Are precipitation-based IDF curves appropriate for cost effective and resilient infrastructure design in snow-dominated regions?

Next-generation curves with inclusion of rain-on-snow events



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Limitations of Current IDF Curve Design Procedure (1)

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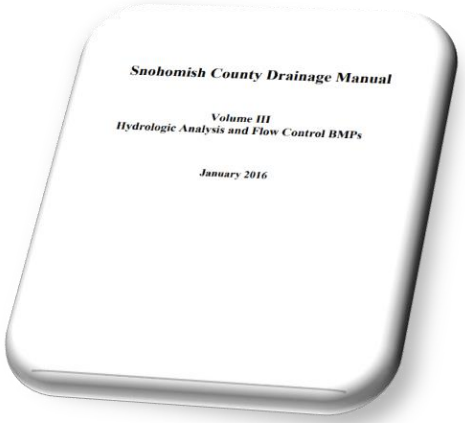
Current IDF curve construction?

- In the U.S., IDF curves are typically constructed based on only the precipitation frequency and duration. Snowmelt and rain-on-snow (ROS) events are generally neglected.
- Assume: *extreme precipitation intensity* > *snowmelt and ROS intensity*.
- Surface water design manuals for many cities and counties suggest/require the use of precipitation IDF-based hydrologic design; even in snow-dominated environments.



Limitations of Current IDF Curve Design Procedure (2)

Why snowmelt is important?

- According to the year 2000 population map, approximately 1/6 of the world's population lives in snowmelt-dominated regions.
- Based on U.S. Department of Transportation, over 70% of the nation's roads are located in snowy regions.
- Snowmelt, especially ROS events can cause life-threatening flooding events and severe landslides in these regions.

ROS resulted in the largest flood event in Oregon in 1990s.
Property damage: > $500 million

Inclusion of Snow Process in IDF Curve Design

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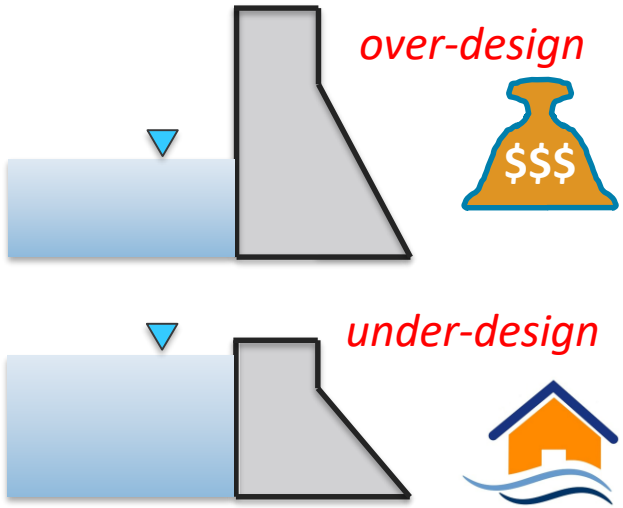
Why snowmelt process should be included?

- Current precipitation-based IDF design implicitly assumes precipitation is in the form of rainfall that is immediately subject to “rainfall-runoff” processes.
- In snow-dominated regions, much of the precipitation is stored as snowpack and may not be immediately available for the “rainfall-runoff” processes.
- It is necessary to estimate the actual amount of water reaching the land surface (rainfall/snowmelt/ROS)

What are the possible consequences?

- If actual water available for runoff intensity < precipitation intensity, the infrastructure may be **over-designed**, leading to unnecessary cost.
- If actual water available for runoff intensity > precipitation intensity, the infrastructure may be **under-designed**, leading to significant underestimates of flood risk.



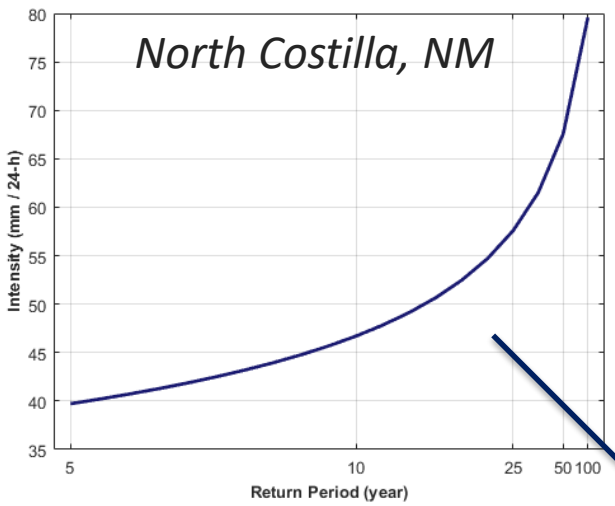
Next-generation IDF (NG-IDF) Curves (1)

