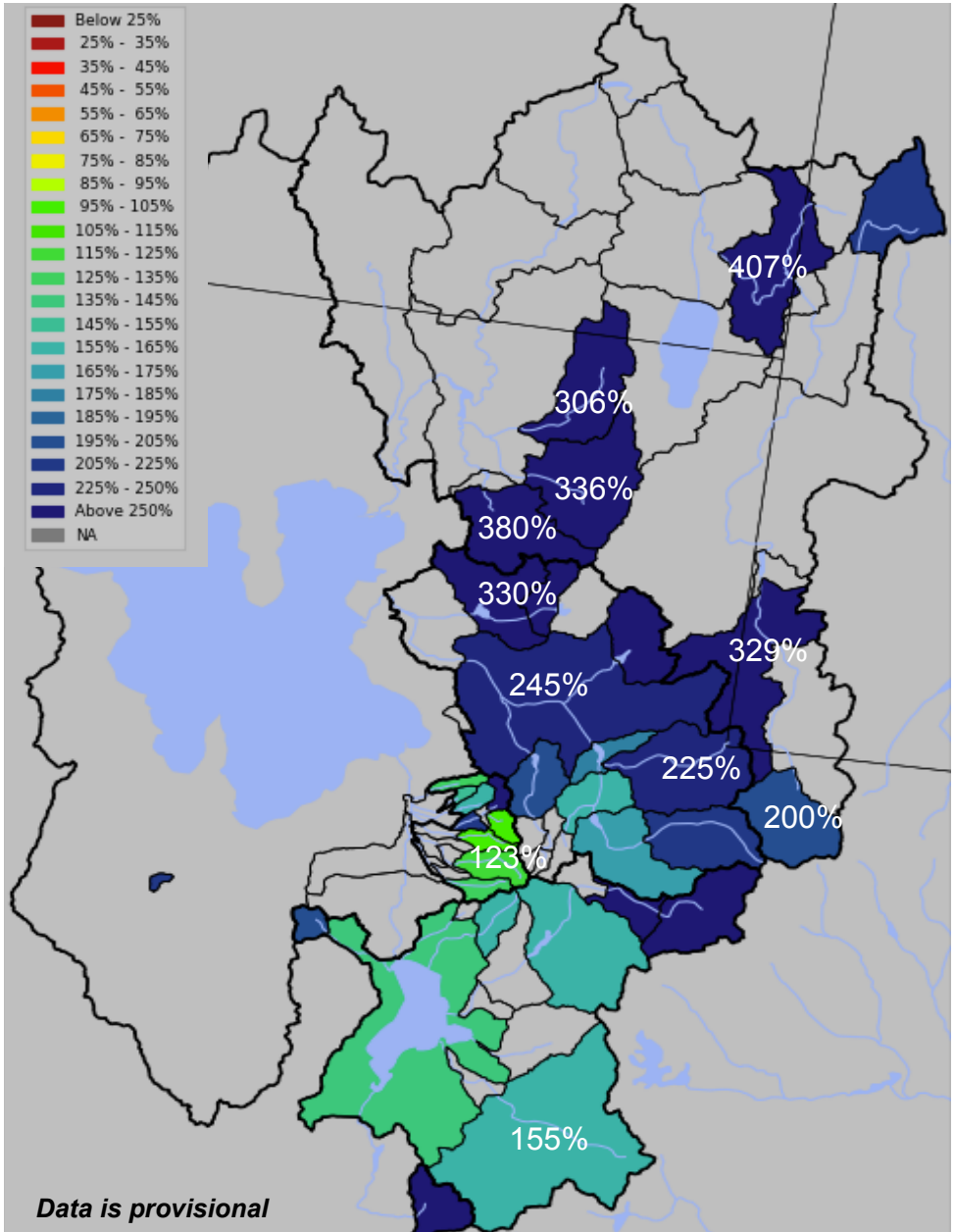
Site (Rank/POR) – Mar Vol KAF / % Avg – old record (year)			
Fontenelle (1/52)*	180 / 343%	99	(1986)
Flaming Gorge (1/55)*	400 / 392%	237	(1997)
Granby (1/90)*	9.7 / 206%	9.1	(2015)
Willow Creek (1/98)*	3.1 / 254%	2.3	(1920)
Green Mtn (1/80)*	14.9 / 153%	14.4	(2015)
Colo-Kremmling (1/55)*	52 / 167%	52	(2015)
Blue Mesa (1/49)*	70 / 193%	55	(1951)
Mcphee(2/37)	57 / 270%	59	(1997)
Vallecito (1/76)*	24 / 285%	16	(2007)
Navajo (4/47)	177 / 191%	198	(1995)
Lemon Res(1/54)*	4.1 / 259%	3.8	(1989)
Lake Powell(3/54)	1109 / 167%	1141	(1985)

Many more sites in top 2 or 3 of record

Data is provisional – not all basin stream flow sites included

March Weather Impacts: Record March Runoff

March % of Average Unregulated Streamflow for March



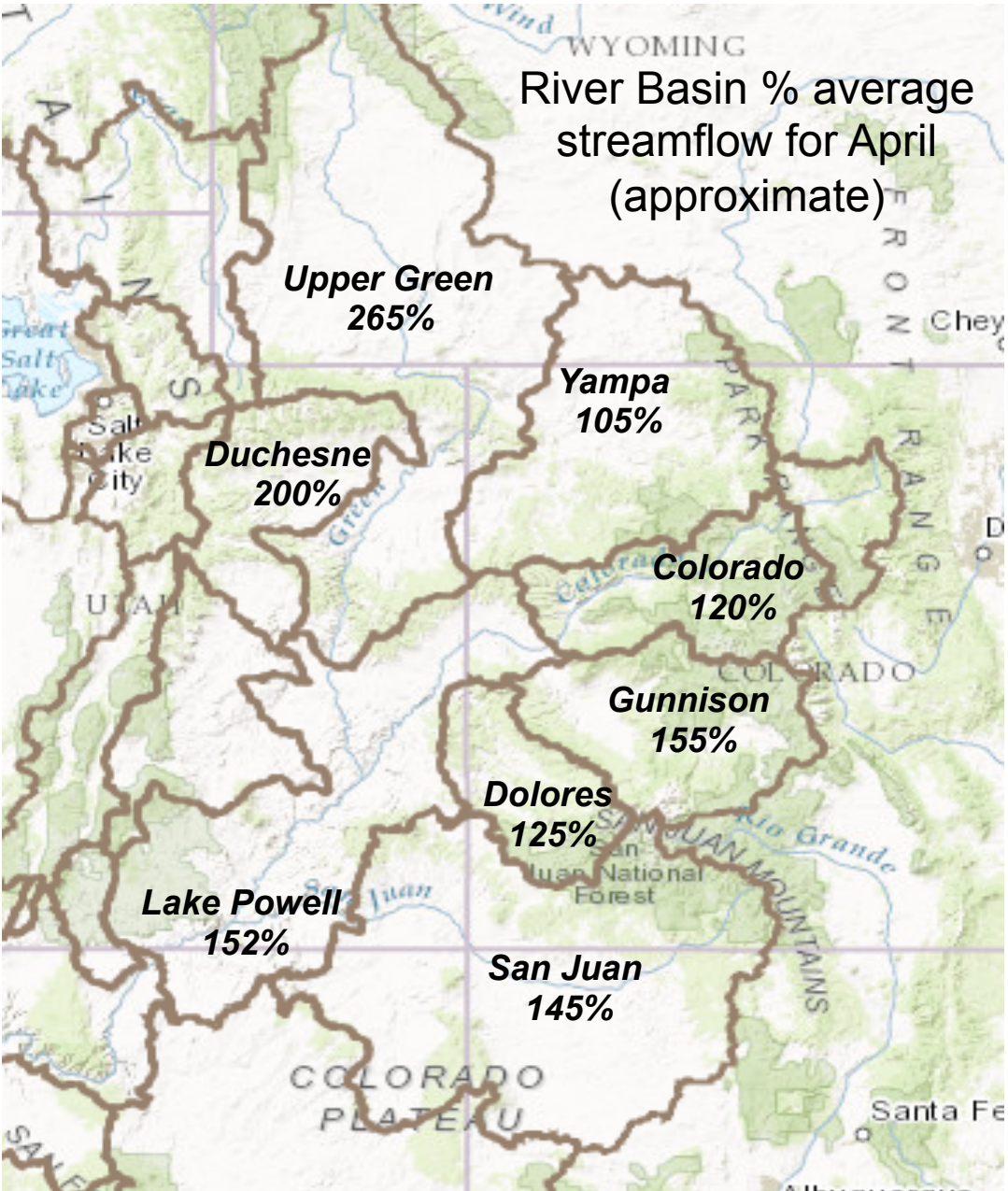
Notable March Volumes

Site (Rank/POR) –	Mar Vol KAF / % Avg	– old record (year)
Bear-UT/WY (1/75)*	5.8 /200%	4.8 (2015)
Smiths Fork (1/75)*	8.8 /224%	6.2 (2015)
Stewart Dam (1/89)*	98 /407%	82 (1986)
Logan River (1/52)*	25 /306%	23 (1986)
Blacksmith Fork (1/99)*	23 /336%	22 (1986)
Little Bear River(1/73)*	29 /380%	24 (1986)
South Fork Ogden (1/94)*	29/400%	25 (1986)
Pineview Inflow (1/79)*	80/330%	72 (1986)
Provo-Woodland(1/52)*	11.6/265%	11.4 (1986)
Provo-Hailstone(1/62)*	18.3/319%	16.5 (1986)

Saturated conditions, warm temperatures, low elevation snowmelt and precipitation resulted in record flows at many locations.

Many more sites in top 2 or 3 of record

April Weather Impacts: Record April Runoff



Notable April Volumes

Site (Rank/POR) – Apr Vol KAF / % Avg – old record (year)			
Fontenelle (1/52)*	225 / 264%	180	(1986)
Flaming Gorge (1/55)*	350 / 262%	299	(1969)
Granby (2/90)	26 / 191%	30	(1962)
Willow Creek (2/98)	15 / 357%	16	(1962)
Blue Mesa (1/49)*	145/ 188%	137	(1985)
McPhee(7/37)	95 / 134%	162	(1985)
Vallecito (1/76)*	45 / 192%	42	(2005)
Navajo (8/47)	234 / 138%	392	(1985)
Lemon Res(5/54)	10 / 173%	13	(2005)
Lake Powell(5/54)	1607 / 152%	2708	(1985)

At least 9 sites in Upper Green River and Duchesne basins with records

Many more sites in top 5 of record across the area

Data is provisional – not all basin stream flow sites included

Forecast Verification:

What impacts might we expect from the weather scenario that played out?

Extreme wet conditions Dec-Feb

- Anticipate large forecast errors with early season forecasts.
- Forecasts too low since precipitation received was much above normal.

Dry and very warm conditions developed by March

- Forecasts would trend down in many areas – drier than climatology
- Forecast errors may be on the high side some areas.

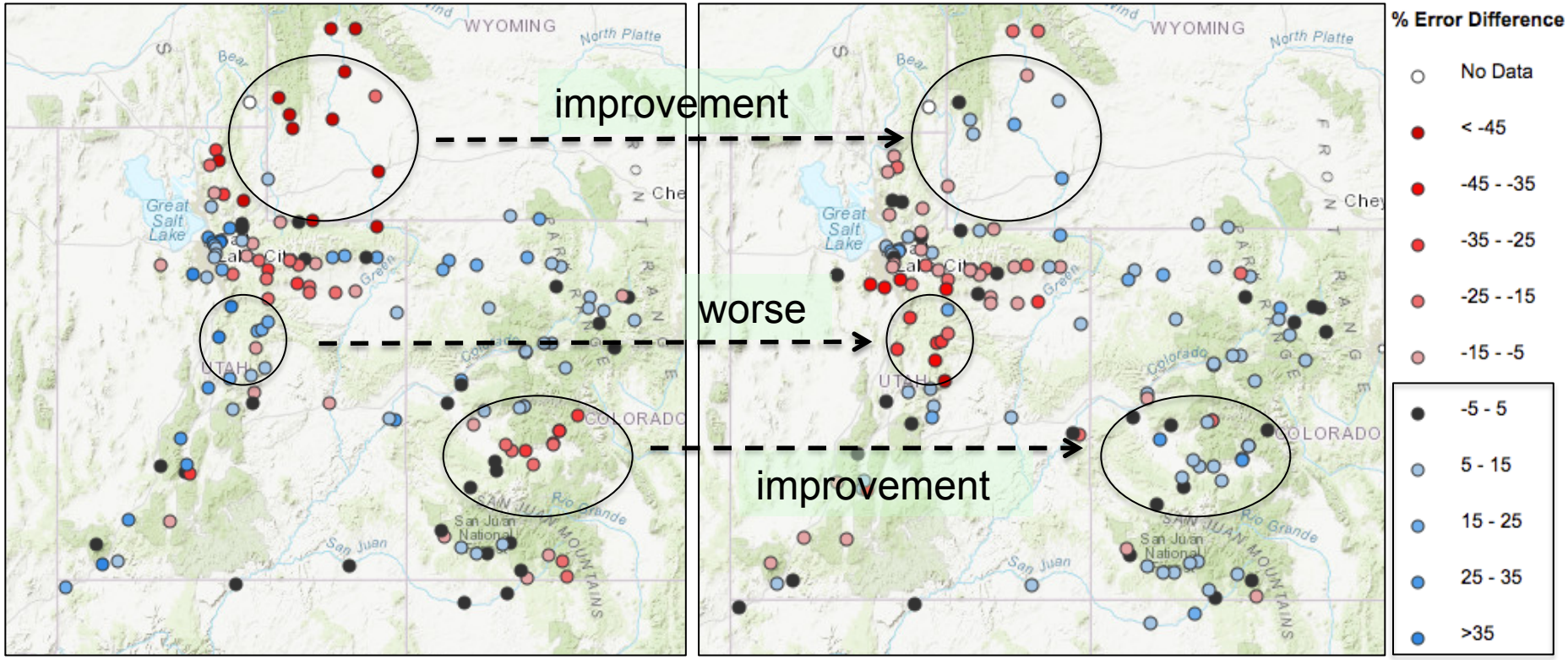
Impacts of the early snow melt in many areas.

- Did we shift some of the April-July runoff into March ?
- Did the model handle the melt properly – could impact the accuracy of late season snow states in the model ?

