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# Overview

# Logistics

Sign-in Sheet

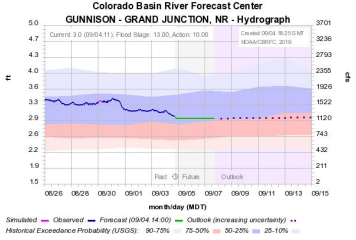
Bathrooms

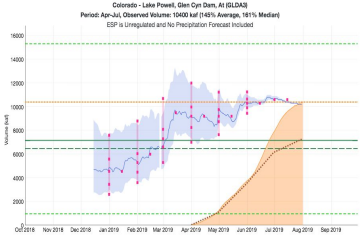
Slides will be available on our website after the meeting

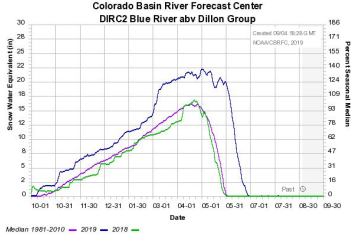
Break for lunch about 11:45

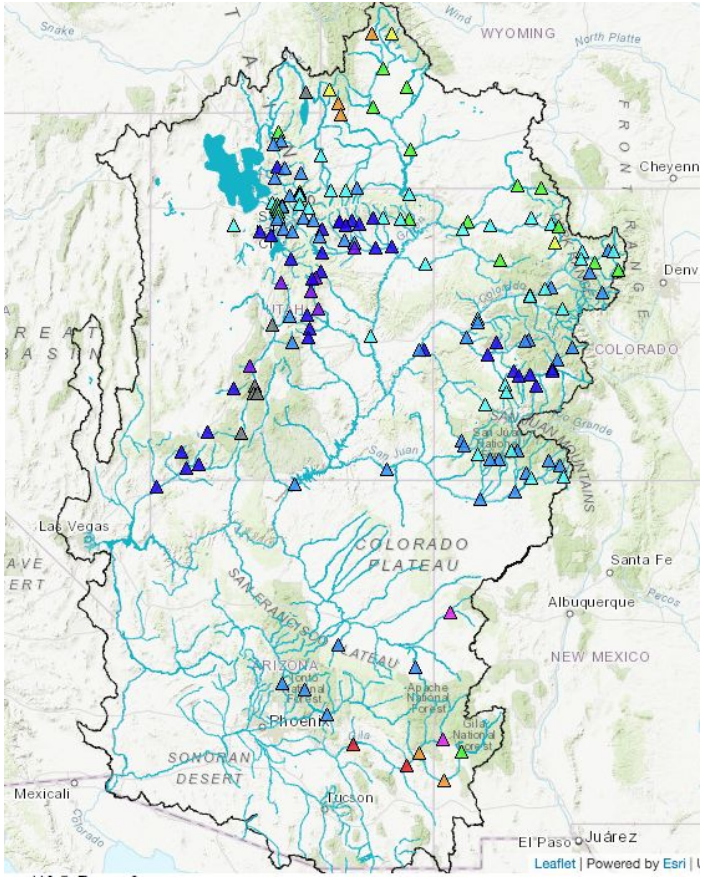
# Overview

- Action Items from our last meeting
- Quick overview of operations
- Water Supply Focal Point Changes



# Action Items From 2018 Meeting

- ☑ Improved web page functionality
  - ❑ Easier way to save interactive graphs
  - ❑ Added SNOTEL sites east of the divide (snow group plots)
- ☑ Make historical fall soil moisture grids available
  - ❑ 1981-2010 now available
  - ❑ 2011 - 2015 currently being updated
- ☑ Work with neighboring RFCs to provide similar products and services
  - ❑ Available through Western Water Supply Forecast Map
  - ❑ Still being advanced

# Action Items From 2018 Meeting

- ☑ Improve publicizing work done over the course of the year
  - ❑ Currently in the works
  - ❑ Expect a “White Paper” out by the end of the year
  - ❑ Will distribute by e-mail and post on website
- ❑ Add percent of area information to modeled snow plots
- ☑ Working to expand more robust future diversion estimates throughout the CBRFC area of responsibility
- ❑ Extend historical record of intervening flows, so additional verification can be performed

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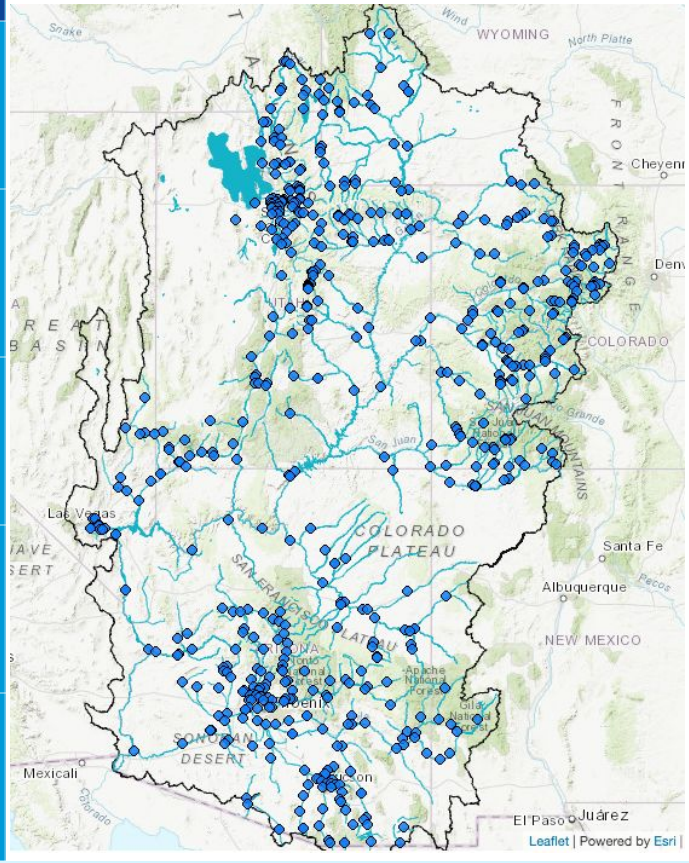
# CBRFC Introduction

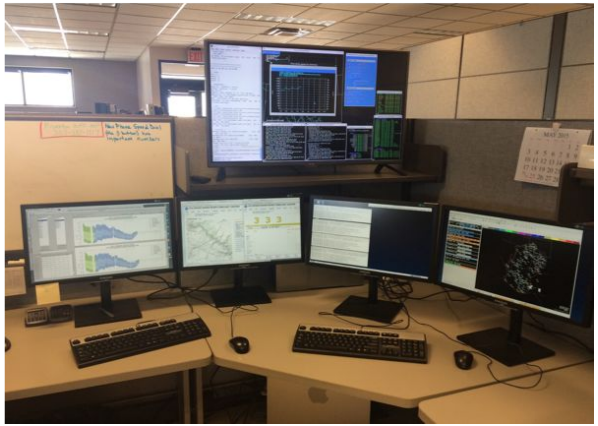
# Routine Forecasts

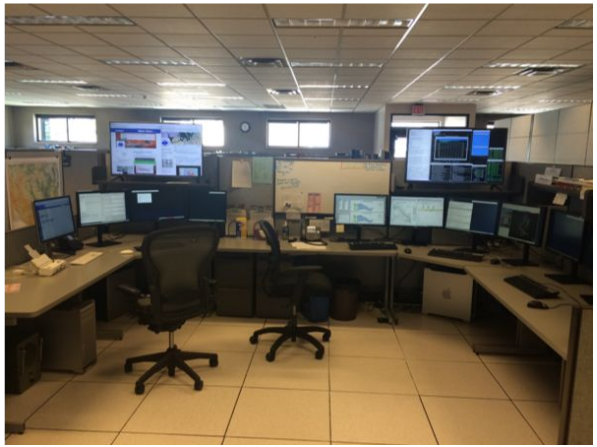



- 587 points forecasted daily
  - 471 modeled river points
  - 92 reservoirs
  - 24 routed locations
  - 159 points are also Water Supply Points
- Flexible web interface cbrfc.noaa.gov
- Requires a large amount of data (e.g. precip, temps, streamflow)

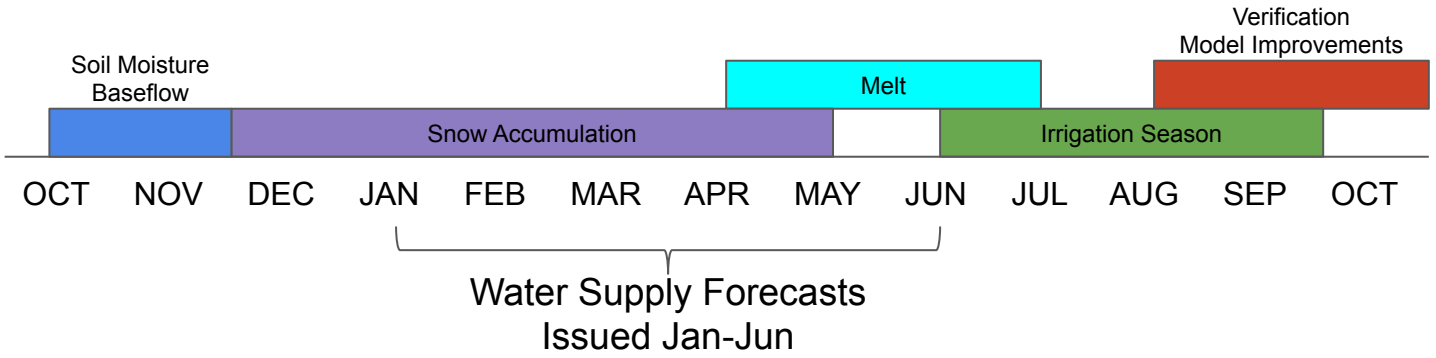
# Typical Operations Day

- Quality Control (observations and forecast data)
- Other data input (e.g., reservoir release schedules) / Update ratings
- Hydrologic Model Interaction (CHPS)
- Forecast Output / Product Dissemination (daily by 10 am Mountain Time)
- Provide forecast updates / WFO and stakeholder coordination as needed





# CBRFC Operational Timeline

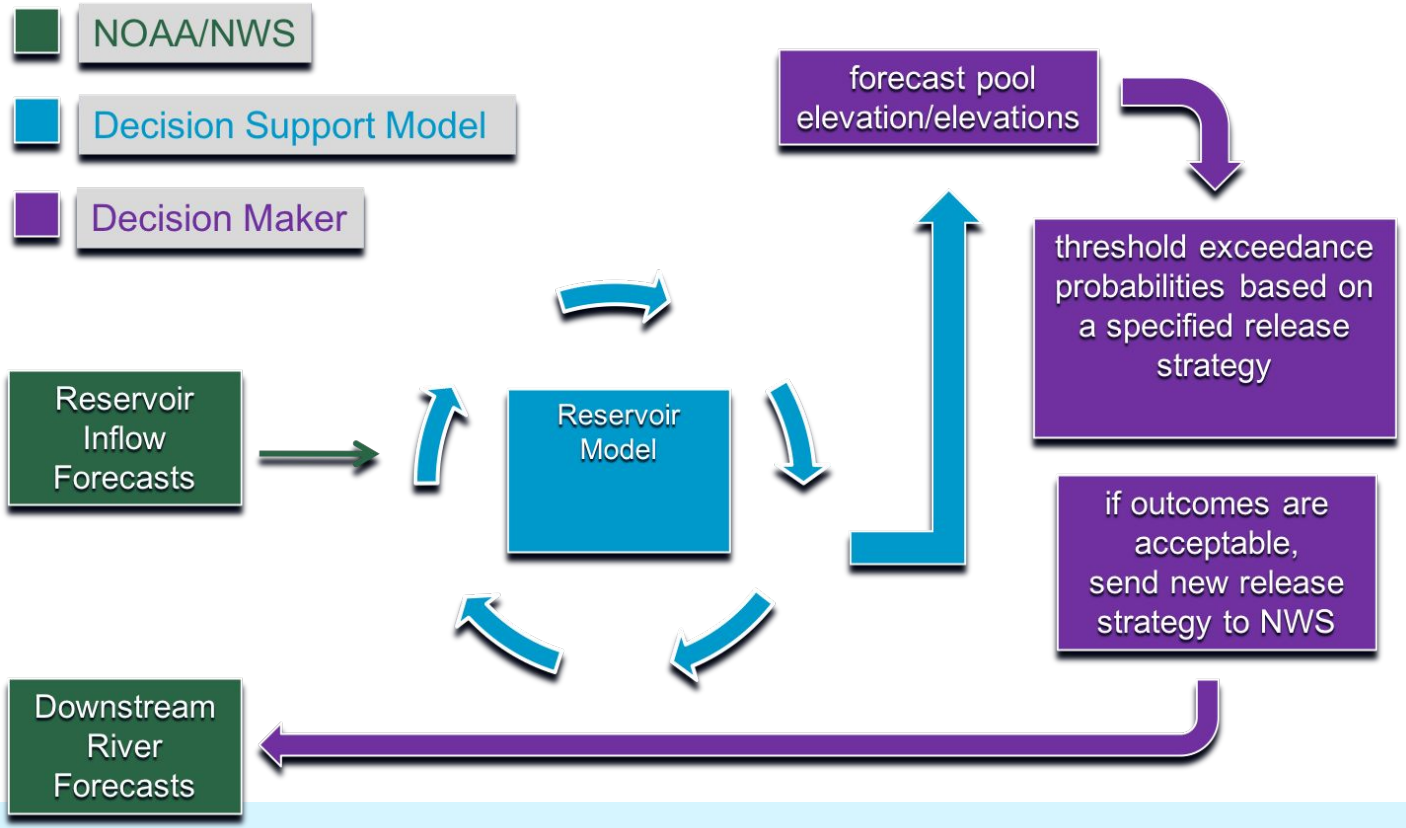



- 10-day deterministic streamflow forecasts are issued daily
- Water supply probabilistic forecasts are issued starting in January, however we begin posting ESP model guidance on our website in mid-December (forecast evolution plots).
- Peak flow forecasts are issued starting in March; updated ~2x/month
- Verification and model improvements actually go all year round, but we place an emphasis on them after the runoff season

# CBRFC Operations

- Forecasters are familiar with all basins
  - Focal points are typically first points of contact, but you can work with anyone
  - Others will cover when focal points aren't available
- Notes are shared within the model
- Don't hesitate to reach out to any of us with any questions you might have

# Role of Forecasts in Decision Support for Reservoir Operations



# CBRFC Contacts

Michelle Stokes – Hydrologist In Charge
michelle.stokes@noaa.gov

Paul Miller– Service Coordination Hydrologist
paul.miller@noaa.gov

**Basin Focal Points (Forecasters)**

Brenda Alcorn - Upper Green, White, Yampa, Duchesne
brenda.alcorn@noaa.gov

Tracy Cox - San Rafael, Price
tracy.cox@noaa.gov

Cody Moser – Upper Colorado Mainstem
cody.moser@noaa.gov

Ashley Nielson – San Juan, Gunnison, Dolores, Lake Powell
ashley.nielson@noaa.gov

Zach Finch – Virgin, Lower Colorado Basin
zach.finch@noaa.gov

Patrick Kormos – Bear, Weber
patrick.kormos@noaa.gov

Brent Bernard – Six Creeks, Provo , Sevier
brent.bernard@noaa.gov

Best phone number is: 801-524-4004

Michelle's Cell: 801-819-5967

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# NBM Temperature Implementation & Verification in CBRFC Operations

Cody Moser
Hydrologist, CBRFC

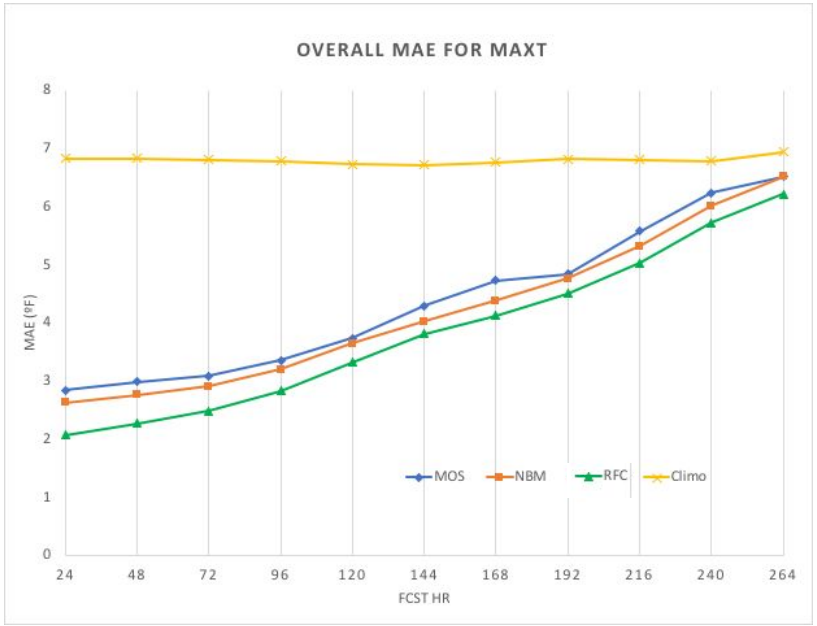
- What is the NBM?
  - National Blend of Models
  - National forecast guidance based on a blend of both NWS and non-NWS models
    - Weather models are weighted based on running 30-day verification (dynamic)

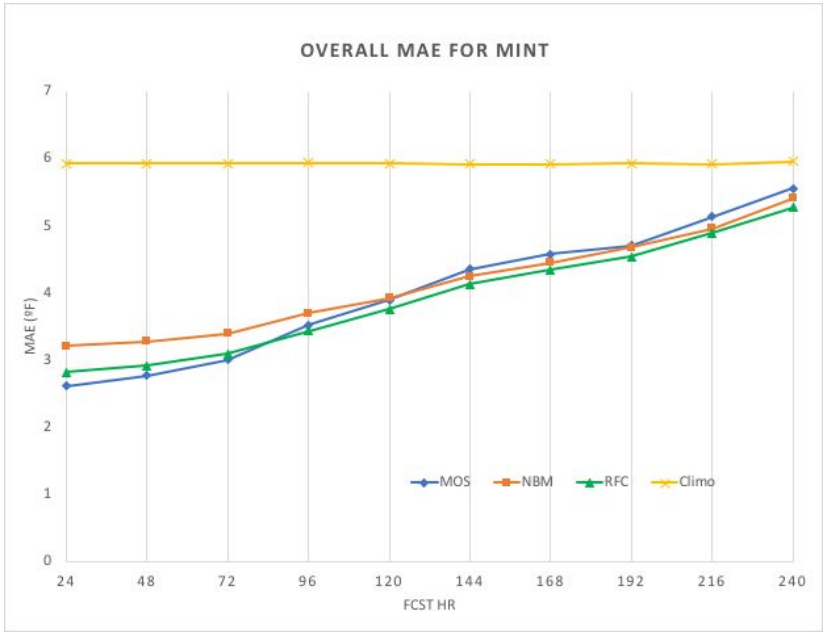
- Why use the NBM?
  - Consensus forecasts produce a more accurate forecast than any single forecast when verified over an extended period of time
  - More likely to be trending towards a more accurate forecast with ensemble approach

- When did CBRFC implement the NBM temperature forecast in operations?
  - August 2018
  - Prior to August 2018, used GFS-Based Model Output Statistics (MOS) as starting point

- CBRFC NBM forecast methodology:
  - bcNBM (bias corrected) - will be referred to as RFC forecast in future slides
  - take the raw NBM temperature forecasts and bias correct using observations
    - compute average Day 1 bias over past 30 days
    - apply bias correction to all forecast hours

- CBRFC verification methodology:
  - compute verification statistics (MAE/bias) for MOS, NBM, bcNBM, and Climatology
  - verify forecast lead times of 1-10 days (24-240 hours)
  - March - June 2019 (10,000+ observations)

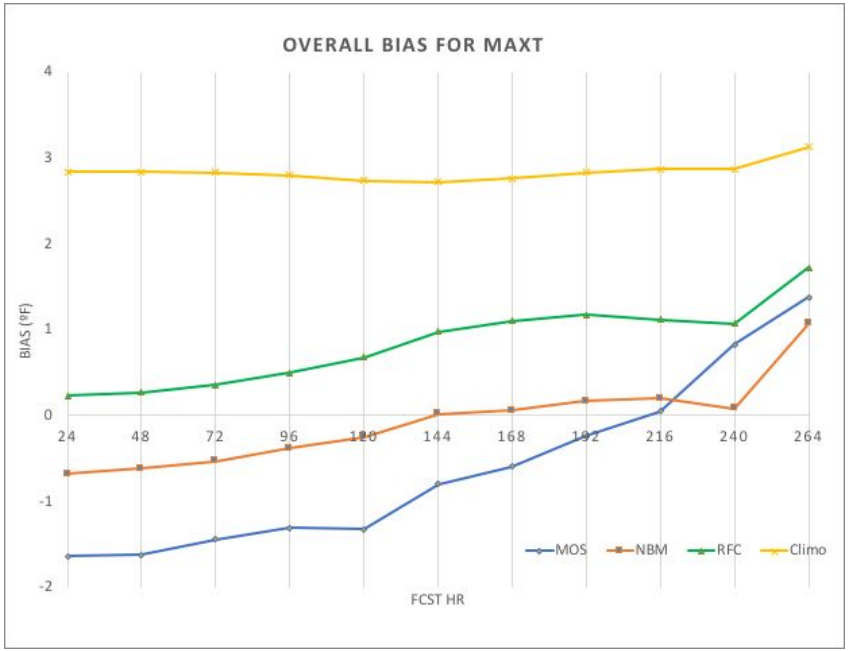


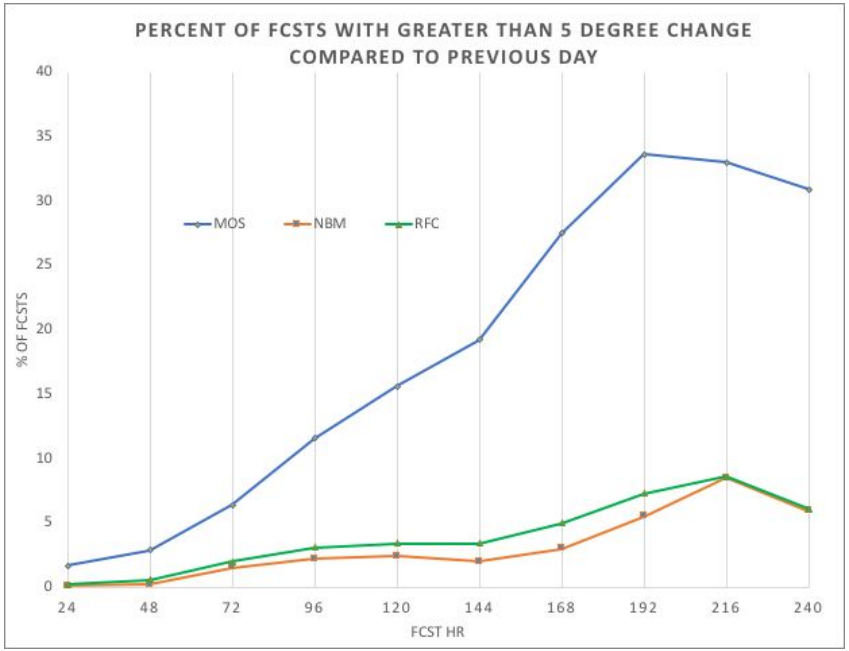

RFC (bcNBM) maximum temperature forecasts are most skillful on average at all lead times. Even at a lead time of ten days, RFC forecasts show more skill than climatology.

For minimum temperature forecasts, RFC forecasts are the best at nearly all lead times, except the short term where MOS is slightly better.

## Model Flip Flopping



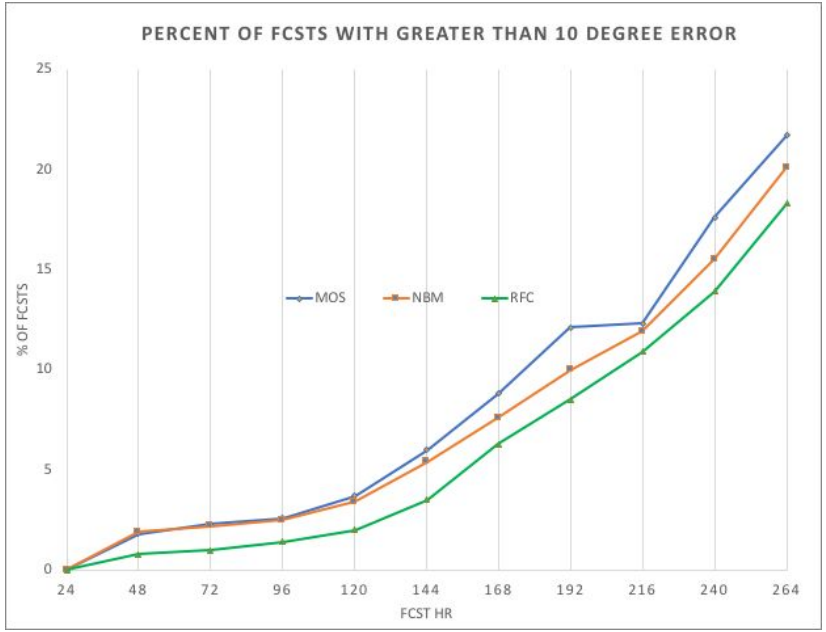

RFC temperature forecast procedure has slightly positive bias.




The MOS forecasts are much more inconsistent from one day to the next, especially at longer lead times.

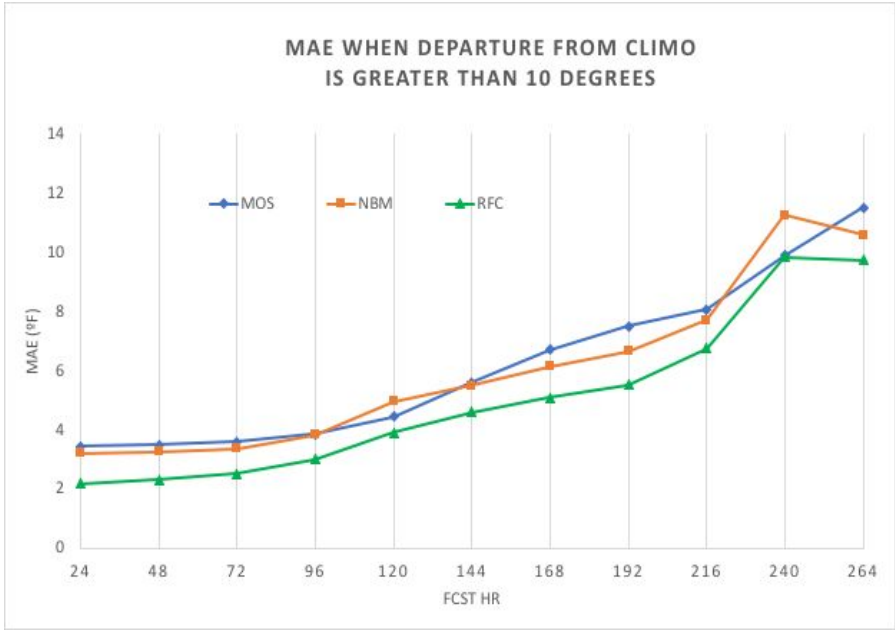
In contrast, the NBM and RFC produce much less flip flopping.

## How often does model forecast bust?




RFC method has fewer instances of days with error >10 degrees.

## Model performance during warm spells




RFC method shows superior performance during periods of anomalous warming.

- bcNBM (RFC) is the best performing model, on average
  - produces the most accurate and consistent forecast at all lead times.

- Previous temperature forecast methodology (MOS)
  - more inconsistent, especially at longer lead times -> inconsistent hydrographs.

- The change to using the bcNBM as the starting point for CBRFC forecasts has improved temperature forecasts while reducing the time editing hydrologic model forcing grids.
  - more consistent temperature forecasts during spring runoff lead to more consistent forecast streamflows
  - if there is a significant change it is more likely to be moving in the right direction rather than flip-flopping

- Performance/verification will continue to be tracked.

- QUESTIONS?