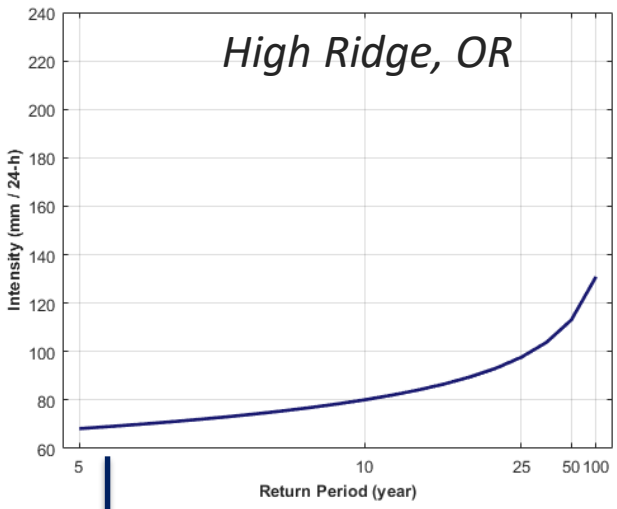
What is the next-generation IDF (NG-IDF) curve?

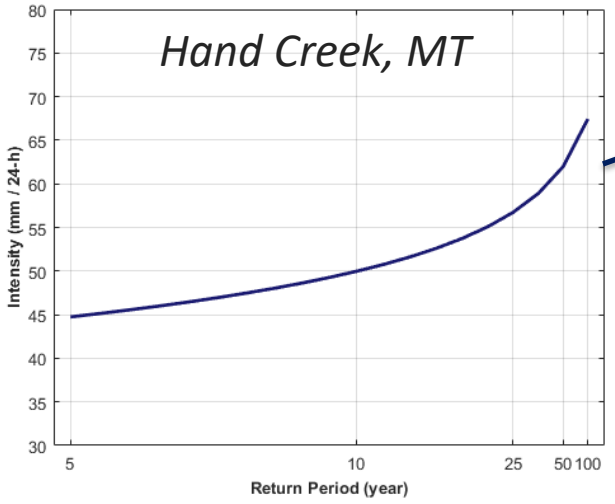
- The NG-IDF curves quantify the actual available amount of water for "rainfall-runoff" process through mass balance: ***P - ∆SWE***
- The NG-IDF curves include all melt events (snowmelt and ROS), plus rainfall on snow-free ground.
- The NG-IDF curves can characterize the actual maximum extreme events.

So, what does the NG-IDF curve look like?

Next-generation IDF (NG-IDF) Curves (2)







Traditional precipitation-based IDF (rainfall + snowfall)

Next-generation IDF (NG-IDF) Curves (2)

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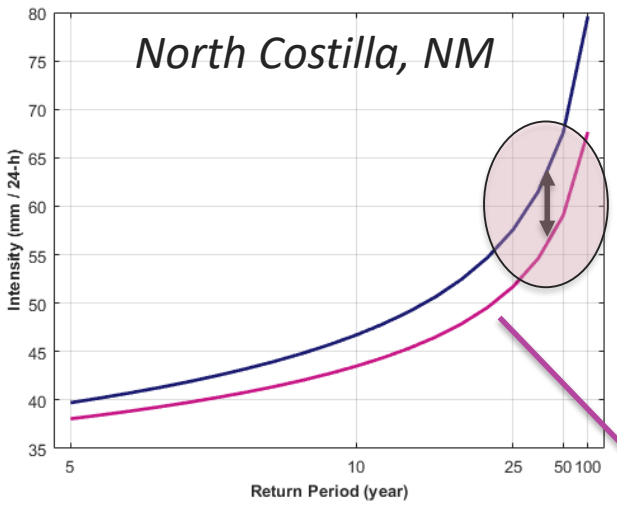

