What Will Happen When it Rains?
Runoff Efficiency using the BCM

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Characterizing Drought and Impacts on Resources

Both Water Supply and Landscape

- Water supply drought, lack of recharge and runoff, is a shorter-term impact that can be ameliorated with shorter wet periods.
- Even if reservoirs are full, longer droughts can reduce recharge to the aquifer.
- Landscape droughts are exacerbated by dry conditions and HOT temperatures, drying out the vegetation, soils, and unsaturated zone and take much more to reverse.
Sierra Nevada Snowpack

• Large indicator of drought conditions because it incorporates both precipitation and temperature
• It doesn’t tell you what it takes to get out of drought as it differs year to year
• Hydrologic modeling can use this climate information to accumulate drought conditions over time and better characterize the environment

Snow Drought
Characterizing Drought and Impacts on Resources

• Tools in the toolbox:
  • Monitoring to understand current and antecedent conditions
  • Remote sensing to spatially distribute data
  • Modeling to forecast water supply and climate extremes
  • Modeling to analyze the range of accumulated drought conditions across the state

• The Basin Characterization Model
  • Under development since 2007, with DWR since 2010
  • Published as a USGS code in 2021
Precipitation = Evapotranspiration + Runoff + Sublimation
+ Recharge + ▲Soil Water Content
A grid-based water balance model

- Uses gridded climate data downscaled to fine spatial scales 270-m (historical and future)
- Develops a rigorous energy balance
- Incorporates detailed soil properties and estimates of bedrock permeability
- Calculates spatially distributed water supply as recharge and runoff
- Calculates climatic water deficit as an estimate of demand and stress
Climatic Water Deficit: a Calculation of Landscape Condition
Climatic Water Deficit

Annual evaporative demand that exceeds available water

Potential – Actual Evapotranspiration

- Integrates climate, energy loading, drainage, and available soil moisture storage
- Addresses irrigation demand
- Defines level of stress on landscape
- The earlier the snowmelt the higher the annual CWD
- The hotter it is the higher the potential evapotranspiration, and the higher the accumulated CWD over the season
- When accumulated over multiple seasons it can describe the loss of water from a deep unsaturated zone
Climatic Water Deficit

When calculated over a region it is obvious where cooler, wetter places are and where it is hot and dry.

North and south facing slopes are notable due to the energy loading in potential evapotranspiration.
Drought Indicator: CWD can be used to indicate drought severity and landscape stress.
Landscape drought: The influence of temperature

1977: A year with no water
Jan 2014: A HOT year with no water
Using CWD as a drought indicator

WY 1981-2010 baseline (All units mm/year)
To analyze drought conditions since 2011
Subtract current year from baseline 1981-2010

WY 2011 - baseline
- Low
- Med
- High

WY 2012 – baseline
Beginning of drought
Accumulate Differences from Baseline over Water Years

Wy 2012+2013

Wy 2012-2014

Wy 2012-2015

Wy 2015 is the year of the massive foothills tree die-off. Stressed trees from 2014 succumbed in 2015.
Accumulate Differences from Baseline over Water Years

Wy 2012-2016

Low
Med
High

Wy 2012-2017
Wy 2017 wet winter. Has a little reset in some areas

Wy 2012-2018
Wy 2019 also has a decline in CWD in some areas.

Wy 2020 was hottest on record...

...Until 2021.
Wildfires this year are coincident with the highest accumulation of CWD.

Note that fire perimeters stop at low CWD boundaries.
Sierra Nevada Water Supply Basins

Northern

Central

Southern
Recharge and Runoff are Water Supply
Long Term Climate Trends
Northern Sierra

Precipitation

Air Temperature

Annual Snowpack

**Non-Publicly releasable information for business use only...**
## Recharge + Runoff

<table>
<thead>
<tr>
<th></th>
<th>Northern Sierra</th>
<th>Central Sierra</th>
<th>Southern Sierra</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Acre-feet per year</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WY1981-2010</td>
<td>10,284,910</td>
<td>7,173,061</td>
<td>7,720,228</td>
</tr>
<tr>
<td>WY2021</td>
<td>2,568,494</td>
<td>2,087,414</td>
<td>1,913,486</td>
</tr>
</tbody>
</table>

### Percent of average (1981-2010)

- **avg *110% precip**: 11% 10% 7%
- **avg * 120%**: 26% 26% 23%
- **avg * 130%**: 43% 41% 39%
- **avg * 140%**: 59% 57% 56%
- **avg * 150%**: 76% 73% 73%
- **avg * 160%**: 93% 89% 90%

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**How much precipitation will it take to return to average water supply conditions?**
<table>
<thead>
<tr>
<th>Year</th>
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**% difference (1981-2010)**

<table>
<thead>
<tr>
<th></th>
<th>-75%</th>
<th>-71%</th>
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**Acre-feet per year**

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How much precipitation will it take to return to average water supply conditions?

