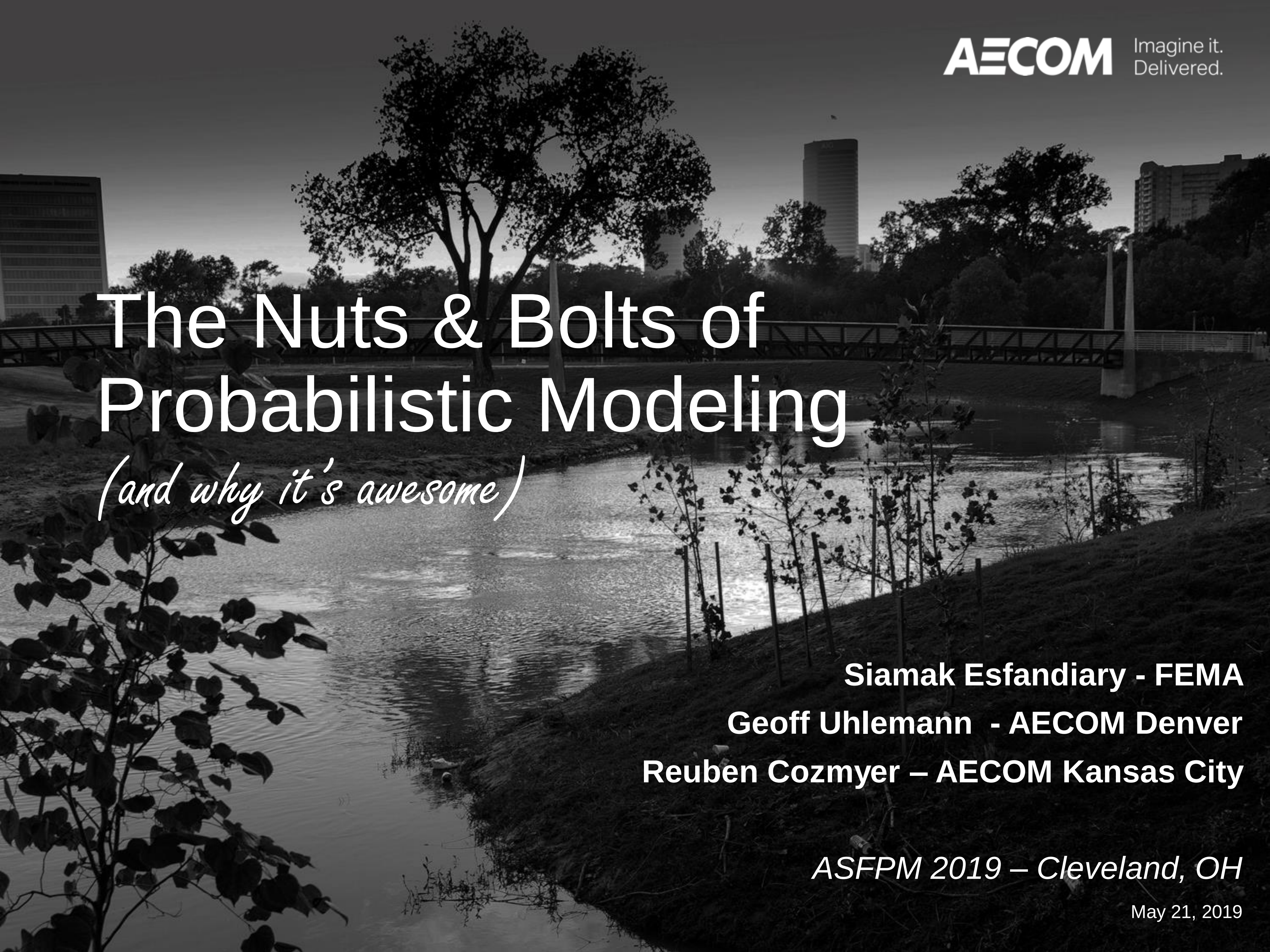


AECOM Imagine it. Delivered.

The Nuts & Bolts of Probabilistic Modeling

(and why it's awesome)

Siamak Esfandiary - FEMA

Geoff Uhlemann - AECOM Denver

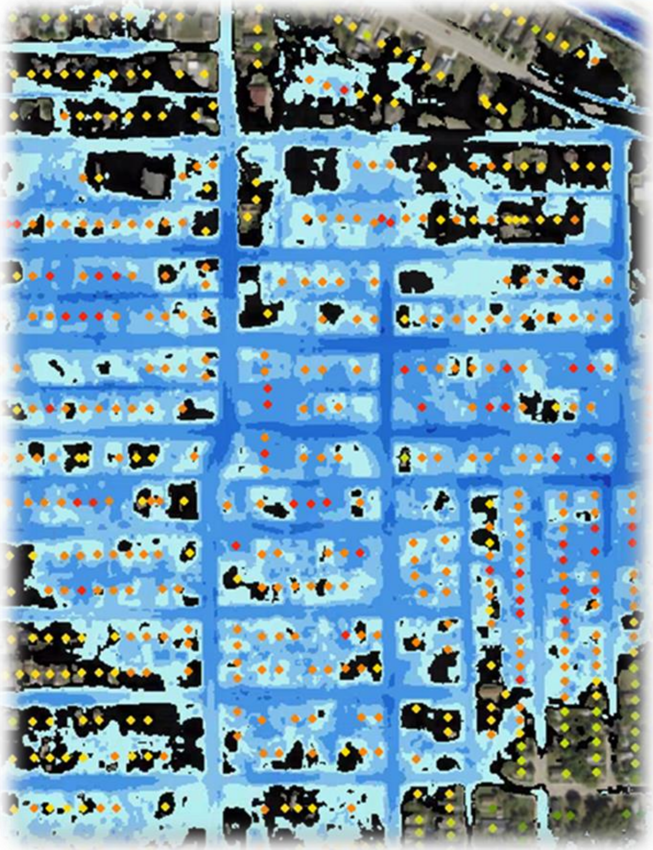
Reuben Cozmyer – AECOM Kansas City

ASFPM 2019 – Cleveland, OH

May 21, 2019

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



FEMA

compass
Identify. Interpret. Integrate

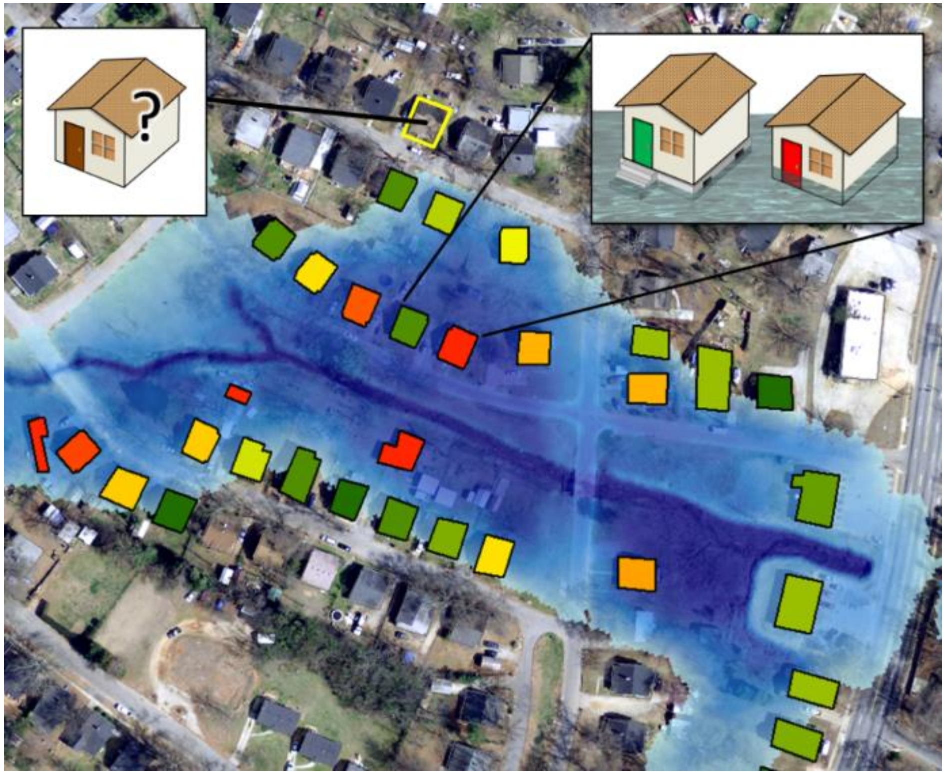
Reasons for a New Approach
Institutional & Policy Drivers

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*

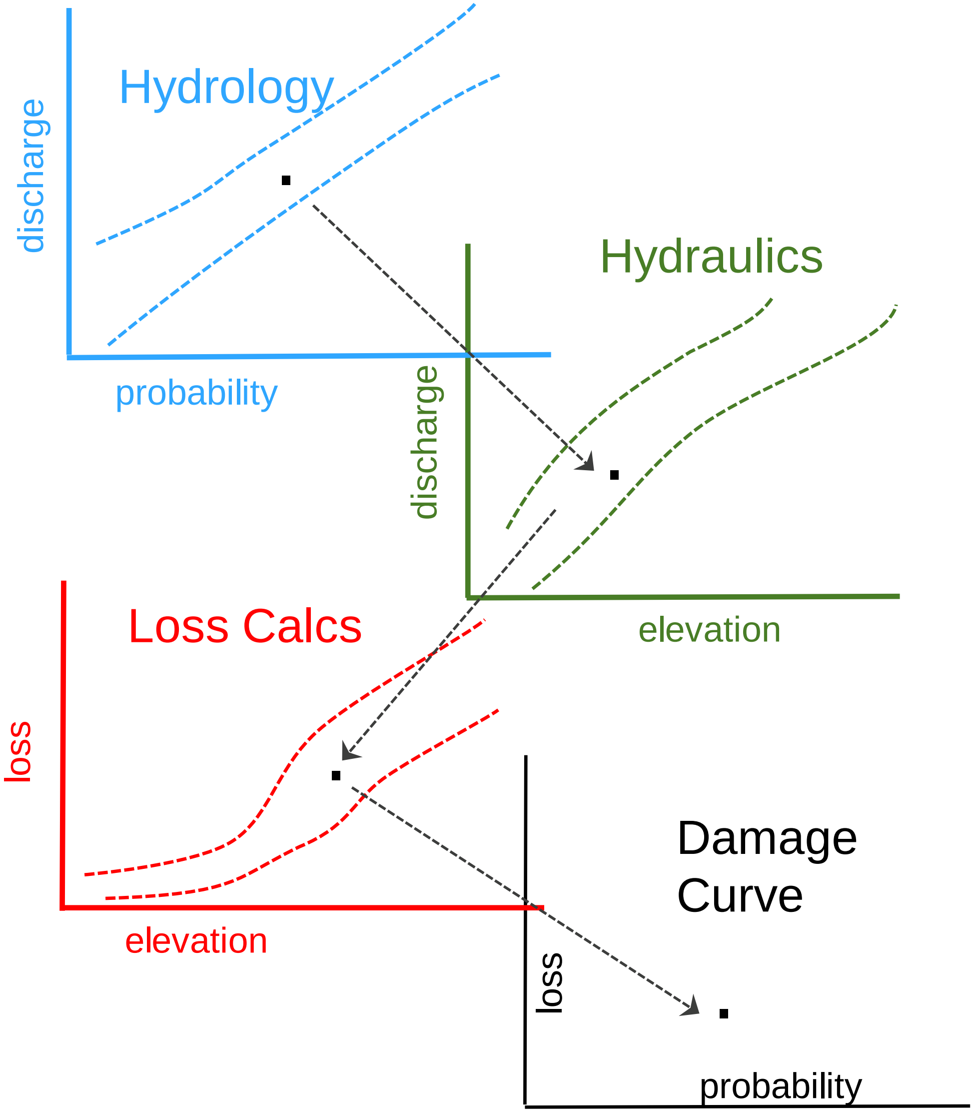
- Showing annual exceedance probability (AEP) rather than zones
- Especially useful behind levees

