

The Nuts & Bolts of Probabilistic Modeling

(and why it's awesome)

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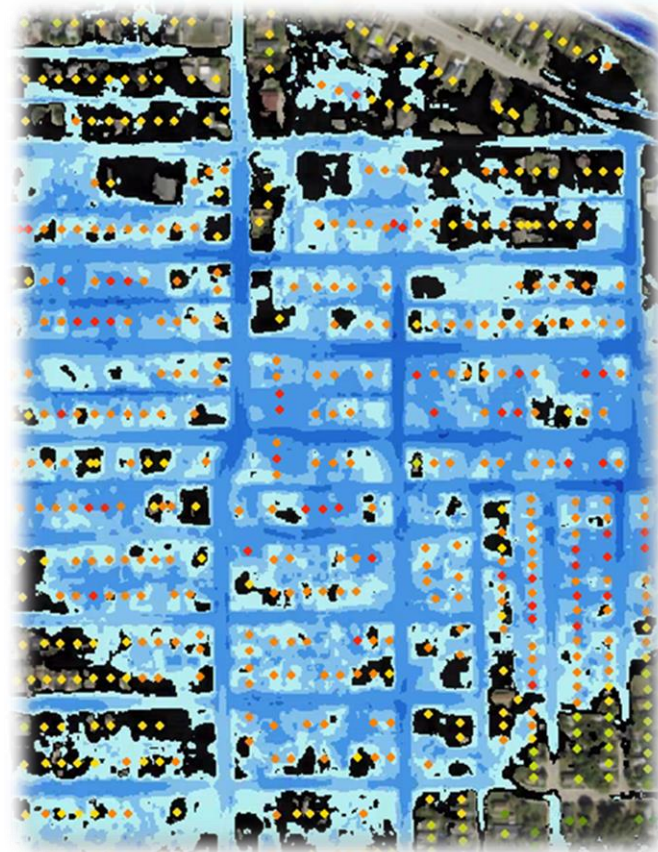
ASFPM 2019 – Cleveland, OH

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Outline

(Evidence for Awesomeness)

- ❖ Reasons for a new approach
- ❖ Few example differences
- ❖ Big picture of the overall process conceptually
- ❖ Crash course in details
- ❖ Look behind the curtain at risk assessment
- ❖ View example results
- ❖ Discuss benefits
- ❖ Share future study considerations



Reasons for a New Approach

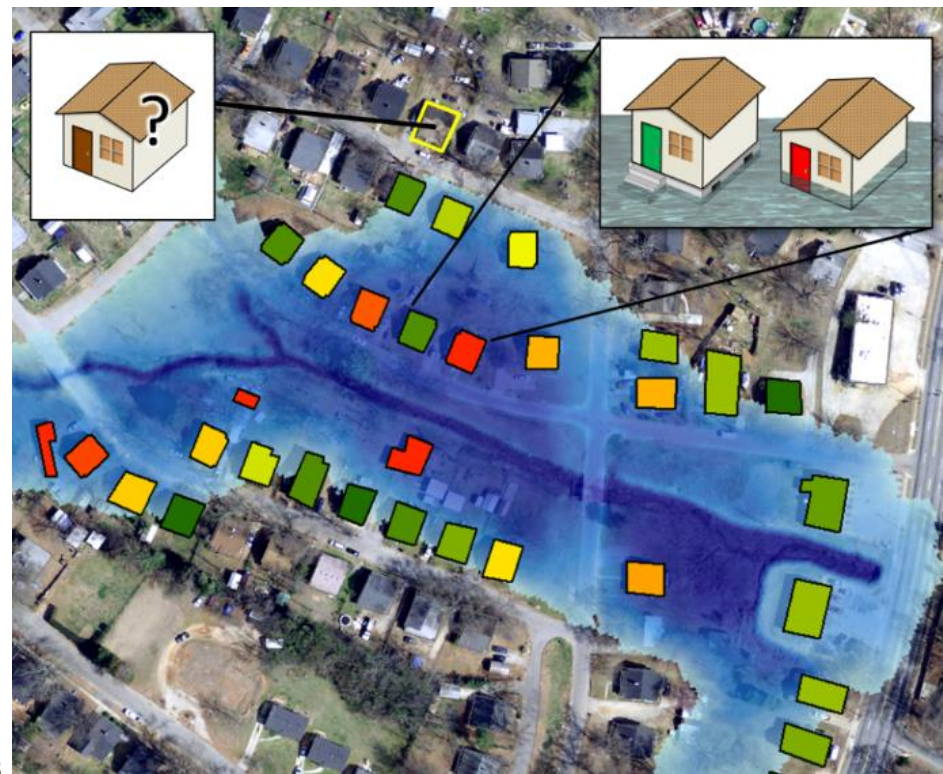
Institutional & Policy Drivers

Learning from the Past

- ▶ >25% NFIP claims are structures outside SFHA (about 60% of losses)
This moves away from SFHA zones
- ▶ Current insurance rating system doesn't reflect risk (NFIP deficit)
This reflects potential loss (frequency, value, damage)
- ▶ Technical & catastrophic modeling improvements

Core Goals (RR 2.0)

- ▶ Intuitive rating variables
policyholders understand risk
- ▶ Reflect replacement value
Link rates to damages & fixes inequities
- ▶ Communicate location-specific risk
Move away from “in-or-out” discussions



Reasons for a New Approach

Technical Advances

In Analysis

- ▶ To account for uncertainty
- ▶ Model future & varied conditions
- ▶ Information on wide range of events, (2-3000 yr)

In Data Use

- ▶ Show graduated risk within floodplain
- ▶ Include full risk profile
 - Fluvial (riverine)*
 - Residual (behind levees)*
 - Pluvial (localized rainfall)*
 - Coastal (in pilot phase)*
- ▶ Structure-specific risk information
- ▶ Gridded data for nearly any return period



Example Assessment Shift *from Zones to Graduated Risk*

- ▶ Showing annual exceedance probability (AEP) rather than zones
- ▶ Especially useful behind levees



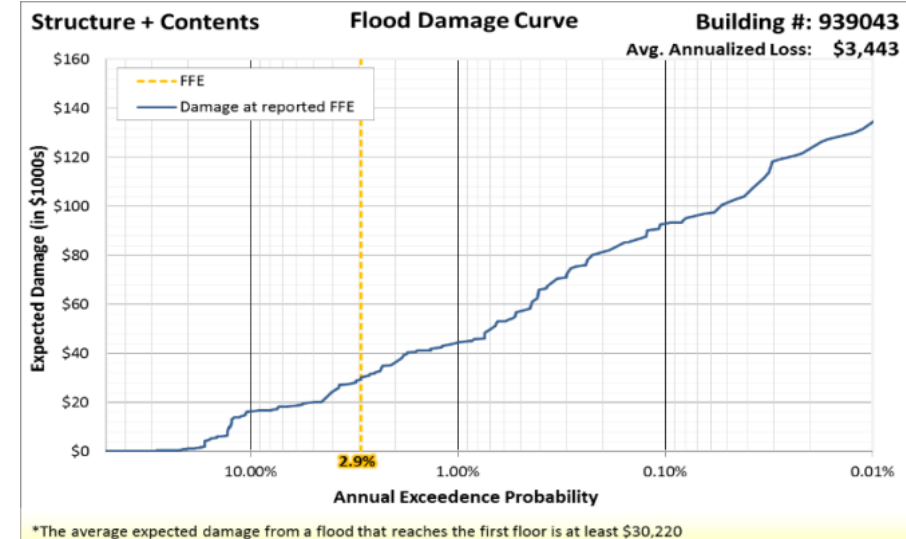
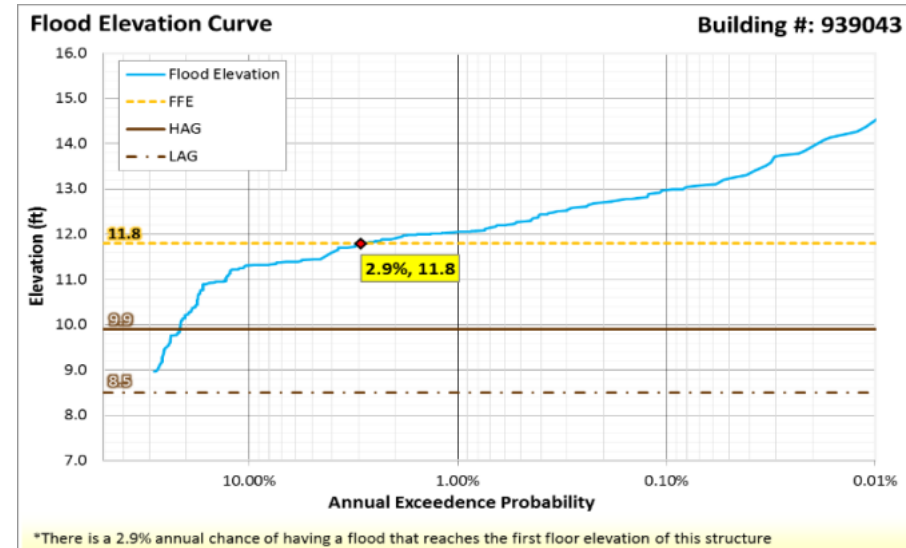
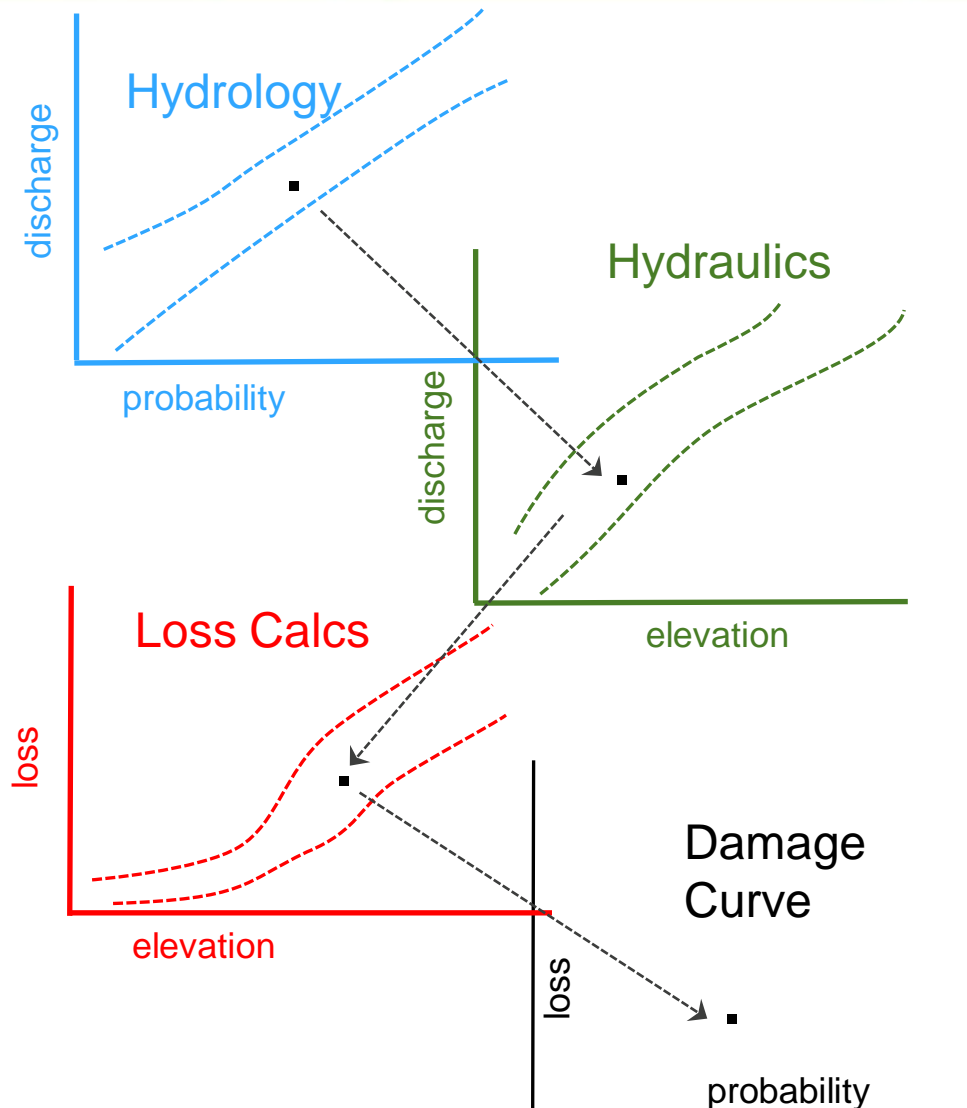
Example Risk Discretization *from Zones to Damages*

