Enhancing Hydrologic Design using Next-Generation Intensity-Duration-Frequency (NG-IDF) Curves over the Conterminous United States

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1. Introduction

Precipitation (P) intensity-duration-frequency (PREC-IDF) curves are a standard tool used worldwide to derive design floods for hydraulic infrastructure. In snow-dominated regions where a large percentage of flood events are caused by snowmelt and rain-on-snow (ROS) events, PREC-IDF curves can underestimate or overestimate the water reaching the land surface, and consequently, lead to under- or over-design of infrastructure. In this study, we propose the use of next-generation IDF (NG-IDF) curves, which characterize the actual water reaching the land surface (W) through mass balance as:

$$W = P - \Delta SWE\ (\boldsymbol{Snow\ Water\ Equivalent}) \qquad (1)$$

The NG-IDF curves can be considered as an enhancement to PREC-IDF curves, providing a science-based, consistent design approach which works in both rainfall- and snow-dominated environments (Yan et al., 2018a).

2. IDF Curves based on Daily SNOTEL Observations

We compared PREC-IDF and NG-IDF curves at 399 SNOTEL stations based on observed P and W calculated through eq. (1), demonstrating the need to update PREC-IDF curves in snow-dominated regions. For a 1 day duration, the ratio W/P >1.1 at 45% and 44% of the stations for the 10 and 100 year events. For a 15 day duration, W/P >1.1 at 97% and 92% of the stations for the 10 and 100 year events.

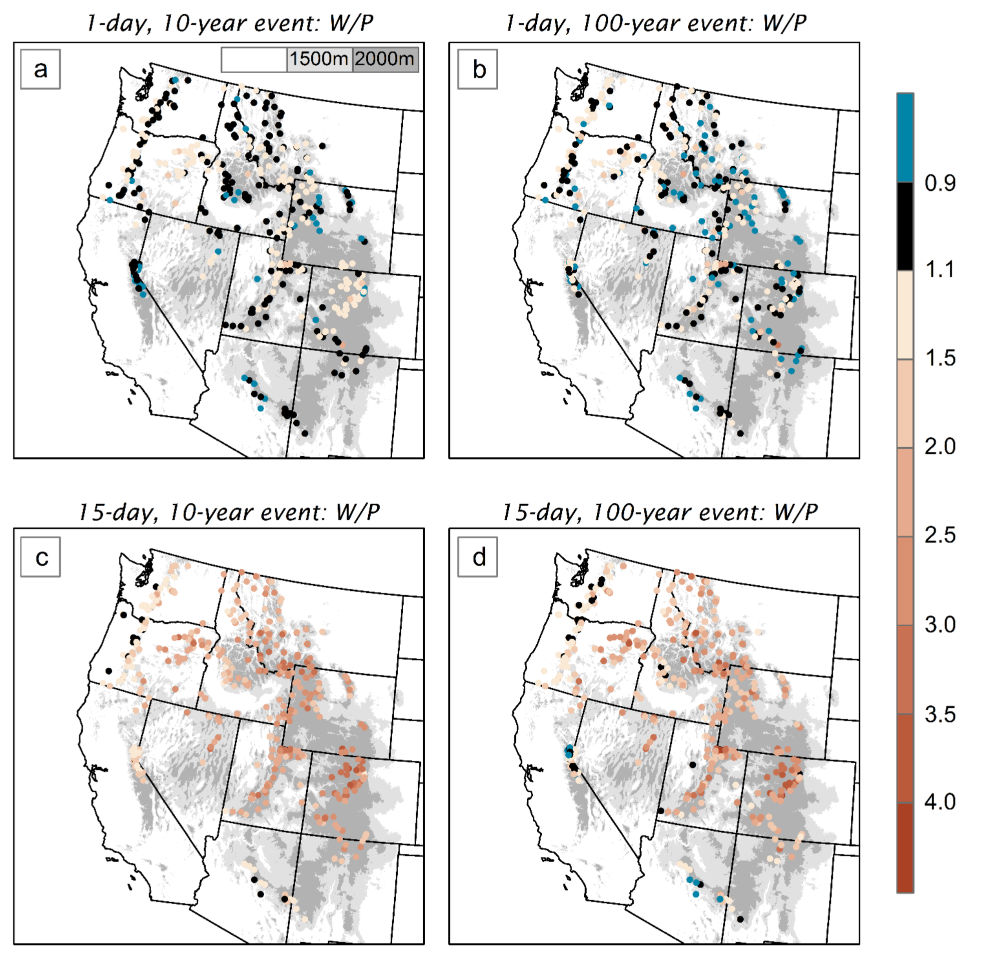


Figure 1. Ratios of water available for runoff (W) to precipitation (P) for 10 and 100 year return periods and 1 day and 15 day durations at 399 SNOTEL stations across the western U.S. (Yan et al., 2018b).