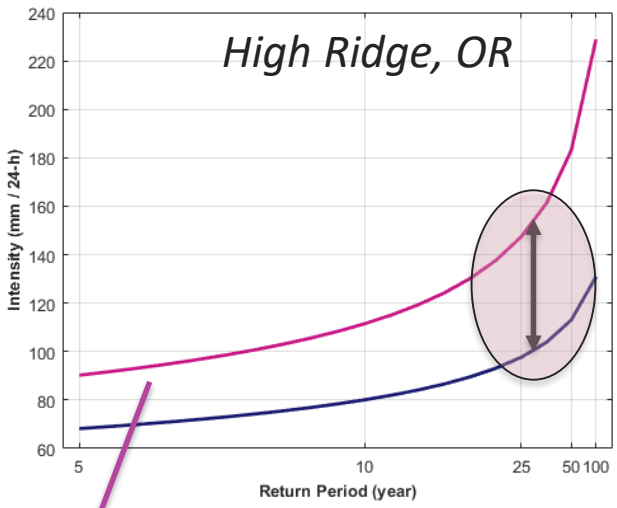

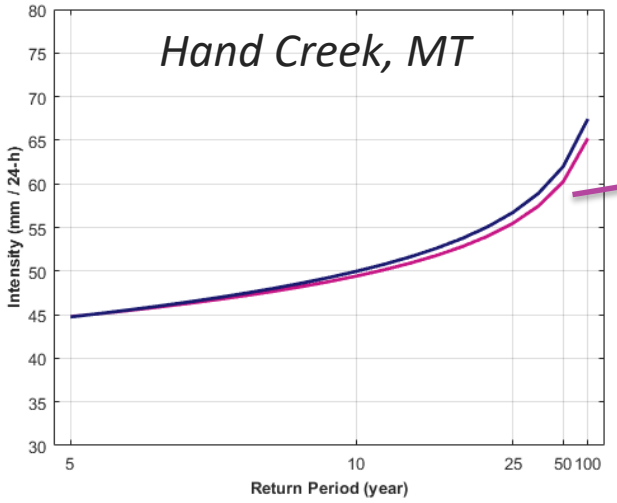

NG-IDF

Quantify the actual water reaching the land surface including all combinations of melt/ROS/rainfall

