ARE PRECIPITATION-BASED INTENSITY-DURATION-FREQUENCY CUREVES APPROPRIATE FOR COST-EFFECTIVE AND RESILIENT DESIGN INFRASTRUCTURE DESIGN IN SNOW DOMINATED REGIONS? NEXT-GENERATION CURVES WITH INCLUSION OF RAIN-ON-SNOW EVENTS

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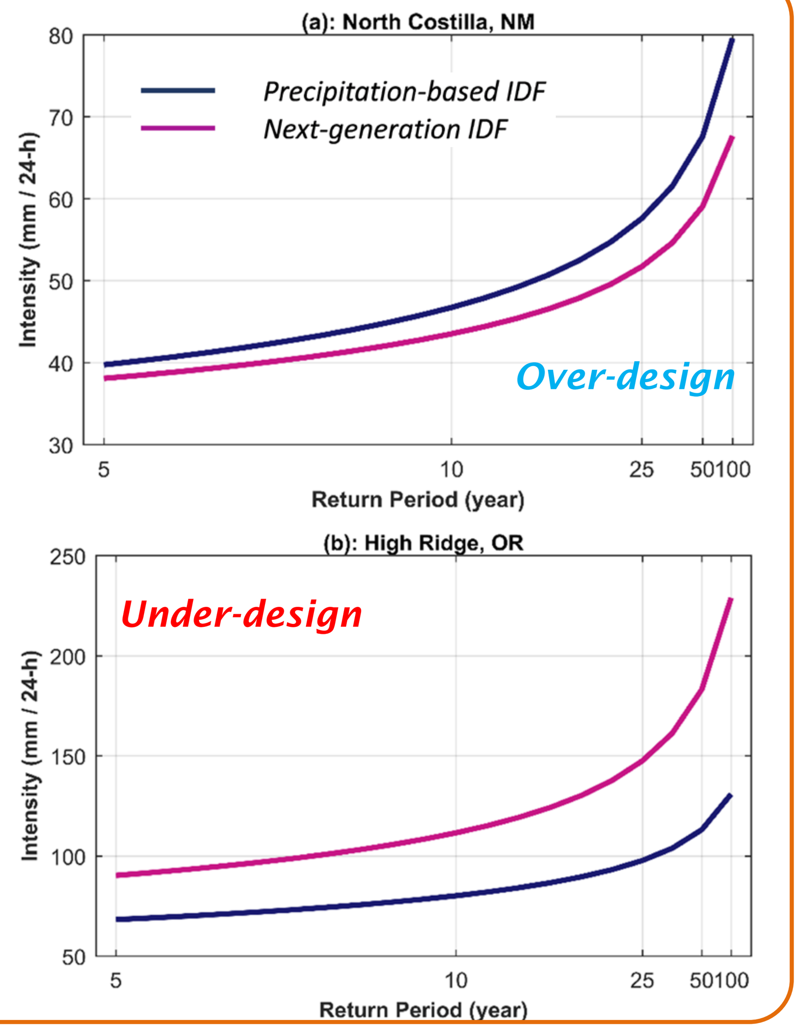
1. Introduction

While precipitation-based intensity-duration-frequency (IDF) curves are commonly used as part of infrastructure design, a large percentage of peak runoff events in snow-dominated regions are caused by snowmelt, particularly during rain-on-snow (ROS) events. In these regions, precipitation-based IDF curves may lead to substantial over-/under-estimation of design basis events and subsequent over-/under-design of infrastructure. We proposed next-generation IDF (NG-IDF) curves to improve infrastructure design in snow-dominated environments.



2. SNOTEL Dataset

Screen 785 active Snowpack Telemetry (SNOTEL) stations across the western United States for data accuracy, consistency, and length of record. 376 stations with at least 30 years of record passed the screen.