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# CBRFC
# Model Snow

Cody Moser
Hydrologist, CBRFC

# COLORADO BASIN RIVER FORECAST CENTER

NATIONAL WEATHER SERVICE / NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

https://www.cbrfc.noaa.gov/

HOME RIVERS SNOW WATER SUPPLY RESERVOIRS WEATHER CLIMATE HELP ABOUT NEWS SEARCH

Conditions Map
Conditions List
Snow Groups
Model Snow

**Gridded Maps**

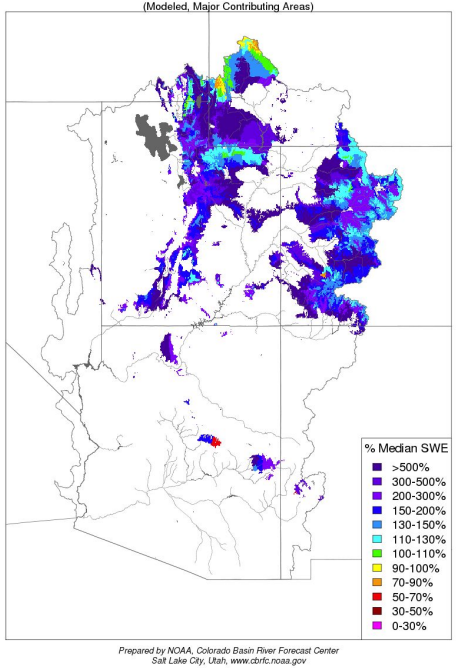
**Type:** Monthly Precipitation Water Year Precipitation Month to Date Precipitation Monthly Temperature Model Snow Model Soil Saturation Model Dust Impact Model % Soil Moisture

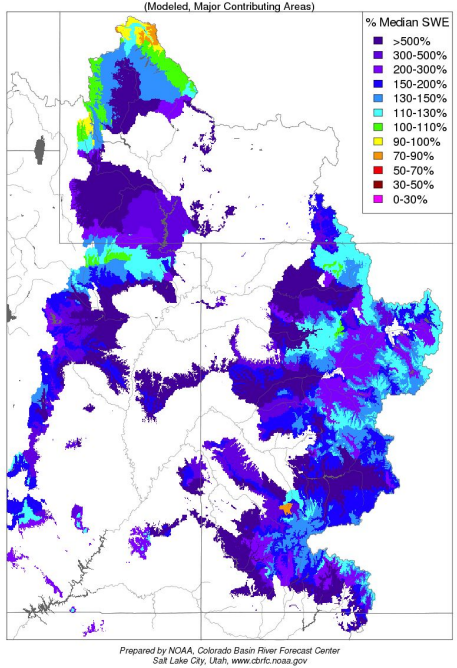
**Water Year:** 2019 2018 2017 2016

**Month:** 07 06 05 04 03 02 01 12 11 10

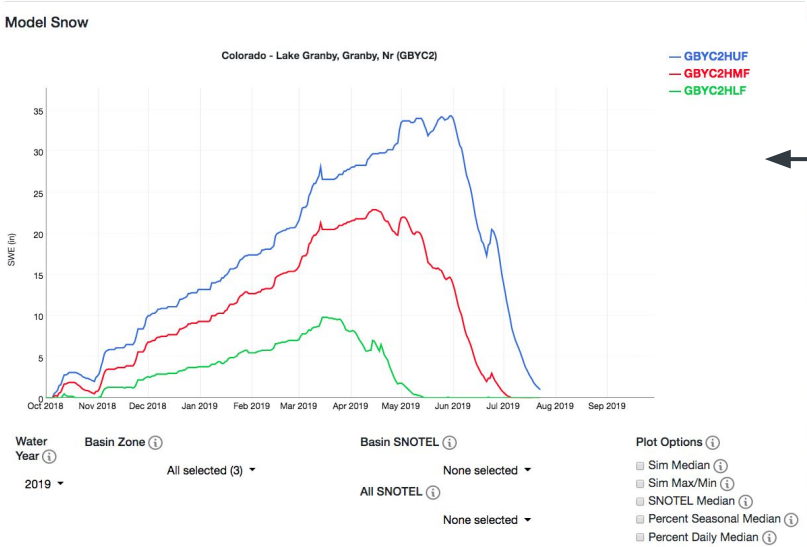
**Area:** CBRFC Upper Colorado Great Lower Colorado Utah

**Basins:** All Significant

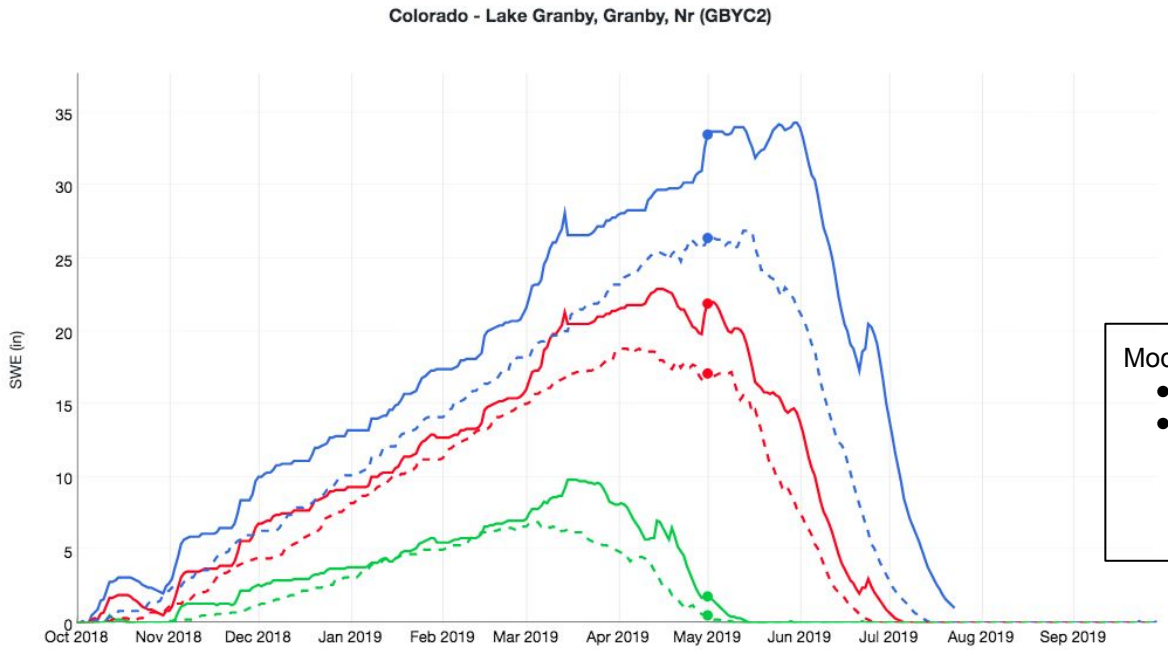


https://www.cbrfc.noaa.gov/


## Model Snow




2019/05/01:
GBYC2HUF: 33.5
GBYC2HMF: 21.9
GBYC2HLF: 1.8
GBYC2HUF Median: 26.4
GBYC2HMF Median: 17.1
GBYC2HLF Median: 0.5

Model daily snow water equivalent (SWE)
- for each basin zone in CBRFC model
- supplements streamflow products:
  - 10-day forecast
  - water supply forecast
  - peak flow forecast

Water Year
2019

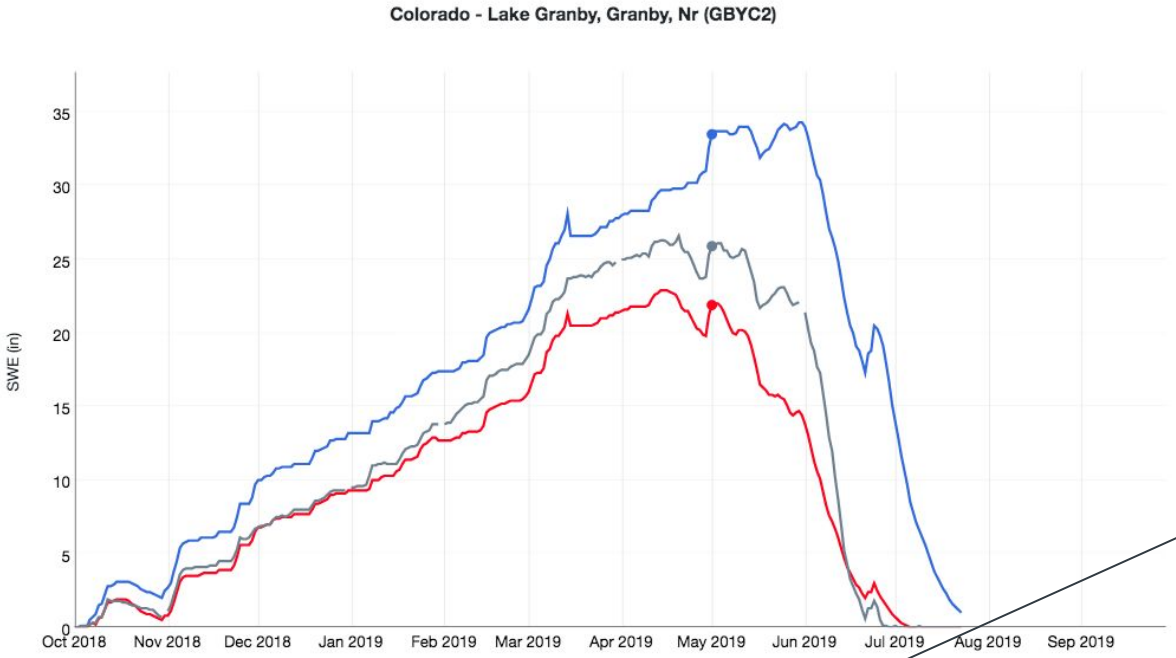
Basin Zone
All selected (3)
- GBYC2HUF (11000-12867 ft)
- GBYC2HMF (9500-11000 ft)
- GBYC2HLF (8199-9500 ft)

Basin SNOTEL
None selected

All SNOTEL
None selected

Plot Options
- Sim Median
- Sim Max/Min
- SNOTEL Median
- Percent Seasonal Median
- Percent Daily Median

## Model Snow



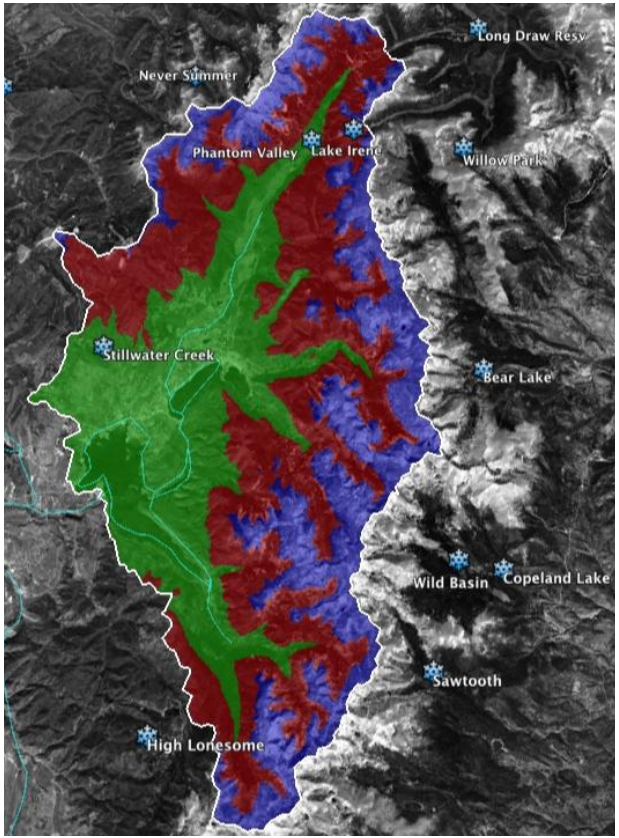

SNOTEL stations used during the basin calibration process.

Water Year
2019

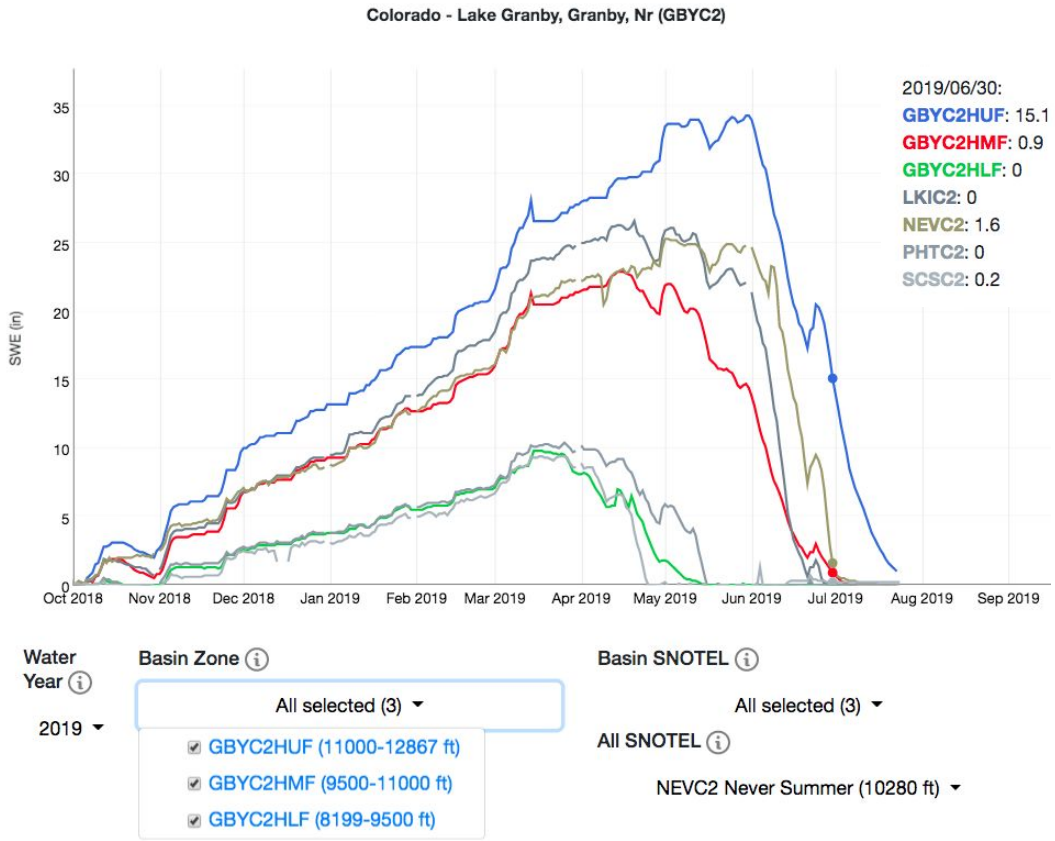
Basin Zone
GBYC2HUF (11000-12867 ft), GBYC2HMF…
- GBYC2HUF (11000-12867 ft)
- GBYC2HMF (9500-11000 ft)
- GBYC2HLF (8199-9500 ft)

Basin SNOTEL
LKIC2 Lake Irene (10700 ft)
- LKIC2 Lake Irene (10700 ft)
- PHTC2 Phantom Valley (9030 ft)
- SCSC2 Stillwater Creek (8720 ft)

Plot Options
- Sim Median
- Sim Max/Min
- SNOTEL Median
- Percent Seasonal Median
- Percent Daily Median


Long Draw Resv
Never Summer
Phantom Valley
Lake Irene
Willow Park
Stillwater Creek
Bear Lake
Wild Basin
Copeland Lake
Sawtooth
High Lonesome

## Model Snow


Colorado - Lake Granby, Granby, Nr (GBYC2)
SWE (in)
0
5
10
15
20
25
30
35
Oct 2018
Nov 2018
Dec 2018
Jan 2019
Feb 2019
Mar 2019
Apr 2019
May 2019
Jun 2019
Jul 2019
Aug 2019
Sep 2019
2019/06/30:
GBYC2HUF: 15.1
GBYC2HMF: 0.9
GBYC2HLF: 0
LKIC2: 0
NEVC2: 1.6
PHTC2: 0
SCSC2: 0.2
Water Year
2019
Basin Zone
All selected (3)
GBYC2HUF (11000-12867 ft)
GBYC2HMF (9500-11000 ft)
GBYC2HLF (8199-9500 ft)
Basin SNOTEL
All selected (3)
All SNOTEL
NEVC2 Never Summer (10280 ft)

- New (WY19) CBRFC model snow feature
  - adds transparency to streamflow forecast products
  - provides mean areal (sub-basin) SWE information within Colorado River Basin
  - valuable tool after SNOTEL station SWE has melted out

- Current Capabilities:
  - current CBRFC model SWE; historical (calibration period) model SWE
  - current and historical observed (SNOTEL) SWE
  - median, max/min, percent daily/seasonal model dataset time series available

- Proposed development work (no timeline):
  - additional plot capabilities (multiple years/basins on a single plot)
  - additional parameters: snow cover, snow density, ranking/percentile
  - additional basin metadata
  - tabular output feature
  - stakeholder/user recommendations

- Questions / Comments / Suggestions?
  - Did you use/view this during WY19?

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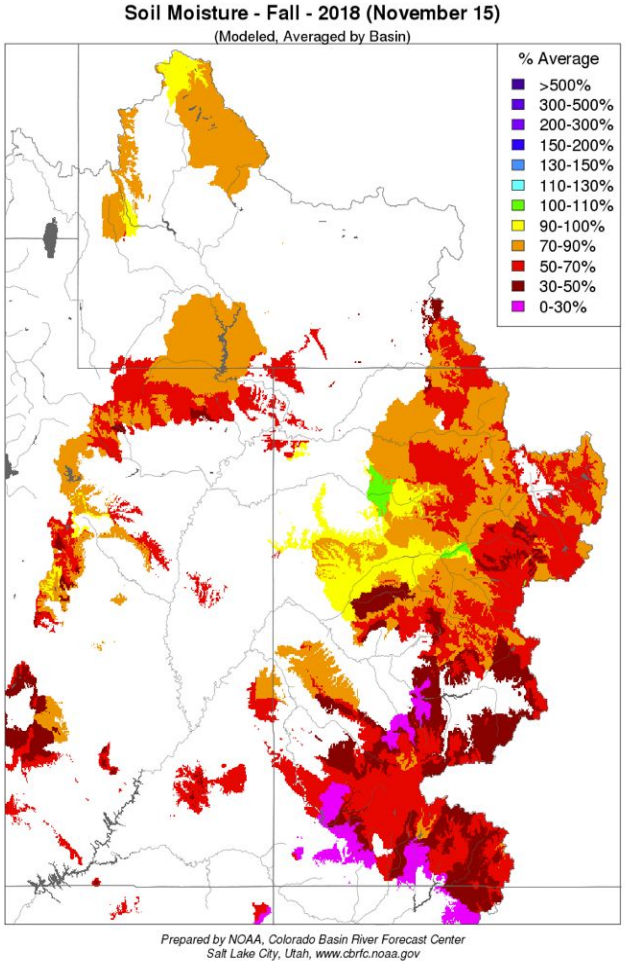
# Challenges of WY2019

Ashley Nielson
Hydrologist, CBRFC

# Forecast Challenges: WY2019

1. Dry antecedent soil moisture conditions
2. Major weather pattern shifts
    a. Dry Start to the season in some areas
    b. Record Wet February/Early March
    c. Cold/Wet Late May
3. Above average low/mid elevation snow conditions at start of runoff season
4. Late season precipitation (late June/early July event in Yampa/UC)
5. Inconsistent meteorological guidance during melt period
6. Observed streamflow issues (can be more frequent and significant in high years)
7. Summer rain events

# Forecast Challenges: How would dry soils impact overall runoff volumes ?




## Dry soils entering the winter season

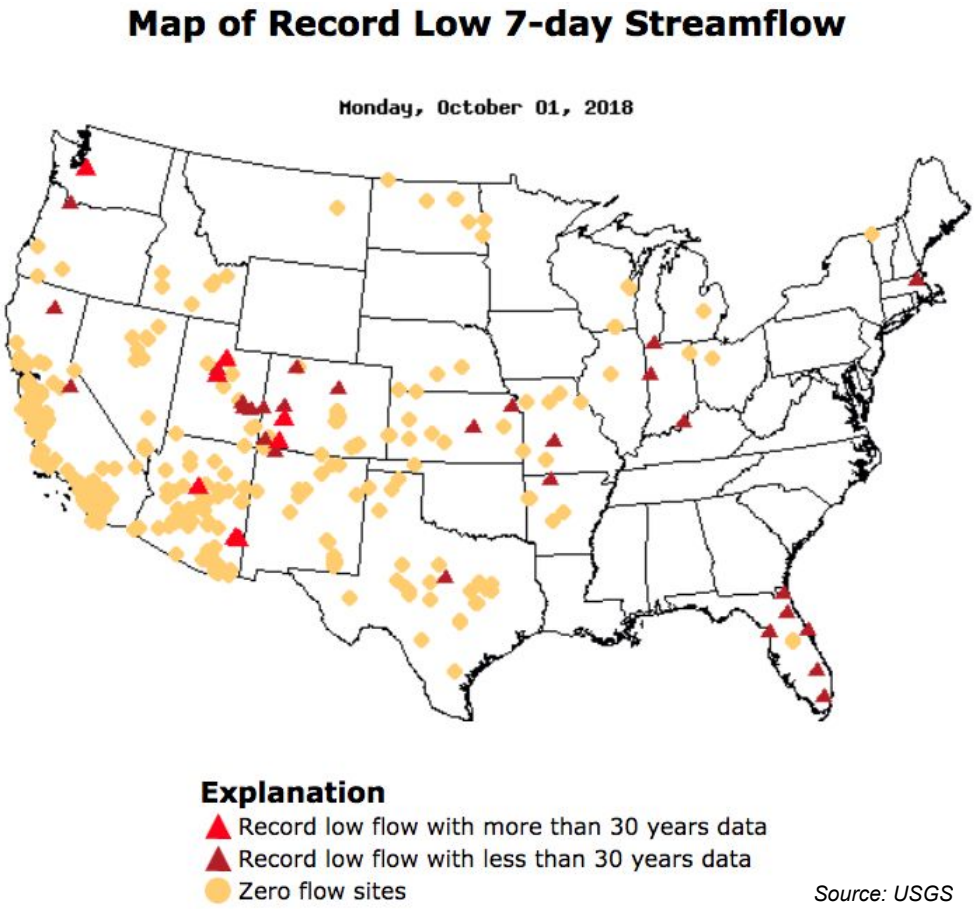
Near record low levels in San Juan/Gunnison

## The Questions:

Would a slower melt result in lower volumes overall?

Was there enough snow to overcome soil moisture deficits?

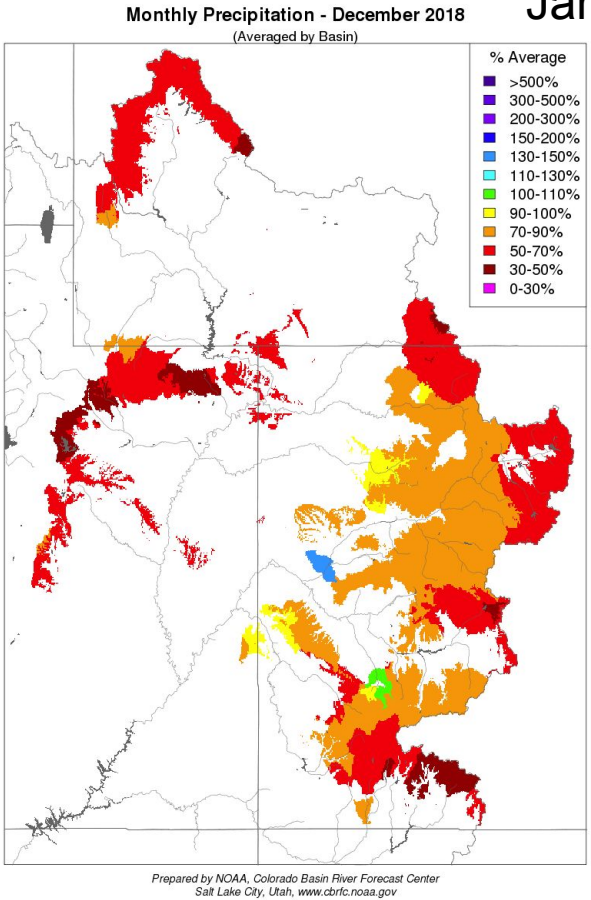
# Forecast Challenges: Record low flows to start water year 2019

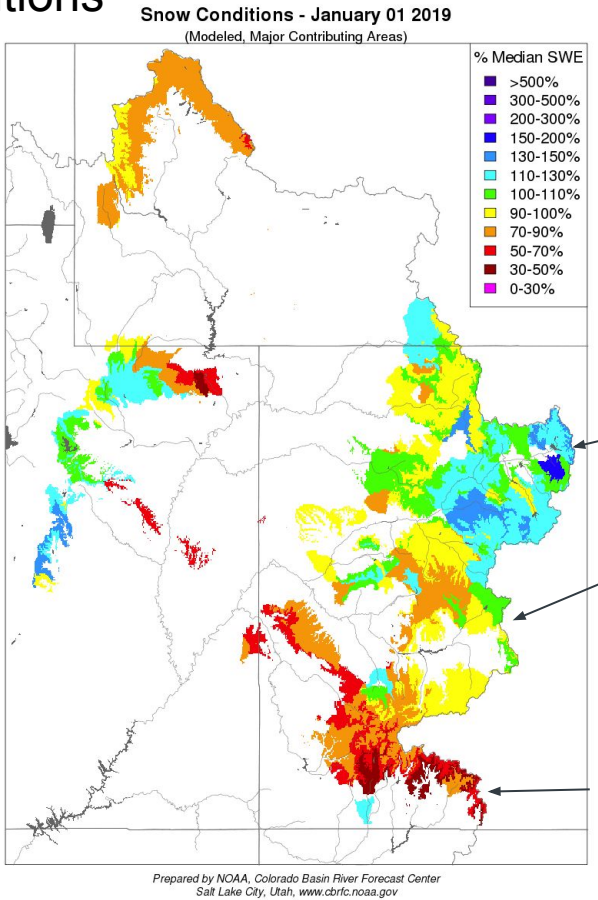



*Source: USGS*

# Forecast Challenges: Slow start to the season in some areas

## January 1 Conditions



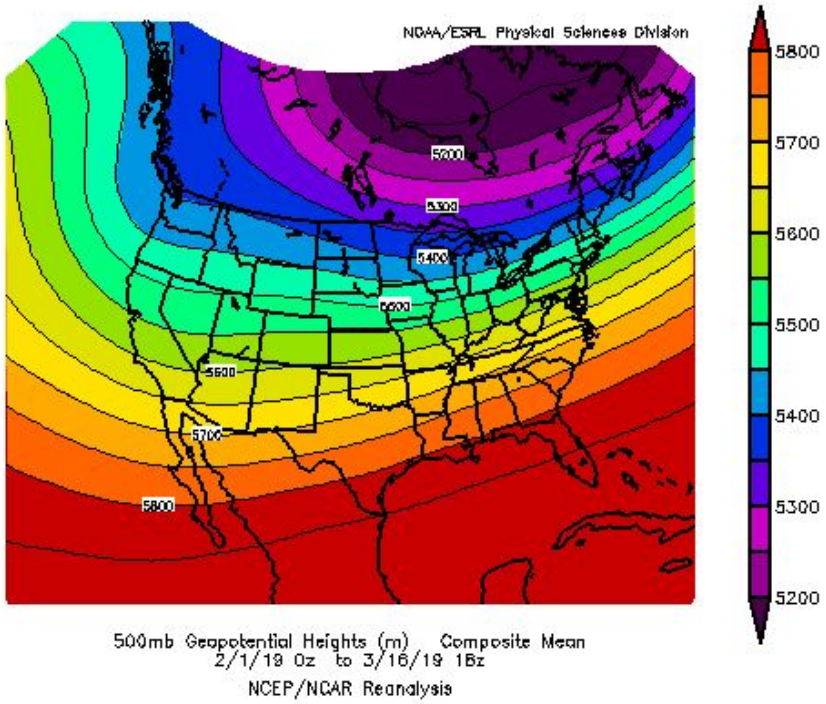



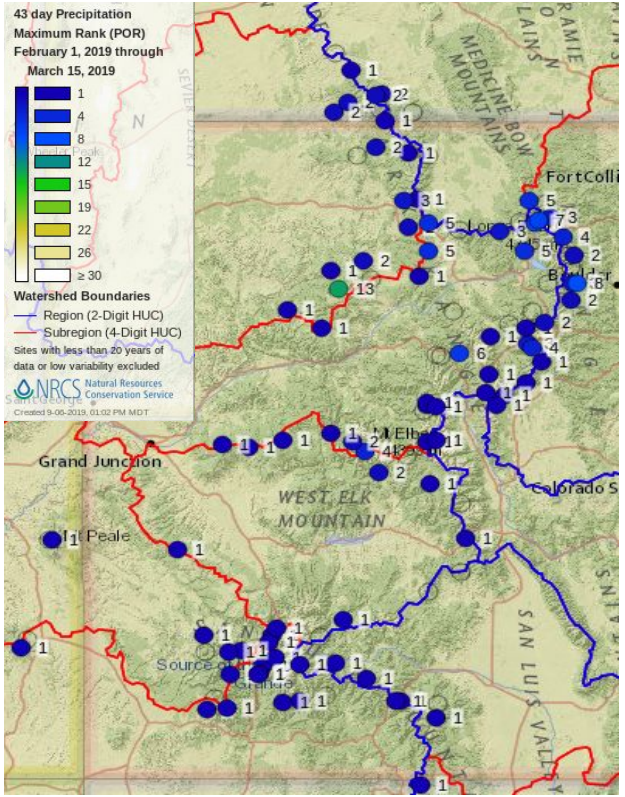

Upper Colorado:
Wet Nov

Gunnison:
OK snowpack +
extremely low
soil moisture

San Juan:
Poor snowpack +
extremely low
soil moisture

# Weather Pattern Shift: Very Wet February/March

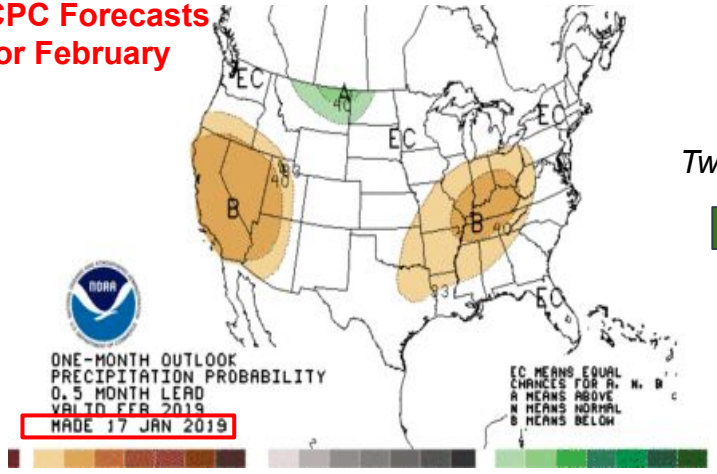


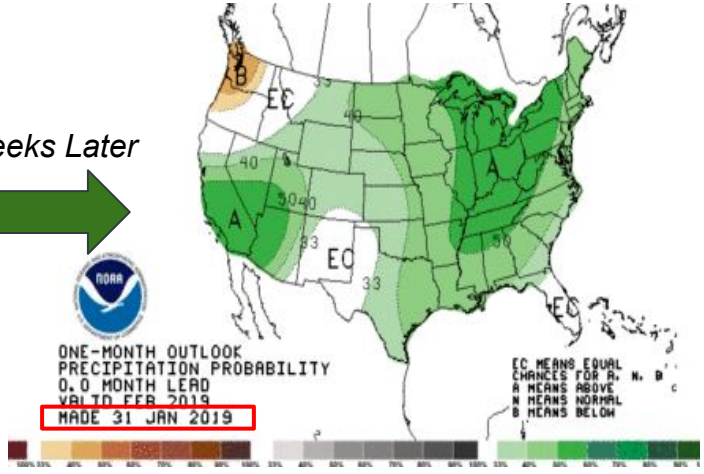

Persistent trough over the western U.S. directed a series of storm systems across the Colorado River Basin during the months of Feb/Mar. Many of the SNOTELs in Utah/Colorado had record precipitation totals for the Feb 1- Mar 15 period. This very wet pattern was the main source of early season (Jan-Mar) water supply forecast error.