Assessment of NG-IDF Curves in Infrastructure Design

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a). Over-design

if the precipitation IDF value > NG-IDF value

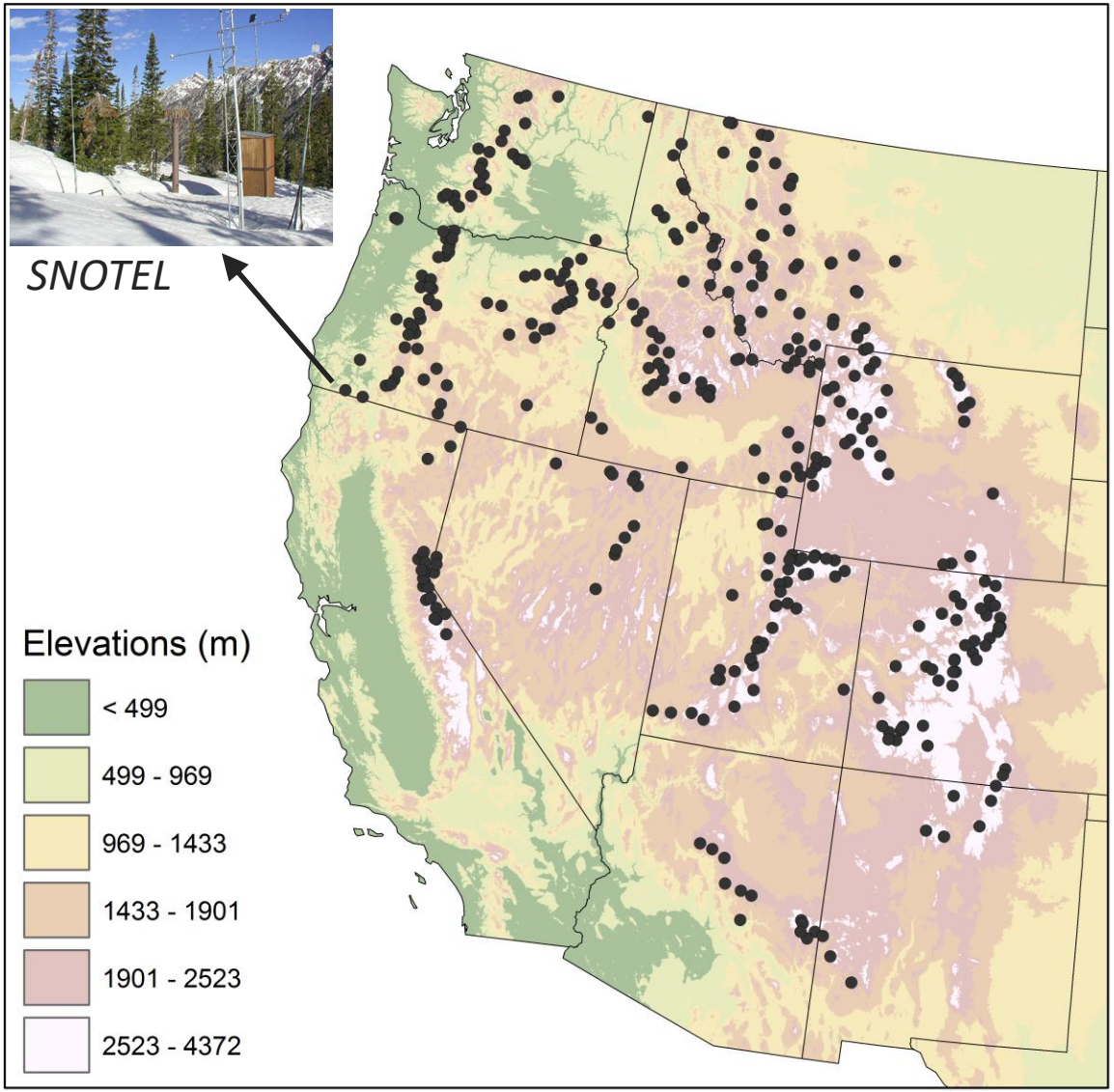
b). Under-design

if the NG-IDF value > precipitation IDF value

c). Proper design

if the differences between the precipitation IDF and NG-IDF values are trivial (< 10%)

Study Area, Data Sources, and Quality Control



- Snowmelt is responsible for 70% of the total runoff in the western U.S.
- Long-term meteorological and snowpack observations are acquired from USDA-NRCS SNOTEL stations across the western U.S.
- After a rigorous QAQC procedure, a total of 376 out of 785 SNOTEL stations are selected that have at least 30 years of record.

Snowmelt, ROS, and Actual Water for Runoff based on Daily SNOTEL

RAINFALL VS. MELT

- **Melt only (*M_o*)**
  No precipitation with a decrease in *SWE*
- **All melt events + ROS (*M_ros*)**
  Decrease in *SWE* with/without precipitation
- **Actual water for runoff (NG-IDF)**
  All melt events plus rainfall on snow-free ground