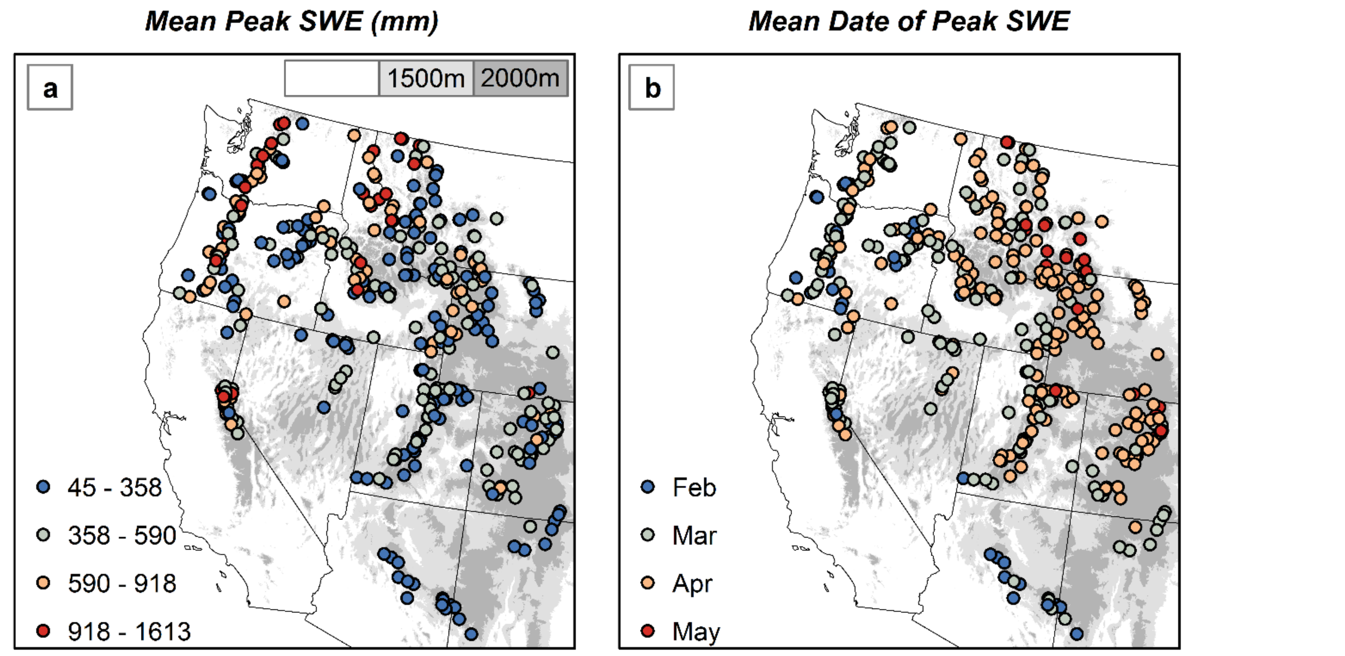


Figure 1. (a) The mean annual peak snow water equivalent (SWE) in mm for each SNOTEL site over the total length of record. (b) The mean date of the annual peak SWE.

3. Results

We found that the 10- and 100-year snowmelt events generally exceeded those based on rainfall and precipitation (Figure 2). This is particularly true in the Cascade Range, Colorado Front Range, and northern Rockies. Rain-on-snow (ROS) events are a common component of extreme events in the Pacific Northwest as compared to the Colorado Front Range (Figure 3). On average, when ROS events were included, the 10- and 100-year events increased by 26% and 35%, respectively.

