Exploration of Probabilistic Modeling

ASPFM 2018
Phoenix, AZ
Defining the Need

- No consideration of uncertainty
- More than 25% of NFIP claims are for structures outside the SFHA (about 60% of losses)
- Need structure-level risk assessment
- Graduated risk within 0.2% floodplain
- Risk behind levees and ultimately performance based levee analysis
- Future conditions
- Risk-informed decision making process
- Residual and Pluvial risk
- Total flood risk (fluvial + pluvial)
Existing Approach (Hydrology)

- Collect Gage Data
- Flood Frequency Analysis
Existing Approach (Hydraulics)

1D or 2D Hydraulic Modeling
Probabilistic Approach

Hydraulics

Loss Calculations

Hydrology
Probabilistic Approach

- Individual model results plotted out to produce various curves
Rather than selecting the 5 typical discharges along the median line, discharges are randomly sampled between the 5% and 95% confidence limits for a large number of probabilities, from the 50% (2-yr) to the 0.05% (2000-yr) or beyond annual-chance probability.

- Wider and more comprehensive range of flood scenarios analyzed.
Probabilistic Approach (Hydraulics)

- 2D model scenarios are run in a batch, automated process
Hydraulics

- Uncertainty in Manning’s n-values are factored into models
- Hundreds of scenarios run through 2D hydraulic models

<table>
<thead>
<tr>
<th>NLCD Classification</th>
<th>Manning’s Roughness</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Minimum</td>
<td>Normal</td>
</tr>
<tr>
<td>Open Water</td>
<td>0.025</td>
<td>0.03</td>
</tr>
<tr>
<td>Developed, Open Space</td>
<td>0.01</td>
<td>0.013</td>
</tr>
<tr>
<td>Developed, Low Intensity</td>
<td>0.038</td>
<td>0.05</td>
</tr>
<tr>
<td>Developed, Medium Intensity</td>
<td>0.056</td>
<td>0.075</td>
</tr>
<tr>
<td>Developed, High Intensity</td>
<td>0.075</td>
<td>0.1</td>
</tr>
<tr>
<td>Barren Land</td>
<td>0.025</td>
<td>0.03</td>
</tr>
<tr>
<td>Deciduous Forest</td>
<td>0.1</td>
<td>0.12</td>
</tr>
<tr>
<td>Evergreen Forest</td>
<td>0.1</td>
<td>0.12</td>
</tr>
<tr>
<td>Mixed Forest</td>
<td>0.1</td>
<td>0.12</td>
</tr>
<tr>
<td>Scrub/Shrub</td>
<td>0.035</td>
<td>0.05</td>
</tr>
<tr>
<td>Grassland Herbaceous</td>
<td>0.025</td>
<td>0.03</td>
</tr>
<tr>
<td>Pasture/Hay</td>
<td>0.03</td>
<td>0.04</td>
</tr>
<tr>
<td>Cultivated Crops</td>
<td>0.025</td>
<td>0.035</td>
</tr>
<tr>
<td>Woody Wetlands</td>
<td>0.08</td>
<td>0.1</td>
</tr>
<tr>
<td>Emergent Herbaceous Wetland</td>
<td>0.075</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Calenda, et al. 2005
Chow 1959
Using the results and probabilities from each model run, a probability grid is generated.
Annual Exceedance Probability Grid vs. 1-Percent-Annual-Chance Line (Deterministic)

- Probabilistic Approach: uncertainties considered, wide range of possible flood scenarios, credible risk gradation
- Deterministic (Current) Approach = No uncertainties, focused on 1%-annual chance flood, no risk gradation

Effective SFHA Boundary

<table>
<thead>
<tr>
<th>Annual Exceedance Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.1% (&gt;1000-yr)</td>
</tr>
<tr>
<td>0.1 - 0.2% (1000-yr)</td>
</tr>
<tr>
<td>0.2 - 1% (500-yr)</td>
</tr>
<tr>
<td>1 - 2% (100-yr)</td>
</tr>
<tr>
<td>2 - 4% (50-yr)</td>
</tr>
<tr>
<td>4 - 10% (25-yr)</td>
</tr>
<tr>
<td>10 - 50% (10-yr)</td>
</tr>
<tr>
<td>&gt;50% (&lt;2-yr)</td>
</tr>
</tbody>
</table>
Structure-Level Risk

