New at the CBRFC for 2020
Overview

- Water Year 2020
- New at the CBRFC
  - Year In Review and Sensitivity Analysis
  - Intervening Flow Update
  - QPF Improvements
  - Lower Basin ENSO Weighting Scheme
  - Incorporating Post-Fire Information
  - National Water Center Backup
Conditions at Start of WY2020

- Very poor monsoon in the summer of 2019
- Model fall soil moisture conditions tended to be below normal in most areas
- ESP forecasts tended to range from 70 - 100%
First Half of WY 2020

Precip Percentiles from Oct 1 - March 31

Somewhat of a mixed bag through the first half of WY 2020, but most locations were near normal. Lower Basin and Upper Colorado headwaters were generally above normal.
Precip Percentiles for Apr 1 - Sep 30
Note large portion of Colorado Basin and Great Basin below 15th percentile. Several sites near record lowest (below 5th percentile).
Water Supply at Lake Powell

Obs volume below 90% exceedance owing to very dry spring
Worsening Drought

October 1, 2019

October 20, 2020
CBRFC Hydrologic Model Sensitivity Analysis
Overview

• Background
• Methodology
• Annual Results
  • Timeframe
  • Parameters
Overview

• Background
  • Colorado River Climate and Hydrology Workgroup
  • Scope of Work
• Methodology
• Annual Results
  • Timeframe
  • Parameters
**Scope of Work**

- Part 1 asks for CBRFC to provide an annual report summarizing activities
- First annual report released earlier this year and available on CBRFC website
Scope of Work

• Year In Review
  • An overview of water supply forecasting conditions and climate
  • Updates to model
  • New products and services
  • Research and Investigations
  • Anything of consequence really!

CBRFC Water Year In Review
An Overview of Operational Changes, Improvements, and Investigations over the course of Water Year 2019

April, 2020

National Oceanic and Atmospheric Administration (NOAA)
National Weather Service (NWS)
Colorado Basin River Forecast Center (CBRFC)
CBRFC Water Year In Review 2020

WY 2020 report likely out by March 2021, if not earlier...
Sensitivity Analysis - Scope of Work

- Parameters and site selection
  - Precipitation, Soil Moisture, and Evapotranspiration
    - +2.5%, +5.0%, and +10.0%
  - Temperature
    - +0.5 °F, +1.0 °F, +2.0 °F
Scope of Work

- **Site Selection**
  - Green River at Warren Bridge (WBRW4)
  - Elk River near Milner (ENMC2)
  - Crystal River near Redstone (RCYC2)
  - East River at Almont (ALEC2)
  - Gunnison at Durango (DRGC2)
  - GLDA3 (Lake Powell)
  - OAWU1* - (Weber at Oakley in Great Basin)

- Sites have minimal regulation and diversions, so easier to isolate impacts
Methodology

- 1981-2015 traces for each parameter at each site
  - 1981 not considered for analysis (used as a spin-up year)
  - 816 scenarios (4 parameters X 6 perturbations X 34 years) for each site
- There are equivalent figures for all sites, all years, and all timeframes
- All data is available on our website
Methodology

Not quite apples to apples….

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Methodology</th>
<th>Perturbation</th>
<th>Time Scale</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>Gage-derived</td>
<td>Perturbed by °F</td>
<td>6-hourly MAT values</td>
</tr>
<tr>
<td>Precipitation</td>
<td>Gage-derived</td>
<td>Perturbed by %</td>
<td>6-hourly MAP values</td>
</tr>
<tr>
<td>Soil Moisture</td>
<td>Developed during calibration</td>
<td>Perturbed by %</td>
<td>October 1st value</td>
</tr>
<tr>
<td>Evapotranspiration</td>
<td>Developed during calibration</td>
<td>Perturbed by %</td>
<td>Monthly, static, coefficients</td>
</tr>
</tbody>
</table>
Annual Results

