LAND USE PLANNING

Quantifying the Impact of Land Cover Change and of Climate Change on Floods in Northeastern Illinois

Abstract

Trend analysis of the annual flood peaks on twelve small urbanizing watersheds in the northeastern Illinois indicated that the annual peaks increased in the recent decades. The increase in peaks can be explained by intensive urbanization, which is generally considered a major contributor to the increase in flood peaks. In addition, recent precipitation studies pointed to increasing intensity and frequency of the heavy rainfall, which could have further increased the flood peaks. A hydrologic model was calibrated on two large floods (1954 and 1996) containing simultaneous hourly rainfall-runoff data on all 12 watersheds (1954). It was demonstrated that significant increase in precipitation, and land-use change occurred between 1954 and 1996. Precipitation frequency analysis for different time periods was calculated based on L-moments, hydrologic parameters for different land-use categories were determined using Geographical Information System (GIS), and hydrologic analysis was performed using the HEC-HMS model. This study quantified the increase in flood peaks between 1954 and 1996; quantified the increase in calculated design precipitation; identified the land-use changes in the watershed areas; identified the relative contributions of land cover change and climate change on increasing flood discharges; compared the published regulatory discharges with flood discharges computed for current conditions; and provided tools to analyze future land use and climate scenarios.

Introduction

This research determines the amounts of increase in flood discharges in Northeastern Illinois over the past decades, focusing on streams with drainage areas less than 36 square miles. The goal of this research is to identify the contributions of land cover change and climate change on increasing flood discharges; provide tools to assist in projections of future flood magnitudes that can be used with existing management practices to reduce flooding impacts; provide input for flood study prioritization through a comparison of published regulatory discharges with flood discharges computed for current conditions, and investigate possible future impacts of changes in land cover and precipitation on flood peaks.

Narrative Report

Floods are defined as temporary overflows of a river onto adjacent lands not normally covered by water. One-hundred-year floods, the floods that have a 1 percent chance of occurrence every year, in NE Illinois increased in the last several decades. The relative contributions of land-use and climate changes to the increase in flood discharges were estimated in this research. The 100-year rainfall amounts at gaging sites in Northeastern Illinois were calculated and compared with those of TP-40 (Hershfield 1961), NOAA-14 (NOAA 2005) and Bulletin 71 (Huff and Angel 1992). The 100-year discharges were calculated and compared with those certified by FEMA as of 2004 (FEMA 1980, FEMA 1986, FEMA 2000a, FEMA 2000b, FEMA 2002, FEMA 2005) and USGS studies (Curtis 1987, Soong et al. 2004). This method could also serve as a planning tool to include various future scenarios. The modeling approach is presented in Figure 1.

