CASFM 2018 Annual Conference

Emergency Preparation Sessions:

Session1: Extreme Rainfall Events Along the Front Range of CO

Baxter Vieux (Vieux), Kevin Steward (UDFCD)

Session2: Structure-Level Risk Assessment Using 2D Modeling

Geoff Uhlemann (AECOM)

Mapping Fluvial Hazard Zones: Developing Guidance, Applications, Pilot

Stephanie DiBettito (CWCB), Joel Sholtes (USBR), Michael Blazewicz (Round River Design), Katie Jagt (Watershed Science)

Evacuation Planning for Extreme Events: Failure of Cherry Creek

Jeffrey Brislawn, Kyle Karsjen (Wood)

Innovation in Colorado: High Hazard Dam Release – Downstream Floodplain Impacts

Bill McCormick, Kallie Bauer (CO Division of Water Resources)

Showcasing the Pilot Boulder County FRIS

Madeline Kelley (DU), Thuy Patton (CWCB)

2018 CASFM Conference will be held September 25-28, 2018
Westin Snowmass Resort Snowmass, CO
Emergency Preparation EP1, Thursday, September 27, 2018 1:30pm Cathedral Peak

Extreme Rainfall Events along the Front Range of Colorado:

How much did we find, and How much did we miss?

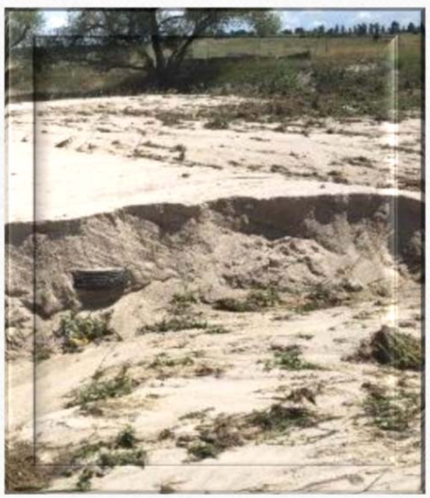
Baxter E. Vieux P.E. Ph.D., CTO Vieux & Associates, Inc.
Kevin Stewart, P.E., UDFCD Program Manager
Flood Warning & Information Services

On July 26, 2017 news media reported street flooding in Greenwood Village…

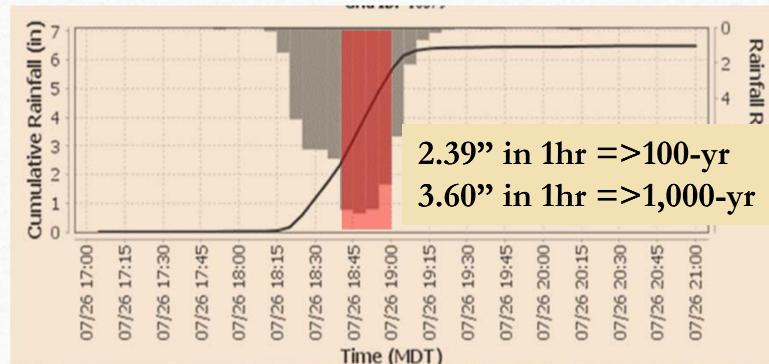
- A small stream out of its banks but no notable damages.
- Consistent with evening news reports about street flooding in Greenwood Village…
- **But where was the most extreme rainfall?**

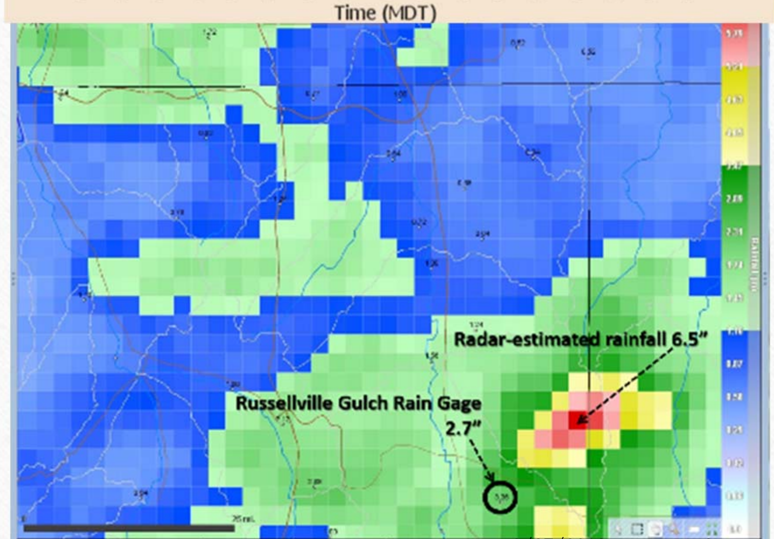
  (Hint: Not Greenwood Village!)