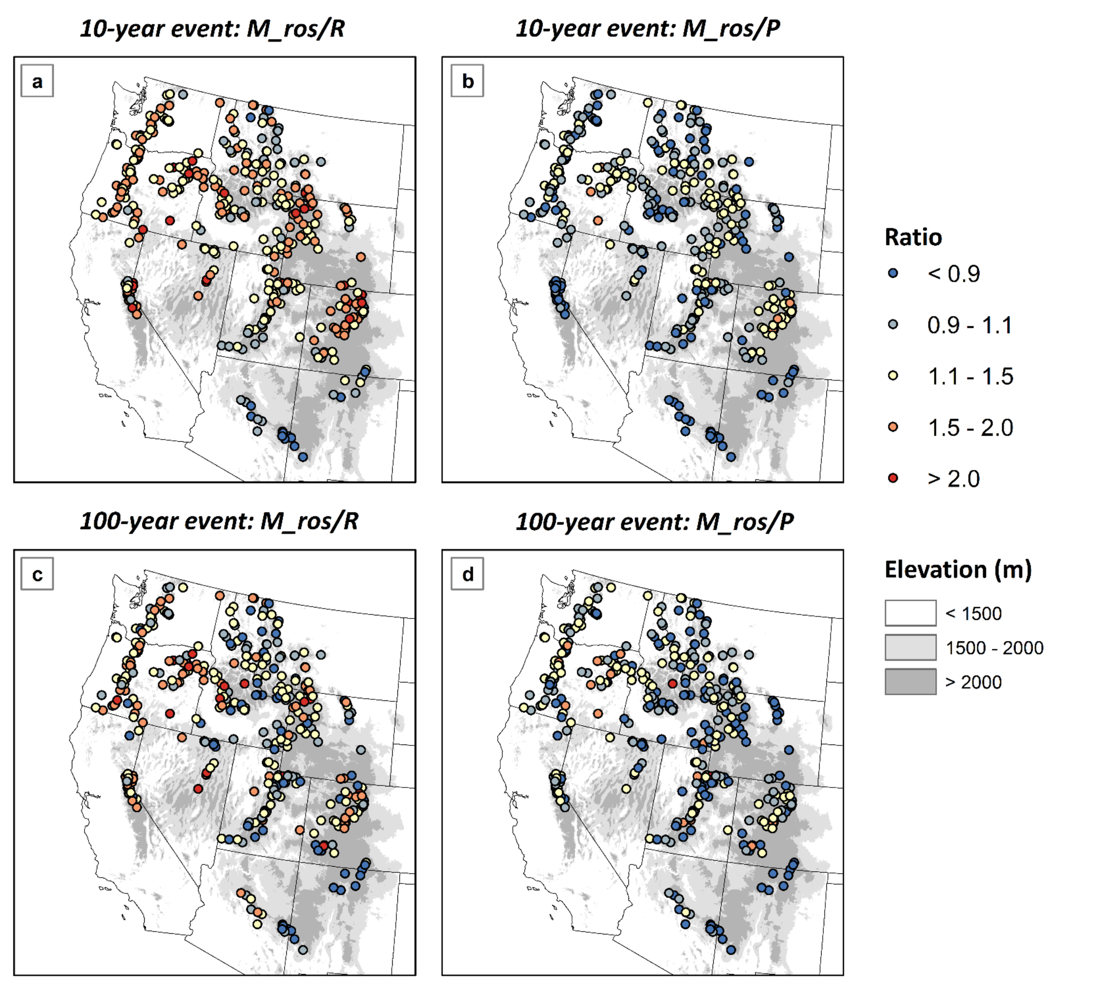


Figure 2. Ratio of the 10- and 100-year, 24-hour all melt events including rain-on-snow (M_ros) to the precipitation (P) and rainfall only (R). Ratios less than 1.0 indicate M_ros events smaller than P or R; while ratios greater than 1.0 suggest M_ros events exceed P or R.