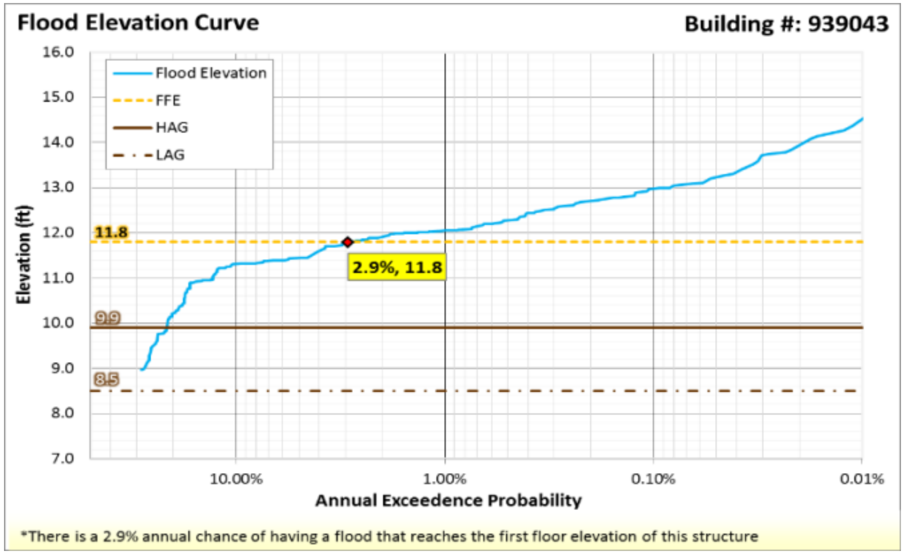
Example Risk Discretization *from Zones to Damages*

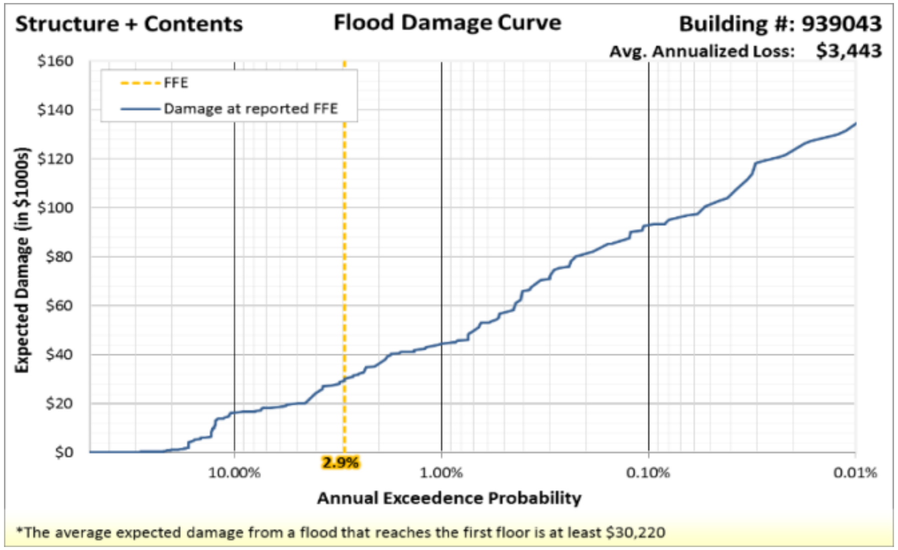
- Spatially varied insurance premiums based on AALs
- Can vary behind levees then & account for pluvial

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

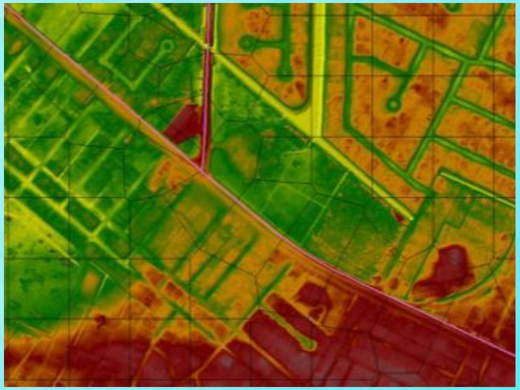
PFRA Overview
at a glance

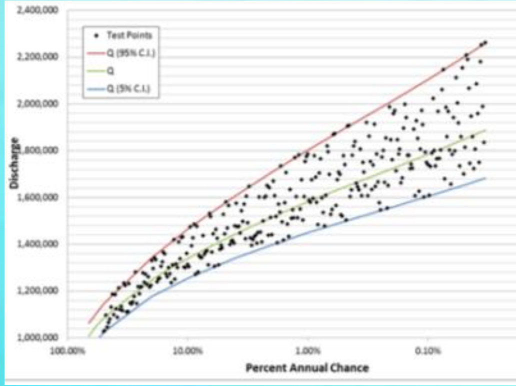


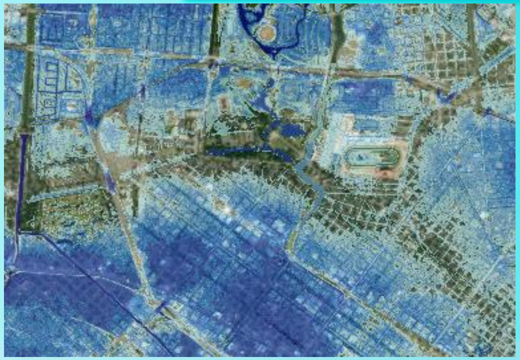


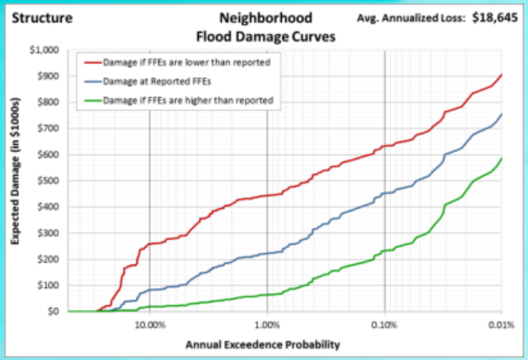


Crash Course of Probabilistic Approach





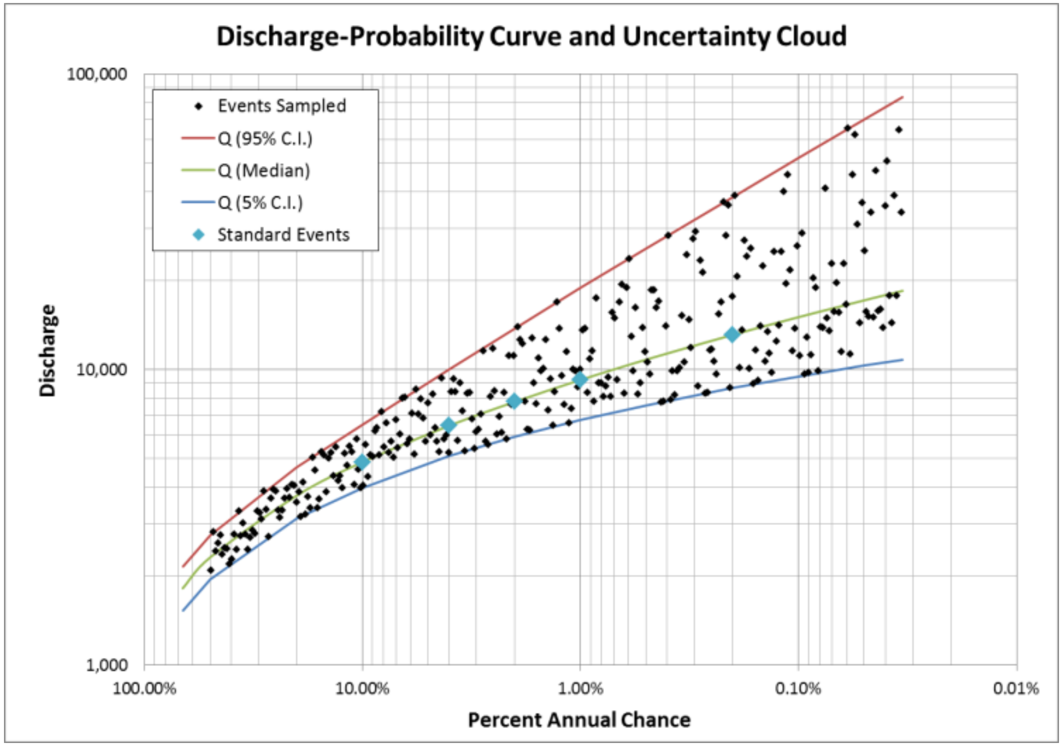




Crash Course of Probabilistic Approach

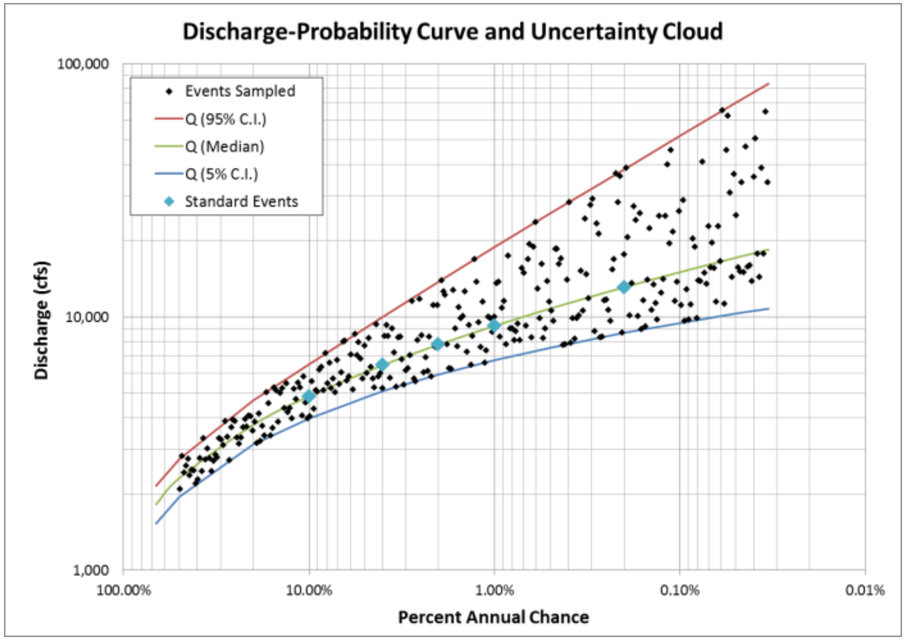
Sampling Methodology

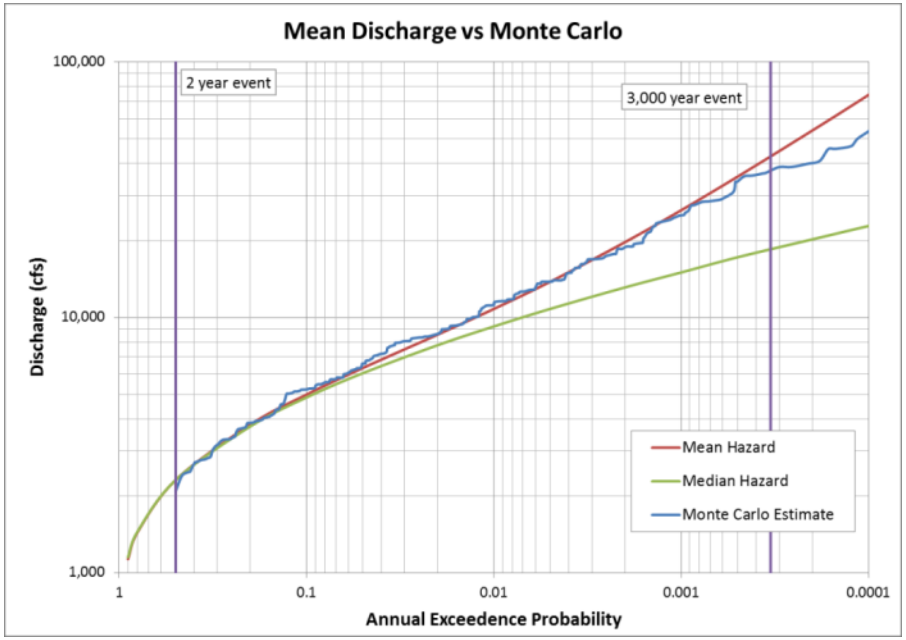
- **Traditional flood risk analysis samples only a few points along the median discharge curve – 10, 4, 2, 1, 0.2% annual chance events**
- **Higher resolution?**
- **Higher return periods?**
- **This approach can also capture the uncertainty inherent in a hydrologic analysis**



