Results of Intensity-Duration-Frequency Analysis for Precipitation and Runoff under Changing Climate

Supporting Casco Bay Region Climate Change Adaptation RRAP

Eugene Yan, Alissa Jared, Julia Pierce, Vinod Mahat, Duane Verner, and Thomas Wall
Argonne National Laboratory
Edom Moges and Yonas Demissie
Washington State University

November 30, 2016  Portland, ME
Rainfall Intensity-Duration-Frequency Analysis

IDF curves provide a graphic representation of the likelihood that a rainfall event of a given intensity over a given duration will occur; this information is widely used for developing the design basis for precipitation-affected infrastructure systems, engineering standards, building codes, and maintenance standards.

- Urban drainage system (storm water system, sewer system) designed for 10-yr rainfall event
- Road design: Maine Department of Transportation (DOT) specifies designing for the 50-year storm event for culverts and 10-year event for pavement drainage
- Hydraulic structures along the rivers (bridges, dams, etc)
- Climate change may cause shift in intensity of storms → 50-year storm may become more intense in future
- Projected rainfall and runoff IDF curves will enable designs today to remain robust in the future

Key Findings from This Study

- Greater increase in intensity in the less frequent but severe storm events

- The mean intensity of 85 gauge stations
  - 10% increase (10-year storm event)
  - 19% increase (50-year storm event)
  - 25% increase (100-year storm event)
  - The maximum increase among 85 gauges is 56% for 100-year storm event

- Higher intensity identified in the updated IDF at higher elevation areas and coastal areas

- The peak streamflow for the main drainage area in the Casco Bay Watershed increases by 27% for 10-year storm event, 55% for 50-year storm event, and 68% for 100-year storm event
Data Package Provided from This Study

1. Gridded precipitation IDF$s$ considering bias-corrected future climate projections and snowmelt

2. At-station and gridded precipitation IDF$s$ considering snowmelt effects using historical data only

3. Graphic plots for IDF$s$ at all gauge stations

4. Precipitation IDF for the major cities in the study area

5. Maps for the selected gridded IDF$s$

6. Runoff IDF$s$ at 11 subbasins in Casco Bay Watershed
**Need to Update IDF Curve Development**

- **Change in extreme events**
  - The most extreme precipitation events (or heaviest 1% of all daily events) have increased in every region of the contiguous states since the 1950s.
  - Rain gauge stations with longer records show increasing trend in precipitation.
  - Climate change projections suggest increased likelihood of extreme precipitation events.

- **IDF development needs to consider the future climate change.**

---

*Source: National Climate Assessment Report, 2014*
Rain-on-snow events have the potential to generate devastating floods
- Flooding in East Coast in Jan 13, 2016 was caused by heavy rain, snow and snowmelt
- Willamette Valley Flood of 1996 was the Oregon’s largest flood event in terms of fatalities and monetary damage, and it was caused by the combination of the rain on snowmelt event (USACE, 1996)

- Does snowmelt affect IDF in Maine?
- How to incorporate snowmelt effects into IDF development?
Need to Update IDF Curve Development (Cont’d)

- Precipitation frequency is not necessarily similar to flood frequency
  - Effect of drainage characteristics of the watershed, including human roles
- Local stream monitoring were scaled down or terminated because of lack of funding

Observed change in heavy precipitation from 1958 to 2012

Source: National Climate Assessment Report, 2014
Casco Bay Region

- Casco Bay watershed
  - City of Portland located downstream of the watershed
  - Recent flooding in 2007, 2014, and 2015 impacted by both stream flow and costal storm

- Data sources:
  - Historical precipitation records from daily and hourly rain gauges from the NOAA network
  - Future precipitation projections (shown as grids) extracted from regional climate modeling results by Argonne using WRF (1975-2004; 2035-2065)
Framework of IDF Development

- Major IDF computation components
  - Bias corrections for dynamically downscaled future climate projections
  - Snowmelt modeling to estimate rain-on-snow effects using Utah Energy Balance snowmelt model
  - Precipitation IDF development: (a) a Bayesian approach to incorporate multiple distribution models, estimate distribution parameters and quantify uncertainty; and (b) evaluate distribution model performance with 3 measurement criteria
  - Hydrologic modeling to compute runoff IDF
Procedure for IDF Development

**Step 1 Pre-process data**

**Step 2 Calculate snow pack and melting**
Energy Balance Snowmelt Model

- State Variables
  - Energy Content $U_s$
  - Water Equivalent $W_s$

**Step 3 Screen distribution models**

- L-moment parameters:
  - $L$ – mean
  - $L$ – coefficient of variance
  - $L$ – skewness
  - $L$ – kurtosis

**Step 4 Determine model parameters and combine models**

- Top 3 Distribution Models
- Parameter Uncertainty
- Merge Frequency Distributions (BMA)

- Added Steps 2 and 4
Procedure for IDF Development (Cont’d)

**Step 5 Evaluate model performance**
- Taylor Diagram
- Anderson-Darling
- Bootstrap

**Step 6 Interpolate IDF**
- Interpolation
- Gridded IDF

**Step 7 Incorporate future projections using non-stationary frequency distribution models**
- Observed 1965-2004
- Future Run 2035-2064

**Step 8 Runoff IDF**

- Added Steps 5, 7 and 8
Results of IDF Analysis at Gauge Stations

Comparison of IDFs with existing NOAA IDFs

- Greater increase in intensity in the less frequent, but severe storm events
- The mean intensity of 85 gauge stations
  - 10% increase (10-year storm event)
  - 19% increase (50-year storm event)
  - 25% increase (100-year storm event)
- Maximum increase by 56% for a 100-year storm event
Results of Gridded IDF for the Study Area

- Higher precipitation intensity in the southern part of the study region for extreme events (50- and 100-year events)
- The updated IDF has higher intensity at higher elevation areas and coastal areas
- Significant increase in intensity under extreme events

1 day duration

units=inches
Streamflow from the outlet of Presumpscot River near the City of Portland contributed from a drainage of >600 mi²

The peak streamflow is 27%, 55%, and 68% higher than the FEMA results for 10-year, 50-year, 100-year storm events, respectively.

The upper and lower bounds of peak streamflow define the uncertainty from (1) precipitation uncertainty and (2) the antecedent moisture condition uncertainty.
Major Improvements in IDF Development

- Incorporated bias-corrected future climate projections into IDF development

- Included snowmelt effects with dynamic energy balance snowmelt model

- Applied Bayesian approach for incorporation of multiple distribution models and estimation of model parameters and their uncertainties

- Applied non-stationary distribution models to capture the increasing trend in precipitation over 90 years

- Evaluated distribution model performance with 3 measurement criteria

- Developed runoff IDFś with hydrologic model for the Casco Bay Watershed (The study area suffered a loss in streamflow monitoring gauges in 1990s and 2000s)