# Pattern Shifts are Difficult to Predict Outside a Week!

**CPC Forecasts for February**

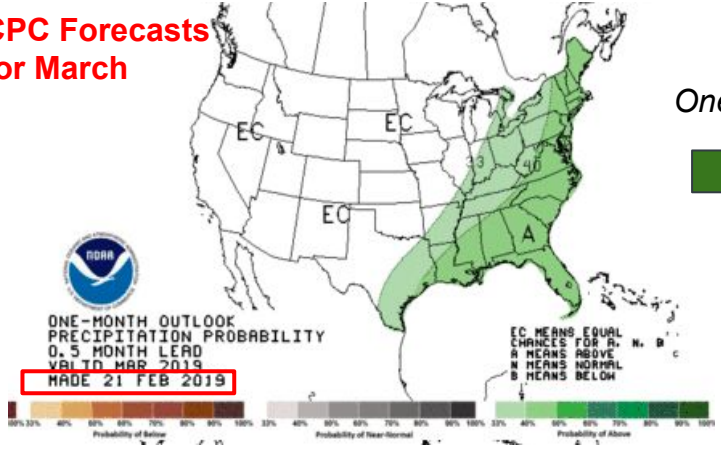



*Two Weeks Later*

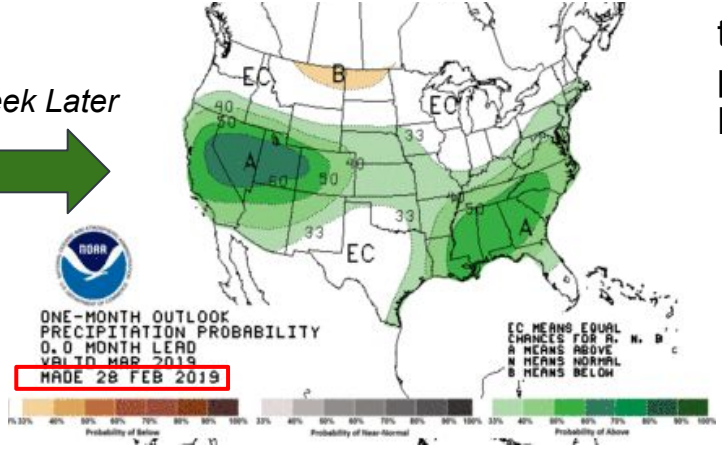



Forecasting the weather pattern outside a week, or perhaps 10-15 days in some instances, is purely speculative!

**CPC Forecasts for March**

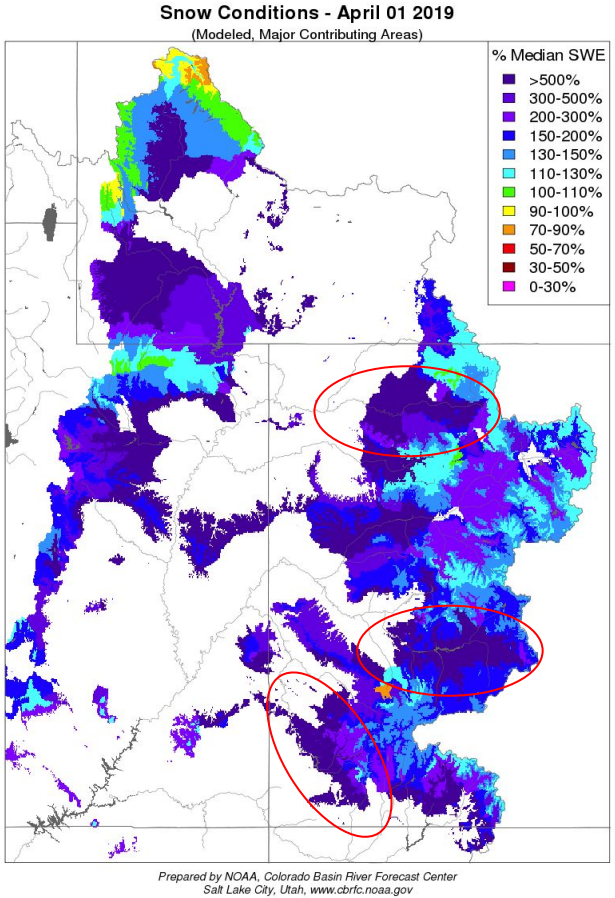



*One Week Later*




We can incorporate the next 5 days of precipitation into our ESP model runs.

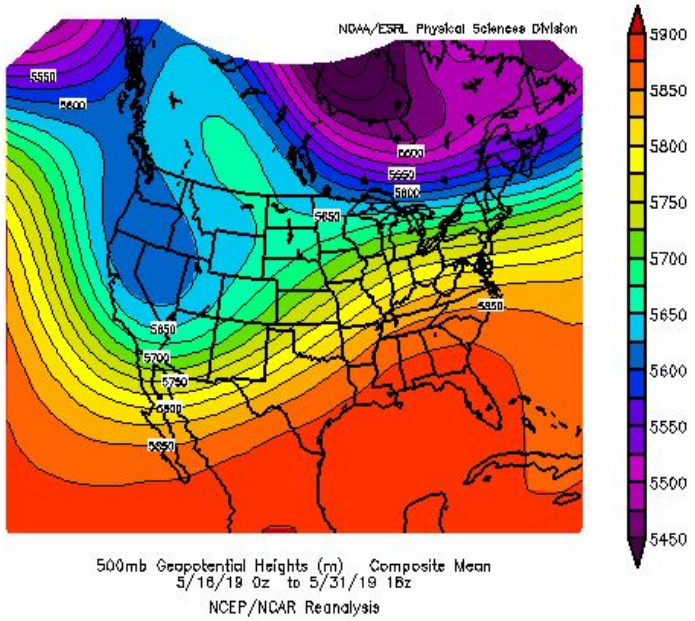
# Forecast Challenges: How would above average low/mid (<8500') elevation snow impact overall volumes?

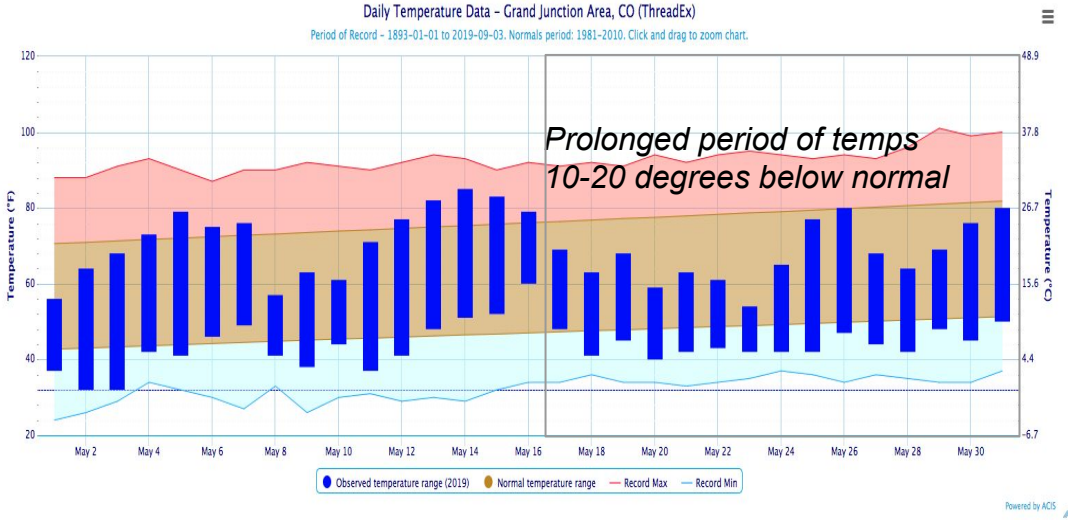



## April 1 Conditions

- Model snow includes area above and below SNOTEL locations.
- Much above average low/mid elevation snow conditions
- Low elevation snow typically melts in March and doesn't contribute to April-July volumes

# Weather Pattern Shift: Wet/Cold Last Half of May

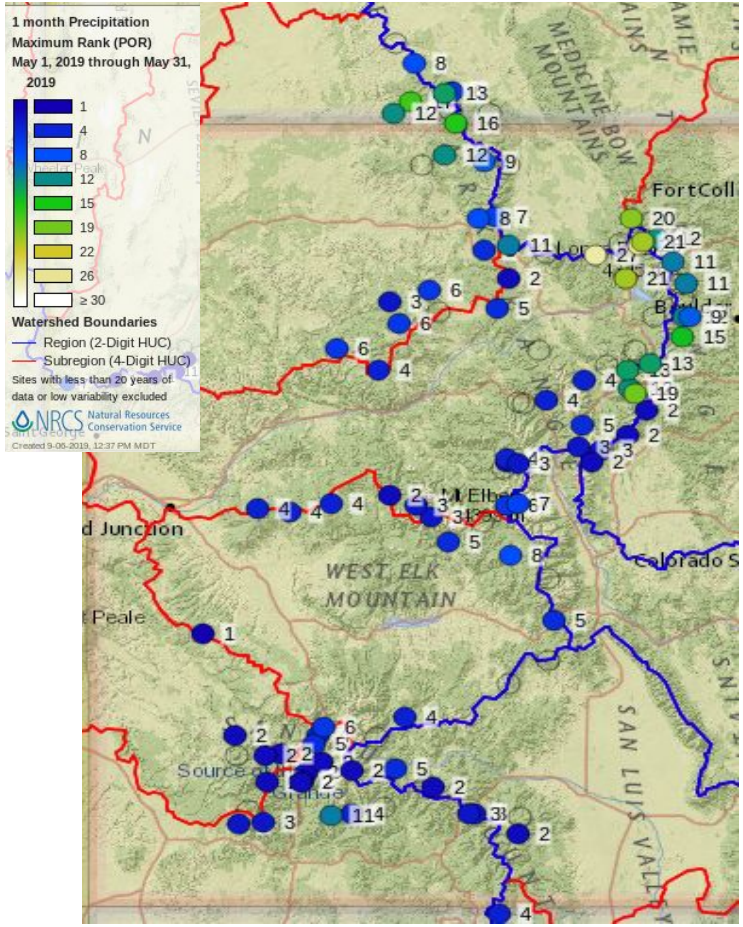


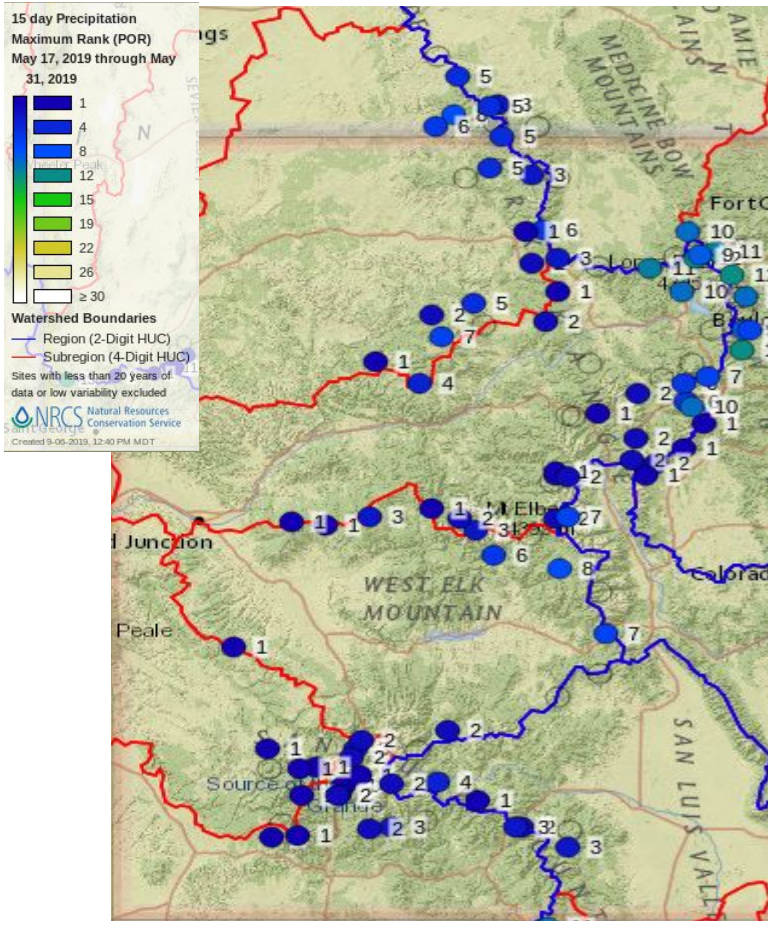

A deep and persistent trough settled over the Intermountain West during the last two weeks of May. This resulted in a prolonged period of below normal temperatures and above normal precipitation. The effect was to delay snowmelt, and many water supply sites showed an increase in ESP over the last half of the month due to additional snow accumulation.

# Weather Pattern Shift: Wet/Cold Last Half of May

Full month of May precipitation: top 5



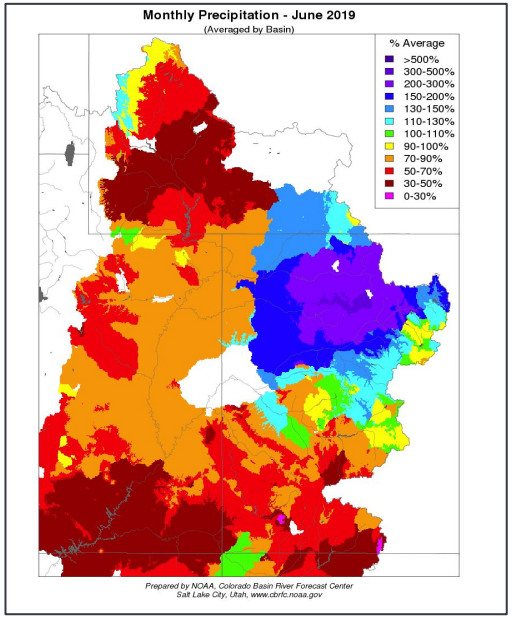

Last half of May precipitation: many records

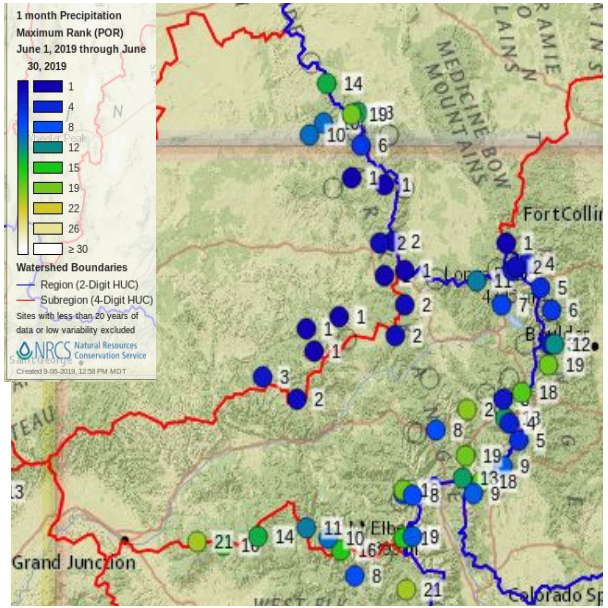


# Forecast Challenges: June Weather

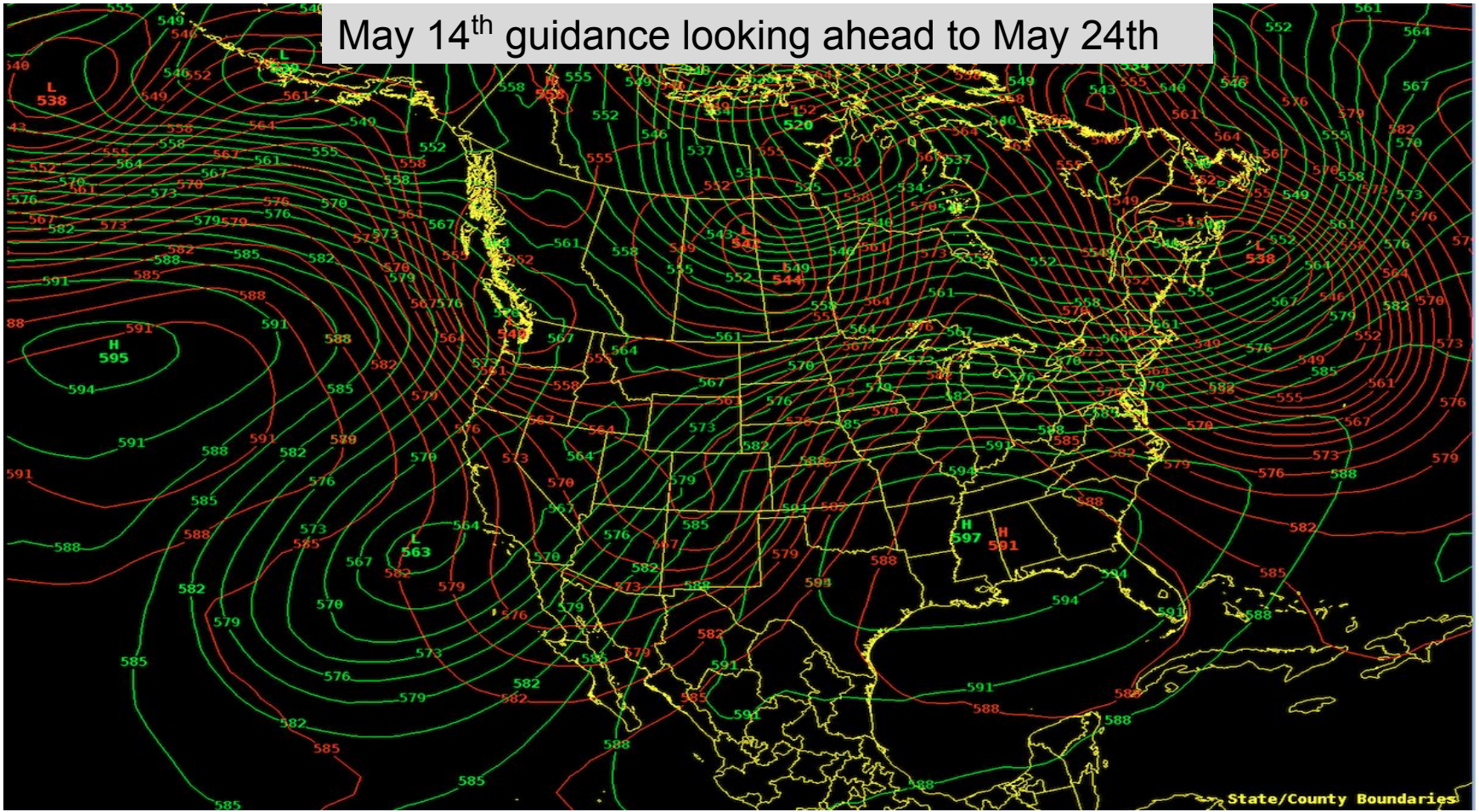
- June remained cool and wet in northwest Colorado (Yampa and Upper Colorado mainstem)
  - Late season rain
  - Late season high elevation snow accumulation
- Wild swings in temperatures impacting snowmelt pattern
- Uncertainty in meteorological guidance (impacting peak forecasts/reservoir operations)


First day of summer = ~ 2ft of snow!

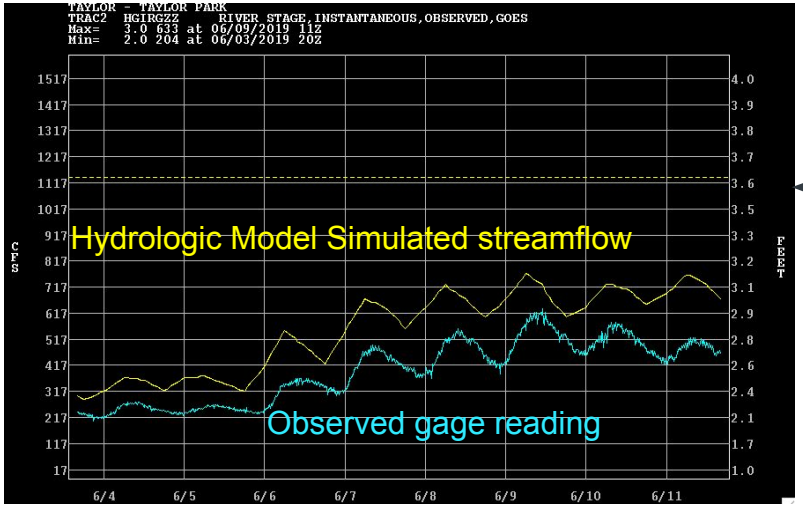


# Forecast Challenges: Different scenarios in meteorological guidance (impacting peak forecasts)



# Forecast Challenges: Observed data issues (not uncommon especially in wet years)



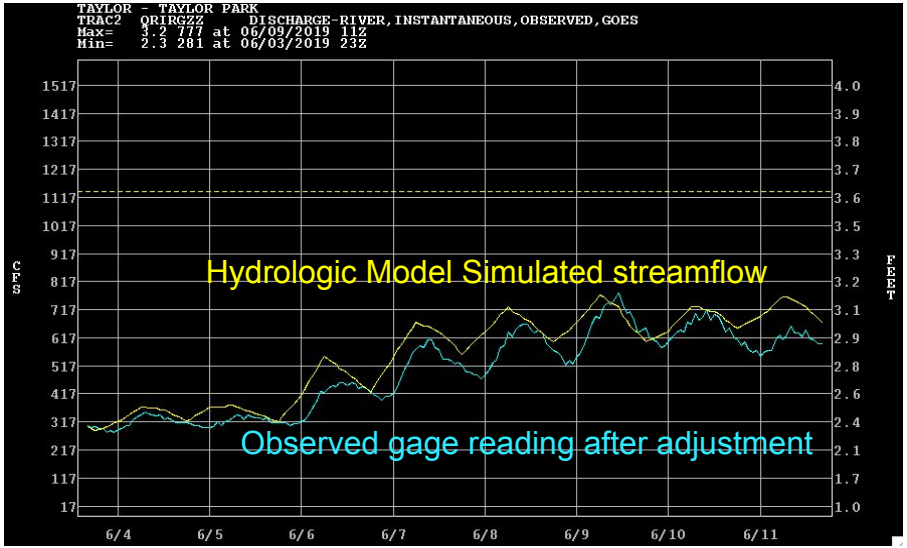

**Daily Operations:**
We often see a discrepancy between an observed reading and our model

**The Decision:**
Is a model state incorrect or might something in the stream be impacting readings (debris, scour, etc.)?

Eventually a field measurement was made and the gage readings adjusted, validating the model performance.

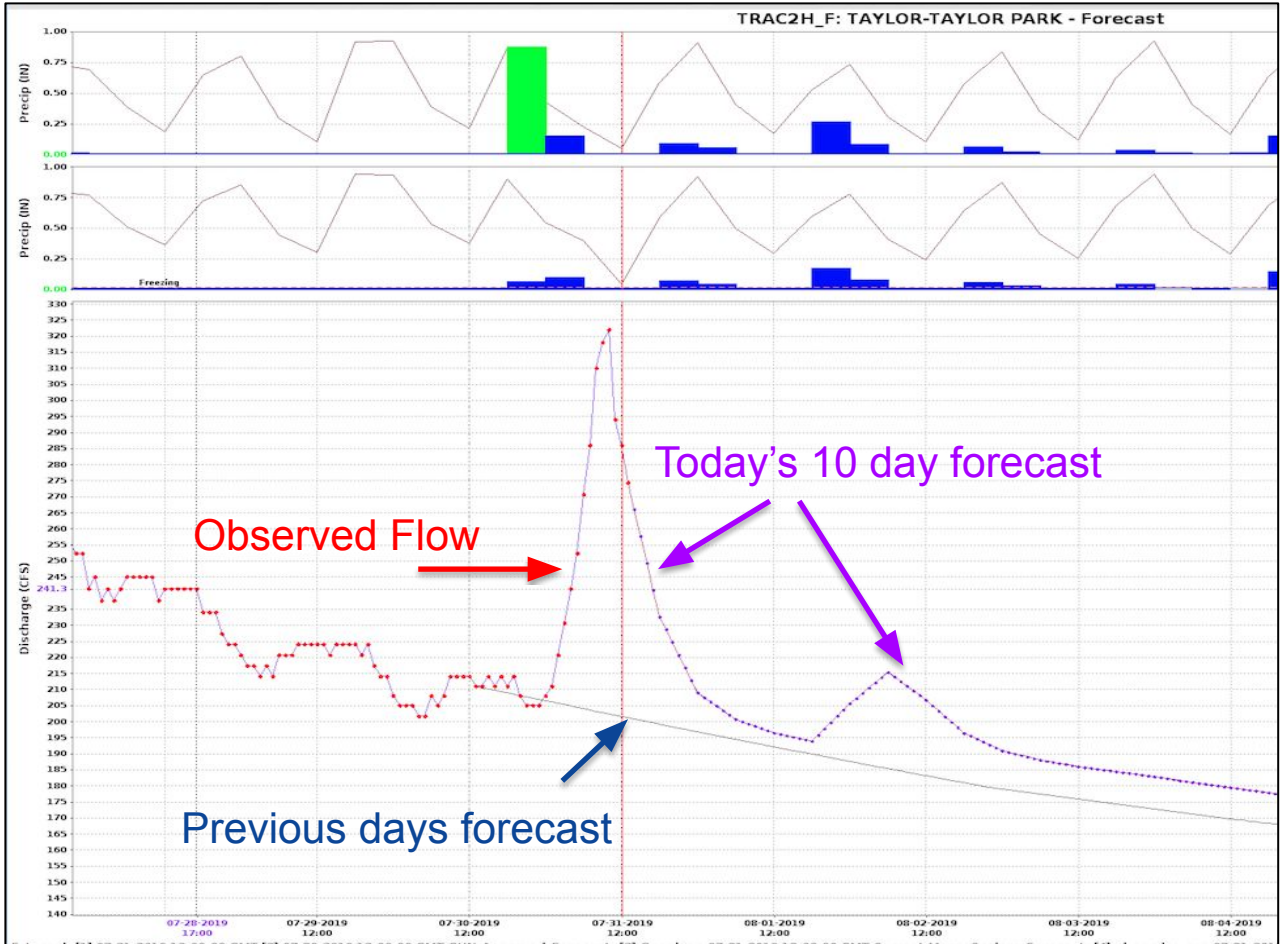
The decision to be patient and not adjust model snow states to lower values was correct.

This result is not always the case however, especially in data sparse areas and if the gage reading was indeed accurate.