2017 Forecast Verification Map:

January 2017 Verification Map

April 2017 Verification Map

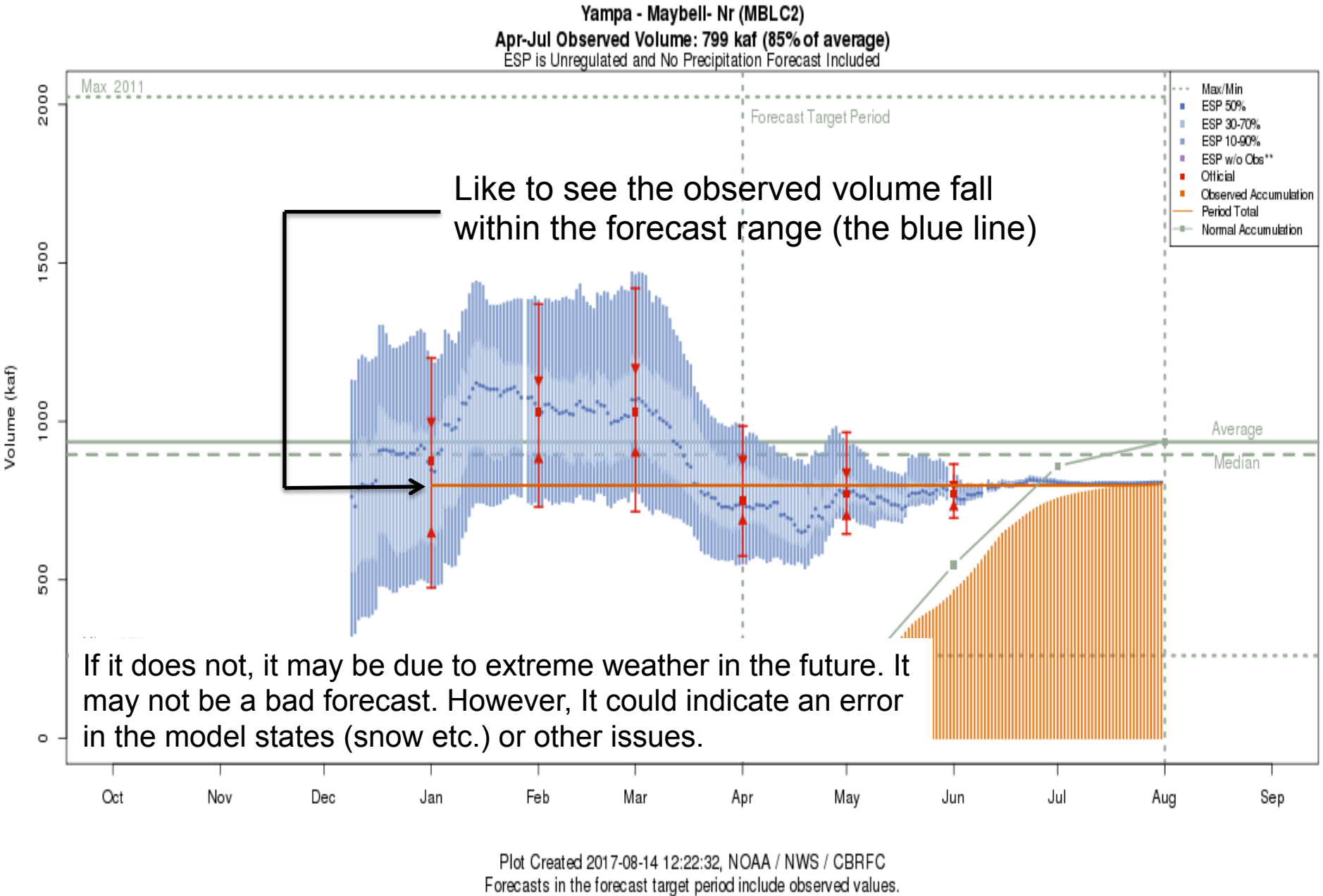


Reds – This years forecast higher than ESP historical model error.

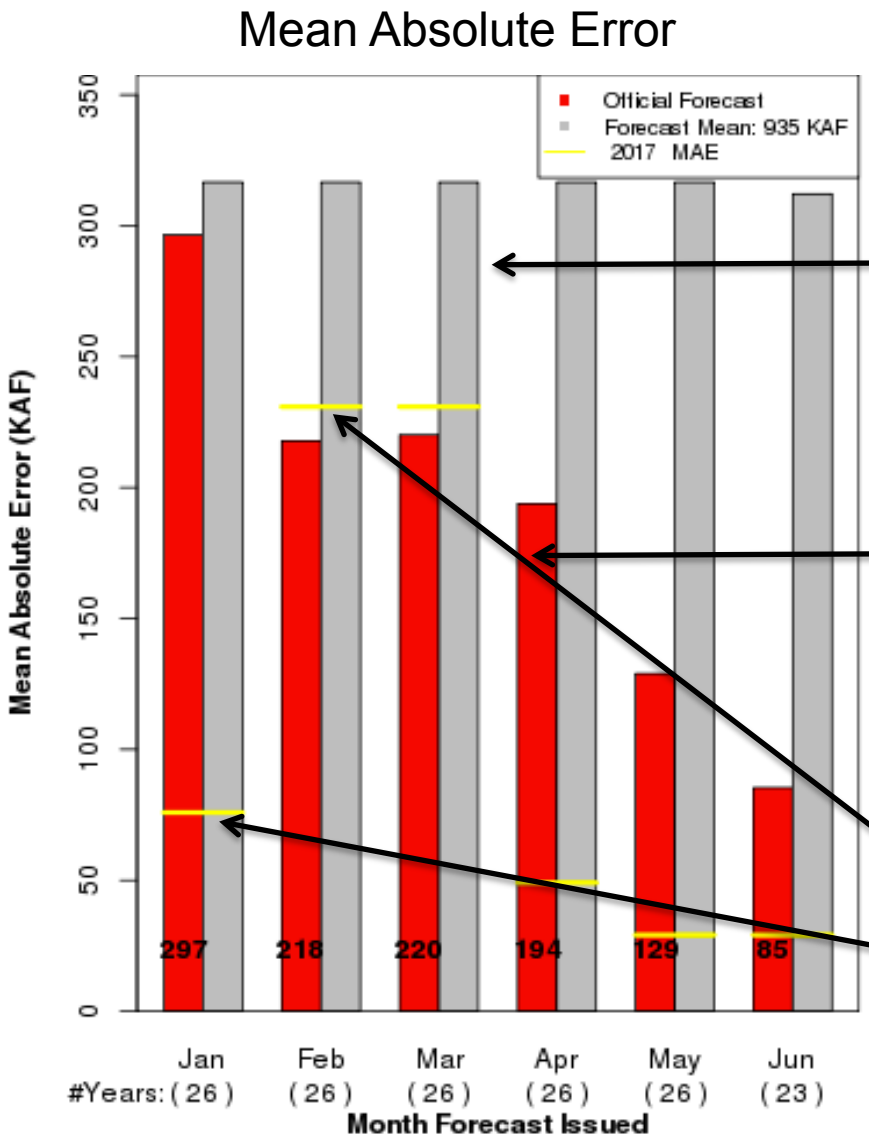
Blues – This years forecast lower than the ESP historical model error.

Blacks – This years forecast similar to the ESP historical model error.

Forecast Verification Plots: So what are we looking for ?



2017 Error Plots: So what are we looking for ?



Grey Bars – If we just forecast average every month, this would be the historical error.

Red Bars - The historical forecast error. So we do provide information that is better than just going with average.

2017 error in yellow

Worse than the historical forecast error *

Better than the historical forecast error

* does not necessarily mean a bad forecast

2017 Forecast/Runoff Impacts

Upper Green River Basin

- Early season forecast errors due to extreme wet weather that followed.
- Seasonal forecasts and the model performed very well despite concerns of higher forecast uncertainty due to record conditions

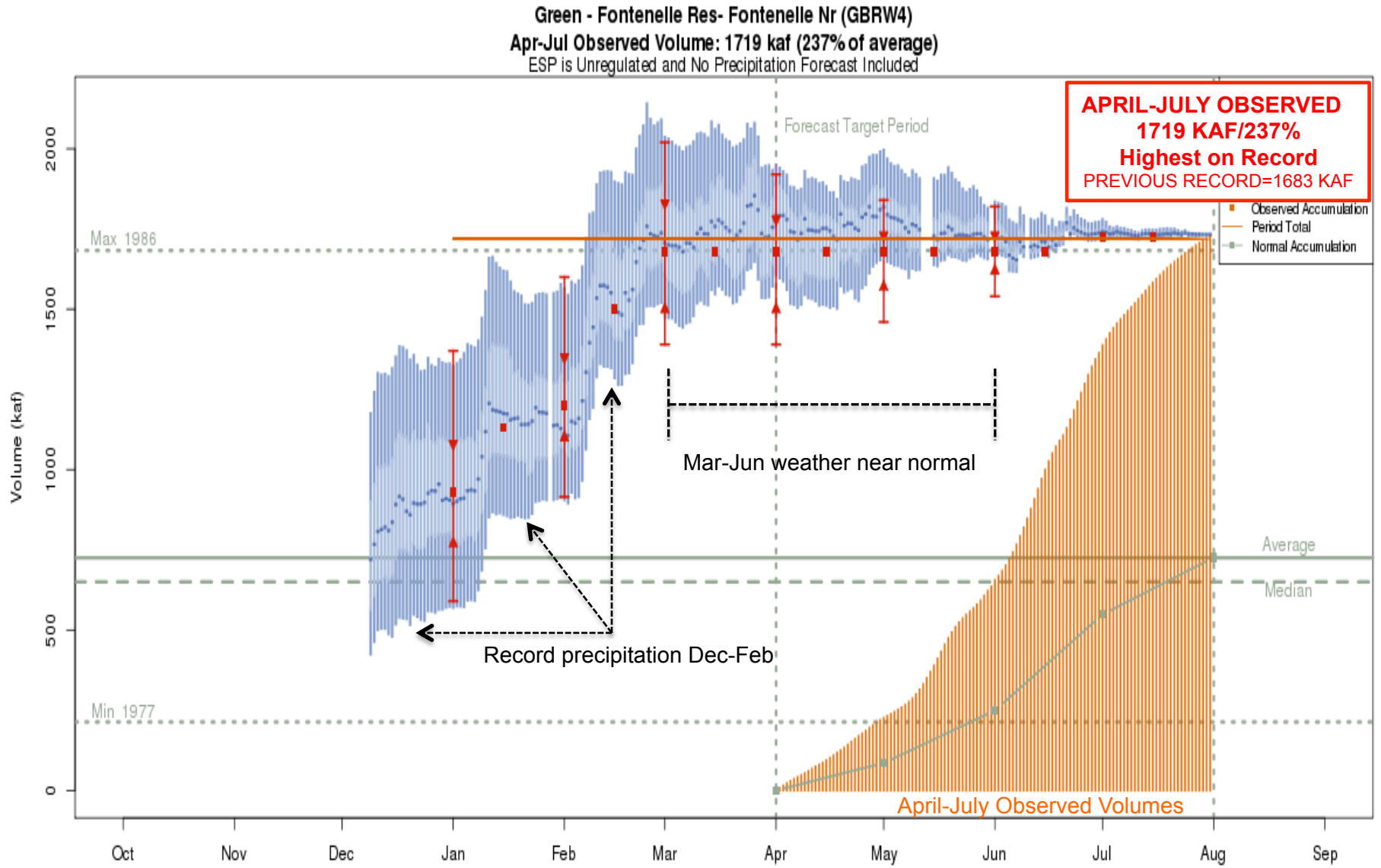
Yampa River Basin

- Largest forecast errors were in February and March. Errors were primarily weather related as March was very dry and warm.
- Seasonal forecasts and the model performed well with no major adjustments required.

Duchesne River Basin

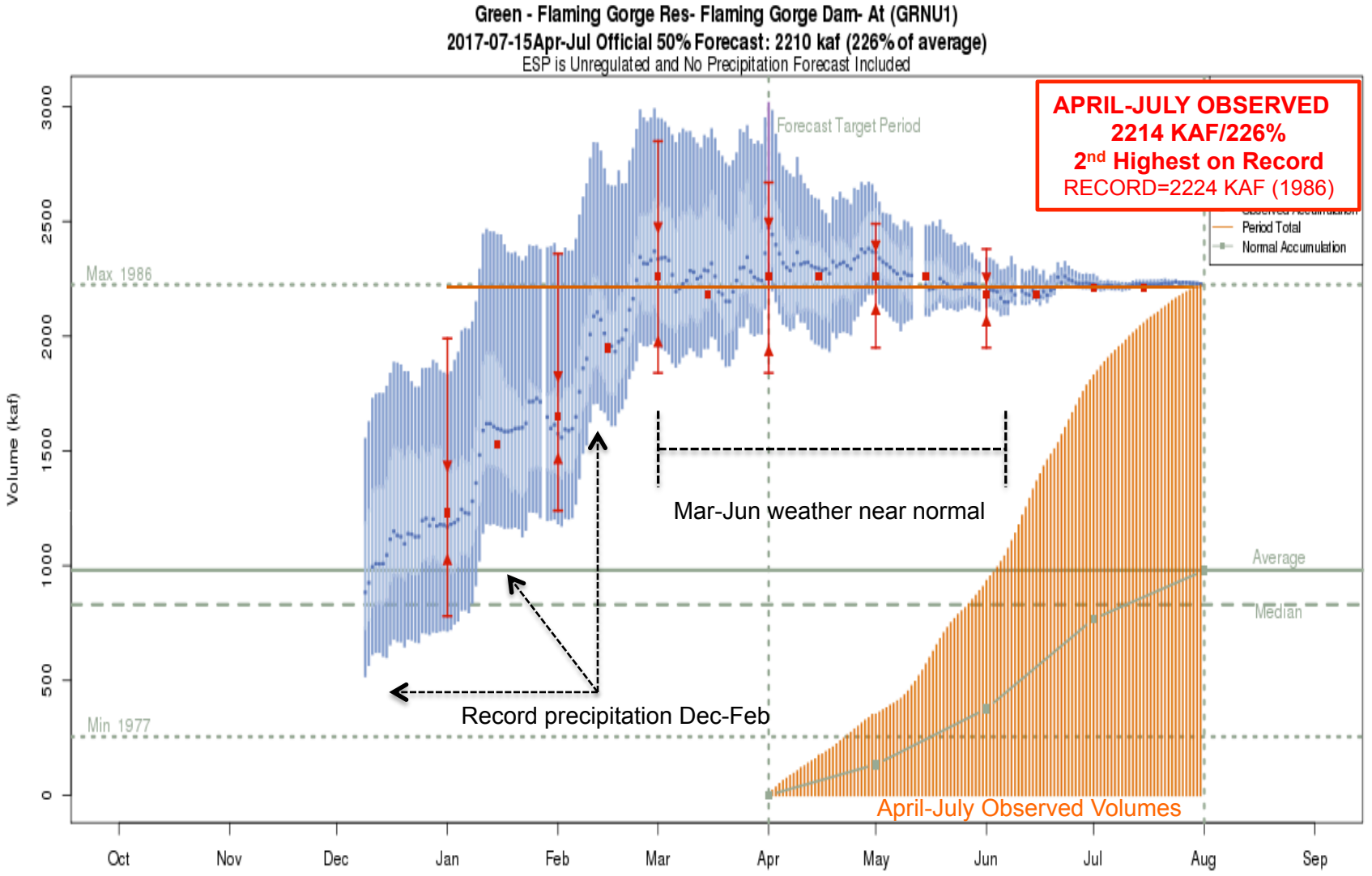
- Largest forecast errors were early and again in May. Extreme wet followed by very dry and warm conditions April-June.
- Seasonal forecasts and the model guidance too high. Possible model snow states were a little off but conditions were also very dry later in spring.

Forecast Evolution Plot: Fontenelle Reservoir Inflow



Near record snow + saturated soil conditions +June rain event = record runoff!