- Detailed Flood Elevation-Probability Curves can be extracted for any structure of interest based on the underlying model results.
Structure-Level Risk

- Flood Damage Curves can be generated, taking into account uncertainties in structure occupancy and first floor elevations (FFE)
Structure-Level Risk

- Average Annualized Losses (AAL) much more accurate – little to no extrapolation required, unlike with typical studies.
Structure-Level Risk

- “Neighborhood” Damage Curves aggregated from structure data can provide insight into expected damages for multiple properties
Risk Behind Levees

- Probabilistic approach can consider accredited, breaching, and natural valley levee scenarios (each with associated probabilities)

**Natural Valley**

**Accredited (w/ Levee)**

**AAL: $1,420**

**AAL: $24**
Pluvial Flooding

- Runoff (excess rainfall that is not absorbed into the ground through infiltration)
- Major contributor to the residual risk in leveed areas
- Not captured in interior drainage analysis
- Currently not mapped on FIRMs or any of the existing flood products
- Catastrophic models used by private insurance companies capture this hazard
- Could be the reason structures outside the SFHA are flooded
- Could be the reason for repetitive and significant repetitive loss
- Major contributing element in urban flooding
Probabilistic Approach (Pluvial Hydrology)

- Precipitation values sampled between the 5% and 95% confidence limits for probabilities from the 50% (2-yr) to the 0.05% (2000-yr) or beyond
- 16 different unique storm duration (6-, 12-, 24-, and 96-hr) vs. temporal distribution (1st, 2nd, 3rd, or 4th quartile) scenarios are analyzed
- Curve Number variation is considered and randomly selected in between +/- one standard deviation
- HEC-HMS generated hyetographs that were then used in HEC-RAS to map the excess rainfall on the grid

From NOAA Atlas 14 Precipitation Frequency Data Server
Probabilistic Approach (Levees)

- USACE fragility curves (system response curves) can be incorporated in the mapping analysis
- Multiple frequencies from 2- to 3000-yr floods modeled, taking into account uncertainties in discharge and land use roughness (Manning’s n-values)
- Non-Breaching scenario – levees remain intact and are not allowed to breach before overtopping
- Breaching scenarios:
  - Probability of breaching defined by USACE system response (fragility) curves when available

<table>
<thead>
<tr>
<th>River Elevation (NAVD 88)</th>
<th>System Response Probability (BL2a) w/ Intervention</th>
<th>System Response Probability (BL2a) w/o Intervention</th>
</tr>
</thead>
<tbody>
<tr>
<td>415.00</td>
<td>0.00000377%</td>
<td>0.00000419%</td>
</tr>
<tr>
<td>421.25</td>
<td>0.00003466%</td>
<td>0.0000230%</td>
</tr>
<tr>
<td>427.50</td>
<td>0.108%</td>
<td>0.553%</td>
</tr>
<tr>
<td>432.90</td>
<td>1.50%</td>
<td>7.05%</td>
</tr>
<tr>
<td>440.00</td>
<td>8.32%</td>
<td>37.0%</td>
</tr>
</tbody>
</table>
Example Fragility Curves at Different Breach Locations

River Levee

- BL-2a
- BL-2b
- BL-2c
- BL-3a
- BL-3b
- BL-4
Depth-Damage Functions used in Risk Assessments

- Composite Depth-Damage curves for each structure type were used based on available curves from Hazus
Fluvial (Riverine) Results: Aggregate

- # Structures with Damage: 35,197 of 35,236 (99.9%)
- Avg. Annualized Loss (AAL): $4,848,716
Fluvial (Riverine) Results: Structure Level