3. IDF Curves to Design Floods using TR-55 Rainfall-Runoff Model

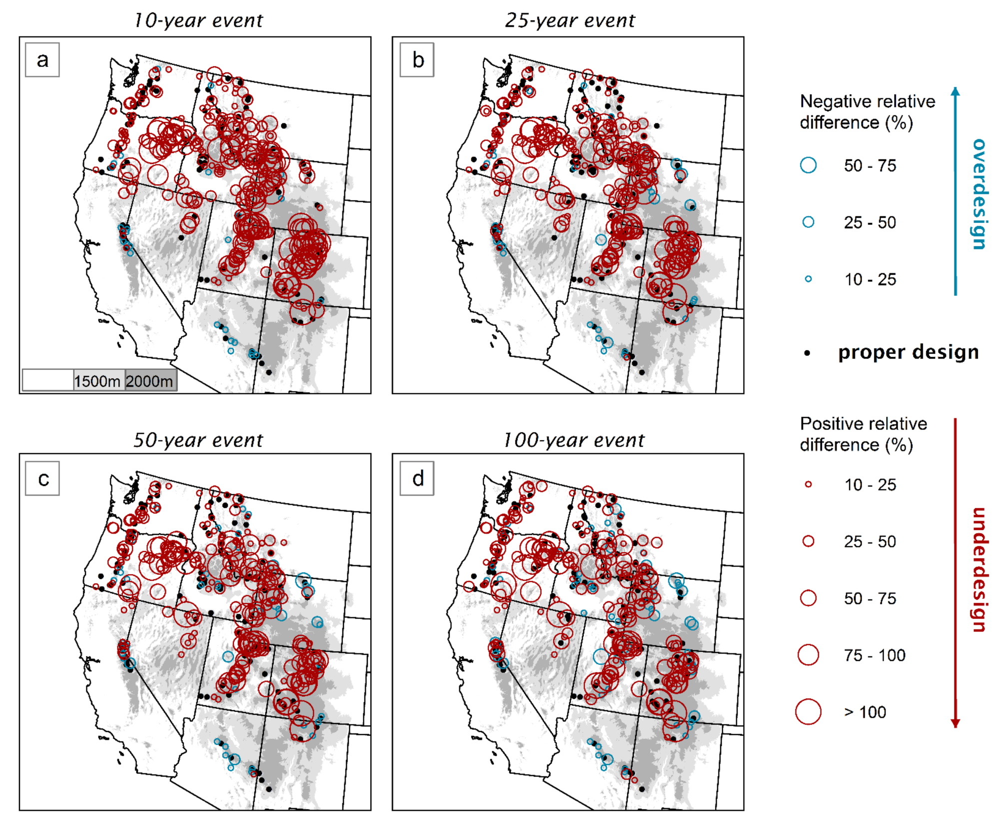
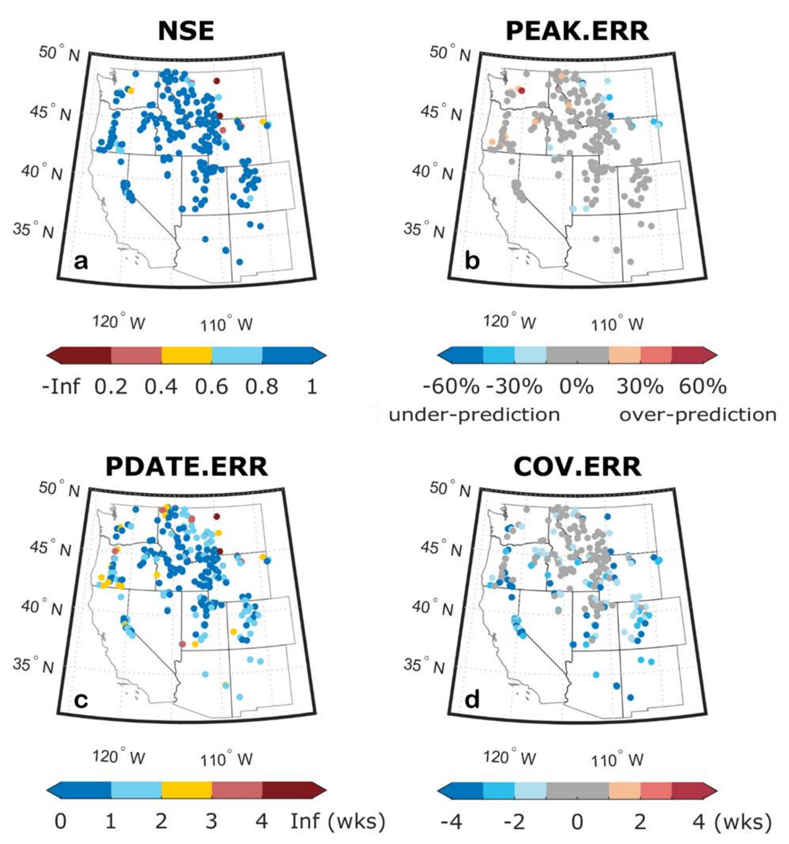