Forecast Evolution Plot: Flaming Gorge Inflow

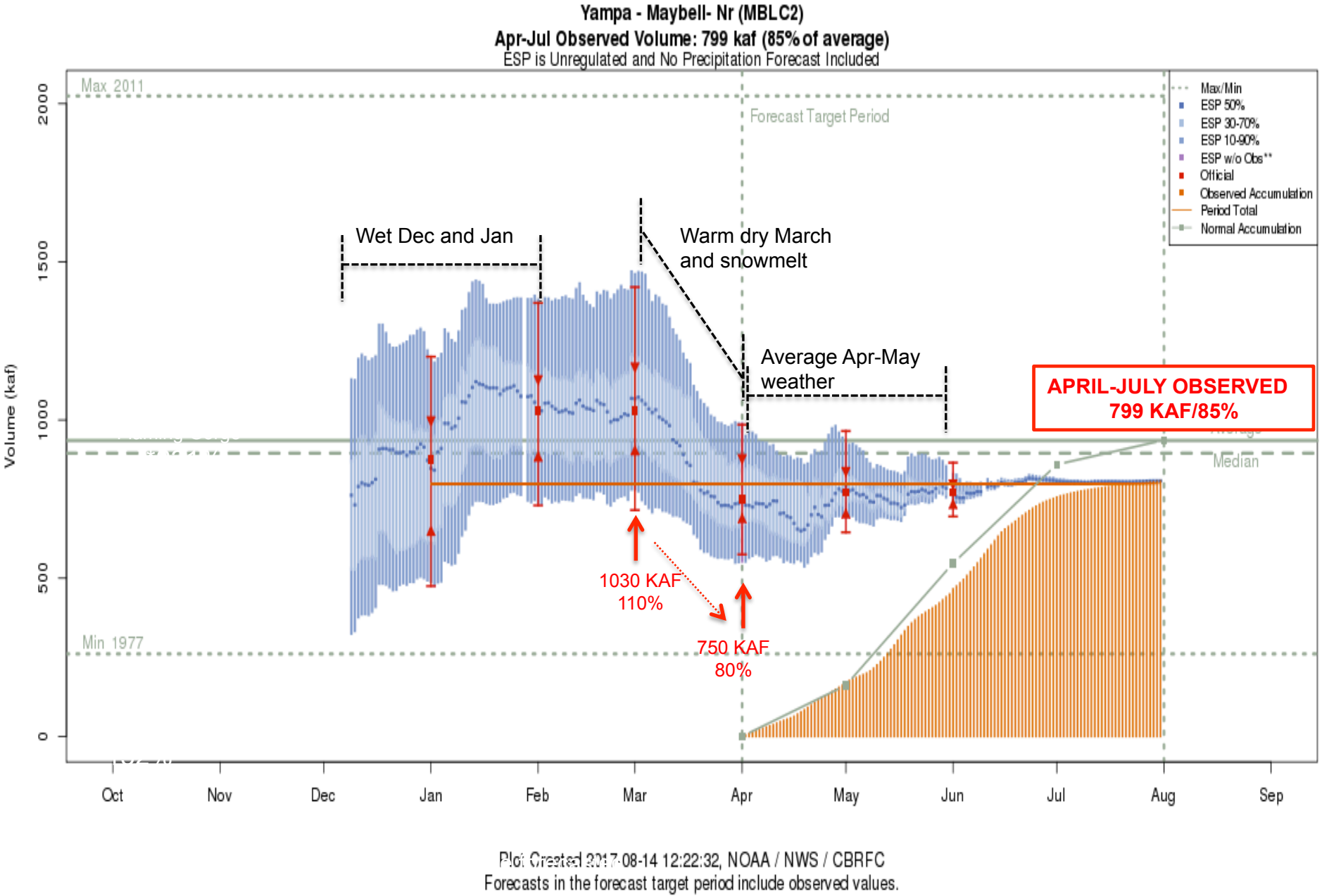


April-July volume impacted more by March warm up and snowmelt.

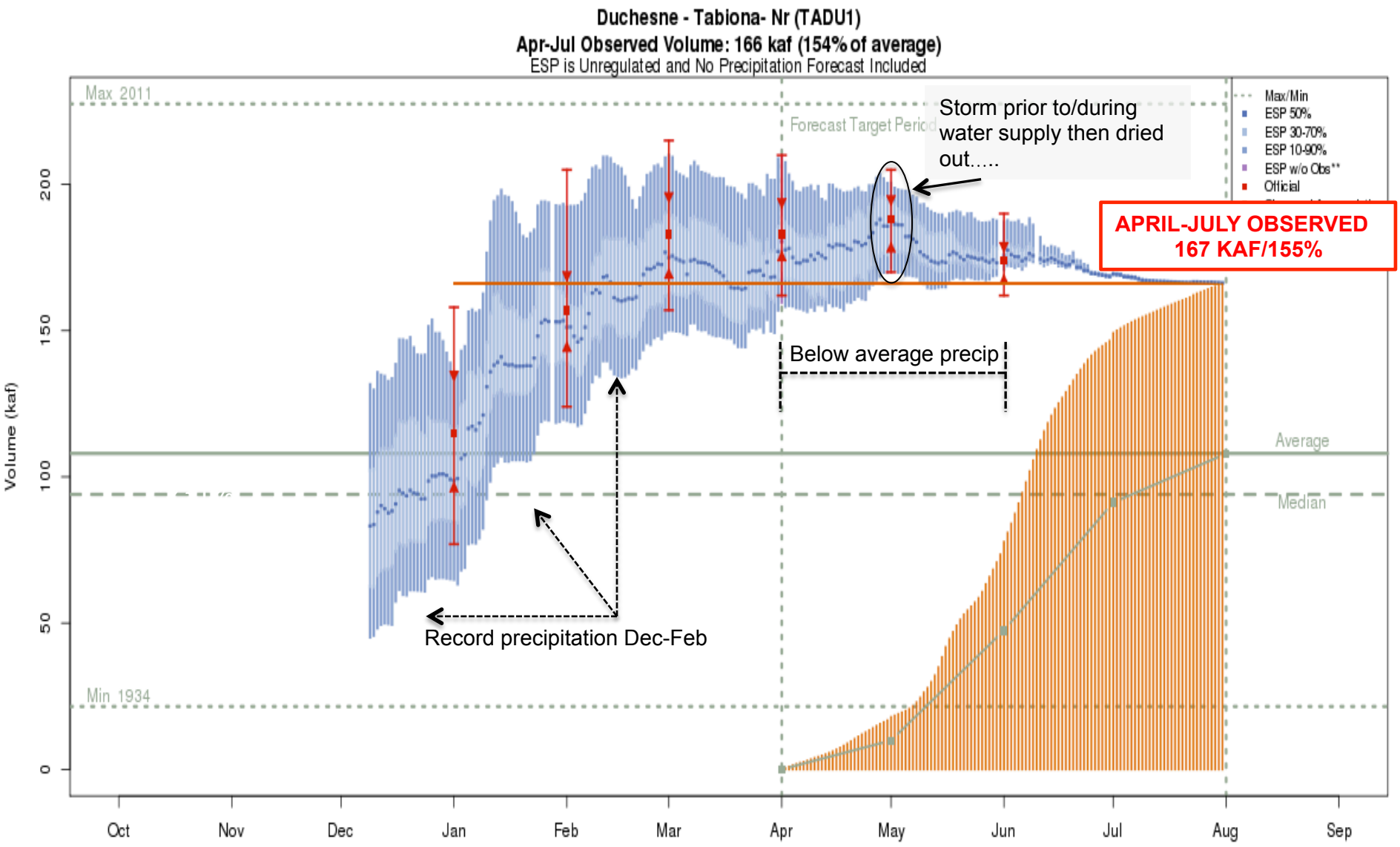
2017 March-July Observed = 2614 KAF

March-July Record (1986) = 2385 KAF

Forecast Evolution Plot: Yampa River-Maybell

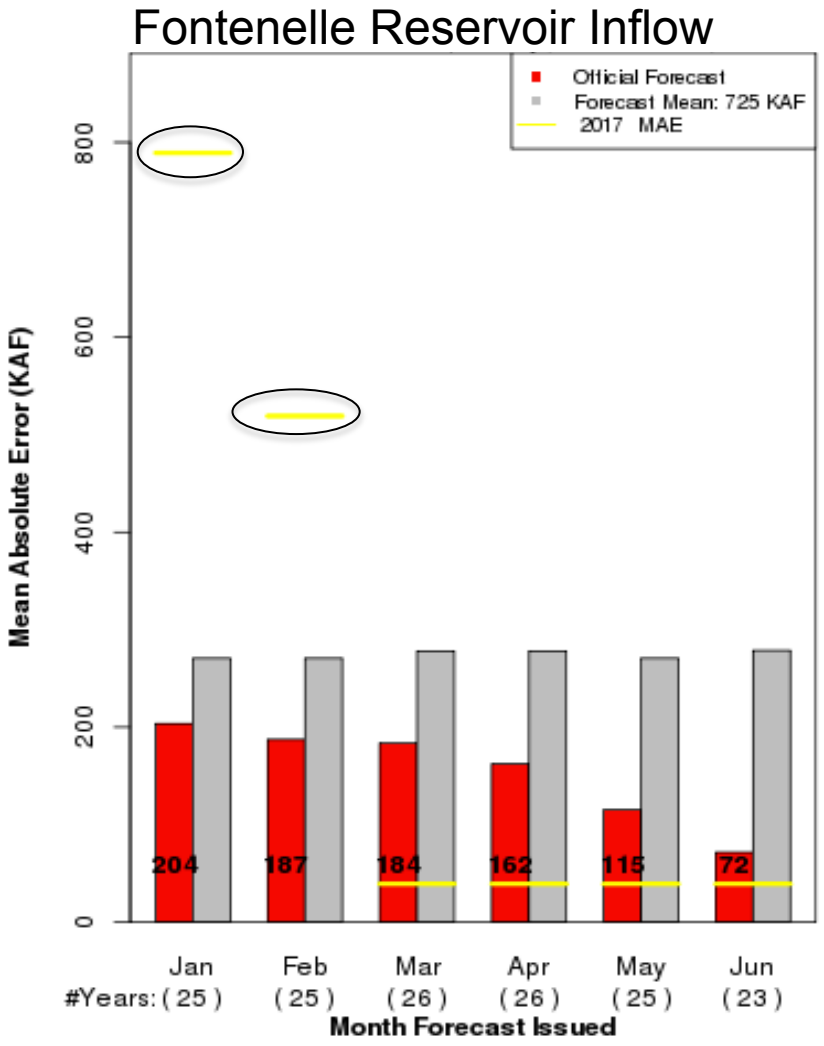


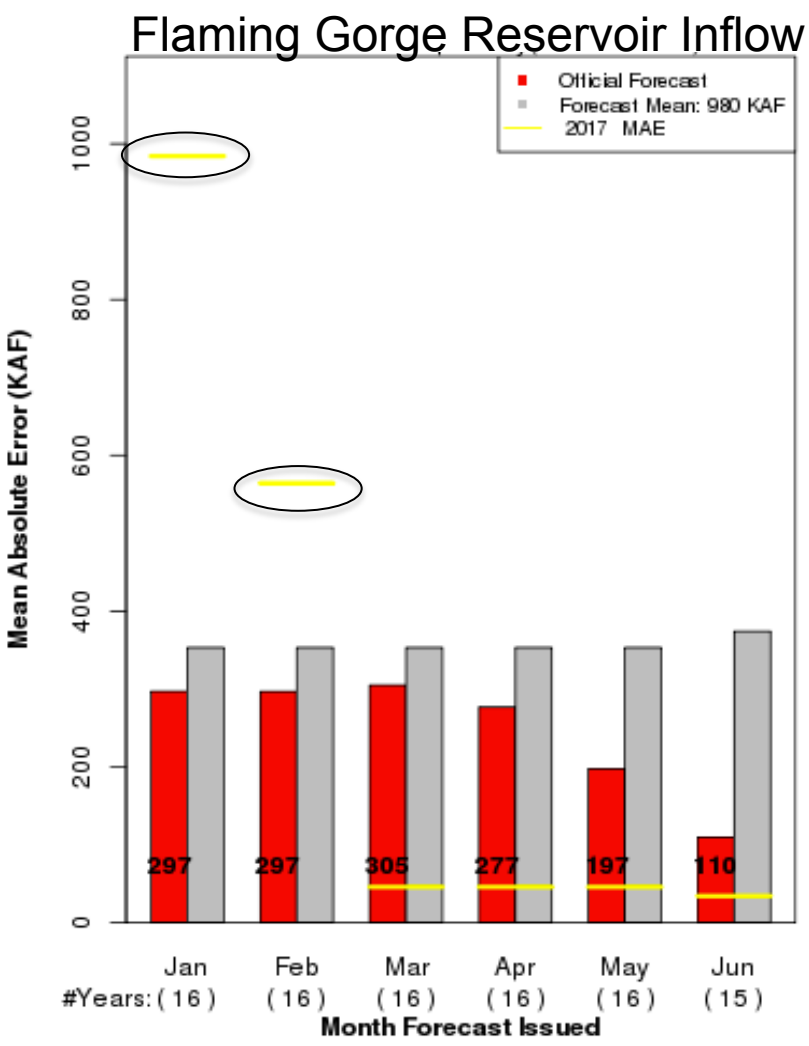
Forecast Evolution Plot: Duchesne River-Tabiona



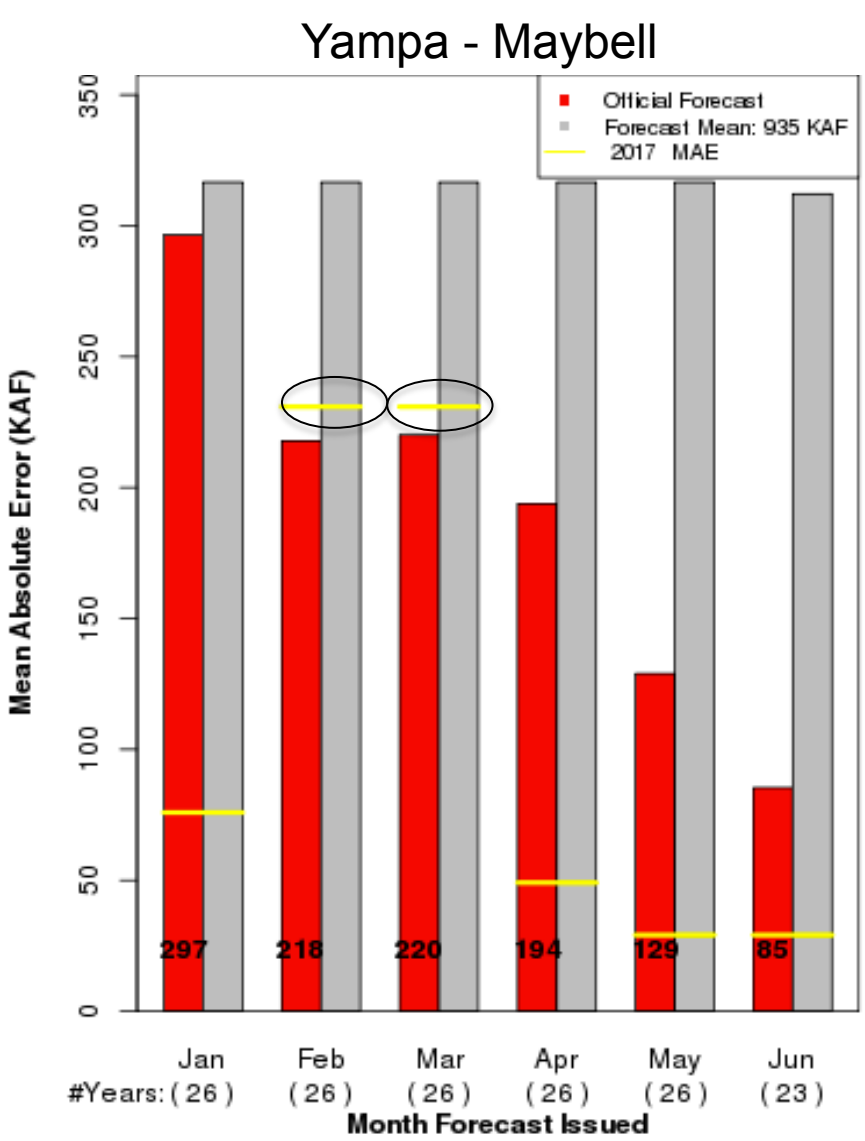
Forecasts were too high from March on.
Conditions were dry but model snow states may have been off.