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





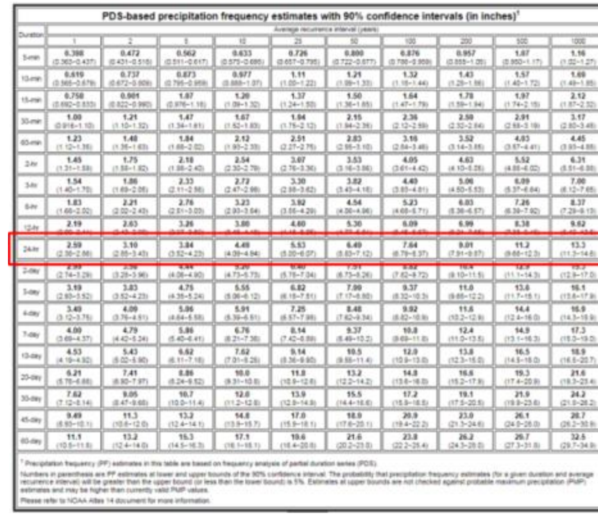
Crash Course of Probabilistic Approach
Pluvial Flooding

- **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**

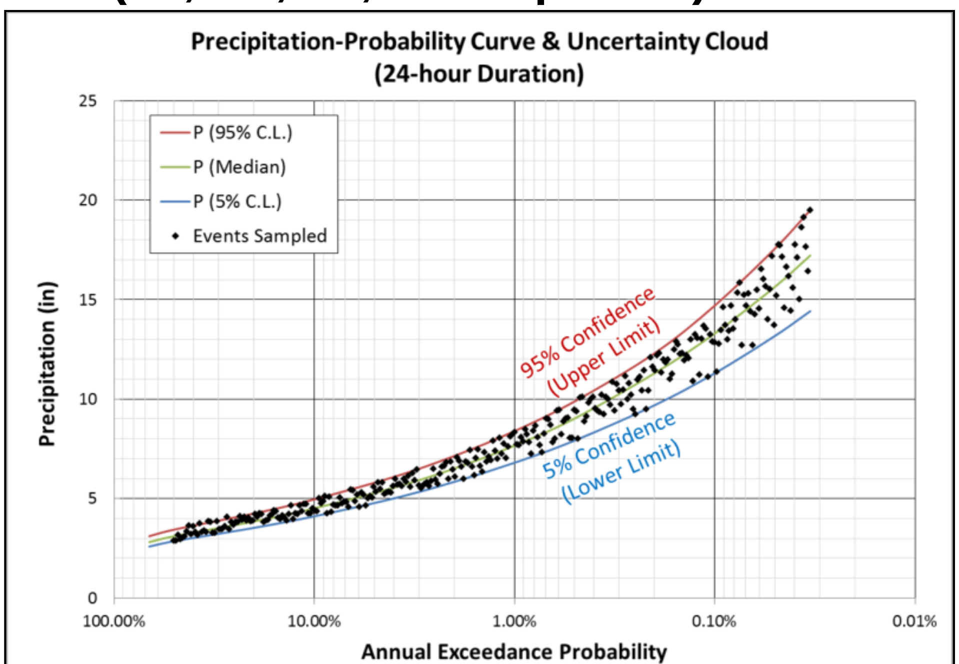
Crash Course of Probabilistic Approach

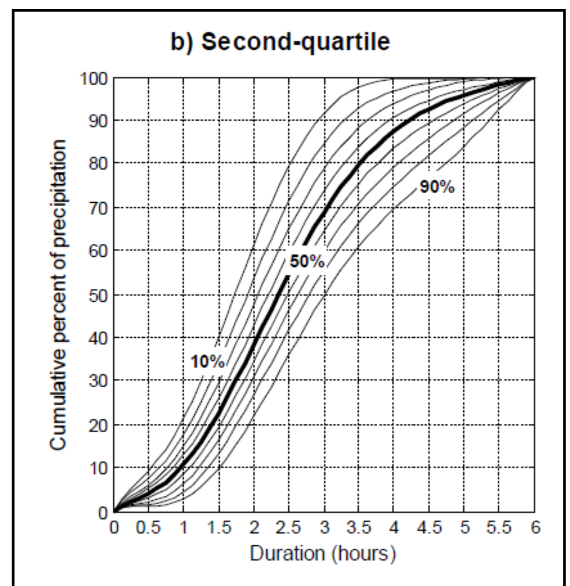
Pluvial Hydrology

- **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**



From NOAA Atlas 14 Precipitation Frequency Data Server



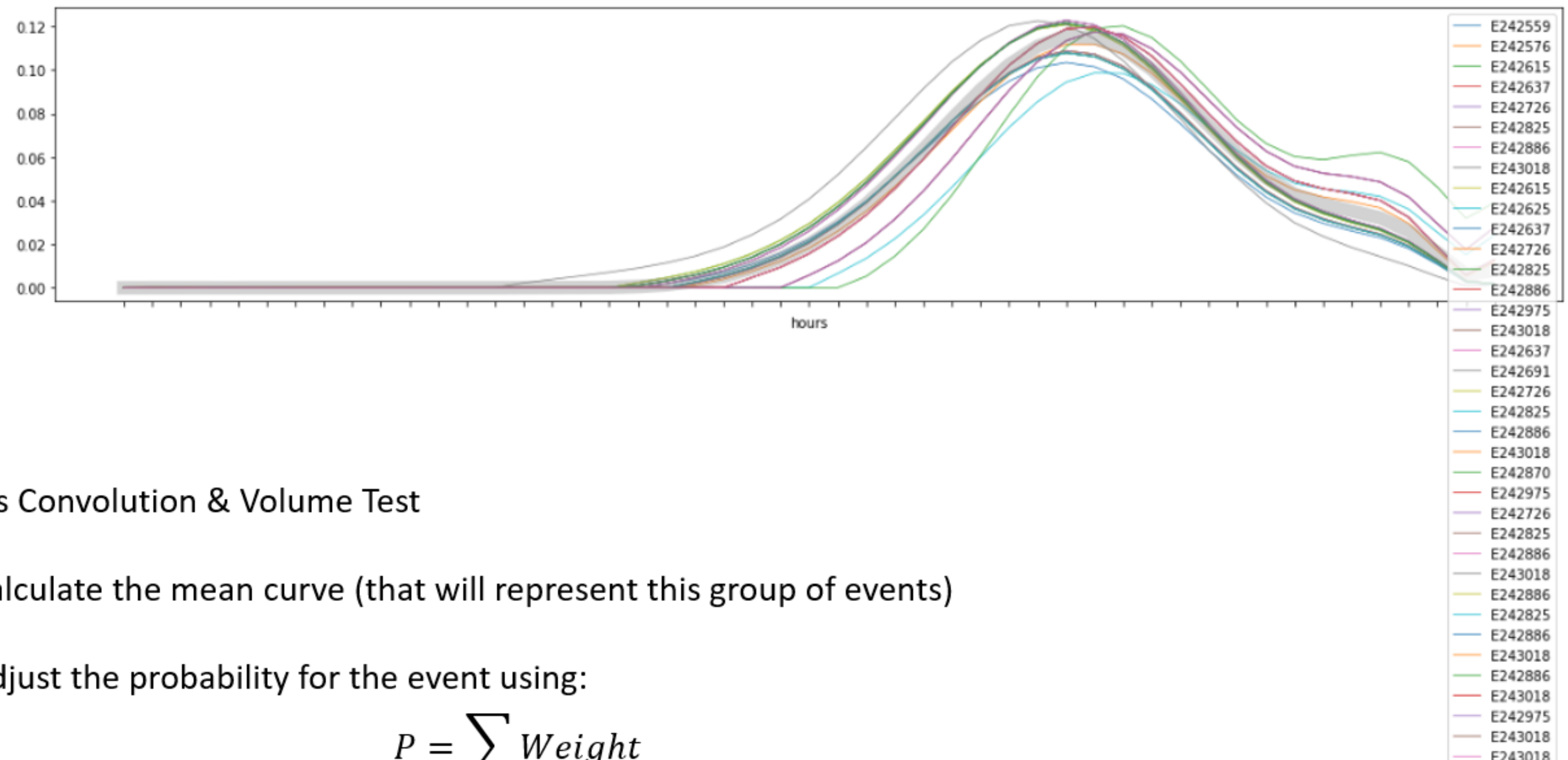


Crash Course of Probabilistic Approach
Pluvial Hydrology

- **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)

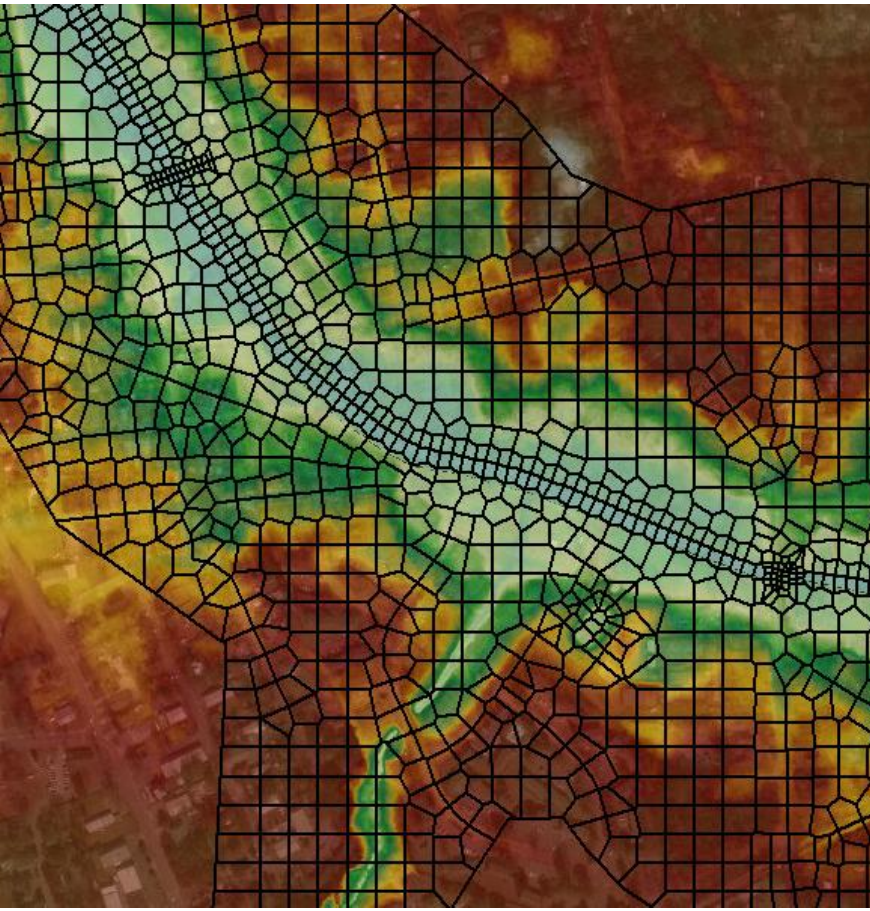
2. Adjust the probability for the event using:

$$P = \sum Weight$$

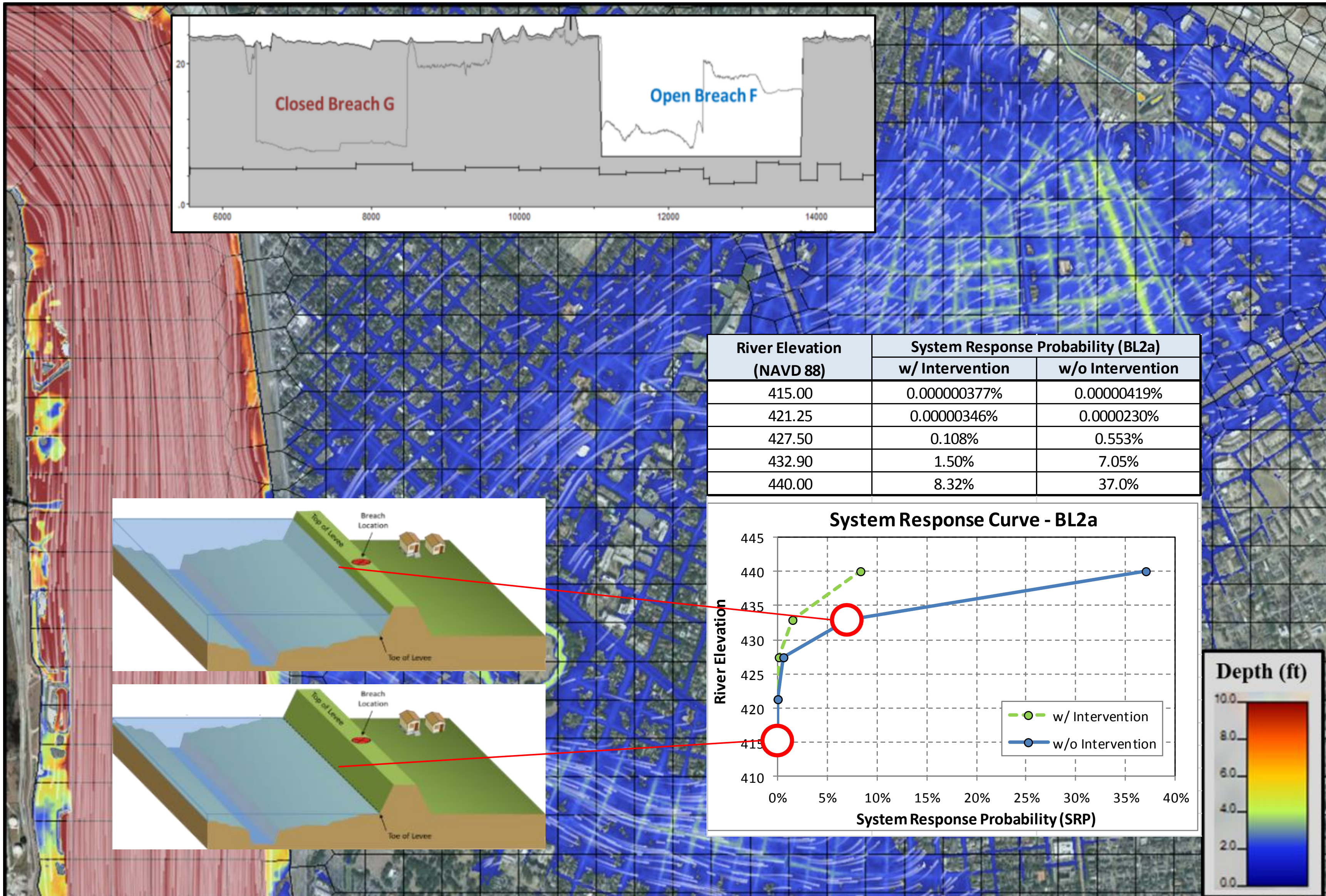
Pluvial convolution methodology developed by STARR II

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**



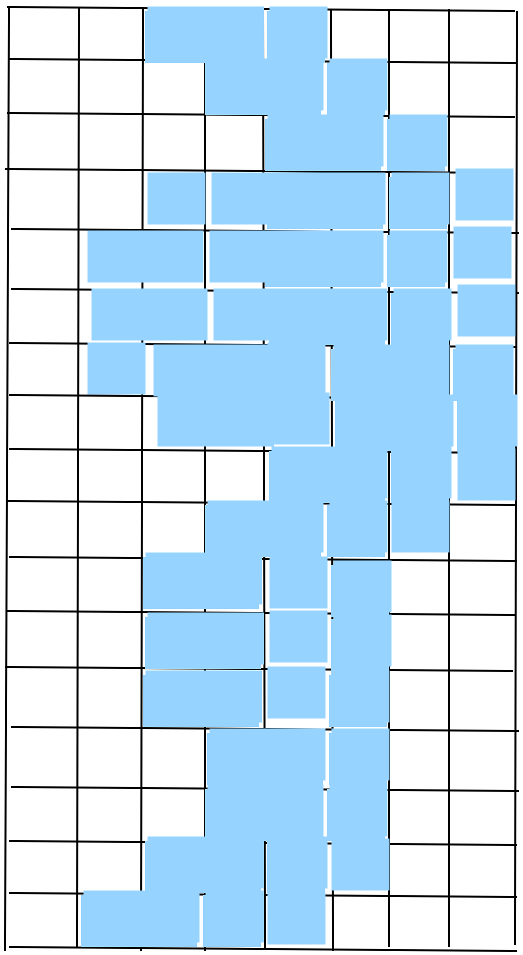
Probabilistic Approach (Levees)



River Elevation (NAVD 88)	System Response Probability (BL2a)	
	w/ Intervention	w/o Intervention
415.00	0.000000377%	0.00000419%
421.25	0.00000346%	0.0000230%
427.50	0.108%	0.553%
432.90	1.50%	7.05%
440.00	8.32%	37.0%

AEP Generation Concept

Flood Plain



AEP Database

0	0	1/2	1/2	1/2	0	0	0
0	0	0	1/2	1/2	1/2	0	0
0	0	0	0	1/2	1/2	1/2	0
0	0	0/1	0/1	1/2	1/2	1/2	0/1
0	0/1	0/1	0/1	1/2	1/2	1/2	0/1
0	0/1	0/1	0/1	1/2	1/2	1/2	0/1
0	0/1	0/1	0/1	0/1	1/2	1/2	1/2
0	0	0/1	0/1	0/1	1/2	1/2	1/2
0	0	0	0	1/2	1/2	1/2	0/1
0	0	0	1/2	1/2	1/2	0/1	0
0	0	1/2	1/2	0/1	1/2	0	0
0	0	1/2	1/2	0/1	1/2	0	0
0	0	1/2	1/2	0/1	1/2	0	0
0	0	0	1/2	1/2	1/2	0	0
0	0	0	1/2	1/2	1/2	0	0
0	0	1/2	1/2	1/2	0/1	0	0
0	1/2	1/2	1/2	0/1	0	0	0