Annual Chance of Flooding

Parcel Elevation Curve
Parcel No: Mad_Cat1N2_934608795
Land Use Type: Cat1N2

Parcel Elevation Curve
Parcel No: StC_Cat1B3_941010455
Land Use Type: Cat1B3
Fluvial (Riverine) Results: Structure Level

Annual Chance of Flooding

Structure AAL: $127
Parcel Flood Damage Curve
Parcel No: Mad_Cat1N2_934608795
Land Use Type: Cat1N2

Structure Value: $91,131

Structure AAL: $235
Parcel Flood Damage Curve
Parcel No: StC_Cat1B3_941010455
Land Use Type: Cat1B3

Structure Value: $121,050
Pluvial (Rainfall) Results: Aggregate

# Structures with Damage | 21,491 of 35,236 (61%)
---|---
Avg. Annualized Loss (AAL) | $10,179,415

Annual Chance of Flooding

Aggregate Flood Damage Curve

Expected Damage ($)

Annual Exceedance Probability

Total Structure Value: $2,603,961,108

Damage Curve
Pluvial (Rainfall) Results: Structure Level

Annual Chance of Flooding

Structure AAL: $20
Parcel Flood Damage Curves
Parcel No: Mad_Cat1N2_934608795
Land Use Type: Cat1N2

Structure Value: $91,131

Structure AAL: $295
Parcel Flood Damage Curves
Parcel No: StC_Cat1B3_941010435
Land Use Type: Cat1B3

Structure Value: $121,050

Expected Damage ($) vs. Annual Exceedance Probability
Combined Fluvial & Pluvial: Aggregate

AAL (Fluvial): $4,848,716

AAL (Pluvial): $10,179,415

Total AAL: $15,028,131
Combined Fluvial & Pluvial: Structure Level

StructID: Cat1N2_934608795

<table>
<thead>
<tr>
<th>Structure ID</th>
<th>AAL (Fluvial)</th>
<th>AAL (Pluvial)</th>
<th>AAL (Total)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cat1N2_934608795</td>
<td>$127</td>
<td>$20</td>
<td>$147</td>
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</table>

StructID: Cat1B3_941010455

<table>
<thead>
<tr>
<th>Structure ID</th>
<th>AAL (Fluvial)</th>
<th>AAL (Pluvial)</th>
<th>AAL (Total)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cat1B3_941010455</td>
<td>$235</td>
<td>$295</td>
<td>$530</td>
</tr>
</tbody>
</table>
Natural Valley Results: Aggregate

# Structures with Damage | 35,175 of 35,236 (99.8%)
---|---
Avg. Annualized Loss (AAL) | $120,692,726

AAL (Natural Valley) – AAL (Fluvial/Pluvial) = $105,664,595
Natural Valley: Structure Level

Annual Chance of Flooding

Structure AAL: $2,723
Parcel No: Mad_Cat1N2_934608795
Land Use Type: Cat1N2

Structure Value: $91,131

Parcel Flood Damage Curve

Structure AAL: $3,854
Parcel No: StC_Cat1B3_941010455
Land Use Type: Cat1B3

Structure Value: $121,050

Parcel Flood Damage Curve
Hot Spot Map of AAL Loss Ratio (Combined Fluvial and Pluvial)

AAL Loss Ratio = \( \frac{AAL}{Structure\ Value} \)
Probabilistic Mapping – Benefits

- More comprehensive analysis of the flood hazard – from the 50% (2-yr) to the 0.05% (2000-yr) annual chance or greater
- More credible analysis of the flood hazard – modeled scenarios consider multiple uncertainties
- Increased confidence in the probability at which a flood would reach a structure’s first floor elevation
- More accurate flood risk and annualized loss estimates
- Improved way to look at risk behind levees
- True multi-frequency grid outputs (WSEL, depth, velocity, and depth * velocity) – applications in both pre- and post-disaster environments
Next Steps

- Additional pilots being planned
- Methodology and approach being refined based on continued lessons learned
- Development of eventual guidelines and/or best practices
- Complete a more comprehensive evaluation of level of effort (initial levee pilots show favorable results to FEMA blue book for LAMP H&H)