- Precipitation most impactful
  - 1.5% increase per 1% increase in precipitation
- Evapotranspiration and Soil Moisture next most impactful parameters
  - 0.5% increase per 1% increase in soil moisture
  - 0.4% decrease per 1% increase in ET
- Temperature least impactful over course of a year
  - 0.35% decrease per 1 °F increase in temperature
  - Other parameters are not dependent on temperature
Annual percent change to historical flow over Animas River at Durango

Precipitation, by far, the most impactful parameter over the course of the year.
Relatively little temperature impact to volumes over the course of the year. Timing more affected.
The Take Away

- The Colorado Basin River Forecast Center conducted a sensitivity analysis investigating how changes to temperature, precipitation, evapotranspiration, and soil moisture affected streamflow volumes
  - Annual, Apr - Jul, Oct - Dec, and monthly timeframes considered
  - Not a climate change study
- Precipitation typically the most impactful parameter
  - Temperature impacts are greatest in Fall/Winter and timing of runoff
  - Soil Moisture and Evapotranspiration can also be significant at times

NOT A CLIMATE CHANGE STUDY
Where to find these reports

Year In Review -

Sensitivity Analysis -

Supplemental Info -
https://www.cbrfc.noaa.gov/report/Sensitivity_Analysis_Supplemental_Information.zip
Intervening Flow (LML) Update

Main areas contributing flow between Powell and Mead

Virgin / Muddy

Grand Canyon Baseflow/Springs

Little Colorado
Motivation

• Previously only had ~5 years of verification of ESP method, and only verified the first three months (lead months 1-3)
• Now we have a 30 year (1981-2010) ESP reforecast dataset that goes out a year (lead months 1-12)

• Would like to answer the question:
  1) How does the ESP method verify compared to just using Climo? More specifically, how does the verification vary by the month of issuance and by lead time?
Methodology

Forecasting Methods:
• CBRFC ESP method will be referred to as RFC
• 1981-2010 CBRFC Climo will be referred to as Climo
• The average of RFC and Climo will be referred to as Blend
• Verified against the CBRFC LML observation.

Verification Stats:
• Monthly Mean Absolute Error (MAE) and running 3-month Seasonal MAE
Here is a table that shows what forecast method is superior as a function of issuance month and lead time. *Seasonal* (3-month running total volume) verification is considered here.

| InitMonth | ond | ndj | djf | jfm | fma | mam | amj | mij | jja | jas | aso | son | ond | ndj | djf | jfm | fma | mam | amj | mij | jja |
|-----------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| oct       | Blend | Blend | Blend | Blend | Blend | Blend | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo |
| nov       | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend |
| dec       | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Climo | Climo | Climo | Climo | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend |
| jan       | Blend | RFC | RFC | RFC | RFC | RFC | RFC | RFC | Climo | Climo | Climo | Climo | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend |
| feb       | RFC | RFC | RFC | RFC | RFC | RFC | RFC | RFC | Climo | Climo | Climo | Climo | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend |
| mar       | RFC | RFC | RFC | RFC | RFC | RFC | RFC | RFC | Climo | Climo | Climo | Climo | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend |
| apr       | Blend | RFC | RFC | RFC | RFC | RFC | RFC | RFC | Climo | Climo | Climo | Climo | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend |
| may       | RFC | RFC | RFC | RFC | RFC | RFC | RFC | RFC | Climo | Climo | Climo | Climo | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend | Blend |
| jun       | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo |
| jul       | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo |
| aug       | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo |
| sep       | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo | Climo |

One can argue that outside of the summer (Climo) and portions of the late winter/spring (RFC), the **Blend** is tough to beat. The verification I have done over the past six water years (WY 15-20) also shows this.
What’s Next?

• The largest potential for further improvement could be from incorporating ENSO into the prediction for winter-spring LML. For example, does weighting the ESP traces based on the ENSO state work for the intervening flow region? This is an avenue for further research.