Number of events

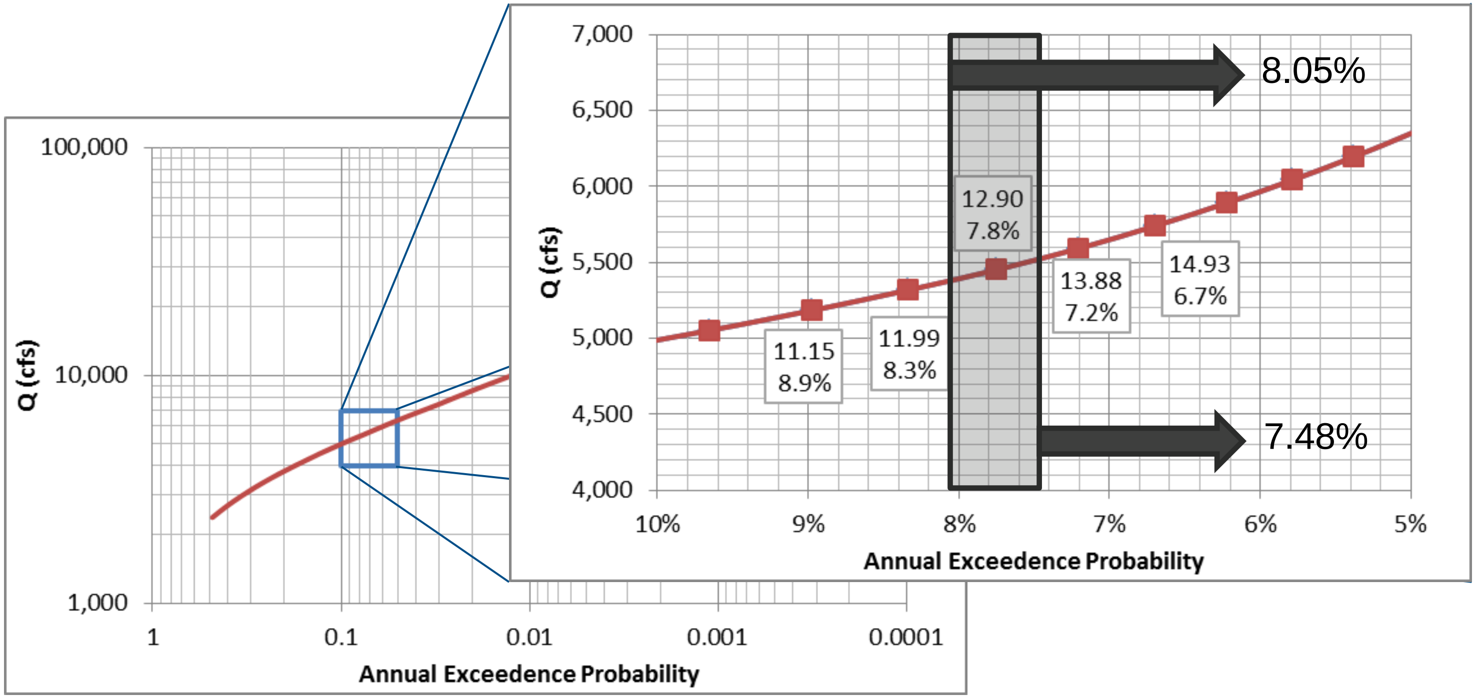
0/1/2

AEP= grid value/number of events

Example illustration borrowed from USACE

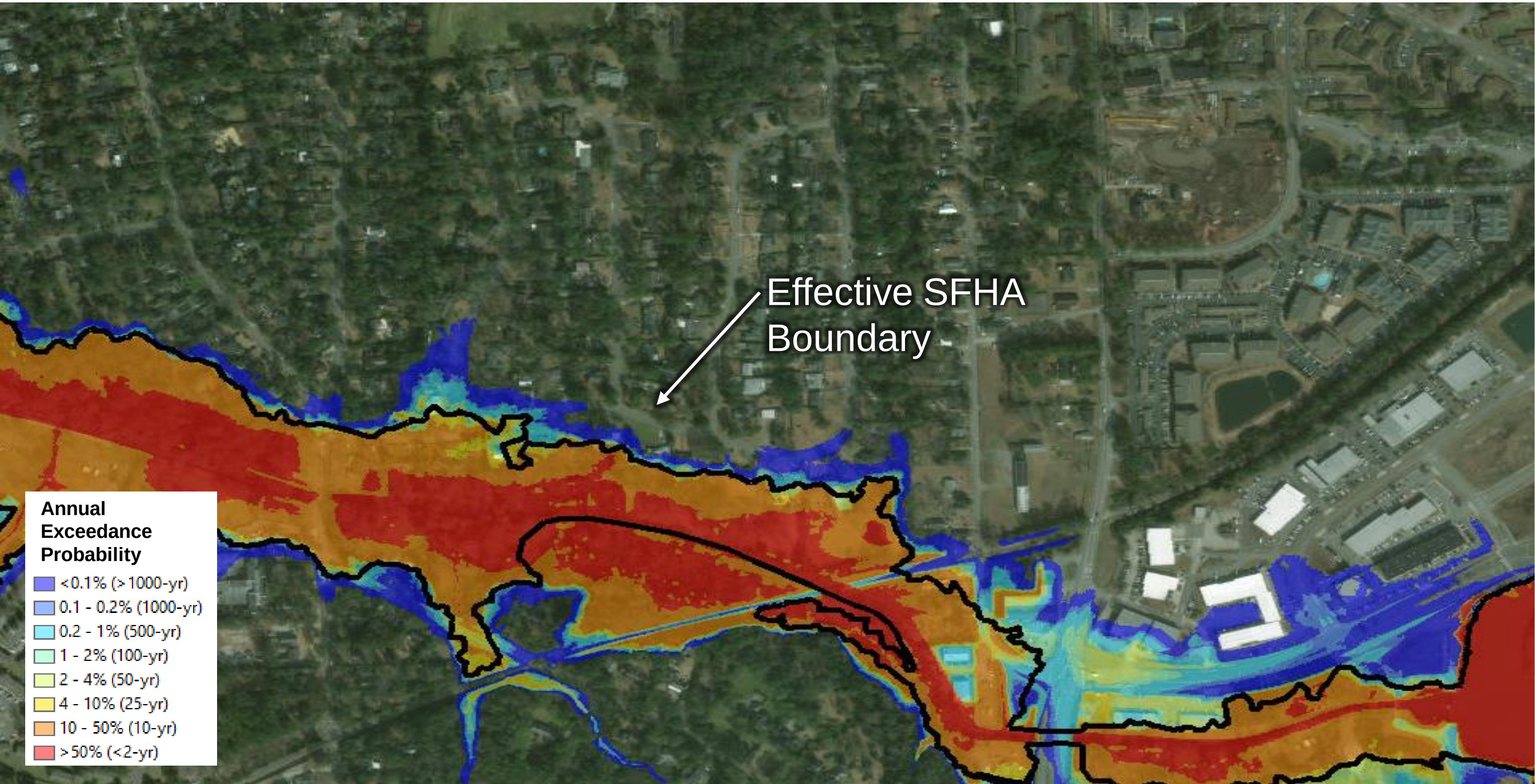
Risk Assessment

- **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**



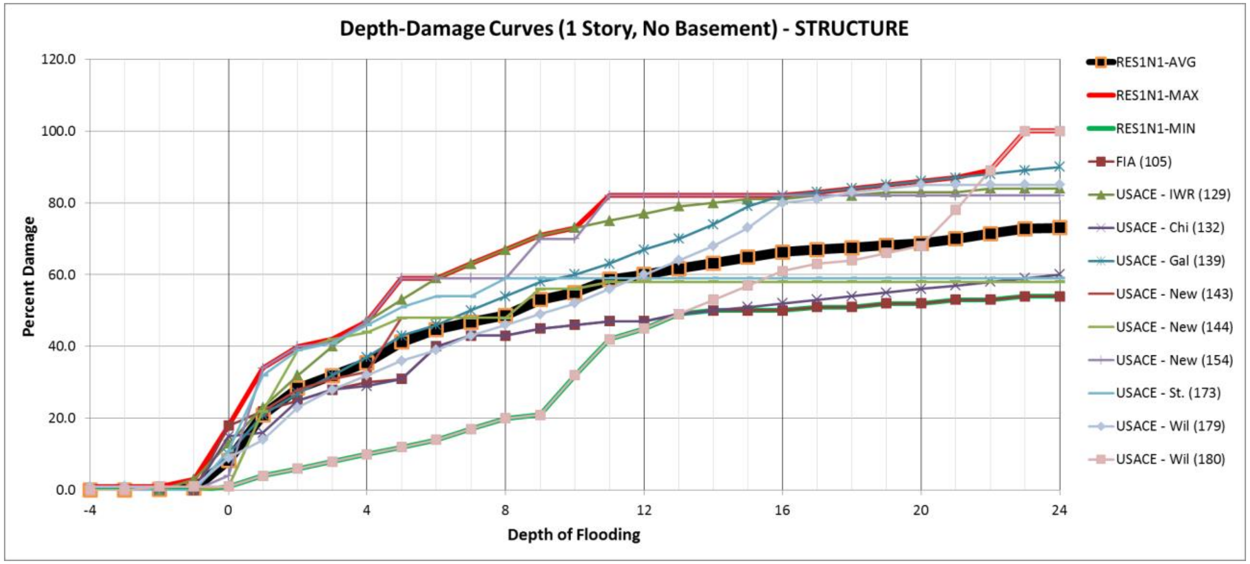
Annual Exceedance Probability Grid

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



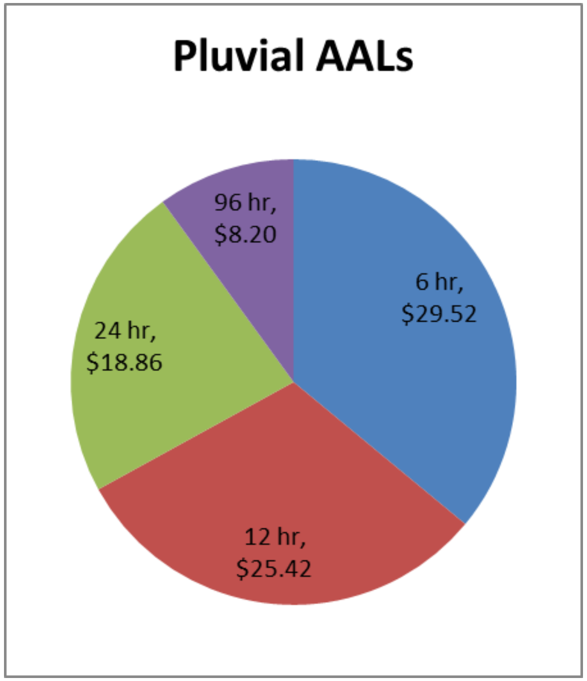
Risk Assessment

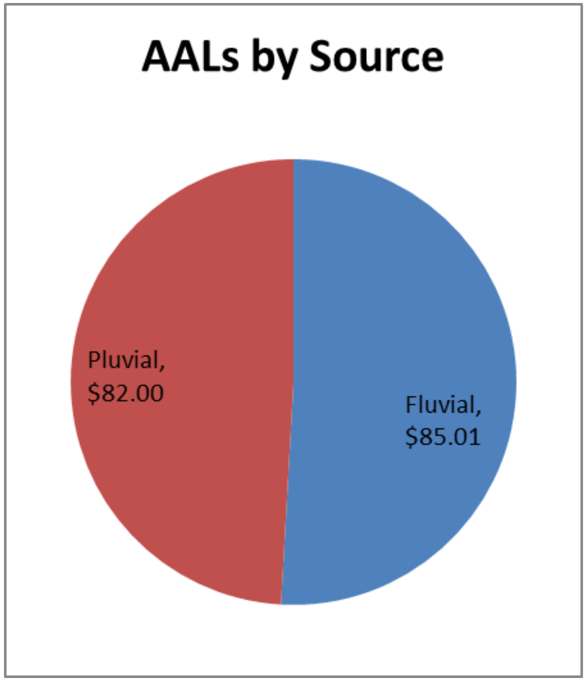
- **How do you go from thousands of water surface elevation rasters to a single value for damage?**
- **Damages for each simulation, then weighting factor to sum up**
  - Depth damage curves
  - Damage per event, multiplied by weight
- **Composite Depth-Damage curves for each structure type were used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

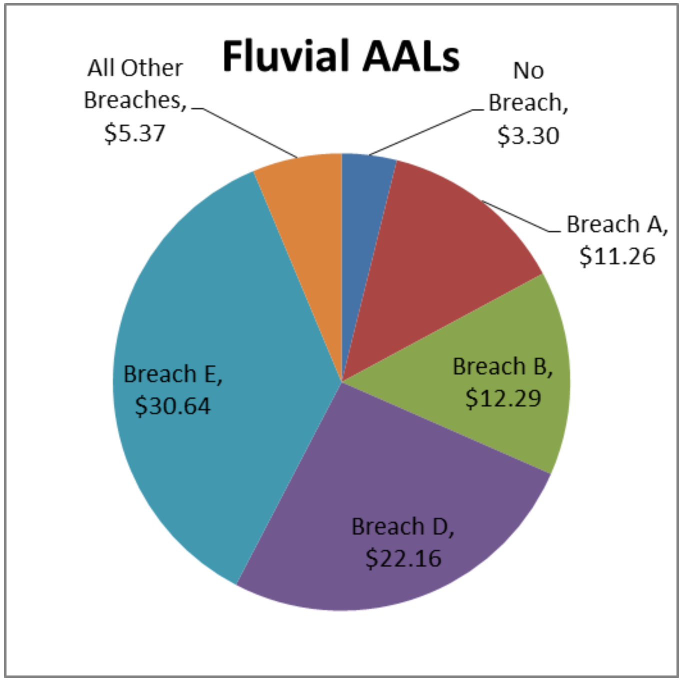


Risk Assessment

- 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?