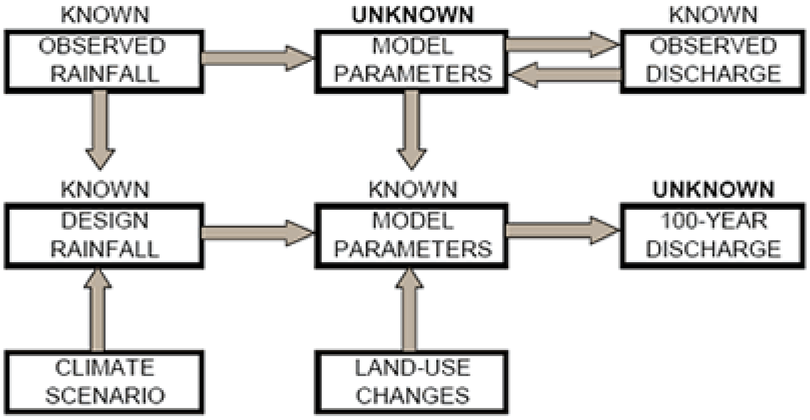

Figure 1. Schematic of the modeling approach

Twelve watersheds in the Northeastern Illinois (Figure 2) were selected for rainfall-runoff modeling for two major flood events, one in 1954, and the other in 1996. The observed rainfall-runoff events (Figure 1, top row) were used to calibrate parameters of the HEC-HMS model for both floods. This resulted in a set of model parameters describing the rainfall-runoff relationships at two different stages of development in the watersheds. In particular, the data of 1954 described the basin development during the early stage of the urbanization, and the data of 1996 describes the rainfall-runoff relationship during the advanced stage of urbanization in most of the 12 studied watersheds. The known parameters were then used along with the design precipitation (Huff and Angel 1992, Hosking and Wallis 1997) to calculate design runoff (Figure 1, middle row).

Calibrating one “historical” and one “contemporary” model of the watershed facilitated extrapolation to the hypothetical future conditions by testing various urbanization and rainfall scenarios (Figure 1, bottom row).

Statistical analysis indicated that 10 out of 12 watersheds exhibited positive trend in annual flood peaks with significance level of 90%. The remaining two watersheds had no trend. The parameters of the hydrologic rainfall-runoff model changed between 1954 and 1996. The results presented in Figure 3a suggest that the curve number increased, and that the time of concentration and storage coefficient decreased. The values of the initial loss for the floods of 1954 and 1996 do not differ significantly.

The relative contribution of the land-use and precipitation changes to the increases in flood peaks is presented in Figure 3b. The results suggest that the land-use changes contributed to the increasing flood peaks more than the rainfall increase.

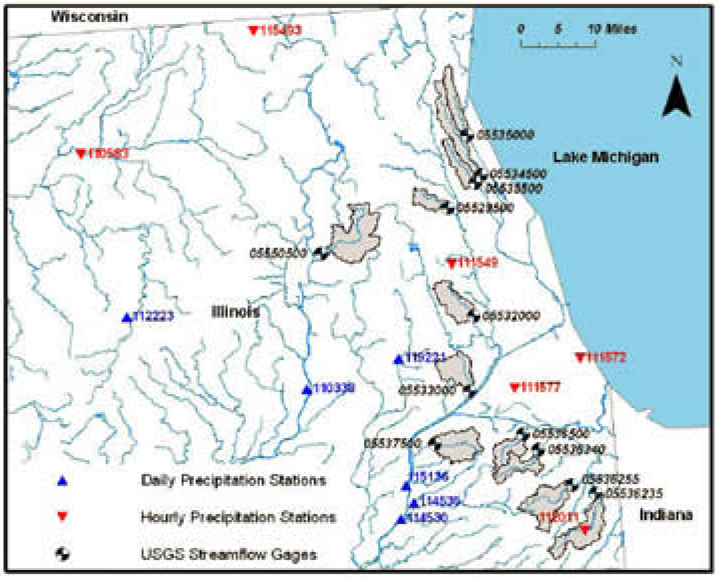

Figure 2. Streamgages, basins and precipitation stations used in rainfall-runoff modeling

