Potential Concerns of the Storm Typing Approach in Estimating Extreme Rainfall Estimates

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Concern

Initial review of the Robinson Nuclear Plant precipitation frequency analysis finds that the point precipitation frequency estimates produced by MetStat are lower than the point precipitation frequency estimates available from NOAA Atlas 14. This results in less conservative precipitation inputs for hydrologic modeling. The main difference between the two analyses is that MetStat only evaluates precipitation associated with tropical storm remnants (TSRs), while NOAA Atlas 14 considers all precipitation events.

Background

Given an annual exceedance probability (AEP) of interest, our goal is to identify a threshold x that satisfies the following equation:

$$P[\mathbf{X} > x] = AEP \tag{1}$$

where $\mathbf{X}$ is a random variable representing the maximum rainfall depth within a year. The probability distribution of $\mathbf{X}$ can be derived from any existing frequency analysis method, such as L-moment in this case.

When focusing a specific type of storm, such as the tropical storm remnants (TSRs), the assessment will reduce $\mathbf{X}$ into smaller subsets. To support the discussion, we use $\mathbf{X}_{\boldsymbol{TSR}}$ to represent the random variable of maximum TSR rainfall depth within a year, and $\mathbf{X}_{\boldsymbol{non-TSR}}$ to represent the maximum non-TSR rainfall depth within a year. Jointly $\mathbf{X}_{\boldsymbol{TSR}}$ and $\mathbf{X}_{\boldsymbol{non-TSR}}$ forms the space of $\mathbf{X}$. Therefore, $P[\mathbf{X} > x]$ can be rewritten as:

$$P[\boldsymbol{X} > x] = P[\mathbf{X}_{\boldsymbol{TSR}} > x] + P[\mathbf{X}_{\boldsymbol{non-TSR}} > x] - P[\mathbf{X}_{\boldsymbol{TSR}} > x \cap \mathbf{X}_{\boldsymbol{non-TSR}} > x] \tag{2}$$

For simplification, let us assume that $\mathbf{X}_{\boldsymbol{TSR}}$ is independent to $\mathbf{X}_{\boldsymbol{non-TSR}}$. Therefore, Eqs. (1) and (2) can be rewritten as:

$$P[\mathbf{X}_{\boldsymbol{TSR}} > x] + P[\mathbf{X}_{\boldsymbol{non-TSR}} > x] - P[\mathbf{X}_{\boldsymbol{TSR}} > x] * P[\mathbf{X}_{\boldsymbol{non-TSR}} > x] = AEP \tag{3}$$

Eq. (3) is hence the statistically complete form when evaluating x for a given AEP.

Special Case 1 – TSR fully controls

If TSR fully controls all annual maximum precipitation, then we will have the following condition:

$$P[\mathbf{X}_{\boldsymbol{TSR}} > x] \gg P[\mathbf{X}_{\boldsymbol{non-TSR}} > x] \tag{4}$$

Therefore, Eq. (3) will reduce to:

$$P[\mathbf{X}_{\boldsymbol{TSR}} > x] \approx AEP \tag{5}$$

In this special case, both $\mathbf{X}$ and $\mathbf{X}_{\boldsymbol{TSR}}$ would share the same AEP. So a 1000-year $\mathbf{X}_{\boldsymbol{TSR}}$ would have the same value as a 1000-year $\mathbf{X}$.

Special Case 2 – TSR and non-TSR jointly control

If both TSR and non-TSR are equally strong and share similar distributions, we can assume that:

$$P[\mathbf{X}_{\boldsymbol{TSR}} > x] \approx P[\mathbf{X}_{\boldsymbol{non-TSR}} > x] \tag{6}$$

When combing both Eqs. (3) and (6), we can solve $P[\mathbf{X}_{\boldsymbol{TSR}} > x]$ as:

$$P[\mathbf{X}_{\boldsymbol{TSR}} > x] = 1 - \sqrt{1 - AEP} \tag{7}$$

In this special case, $\mathbf{X}_{\boldsymbol{TSR}}$ would have a smaller AEP than $\mathbf{X}$. For instance, a 1000-year $\mathbf{X}_{\boldsymbol{TSR}}$ ($P[\mathbf{X}_{\boldsymbol{TSR}} > x]$ = 10^{-3}) would lead to around a 500-year $\mathbf{X}$ (AEP = $2*10^{-3}$).

Implications

In reality, while TSR mostly produces the largest annual rainfall depth, it may not occur every year (and non-TSR events may produce annual maxima in other years), so Special Case 1 cannot really occur. The true answer, such as the case for the Robinson watershed, would likely lie in-between Special Cases 1 and 2.

In other words, the current application only considers Special Case 1 and will lead to a smaller precipitation frequency value for a given AEP. This should be one main reason to explain the large difference between the MetStat value (TSR-only) versus the NOAA Atlas 14 value (considers all storm types).