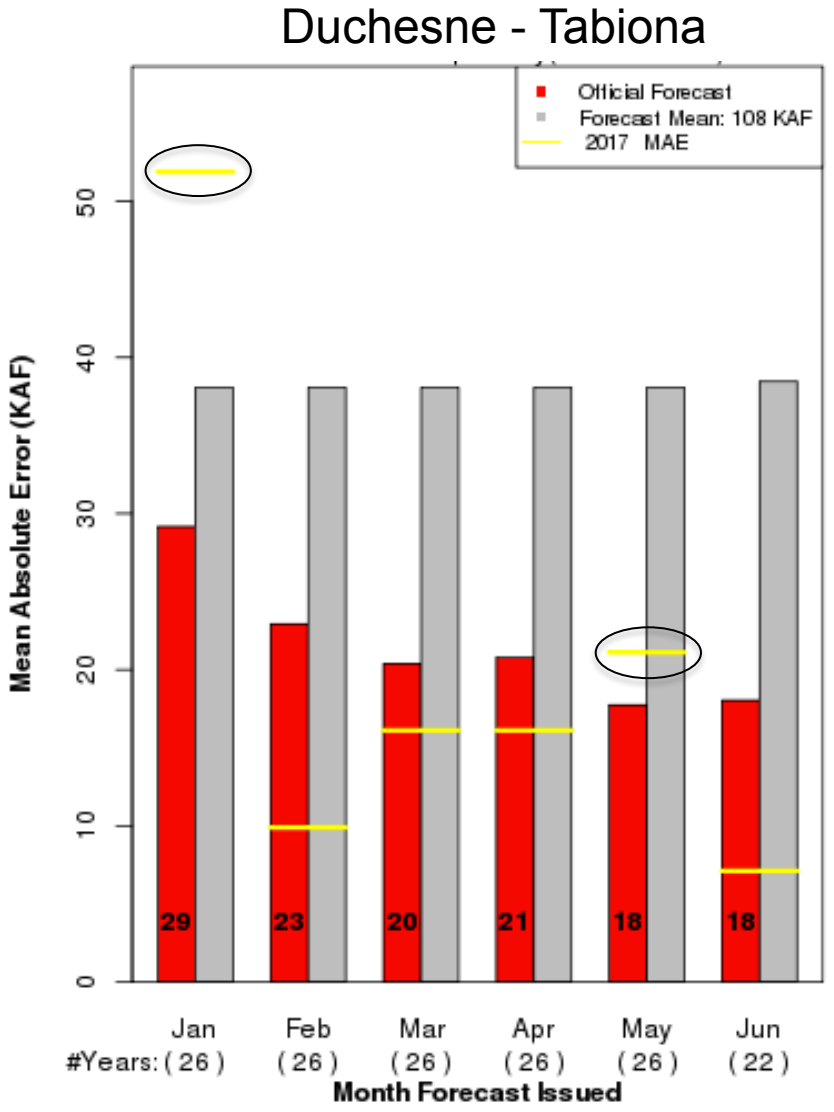
Forecast Verification: Fontenelle and Flaming Gorge Inflows





Forecast Verification:





2017 Forecast / Runoff Impacts

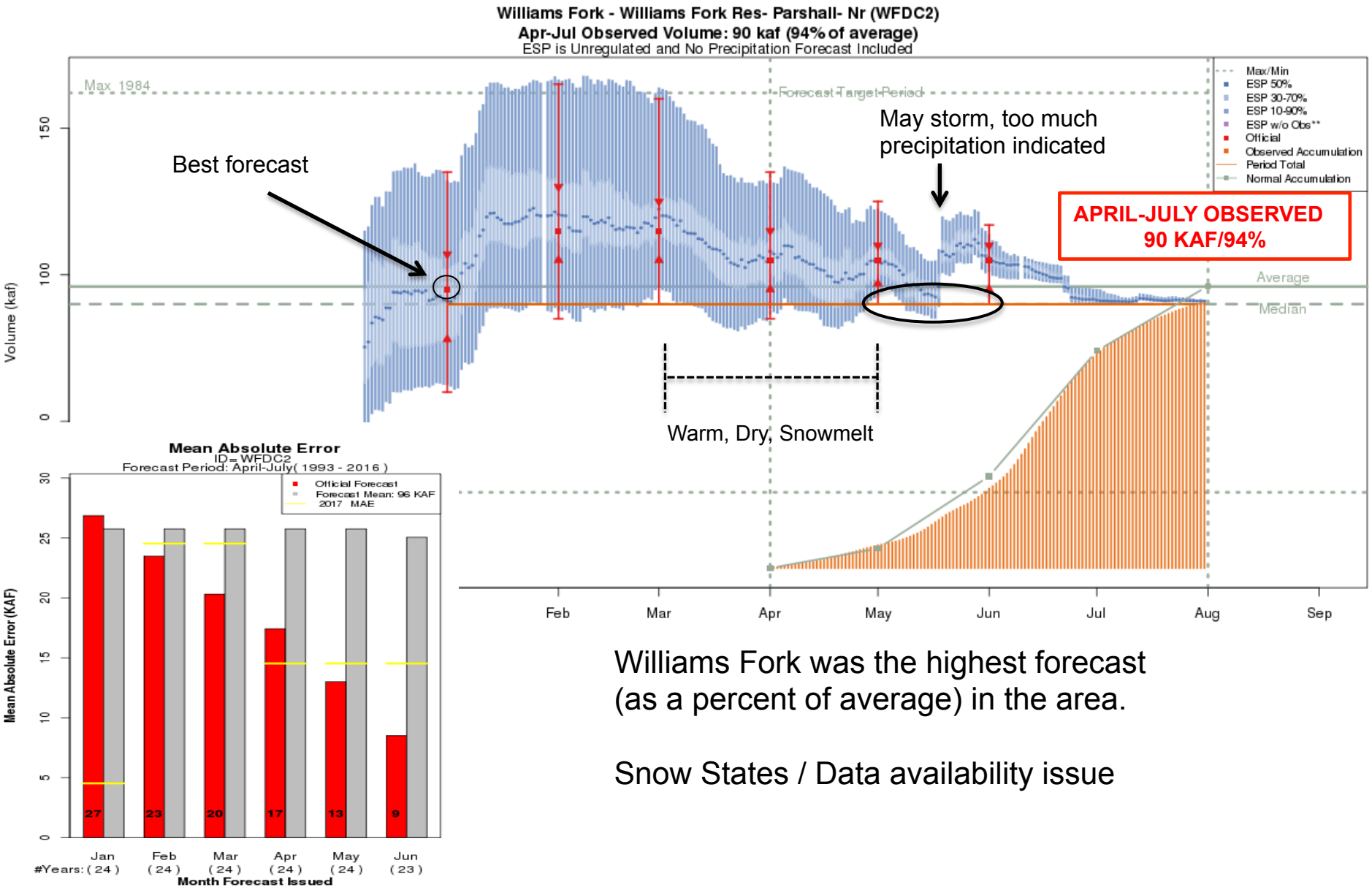
Colorado River Headwaters

- Early season forecast errors were better than usual. Forecast errors increased above historical errors most likely due to snow state issues as well as the dry warm March.

- Farther downstream (Colorado-Cameo) forecast errors were minimized as upstream errors (too high, too low) cancelled each other out.

- Model performed as expected. Issues with the snow states have been identified as due to data limitations. The use of newer SNOTEL sites, once they have a sufficient record, may result in better snowpack representation.

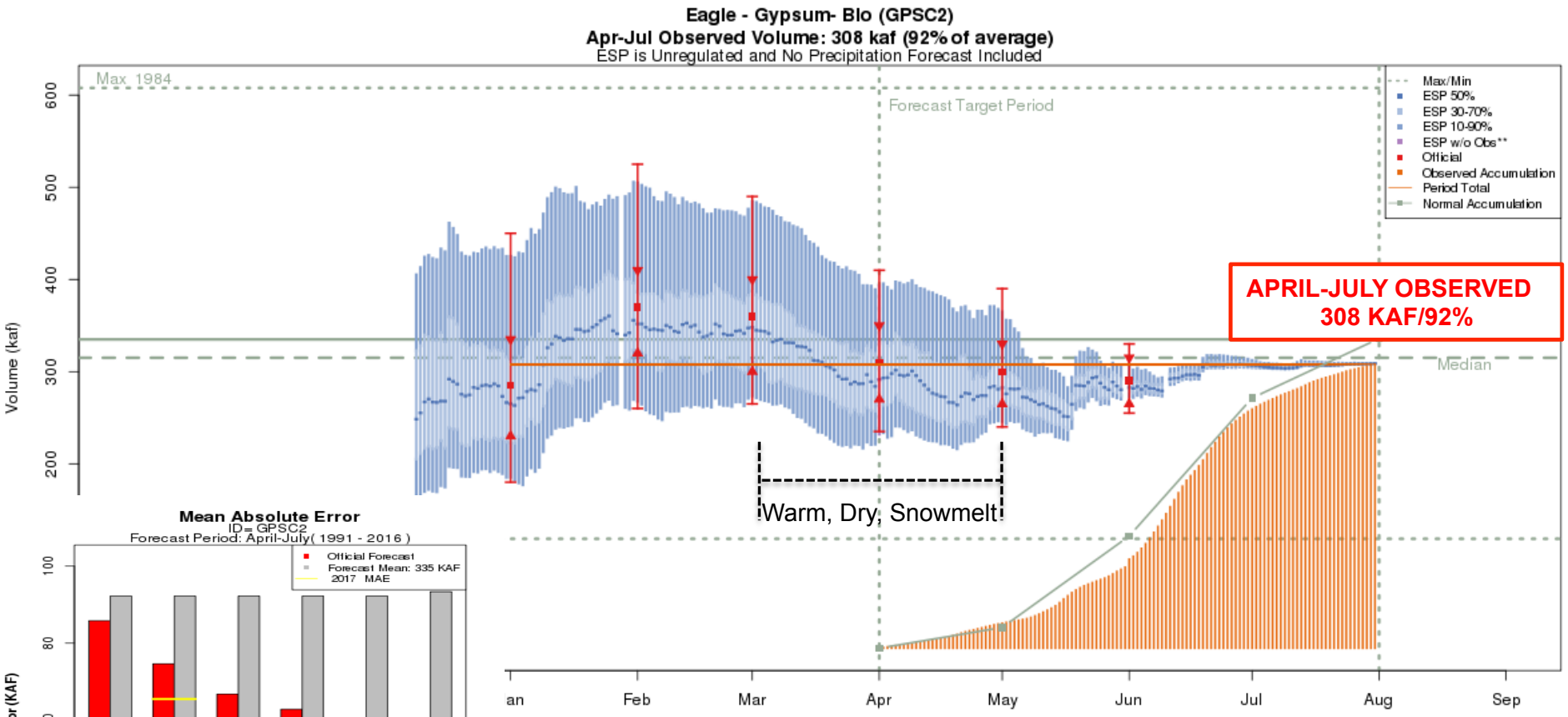
Forecast Evolution Plot: Williams Fork Reservoir

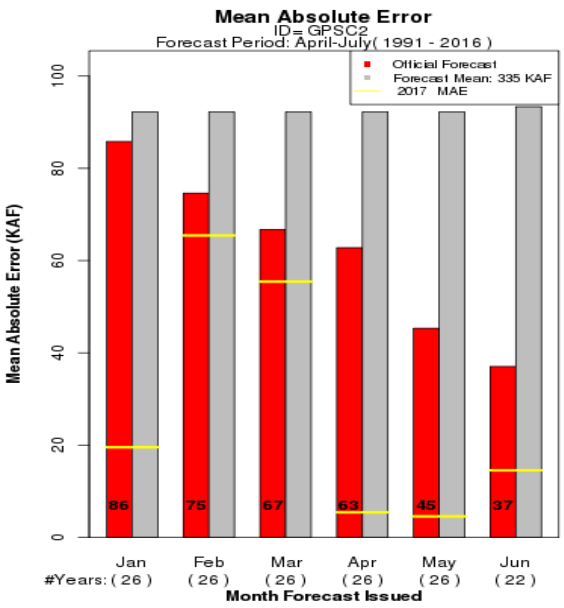


Williams Fork was the highest forecast (as a percent of average) in the area.

Snow States / Data availability issue

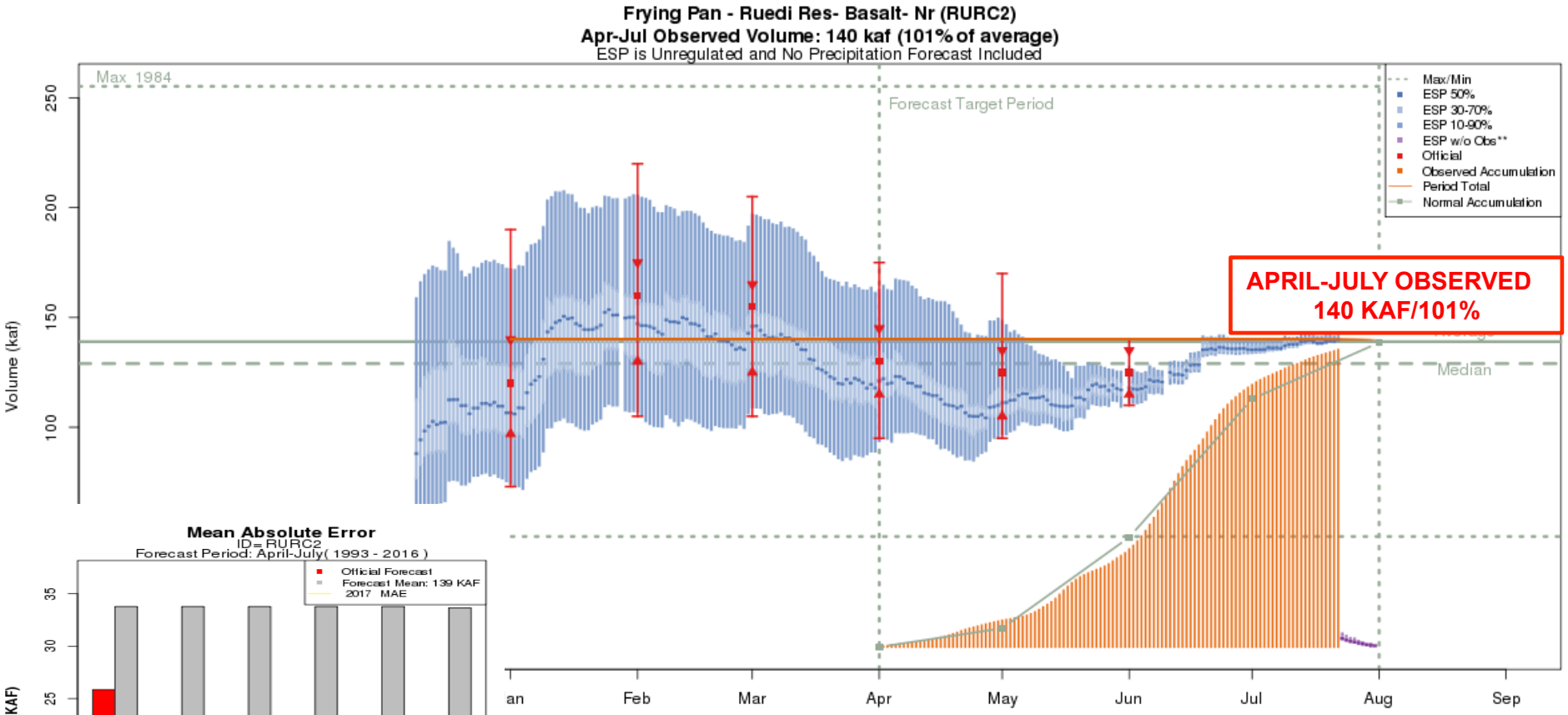
Forecast Evolution Plot: Eagle Bellow Gypsum

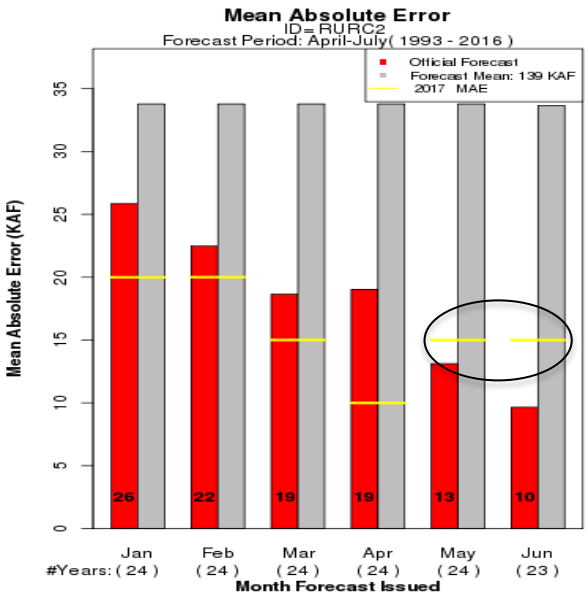




Model performed rather well. Observed volumes fell within the 10/90 forecast range throughout the season.