Importance of Rain-on-Snow (ROS) Events

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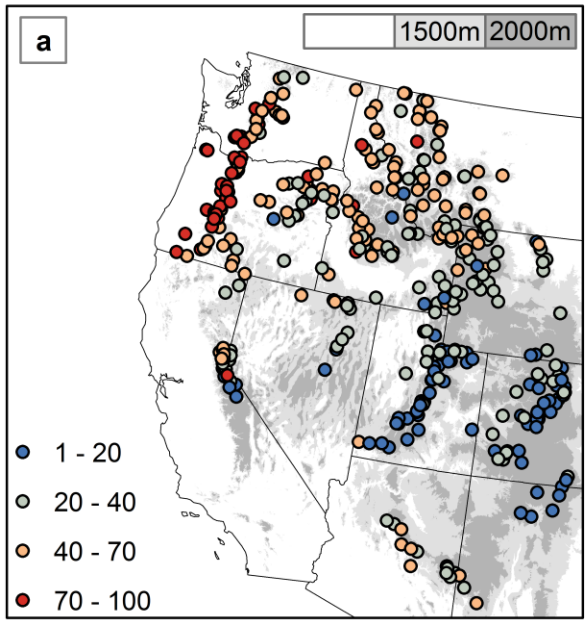
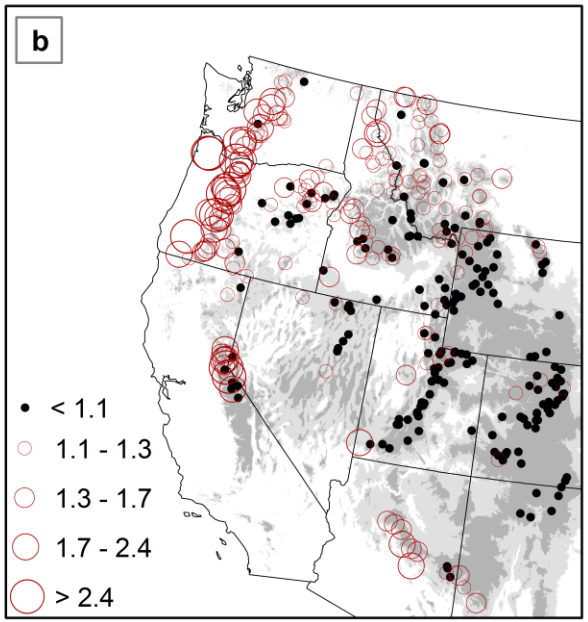
- ROS events are more frequent in the PNW and Sierra Nevada.
- The ratios between all melt events (*M_ros)* and melt only (*M_o)* are greater than 1.1 for the 10- and 100-year events at 197 and 210 of the 376 stations, respectively.
- On average, when ROS events are included, the 10- and 100-year events increased by 26% and 35%, respectively.

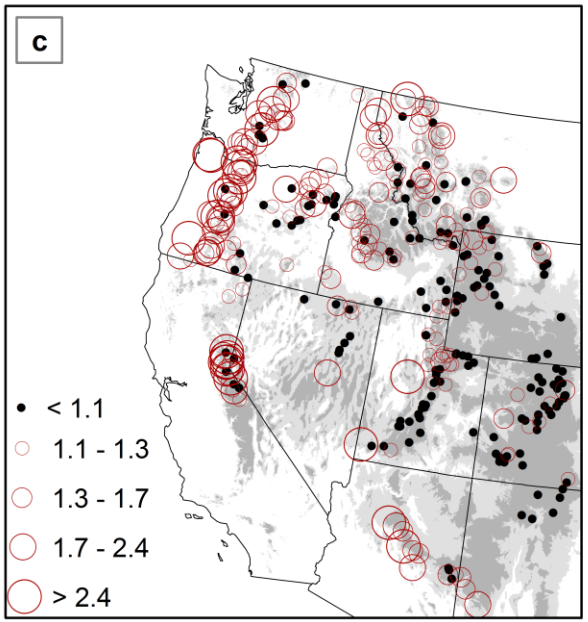
Percentage of rain-on-snow events



10-year event ratio: M_ros/M_o



100-year event ratio: M_ros/M_o



NG-IDF for Infrastructure Design in Western U.S.