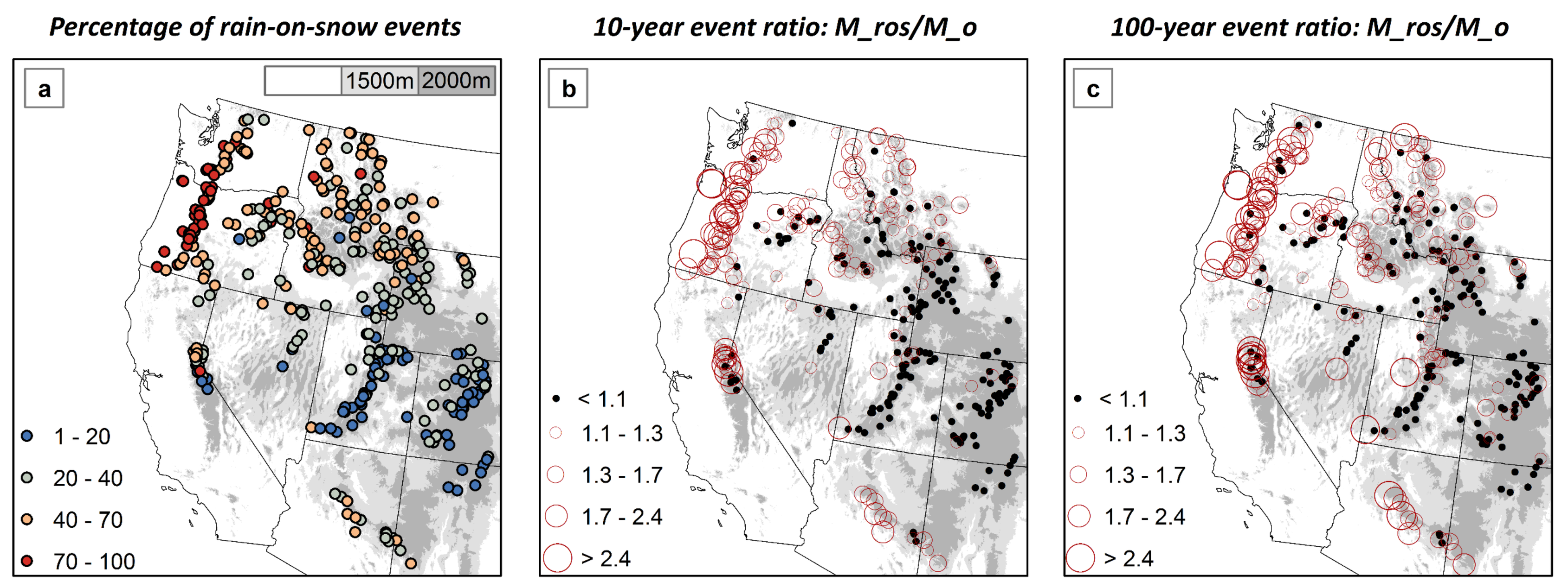


Figure 3. (a) Rain-on-snow events as a percentage of all melt events, (b) The 10-year, 24-hour event ratio between all melt events including rain-on-snow (M_ros) and melt without precipitation (M_o), (c) similar to (b) but showing the ratio for the 100-year, 24-hour events.

The relative differences between the NG-IDF and precipitation-based IDF curves for the 10- and 100-year events are presented in Figure 4. About 45% and 43% of the 376 stations indicated the potential for under-design for the 24-hour, 10- and 100-year events, respectively. For these stations, water available for runoff ($W = P - \Delta SWE$) exceeded precipitation by 10–75% for the 10-year event and 10–125% for the 100-year event. We found the potential for over-design of 9% and 20% for the 10- and 100-year events, respectively. The difference between NG-IDF and precipitation-based IDF values was less than 10% at 36% of the stations (proper design).

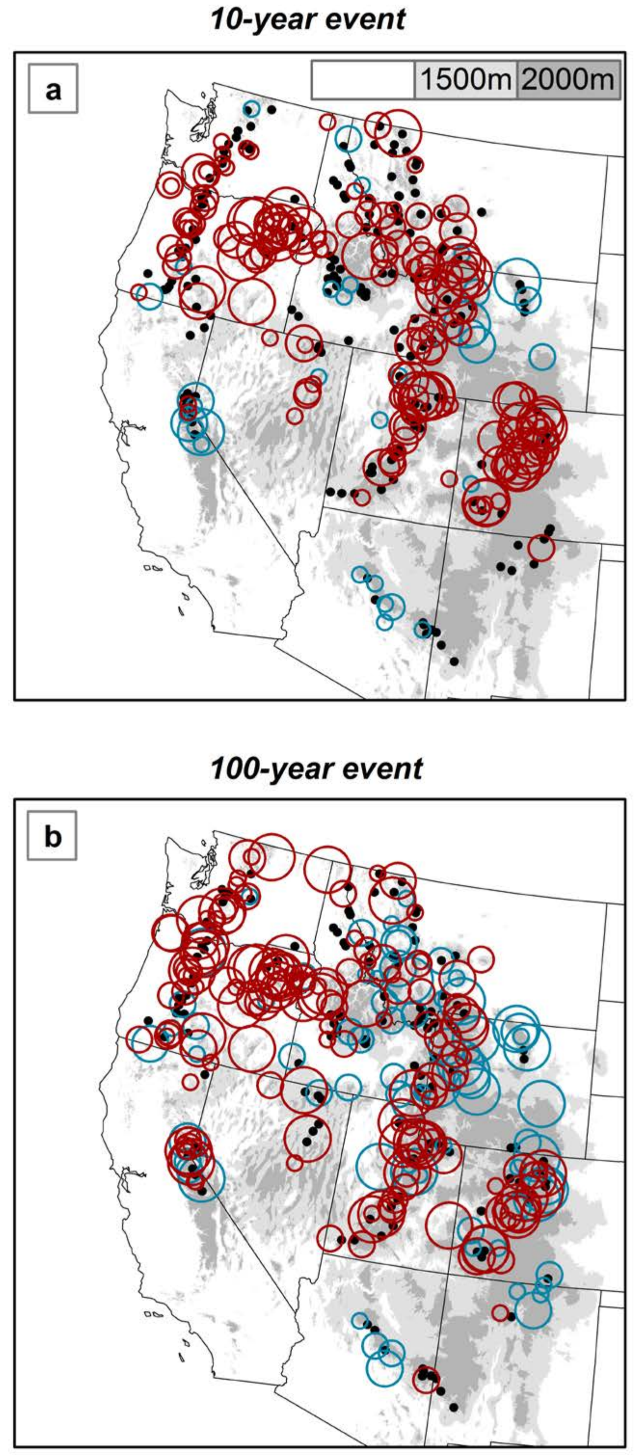
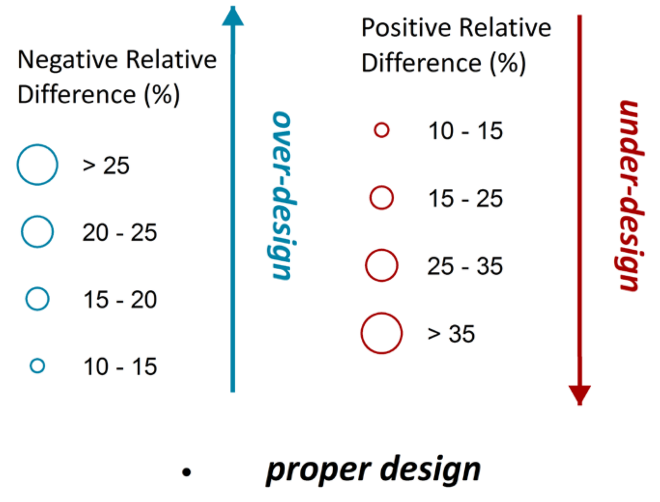