# Forecast Challenges: Summer rain events difficult to forecast (thunderstorm location)

*Saturated soils resulted in efficient runoff and sustained higher flows in areas*



NOAA
National
Weather
Service

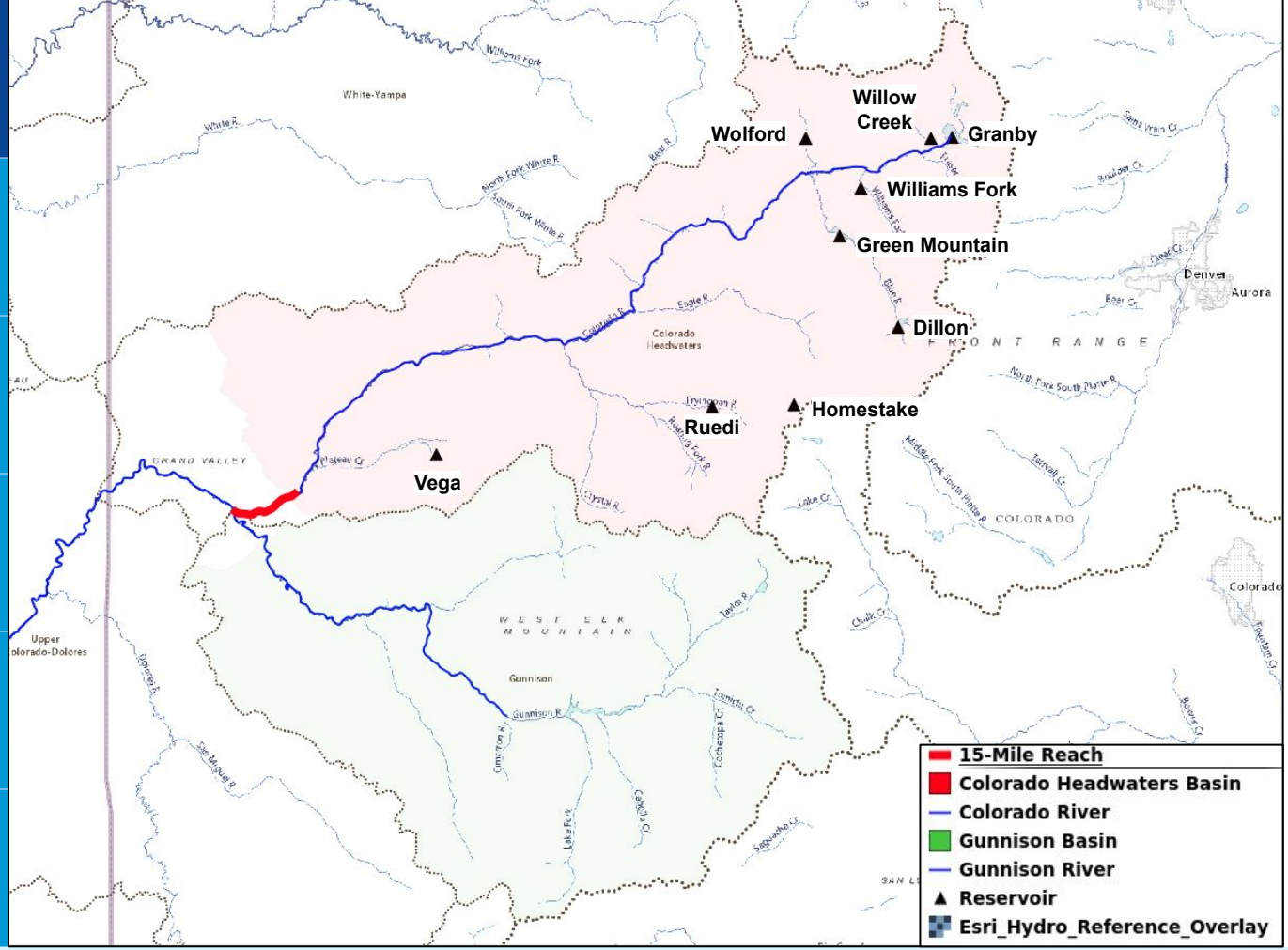
# CBRFC
# 2019 CROS Review

Cody Moser
Hydrologist, CBRFC

- What is CROS?
  - Coordinated Reservoir Operations Study
  - Established in 1995 as part of the Upper Colorado River Endangered Fish Recovery Program

- What are the goals of CROS?
  - Identify potential opportunities to coordinate releases from various reservoirs to enhance habitat in the 15-mile reach of the Colorado River
    - River section determined to be critical to the survival of endangered fish species
    - Reach extends upstream from the Gunnison River confluence to the Grand Valley Diversion dam at Palisade, CO
  - Focus is to enhance/extend spring peak flows -> improve fish spawning habitat
  - Enhance natural peak flows on the Colorado River for 10-14 days
  - Without diminishing reservoir yields, affecting reservoir fill timing, exceeding flood stage at Cameo

- Thresholds/Conditions/Timing
  - 12,900 - 26,600 cfs
  - CROS occurs in years when runoff conditions allow
  - Typically occurs during the last week of May / first week of June
  - 2019 focused on extending period of high flows, not enhancing peak flow magnitude




Est. Travel Time to 15-mile Reach

| | |
|---|---|
| Granby | 60 hrs |
| Williams Fork | 48 hrs |
| Wolford | 42 hrs |
| Green Mountain | 48 hrs |
| Homestake | 100 hrs |
| Ruedi | 24 hrs |

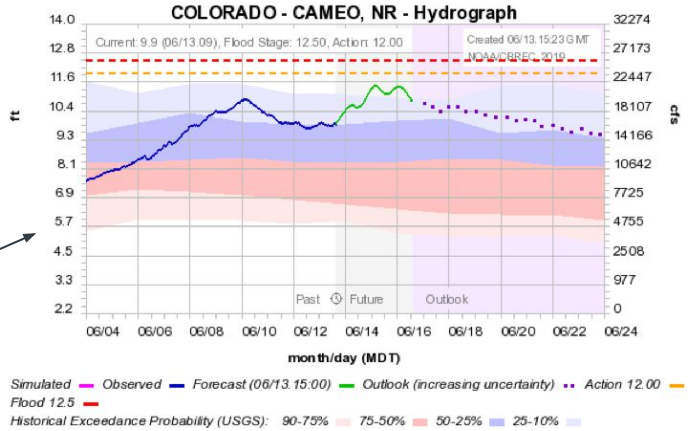
*Note: lower flows have longer travel times

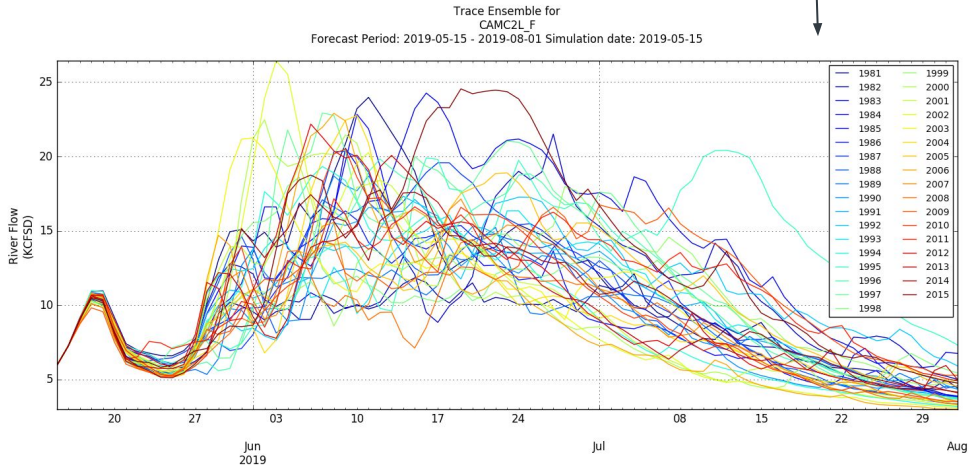
| AGENCY | RESPONSIBILITY |
|---|---|
| U.S. Fish & Wildlife Service | Flow targets in the 15-Mile Reach<br>Monitoring of endangered fish in critical habitat and influences on critical habitat<br>Coordinate reservoir operations with CDWR and reservoir operators |
| National Weather Service | Develop list of forecast locations<br>Provide runoff forecasts (peak volume, rate and time) **CBRFC** |
| U.S. Bureau of Reclamation & SEWCD | Annual operating plan for Ruedi |
| U.S. Bureau of Reclamation & NCWCD & CRWCD | Annual operating plan for Green Mountain |
| U.S. Bureau of Reclamation & NCWCD | Annual operating plans for Granby, Windy Gap, and Willow Creek |
| U.S. Bureau of Reclamation | Organize meeting locations and times<br>Prepare and mail press releases and necessary public notices |
| Colorado Water Conservation Board | Co-chair meetings<br>Coordinate mailing list development<br>Access to CRDSS as required<br>Coordinate annual report preparation |
| Colorado Division of Water Resources | Co-chair meetings<br>River administration<br>Water rights accounting<br>Coordinate reservoir operations with USFWS and reservoir operators |
| Colorado Division of Wildlife | Monitoring of cold water fisheries & habitat |
| Upper Colorado River Recovery Program | RIPRAP implementation & monitoring of program reports & benefits |
| Colorado River Water Conservation District | Annual operating plan for Wolford Mountain |
| Denver Water | Annual operating plan for Dillon<br>Annual operating plan for Williams Fork |
| Cities of Aurora & Colorado Springs | Annual operating plan for Homestake |

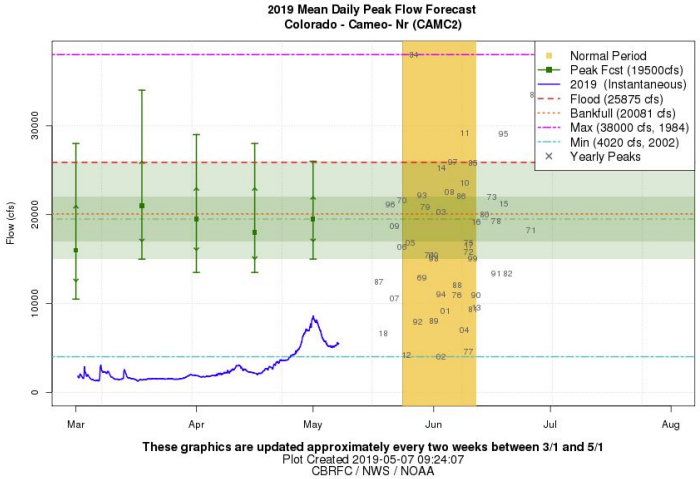
*Source: 1997 CROS Annual Summary of Operations Report*

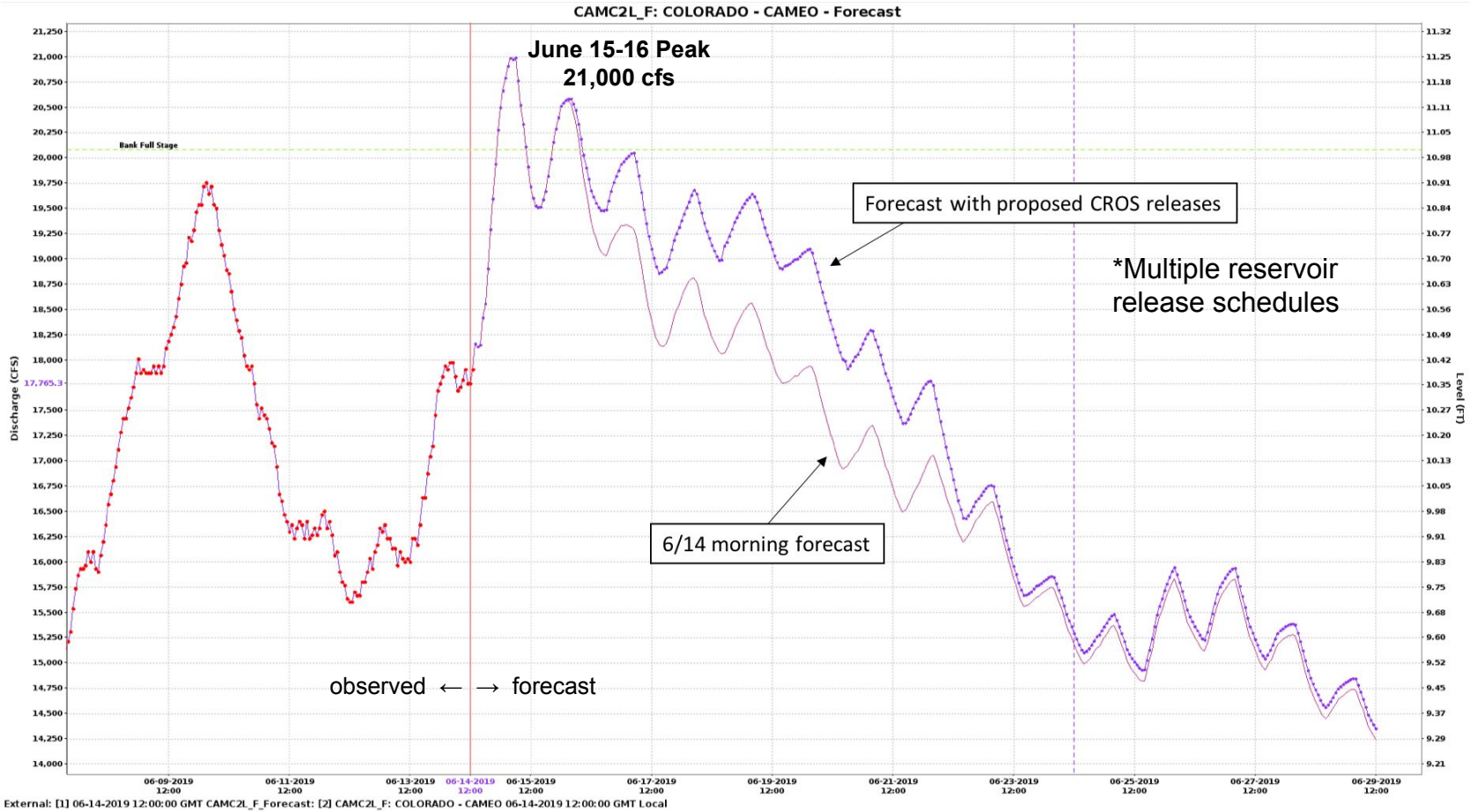
- CBRFC Model
  - Current model states (snow, soil moisture, etc..)
  - 5-day precipitation forecast
  - 10-day temperature forecast
  - Future diversion/reservoir release assumptions

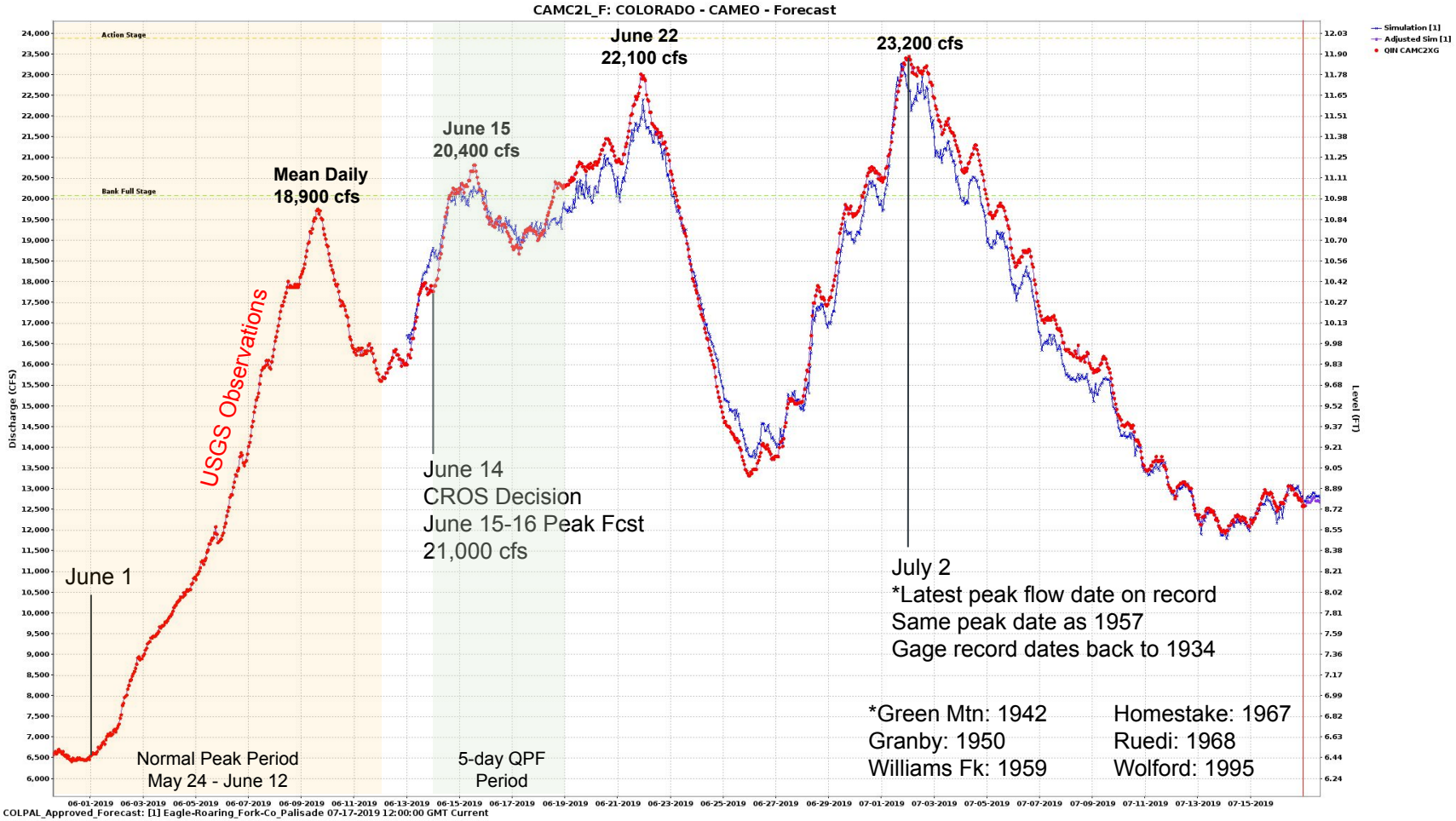
- Peak Flow Magnitude & Timing
  - Mean daily peak flow forecast
  - If peak flow is < 10 days from now -> use 10-day flow forecast
  - If peak flow is > 10 days from now -> use ESP guidance



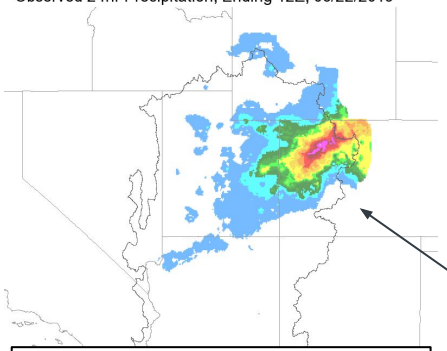




CAMC2L_F: COLORADO - CAMEO - Forecast
June 15-16 Peak
21,000 cfs
Bank Full Stage
Forecast with proposed CROS releases
*Multiple reservoir release schedules
6/14 morning forecast
observed ← → forecast
Discharge (CFS)
Level (FT)
17,765.3
Adjusted Sim [2]
Prv Fcst -0 hour [1]
QIN CAMC2XG
External: [1] 06-14-2019 12:00:00 GMT CAMC2L_F_Forecast: [2] CAMC2L_F: COLORADO - CAMEO 06-14-2019 12:00:00 GMT Local

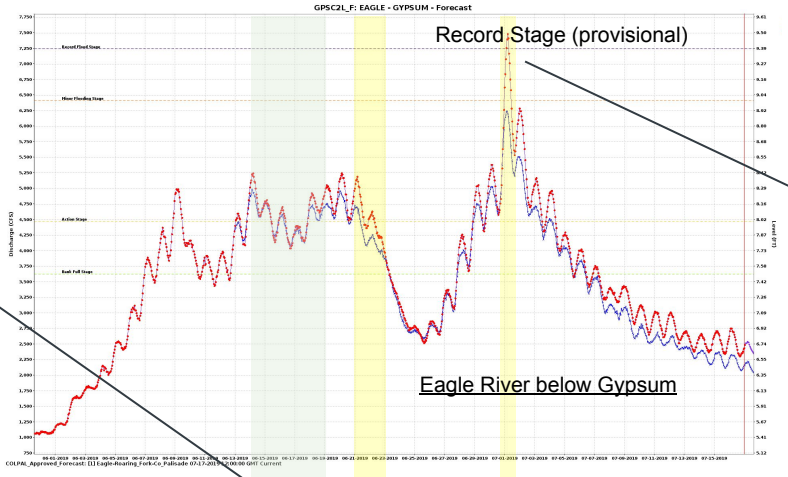



**Cameo Observed Hydrograph (June 1 - July 16)**

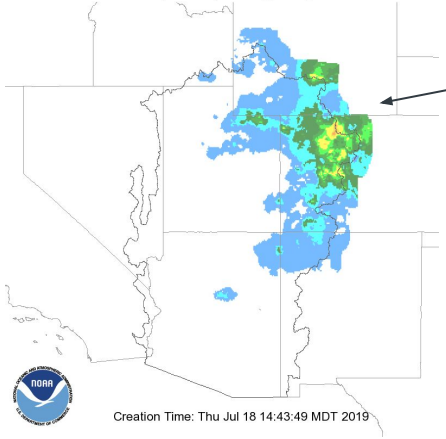
Observed 24hr Precipitation, Ending 12Z, 06/22/2019



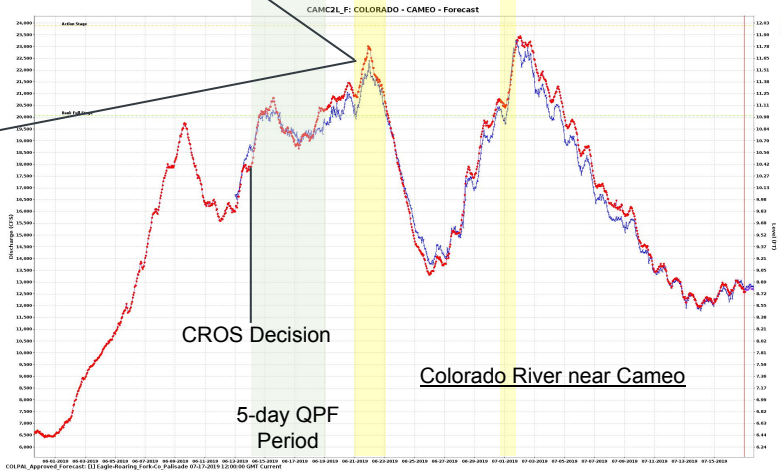
2” new SWE higher elevations
Rain lower elevations



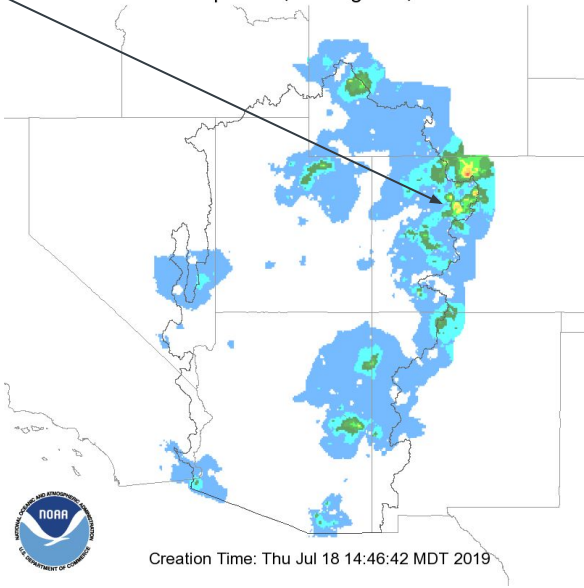

Observed 24hr Precipitation, Ending 12Z, 06/23/2019



Creation Time: Thu Jul 18 14:43:49 MDT 2019

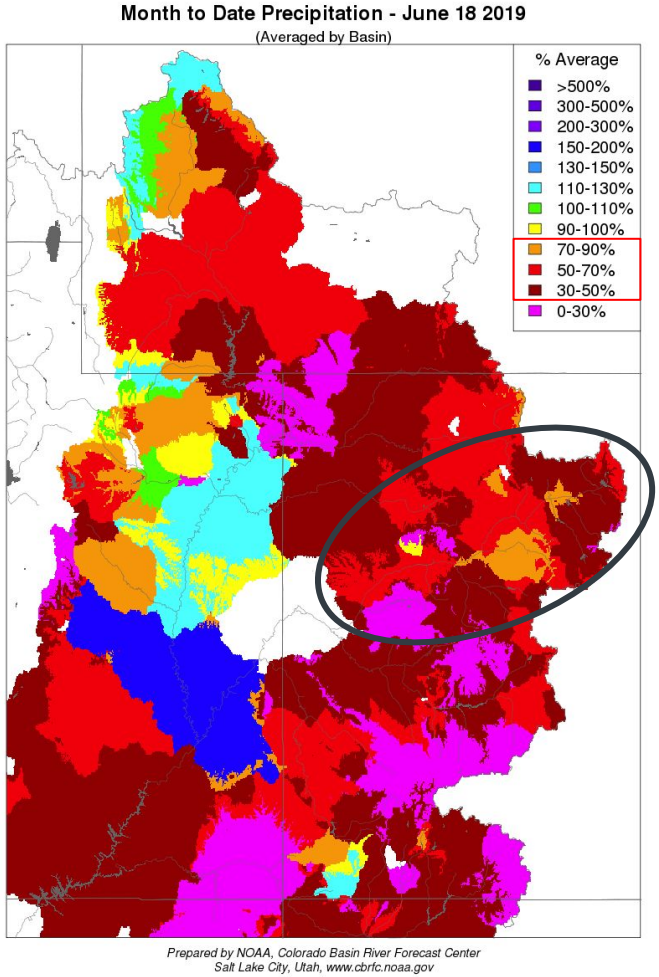


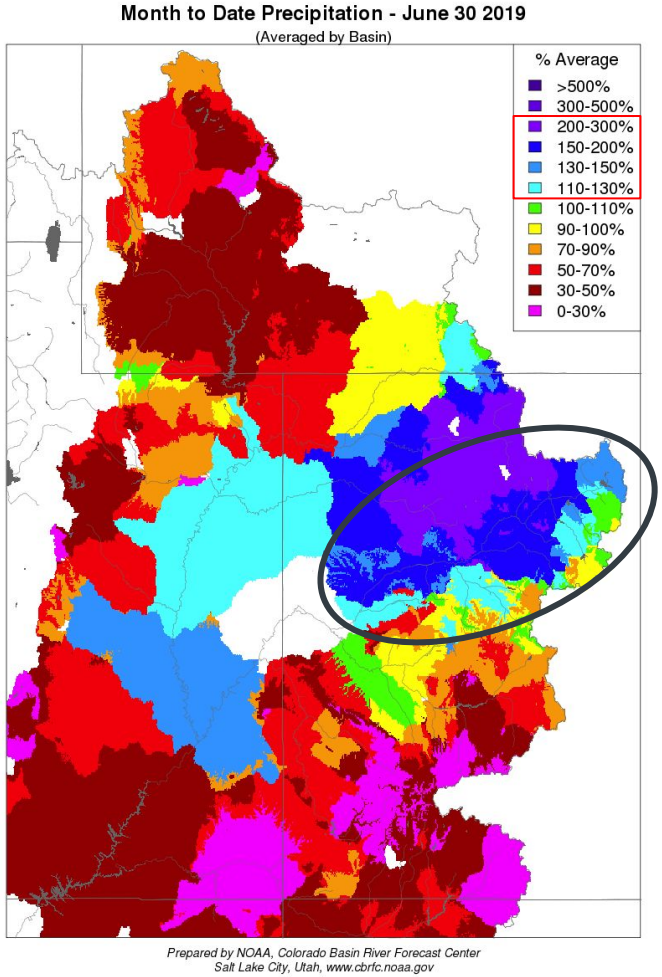

Observed 24hr Precipitation, Ending 12Z, 07/01/2019



Creation Time: Thu Jul 18 14:46:42 MDT 2019

Less Precipitation
Warmer, but Near Normal Temperatures
Ripe Snowpack
Mid+High Elevation Rain-on-Snow Melt
5+ inches mid elevation swe
20+ inches high elevation swe


Month to Date Precipitation - June 18 2019
(Averaged by Basin)
% Average
>500%
300-500%
200-300%
150-200%
130-150%
110-130%
100-110%
90-100%
70-90%
50-70%
30-50%
0-30%
Prepared by NOAA, Colorado Basin River Forecast Center
Salt Lake City, Utah, www.cbrfc.noaa.gov


Month to Date Precipitation - June 30 2019
(Averaged by Basin)
% Average
>500%
300-500%
200-300%
150-200%
130-150%
110-130%
100-110%
90-100%
70-90%
50-70%
30-50%
0-30%
Prepared by NOAA, Colorado Basin River Forecast Center
Salt Lake City, Utah, www.cbrfc.noaa.gov

- Weather Forecast
  - Precipitation -> large impact on 2019 peak flow magnitude & timing
  - Temperature
  - Cloud cover / solar radiation

- Hydrologic Model States
  - Snow: swe, ripeness
  - Soil moisture
  - Melt rate: during both cool down/recession & warm up/rising limb of hydrographs
    - multiple warm ups and cool downs (-15ºF) during 2019 spring runoff season

- Future Water Use
  - Diversions: model assumptions, east slope vs. west slope storage availability
  - Consumptive use: below avg temp + above avg precip = less consumptive use

- Streamflow Measurement
  - +/- 5 to 10 %
  - 20,000 cfs +/- 1,500 cfs
  - CBRFC model was suggesting slightly lower (500-1,000 cfs) flows in 15-mile reach
    - confirmed by USGS measurements ~June 17

- Peak flow forecast magnitude & timing did not verify

- Could anything have been done differently in order to more accurately forecast the peak flow magnitude and timing?
  - extend QPF period beyond 5 days?
    - accuracy of QPF beyond 5 days?
    - Cameo peak occurred >2 weeks later than expected

- Would it have been possible to receive more detailed / accurate future diversion information from partners / stakeholders?
  - would rather have current best estimate of future diversions vs. going off of historical diversion pattern assumptions
  - major diversions seem to operate / react to near real-time conditions

- High water impacts
  - did not hear of any high water issues along 15-mile reach
    - extra work required by irrigation companies to deal with increased debris
  - some impacts on the Gunnison and Colorado below the confluence, but not during Cameo peak

- QUESTIONS

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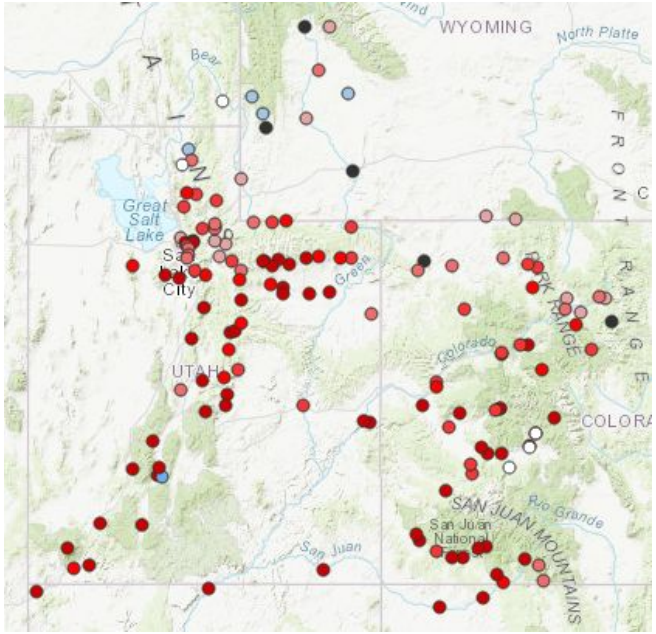
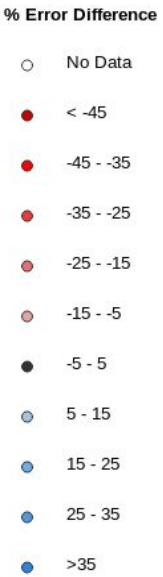
# 2019 Water Supply Forecast Verification

Brenda Alcorn
Hydrologist, CBRFC

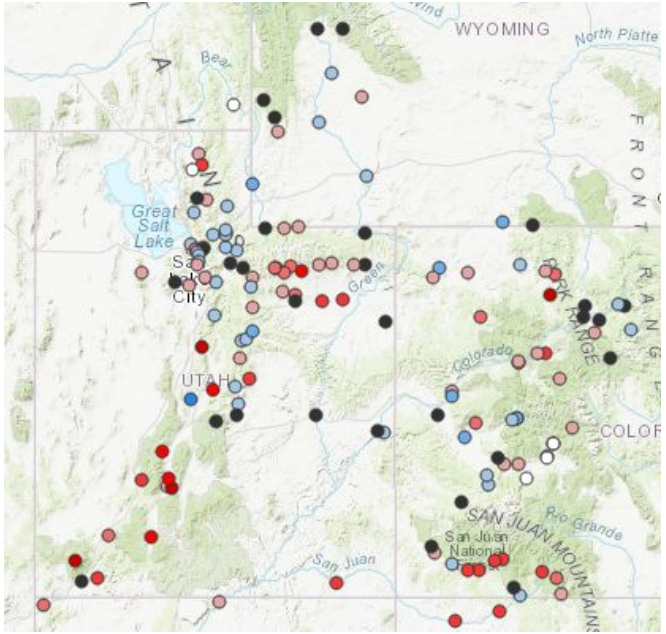
# 2019 Verification Maps

**January**




**May**



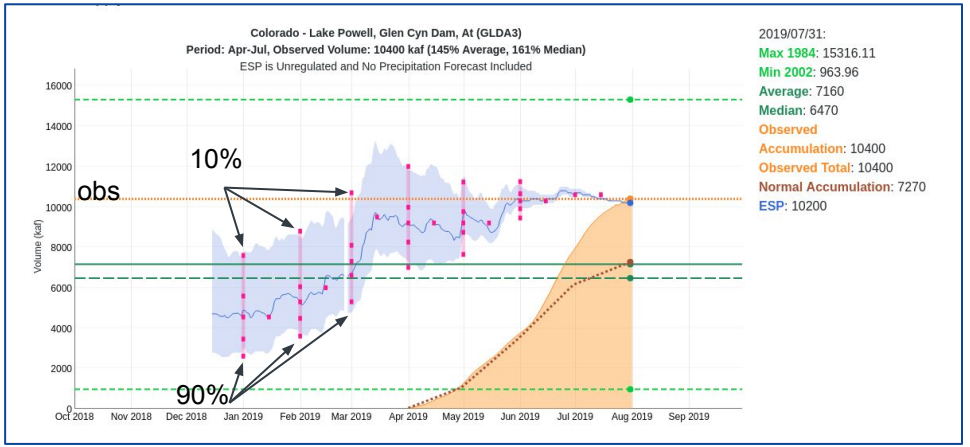

Red = This year's forecast error larger than ESP historical error.
Blue = This year's forecast error smaller than ESP historical error.
Black = This year's forecast error similar to ESP historical error.