- ▶ Spatially varied insurance premiums based on AALs
- ▶ Can vary behind levees then & account for pluvial

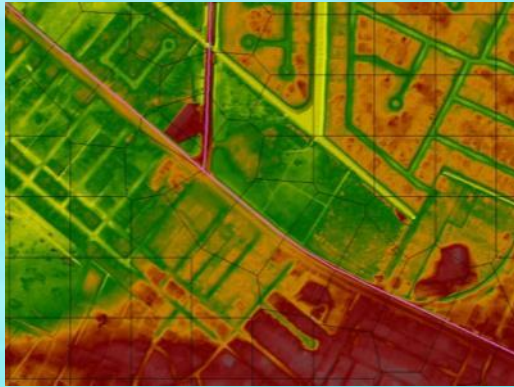
Fluv_AAL	Pluv_AAL	Lake_AAL	Total_AAL
1073.84	1366.1	25.59	2465.53
145.13	62.03	1093.38	1300.54



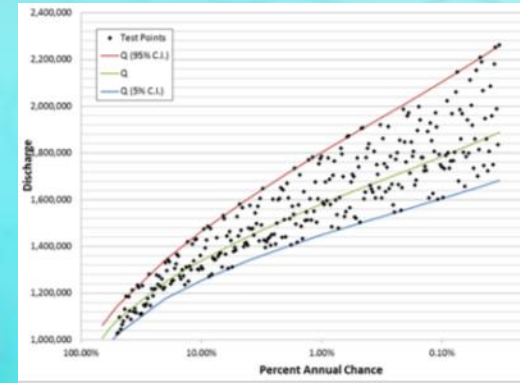
PFRA Overview *at a glance*



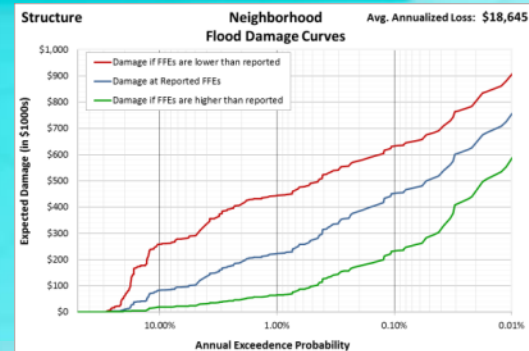
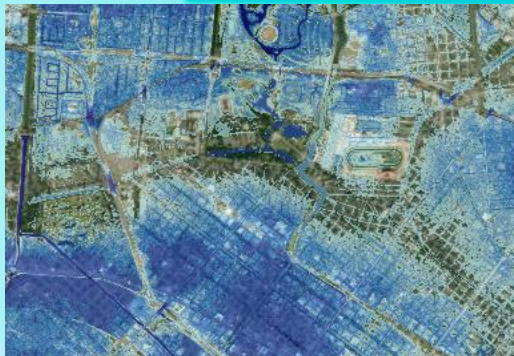
Crash Course of Probabilistic Approach



PFRA



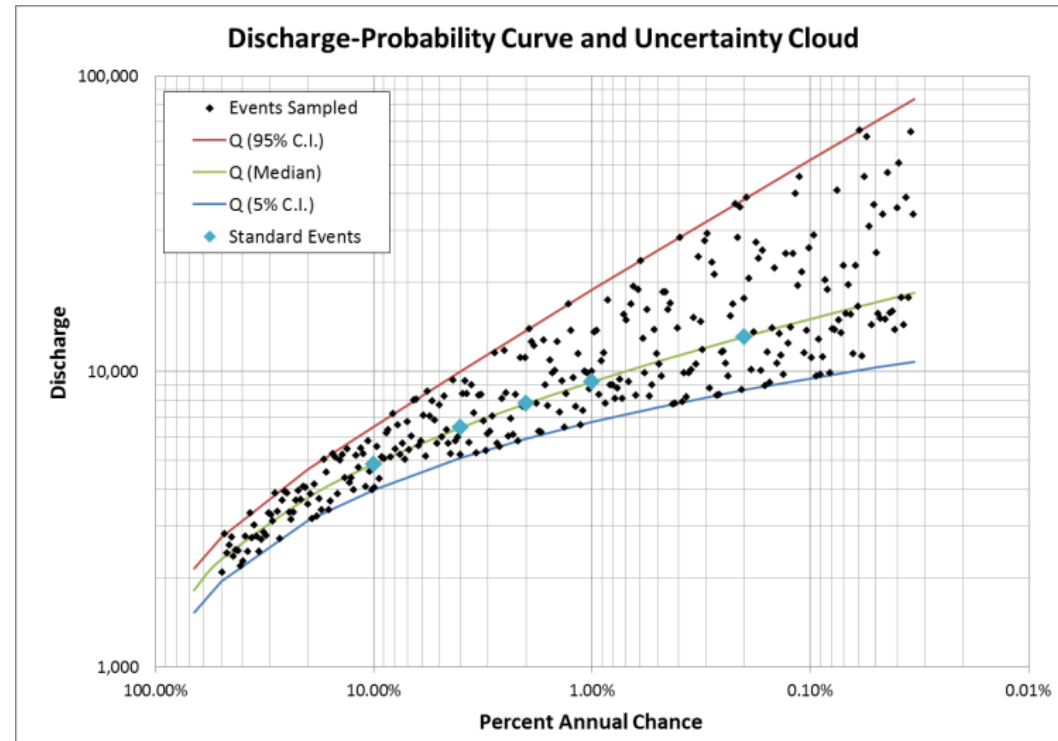
CRASH COURSE



Crash Course of Probabilistic Approach

Sampling Methodology

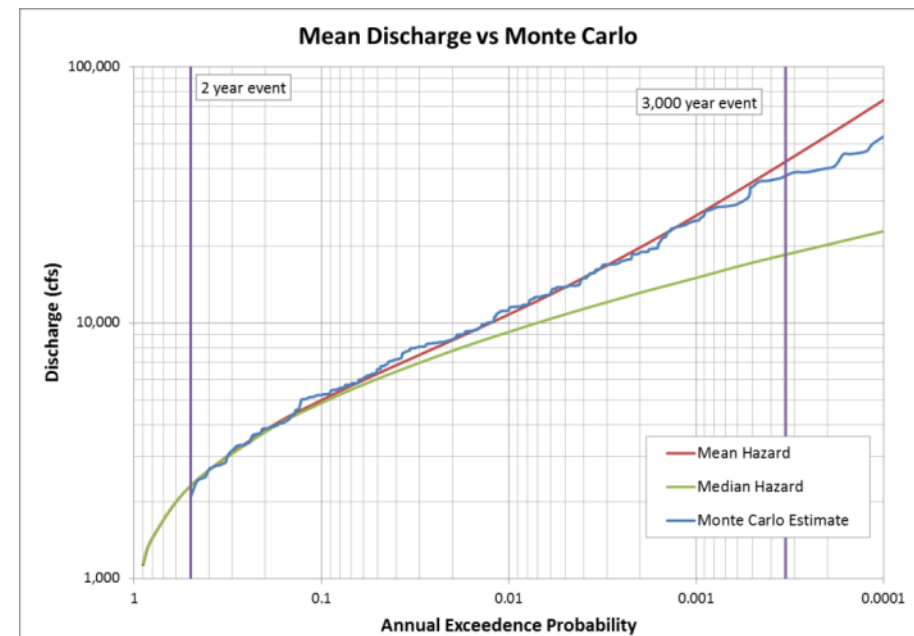
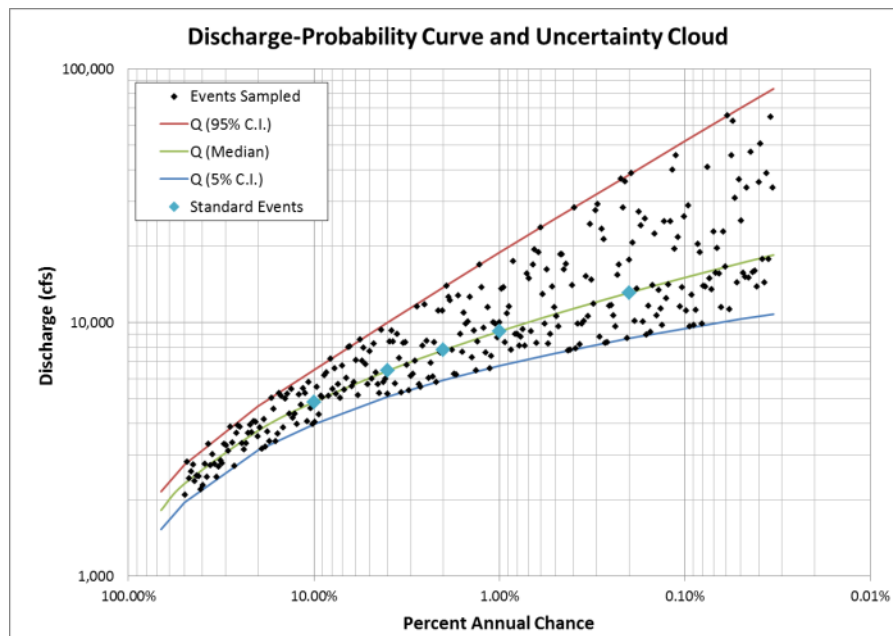
- ▶ **Traditional flood risk analysis samples only a few points along the median discharge curve – 10, 4, 2, 1, 0.2% annual chance events**
- ▶ **Higher resolution?**
- ▶ **Higher return periods?**
- ▶ **This approach can also capture the uncertainty inherent in a hydrologic analysis**



Crash Course of Probabilistic Approach

Fluvial Hydrology

- ▶ As the number of modeled events increases, the Monte Carlo discharge curve converges with the Mean Discharge Curve
- ▶ Using the mean discharge curve can increase consistency and reproducibility
- ▶ Model 100 events between the 2- and 3000-year flood events
 - Vary flood durations & hydrographs based on return period



Crash Course of Probabilistic Approach

Pluvial Flooding

- ▶ Major contributing element in urban flooding
- ▶ Major contributor to the residual risk in leveed areas
- ▶ Currently not mapped on FIRMs or any of the existing flood products
- ▶ Catastrophic models used by private insurance companies capture pluvial hazard
- ▶ One reason structures outside the SFHA are flooded
- ▶ One cause of repetitive and significant repetitive loss
- ▶ Evaluates runoff – applied as excess precip to 2D area