Figure 2. Relative percentage differences for the 10, 25, 50, and 100 year events between the peak design floods derived from NG-IDF (q_{NG}) and PREC-IDF (q_{PREC}) curves (Yan et al., 2018b).

Consistent with standard hydrologic design, design flood estimates were made for both PREC-IDF and NG-IDF curves using the TR-55 rainfall-runoff model (q_{PREC} and q_{NG}). In Figure 2, about 72%, 64%, 63%, and 57% stations indicate the potential for under-design when using PREC-IDF curves for the 10, 25, 50, and 100 year events, respectively. The potential for over-design exists at 7%, 10%, 12%, and 16% for the 10, 25, 50, and 100 year events, respectively. The q_{NG} exceeds q_{PREC} by as much as 324% for the 100 year event.

4. DHSVM Snow Modeling



SNOTEL based NG-IDF curves are only available for about 400 point locations across the western U.S. We used the DHSVM Hydrologic model to extend the NG-IDF curves in space and time. The DHSVM snow model was calibrated and evaluated at 246 SNOTEL stations with continuous meteorological observations during 2007–2013. DHSVM simulated daily SWE has NSE>0.8 at 91% of the stations and the average NSE is 0.9. The error in predicted peak SWE (PEAK.ERR) is within ±10% and ±20% at about 73% and 92% of the stations. The error in predicted date of peak SWE (PDATE.ERR) and snow cover duration (COV.ERR) is within 14 days at 88% and 74% of the stations, respectively.

Figure 4. DHSVM SWE prediction skills evaluated by NSE, peak SWE (PEAK.ERR) and date (PDATE.ERR), and snow cover duration (COV.ERR) (Sun et al., 2018a).

5. Assessment of NG-IDF Curves in Practical Design

We compare IDF based design flood estimates through TR-55 with design flood estimates based on long-term streamflow simulated by the calibrated DHSVM. In Figure 5, the average design flood error between the PREC-IDF method and DHSVM is 32% among the three return periods; the error decreases to 13% with the use of the NG-IDF curves.