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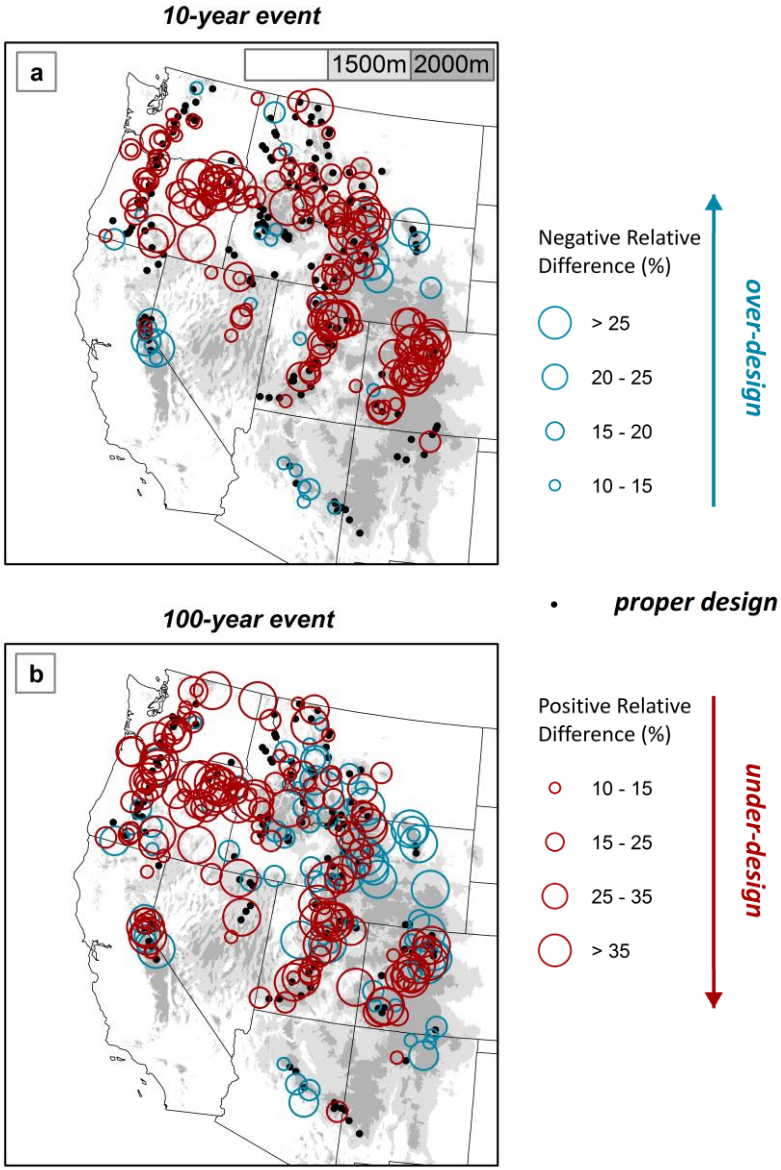

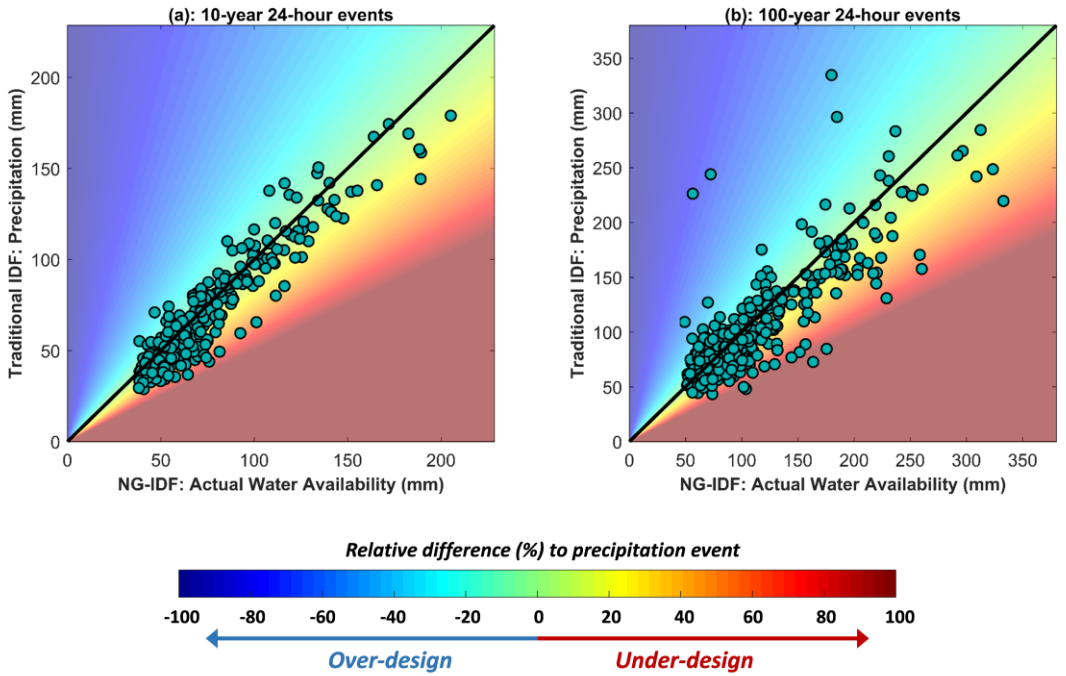

- **Under-design:** at 45% and 43% stations for the 24-h, 10- and 100-year events. NG-IDF values exceed precipitation IDF values by 10-75% for the 10-year event and 10-125% for the 100-year event.
- **Over-design:** at 9% (10-year) and 20% (100-year) stations. Precipitation IDF overestimate by 10-34% (10-year) and 10-75% (100-year).
- **Proper design:** at 36% stations for both 10- and 100-year events.