Crash Course of Probabilistic Approach *Pluvial Hydrology*

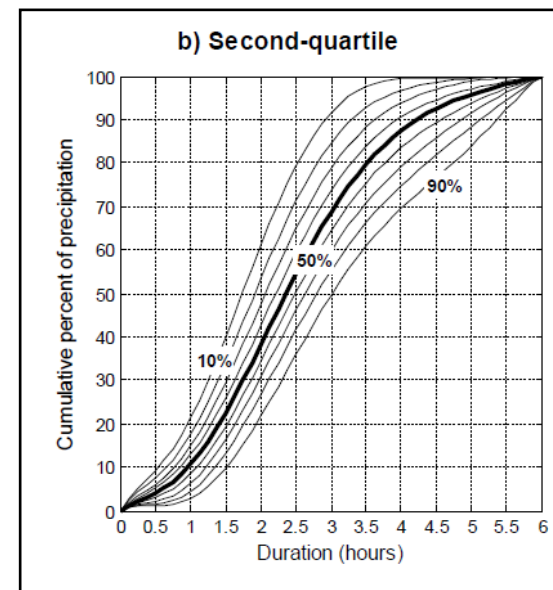
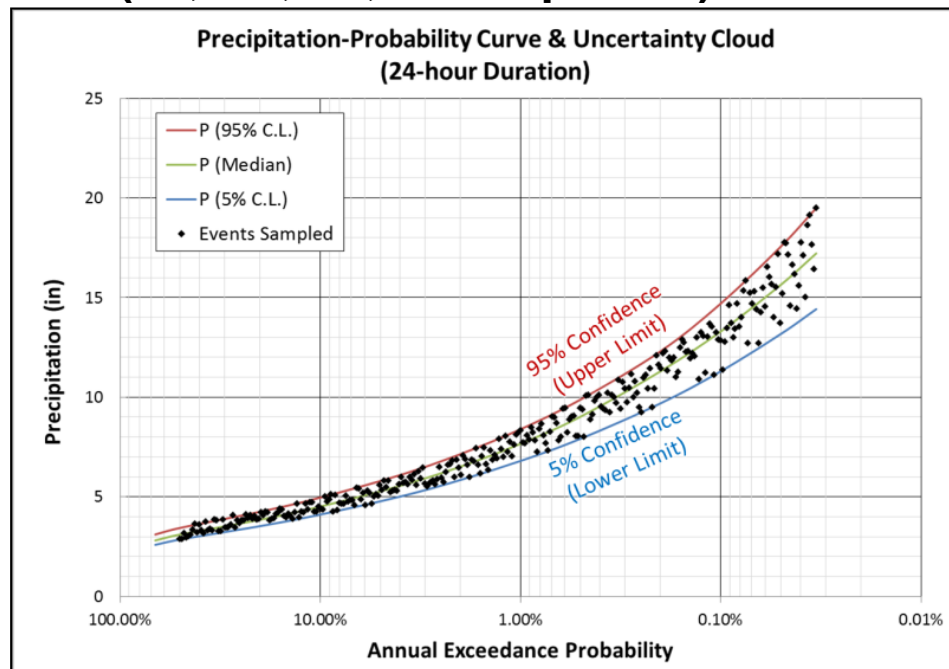
- Precipitation values sampled between the 5% and 95% confidence limits for probabilities from the 50% (2-yr) to the 0.033% (3000-yr) or beyond
- Thousands of depths for 16 different unique storm duration (6-, 12-, 24-, and 96-hr) vs. temporal distribution (1st, 2nd, 3rd, or 4th quartile) scenarios

PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)¹

Duration	1	2	5	10	25	50	100	200	500	1000
6-min	0.388 (0.362-0.421)	0.472 (0.431-0.515)	0.562 (0.511-0.617)	0.633 (0.575-0.688)	0.726 (0.657-0.785)	0.800 (0.722-0.877)	0.876 (0.785-0.968)	0.957 (0.855-1.05)	1.07 (0.951-1.17)	1.16 (1.02-1.27)
15-min	0.616 (0.565-0.676)	0.737 (0.672-0.805)	0.873 (0.795-0.958)	0.977 (0.888-1.07)	1.11 (1.00-1.22)	1.24 (1.10-1.37)	1.32 (1.16-1.48)	1.43 (1.25-1.61)	1.57 (1.40-1.72)	1.68 (1.49-1.85)
30-min	0.758 (0.692-0.825)	0.901 (0.822-0.980)	1.07 (0.979-1.16)	1.20 (1.09-1.32)	1.37 (1.24-1.50)	1.50 (1.35-1.65)	1.64 (1.47-1.78)	1.78 (1.59-1.94)	1.97 (1.74-2.15)	2.12 (1.81-2.32)
60-min	1.00 (0.81-1.15)	1.21 (1.01-1.32)	1.47 (1.24-1.69)	1.67 (1.42-1.89)	1.94 (1.70-2.12)	2.15 (1.84-2.38)	2.38 (2.02-2.64)	2.59 (2.22-2.84)	2.91 (2.50-3.19)	3.17 (2.65-3.48)
120-min	1.23 (1.01-1.36)	1.48 (1.24-1.65)	1.84 (1.58-2.02)	2.12 (1.85-2.35)	2.51 (2.17-2.76)	2.82 (2.46-3.13)	3.16 (2.74-3.55)	3.52 (3.04-3.95)	4.01 (3.51-4.41)	4.48 (3.85-4.85)
24-hr	1.45 (1.15-1.71)	1.75 (1.50-1.92)	2.19 (1.86-2.42)	2.54 (2.20-2.79)	3.07 (2.65-3.56)	3.53 (3.05-3.95)	4.05 (3.47-4.42)	4.62 (4.00-5.15)	5.52 (4.80-6.22)	6.21 (5.31-7.02)
36-hr	1.54 (1.40-1.71)	1.86 (1.69-2.08)	2.33 (2.01-2.56)	2.72 (2.47-2.88)	3.30 (2.89-3.62)	3.82 (3.43-4.18)	4.40 (3.93-4.81)	5.06 (4.55-5.53)	5.89 (5.37-6.44)	7.00 (6.12-7.65)
48-hr	1.63 (1.49-2.02)	2.01 (1.82-2.42)	2.56 (2.21-2.82)	3.02 (2.65-3.64)	3.68 (3.25-4.26)	4.34 (3.86-4.95)	5.03 (4.49-5.71)	5.83 (5.28-6.57)	6.87 (6.20-7.52)	8.27 (7.29-9.13)
72-hr	2.19 (2.00-2.42)	2.63 (2.35-3.40)	3.36 (2.93-3.84)	3.89 (3.40-4.26)	4.60 (4.06-5.15)	5.30 (4.69-5.71)	6.09 (5.38-6.87)	6.99 (6.20-7.85)	8.38 (7.49-9.24)	9.62 (8.54-10.64)
96-hr	2.69 (2.50-2.86)	3.10 (2.85-3.40)	3.84 (3.52-4.23)	4.49 (4.09-4.94)	5.53 (5.03-6.07)	6.49 (5.87-7.12)	7.64 (6.97-8.37)	8.91 (8.19-9.67)	11.2 (10.0-12.3)	13.3 (11.9-14.6)
2-day	2.79 (2.54-3.06)	3.25 (2.95-3.56)	4.04 (3.64-4.40)	4.70 (4.25-5.15)	5.70 (5.15-6.25)	6.70 (6.05-7.35)	7.85 (7.10-8.55)	9.15 (8.35-9.95)	11.5 (10.3-12.7)	13.8 (12.4-15.1)
3-day	3.19 (2.90-3.52)	3.67 (3.32-4.03)	4.50 (4.04-4.95)	5.15 (4.64-5.61)	6.15 (5.57-6.70)	7.15 (6.48-7.80)	8.35 (7.58-9.10)	9.70 (8.85-10.5)	12.0 (10.7-13.3)	14.3 (12.9-15.6)
4-day	3.40 (3.12-3.71)	4.00 (3.70-4.31)	4.86 (4.44-5.28)	5.51 (4.98-5.91)	6.50 (5.87-7.08)	7.50 (6.82-8.14)	8.65 (7.92-9.35)	9.95 (9.15-10.7)	12.3 (11.0-13.5)	14.6 (13.2-15.8)
7-day	4.00 (3.69-4.37)	4.70 (4.40-5.04)	5.66 (5.12-6.17)	6.36 (5.72-6.95)	7.35 (6.65-8.00)	8.35 (7.60-9.05)	9.55 (8.75-10.3)	10.8 (10.0-11.5)	13.2 (11.9-14.5)	15.5 (14.1-16.8)
10-day	4.50 (4.19-4.82)	5.43 (5.02-5.85)	6.42 (5.77-7.05)	7.32 (6.65-7.95)	8.30 (7.58-9.00)	9.30 (8.55-10.0)	10.5 (9.70-11.2)	11.8 (10.9-12.6)	14.2 (12.9-15.4)	16.5 (15.1-17.8)
20-day	5.21 (4.79-5.68)	6.20 (5.69-6.70)	7.21 (6.58-7.81)	8.10 (7.44-8.70)	9.10 (8.35-9.80)	10.1 (9.30-10.8)	11.3 (10.4-12.1)	12.6 (11.7-13.4)	15.0 (13.6-16.3)	17.3 (15.9-18.6)
30-day	5.69 (5.20-6.14)	6.70 (6.17-7.20)	7.71 (7.07-8.33)	8.59 (7.91-9.25)	9.60 (8.85-10.3)	10.6 (9.85-11.3)	11.9 (11.0-12.7)	13.2 (12.3-14.0)	15.6 (14.2-16.9)	17.9 (16.5-19.2)
45-day	6.09 (5.55-6.61)	7.10 (6.55-7.61)	8.11 (7.46-8.71)	8.99 (8.30-9.65)	10.0 (9.25-10.7)	11.0 (10.2-11.7)	12.3 (11.4-13.1)	13.6 (12.7-14.4)	16.0 (14.6-17.3)	18.3 (16.9-19.6)
60-day	6.50 (5.95-7.00)	7.50 (6.95-7.95)	8.51 (7.86-9.11)	9.39 (8.69-10.0)	10.4 (9.65-11.1)	11.4 (10.6-12.1)	12.7 (11.8-13.5)	14.0 (13.1-14.8)	16.4 (15.0-17.7)	18.7 (17.3-20.0)

¹ Precipitation frequency (PFD) estimates in this table are based on frequency analysis of point duration series (PDS).
 Numbers in parentheses are 90% confidence intervals for the PFD estimates. The probability that precipitation frequency estimates for a given duration and average recurrence interval will be greater than the upper bound or less than the lower bound is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.
 Please refer to NOAA Atlas 14 document for more information.