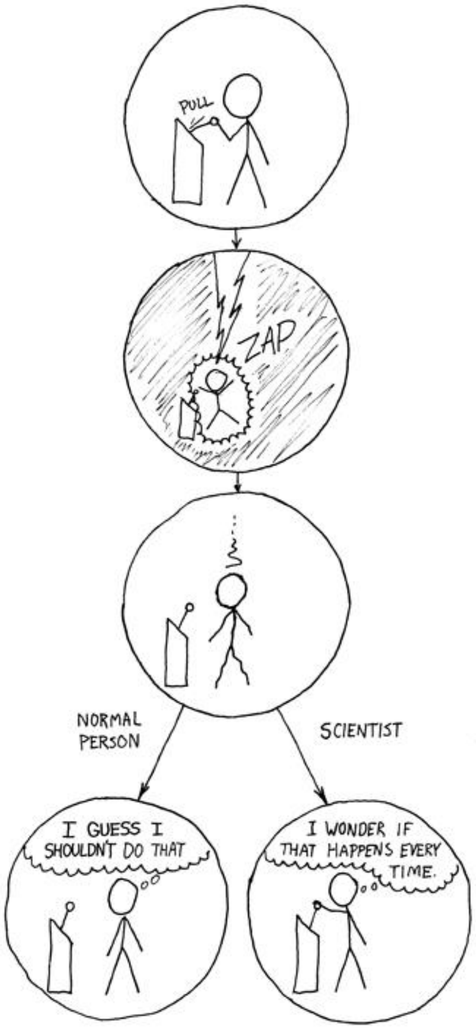






Traceability – not a black box

- **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



xkcd #242 "The Difference"

Results

Grids with any return period (WSEL, depth, d×v)

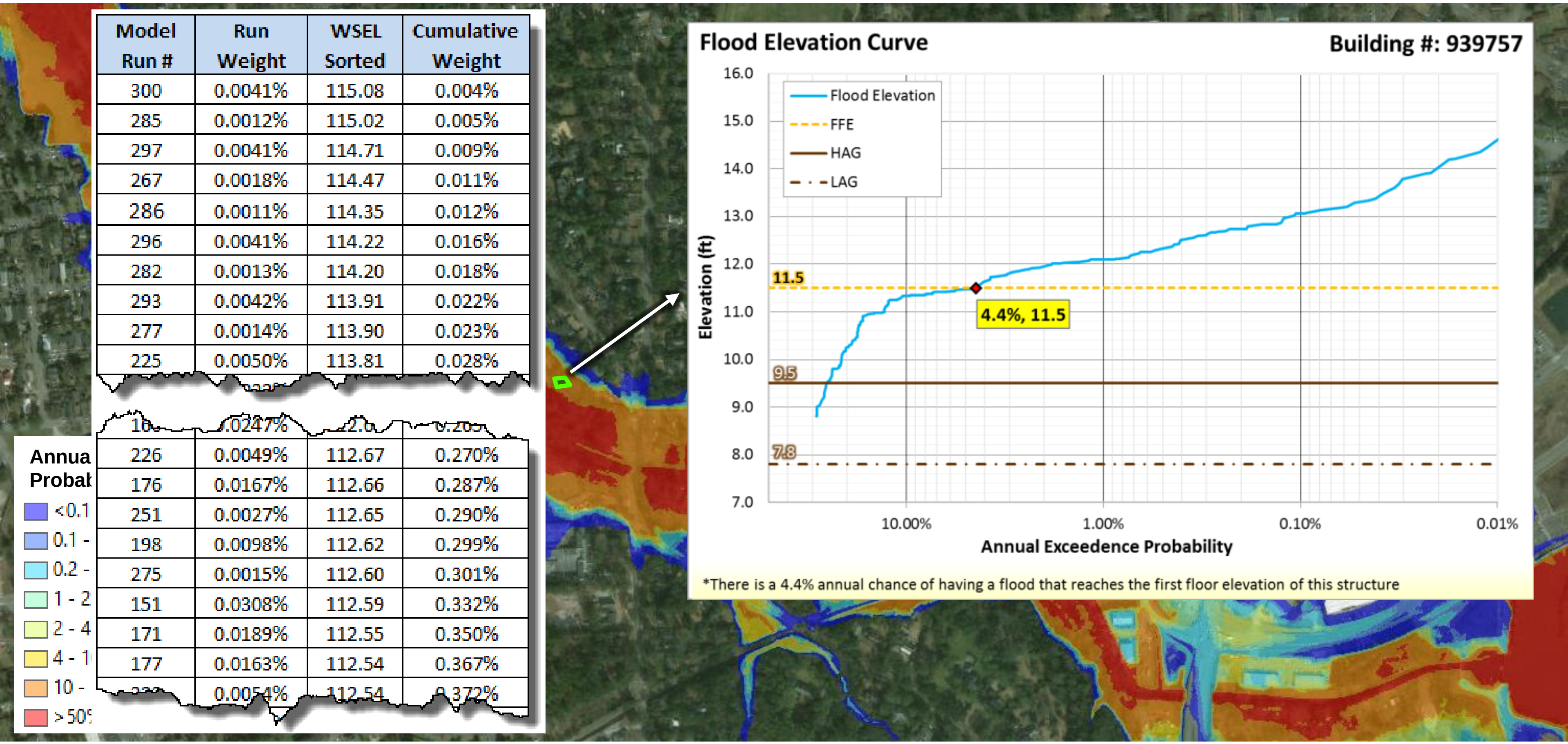
AEP grids

Structure-specific WSEL & damage curves

AALs for structures, areas, or systems

Structure-Level Risk
WSEL Curve

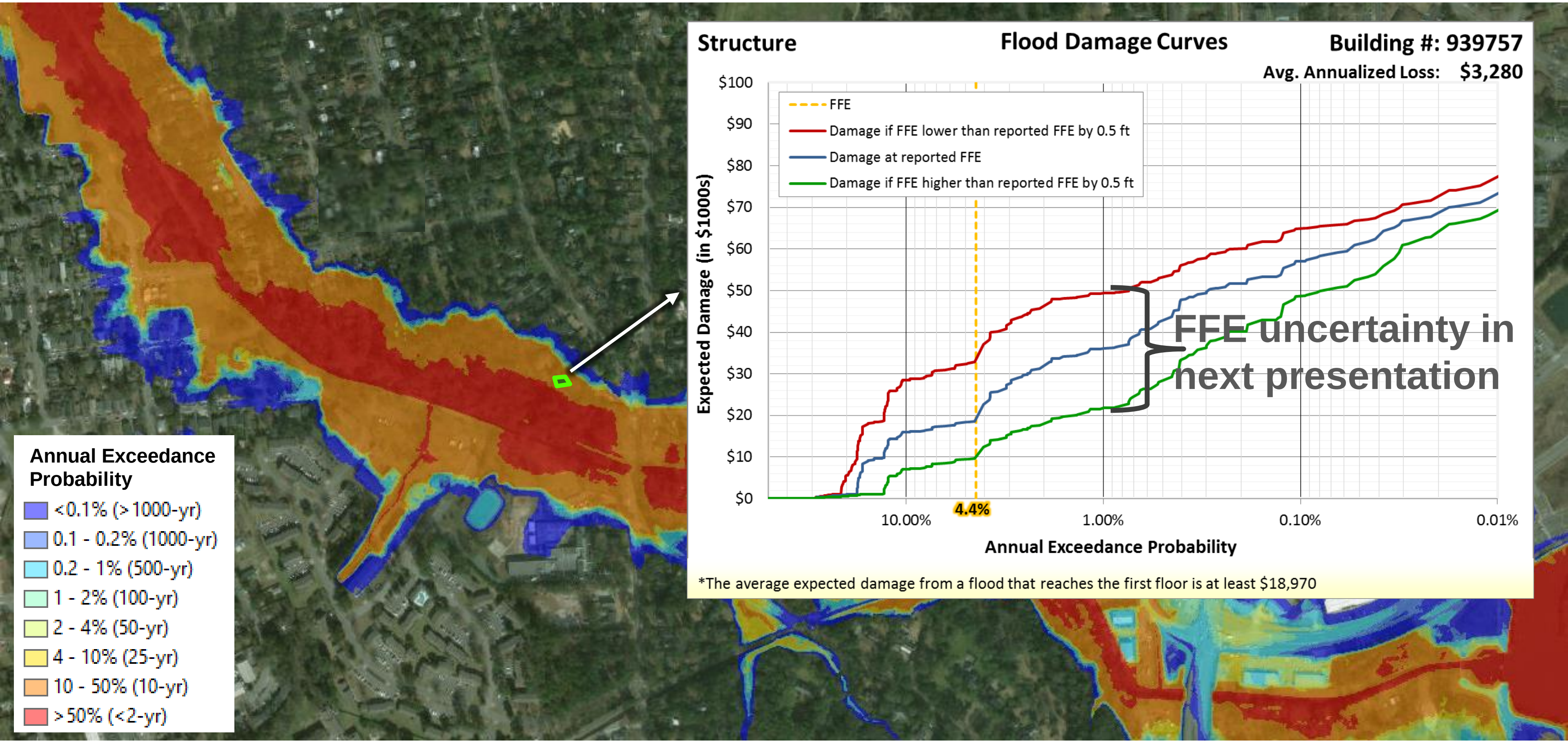
- **Detailed Flood Elevation-Probability Curves can be extracted for any structure of interest based on the underlying model results**



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%
[illegible]	[illegible]	[illegible]	[illegible]
226	0.0049%	112.67	0.270%
176	0.0167%	112.66	0.287%
251	0.0027%	112.65	0.290%
198	0.0098%	112.62	0.299%
275	0.0015%	112.60	0.301%
151	0.0308%	112.59	0.332%
171	0.0189%	112.55	0.350%
177	0.0163%	112.54	0.367%
[illegible]	0.0054%	112.54	0.372%