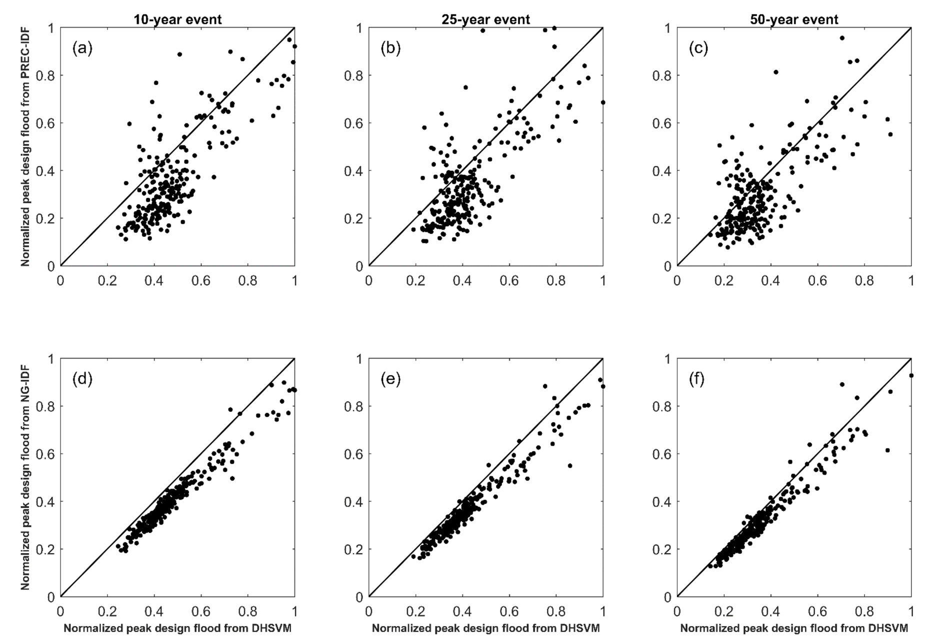


Figure 5. Scatterplots of the 10, 25, and 50 year normalized peak design floods from PREC-IDF (upper) and NG-IDF curves (lower) versus DHSVM continuous simulation (Yan et al., 2018c).

6. NG-IDF Curves over CONUS

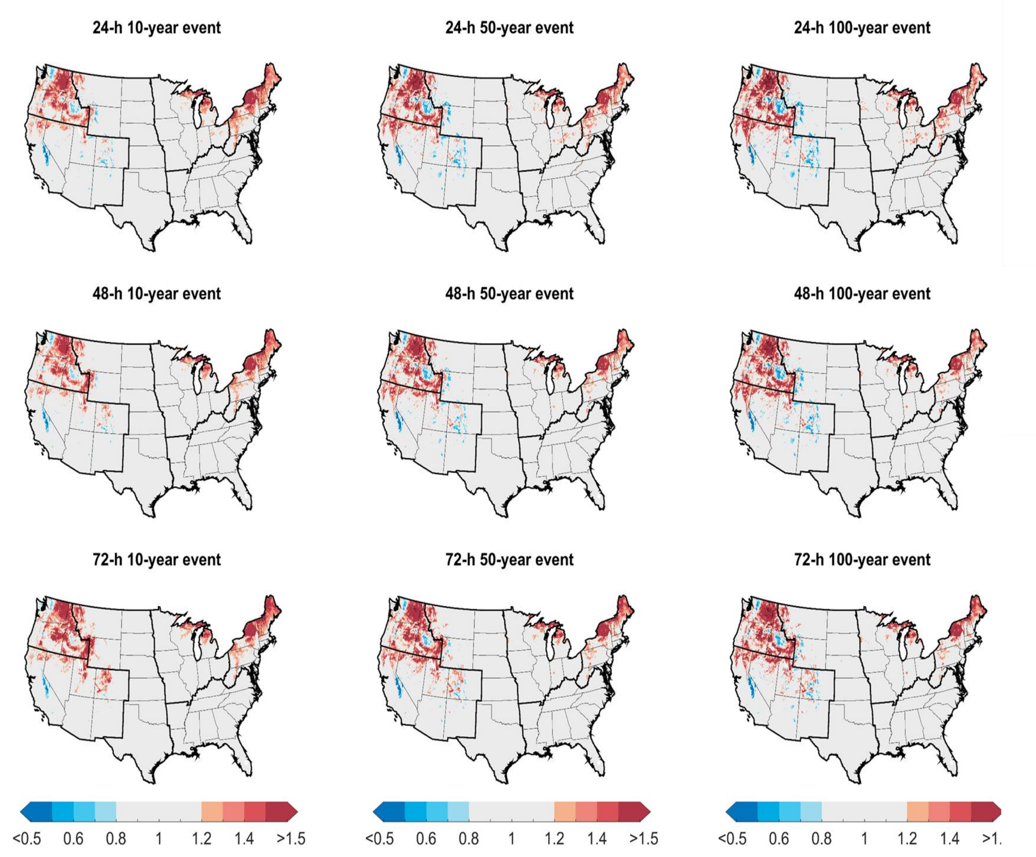


Figure 6. Ratio of W (NG-IDF curves) to P (PREC-IDF curves) for varying durations over CONUS (Sun et al., 2018b)