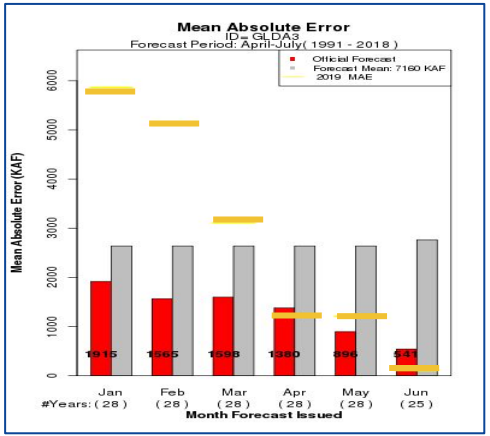
Access from cbrfc homepage: WATER SUPPLY menu -> 2019 Verification Map
https://www.cbrfc.noaa.gov/arc/verif/verif.diff.php

# Water Supply Forecast Verification

## What are we looking for?

- Forecast Evolution Plots:
  - Like to see the observed volume fall within the 10%/90% forecast range.
    - If not, was it due to extreme weather or model states error?
- Mean Absolute Error (MAE):
  - Did we do better or worse than the historical forecast error?
    - Why?

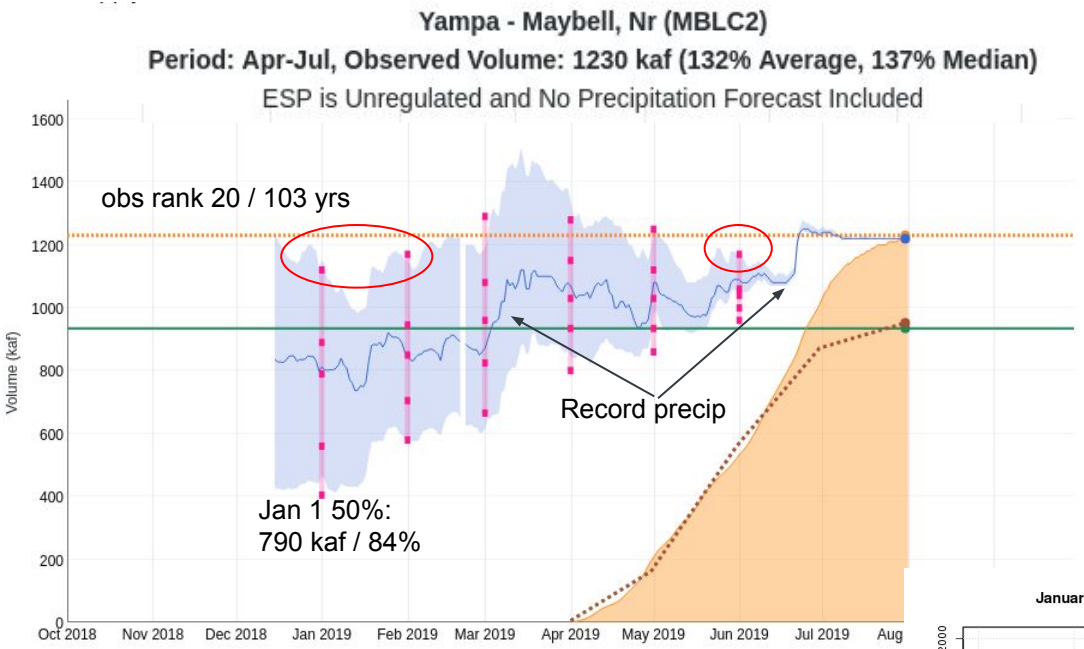


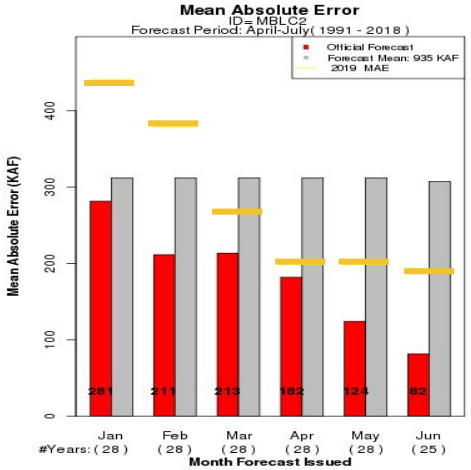

Grey bars = if we just forecast average

Red bars = historical forecast error

Yellow lines = current year error

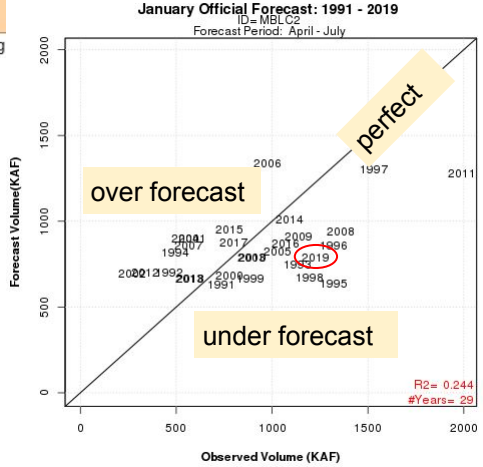


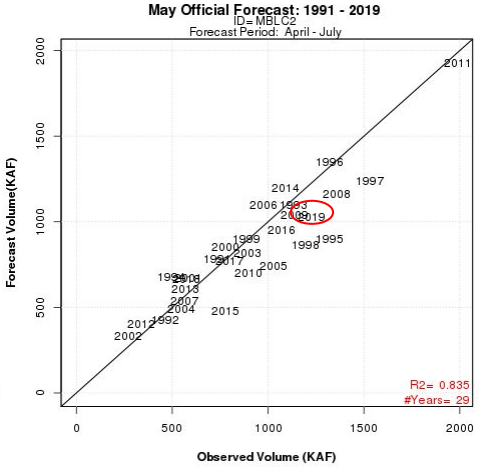

2019/07/31:
Average: 935
Observed
Accumulation: 1220
Observed Total: 1230
Normal Accumulation: 952
ESP: 1220

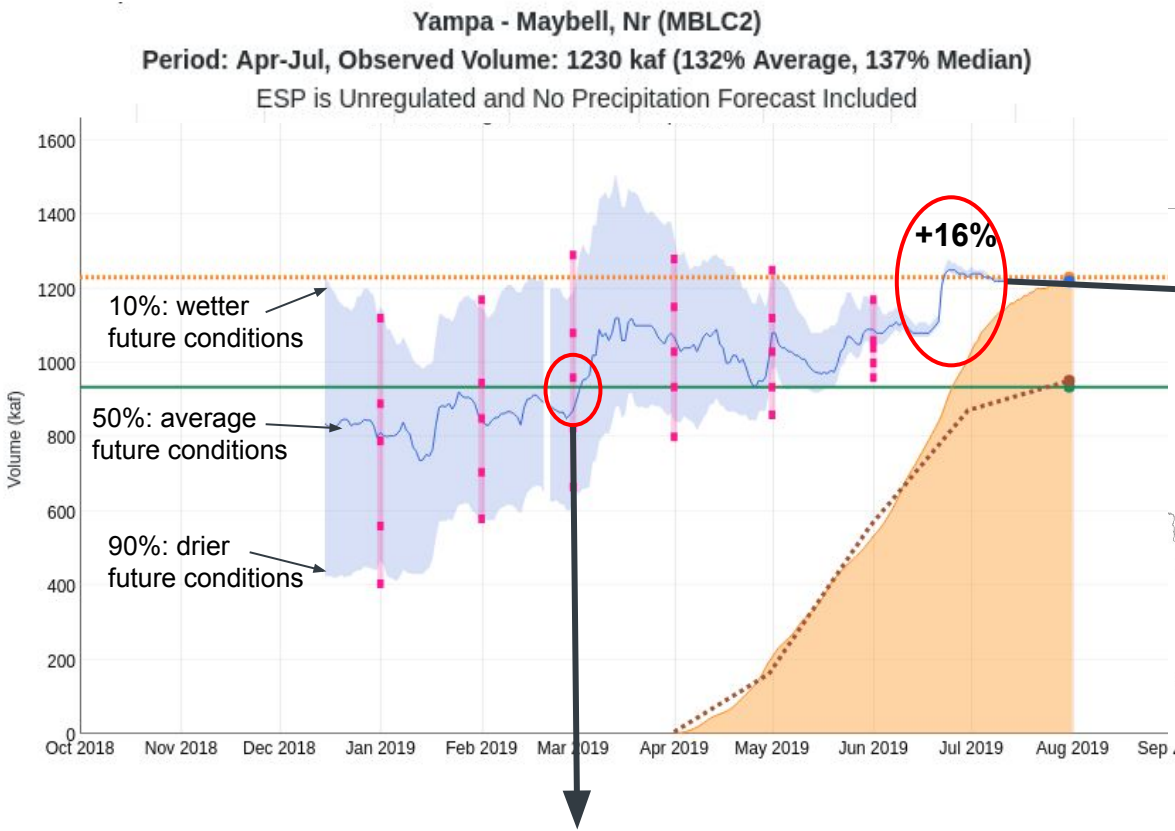


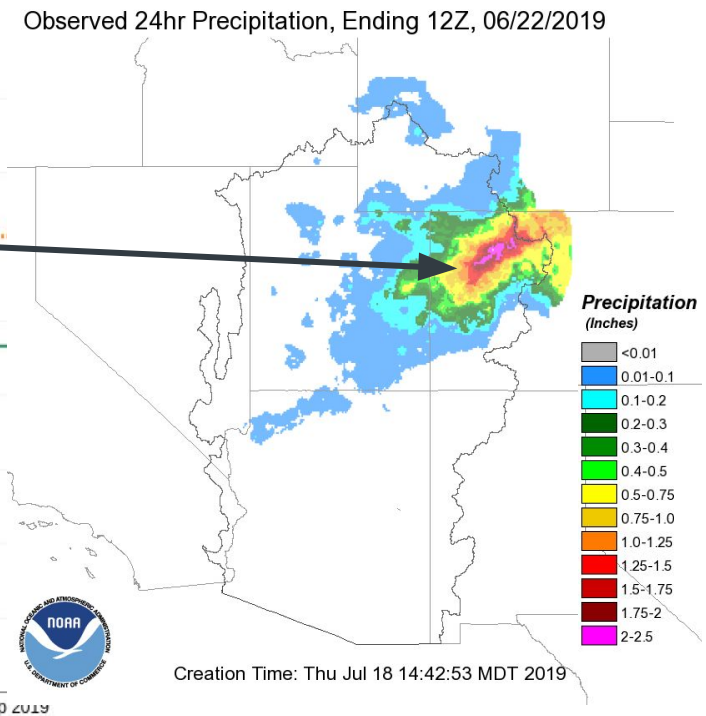

Final observed volume was above 10% exceedance forecast for Jan, Feb, and Jun. In addition, MAE was larger than historical error for all months.

- Record precipitation in March and June so this explains large forecast errors.
- *Forecasts were not bad based on information available at the time (model states reflected current hydrologic conditions).*



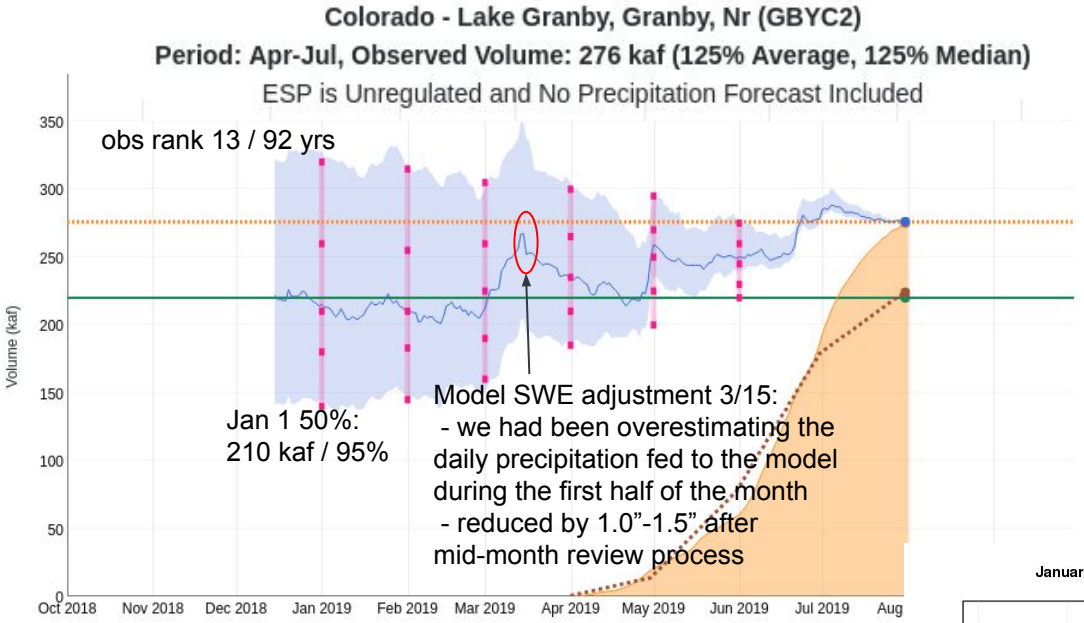





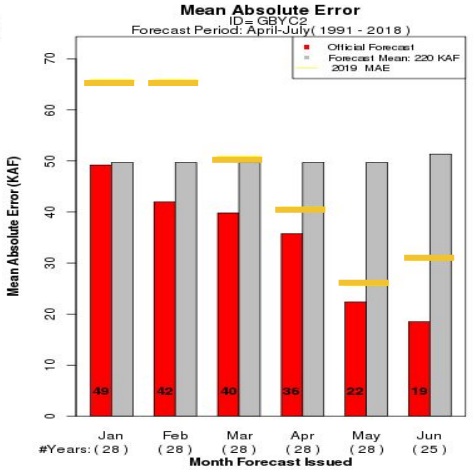




Official forecast ~10% higher than ESP guidance

➢ High confidence in large event / wet first half of March

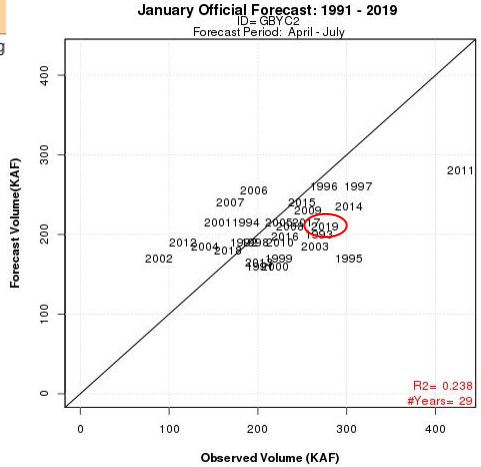


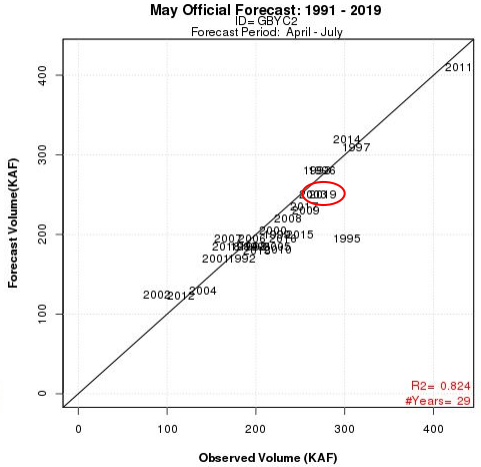

2019/07/31:
Average: 220
Observed Accumulation: 275
Observed Total: 276
Normal Accumulation: 224
ESP: 276

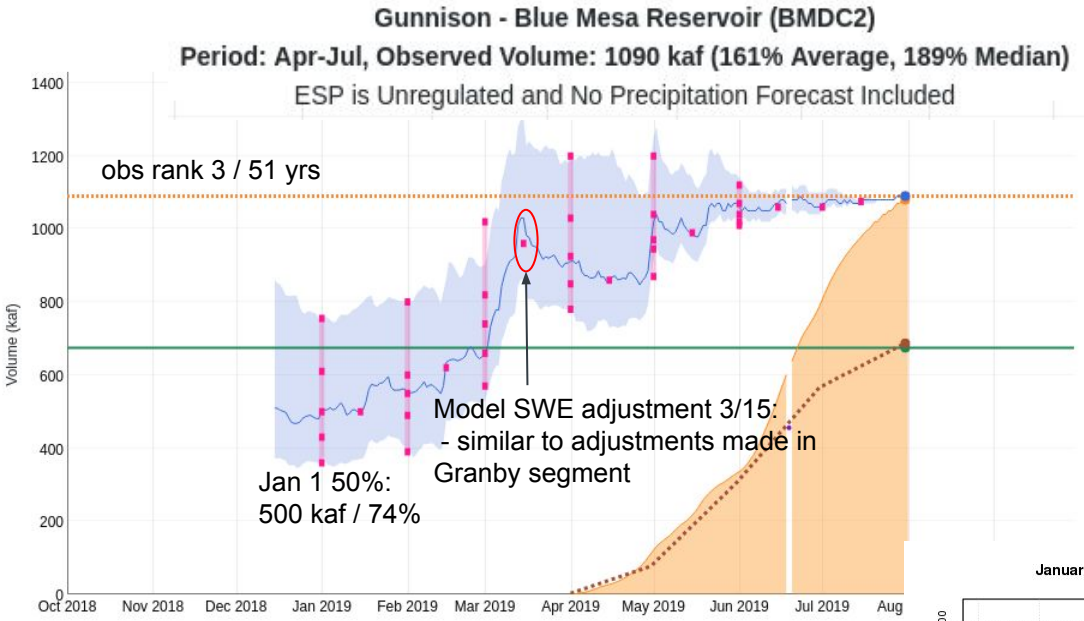



Final observed volume was above 10% exceedance forecast only for June. However, MAE was larger than historical error for all months due to wetter than normal future weather.

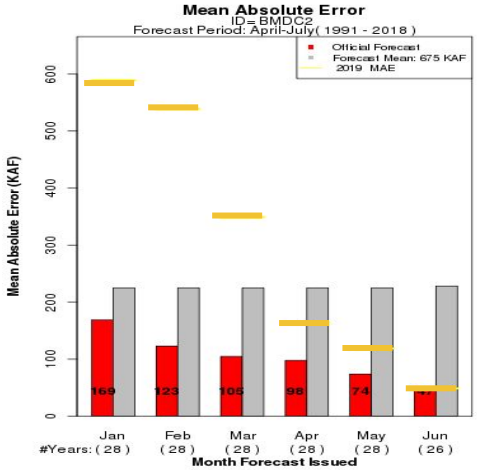
- March precipitation top 5; May precipitation top 10; June precipitation near record.
- Model snow states did get off track the first half of March, but this was caught and corrected before the April official forecast.



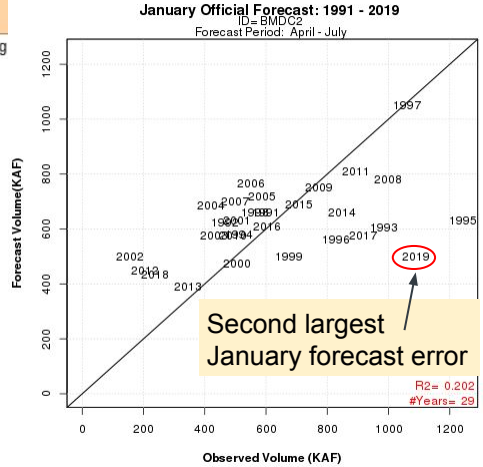


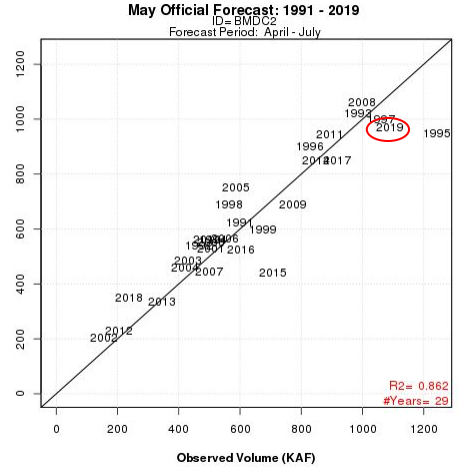

2019/07/31:
Average: 675
Observed Accumulation: 1080
Observed Total: 1090
Normal Accumulation: 687
ESP: 1090

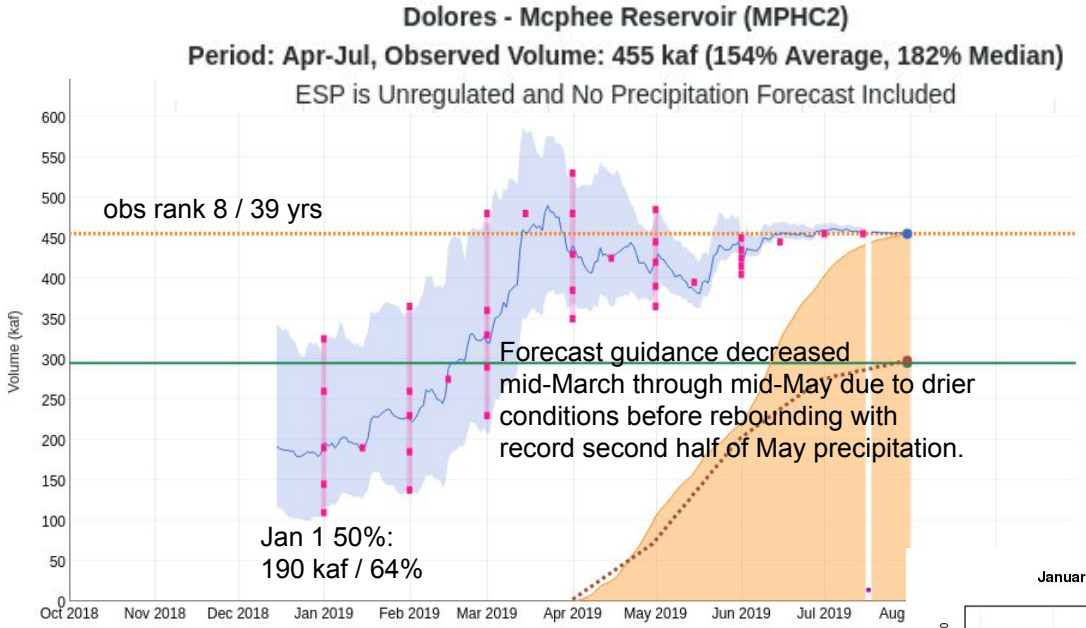



Final observed volume was above 10% exceedance forecast Jan, Feb, and Mar. MAE was larger than historical error for all months.

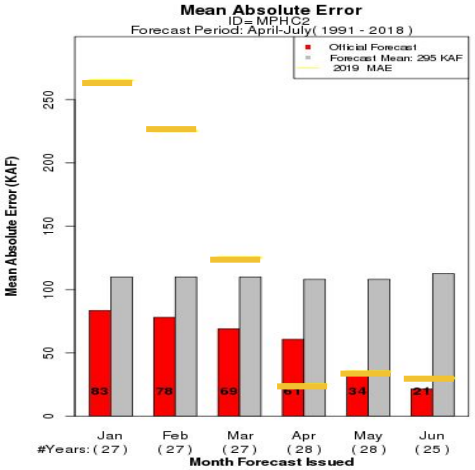
- Came into the year with near record low model soil moisture; January 1 forecast much below normal.
- Record March precipitation; May precipitation top 10; June precipitation near normal.
- March mid-month forecast undercut guidance as drier conditions were anticipated for the second half of the month and model swe updates were in progress as well.