In the last 50 years there has been precipitation in CA of 150% or more greater than average in 1983, 1995, 1996, and 1998.
Cumulative Climatic Water Deficit monthly anomaly from 1981-2010 mean

Northern Sierra

Dry more stress
Wet less stress

Central Sierra

Southern Sierra
Sierra Nevada Runoff Efficiency 1970-1999 vs 2000-2021
Drought Evolution in the Colorado River Basin
Accumulated CWD Difference from 1951-1980 mean

Upper Basin

"Megadrought"

Lower Basin
April 1 Snow Water Equivalent
Runoff Efficiency
1950-1999 vs 2000-2021

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<th>Lower Basin</th>
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<tbody>
<tr>
<td><strong>% difference</strong></td>
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<td></td>
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<tr>
<td>(1981-2010)</td>
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<td><strong>Acre-feet/year</strong></td>
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<tr>
<td>WY1981-2010</td>
<td>25,695,209</td>
<td>40,793,662</td>
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<tr>
<td>avg * 10% precip</td>
<td>11,646,737</td>
<td>25,674,071</td>
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<tr>
<td>avg * 20% precip</td>
<td>13,880,870</td>
<td>30,364,497</td>
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<tr>
<td>avg * 30% precip</td>
<td>16,376,078</td>
<td>35,915,185</td>
</tr>
<tr>
<td>avg * 40% precip</td>
<td>18,960,553</td>
<td>41,904,041</td>
</tr>
<tr>
<td>avg * 50% precip</td>
<td>21,634,296</td>
<td>48,331,065</td>
</tr>
<tr>
<td>avg * 60% precip</td>
<td>24,397,307</td>
<td>55,196,256</td>
</tr>
<tr>
<td>avg * 70% precip</td>
<td>27,249,585</td>
<td>62,499,616</td>
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<table>
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<th>Percent Difference from 1981-2010</th>
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<td>avg * 10% precip</td>
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<td>-46%</td>
<td>-26%</td>
</tr>
<tr>
<td>avg * 30% precip</td>
<td>-36%</td>
<td>-12%</td>
</tr>
<tr>
<td>avg * 40% precip</td>
<td>-26%</td>
<td>3%</td>
</tr>
<tr>
<td>avg * 50% precip</td>
<td>-16%</td>
<td>18%</td>
</tr>
<tr>
<td>avg * 60% precip</td>
<td>-5%</td>
<td>35%</td>
</tr>
<tr>
<td>avg * 70% precip</td>
<td>6%</td>
<td>53%</td>
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To return the basin to average water supply conditions it takes about 140% of average precipitation for the lower basin, and about 165% for the upper basin.
What did the AR5 that hit California in late October do to help the drought?

How much rain would it take to fill up the dry soils and create some runoff?
This is Folsom on Oct 20, a lot of dry soil for rain to soak into.

This is Lake Mendocino ➔
As the AR5 passed over the Russian basin streamflows upstream of the reservoir went from 10 cfs to 2000 but quickly fell to only 100 cfs baseflow.
October 2021 water supply

Runoff makes it to the reservoir first and recharge becomes baseflows
Colorado River Basin

October 2021

0-4” of water supply

Soil deficit will need to be filled before significant runoff and recharge occur this winter
Summary and Conclusions

- 2020 & 2021 were the hottest and driest years on record in the Sierra Nevada and the CRB.

- Increased landscape stress persists, in comparison to long term means and will likely take much longer than the water supply to recover.

- Runoff efficiency has declined in recent years for the Sierra Nevada and lower CRB, indicating that it will take more rain to fill soils and become runoff.
Summary and Conclusions

• Water balance modeling can be used to characterize the spatially variable hydrologic processes that lead to drought effects and highlight where on the landscape management actions could be prioritized.

• It can be used to update antecedent conditions and provide information to inform forecasts.

• Monitoring and modeling should combine to inform resource management.