Future Study (ongoing)

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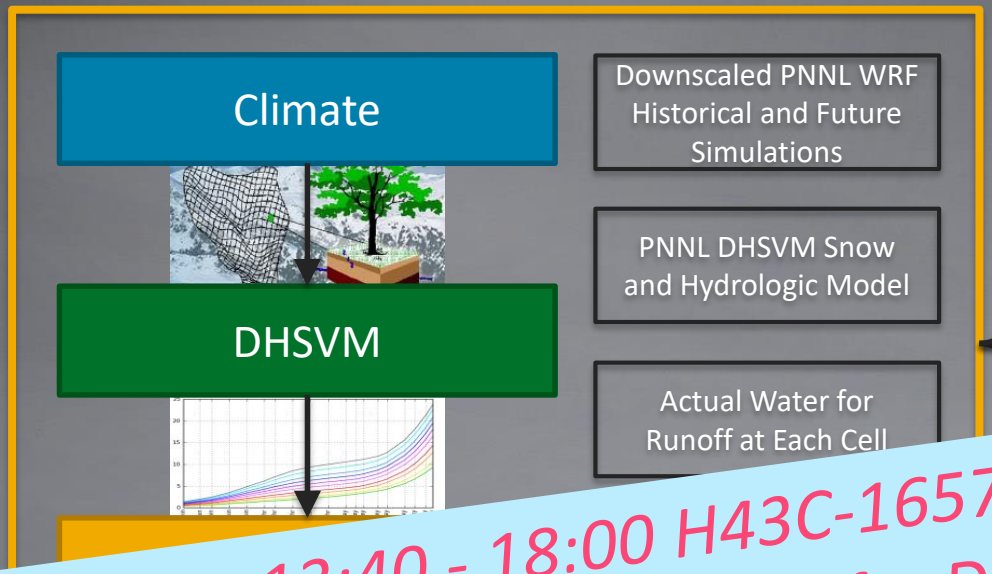
To update traditional precipitation IDF curves:

Grid cell (800m) based NG-IDF curves over the western U.S.



Improvements
- NG-IDF covers western U.S.
- Coastal lowlands to mountains
- Ensemble simulation (uncertainty)
- Consider future scenario

Assessments
- DHSVM continuous vs. IDF-based event modeling
- Accuracy and ...ess of

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- ...pproach
- ...require little extra training for practical engineers

Thursday 13:40 - 18:00 H43C-1657: Ensemble-Based Parameter Evaluation for Distributed Snow Modeling in the Western United States

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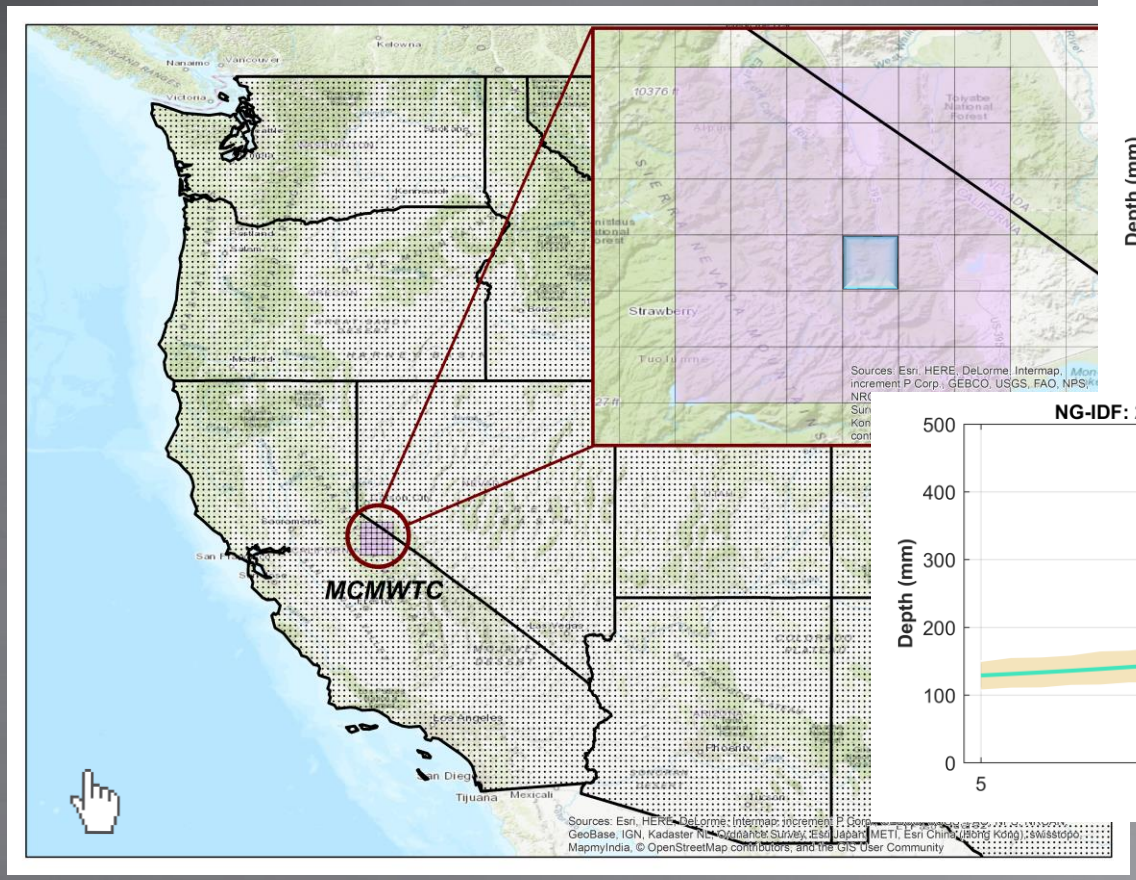