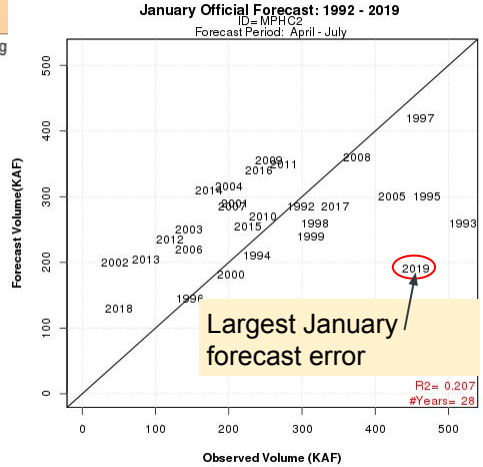


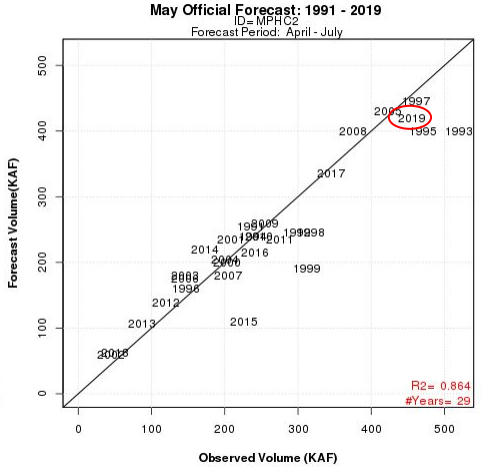

2019/07/31:
Average: 295
Observed Accumulation: 455
Observed Total: 455
Normal Accumulation: 298
ESP: 455

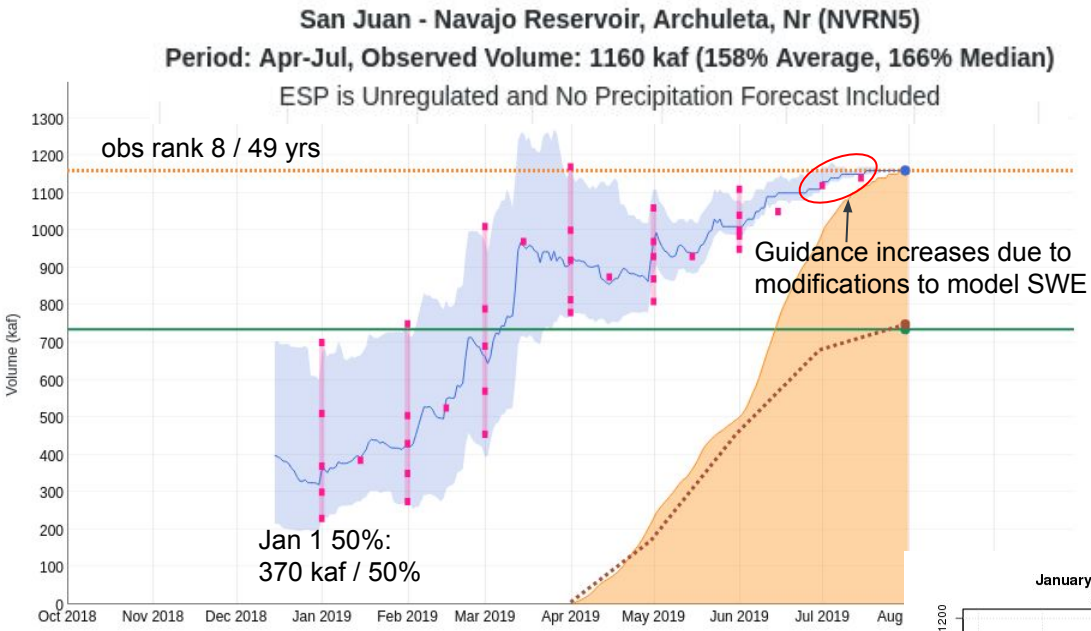



Final observed volume was above 10% exceedance forecast Jan, Feb, and Jun. MAE was larger than historical error Jan-Mar, below in Apr, and near May-Jun.

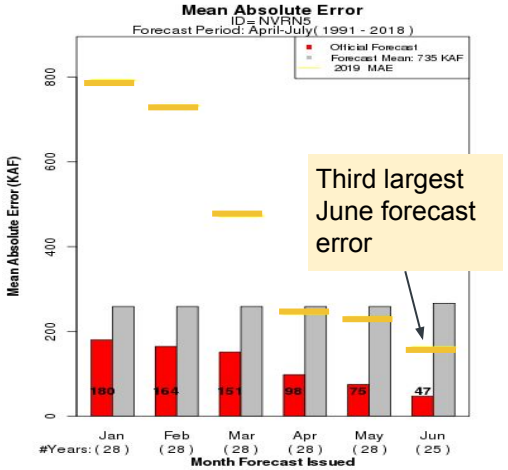
- Came into the year with near record low model soil moisture; January 1 forecast much below normal.
- Record March and May precipitation; April precipitation much below normal; June precipitation near normal.
- Model guidance was in the ballpark by mid-March; nice to see the model handle such a large turn around.



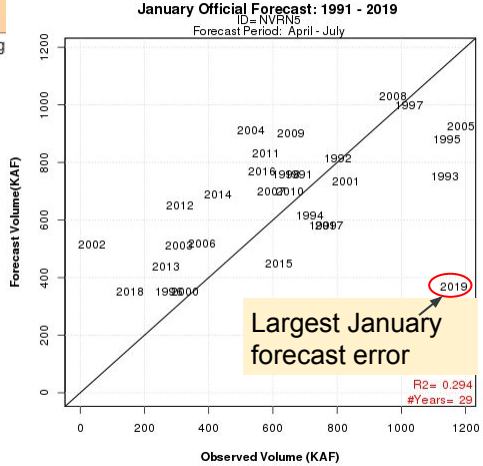


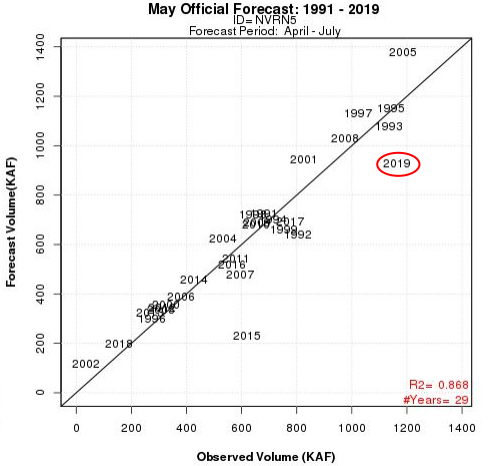

2019/07/31:
Average: 735
Observed Accumulation: 1160
Observed Total: 1160
Normal Accumulation: 749
ESP: 1160

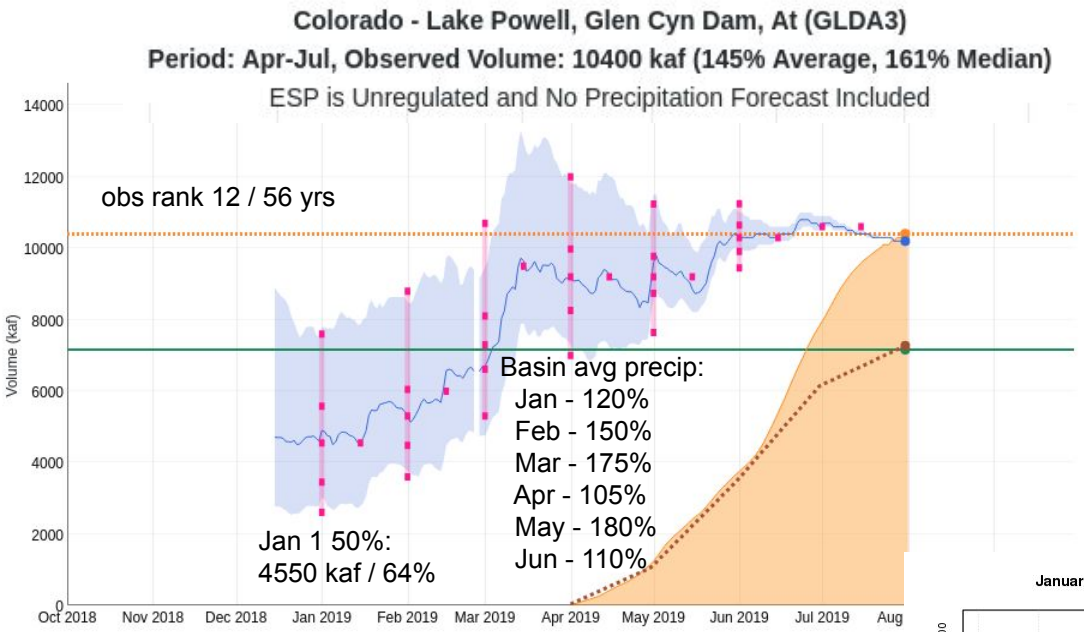



Final observed volume was above 10% exceedance forecast for all months except Apr. MAE was larger than historical error for all months.

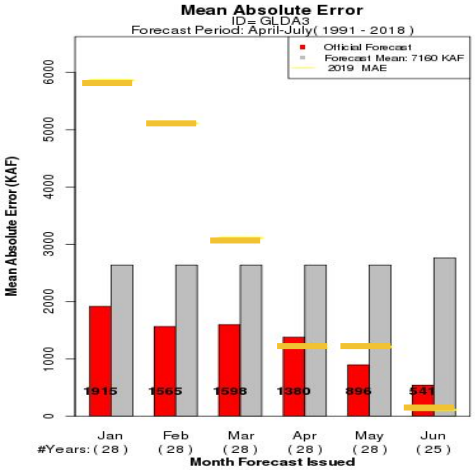
- Came into the year with near record low model soil moisture; January 1 forecast much below normal.
- Record March and May precipitation.
- Added snow to the model late in the season - likely a model state/calibration error.



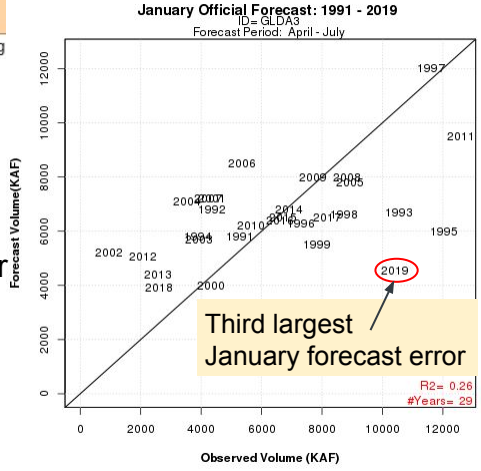


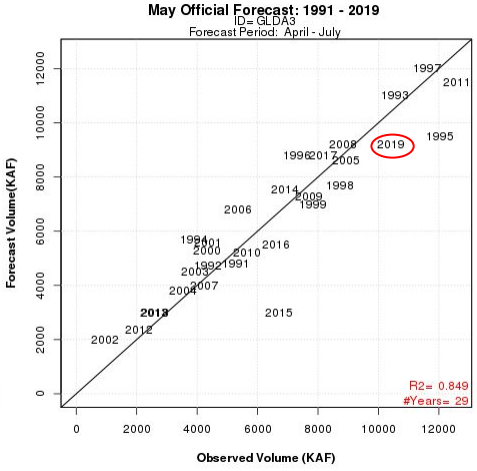

2019/07/31:
Average: 7160
Observed
Accumulation: 10400
Observed Total: 10400
Normal Accumulation: 7270
ESP: 10200

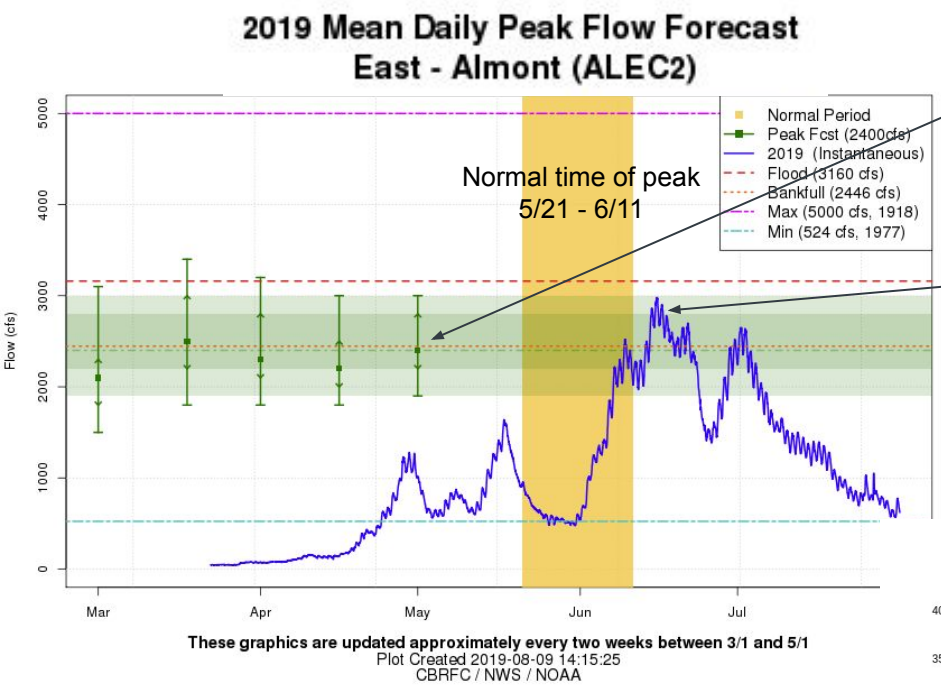



Final observed volume was above 10% exceedance forecast for Jan and Feb. MAE was larger than historical error for all months except Apr and Jun.

- Forecasts follow a similar pattern to the sampling of western Colorado points that were just reviewed.
- In addition, the upper Green River in Wyoming is a major contributor to Lake Powell inflow.
  - Forecasts for Flaming Gorge were below average through April 1.
  - Above average precipitation in Apr and May brought final observed to ~120% of average.



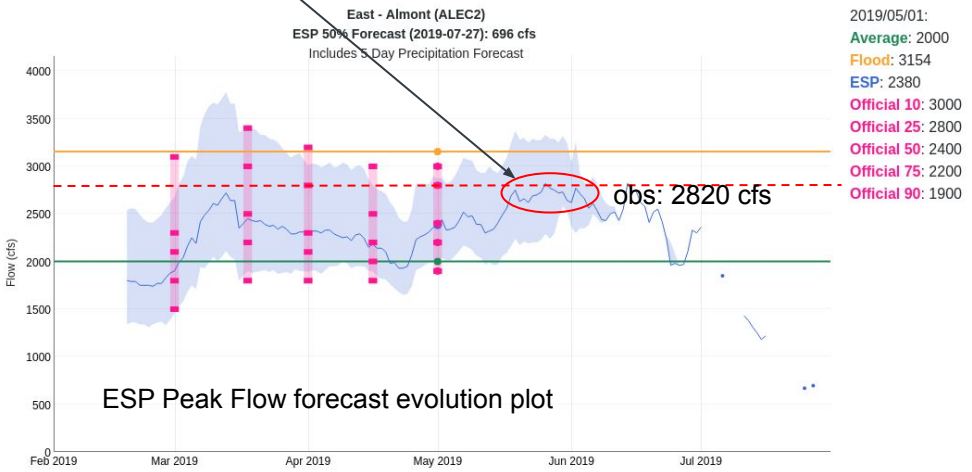






Last official long lead peak flow forecast (5/1): 2400 cfs
ESP guidance still indicating 'normal' timing
(we do not forecast peak timing)

2019 provisional mean daily peak: 6/15 - 2820 cfs

ESP forecasts from 5/19-6/2 were indicating a higher (2600-2800 cfs) and later-than-usual (6/9-6/20) peak.




ESP Peak Flow forecast evolution plot

*Note: ESP guidance for peaks is most useful beyond the 10-15 day window; once the peak looks like it will occur within the next two weeks the daily forecast hydrographs are the best source of information.*

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# Operational Updates During WY2019

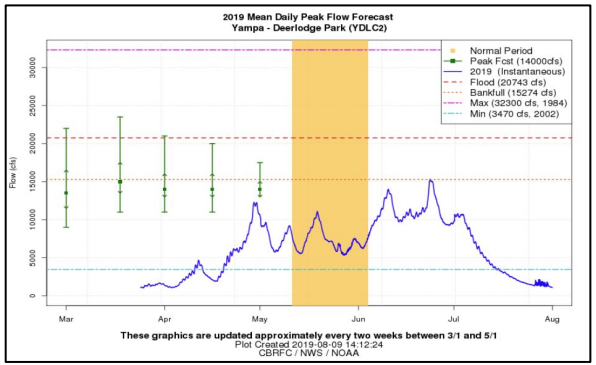
Ashley Nielson
Hydrologist, CBRFC

# Peak Flow Forecast Improvements

## *Existing Product*

### Snowmelt Peak Flow Forecasts

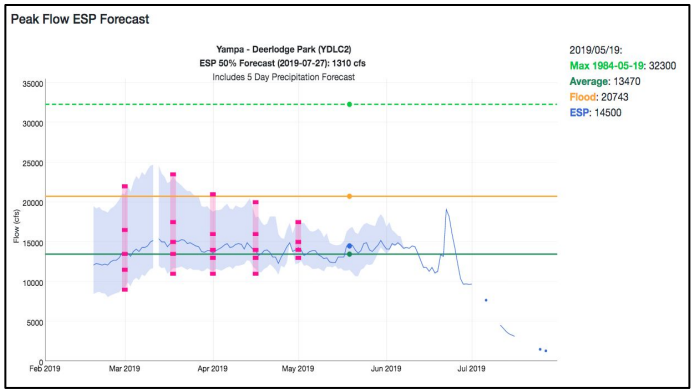
- Probabilistic (regulated ESP)
  - Likelihood of exceeding flood thresholds
  - Update bi-weekly March - May
- Do not provide specific date of peak
- Challenges:
  - Peak timing
  - Infrequent updates
  - Lack of late season guidance
  - Only for locations with defined thresholds
  - Lacks historical relevance




## *New Product WY2019*

### Flood Potential Dashboard

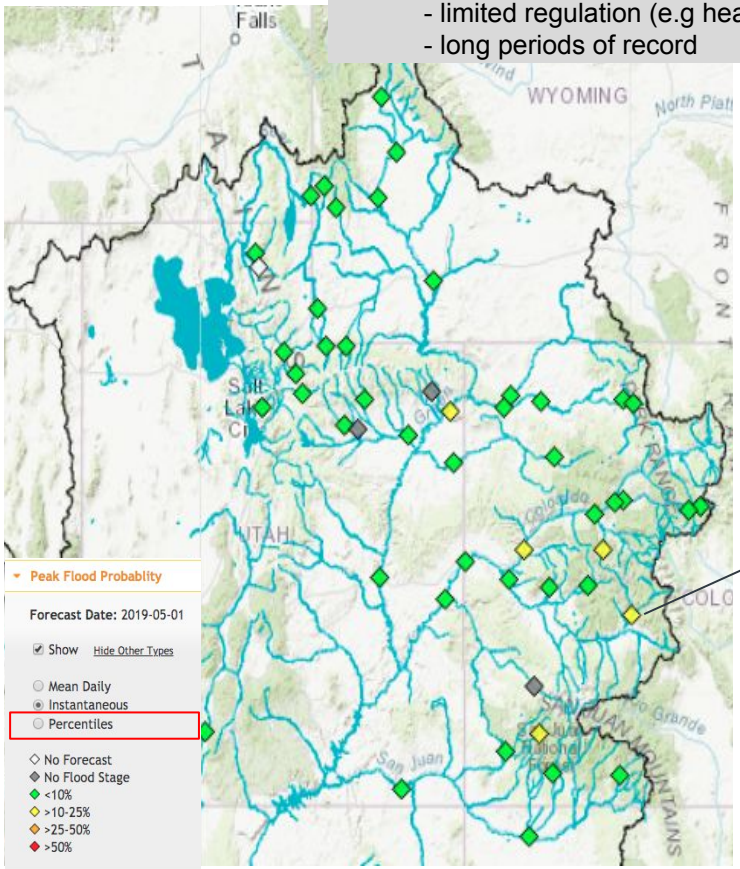
- New Flood Potential Dashboard
  - Launched internally in mid May 2019
- Does not replace traditional peak flow forecast products
- Percentile Ranking
  - Provides context to historical record
  - Includes points without defined critical levels
- Daily Updates
- Helpful in tracking the flooding potential in late melts
- Additional improvements to come
- Feedback welcome



# Flood Potential Dashboard

## Conditions Map

Percentile map contains more locations
Sites included have:
- limited regulation (e.g headwaters)
- long periods of record




Peak Flood Potential - ALEC2 - Rank: / (%)

**ESP Peak Flow Evolution Plot**

**ESP Peak Flow Forecast Table**

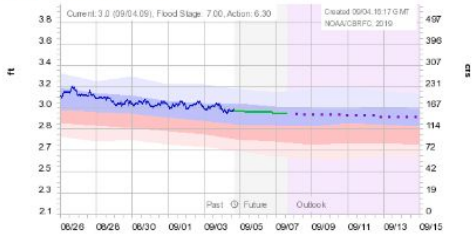
ALEC2
ESP Mean Daily Peak Includes 5 Day Precipitation Forecast
Forecast Date: 2019-07-27
Flood Flow: 3154 CFS

| Exceedance Probability | Mean Flow CFS |
|---|---|
| min | 696 |
| 90% | 696 |
| 75% | 696 |
| 50% | 696 |
| 25% | 696 |
| 10% | 696 |
| max | 696 |

ALEC2
ESP Date of Peak Includes 5 Day Precipitation Forecast
Forecast Date: 2019-07-27
Normal Time of Peak: 05/21 - 06/11

| Exceedance Probability | Date of Peak |
|---|---|
| min | 2019-07-27 |
| 90% | 2019-07-27 |
| 75% | 2019-07-27 |
| 50% | 2019-07-27 |
| 25% | 2019-07-27 |
| 10% | 2019-07-27 |
| max | 2019-07-27 |

**10 Day Streamflow Forecast**




**10 day Streamflow Forecast Table**

EAST - ALMONT
Daily Average Forecast Flow (ending at given date/time)
Units: CFSD
csv file

| DATE | TIME | FLOW |
|---|---|---|
| 9/5/2019 | 12Z | 156 |
| 9/6/2019 | 12Z | 155 |
| 9/7/2019 | 12Z | 153 |
| 9/8/2019 | 12Z | 151 |
| 9/9/2019 | 12Z | 150 |
| 9/10/2019 | 12Z | 148 |
| 9/11/2019 | 12Z | 147 |
| 9/12/2019 | 12Z | 146 |
| 9/13/2019 | 12Z | 145 |
| 9/14/2019 | 12Z | 144 |

**Model Snow**

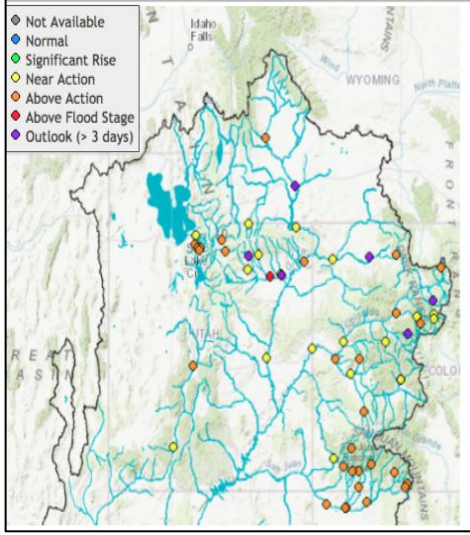
**Apr-Jul Historical Peaks**

ALEC2 QRD5ZZZ Apr-Jul Historical Peaks
High -> Low (reverse table order)
csv file

| RANK | YEAR | PEAK | DATE |
|---|---|---|---|
| 1 | 1918 | 5000.0 | 6/13 |
| 2 | 1995 | 4020.0 | 6/19 |
| 3 | 1920 | 3870.0 | 6/10 |
| 4 | 1957 | 3820.0 | 6/30 |
| 5 | 1984 | 3700.0 | 5/26 |
| 6 | 1917 | 3540.0 | 6/19 |
| 7 | 1952 | 3410.0 | 6/9 |
| 8 | 1914 | 3340.0 | 6/2 |

# Weekly Hydrologic Outlooks

## CBRFC Hydrologic Outlook - June 11, 2019




**General river trends: Very active hydrologic period**
Significant rises occurred over the weekend.
Leveling off or falling due last 2 days due to recent colder temperatures.

Rises (some significant) through this week.

**Flood Stage** - A river stage level where there are impacts / threats to life and / or property.

**Action Stage** - A river stage level where the NWS or a partner may take some type of mitigating action. This could result in increased monitoring or dissemination of specific forecasts for the site.

www.cbrfc.noaa.gov (Default Map)

- Weekly Webinar: 5/14-6/11
- Overview of:
  - Current Hydrologic Conditions
  - Areas of Flooding Concerns
  - Weather Forecasts
  - Streamflow Forecasts
- Stakeholder motivated

## CBRFC Hydrologic Outlook - Critical Thresholds (Flood Stage)

**Rivers currently above Flood Stage:**
None

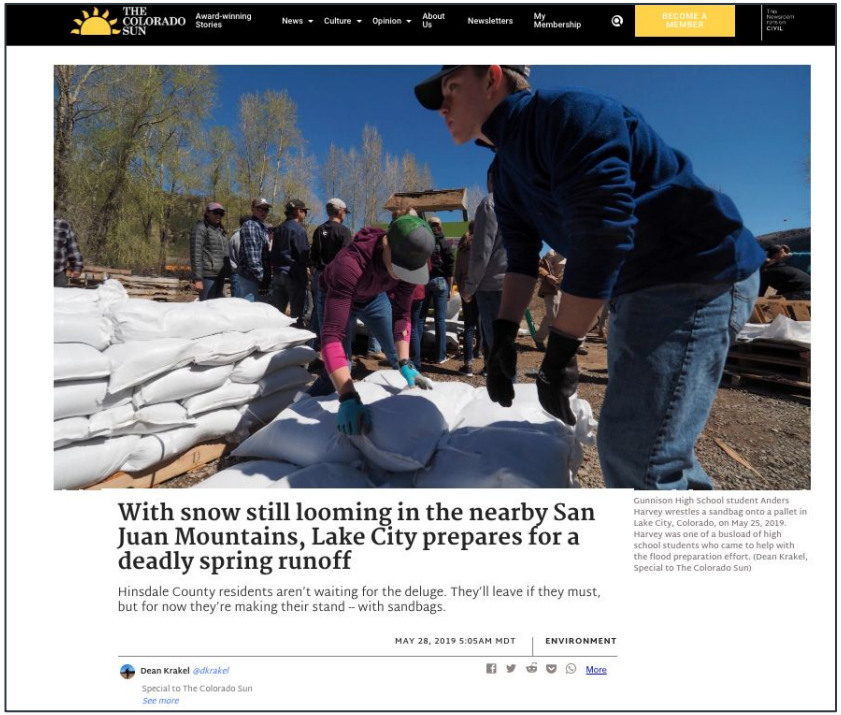
**River Forecast to reach Flood Stage:**

| | |
|---|---|
| Duchesne River near Myton, UT | June 13/14 and beyond |

**Rivers Forecast close to Flood Stage:** **(Enough forecast uncertainty Flood levels could be realized)**

| | |
|---|---|
| Little Cottonwood Creek - SLC | June 14/15 |
| Duchesne River near Randlett, UT | June 14/15 |
| Dolores River near Rico, CO | June 13/14 |
| Elk River near Milner, CO | June 14 and beyond |
| San Juan - Pagosa Springs, CO | June 13/14 |

# Lake City/Henson Creek Event Support



THE COLORADO SUN Award-winning Stories News Culture Opinion About Us Newsletters My Membership BECOME A MEMBER

Gunnison High School student Anders Harvey wrestles a sandbag onto a pallet in Lake City, Colorado, on May 25, 2019. Harvey was one of a busload of high school students who came to help with the flood preparation effort. (Dean Krakel, Special to The Colorado Sun)

**With snow still looming in the nearby San Juan Mountains, Lake City prepares for a deadly spring runoff**

Hinsdale County residents aren't waiting for the deluge. They'll leave if they must, but for now they're making their stand – with sandbags.

MAY 28, 2019 5:05AM MDT | ENVIRONMENT

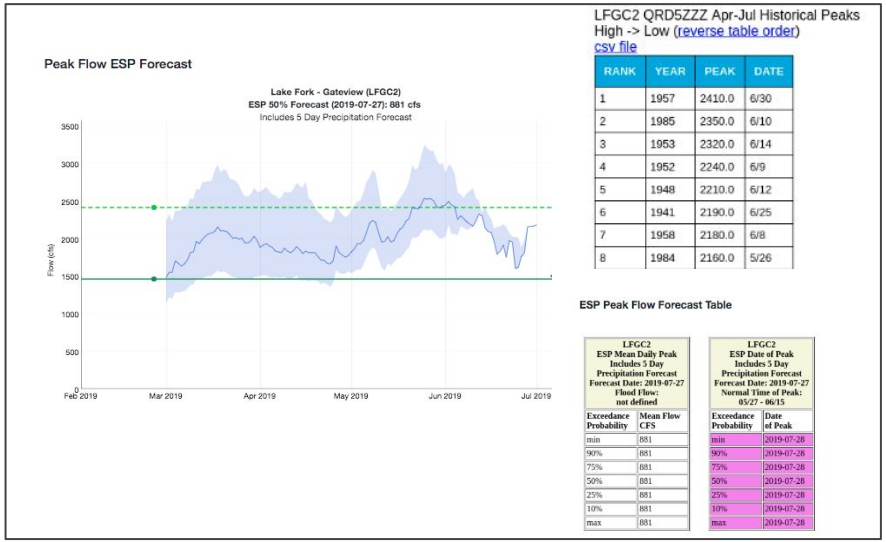
Dean Krakel @dkrakel
Special to The Colorado Sun
See more

More

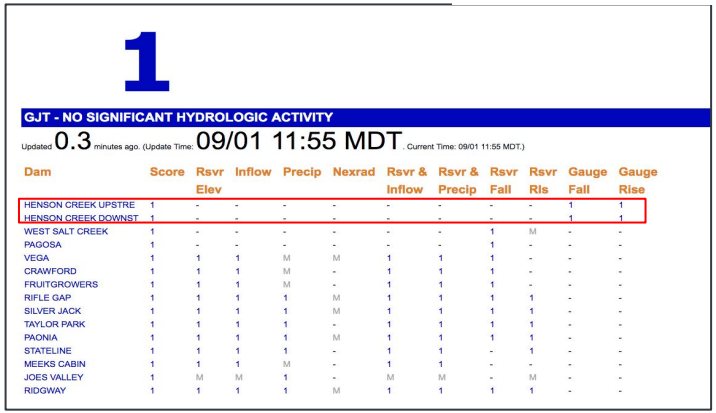
- WFO Grand Junction informed of us of the situation and possible flooding concerns in mid May

- Could we provide any forecasting support to help with the emergency?
  - Timing/magnitude of peak flow?
  - How to utilize new USGS gages?
  - Real-time monitoring?