Figure 4. Relative percentage of differences ($(W - P)/P \times 100$) of the 10- and 100-year, 24-hour events between actual water available for runoff (W) from the NG-IDF and precipitation (P) from the traditional IDF curves. Stations with red circles indicate under-design ($W > P$); stations with blue circles suggest over-design ($P > W$); and black dots indicate proper design for the stations. The diameter of the circles indicates the magnitude of the relative difference.



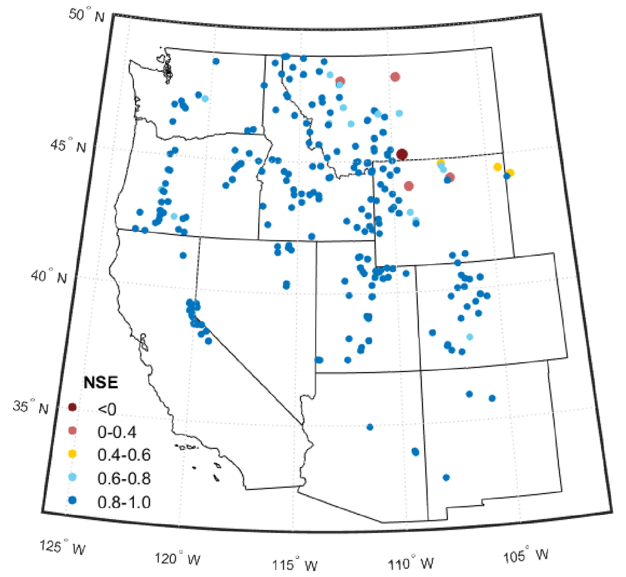
4. Conclusions

We compared NG-IDF curves to standard precipitation-based IDF curves for estimates of extreme events at 376 Snowpack Telemetry (SNOTEL) stations across the western United States that each had at least 30 years of high-quality records. We found standard precipitation-based IDF curves at 45% of the stations were subject to under-design, many with significant under-estimation of 100-year extreme events, for which the precipitation-based IDF curves can underestimate water potentially available for runoff by as much as 125% due to snowmelt and ROS events. The regions with the greatest potential for under-design were in the Pacific Northwest, the Sierra Nevada Mountains, and the Middle and Southern Rockies. We also found the potential for over-design at 20% of the stations, primarily in the Middle Rockies and Arizona mountains. These results suggest use of the more robust NG-IDF curves for hydrologic design in snow-dominated regions.

5. Ongoing Work

We implemented DHSVM at 246 Snow Telemetry (SNOTEL) sites across the western United States with 10,000 Monte Carlo ensemble parameter sets to examine model predictive uncertainties in association with parametric uncertainties and model physics. This will allow us to generate time series of water available for runoff and NG-IDF curves, with knowledge of uncertainty that would be translated into uncertainty in infrastructure design parameters, for historic and future climate in the western United States based on the 6 km WRF simulations from this project. The NG-IDF products can be used for hydrologic design from coastal areas to snow-dominated mountains and results in resilient design under a changing climate.

Figure 5. Nash-Sutcliffe efficiency (NSE) for DHSVM snowpack simulation versus daily observations at 246 SNOTEL sites. About 90% of SNOTEL sites (or 220 out of 246) have the NSE ≥ 0.7



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