From NOAA
Atlas 14
Precipitation
Frequency
Data Server



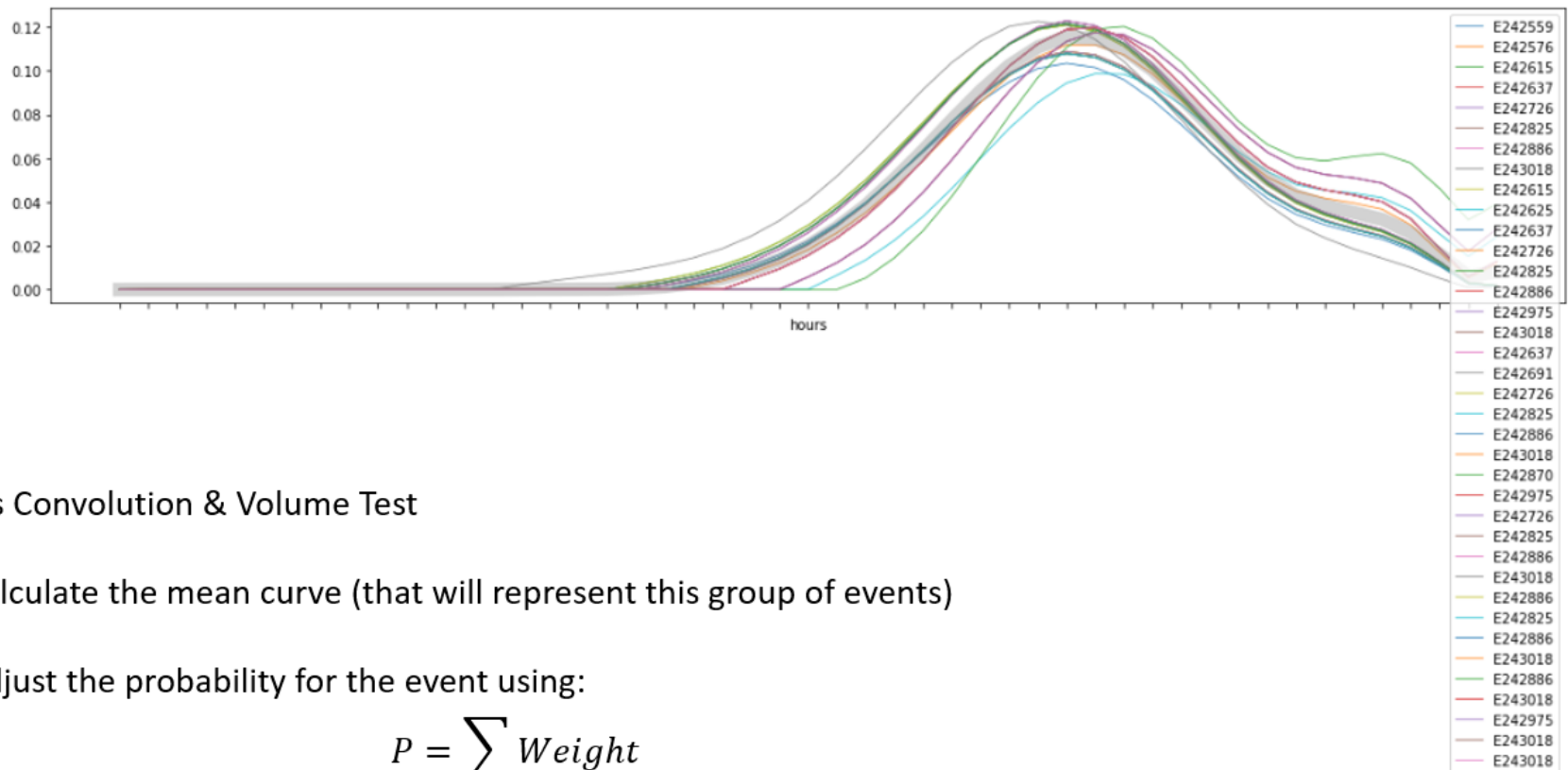
Crash Course of Probabilistic Approach

Pluvial Hydrology

- **Uses convolution to reduce the number of simulation**

Example: 24 Hour Storm

37 Like Storms replaced with a single curve



Passes Convolution & Volume Test

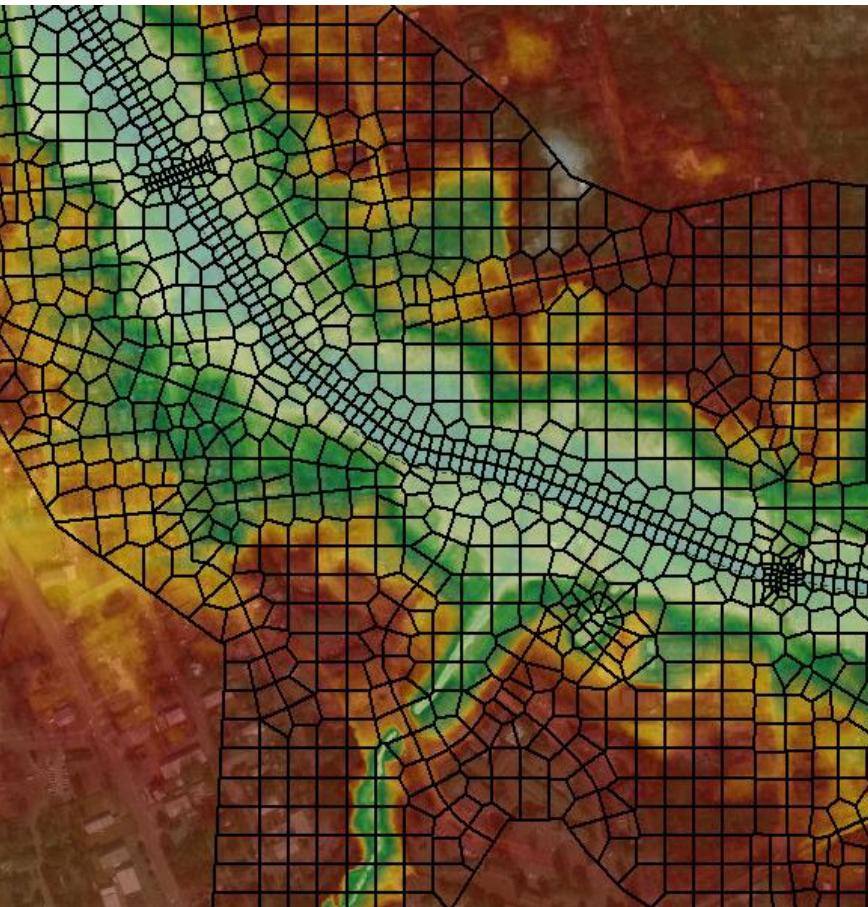
1. Calculate the mean curve (that will represent this group of events)
2. Adjust the probability for the event using:

$$P = \sum Weight$$

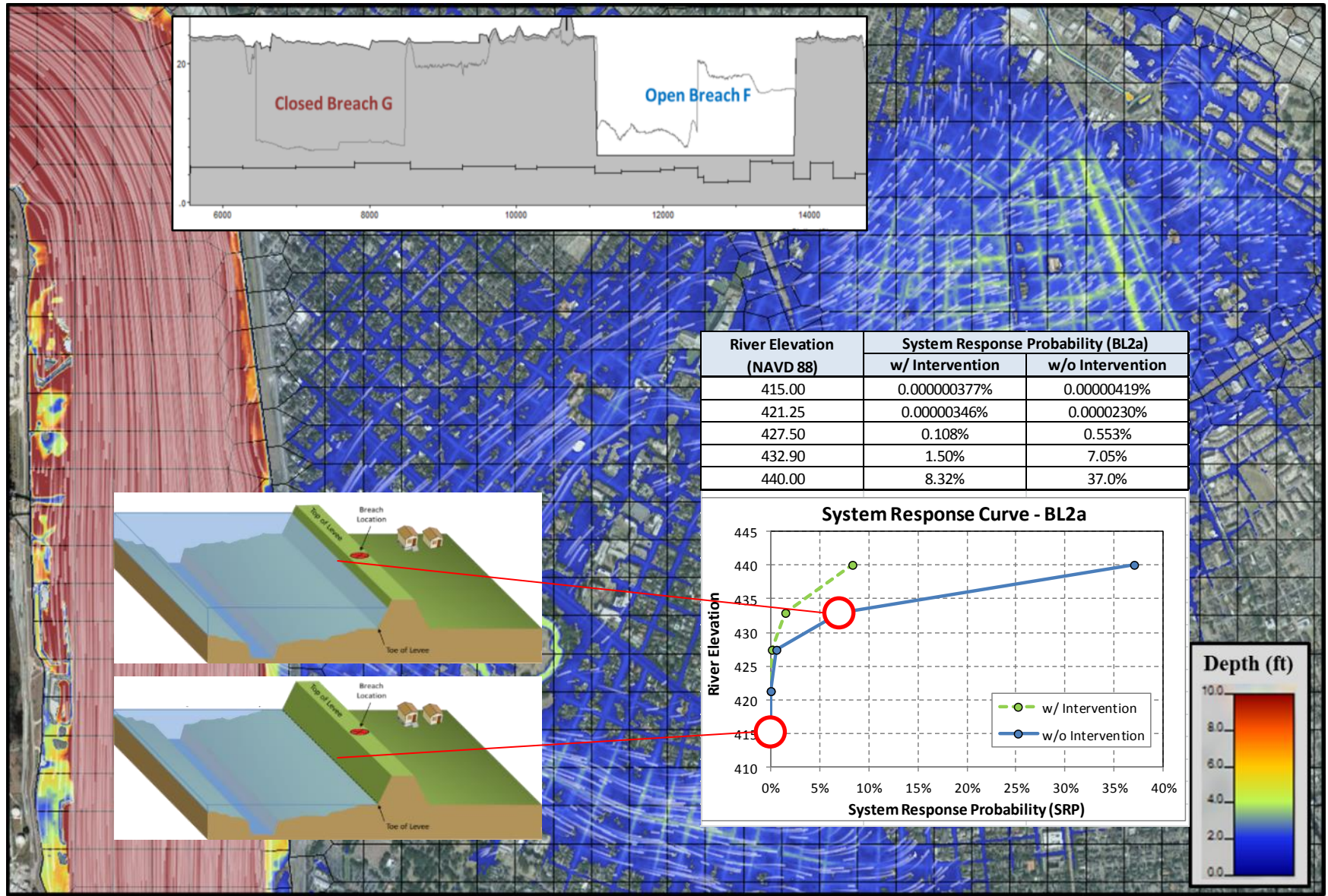
Crash Course of Probabilistic Approach

Hydraulics – Simulations

- ▶ 2D model scenarios are run in a batch, automated process
- ▶ 100 fluvial runs per scenario, up to thousands of pluvial runs

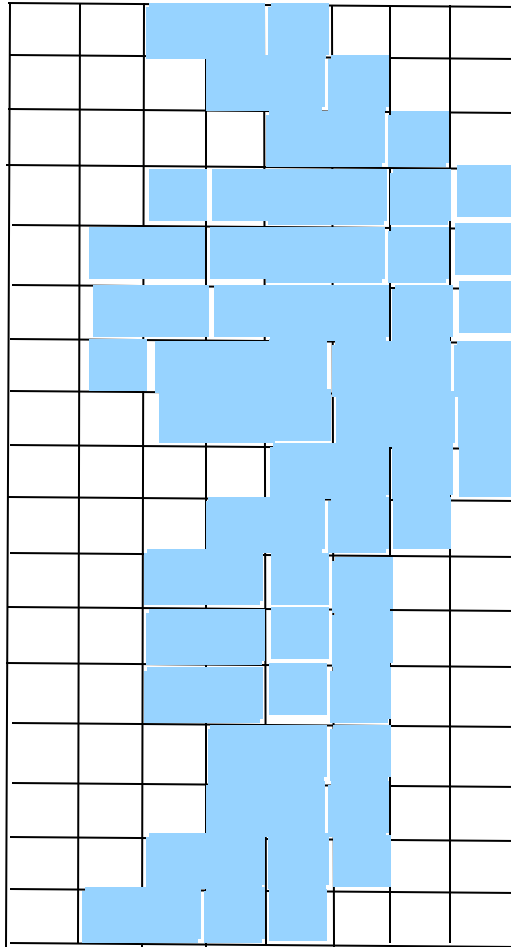


Probabilistic Approach (Levees)



AEP Generation Concept

Flood Plain



AEP Database

0	0	2	2	2	0	0	0
0	0	0	2	2	2	0	0
0	0	0	0	2	2	2	0
0	0	0	0	2	2	2	0
0	0	0	0	2	2	2	0
0	0	0	0	0	2	2	2
0	0	0	0	0	2	2	2
0	0	0	0	2	2	2	0
0	0	0	2	2	0	2	0
0	0	2	2	0	2	0	0
0	0	2	2	0	2	0	0
0	0	0	2	2	2	0	0
0	0	0	2	2	2	0	0
0	0	2	2	2	0	0	0
0	2	2	2	0	0	0	0

