Colorado Basin River Forecast Center

2017 Water Supply Verification / Year in Review

November 14th 2017

Greg Smith
Sr. Hydrologist

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

Current hydrologic model states:

River / Res. Levels
Soil Moisture
Snowpack

Past <- Future Time
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
In fact winter was Very Wet!

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

Narrow corridor of significant moisture transport in the atmosphere
December-January: Very Wet
February: Continued wet in Green, Great, part of Lower Colorado Basins

December 2016

January 2017

February 2017

Prepared by NOAA, Colorado Basin River Forecast Center
Salt Lake City, UT, www.cbrf.noaa.gov
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 - March 06 2017
(Modeling, Major Contributing Areas)

CBRFC Model Snow for March 6th 2017


Above average snow in many other areas.

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

Temperature Impacts: Warm later winter / spring temperatures
March Weather – Temperature Impacts

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

Above Freezing Temperatures

Instantaneous Temperature Plot

Colorado Basin River Forecast Center
HPSU1 - HICKERSON PARK

Significant snowmelt
March Weather – Temperature Impacts

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

Above Freezing Temperatures

Significant snowmelt

Instantaneous Temperature

Colorado Basin River Forecast Center

VLMC2 - VAIL MOUNTAIN

Percent Median To Date: 89% (178 / 202)
Percent Seasonal Median: 78% (179 / 225)
Accumulation rate 0.0 in/dy averaged over last 13 days.
March-May: Generally wetter in northern areas and drier to the south
March Weather – Impacts to the snowpack

Snow Conditions - March 06 2017
(Modelled, Major Contributing Areas)

Snow Conditions - March 31 2017
(Modelled, Major Contributing Areas)
Significant low elevation snowpack melted with above normal temperatures in March. Resulted in record streamflows for the month of March and saturated soil conditions.
March Weather Impacts: Record March Runoff

River Basin % average streamflow for March (approximate)

- Upper Green 375%
- Yampa 135%
- Duchesne 190%
- Colorado 130%
- Gunnison 120%
- Dolores 120%
- Lake Powell 167%
- San Juan 190%
- Lake Powell 167%

Notable March Volumes

<table>
<thead>
<tr>
<th>Site (Rank/POR)</th>
<th>Mar Vol KAF</th>
<th>% Avg</th>
<th>Old record (year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fontenelle (1/52)*</td>
<td>180 / 343%</td>
<td>99</td>
<td>(1986)</td>
</tr>
<tr>
<td>Flaming Gorge (1/55)*</td>
<td>400 / 392%</td>
<td>237</td>
<td>(1997)</td>
</tr>
<tr>
<td>Willow Creek (1/98)*</td>
<td>3.1 / 254%</td>
<td>2.3</td>
<td>(1920)</td>
</tr>
<tr>
<td>Colo-Kremmling (1/55)*</td>
<td>52 / 167%</td>
<td>52</td>
<td>(2015)</td>
</tr>
<tr>
<td>Blue Mesa (1/49)*</td>
<td>70 / 193%</td>
<td>55</td>
<td>(1951)</td>
</tr>
<tr>
<td>Mcphee (2/37)</td>
<td>57 / 270%</td>
<td>59</td>
<td>(1997)</td>
</tr>
<tr>
<td>Vallecito (1/76)*</td>
<td>24 / 285%</td>
<td>16</td>
<td>(2007)</td>
</tr>
<tr>
<td>Navajo (4/47)</td>
<td>177 / 191%</td>
<td>198</td>
<td>(1995)</td>
</tr>
<tr>
<td>Lemon Res (1/54)*</td>
<td>4.1 / 259%</td>
<td>3.8</td>
<td>(1989)</td>
</tr>
<tr>
<td>Lake Powell (3/54)</td>
<td>1109 / 167%</td>
<td>1141</td>
<td>(1985)</td>
</tr>
</tbody>
</table>

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

Data is provisional

Notable March Volumes

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

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

River Basin % average streamflow for April (approximate)

- Upper Green: 265%
- Yampa: 105%
- Duchesne: 200%
- Colorado: 120%
- Gunnison: 155%
- Dolores: 125%
- San Juan: 145%
- Lake Powell: 152%

Notable April Volumes

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

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?
Reds – This year’s forecast higher than ESP historical model error.
Blues – This year’s forecast lower than the ESP historical model error.
Blacks – This year’s forecast similar to the ESP historical model error.

2017 Forecast Verification Map:

January 2017 Verification Map

April 2017 Verification Map
Forecast Verification Plots: So what are we looking for?

Like to see the observed volume fall within the forecast range (the blue line).

If it does not, it may be due to extreme weather in the future. It may not be a bad forecast. However, it could indicate an error in the model states (snow etc.) or other issues.
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.
Near record snow + saturated soil conditions + June rain event = record runoff!
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

Yampa - Maybell- Nr (MBLC2)

Apr-Jul Observed Volume: 799 kaf (85% of average)

ESP is Unregulated and No Precipitation Forecast Included

Max/Min
- ESP 50%
- ESP 30-70%
- ESP 10-90%
- ESP w/o Obs

Forecast Target Period

- Wet Dec and Jan
- Warm dry March and snowmelt
- Average Apr-May weather

APRIL-JULY OBSERVED 799 KAF/85%

1030 KAF 110%
750 KAF 80%

Plot: Created 2017-08-14 12:22:32, NOAA / NWS / CBRFC
Forecasts in the forecast target period include observed values.
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

Fontenelle Reservoir Inflow

<table>
<thead>
<tr>
<th>Month Forecast Issued</th>
<th>Month</th>
<th>Years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Jan</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Feb</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Mar</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>Apr</td>
<td>26</td>
</tr>
<tr>
<td></td>
<td>May</td>
<td>25</td>
</tr>
<tr>
<td></td>
<td>Jun</td>
<td>23</td>
</tr>
</tbody>
</table>

| Mean Absolute Error (KAF) | 204 | 187 | 184 | 162 | 115 | 72 |

Flaming Gorge Reservoir Inflow

<table>
<thead>
<tr>
<th>Month Forecast Issued</th>
<th>Month</th>
<th>Years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Jan</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Feb</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Mar</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Apr</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>May</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td>Jun</td>
<td>15</td>
</tr>
</tbody>
</table>

| Mean Absolute Error (KAF) | 297 | 297 | 305 | 277 | 197 | 110 |
Forecast Verification:

Yampa - Maybell

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

Snow States / Data availability issue
Model performed rather well. Observed volumes fell within the 10/90 forecast range throughout the season.
Model tends to have a low bias. This may be a candidate for recalibration.
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.
Increase in error (compared to historical) late in season. 
Not enough snow at high elevations of the model.
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

Los Pinos - Vallecito Res- Bayfield- Nr (VCRC2)
Apr-Jul Observed Volume: 214 kaf (110% of average)
ESP is Unregulated and No Precipitation Forecast Included

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

APRIL-JULY OBSERVED 214 KAF / 110%
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).
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

Record wet Dec-Feb

APRIL-JULY OBSERVED
178 KAF / 158%

Warm, Dry, Snowmelt

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

Jan-May OBSERVED
458 KAF / 156% median

Jan-May OBSERVED
158 KAF / 282% median

The most recent (2017-05-30) full period 50% ESP forecast is 149 kaf. Plot Created 2017-06-14 12:12:49, NOAA / NWS / GERFC

**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
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

**SITES WITH 30+ YEARS**

- JNPC2 installed 2000
- MFKC2 installed 2002
- FCVC2 installed 2012

**ALL SITES**

- Williams Fork Reservoir Basin
- New SNOTEL sites will provide an opportunity to improve model calibrations
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.