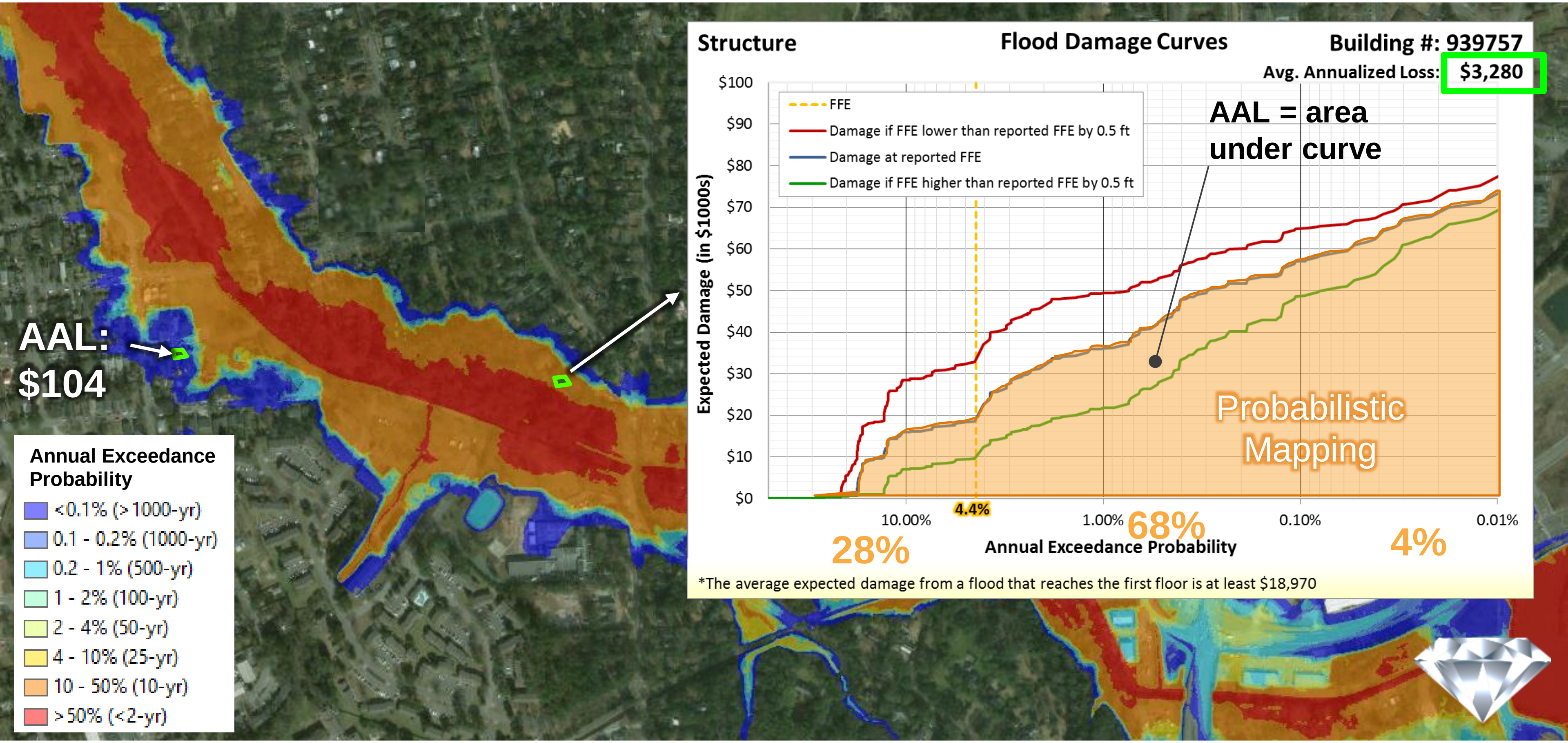
Structure-Level Risk
Damage Curve

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



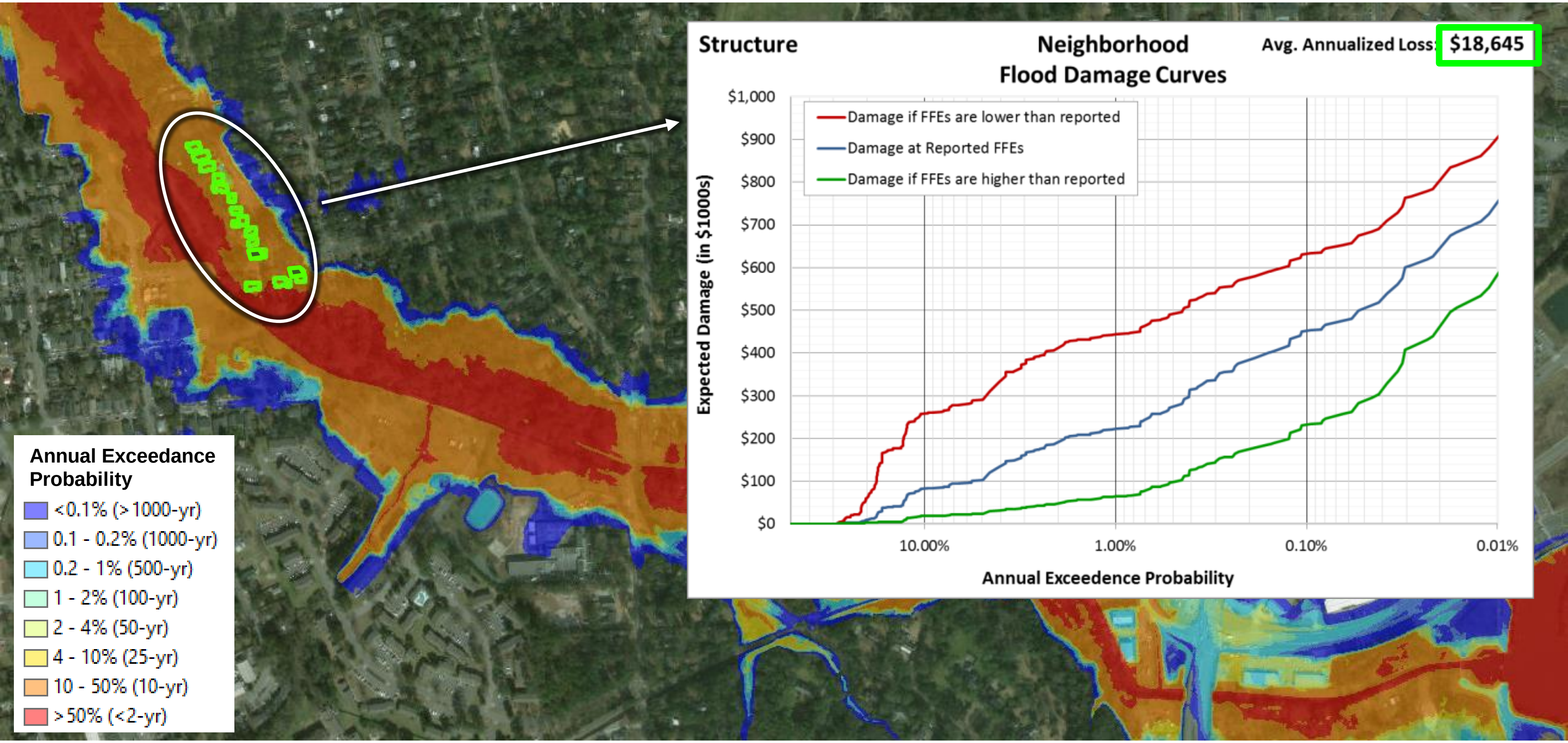
Structure-Level Risk
AALs by Home

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

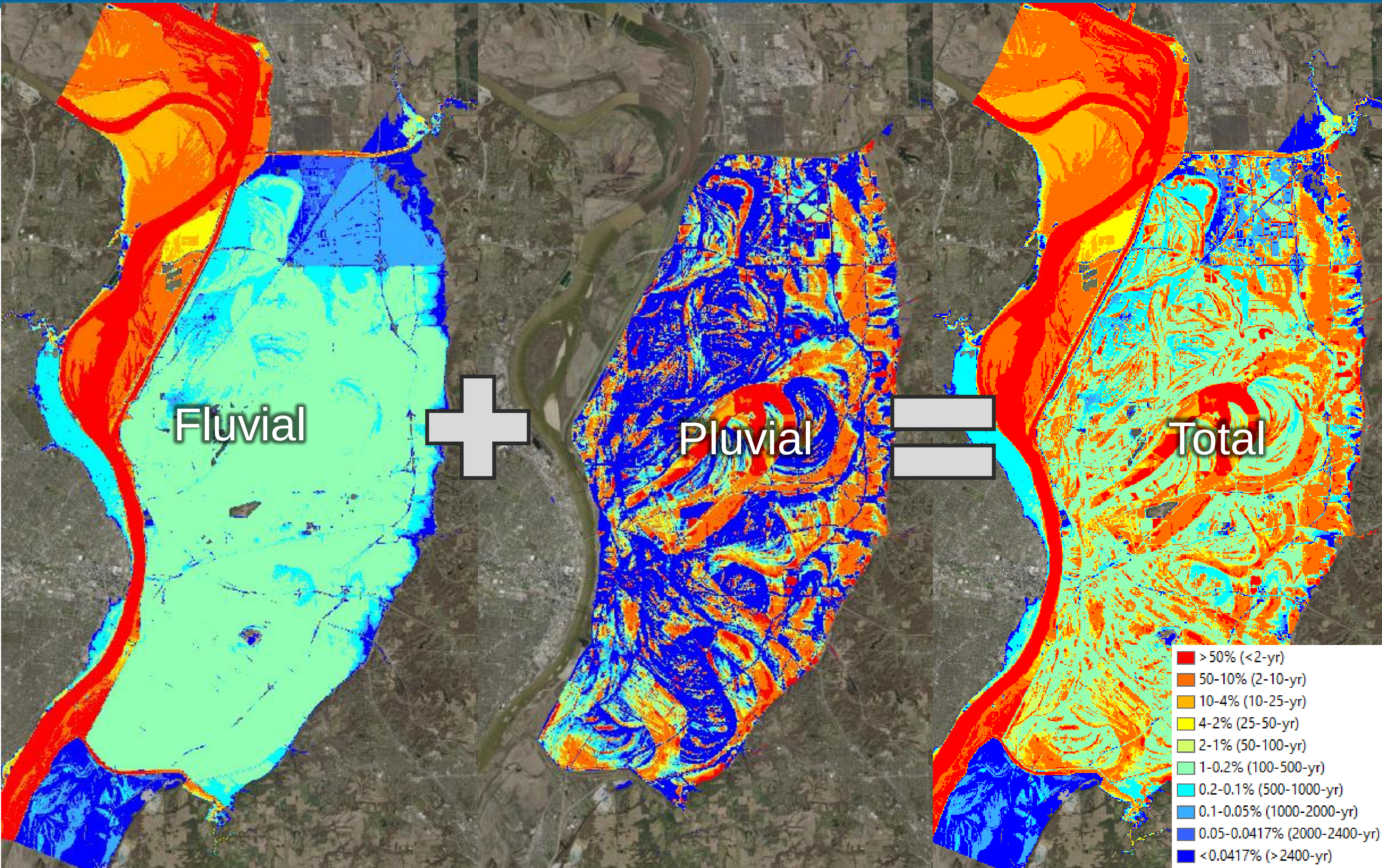


Structure-Level Risk
AALs by Area

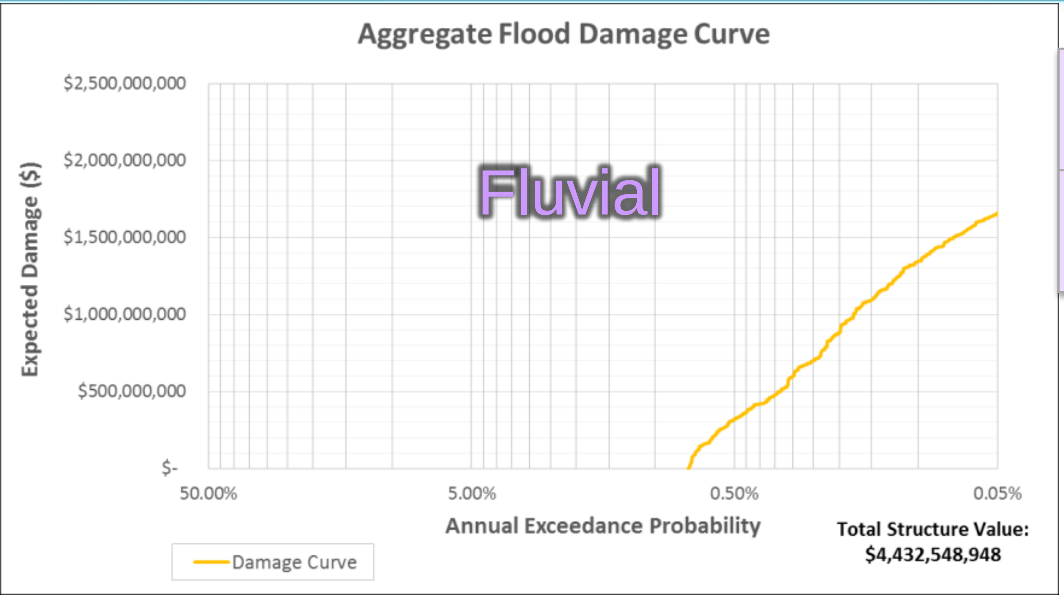
- **“Neighborhood” Damage Curves aggregated from structure data can provide insight into expected damages for multiple properties**