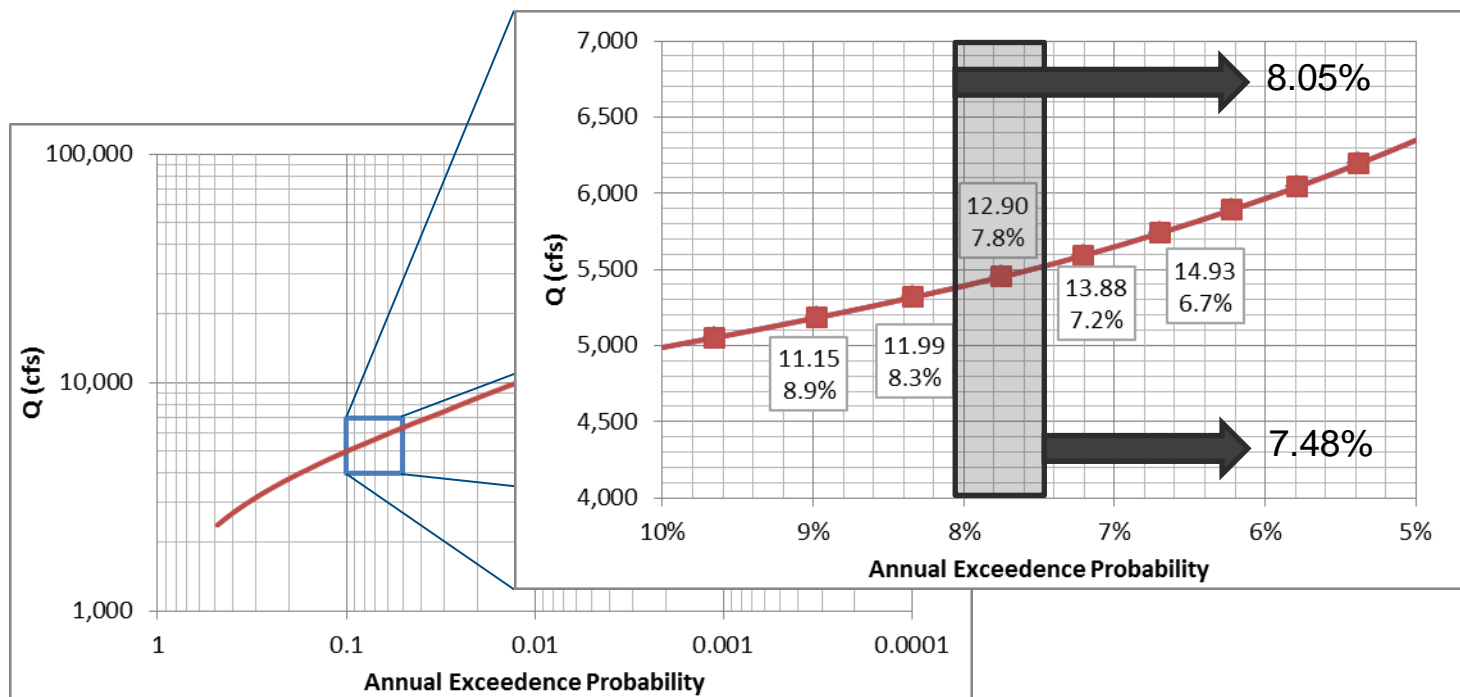
Number
of events



AEP= grid value/number of events

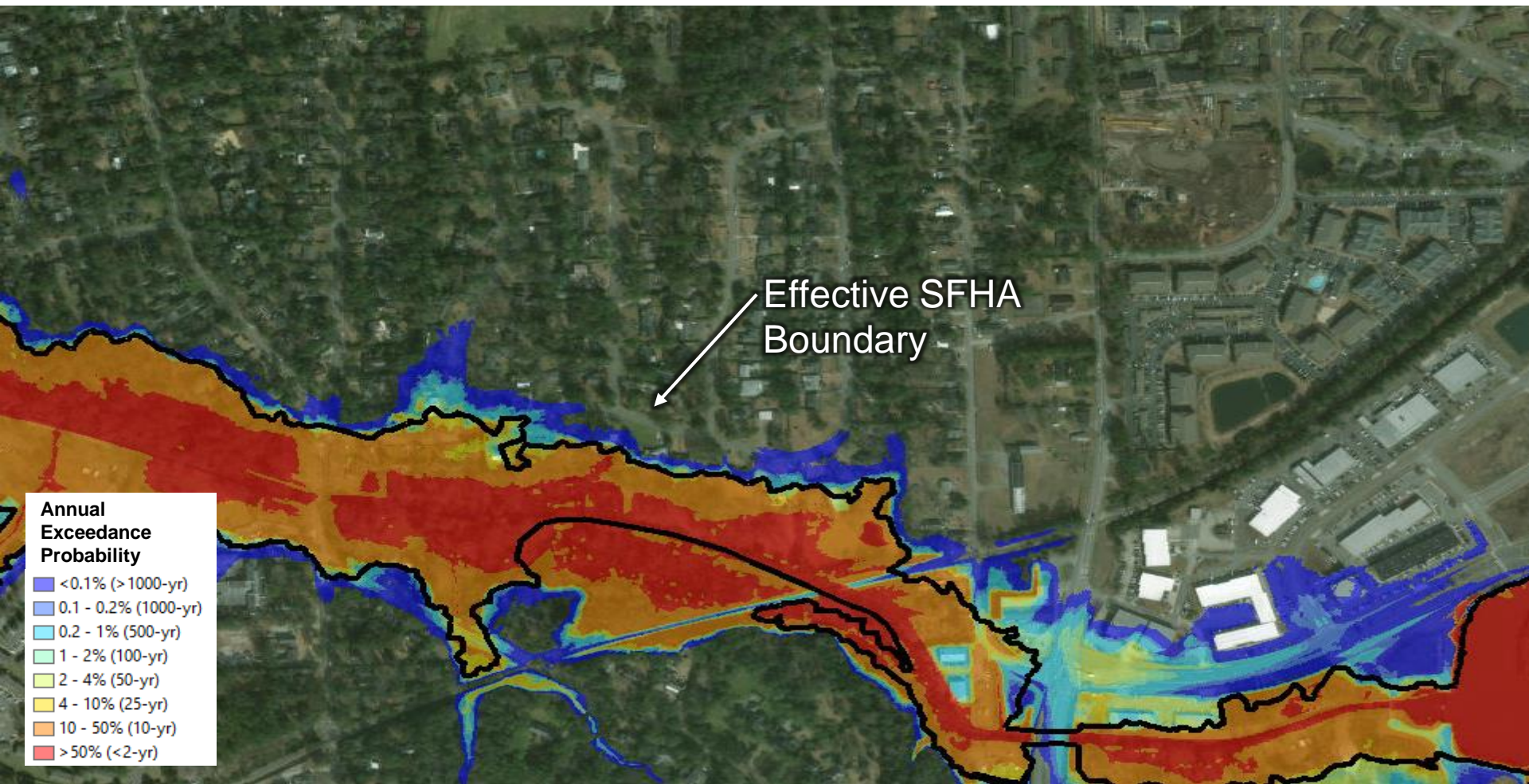
Risk Assessment

- ▶ The full flood risk greater than the 2 year flood is captured by modeling 100 events
- ▶ The percent chance of each event occurring is calculated and used as a weight for the potential damages caused by that event



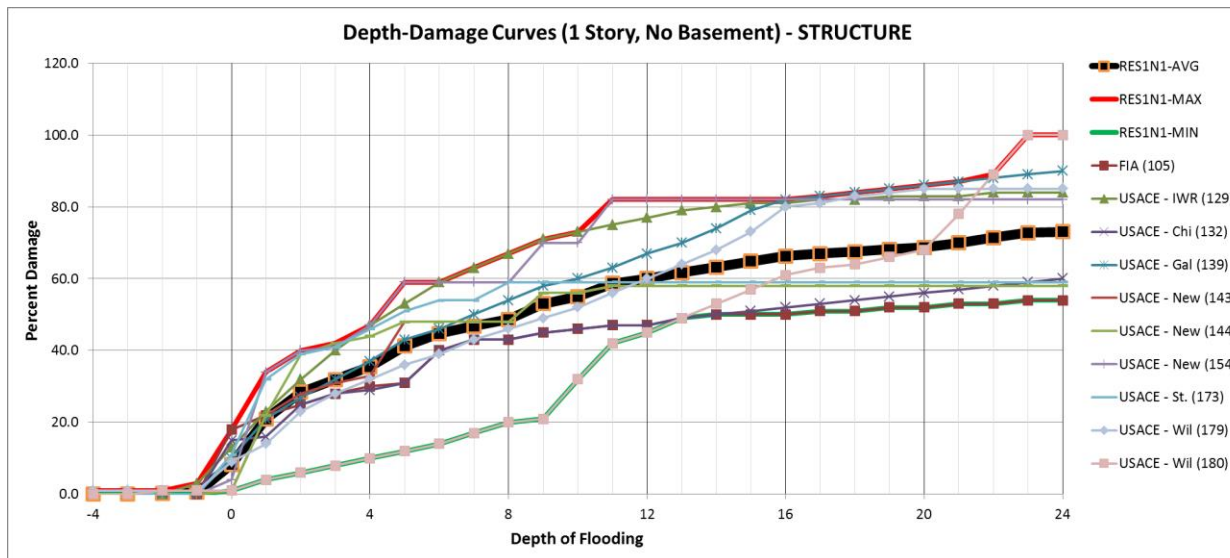
Annual Exceedance Probability Grid

- ▶ Using the results and probabilities from each model run, a probability grid is generated



Risk Assessment

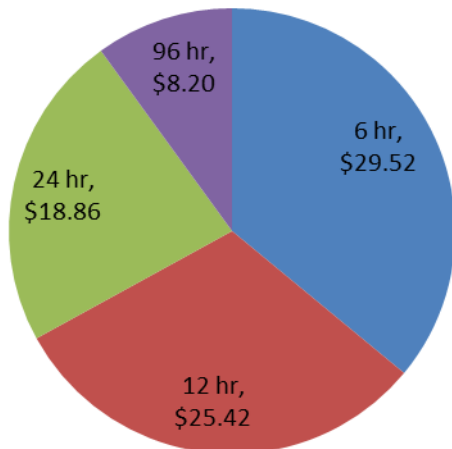
- ▶ **How do you go from thousands of water surface elevation rasters to a single value for damage?**
- ▶ **Damages for each simulation, then weighting factor to sum up**
 - Depth damage curves
 - Damage per event, multiplied by weight
- ▶ **Composite Depth-Damage curves for each structure type were used based on available curves from Hazus**



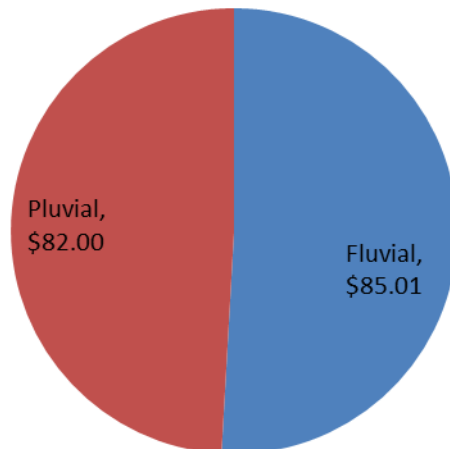
Risk Assessment

- ▶ How much damage can be expected in any given year?
- ▶ Where are the damages coming from? How much is fluvial vs pluvial?
- ▶ Which storm duration causes the most damage?
- ▶ Which levee breaches have the most potential for damage?

