Application of Stochastic Storm Transposition and Hydrologic Modelling to Flood Frequency Analysis: A Case Study for Turkey River, Iowa

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RESEARCH QUESTION

• Can we develop a new framework which can be used to derive robust flood frequency analysis?

• Trying to understand the role of rainfall and antecedent conditions in deriving flood frequency analysis.
I. Conventional Methods:
   • Limitations

II. RainyDay:
   • Stochastic Storm Transposition

III. Hydrological Modelling:
   • Coupled with RainyDay

IV. Case Study:
   • Hydroclimatology of Turkey River Basin
   • Derived Flood Frequency Analysis

A New Framework

- RainyDay:
  Stochastic Storm Transposition

- Hydrological Model:
  Continuous Simulation

- Synthetic Rainfall:
  20 Realizations of 500 years

- Initial Conditions:
  Soil Moisture & Snowpack

- Hydrological Model:
  Event Based Simulation

- Flood Frequency Analysis
Existing methods of flood frequency analyses

Statistical Modelling Approach
- Annual Peak flows
- Peak over threshold
- Regional Analysis

Hydrological Modelling Approach
- Design Storm Approach
- Continuous Simulation
- Joint Probability Approach
**Statistical**

USGS Bulletin 17 B

**Hydrological**

- Select probability of occurrence
- Determine rainfall duration and intensity
- Assume spatially uniform rainfall
- Apply hydrologic model

**NOAA Atlas 14**

Wisconsin River at Wisconsin Dells (1935-2016 Annual Peak)
OUTLINE

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Stochastic Storm Transposition (SST)

Storm Transposition + dynamical flood simulations

Gives “worst case scenarios,” but not the likelihood that they happen...

Hayden, N. G., K. W. Potter, and D. S. Liebl (2016). Evaluating Infiltration Requirements for New Development Using Extreme Storm Transposition: A Case Study from Dane County, WI. JAWRA
Stochastic Storm Transposition (SST)

**Identify storms:**

1. Define a larger “domain” that contains watershed

2. Identify largest X rain events from the N-year remote sensing record → “Storm Catalog”
RainyDay Application: Turkey River Basin

Storm 1: 2011-05-28T20:00
Max Rainfall: 91.0 mm @ Lat/Lon: 40.8°, -91.8°
**Stochastic Storm Transposition (SST)**

**Transpose storms:**

3. Randomly select a storm from catalog and randomly move its starting location

4. Calculate the resulting rainfall over the watershed

**Repeat:**

5. Repeat steps 3-4 $k$ times, where:

   $$k \sim \text{Poisson}(\lambda = X/N \text{ storms/year})$$

6. Repeat step 5 to generate thousands of synthetic rainfall scenarios
RainyDay Application: Turkey River Basin

A synthetic year:

- $k$ events/year
- $k \sim \text{Poisson}$
- The largest of these $k$ events is analogous to an annual rainfall maximum

*Synthetic annual rainfall maximum*
RainyDay Application: Turkey River Basin

Output Format

- Basin Averaged Rainfall Time Series (.txt, .csv, etc.)
- Realistic, Spatially Distributed Rainfall (netcdf)
Web RainyDay: Accessible to Everyone

[her.cee.wisc.edu/projects/rainyday](her.cee.wisc.edu/projects/rainyday)

Project funded by US Bureau of Reclamation
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A Case Study for Turkey River, Iowa

- Located in the northeastern corner of Iowa
- 1545 square miles
- 76% of the land is used for crops and grazing
Hydroclimatology of Turkey River Basin

• Seasonality

- Precipitation
- Streamflow

• Trend Analysis

- Observed Annual Peak
- PDF of flood occurrence

- Snowmelt-driven floods
- Rainfall-driven floods
A Case Study for Turkey River, Iowa

Stage IV Rainfall Data (2002-2016) → 20 Realizations: 500 year synthetic rainfall data

Stochastic Storm Transposition

- Stage IV Rainfall Data
- USGS Stream flow
- NOAA temperature data (2002-2016)

Rainfall Runoff Simulation

15 years initial condition:
- Soil Moisture
- Snow Pack

- 20 Realizations of 500 year streamflow
- Flood frequency analysis
Results: Flood Frequency Analysis

![Graph showing flood discharge over exceedance probability and return period.]

- Stage IV RainyDay (mean + spread)
- USGS Bulletin 17B (mean + spread)
Results: Flood Frequency Analysis

- The rainyday seems able to capture “recent” flood behavior.
- 1500 m³/s is 50-year flood using RainyDay but 200-year flood using USGS 17B.
- Extreme events happens more frequently in recent years.
- Is it time to reevaluate how to define “extreme”?
Results: Flood Frequency Analysis

- The correlation coefficient of rainfall and discharge return period is 0.56.
- Rainfall is not the only factor causes flood.
- Antecedent conditions play a key role in driving the flood.
Summary

• RainyDay, an open source system, can provide spatially detailed rainfall pattern.

• Our derived flood frequency analysis can account for recent changes in extreme rainfall.

• Exploring the flood-generating processes in terms of variability between extreme rainfall and flooding can assist predictions of flooding.

• We’ll help everyone who wants to try it.
Thanks!

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Questions?