An Uncertainty Based Framework for Quantifying the Effects of Climate Change on Extreme Event Flooding in the United States

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FEMA Study Background

- Analyze impact of climate change on the National Flood Insurance Program
  - Recommended by the GAO
  - Rely on recent published findings (IPCC, CCSP, etc.)
  - Work will be reviewed by an expert panel
  - Objectives:
    - Location and extent of U.S. floodplains
    - Relationship between BFEs and insured properties
    - Economic structure of the NFIP
- This presentation represents preliminary work and is for illustrative purposes only – anticipated completion date: March 2010
- This work will not be used by FEMA to revise flood maps – it is purely for long term anticipation of effects on the NFIP
- This is not a study of Howard County or of Maryland specifically – only an illustration of the methodology
Outline

• Introduction
  – Climate Modeling and Extreme Climate Indicators

• Methodology
  – Regression Analysis
  – Observed and Projections
  – Monte Carlo Sampling for Uncertainty

• Results
  – Projections of Change
  – Impacts on Flooding

• Conclusions and Further Work
Climate Change

- Many climate models comprise the results in this report
- In General:
  - Temperature is increasing and will continue to increase
    ➢ How much is the question…
  - Precipitation patterns are becoming more intense and this trend will very likely continue
Climate Indicators

• Extreme Climate Indicators:
  – Focus on extremes in climate
  – Can these provide us with information on how extreme event flooding may change?

• Examples: (these are the important ones)
  – FD – Number of frost days per year
  – CDD – Maximum number of consecutive dry days per year
  – R5D – Maximum 5 day rainfall during a given year
  – There are numerous other temperature and precipitation related indices
Extreme Climate Indicators

• Observations:
  – *Alexander et al. (2006)* used extreme climate indicators to examine trends in climate from 1951-2003
  – 2223 Temperature gages
  – 5948 Precipitation gages
  – Developed gridded global data set

• Projections:
  – *Tebaldi et al. (2006)* reported on climate model projections of extreme climate indicators
  – A suite of IPCC AR4 model runs provide extreme indices projections
    – 43 runs from 10 models across 3 scenarios
  – We identified 8 modeled indices that were analogous to the observed indices
  – 3 of the indices are important in this work
Methodology

1. Perform regression analysis to relate observed extreme indices to observed 1% chance flood
   - Get data to do this from existing gages

2. Use this relationship to project changes to the 1% chance flood using projections of extreme indices
   - Use Monte Carlo sampling to quantify uncertainty

3. Apply these projections to hydraulic modeling studies
   - Accounting for uncertainty
   - Determine new top widths, W.S. elevations, etc.
Regression Analysis

- Determine $Q_{1\%}$ as a function of a variety of other watershed and climate characteristics

- **Outcome variable:**
  - $Q_{1\%}$ - 100-yr, 1% chance discharge

- **Predictor variables:**
  - DA - Drainage area
  - SL - Average slope
  - ST - Storage
  - IA - Impervious area (related to population)
  - Extreme Indices: FD, CDD, and R5D
• Identified 2,370 Urban and Rural Stations – from published USGS reports
• This data provided DA, SL, ST, IA, and Existing Q$_{1\%}$
Extreme Indices at Gages

Average Maximum 5 Day Rainfall Per Year from 1951-2003

- Extreme indices at gages were estimated using inverse distance weighting of the observed gridded extreme indices data set
Maryland Regression Equations

• Developed equations for whole U.S. then adjusted for regional bias in Maryland:

\[ Q_{1\%} : (\text{in } \log_{10} \text{ form}): \]

\[ Q_{1\%} = 0.29227 + 0.711 \ (DA) + 0.169 \ (SL) - 0.329 \ (ST+1) + 0.180 \ (IA+1) \]
\[ - 0.205 \ (FD+1) - 0.176 \ (CDD+1) + 1.444 \ (R5D+1) \]