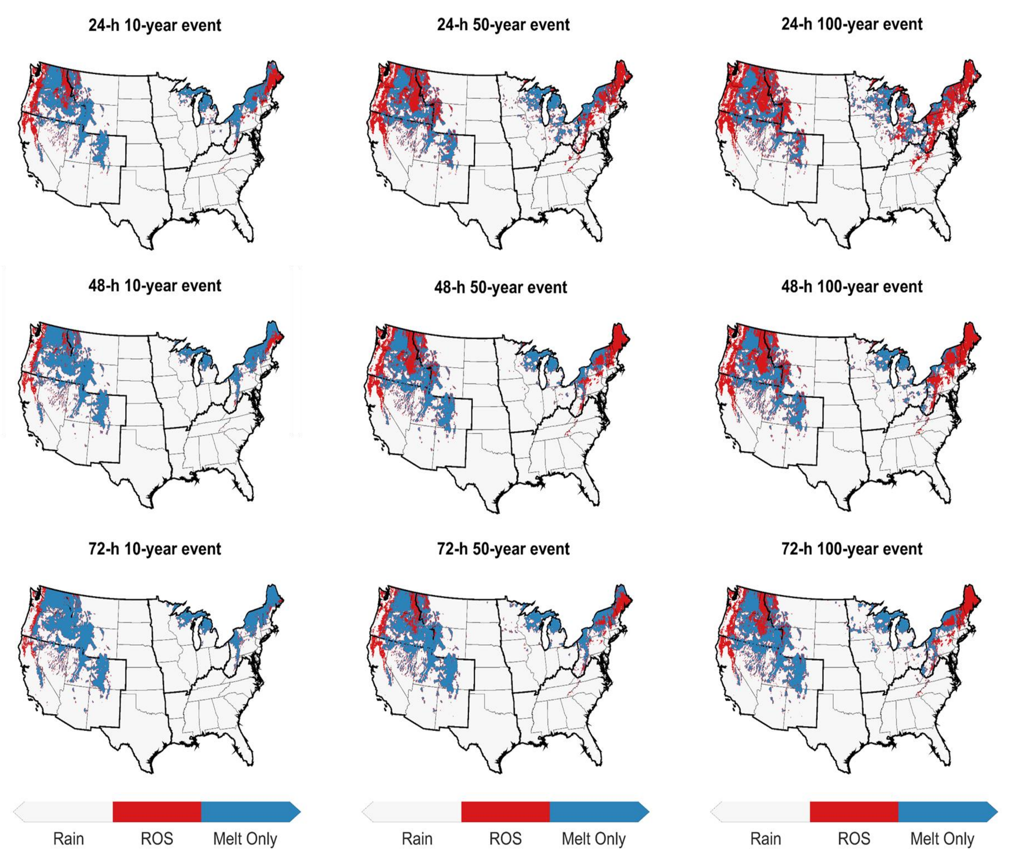


Figure 7. The dominant drivers of design basis extreme events for varying durations over CONUS (Sun et al., 2018b)

To extend SNOTEL observation-based NG-IDF curves in space and time, we developed regional parameters and used the DHSVM model to simulate W and construct NG-IDF curves for the period 1950–2013 at over 200,000 locations in the Conterminous United States (CONUS) using Livneh 1/16 degree meteorological data.

In comparison to extreme P events (Figures 6 and 7), extreme W events are significantly higher in magnitude in most ROS- and melt-dominated mountainous regions (e.g. the mountain ranges in the western and northeastern U.S.), and snowbelts near the Great Lakes strongly affected by lake-effect snowstorms. Results suggest substantial underestimation of design basis extreme events in these regions with PREC-IDF.

7. Path Forward

- Canopy interception: Run DHSVM for different vegetation types to prepare NG-IDF curves for individual land cover classes.
- Real case study: Validate the NG-IDF method in a snow dominated watershed with diverse land cover against observed streamflow.
- Data access: Distribute NG-IDF curves over CONUS for different land cover classes through a web interface at https://dhsvm.pnnl.gov/

8. References

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This research was supported by the U.S. Department of Defense SERDP Project RC-2546 to the Pacific Northwest National Laboratory (PNNL).