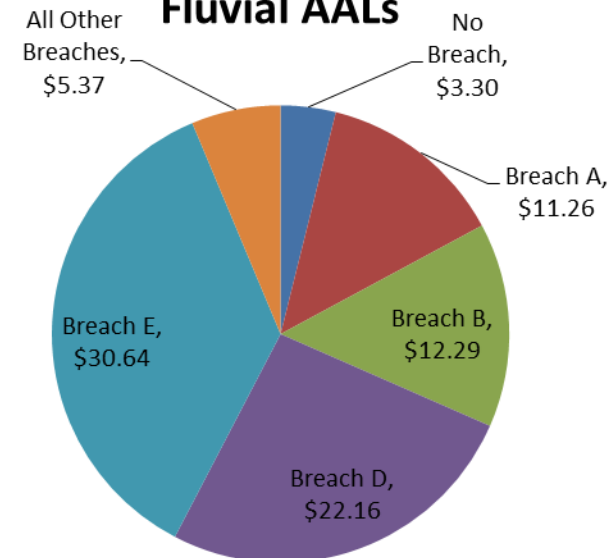
Pluvial AALs



AALs by Source

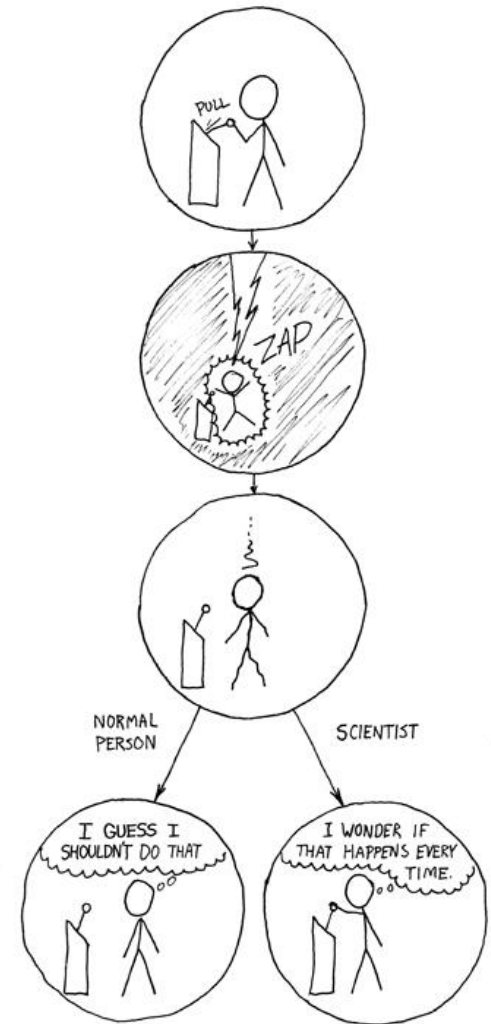


Fluvial AALs



Traceability – not a black box

- ▶ **Can ascribe specific AALs from fluvial modeling, pluvial modeling, specific breaches**
- ▶ **Can further break down into specific return period run**
- ▶ **Random numbers used for assigning are stored to allow for the reproduction of the analysis**
 - Hyetograph decile
 - AMS condition
 - Confidence limits
 - Etc





Results

Grids with any return period (WSEL, depth, dxv)

AEP grids

Structure-specific WSEL & damage curves

AALs for structures, areas, or systems



Ooooooh
SHINY!!!!



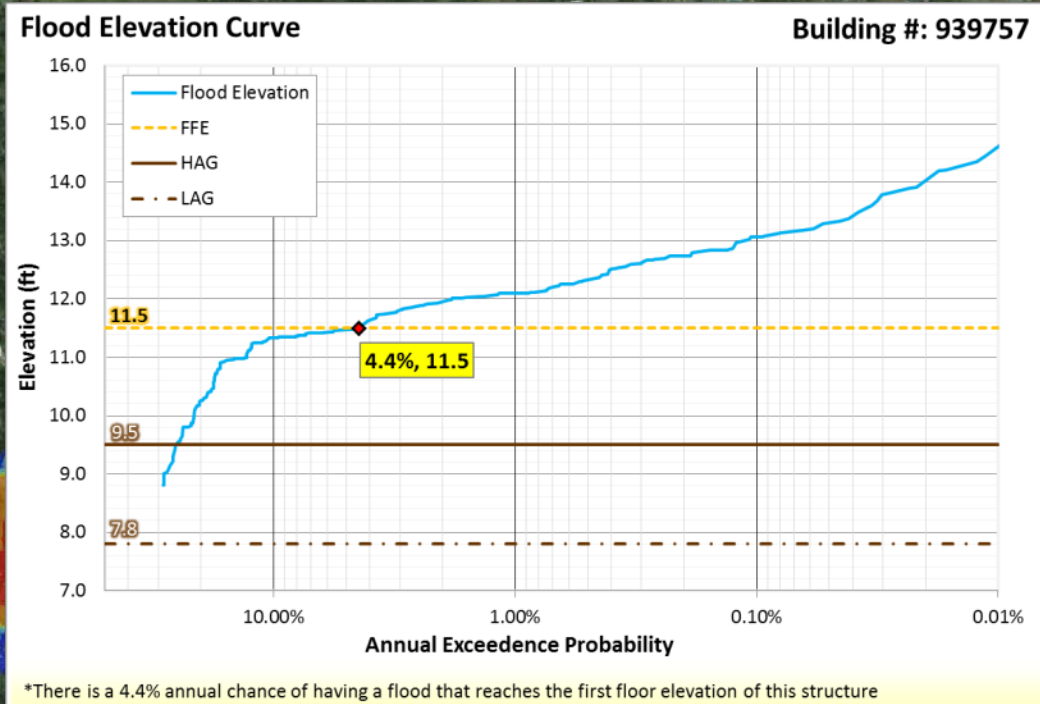
Structure-Level Risk

WSEL Curve

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

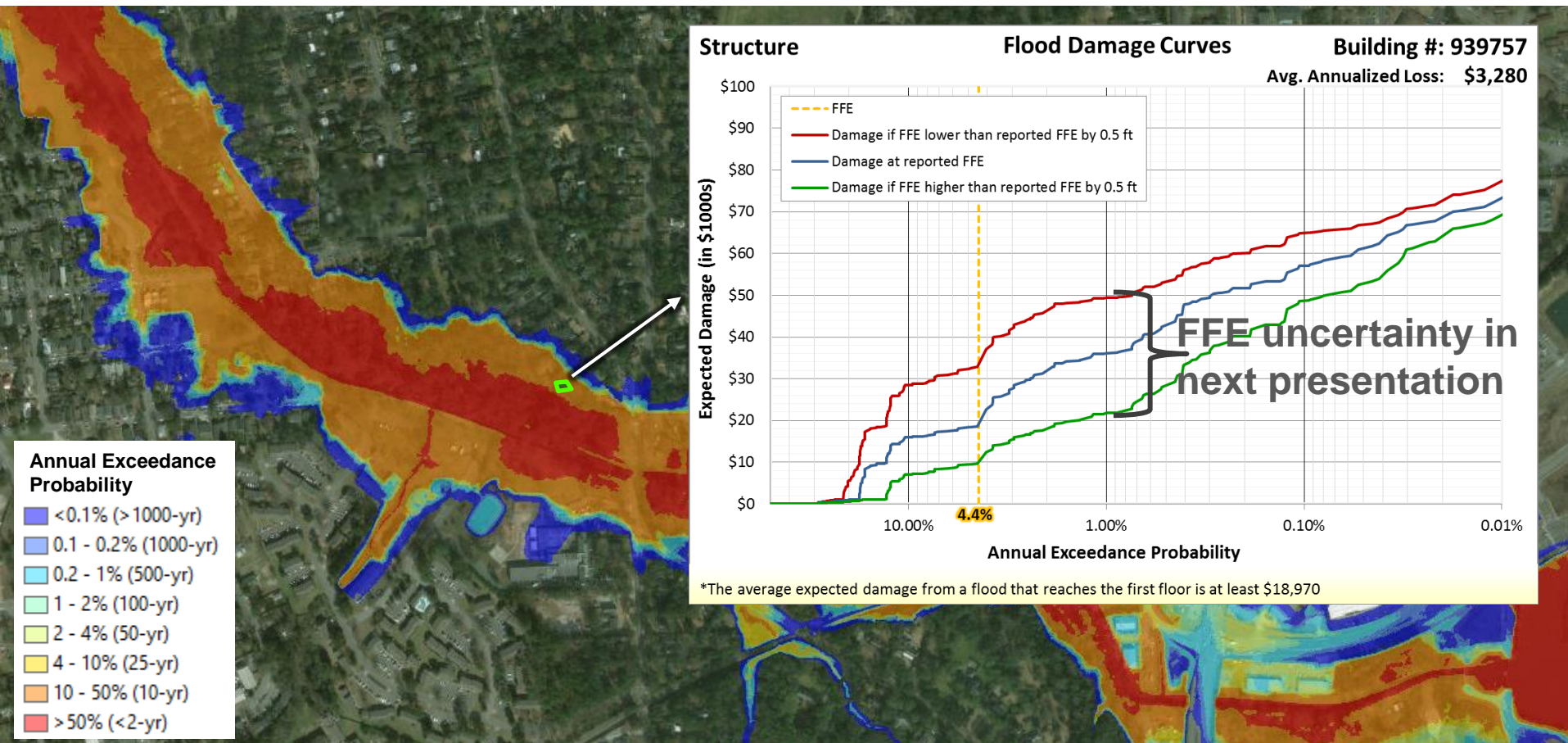
Model Run #	Run Weight	WSEL Sorted	Cumulative Weight
300	0.0041%	115.08	0.004%
285	0.0012%	115.02	0.005%
297	0.0041%	114.71	0.009%
267	0.0018%	114.47	0.011%
286	0.0011%	114.35	0.012%
296	0.0041%	114.22	0.016%
282	0.0013%	114.20	0.018%
293	0.0042%	113.91	0.022%
277	0.0014%	113.90	0.023%
225	0.0050%	113.81	0.028%

Annual Probab	Model Run #	Run Weight	WSEL Sorted	Cumulative Weight
<0.1	16	0.0247%	112.67	0.270%
0.1 -	226	0.0049%	112.66	0.287%
0.2 -	176	0.0167%	112.65	0.290%
1 - 2	198	0.0098%	112.62	0.299%
2 - 4	275	0.0015%	112.60	0.301%
4 - 1	151	0.0308%	112.59	0.332%
10 -	171	0.0189%	112.55	0.350%
>50%	177	0.0163%	112.54	0.367%
	222	0.0054%	112.54	0.372%