• We have provided Reclamation with the 1981-2010 reforecast dataset and they are currently performing their own research. Reclamation will now provide an update.
QPF Improvements
QPF Verification Methods

- Verification since July 2018.
- **QPF24** – 24 hourly QPF (12-12Z)
- Models included: **WPC, NBM, AND RFC** (WPC on Days 1-5, QPF=0 on Days 6-7)
- Considered headwater zones over the *Upper Basin* and *Great Basins*

**Question**: How does the RFC forecast verify compared to WPC/NBM, with specific attention on Days 6/7?
- WPC performance is similar to NBM over all lead times.
- By forecasting QPF=0 on Days 6/7 and not using WPC, overall we are missing out (note big jump in error). How does this vary by season?
When no precip is observed (QPE=0), WPC is slightly worse (but only a few hundredths). However, note that WPC is overwhelming better when precip is observed.

More importantly, at the heaviest events, WPC’s outperformance grows in magnitude (i.e. diff becomes more negative).
• The weight of the evidence indicates that using WPC for Days 6/7 is more accurate than forecasting a QPF=0. This is especially true during the wet months (Oct-May).

Changes as of fall 2020:

1) Switch to using WPC for Days 6/7 QPF in the Upper Basin and Great Basin, similar to the Lower Basin. This impacts our daily operational model. We still use QPF=0 for Days 8-10.

2) Use seven days of QPF/QTF in our ESP run that incorporates QPF (ESP w/QPF). Previously we were only using five days.
OVERALL GOAL
Develop a statistical weighting scheme for Lower Basin water supply basins (Gila, Salt, Verde, Virgin) using teleconnection indices that optimizes skill increase over our current ESP method of equally weighting (EW) every trace.

- Scheme must be *objective* and be applied *operationally* in an easy manner. This means that it will initially be based on *observed* teleconnection indices prior to the runoff period.

- Will rely on reforecasts over the 1981-2020 period to optimize the weighting parameters.

*Question*: What is the sweet spot (number of nearest neighbors) that optimizes skill increase compared to equal weighting (RPSS)?
## CORRELATIONS

