Value of Improving Observations of ROS

- Just one storm can contribute up to 25% of the total annual rainfall (Lamjiri et al., 2018)
- Water supply planning means AR and ROS preparedness
- Flood management means AR and ROS preparedness
- As the State move towards 15-minute data resolution observations will be even more valuable for real-time decision support
Understanding Sierra Nevada Snowpack

Musselman, personal comm
2017 Water Year

- Blue Canyon (5280 ft)
- Greek Store (5600 ft)
- Robinson Cow Camp (6480 ft)
- Huysink (6600 ft)
- Central Sierra Snow Lab (6900 ft)
- Squaw Valley (8200 ft)
Snowpack

Density

Cold Content

Liquid Water

Complex Layers

Preferential Flow Paths

Spatial Distribution

Elevation gradient
Aspect/Ratio
Canopy cover
Burn Areas

Precipitation

Runoff
The entering rainfall is generally irregularly distributed in the snowpack, forming saturated zones, vertical flow fingers and lateral flow forms. The idea of a uniform wetting front is inappropriate.

(Kattelmann and Dozier, 1998)
Can we improve the understanding of the contribution of snowpack to runoff?

15-25% of a cross-sectional area in the snowpack may transmit water and be near isothermal while the remaining area may be colder with lower liquid water. (McGurk & Marsh 1995)

Especially during rain-on-snow events significant volumes of fast lateral flows can contribute to the total runoff amplifying the water responses from soils. Eiriksson et al. (2013)
Can we improve the understanding of the contribution of snowpack to runoff?

Current state-of-the-art hydrological models represent rain-on-snow processes in a much more static manner: snow is regarded as one-dimensional storage with a defined water holding capacity that releases water to the soil surface for infiltration. **Lateral processes in the snow cover are not considered.**

(Rössler et al. 2014)
Basic Snow Monitoring Suite in California

### Snow Depth
**Standard:** Lufft SHM30/31 - laser  
Other options: Ultrasonic, other light-based technologies

### SWE
**Standard:** Stainless Steel Snow Pillow (GE Druk UNIK5000 – pressure transducer)  
Other options: Fluidless pillows/scales, cosmic ray attenuation, GPS attenuation

### All Weather Precipitation
**Standard:** ETI  
Other options: Weighing/Loadcell, Vibrating Wire, Heated Tipping Bucket

### Air Temperature
**Standard:** CSI EE181  
Other options: Dozens
How can we make use of this data now?

**Jan 6-9, 2017**
- 9.5 inches total precipitation
- 42 hours of rain-on-snow*
- 23% to 32.7% (+9.7%) density

**Feb 7-10, 2017**
- 9.4 inches total precipitation
- 46 hours of rain-on-snow*
- 33% to 43.9% (+10.9%) density

Data from Central Sierra Snow Lab SNOTEL & CSSL Monthly Reports
*Rain-on-snow defined as precipitation above 1.5°C (34.7°F)
January 2017 – Primer?

Jan 3, 2017
Oroville: 57%

Jan 7, 2017
Oroville: 75%

https://cdec.water.ca.gov/floodER/hydro/
February 2017

Feb 1, 2017
Oroville: 80%

Feb 10, 2017
Oroville: 100%

Blue Canyon

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https://cdec.water.ca.gov/floodER/hydro/
“New” Observations for ROS

Wind

Soil Moisture

Snow Temp Profile
What can be gained from wind?
What can be gained from wind?

1. Relative humidity is typically 100% when rainfall occurs.

2. Windy “wet” air condenses on the snow and increases snow melt.

3. We know that higher wind events create more snowmelt, increasing the liquid water present in the snowpack and density therefore ripening snowpack conditions.
What can be gained from soil moisture?
Soil Moisture (wvf in %)
Soil Moisture (wwf in %)
A simple example of what we could do...

- **Identify ROS:**
  - 3 mm or more precipitation in the last 2 hours
  - temperature is above 1.5°C

- **Identify snowpack outflow:**
  - Soil moisture increases by 0.3% or greater for any sensor
  - When both conditions are met then ROS snowpack outflow has occurred
What can be gained from snow temperature profiles?
Flow fingers react differently to layers in **cold** vs **warm** snowpack

**Cold Snow**
1. Allows the wetting front to stay apace with the fingers (McGurk & Marsh 1995)
2. Ice layers grow at all premelt strata boundaries (Marsh & Woo, 1985)

**Warm Snow**
1. Promotes rapid advance of fingers ahead of the wetting front (McGurk & Marsh 1995)
2. Water delivered by flow fingers spreads laterally and ponds at a layer until saturation causes break through and formation of new flow fingers (Colbeck, 1975; Marsh, 1990)
Continuous Monitoring

The Snow School Weather Station installed the ladder in 2015 in collaboration by the US Forest Service Rocky Mountain Research Station, Bogus Basin, MesoWest and WWA

Temperature Ladder

Luce, personal comm
Mobile Snow Temperature Profiler

Leverage the existing snow survey efforts
- Snow core provides access to the entire snow profile
- Lower a sensor to measure the temperature profile of the snowpack

9 V 1.2Ah lithium ion battery
~60 hours 100% duty cycle

*Cut out opening and hollow bottom to allow anything to fall through
What does this mean for decision making?

**Snowpack Advisory System**

1. Utilize DWR upgrades on stations
2. Create real-time decision support tools to give meaning to rapid changes in snowpack
3. Maps, reports and/or risk matrix for basins
What does this mean for decision making?

Enhance SNOW-17

Better predict how the snowpack will throttle rain and the release of water to the watershed

A snow state parameter could be incorporated to adjust when rapid changes in the snowpack overtake the capabilities of the model - similar to the UADJ function.
Thank you.

Questions?

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