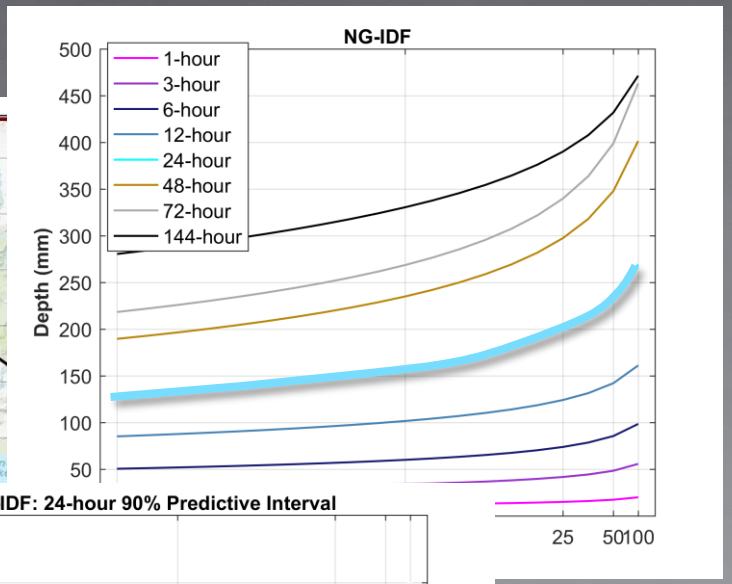

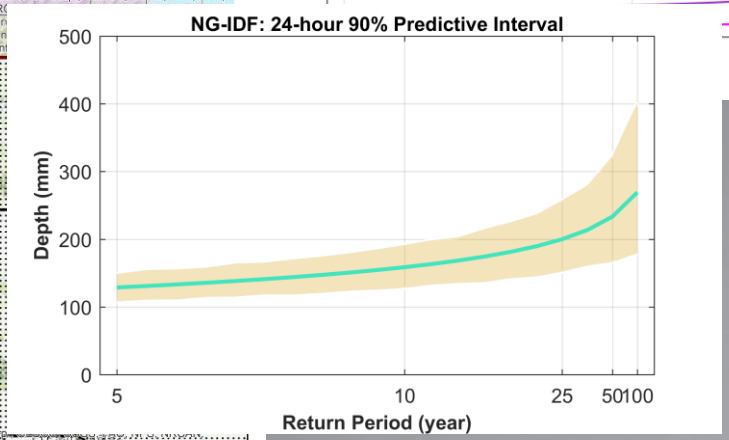

The presented work is under revision by *WRR*: *"Next-Generation Intensity-Duration Frequency Curves for Hydrologic Design in Snow-Dominated Environments"*

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Questions?