### Index vs. JanMay Runoff

<table>
<thead>
<tr>
<th></th>
<th>GLHA3 \n\textit{Gila}</th>
<th>SLRA3 \n\textit{Salt}</th>
<th>VDTA3 \n\textit{Verde}</th>
<th>VIRU1 \n\textit{Virgin}</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>EQSOI</strong></td>
<td>-0.42 Nov</td>
<td>-0.49 Nov</td>
<td>-0.44 Nov</td>
<td>-0.35 Nov</td>
</tr>
<tr>
<td><strong>EQSOI_3mean</strong></td>
<td>-0.39 OND</td>
<td>-0.45 OND</td>
<td>-0.42 OND</td>
<td>-0.29 SON</td>
</tr>
<tr>
<td><strong>MEI</strong></td>
<td>0.44 ND</td>
<td>0.46 ND</td>
<td>0.45 ND</td>
<td>0.29 ND</td>
</tr>
<tr>
<td><strong>NAO</strong></td>
<td>0.36 Aug</td>
<td>0.34 Aug</td>
<td>0.28 Nov</td>
<td>0.2 Aug</td>
</tr>
<tr>
<td><strong>NINO12_anomaly</strong></td>
<td>0.3 Dec</td>
<td>0.32 Dec</td>
<td>0.31 Dec</td>
<td>0.33 Dec</td>
</tr>
<tr>
<td><strong>NINO3_anomaly</strong></td>
<td>0.3 Dec</td>
<td>0.35 Dec</td>
<td>0.34 Dec</td>
<td>0.29 Dec</td>
</tr>
<tr>
<td><strong>NINO34_anomaly</strong></td>
<td>0.34 Dec</td>
<td>0.37 Dec</td>
<td>0.37 Dec</td>
<td>0.27 Dec</td>
</tr>
<tr>
<td><strong>NINO4_anomaly</strong></td>
<td>0.34 Jul</td>
<td>0.33 Dec</td>
<td>0.34 Dec</td>
<td>0.26 Dec</td>
</tr>
<tr>
<td><strong>ONI</strong></td>
<td>0.33 MJJ</td>
<td>0.34 OND</td>
<td>0.32 OND</td>
<td>0.23 OND</td>
</tr>
<tr>
<td><strong>PNA</strong></td>
<td>-0.24 Dec</td>
<td>-0.31 Dec</td>
<td>-0.24 Dec</td>
<td>-0.28 Dec</td>
</tr>
<tr>
<td><strong>PDO</strong></td>
<td>0.29 Oct</td>
<td>0.29 Sep</td>
<td>0.25 Sep</td>
<td>0.23 Sep</td>
</tr>
<tr>
<td><strong>SOI</strong></td>
<td>-0.42 Nov</td>
<td>-0.45 Nov</td>
<td>-0.43 Nov</td>
<td>-0.34 Nov</td>
</tr>
<tr>
<td><strong>SOI_standardized</strong></td>
<td>-0.47 Oct</td>
<td>-0.46 Oct</td>
<td>-0.44 Nov</td>
<td>-0.34 Nov</td>
</tr>
<tr>
<td><strong>SOI_standardized_3mean</strong></td>
<td>-0.47 OND</td>
<td>-0.48 OND</td>
<td>-0.45 OND</td>
<td>-0.29 OND</td>
</tr>
<tr>
<td><strong>TNI</strong></td>
<td>-0.18 DJF</td>
<td>-0.16 DJF</td>
<td>-0.22 DJF</td>
<td>-0.27 DJF</td>
</tr>
</tbody>
</table>

*Correlation coefficient - r*
ENSO Indices

Two ways of tracking the atmospheric part of ENSO

**Equatorial Southern Oscillation Index**

Pressure anomaly over Indonesia compared to pressure anomaly over eastern Pacific

**Southern Oscillation Index**

Darwin pressure anomaly compared to Tahiti pressure anomaly
Does Pairing Two Indices Improve Things?

ONI/PDO and JanMay Precip (AZ_Div7)
The goal is to shift the ESP distribution if there is a \textit{consistent} teleconnection signal. This will likely be possible for the Lower Basin, and maybe even for \textit{some} Upper Basin areas. The Upper Basin has yet to be examined extensively.

There is no holy grail for weighting ESP using teleconnections. Outlier years will always be an issue. However, if we improve upon equal weighting \textit{overall} (say in 10 of 12 La Nina years), then I consider that a success.
Incorporating Post-Fire Information
CBRFC 2020 Fire Hydrology Development Work

- **CBRFC Post Fire DSS Role:**
  - Provide hydrologic support to Weather Forecast Offices (WFOs) in first 24 hours of forecast period
    - CBRFC Lower Colorado basins are forced with 1-hr precipitation during first 24 hours of model run

- **Python/GIS Post Fire Tool Development**

- **Hydrologic Model Considerations**

- **Bush Fire (Arizona) / Sycamore Creek (SYCA3) Example**
• BAER (Burned Area Emergency Response)
  - Within 7 days of fire containment, the BAER Imagery Support Program provides satellite images, burn area severity classifications, and other critical data to BAER teams. One of the team's first tasks in the field is to create a soil burn severity map using BARC data provided by the BAER Imagery Support Program.