Forecast Evolution Plot: Ruedi Reservoir Inflow





Model tends to have a low bias. This may be a candidate for recalibration.

2017 Forecast/Runoff Impacts

Gunnison

- Largest errors were at the beginning of the season. Errors climbed above historical errors late in the season.
- Early season errors were explained by the extreme wet weather that followed. Late season errors were due to inaccurate model snow states at the highest elevations. Too much snow melted out of these areas in the model during the very warm periods earlier in spring.

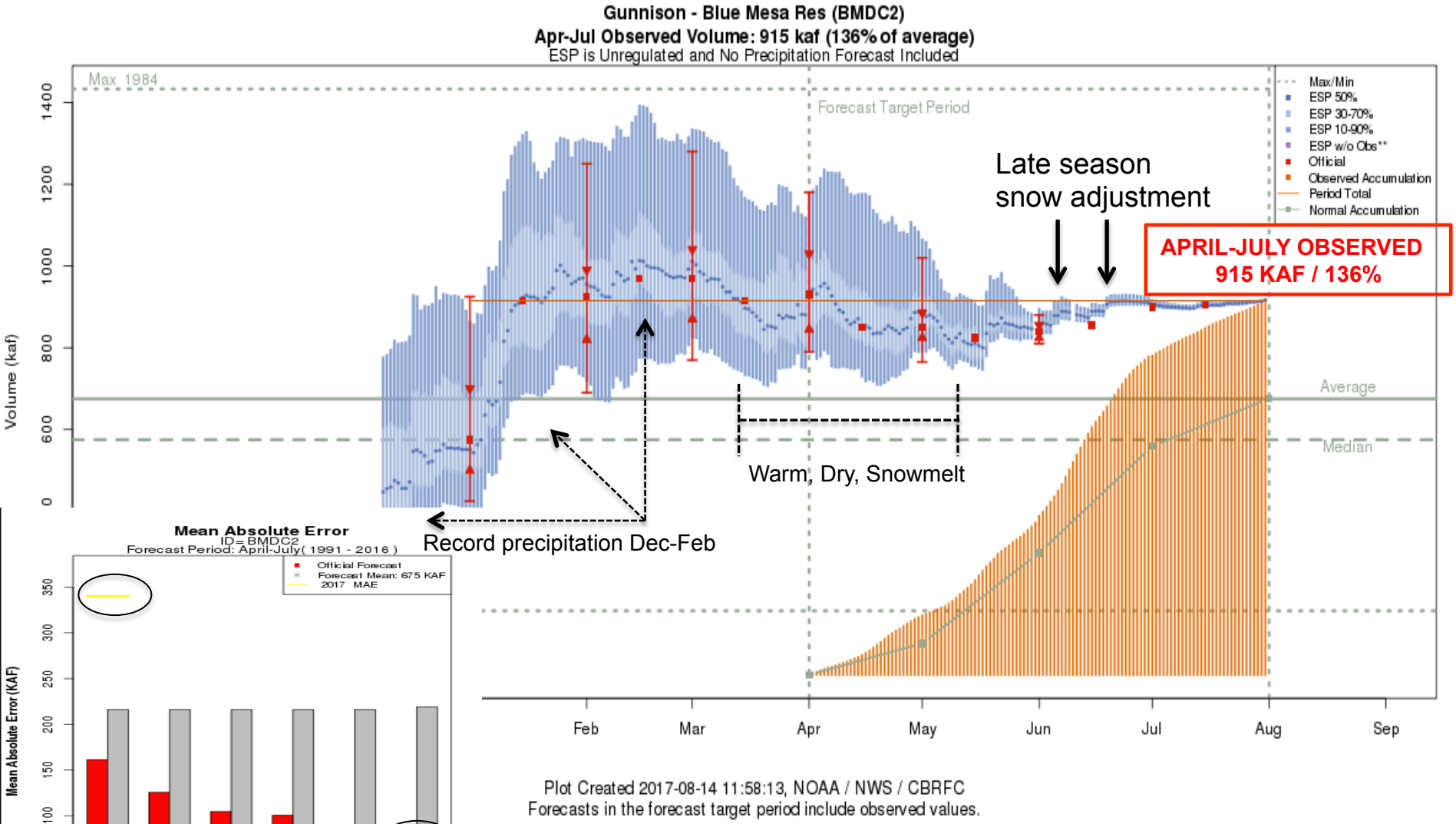
Dolores

- Largest errors were February – April, above historical error. These improved later in the season.
- Forecast error was easily attributed to a record / near record snowpack that developed early to be followed by very dry and warm conditions March-April.

San Juan

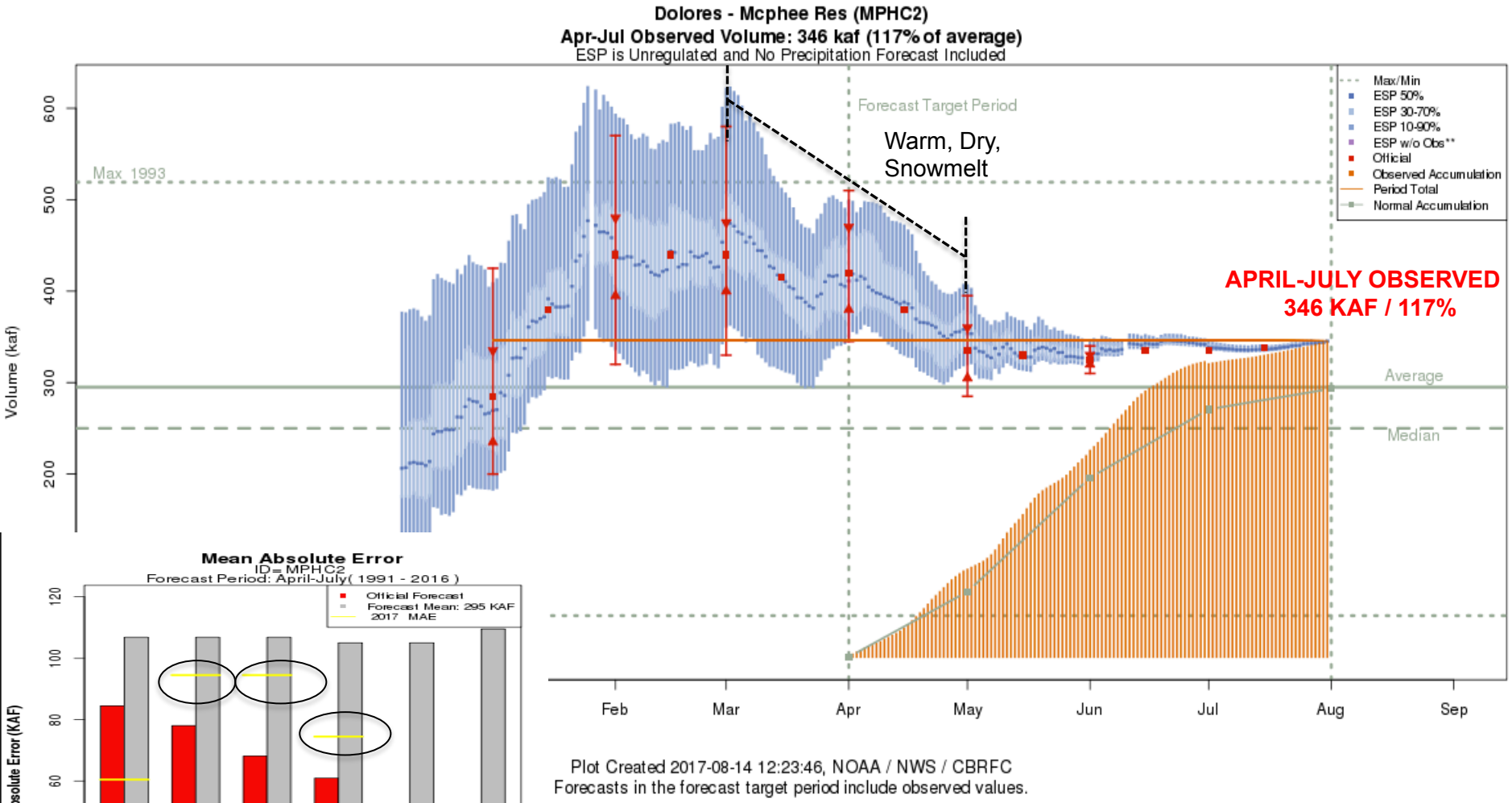
- Early season errors due to wet weather that followed. Some late season errors due to snow states at high elevations too low. Animas and eastern tributaries of the San Juan River.

Forecast Evolution Plot: Blue Mesa Inflow



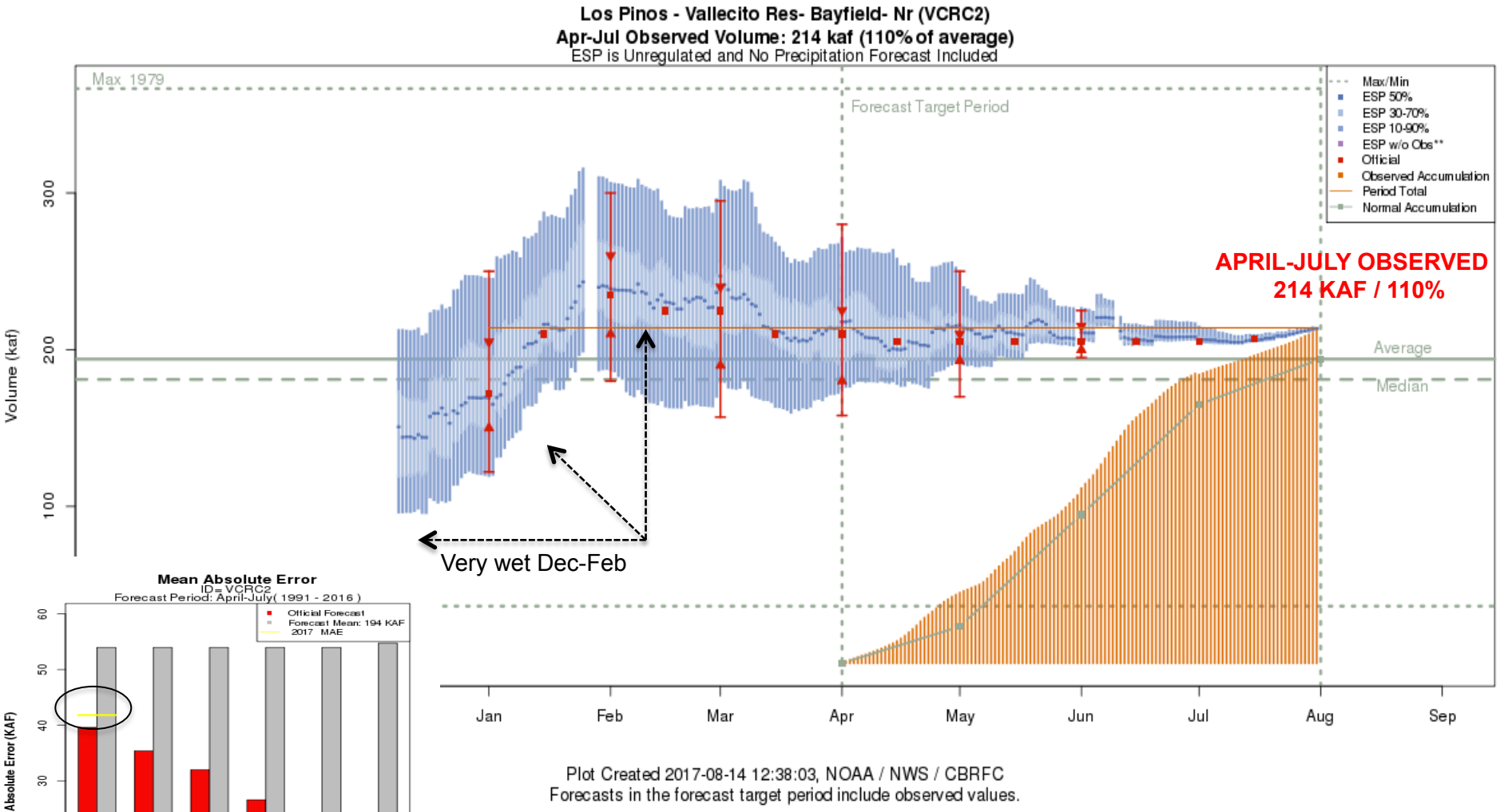
Increase in error (compared to historical) late in season.
Not enough snow at high elevations of the model

Forecast Evolution Plot: McPhee Reservoir Inflow



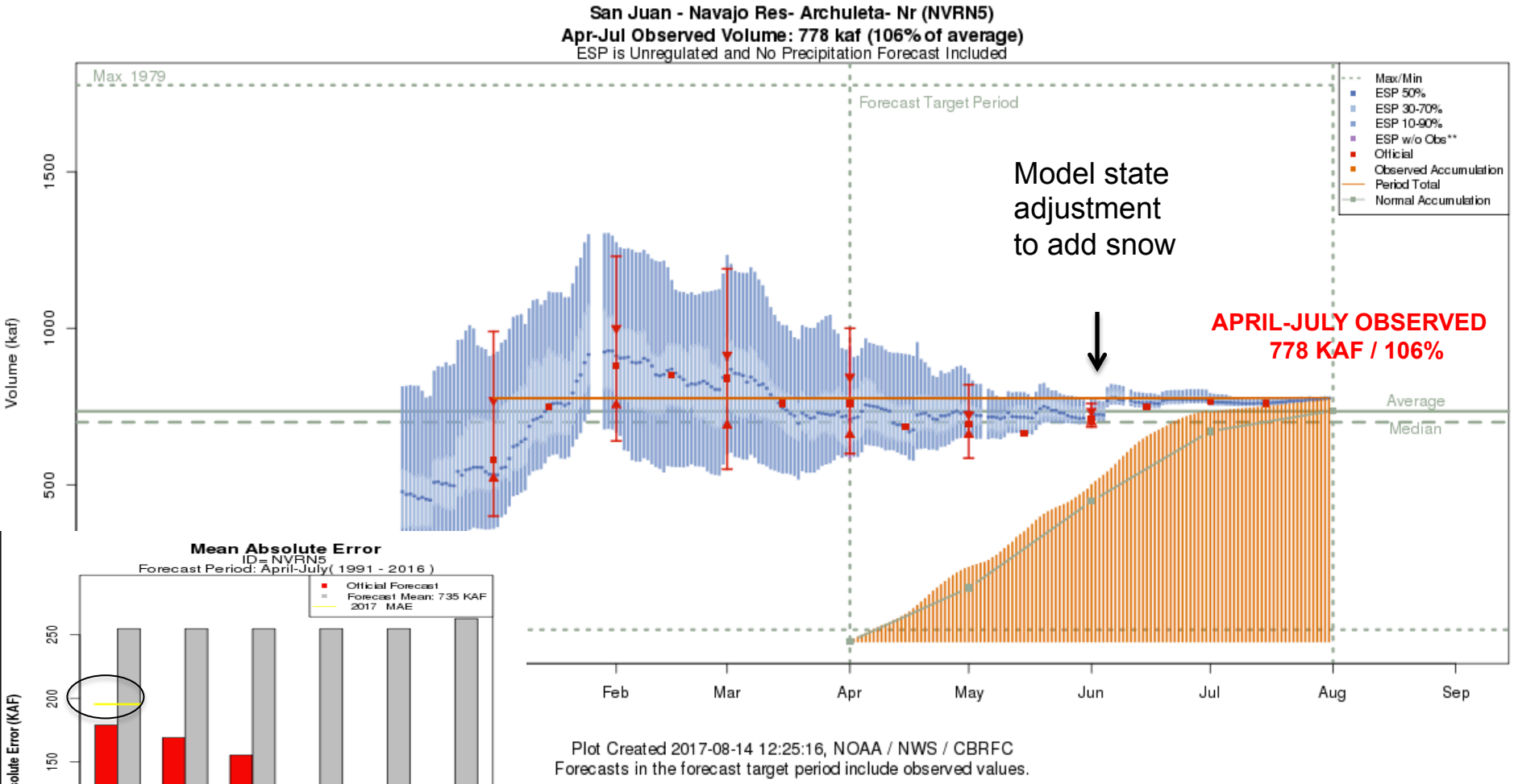
Model performed well. No significant adjustments to model states were necessary. Another dry warm spring had significant impacts on evolving forecasts and runoff.

