Modifying Precipitation Intensity-Duration-Frequency Curves to Design Climate Change-Resilient Stormwater Systems

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Introduction

Climate change has led to an acceleration of the global hydrologic cycle (Trenberth 2011), which manifests itself in the northeast United States as greater total precipitation and more frequent severe storms (DeGaetano 2009). Designers require a simple, practical modeling approach if they are to design stormwater systems that can continue to prevent flooding as the climate changes. This project aims to quantify recent shifts in Pennsylvania's rainfall patterns and to demonstrate a climate-resilient design procedure through a case study.

Modeling Approach

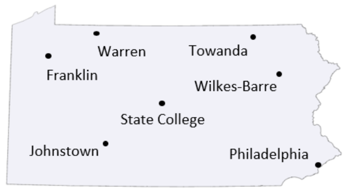


Figure 1. Map of Pennsylvania with observing stations labeled. Not to scale.

The data used were 24-hour annual maximum precipitation depths from seven NCDC observing stations in Pennsylvania, each with at least 100 continuous years of record.

Intensity-duration-frequency curves were developed using the R package extRemes. The data were fitted to GEV distributions using the method of maximum likelihood estimation.

One stationary and two nonstationary GEV distributions were constructed for each station. The resulting precipitation models are described in Table 1 below.

Table 1. Description of precipitation models.

Model	Time-Varying GEV Parameters	Trend Characteristics
stationary	none	none
shift	location	linear
stretch	location, scale	linear, varying with return period

Case Study

Choose a design depth for a stormwater structure intended to remain in service in Philadelphia from 2000 to 2099 with a 10% probability of flooding in any given year.

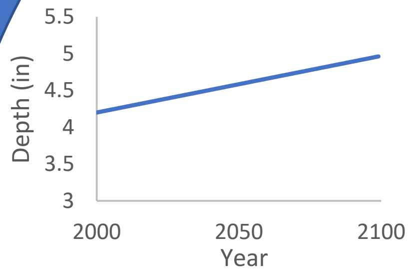
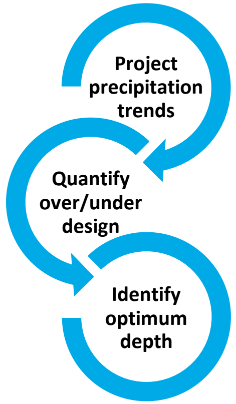


Figure 2. Stretch model results for the 10-year storm – the precipitation depth corresponding to a 10% probability of occurrence -- extrapolated over the structure's lifetime.



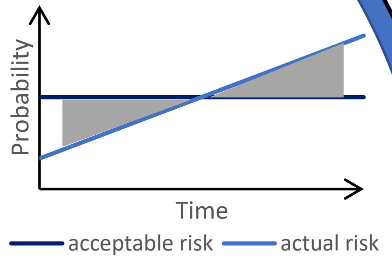


Figure 3. As the 10-year storm depth increases, the probability of flooding rises as well. The structure is oversized and expensive at the beginning of its life and undersized at the end.

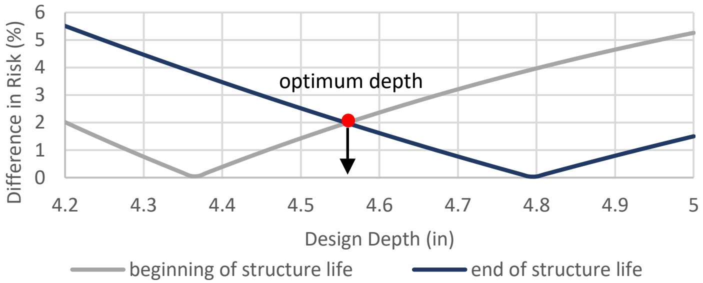


Figure 4. Graphical method for determining design depth. Percent deviation from the acceptable risk level is plotted for a range of depths.

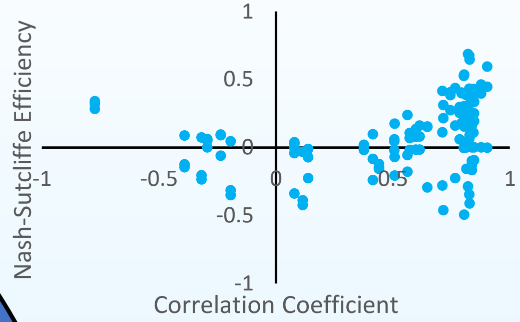


Figure 5. Nash-Sutcliffe efficiency, a measure of model accuracy, plotted against a correlation coefficient relating storm depth and time.

Modeling Results

Annual maximum precipitation depth increased 13% on average during the modeling period.

A high degree of modeling accuracy was only possible for storms that were highly correlated with time (Figure 5).

The stretch model showed an 18% average increase in the 100-year storm depth, but only a 7% increase in the 2-year storm depth.

Conclusions

- The evidence is consistent with a long-term increasing precipitation trend in Pennsylvania.
- Trends vary among storms with different frequencies. In general, extreme storms increase most rapidly.
- Stormwater design under climate change may be framed as an optimization problem, where the goal is to minimize the time a structure is over- or undersized.

References

DeGaetano, A. T. 2009. Time-dependent changes in extreme-precipitation return-period amounts in the continental United States. *Journal of Applied Meteorology and Climatology,* 48: 2086-2099.

Trenberth, K. E. 2011. Changes in precipitation with climate change. *Climate Research* 47: 123-138.