# Lake City/Henson Creek Event Support




Added Lake Fork USGS gages to flood potential dashboard. Included historical peak magnitude and peak timing data.




Developed rate of change thresholds with WFO and added the two new USGS gages to our internal dam early warning program.

Program alerts both WFO/RFC anytime the rate of change thresholds are exceeded.

# Lake City/Henson Creek Event Support

Created and distributed to the WFO a 15-day daily streamflow forecast for the two long-term locations on the Lake Fork River through July. These points were already part of our model.

### 15-Day Streamflow Forecast

```
Lake Fork - Gateview
Daily Average Forecast Flow (ending 12z on given date)
Units: CFSD

Created: June 15 2019

DAILY TOTAL: deterministic forecast flow
DATE,TOTAL,
2019-06-16,1902,Daily Model Output (20190615)
2019-06-17,1965
2019-06-18,2058
2019-06-19,2077
2019-06-20,1998
2019-06-21,1919
2019-06-22,1906
2019-06-23,1848
2019-06-24,1739
2019-06-25,1684
2019-06-26,1666
2019-06-27,1665
2019-06-28,1630
2019-06-29,1586
2019-06-30,1550
```

Provided daily probabilistic forecasts for peak flow magnitude and timing of peak flow to the WFO.

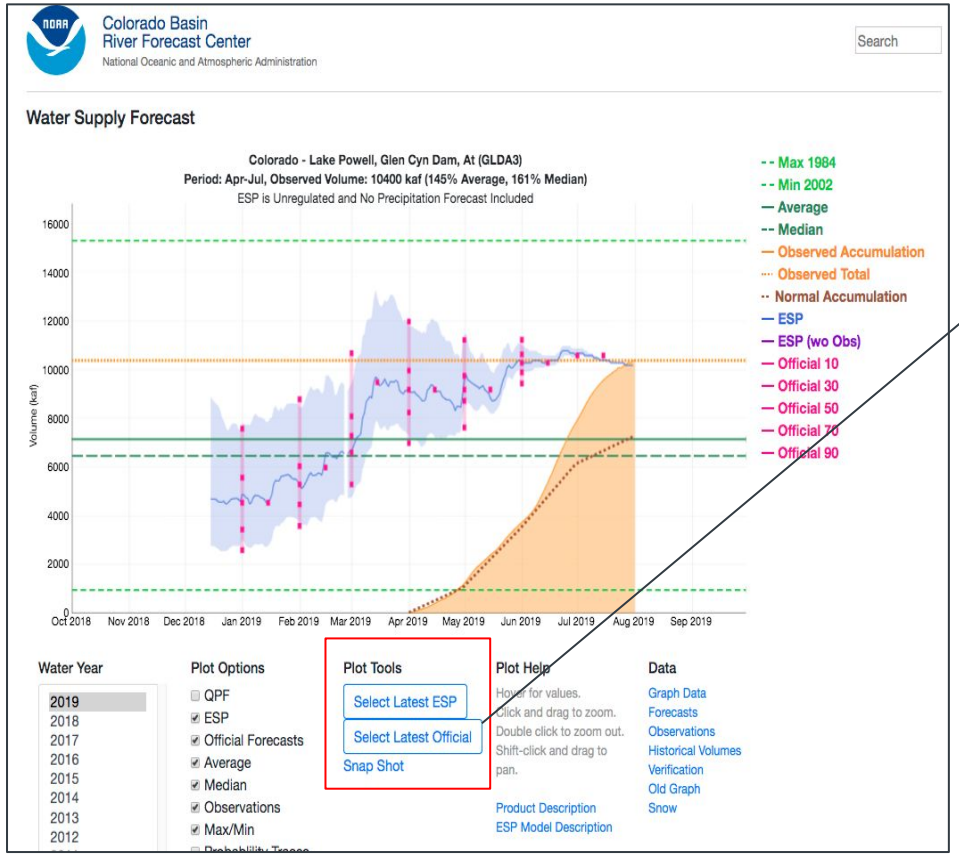
### Peak Flow Magnitude Forecast

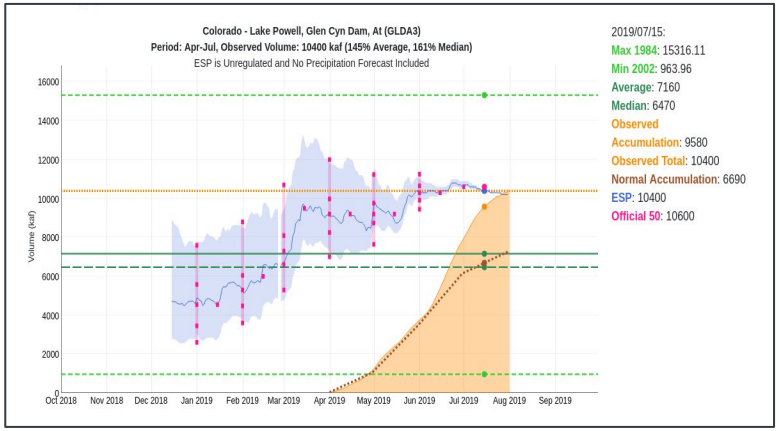
```
Chances of Exceeding Peak CFSD for
LFGC2L_F
Forecast Period: 2019-06-05 - 2019-07-31
Simulation date: 2019-06-05

Period: 2019-06-05 - 2019-07-31
         Reg
min  2036.90
90%  2036.90
75%  2116.10
50%  2254.72
25%  2460.65
10%  2614.17
max  2985.64
```

### Number of Days to Peak Flow

```
Chances of Exceeding NDtoPeak CFSD for
LFGC2L_F
Forecast Period: 2019-06-05 - 2019-07-31
Simulation date: 2019-06-05

Period: 2019-06-05 - 2019-07-31
       Reg
min   8.00
90%  10.00
75%  12.00
50%  14.00
25%  16.00
10%  19.40
max  23.00
```

# Interactive Graphic Snapshot




- Option now available to easily save the Water Supply Forecast graphic
  - Latest ESP
  - Latest Official
- Will be available for other interactive graphics on the webpage

NOAA
National
Weather
Service

# 2019 Development Work and Future Plans

Brenda Alcorn
Hydrologist, CBRFC

# 2019 Development Work

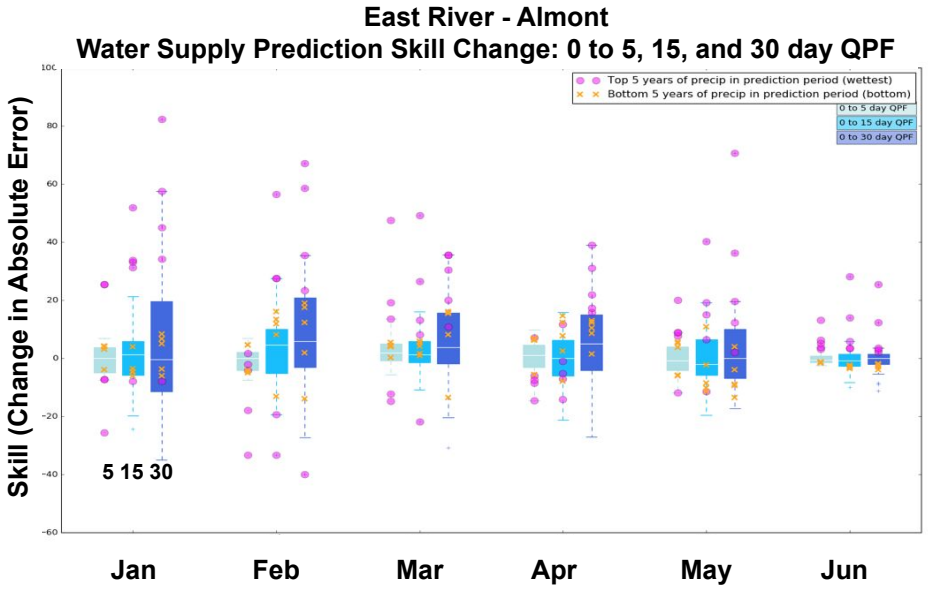
- ESP sensitivity to QPF
  - Examine impact of precipitation forecasts on seasonal water supply volume forecasts.
- Evaluation of NASA Airborne Snow Observatory (ASO) data
  - Compare ASO SWE to CBRFC SNOW-17 SWE.
- Seasonal runoff distribution
  - Examine whether distribution of runoff has changed over time.
- Exploring the National Water Model (NWM)
  - Focus on ET

# ESP Sensitivity to QPF

- Goals:
  - Quantify impact of “perfect” QPF forecast on seasonal runoff volume forecasts at various lead times.
    - Determine point at which skill and predictability are optimized.
  - Provide a benchmark with regard to the potential skill increase to be gained by pursuing QPF methodologies outside of one week (i.e. 8-14 day QPF)
- Method:
  - Run ESP in reforecast mode with “perfect” QPF for “x” number of days starting on the first of each month (January - June) over the 35 year calibration record (1981-2015) targeting the April-July runoff volume.
    - “perfect” QPF was the actual observed precipitation for the year being forecast.
    - “x” = 0 (noQPF), 5, 15, 30 days
  - Done for five sites in the CBRFC area

# ESP Sensitivity to QPF

- Results:
  - A 5 day “QPF” typically did not provide an improvement in the seasonal volume prediction.
  - The 15 day “QPF” generally did provide some improvement.
    - Significant improvement occurred especially for the higher QPF amounts and later in the season (Apr/May).
  - 30 day “QPF” showed the greatest improvement, but has the least amount of predictability in an operational sense.



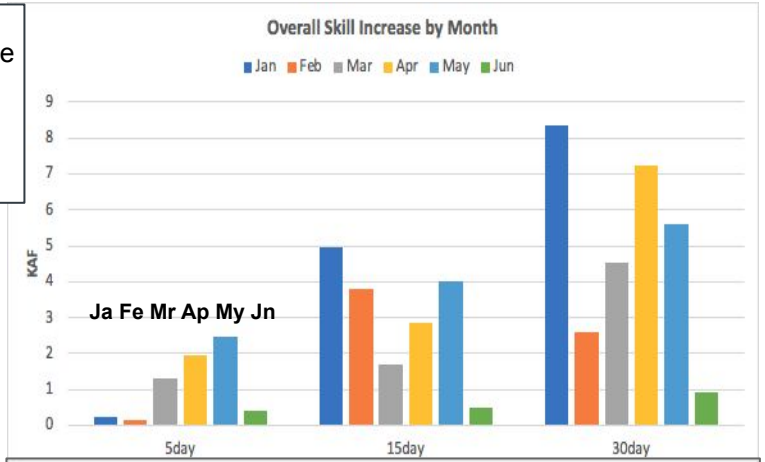

Skill Increase = MAE (noQPF) - MAE (w/QPF)

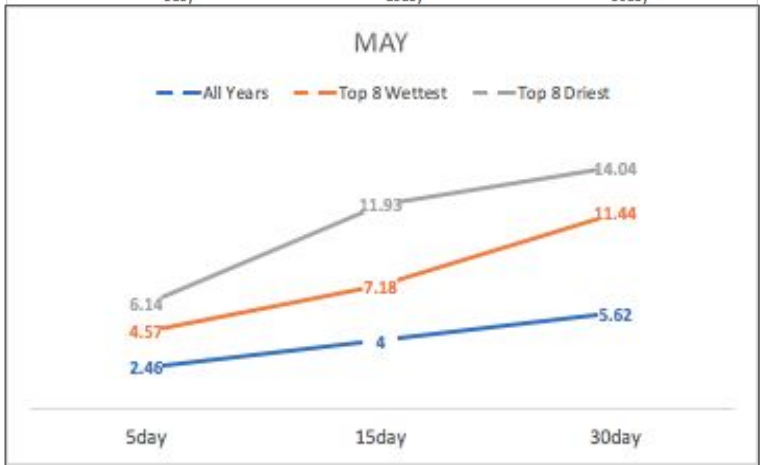
➢ *Given these results we will continue to monitor the progress of improvement of two week forecasts and consider incorporating them when skill is proven sufficient.*

# ESP Sensitivity to QPF

- Results (continued):
  - These graphs are the average statistics for all sites
  - January shows larger skill increase with 15/30 day; it is the highest precip variability month for most sites.
  - For most months (May is shown here), there is a larger skill increase when only considering the extreme (wet/dry) years.
    - Remember from the graph on the previous page that we can also get pushed in the wrong direction, especially early in the season.

Sites included:
Green - Warren Bridge
Elk - Milner
East - Almont
Animas - Durango
Weber - Oakley



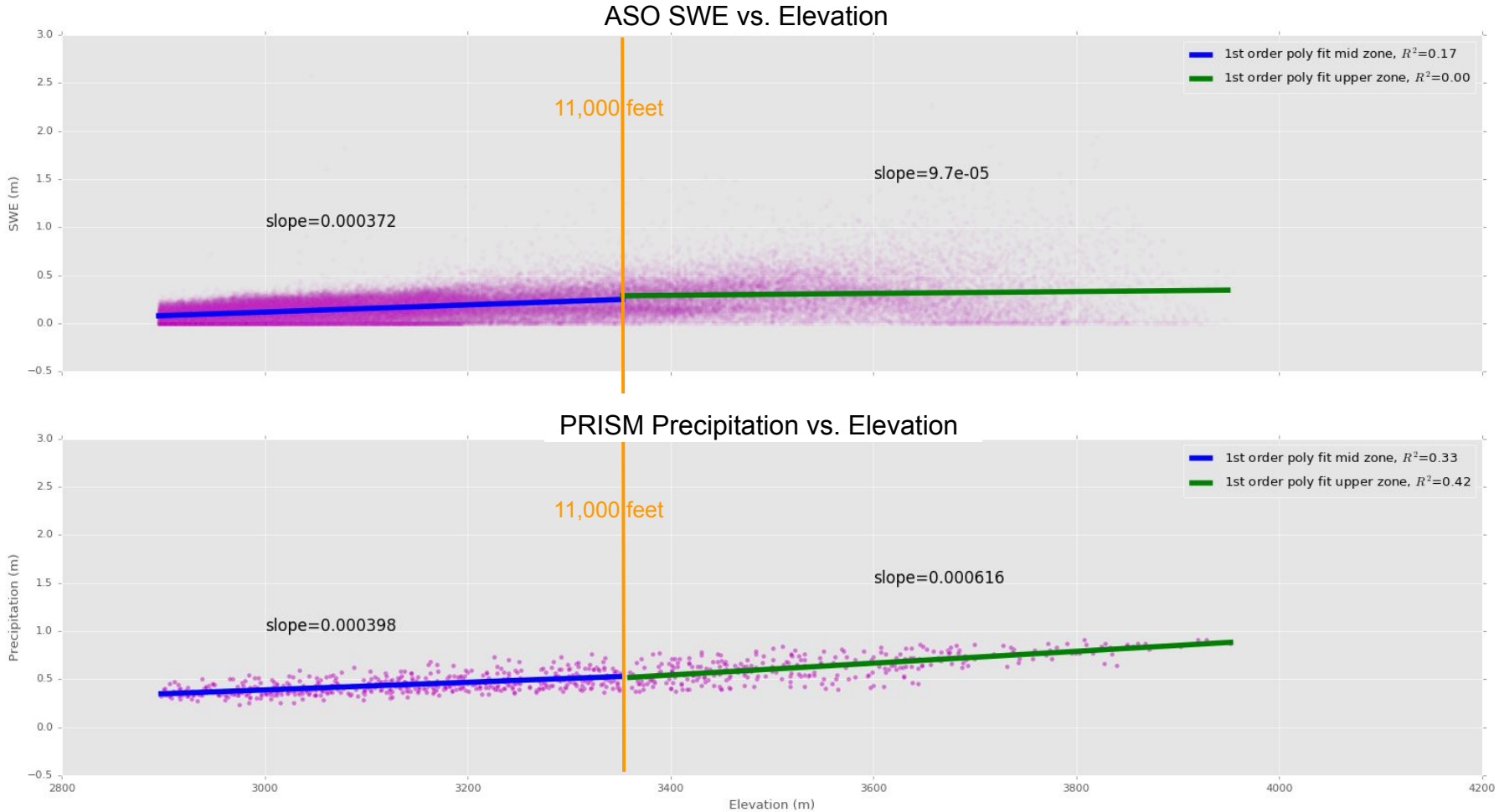
# Evaluation of ASO data

- Goals:
  - Evaluate differences between ASO SWE and CBRFC SWE.
- Method:
  - Compared ASO data provided by NASA JPL for March 31, 2018 over 4 basins in the Upper Gunnison to corresponding SNOW-17 data from CBRFC.
  - Used 31 SNOTEL stations from adjacent areas for density verification.
  - Compared PRISM high elevation precipitation climatology to ASO SWE data.

# Evaluation of ASO data

- Results:
  - ASO depth measurements are very accurate with high spatial resolution.
    - This is the type of information needed to transition from a lumped to a distributed model.
  - ASO density calculations are not robust and are the source of ASO SWE uncertainty.
    - This made comparison to CBRFC SWE difficult.
  - Provided insight into SWE above 11,000 feet.
    - There may be less SWE above the treeline (and highest SNOTELs) than CBRFC model assumes.
    - Further investigation is needed.

OHOC2 March 31

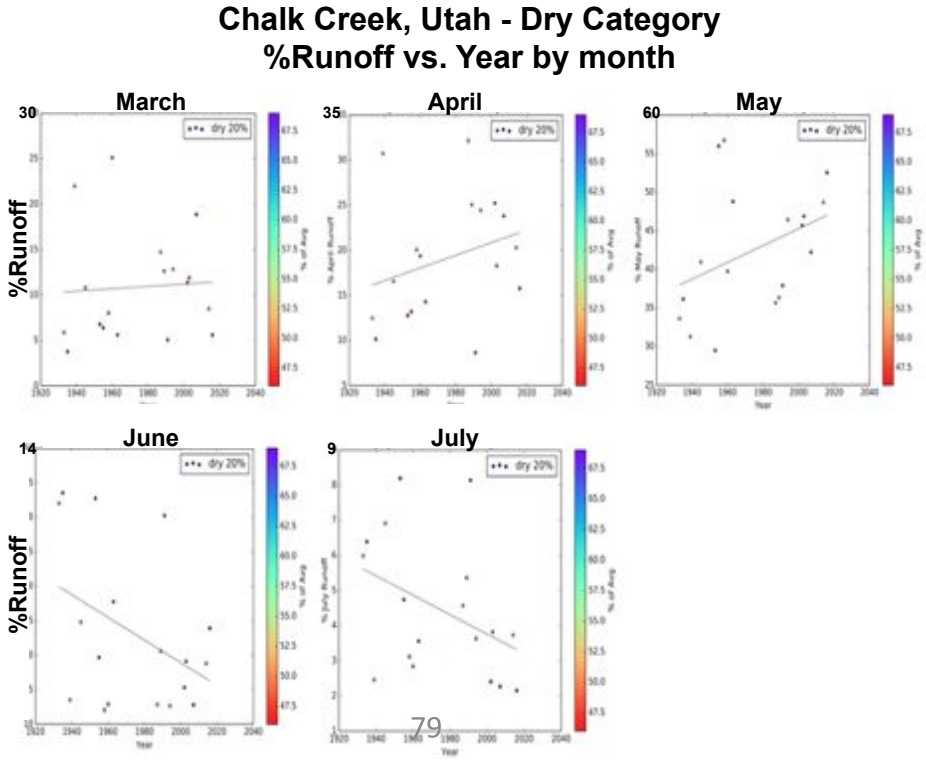


# Seasonal Runoff Distribution

- Goals:
  - Explore changes in runoff distribution over time.
  - Provide a robust method for monthly breakdowns of seasonal volume forecasts.
- Method:
  - Years were ordered by volume and then divided into 5 groups: driest, dry, average, wet, wettest.
  - Trend investigation used only long term stations (>75 years of record).

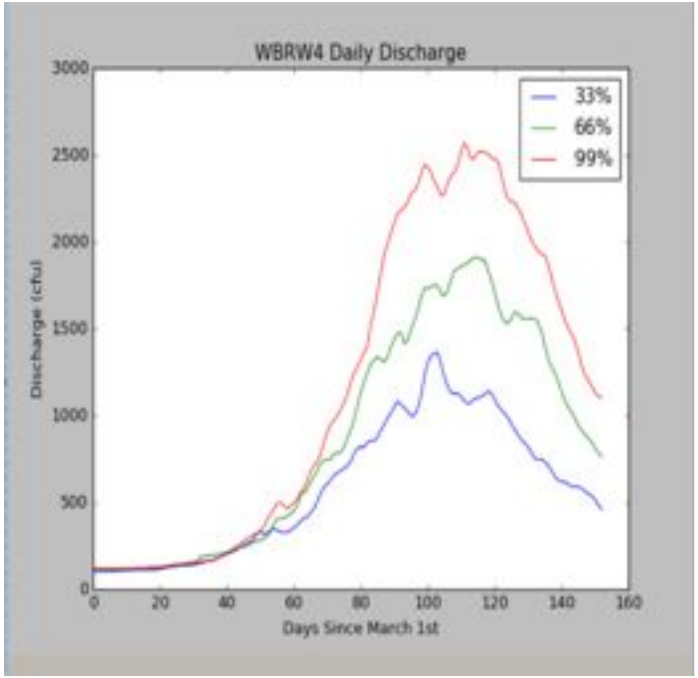
# Seasonal Runoff Distribution
## Trend Over Time

- Results:
  - A trend of earlier melt was found for dry years; this makes sense as shallow snowpacks are more susceptible to higher temperatures.
  - For average to wettest years no trend was found.
  - A drying trend was found over the last 100 years; this helps explain previous studies showing earlier melt.



# Seasonal Runoff Distribution
## Monthly Breakdown

- Follow-up work still to be done:
  - A monthly distribution will be calculated using the relationship between volume and timing for each forecast point.
  - The lookup table will map the monthly distributions for all probabilities (50%, 10%, 90%) such that the sum of the monthly values equal the seasonal value.



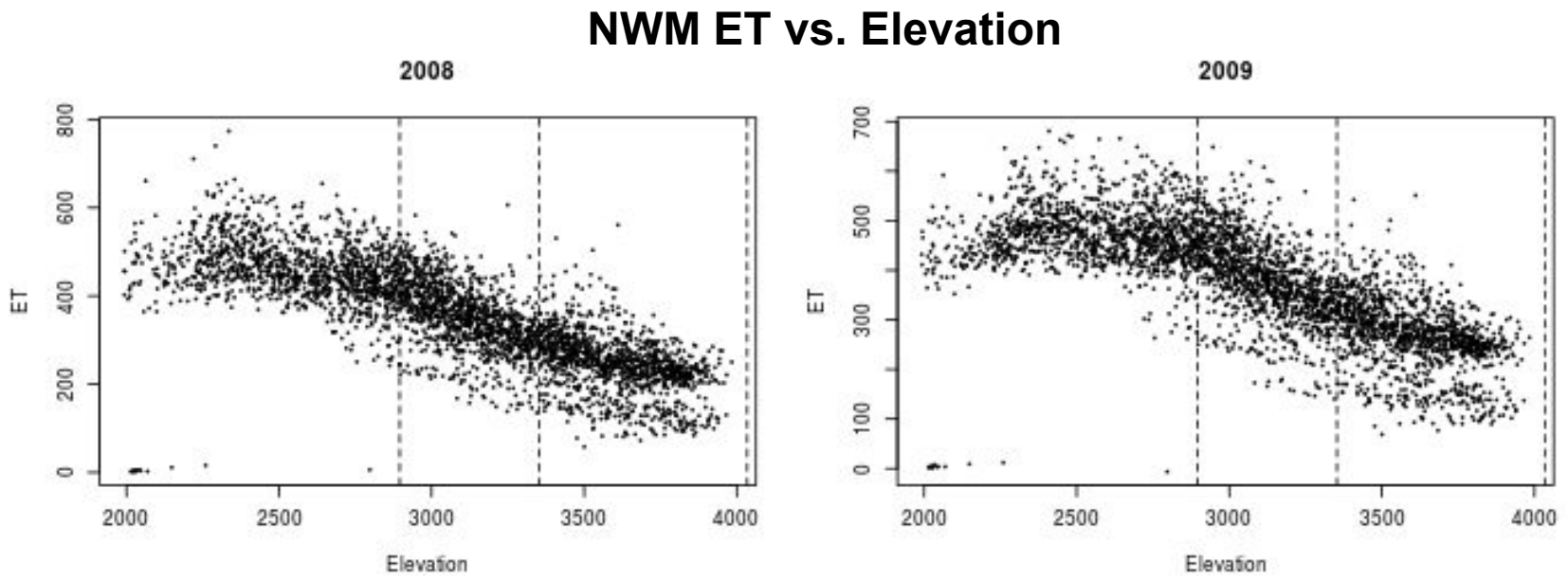
# National Water Model

- Goals:
  - Implement NWM at the CBRFC
  - Understand model physics
  - Examine model forcings
  - Examine model parameterization
  - Improve model calibration
- Methods:
  - NWM was implemented for the Animas - Durango basin
  - The simulation at the CBRFC matched the official simulation
  - Water balance was examined over 8 year period
  - NWM ET was examined in detail

# National Water Model

- Results
  - ET has been documented and is now better understood.
  - Errors within land use have been identified with plans to correct and recalibrate.
  - We will move forward to better understand other model components.
  - The CBRFC believes it can help with the NWM calibration process.

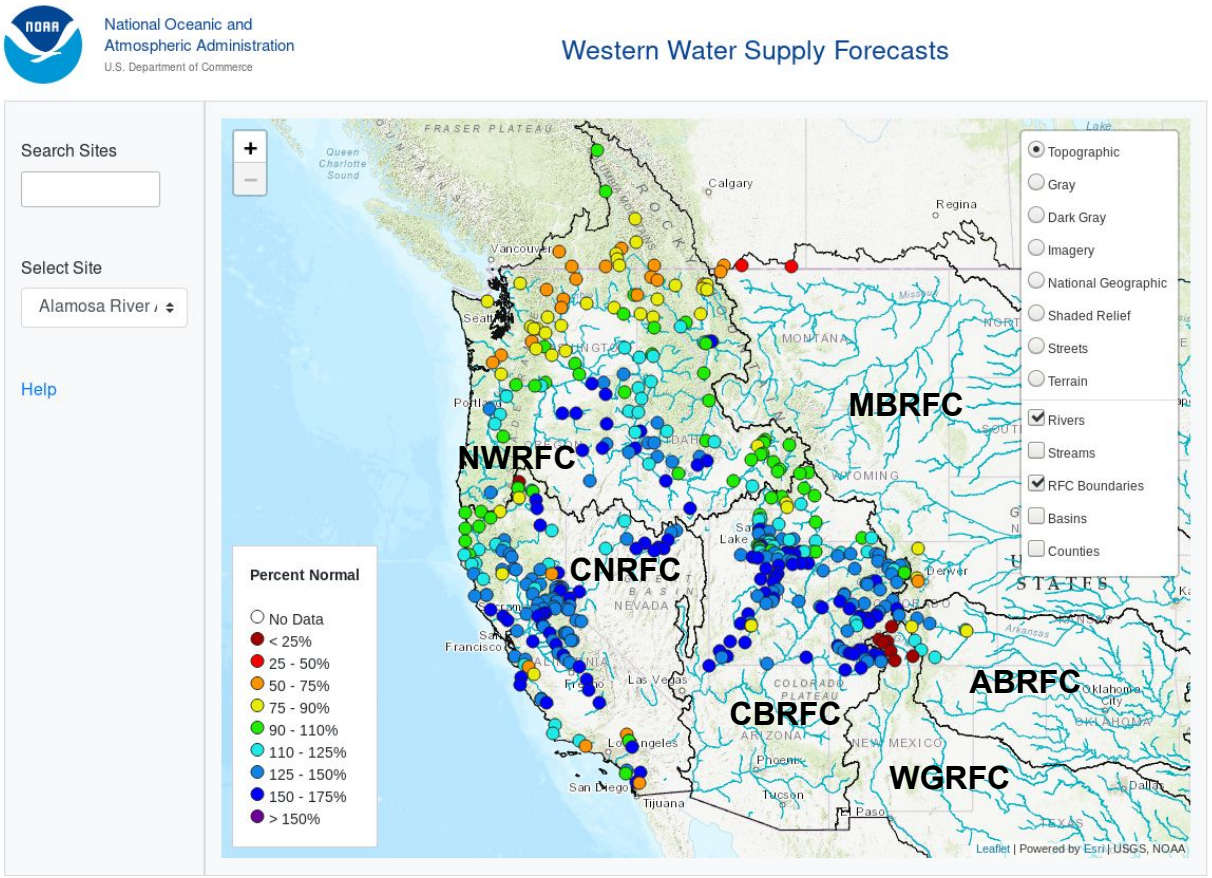
# National Water Model



# Ongoing Work

- Western Water Supply Forecast Map
- Interactive web page hydrographs
- Daily Forecast Verification

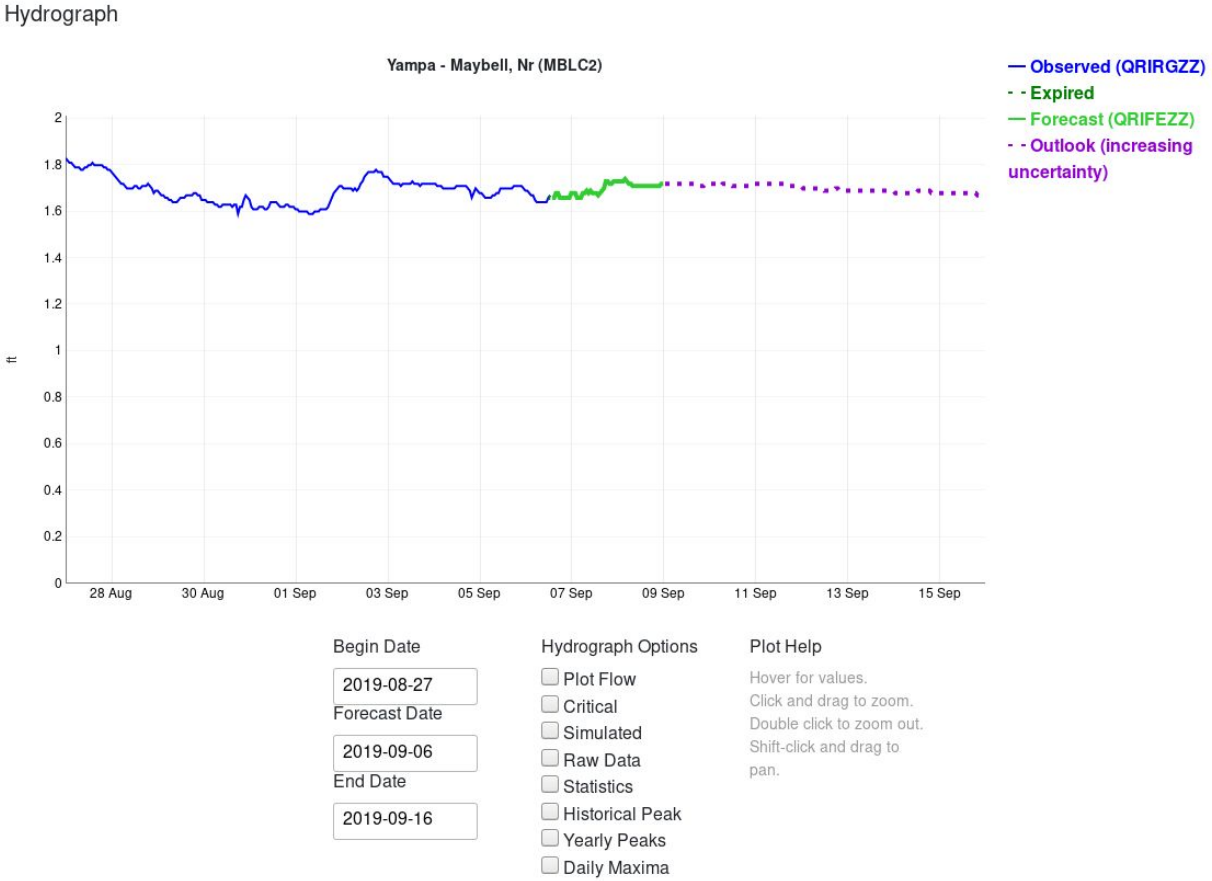
# Western Water Supply Map




CBRFC is hosting a map to allow easy access to water supply forecasts from other RFC's.