Aggregating AEP Maps

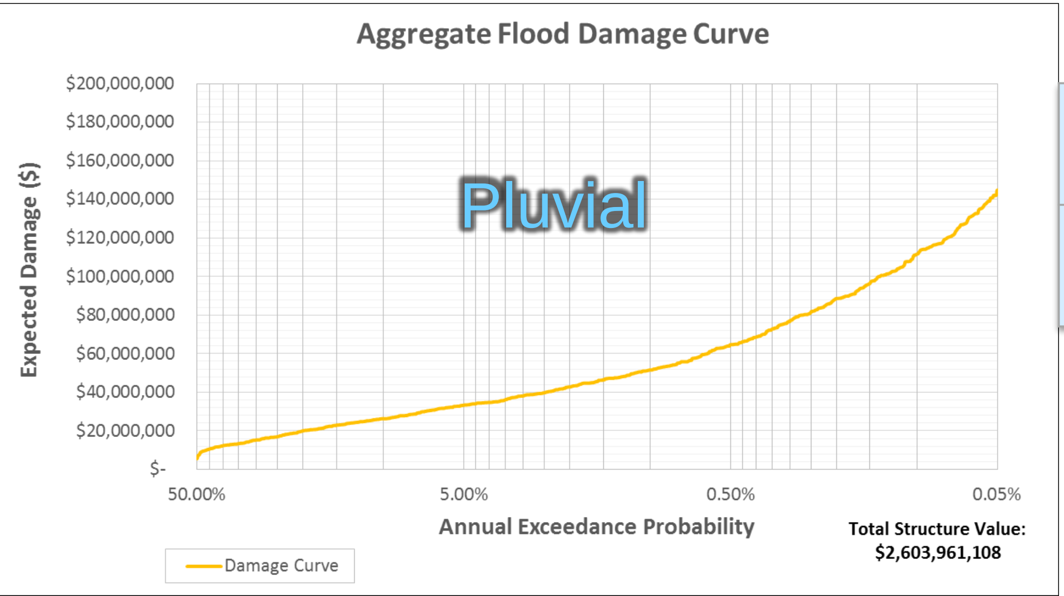


Aggregating AALs



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

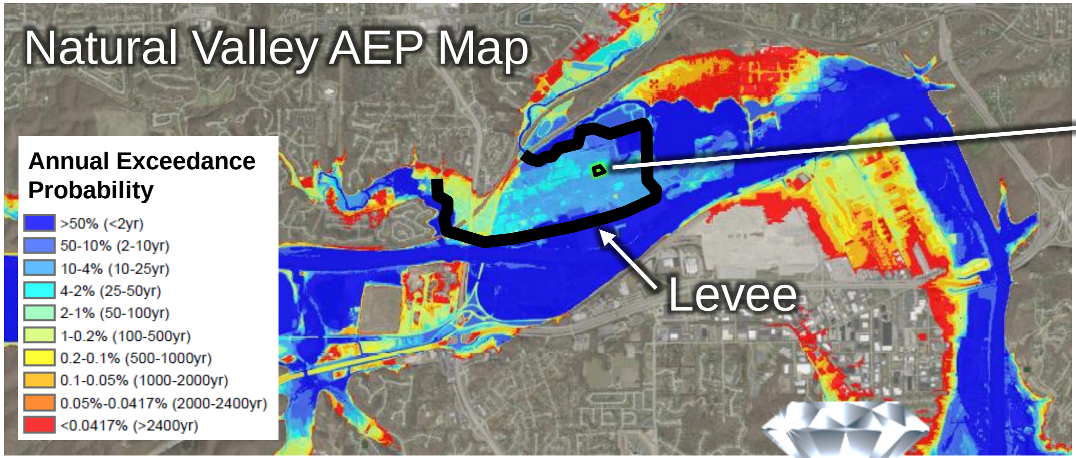
Total AAL
$15,028,131

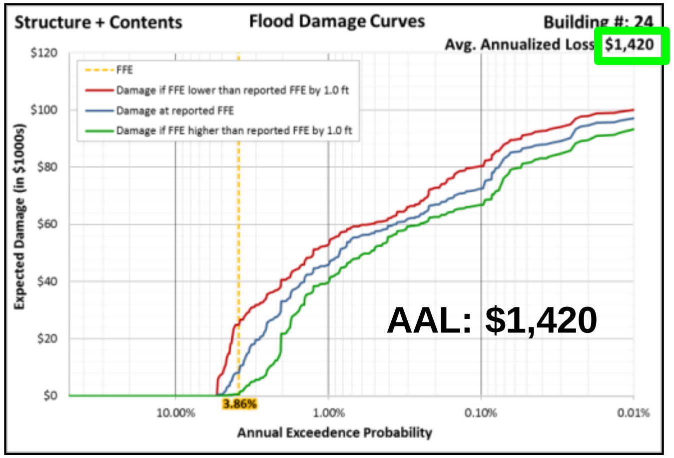


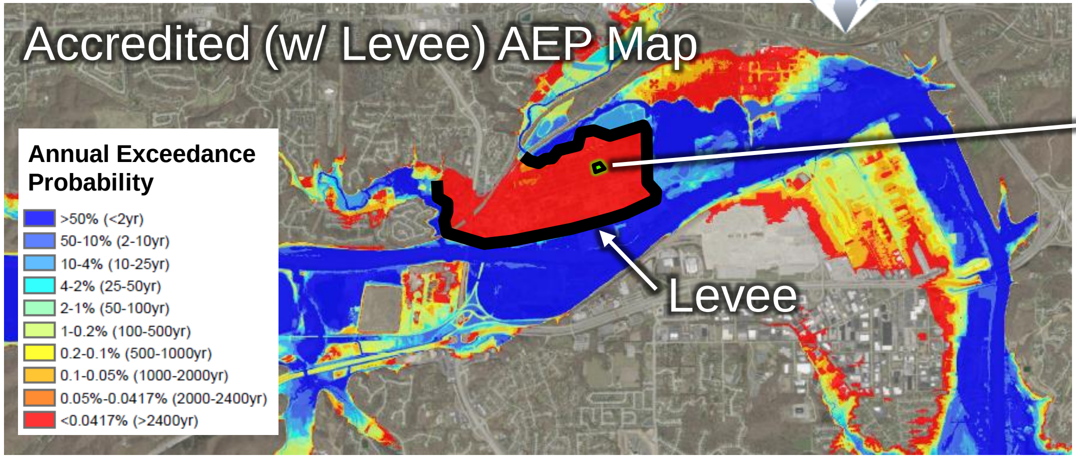
# Structures with Damage	21,491 of 35,236 (61%)
Avg. Annualized Loss (AAL)	$10,179,415

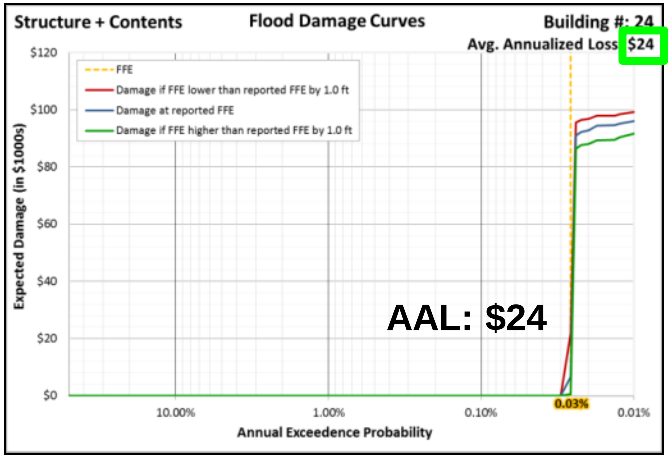
Cost Benefit Analysis for Levees

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







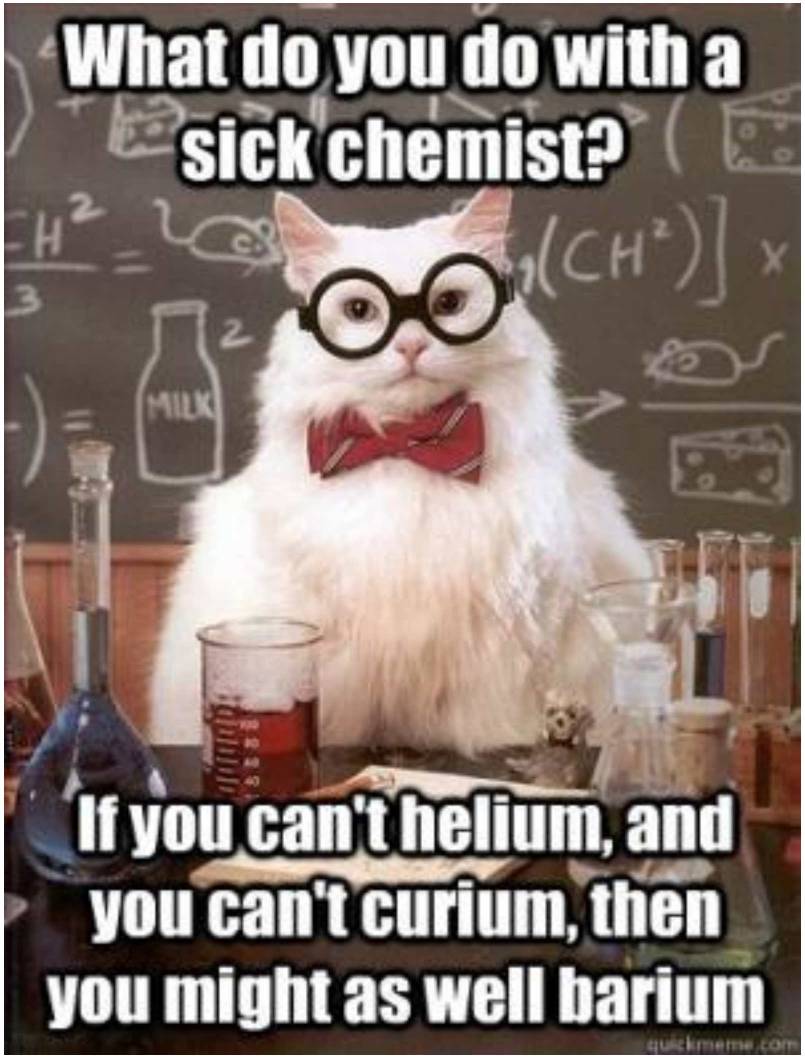


Benefits of PFRA

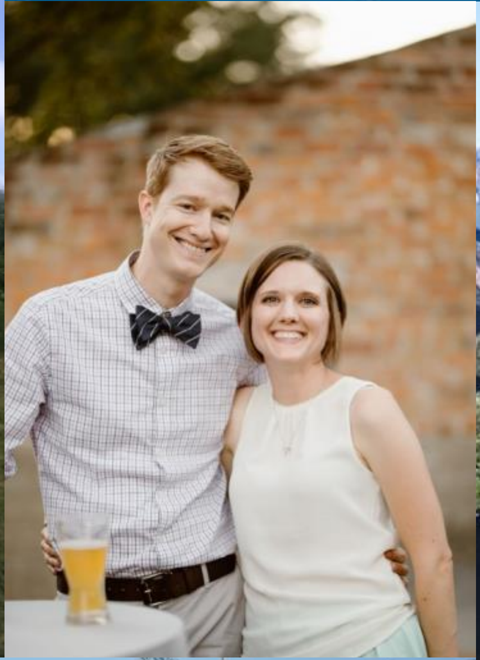
- Analysis
  - Full risk profile (fluvial, pluvial, residual, coastal)
  - Graduated risk between 50% and 0.033% floodplain
  - Accounts for uncertainty bands & varied assumptions
  - Focused on damages, not zones (considers FFE)
- Products
  - High resolution data for any return period
  - AAL estimates for structures and/or systems
  - AEP maps
- Abilities
  - Facilitates benefit-cost analyses for mitigation or CIP
  - Risk-Informed decision making
  - Enhanced outreach and awareness

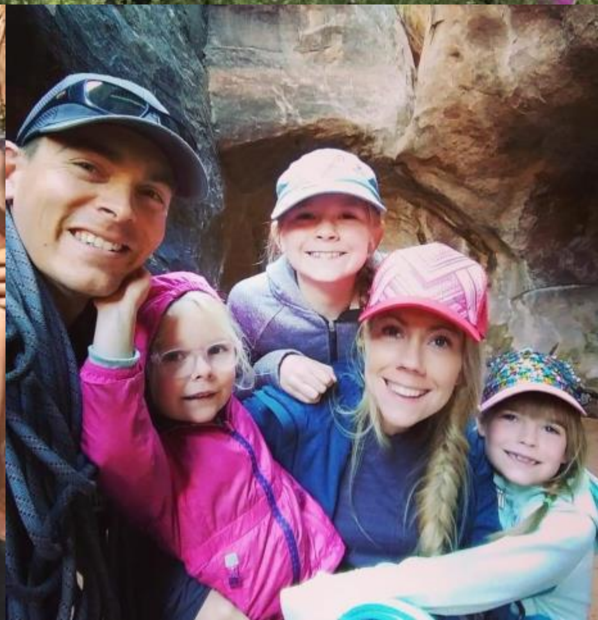
Part of that Exciting Future is… *More Cool Sciency Stuff!*

- **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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