Structure-Level Risk Damage Curve

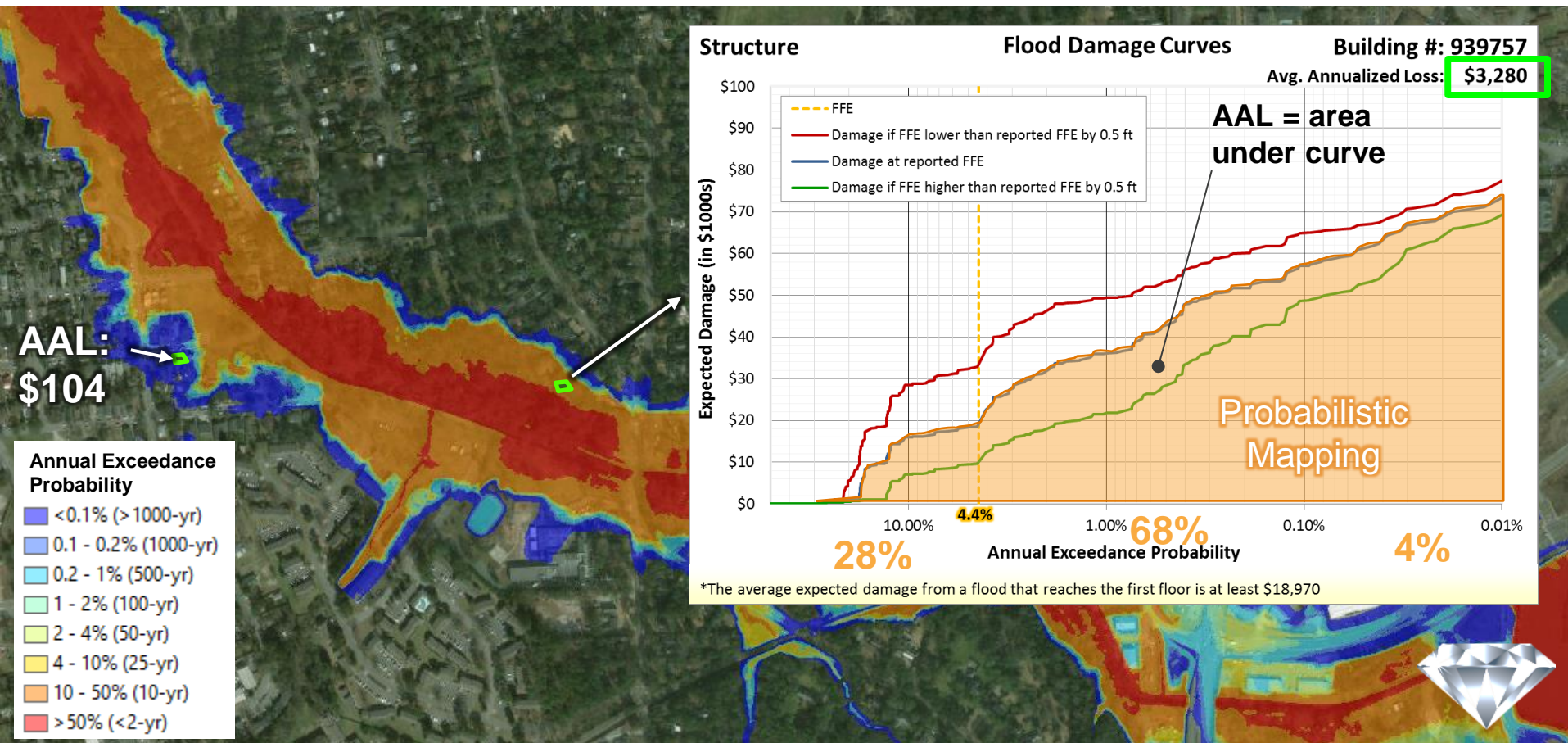
- **Flood Damage Curves can be generated, taking into account uncertainties in structure occupancy and first floor elevations (FFE)**



Structure-Level Risk

AALs by Home

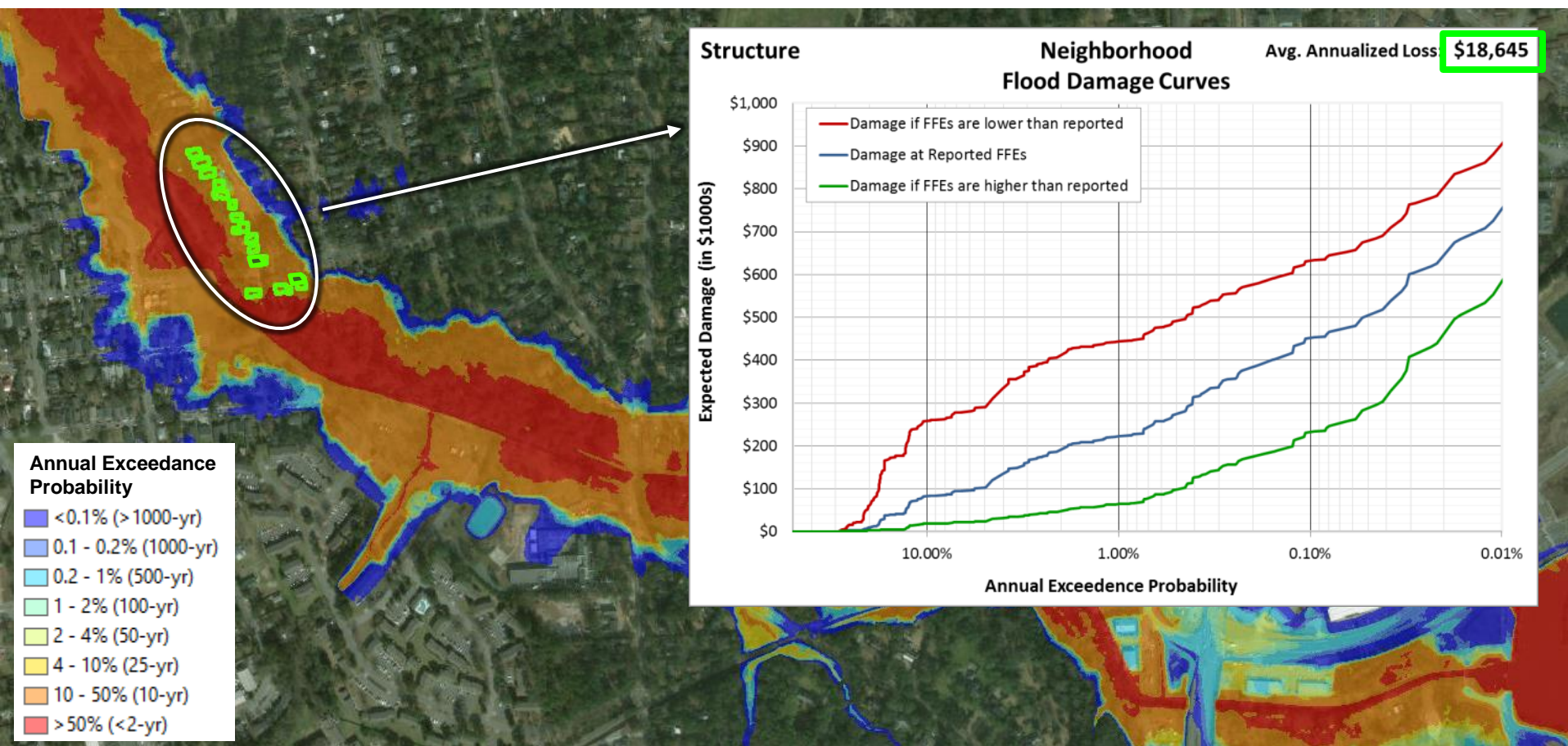
- ▶ Average Annualized Losses (AAL) much more accurate – little to no extrapolation required, unlike with typical studies