– Standard Error: 0.1725 log units or 41.3%
– \( R^2 = 0.764 \)

Note: This and other findings presented here are provisional and are shown for illustrative purposes only.
Projecting Change

• What will likely change?
• Impervious area due to changes in population density
  – Population projections related back to impervious area
  – Population projections consistent with IPCC report
• Extreme indices due to climate change
  – Suite of climate model projections
Population Projections

- **Bengtsson et al. (2006)** – A *SRES-based gridded population dataset for 1990-2100*
- Assumes a uniform rate of change spatially for the whole U.S.
Impervious Area (Related to Population)

- Population projections available
  - Need to be able to relate these back to impervious area

- Used the Hicks curve (blue) since it is based on a wide range of data

1. Determine population based on gage IA
2. Project population to some point in time
3. Determine IA projection from curve

From Bird et al. (2006) – Estimating Imperious Cover from Regionally Available Data
Climate Projections

- Multiple models and multiple runs provide different pictures of change...
- Model extreme indices outputs re-gridded and 20-yr means calculated
- 20-yr Means for 5 Epochs:
  - 2000-2019
  - 2020-2039
  - 2040-2059
  - 2060-2079
  - 2080-2099
Extreme Indices Projections - Changes

- Multiple-model mean projected changes in:

  FD – Number of frost days per year

  over modeled existing conditions
Extreme Indices Projections - Changes

• Multiple-model mean projected changes in:

R5D – Maximum 5 day rainfall per year (mm)

over modeled existing conditions
Monte Carlo Analysis Procedure

Generate $Q_{1\%}$ distribution for each gage in each epoch

Create $N$ input vectors and run them through the regression:

- Vector 1: DA, SL, IA, FD, CDD, R5D
- Vector 2: DA, SL, IA, FD, CDD, R5D
- Vector N: DA, SL, IA, FD, CDD, R5D

- Regression Equation
- Regression Equation

Pr($Q_{1\%}$)

$Q_{1\%}$

Observed Flow (from gage) Mean Projected Flow

- Determined from Population Projections
- Sample from Grab Bag of Model Runs
- Normally distributed standard error noise

- Uncertainty accounted for by sampling from:
  - Multiple models, runs, and scenarios
  - Standard error from the regression equation
Monte Carlo Analysis Procedure

1. Determine the Q resulting from modeled existing conditions
2. Determine the projected Q for an epoch
3. Apply this modeled change in Q as a relative change in the existing observed Q

• This helps correct for model bias

Ultimately, we would like to say:

We estimate that $Q_{1\%}$ will change an average of $n\%$ from its present value over the next century.
Results: Projected Changes

Based on 1-million Monte Carlo simulations at each of the 65 gages in Maryland

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Distribution of Projected Changes

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Analysis for Howard County Maryland

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Projecting Flooding

Existing 1% (100-yr) Water Surface → New 1% (100-yr) Water Surface
Changes in Top Width for Howard County

Projected Top Width Distributions - 2080-2099

Smaller Streams

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Changes in Top Width for Howard County

Projected Top Width Distributions - 2080-2099
Medium Streams

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Summary

• We used a set of 2,370 gages throughout the U.S. to relate watershed characteristics and extreme climate indices to the existing $Q_{1\%}$

• Using a suite of models, runs, and scenarios, we estimated the large uncertainty in climate and population projections and related this to projections of flooding

• Initial results suggest that future $Q_{1\%}$ flooding will become more severe throughout the next century
Future Directions

• More work must be done to further refine this approach

• Scale of study:
  – Although I showed illustrations for Maryland specifically, the scope of the overall study is such that it does not allow for this detailed scale of analysis
  – Future regional studies should focus on regional scale modeling and downscaling techniques

• Improved prediction accuracy of climate models and population models

• Methodologies must be developed within flexible frameworks to allow for the incorporation of new data, predictions, and modeling techniques
Questions - Thank You!

Additional Questions?
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