Forecast Evolution Plot: Vallecito Reservoir Inflow



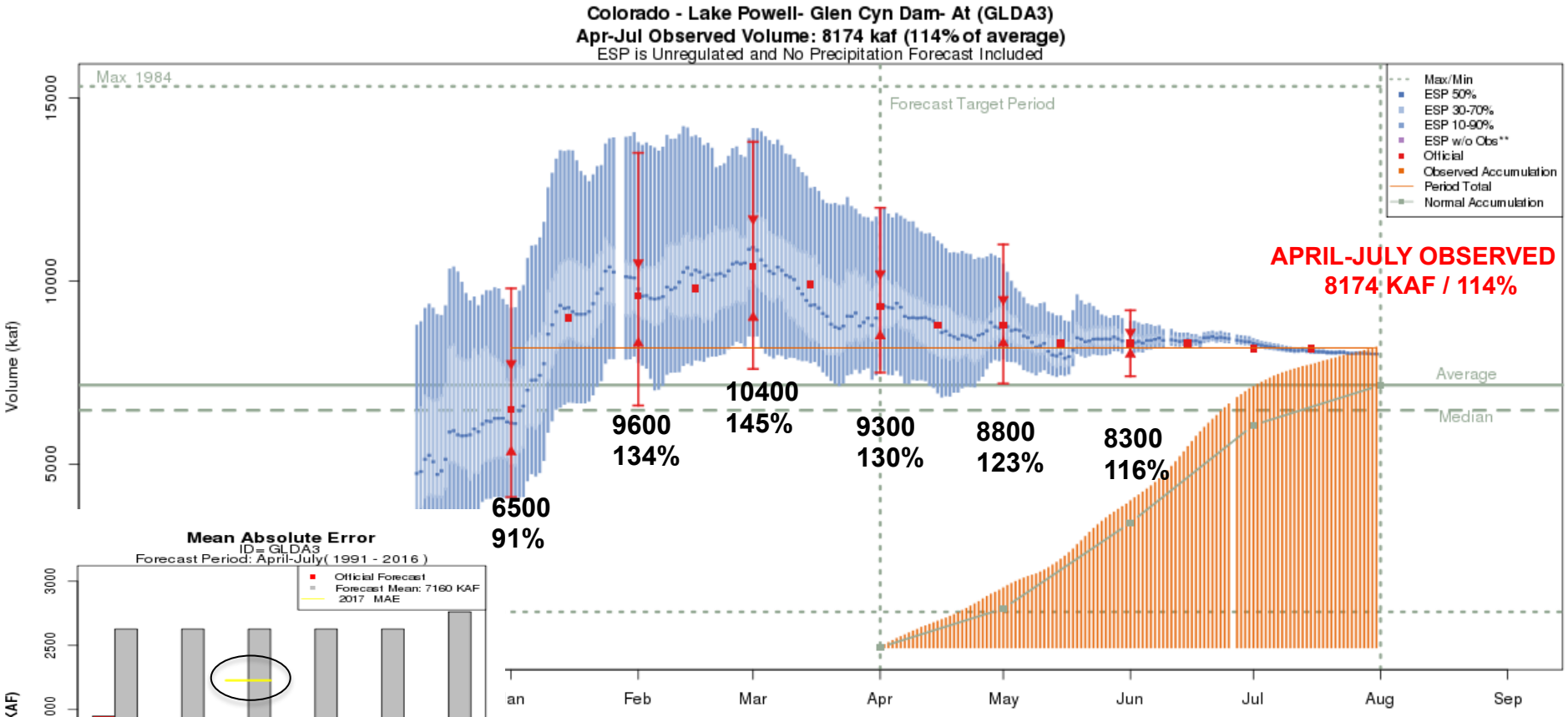
Forecast declined due to dry March-April. May was wetter. Model performed very well with consistent forecasts mid March forward

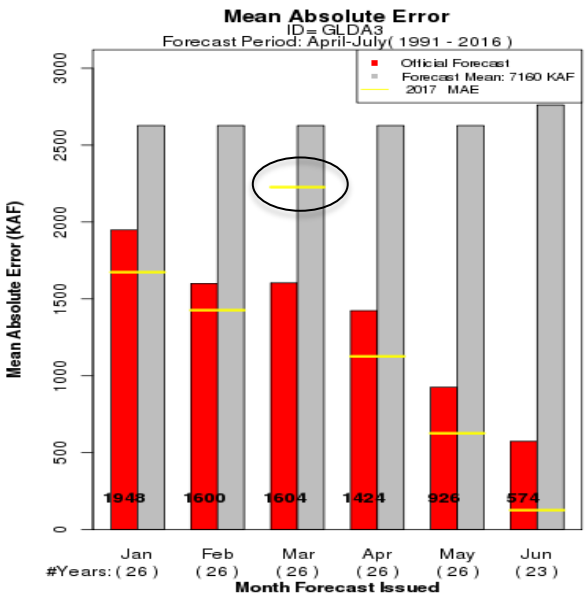
Forecast Evolution Plot: Navajo Reservoir Inflow



Early season error due to wet weather that followed. Late season error was due to a model snow states being too low in eastern headwaters of the San Juan. (Rio Blanco,Navajo).

Forecast Evolution Plot: Lake Powell





Reflected the basin as a whole with early season errors due to wet weather that followed. Forecasts decreased due to warm dry March-April. Overall model performed as expected. Largest error was in March.

2017 Forecast/Runoff Impacts

Eastern Great Basin

- Errors greater than historical existed throughout the forecast season for many sites. Largest errors were early in the season and again in March

- Several things contributed to forecast errors larger than the historical errors. Early season errors can be attributed to the extreme wet conditions that followed. Significant snow at lower elevations melted in February and early March due to warm temperatures. Saturated soils and flooding was the result. Models most likely struggled with soil moisture states as well as how much high elevation snow remained later in the season.

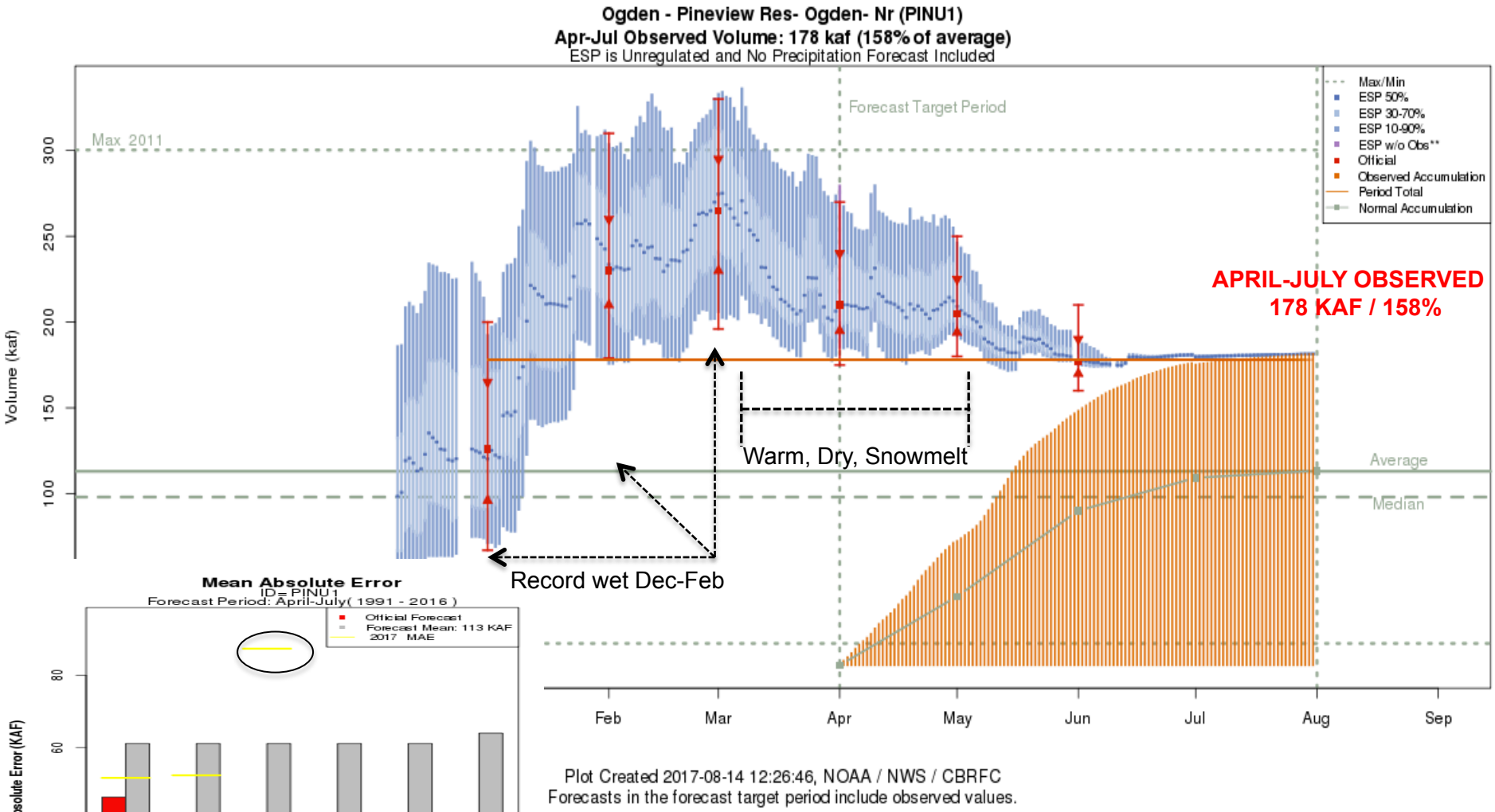
Sevier

- Errors a little above the historical error Feb-May, however historical errors are generally small in the spring. The dry spring weather may have resulted in a little too much melt out of high elevation snow in the model

Virgin

- Forecast errors were below the historical error throughout the season.

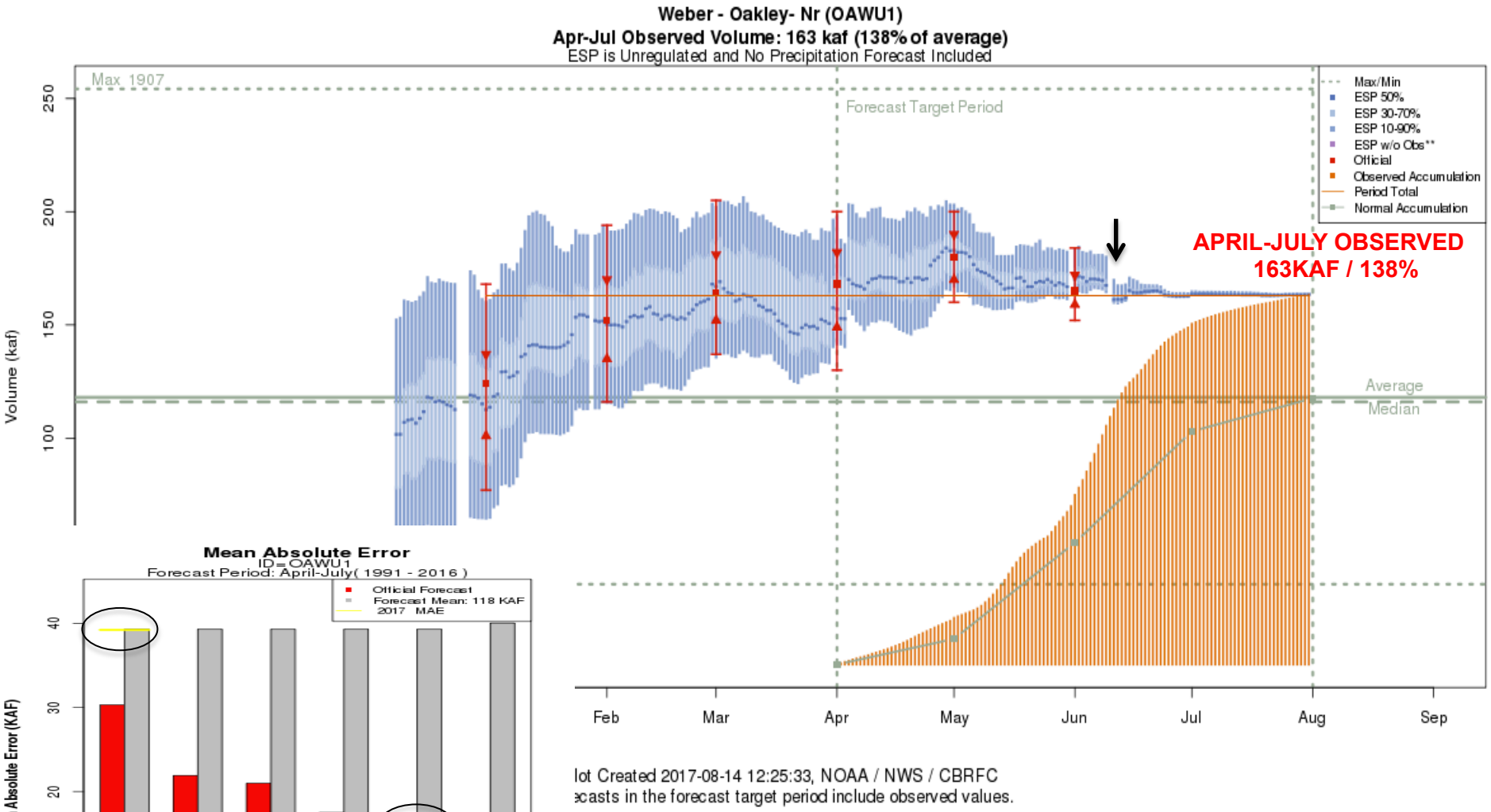
Forecast Evolution Plot: Pineview Reservoir Inflow



Plot Created 2017-08-14 12:26:46, NOAA / NWS / CBRFC
Forecasts in the forecast target period include observed values.