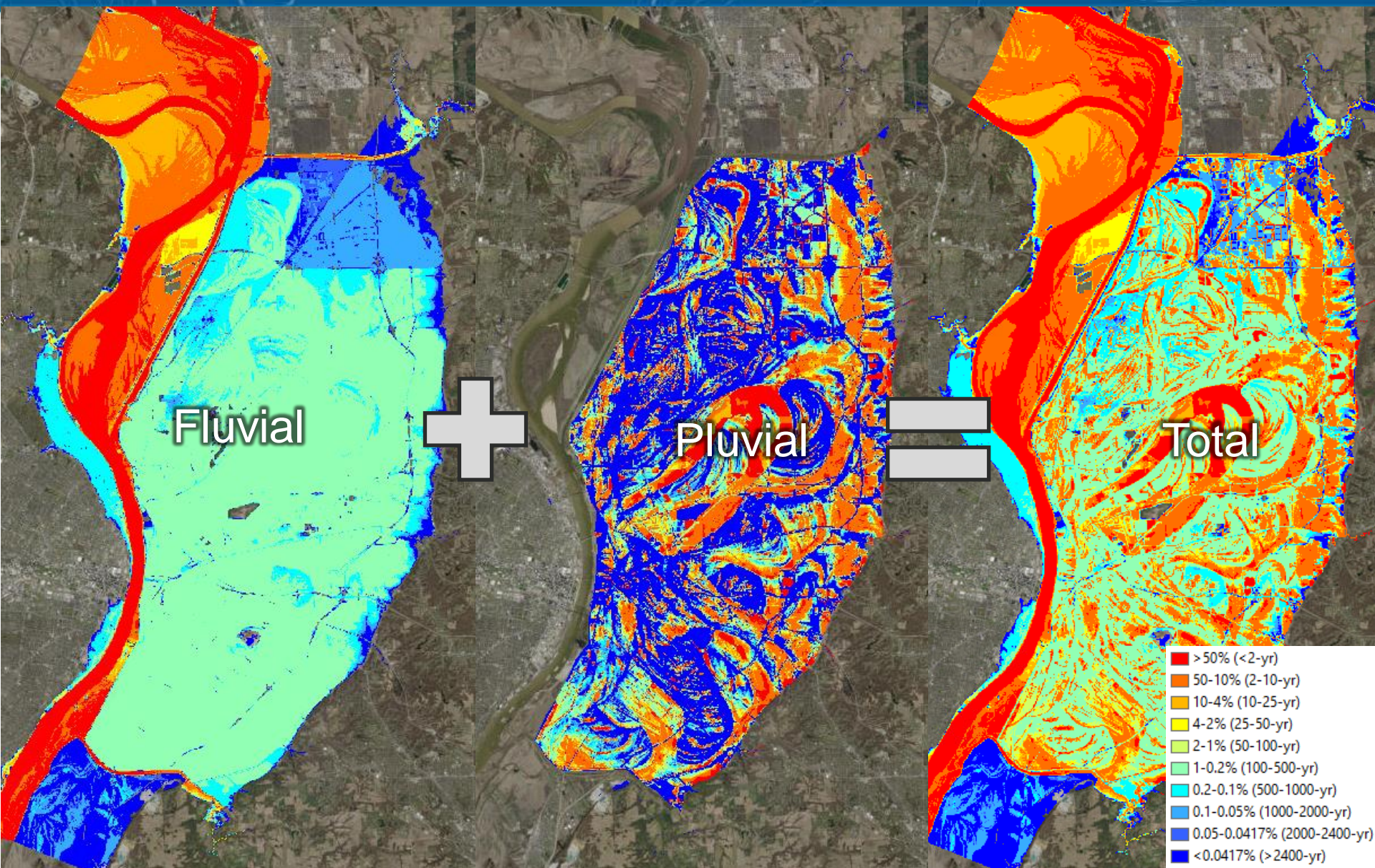
Structure-Level Risk

AALs by Area

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

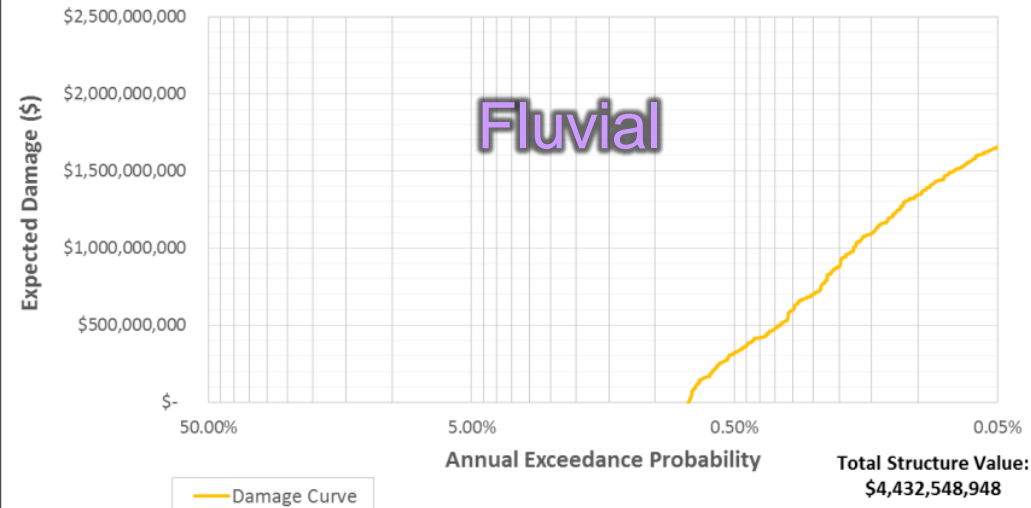


Aggregating AEP Maps



Aggregating AALs

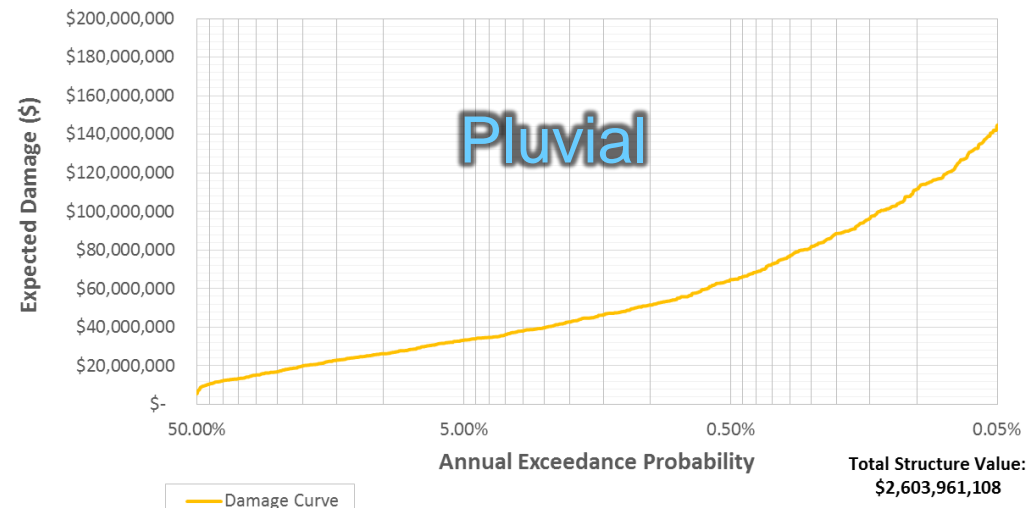
Aggregate Flood Damage Curve



# Structures with Damage	35,197 of 35,236 (99.9%)
Avg. Annualized Loss (AAL)	\$4,848,716

**Total AAL
\$15,028,131**

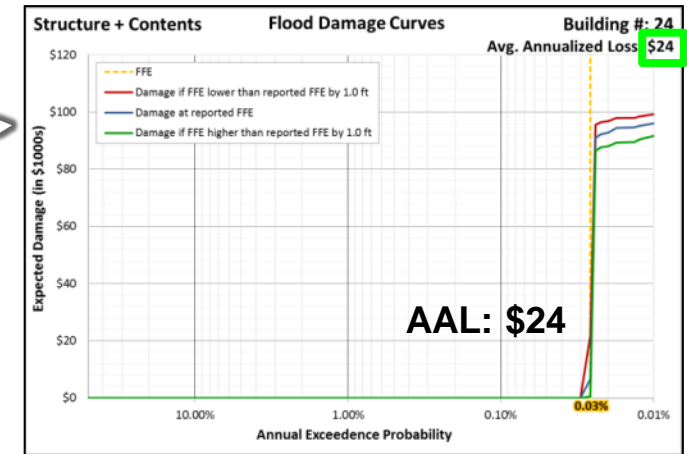
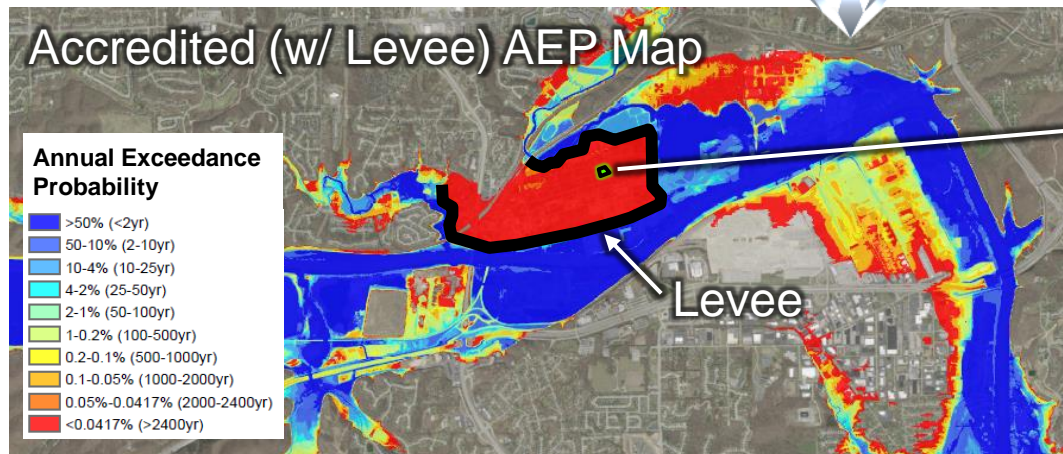
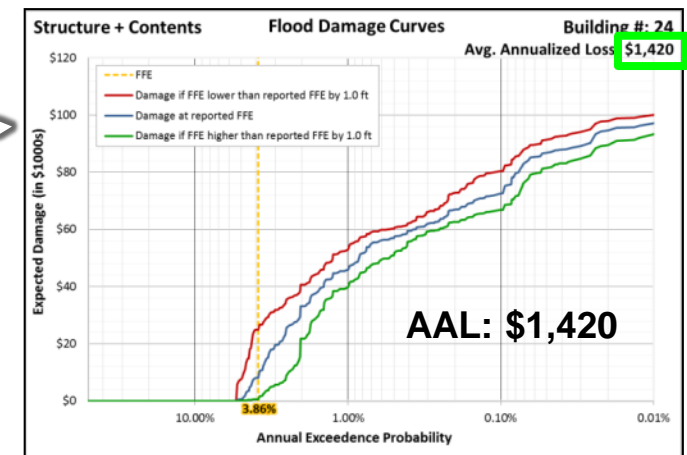
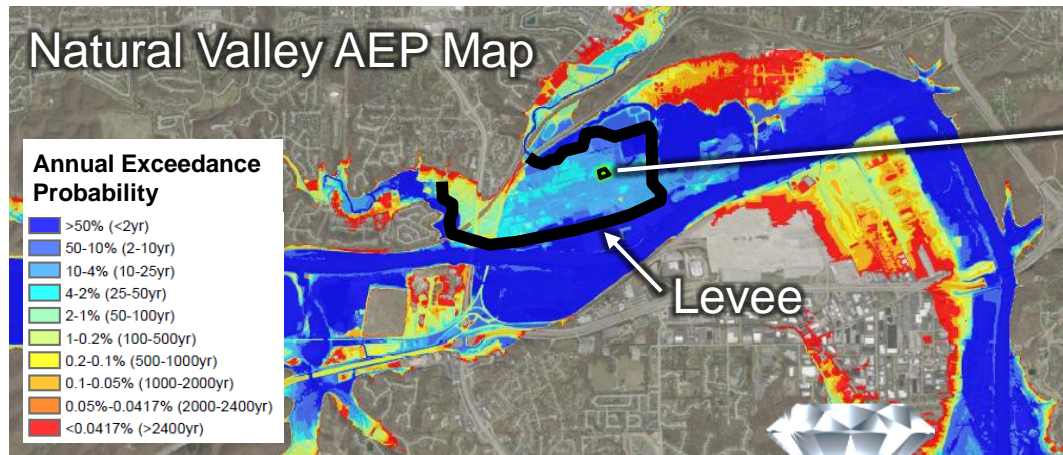
Aggregate Flood Damage Curve



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

Cost Benefit Analysis for Levees

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



Benefits of PFRA

– Analysis

- Full risk profile (fluvial, pluvial, residual, coastal)
- Graduated risk between 50% and 0.033% floodplain
- Accounts for uncertainty bands & varied assumptions
- Focused on damages, not zones (considers FFE)

– Products

- High resolution data for any return period
- AAL estimates for structures and/or systems
- AEP maps

– Abilities

- Facilitates benefit-cost analyses for mitigation or CIP
- Risk-Informed decision making
- Enhanced outreach and awareness



Part of that Exciting Future is... *More Cool Sciency Stuff!*

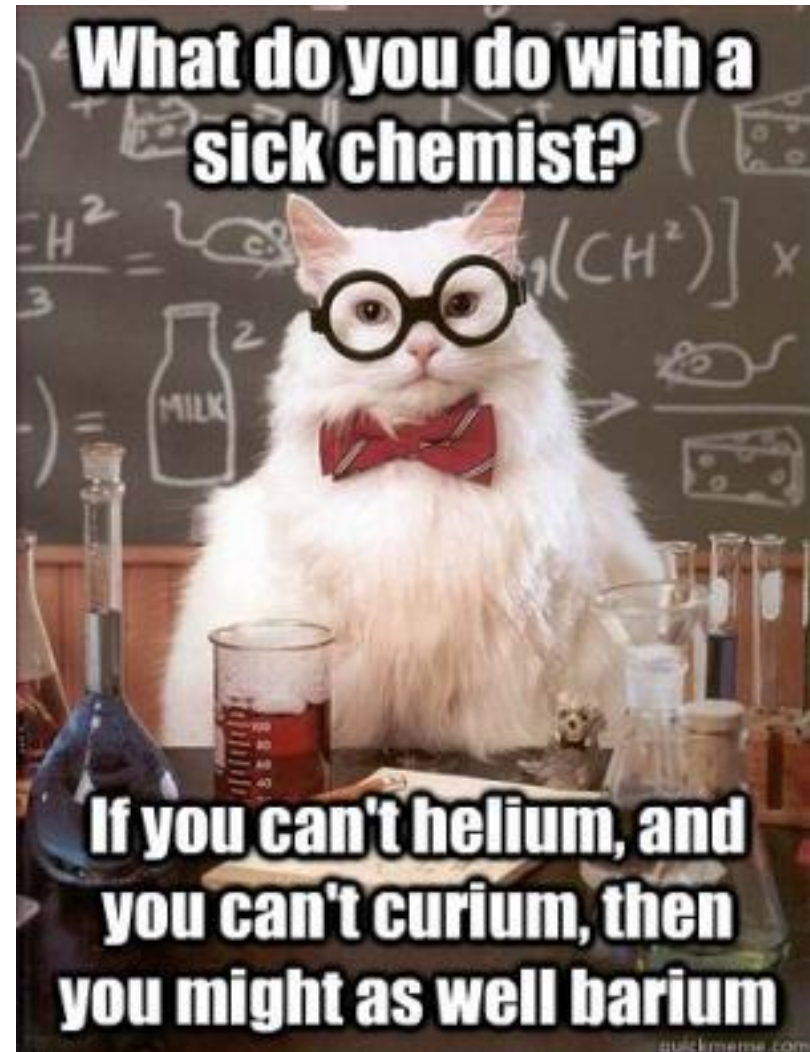
► Pluvial

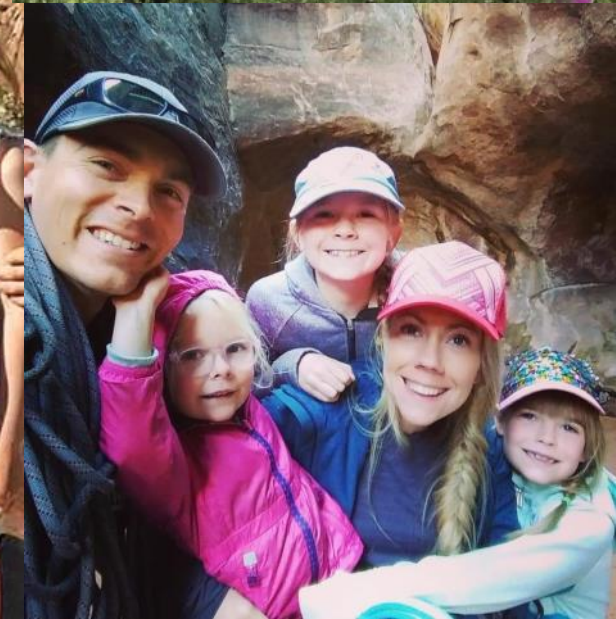
- cell size sensitivity testing
- timing rainfall application across large watersheds
- joint probability with inflows
- reducing Monte Carlo hyetograph datasets by convolution

► Fluvial

- cell size sensitivity testing
- joint probability at confluences
- mean normalized hydrographs
- progressive erosion breaching

Interested in learning more? <https://aecom.jobs/>





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