• BARC (Burned Area Reflectance Classification)
  - BARC is a satellite-derived data layer of post-fire vegetation condition. The BARC has four classes: high, moderate, low, and unburned. This product is used as an input to the soil burn severity map produced by the Burned Area Emergency Response (BAER) teams.
CBRFC Fire Tool Development

• Python/GIS Fire Tool Inputs:
  – BARC geo tiff or .shp file of burn area / severity
  – CBRFC basin elevation zone .shp file

• Outputs
  – Maps (basin scale, forecast group scale)
  – Plots (broken down by CBRFC basin elevation zone)
    • Fire size (mi²)
    • % of elevation zone burned and burn severity
  – Tables
    • Tabular data of plots
  – Shapefiles of burn areas

• Future Development
  – Determine type of vegetation burned (forest, shrub, etc.)
Hydrologic Model Considerations & Initial Burn Thresholds

• CBRFC basin elevation zone:
  – >50% burned
    • Adjust SAC-SMA model parameters for basin elevation zone
  – 25-50% burned
    • Define & configure new burn polygon hydrologic model area using fire tool output .shp file

• Continuously evaluate hydrologic model performance during observed precip on burn events
  – Arizona hydrology is challenging to begin with:
    • Losses to soils
    • Reliability of observed streamflow data (shifty channels/ratings)

• Maintenance
  – Documentation
  – Model Configuration
Example: 2020 Bush Fire (Arizona)  
Sycamore Creek (SYCA3) Basin

Forecast Group Output Map

Basin Scale Output Map
Example: 2020 Bush Fire (Arizona) Sycamore Creek (SYCA3) Basin

SYCA3 upper elevation zone is >50% burned
Adjust SAC-SMA model parameters
SAC-SMA Model Parameter Adjustments

- **UZTWM**: upper soil zone layer tension water capacity (bucket size), units = mm
  - Parameter indicates the amount of rain that must fall after a long dry period before any runoff is produced

- **UZFWM**: upper soil zone layer free water capacity (bucket size), units = mm
  - Primary function is to control when surface runoff occurs
  - Surface runoff can only occur when the intensity rate of rainfall or rain+melt is sufficient to fill the upper zone free water storage

<table>
<thead>
<tr>
<th>SYCA3 Upper Elevation Zone Model Adjustments</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Parameter</strong></td>
</tr>
<tr>
<td>UZTWM</td>
</tr>
<tr>
<td>UZFWM</td>
</tr>
</tbody>
</table>

**Anderson SAC-SMA Calibration Manual**

Table 7-5-1. Guidelines for initial estimate of UZFWM.

<table>
<thead>
<tr>
<th>Frequency of Surface Runoff</th>
<th>Suggested Initial Value of UZFWM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Every moderate to heavy rainfall event (i.e. very frequently)</td>
<td>10 - 20 mm</td>
</tr>
<tr>
<td>Every large rainfall event</td>
<td>15 - 30 mm</td>
</tr>
<tr>
<td>Only during the largest flood events</td>
<td>30 - 60 mm (upper end of range for very wet regions)</td>
</tr>
<tr>
<td>Never or only during a record flood event</td>
<td>40 - 100 mm (upper end of range for very wet regions)</td>
</tr>
</tbody>
</table>
Sycamore Creek (SYCA3) What-If Model Flow Simulations

CBRFC Pre vs. Post Fire Simulation Analysis:
- 1" precipitation in 1 hour
- 2" precipitation in 2 hours (1"/hr)
CBRFC Fire Development
Summary & Final Thoughts

• Developed tool to analyze fire burn areas/severity in relation to CBRFC modeled basins/elevation zones
• Developed initial burn thresholds/modeling approaches
• Continue to evaluate observed precip on burn area runoff events
  – Are initial burn thresholds / modeling approaches reasonable?
• Build & maintain historical fire/burn database

• The process hasn’t been tested by a high impact event
• Only focus has been non-water supply forecast points (Arizona)
• What priority/amount of development time should CBRFC be investing in fire hydrology?
• Continue to collaborate & share tools/event analyses with other RFCs

• QUESTIONS?
National Water Center Backup
• Now have very limited backup capabilities
• Text product only
• Short term 10 day forecast only, ie no water supply forecast
• Limited data inputs and not similar to current operations
• Plans are for capabilities to be expanded