- Selecting points within the NW or CN RFC areas will take you to that office's webpage.
- Selecting points within the MB, AB, or WG RFC areas will bring up the same ESP forecast evolution plot used by CBRFC.
    - Those offices are sending us their data.
    - We are continuing to work with them to get all of the information we need for the plots.

# Interactive Web Hydrographs



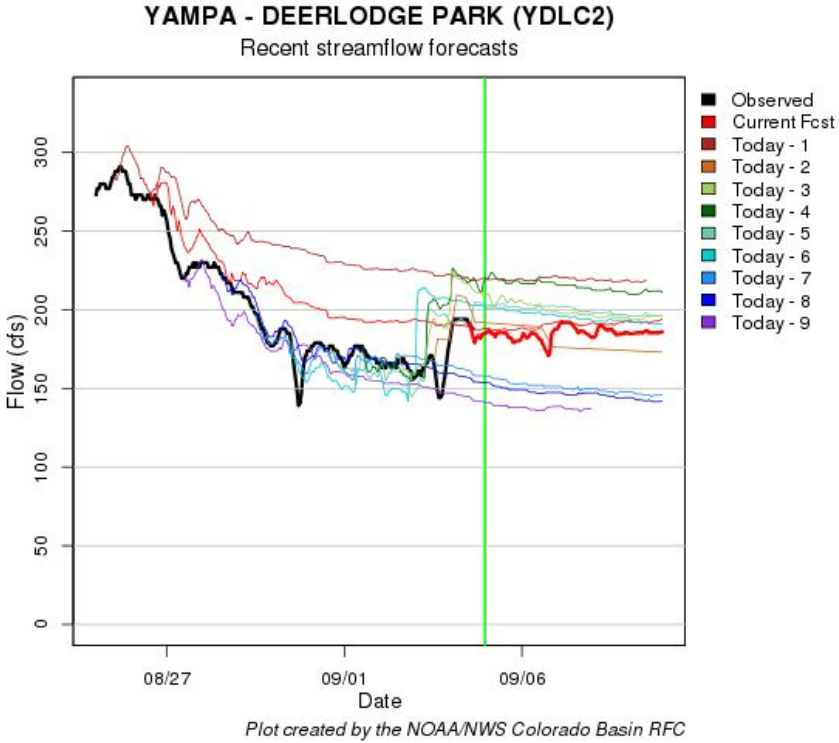

- Has the same hover and zoom capabilities as our other interactive graphs (Water Supply, Model Snow).
- Working to ensure it has the same information and links that are available on current hydrographs.
- New: ability to show previous forecasts and to more easily select a specific date range.
- Goal is to have these operational by the spring runoff season.

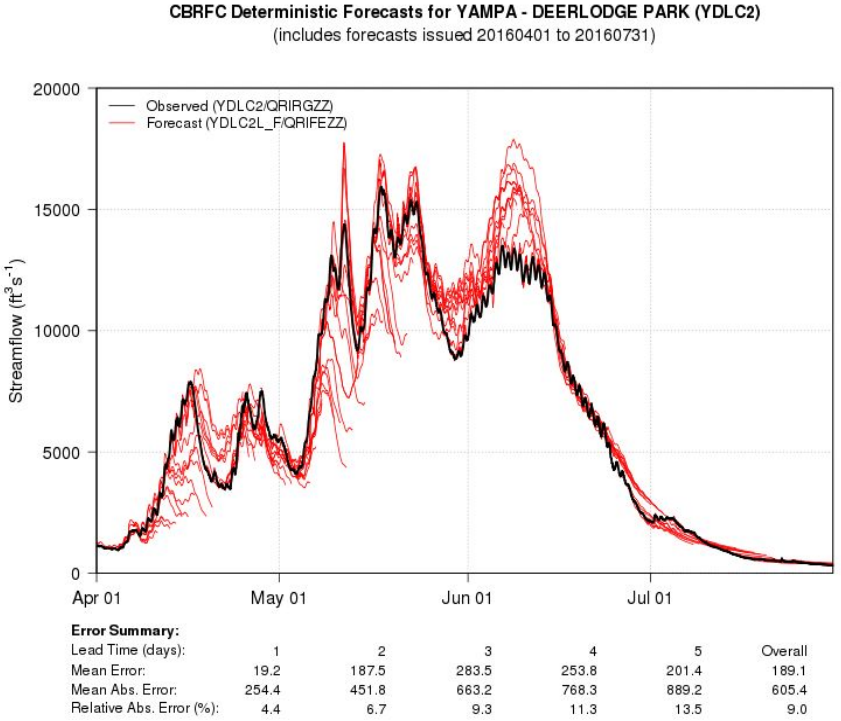
# Daily Forecast Verification

- Stakeholder request
- Looking for feedback on what would be useful
- 9 years of daily forecast data 2011-2019
- Thoughts:
    - How can we communicate quantitative forecast uncertainty?
    - Forecasts are normally x%/xcfs too high/low 1, 5, 10 days out
    - Forecasts are x%/xcfs too high/low in xMonth (e.g May, June)
    - Mean errors? Max? Min?
    - How to account for yearly variability both in magnitude and timing?
    - Upstream operational changes (reservoir/diversions)

# Daily Forecast Verification

- Current Daily Forecast Verification Products
- Are these useful?




**Error Summary:**

| Lead Time (days): | 1 | 2 | 3 | 4 | 5 | Overall |
|---|---|---|---|---|---|---|
| Mean Error: | 19.2 | 187.5 | 283.5 | 253.8 | 201.4 | 189.1 |
| Mean Abs. Error: | 254.4 | 451.8 | 663.2 | 768.3 | 889.2 | 605.4 |
| Relative Abs. Error (%): | 4.4 | 6.7 | 9.3 | 11.3 | 13.5 | 9.0 |

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# CBRFC
# Calibration Plans

Cody Moser
Hydrologist, CBRFC

- Hydrologic model calibration is time consuming

- Calibration Preparation
  - Basin delineation / GIS analysis
  - Data collection & quality control (streamflow, temperature, precipitation, etc..)
  - Basin research (diversions/irrigation/etc..)
  - Station (temperature/precipitation) selection & weighting
  - Water balance analysis

- Model Calibration
  - SAC-SMA (soil moisture model)
  - SNOW-17
  - UNIT-HG
  - LAGK (routing time and attenuation)
  - CHANLOSS/CONS-USE (accounts unmeasured depletions/returns)

- Implementation
  - Configuration into operations
  - Webpage
  - Database maintenance

- Update 30-year normals (1991-2020)
  - PRISM: Precipitation & Temperature

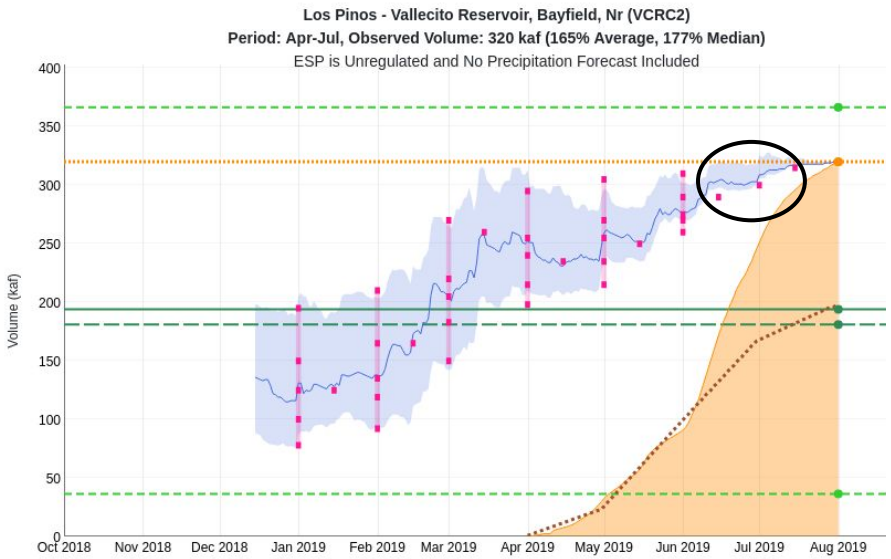
- Calibration/verification of additional 5 water years (2016-2020)
  - 2018 (dry)
  - 2019 (wet)
  - *Note: total calibration period will become 1981-2020 (40 years)*

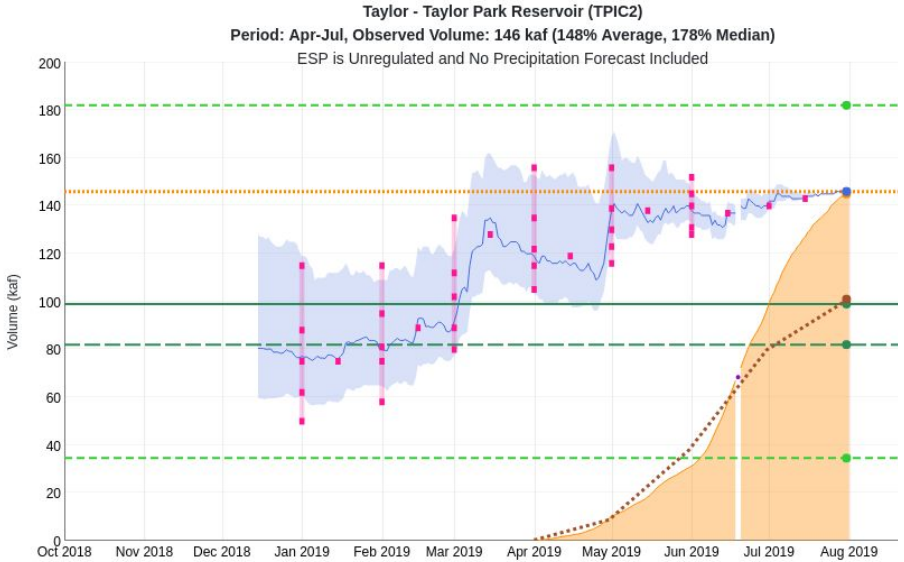
- Incorporate JPL re-processed snow covered area (SCA) data into the calibration process
  - Less uncertainty in:
    - SNOW-17 model parameterization
    - water balance

- Incorporate additional known/measured diversions

- More SNOTEL stations will have adequate period of record to use for hydrologic model calibration
  - At a minimum, SNOTEL station should have 15 years of data in order to use in CBRFC model calibration

- Incorporate lessons learned from ASO and NWM
  - Reduce ET above 11,000 feet



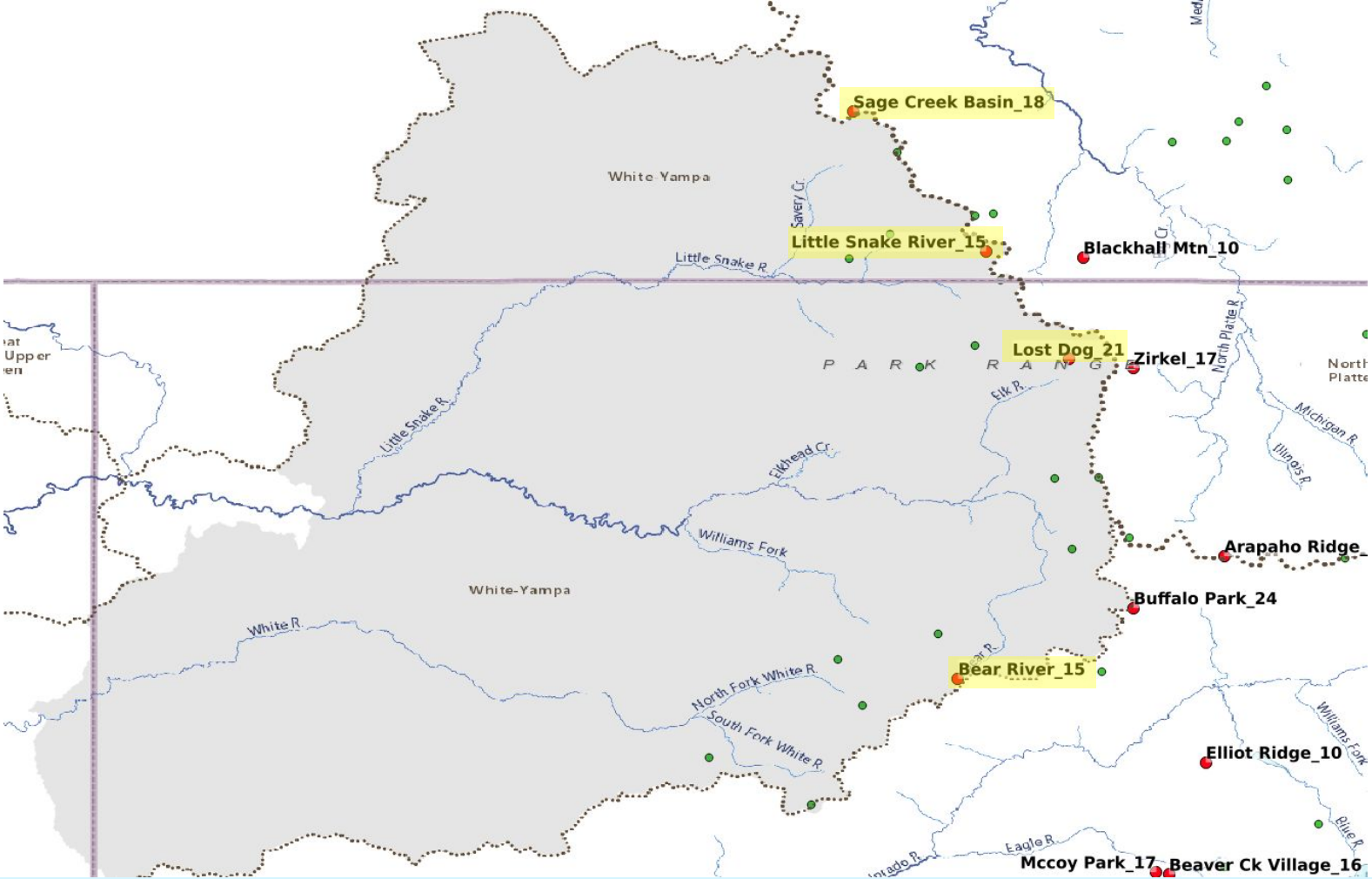




**Older Calibration**

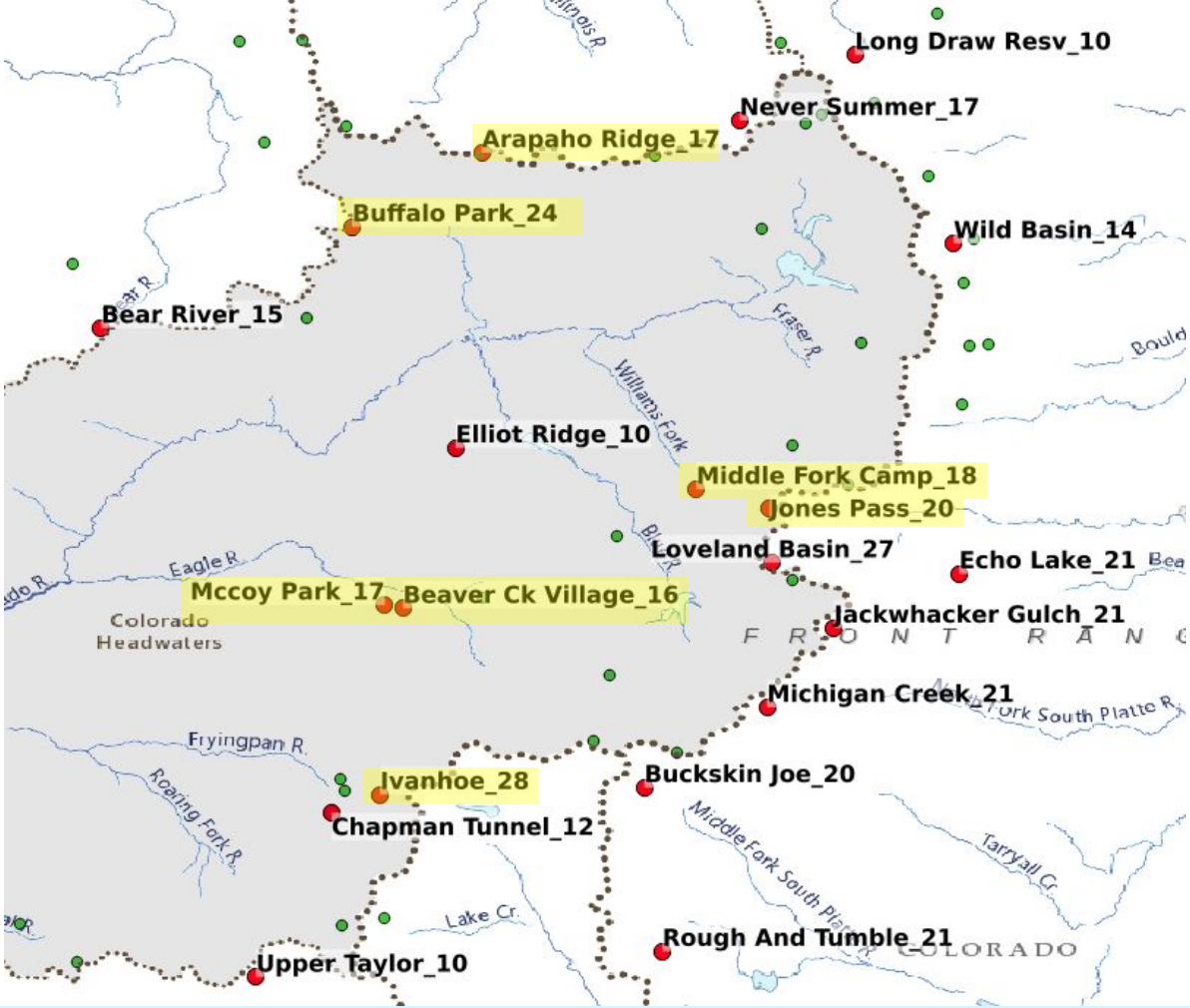
Additional model SWE needed around 7/1 in upper and middle zones

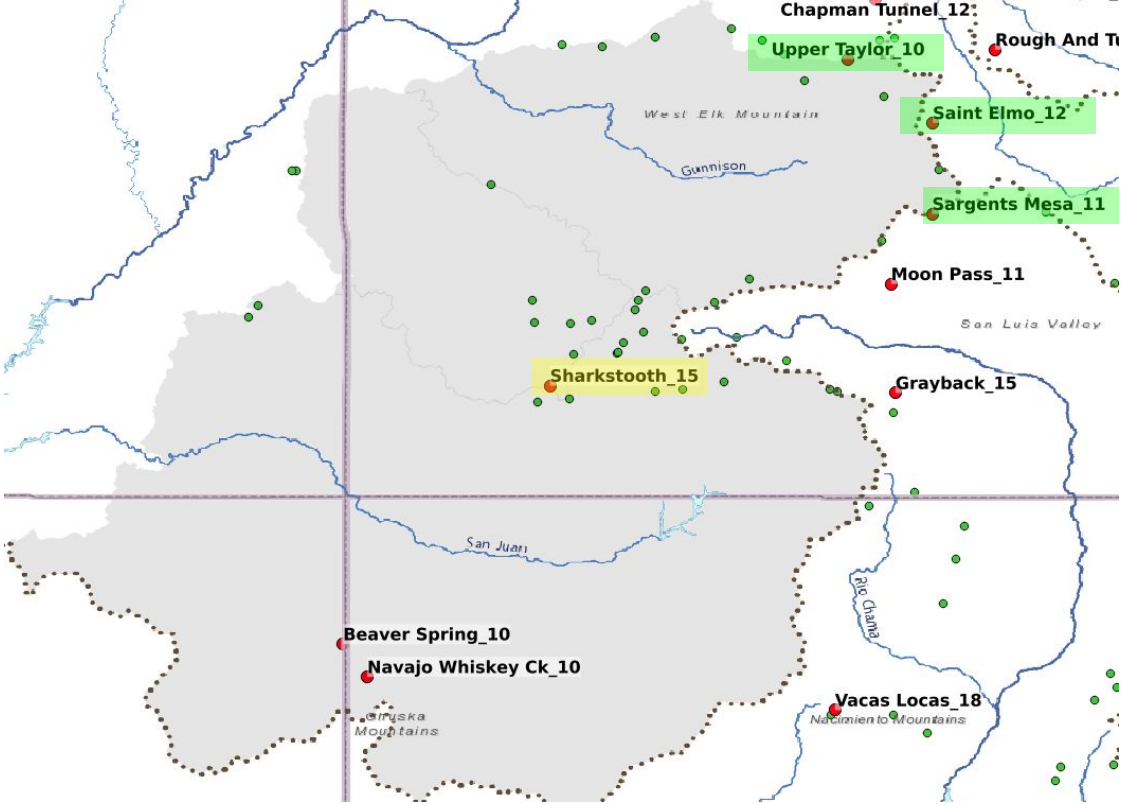
**Recent Calibration**

Updated segment calibration with reduced ET above treeline




# White / Yampa SNOTEL POR


Long Draw Resv_10
Never Summer_17
Arapaho Ridge_17
Buffalo Park_24
Wild Basin_14
Bear River_15
Elliot Ridge_10
Middle Fork Camp_18
Jones Pass_20
Loveland Basin_27
Echo Lake_21
Mccoy Park_17
Beaver Ck Village_16
Jackwhacker Gulch_21
Colorado Headwaters
Michigan Creek_21
Buckskin Joe_20
Ivanhoe_28
Chapman Tunnel_12
Rough And Tumble_21
Upper Taylor_10
Eagle R
Fryingpan R
Roaring Fork R
Lake Cr
Fraser R
Williams Fork
Middle Fork South Platte R
Tarryall Cr
COLORADO




Incorporated these SNOTELs into basin calibrations / operational forecasts recently (stakeholder request).

Calibration process / statistics showed skill increase

- CBRFC is planning to update basin calibrations in the early 2020's using observed data through water year 2020
  - ~500 basins
  - ~1200 zones

- 1991-2020 updated averages (normals)
  - Monthly, annual, and seasonal (April-July) streamflow volumes
  - Precipitation
  - Temperature
  - SWE

- Calibration period will be extended to 40 years (1981-2020)
  - 1981-2010 vs. 1991-2020 comparison / analysis

- QUESTIONS?

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# Future Plans

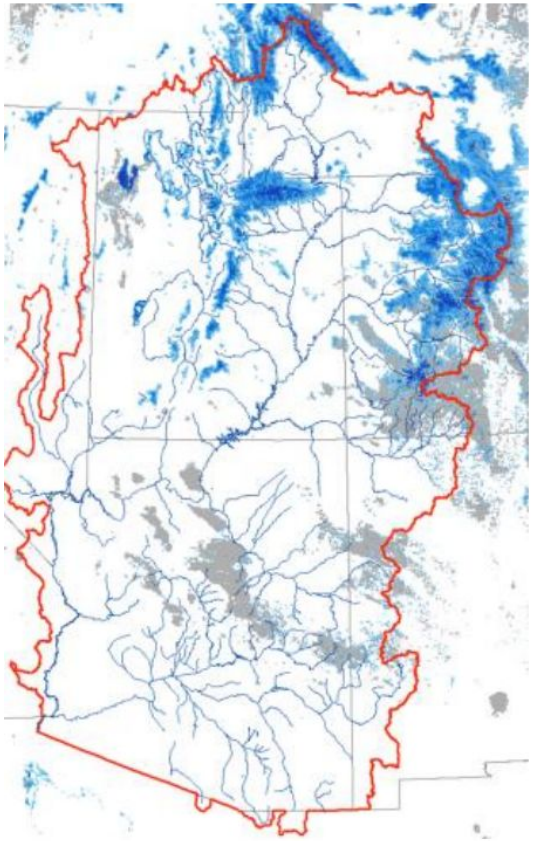
# Consumptive Use Model Development

- Funded through Colorado River Climate and Hydrology Workgroup, Reclamation, and NOAA Office of Weather and Air Quality
  - RTI will lead the project
- Goal is to develop a more robust methodology to model unmeasured depletions in the Upper Colorado River Basin
- Will initially heavily rely on data from the state of Colorado
  - Provide a robust method to predict irrigation use at each node as defined by CDSS

# Remotely Sensed Snow Data

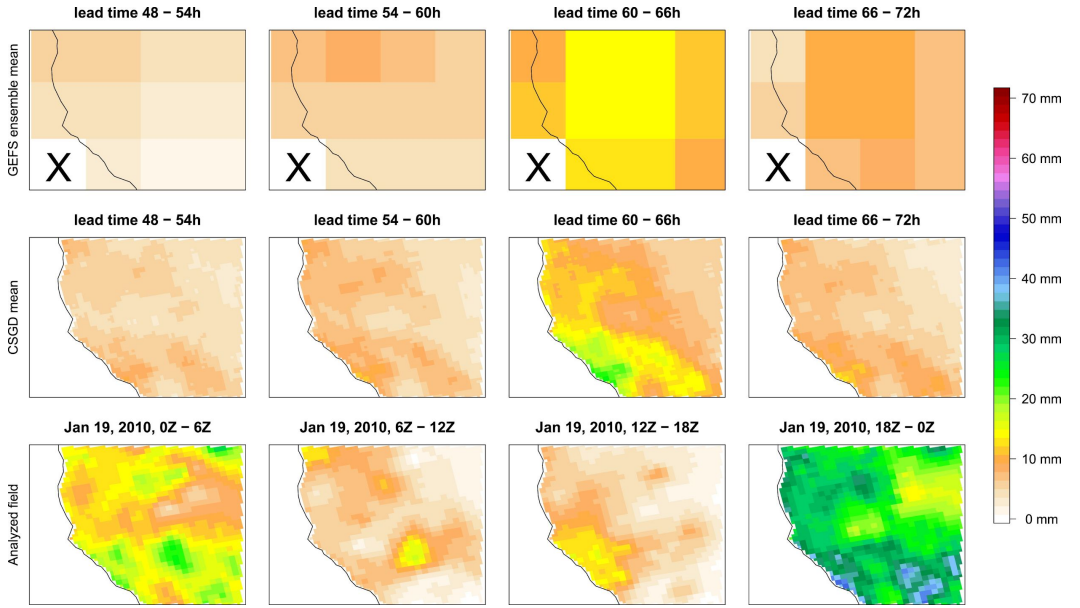
- JPL recently provided the CBRFC with consistent, historical record of MODIS-based snow covered area information

- Would like to utilize this information operationally



# Improved S2S Forecasting

Working to evaluate new Climate Prediction Center temperature and precipitation forecasts at the 2- to 4-week timeframe.



# CBRFC Contacts

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