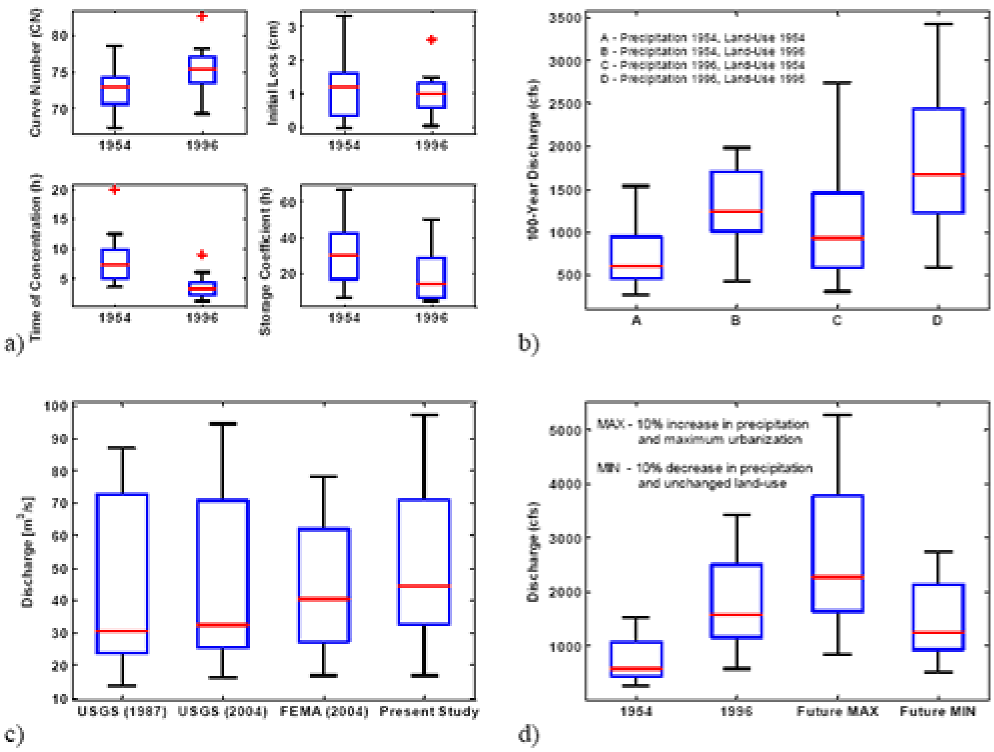

Figure 3. Results: a) Changes in the HEC-HMS parameters, b) Individual contribution of the increased precipitation and urbanization c) Comparison with other studies, and d) Sensitivity of future scenarios to the changes in precipitation and urbanization. Note: each box-and-whisker plot is based on all 12 watersheds in the study.

A comparison between various previous results is presented in Figure 3c. The most notable differences between this study and the previous USGS studies (Curtis 1987, Soong et al. 2004) as well as FEMA certified discharges in 2004 (FEMA 1980, FEMA 1986, FEMA 2000a, FEMA 2000b, FEMA 2002, FEMA 2005) are the difference in the median and the difference in the lower quartile. On the average the flood peaks in this study are 13.5% higher than those of FEMA, and 12.9% larger than those published by the USGS in 2004

(Soong et al. 2004). It was also found that the precipitation values calculated in this study are slightly higher than those of Bulletin 71 (Huff and Angel, 1902), within one percent of those given by NOAA-14, and on the average 15.5% larger than the corresponding precipitation values given in TP-40 (Hershfield 1961).

This methodology could also be used as a planning tool to evaluate various future urbanization and precipitation scenarios. Two scenarios (Fig. 3d) illustrate how the method could be used in water resources planning. The Future MAX scenario includes maximum urbanization and a 10% increase in design rainfall. The Future MIN scenario has no change in urbanization, and a 10% decrease in design rainfall.

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Potential Appplications or Benefits

The study indicates that the rainfall and runoff processes are non-stationary, and that the design precipitation and design discharge could significantly change within a couple decades or less. Based on this variability it is recommended that the design rainfall and flood peaks are periodically recalculated. The results also indicate that frequently, the regulatory discharges (often based on the old data and/or models), are underestimated. Those results need to be updated by including new datasets, and the appropriate techniques. The approach and the method developed in this study could be used as a basis in flood study prioritization through a comparison of published regulatory discharges with current flood discharges.

Keywords
precipation, floods, rainfall-runoff, flood frequency, L-moments, HEC-HMS modelj

Lay Summary
The research detected an increasing trend in flood peaks in small streams in the Northeastern Illinois, in the last several decades. The trend was explained by increasing precipitation and urbanization in the watersheds. Both contributing factors were found significant for the increasing peaks. However, on the average, the urbanization contributed more than the increase in precipitation. It was also found that currently certified regulatory discharges are underestimated in some cases. This study could be used in prioritizing future studies. This model could also serve as a planning tool as it has a capability to include various future urbanization and precipitation scenarios.

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Back to Research Project List (../../research_landuseplan.php)

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