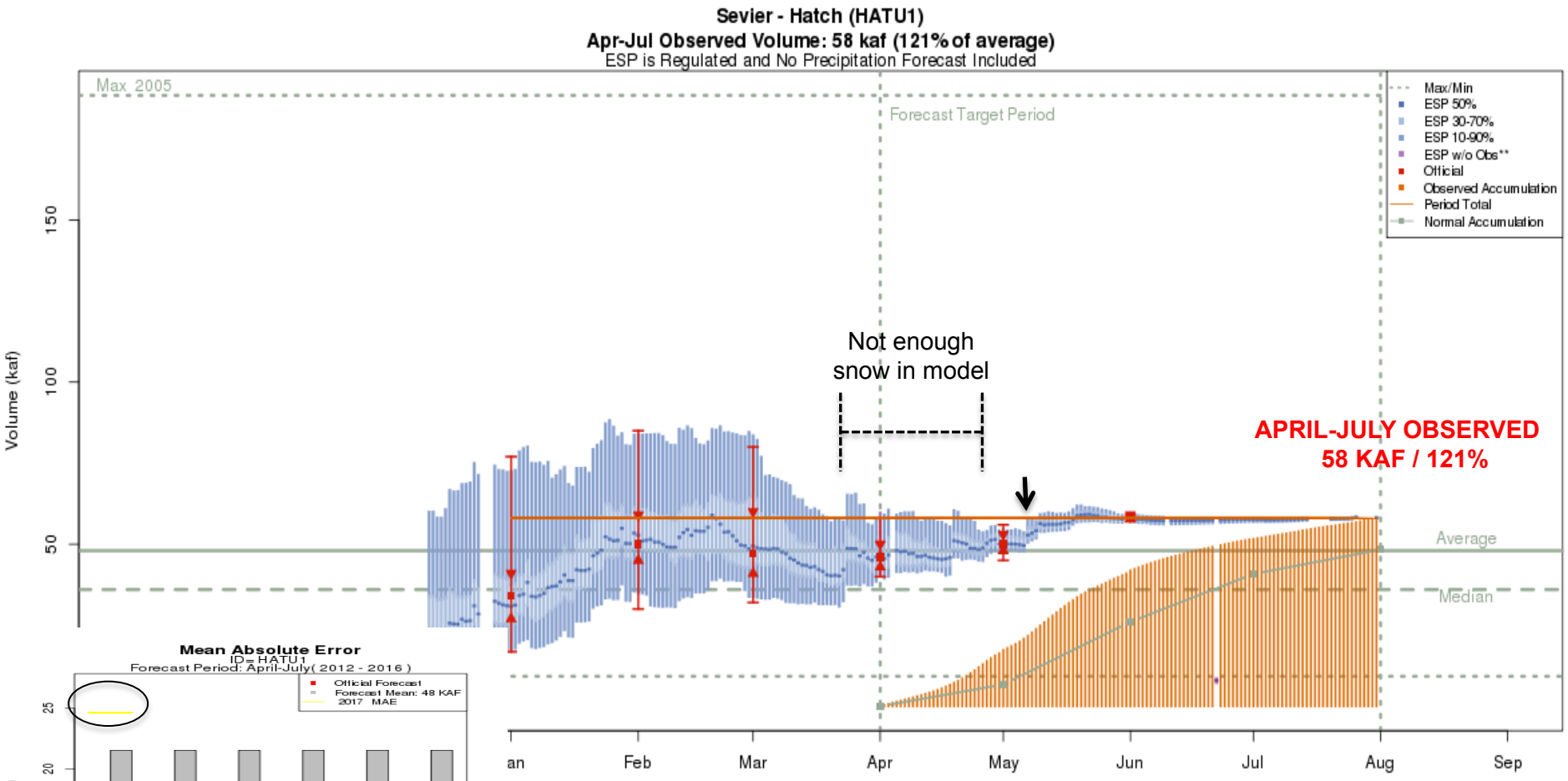
Forecast error was above historical throughout the season. The extreme back and forth weather had a large impact. Model snow states may have been too high.

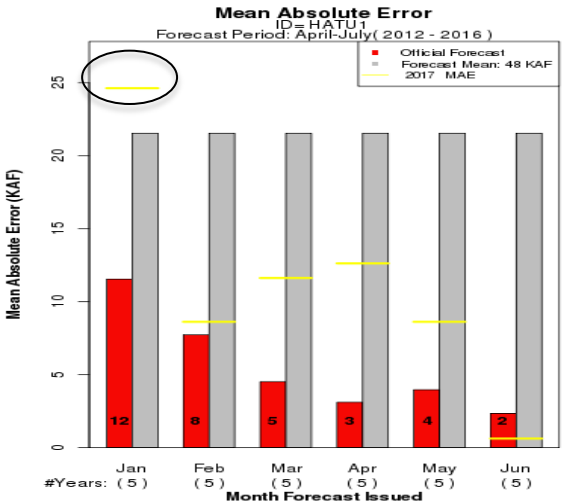
Forecast Evolution Plot: Weber River at Oakley



Model performed much better at this higher elevation site.

Forecast Evolution Plot: Sevier River at Hatch

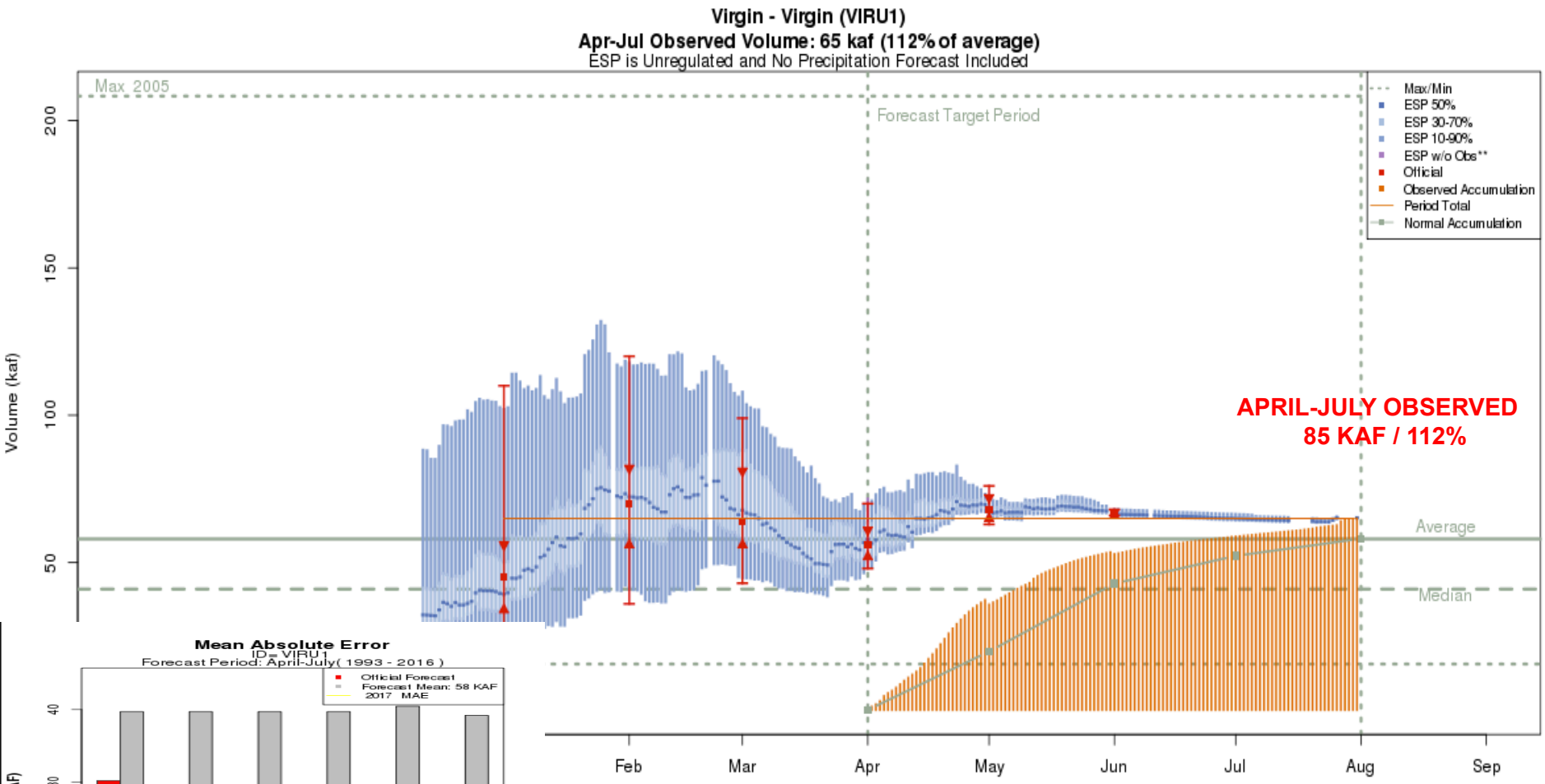


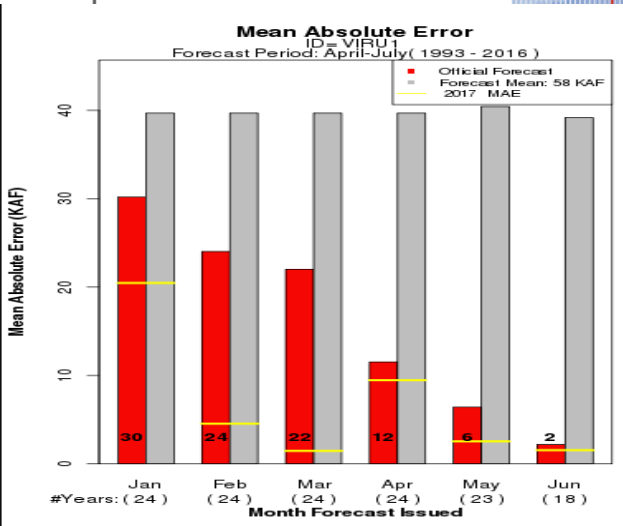


Plot Created 2017-08-14 12:16:49, NOAA / NWS / CBRFC
**Purple ESP forecasts do not include observed and are not total runoff.

Historical errors are low here. Model performed fairly well but may have melted too much high elevation snow during the warm March-April period.

Forecast Evolution Plot: Virgin at Virgin





Plot Created 2017-08-14 12:38:37, NOAA / NWS / CBRFC
Forecasts in the forecast target period include observed values.

A good forecast throughout as the forecast / model error was lower than the historical error.

2017 Forecast / Runoff Impacts

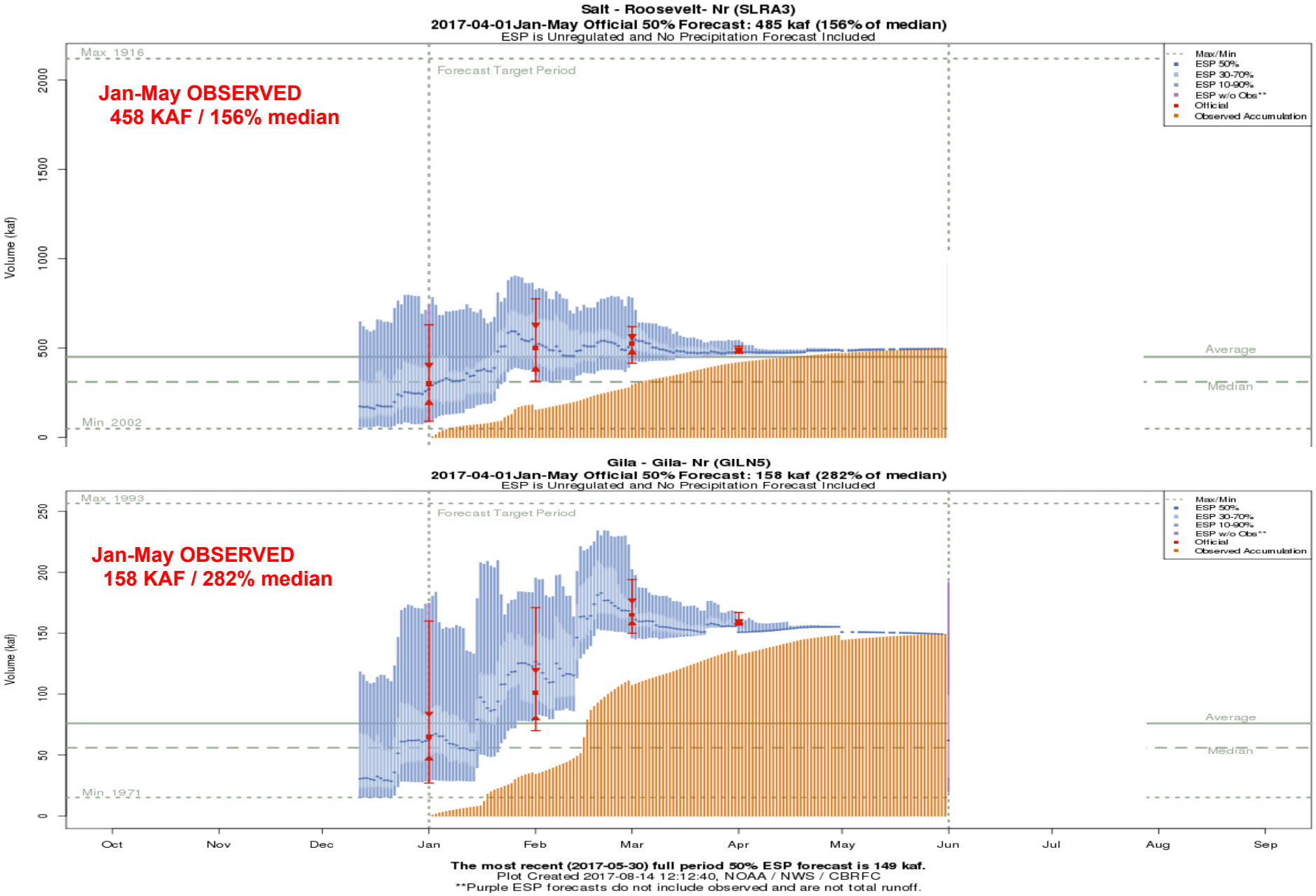
Lower Colorado – Little Colorado, Gila, Salt, Verde

- Forecasts are developed based on current snowpack, soil moisture conditions, ENSO (El Nino outlook), and short term rainfall outlook. Snowpack plays a role but the winter rain events are what really generates the seasonal volumes.

- Above average observed Dec-Feb. Weak La Nina conditions gave way to weak El Nino conditions By February. Forecasts correctly called for above median volumes as the season progressed.

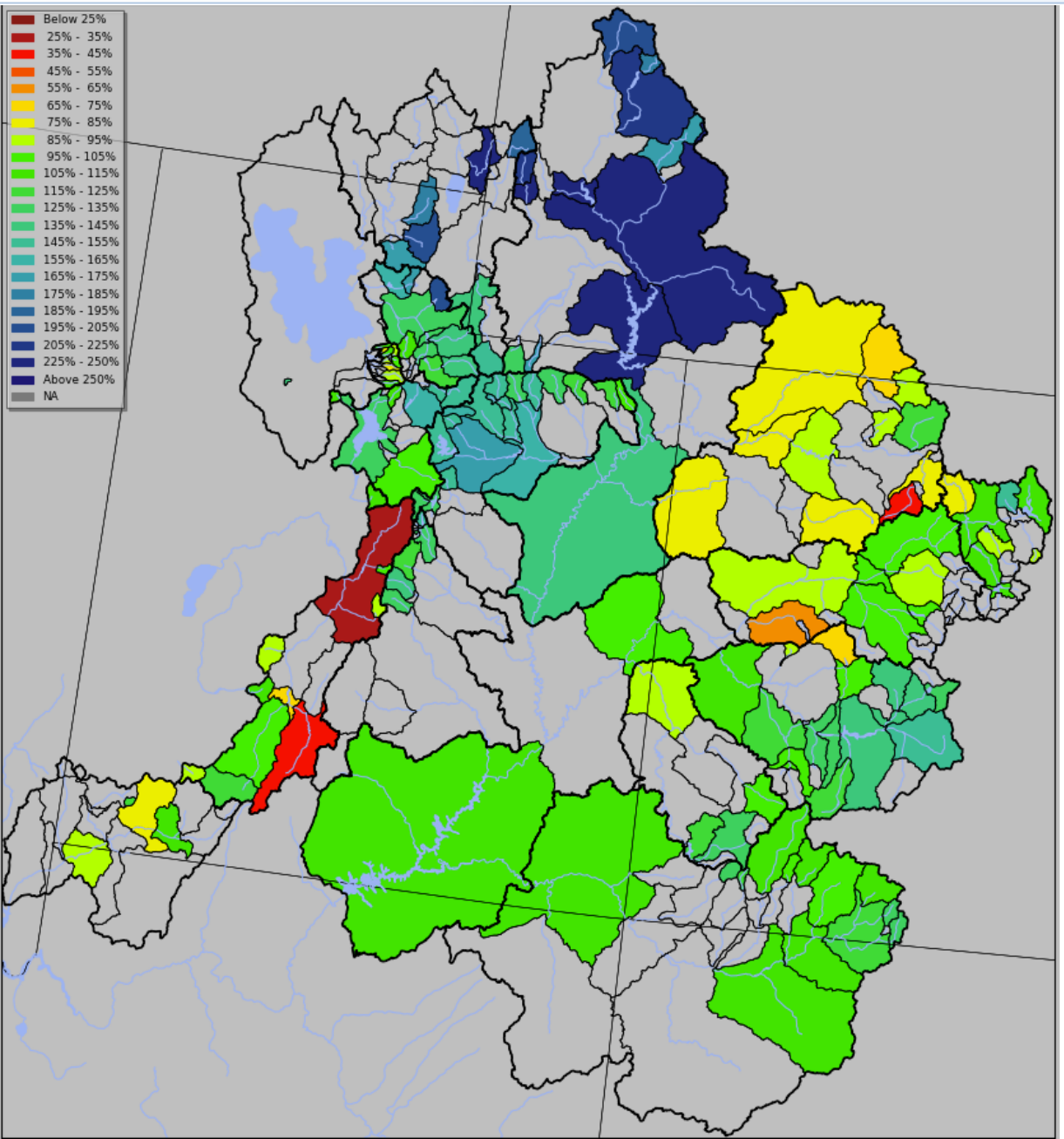
- Notice the forecast range is quite large, anticipating the potential of winter rain events. A wet period from mid January into February had the largest impact on the forecasts.

Forecast Evolution Plots: Lower Colorado River Basin



The most recent (2017-05-30) full period 50% ESP forecast is 149 kaf.
Plot Created 2017-08-14 12:12:40, NOAA / NWS / CBRFC
**Purple ESP forecasts do not include observed and are not total runoff.

Wrapping things up….



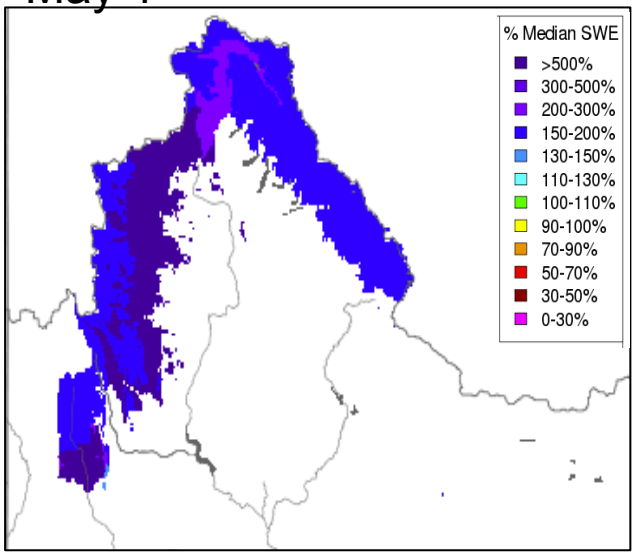
2017 observed
April-July runoff volumes
Percent of Average

Below 25%
25% - 35%
35% - 45%
45% - 55%
55% - 65%
65% - 75%
75% - 85%
85% - 95%
95% - 105%
105% - 115%
115% - 125%
125% - 135%
135% - 145%
145% - 155%
155% - 165%
165% - 175%
175% - 185%
185% - 195%
195% - 205%
205% - 225%
225% - 250%
Above 250%
NA

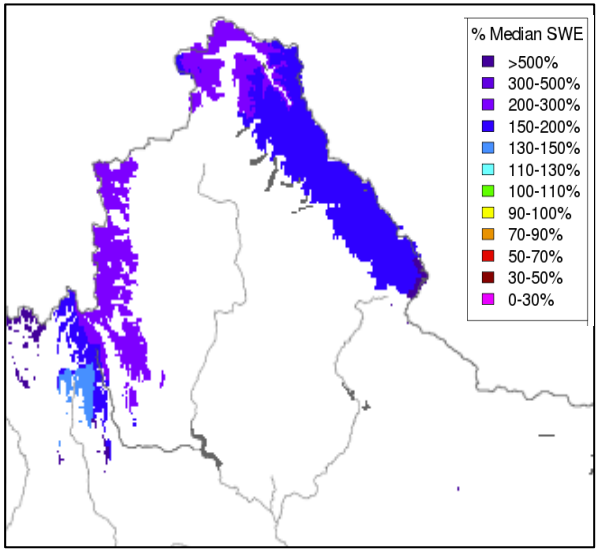
Upper Green Snow (Modeled May –July) – Late Melt !

CBRFC MODEL SNOW (% median)
Significant Runoff Areas

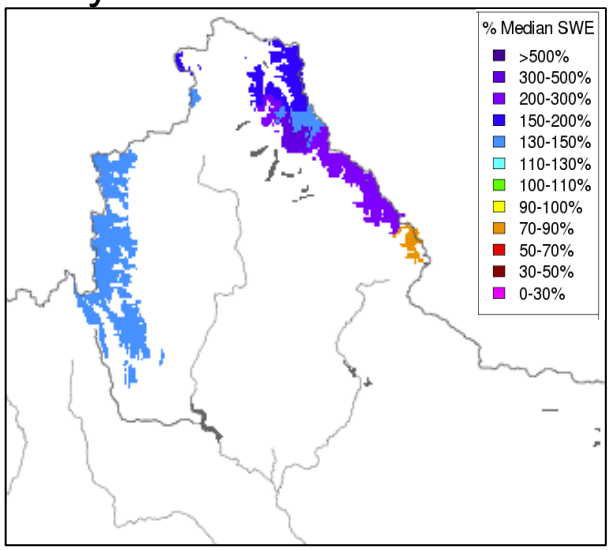
May 1



June 1



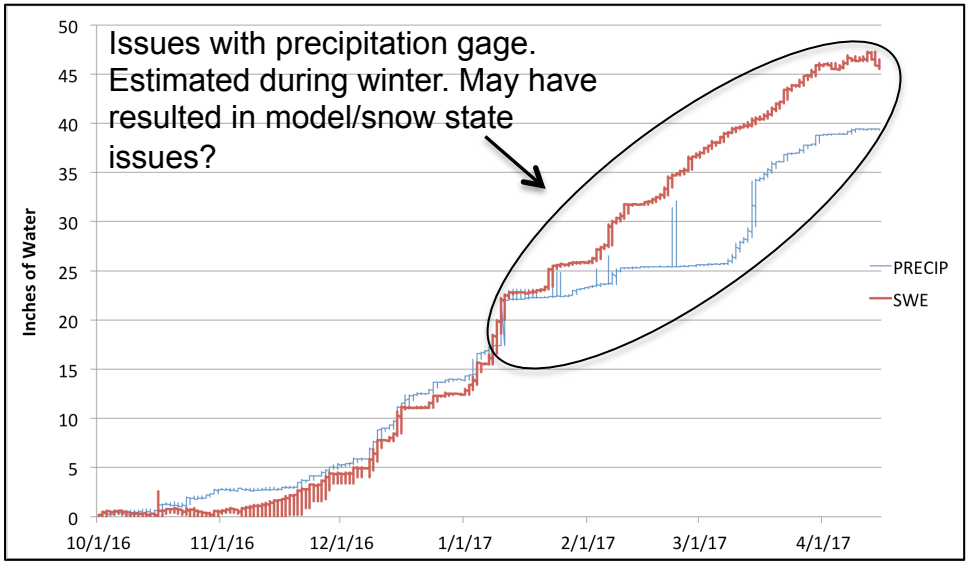
July 1



March/April warm up did not impact high and mid elevation snow. Significant snow remained through July. Diurnal snowmelt pattern was seen well into summer.

Potential data issues due to deep snow

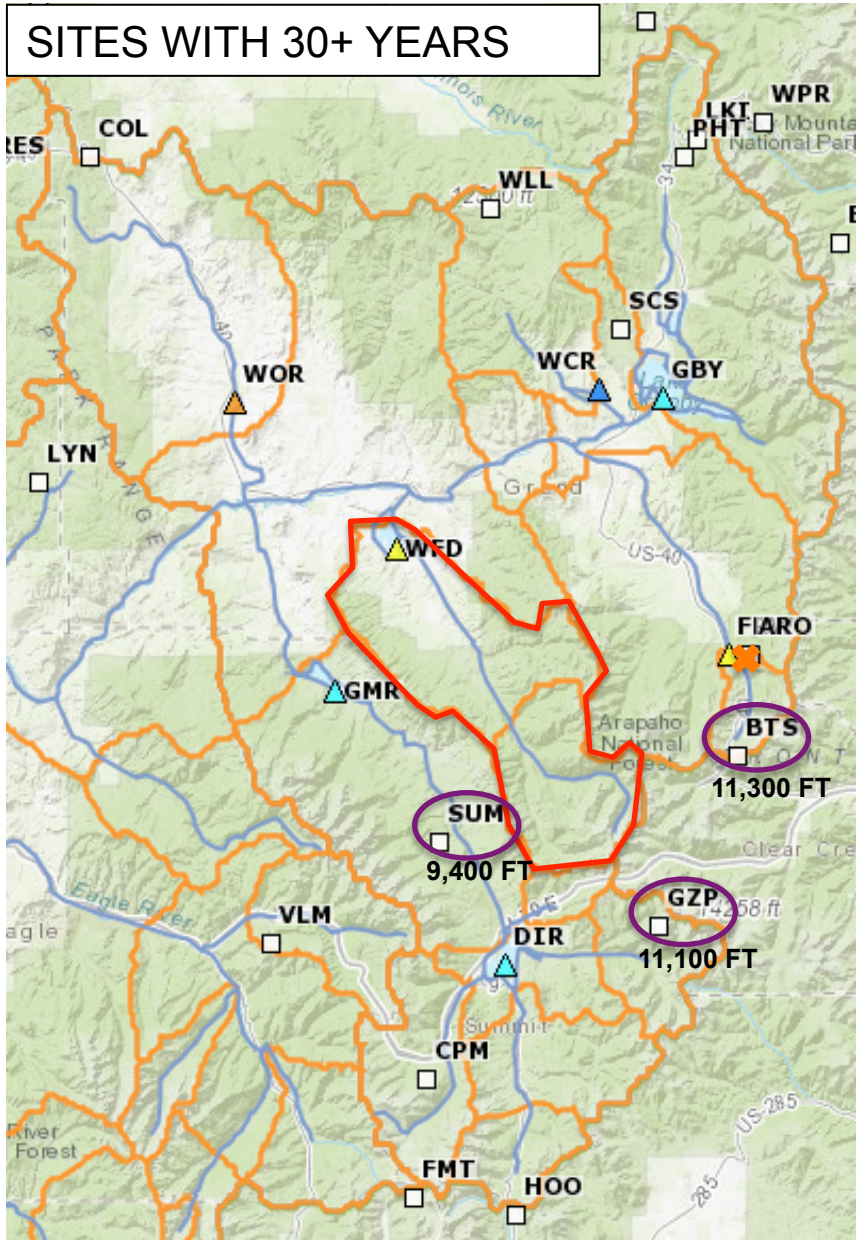
Very deep snow in places this year impacted SNOTEL precipitation gages.

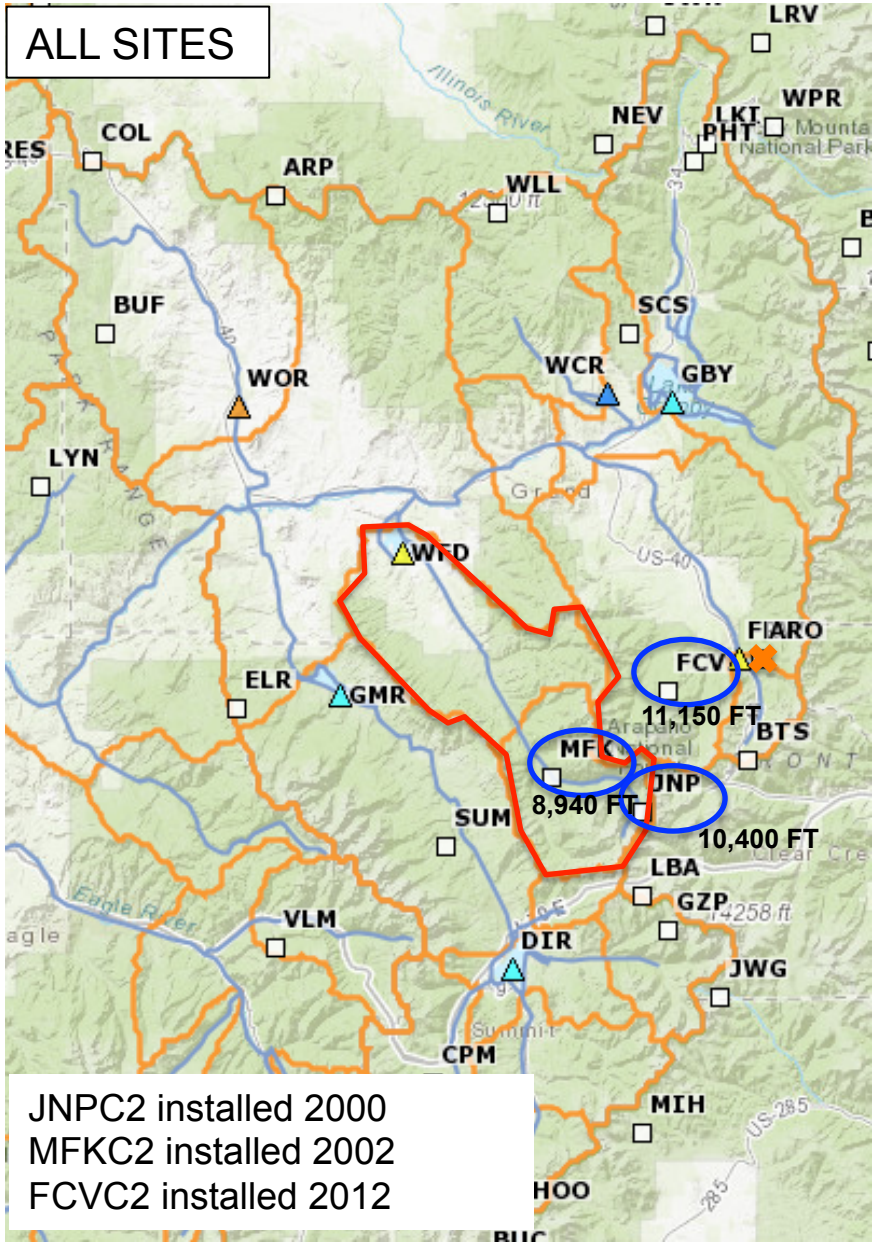


Hard to say how significant but impacts to model snow states were possible.

New SNOTEL sites will provide an opportunity to improve model calibrations

Williams Fork Reservoir Basin





2017 Forecast Review / Verification Summary

2017 had a little bit of everything – we learn a lot in years like this

- We felt we could account for the majority of errors that occurred in the 2017 forecasts
  - Extreme weather in the future
    - Not much can be done pending more advanced / accurate meteorological guidance
    - Adding additional years when recalibrating – wider range of forecast possibilities
    - Communicating the situation, uncertainties, and possibilities continue to be important
  - Late season high elevation snow not represented well by the model in some areas
    - Verify model is handling early season snow melt correctly.
    - Attempting to take advantage of newer SNOTEL sites as soon as realistic to do so.
    - Working to best use potential satellite snow products (ongoing projects with JPL)
- In many ways the model performed very well
  - Upper Green River Basin of Wyoming
- 2018 improvements
  - Expand Great Basin calibration period to 35 years (1981-2015)
  - Add additional stream forecast segments to the model in the Gunnison Basin
- Feedback is always welcome - We are happy to discuss any specific forecast with you.
- A first look at 2018 is scheduled for Thursday December 7th at 11 am MT. Please go to cbrfc.noaa.gov and follow the webinars link to register.