Fox Hill Flood
July 26, 2017



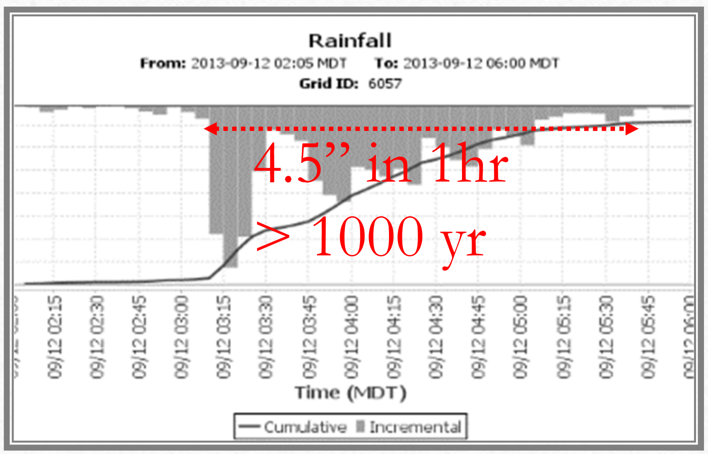
Flood damages from >1000 year rain event

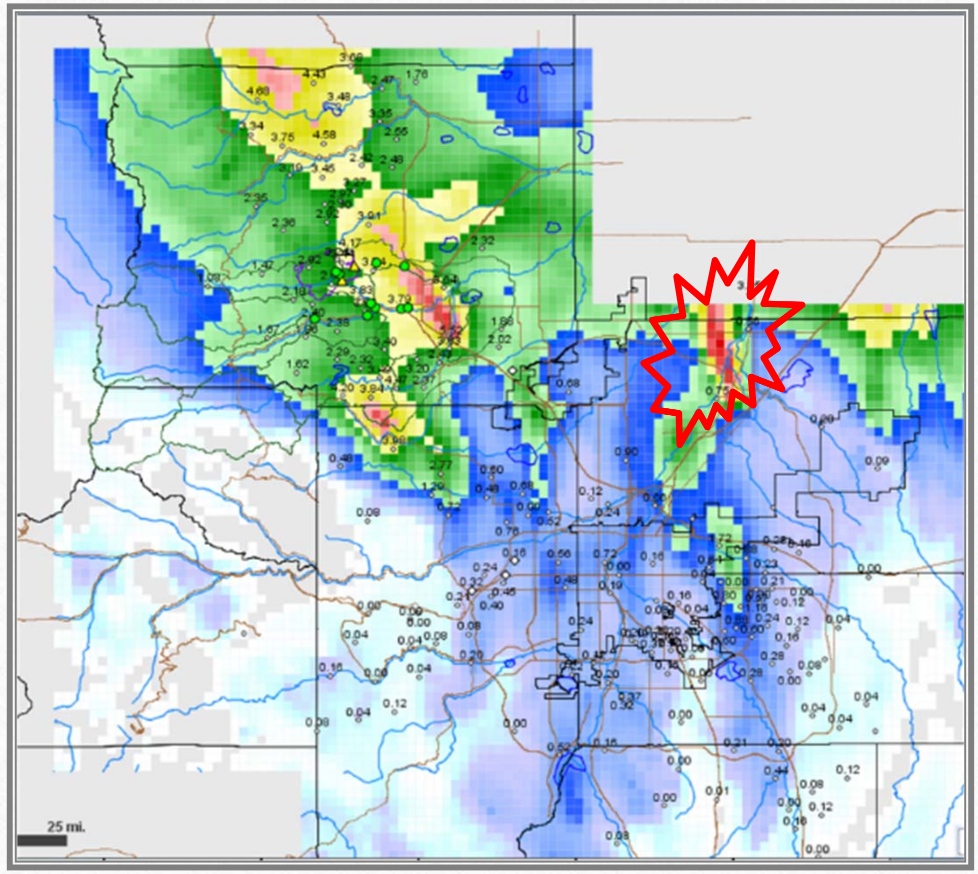




Todd Creek
Adams County

- A 8-hour period from
- 8PM (9/11/13) to 4AM (9/12/13)





Examining Extreme Event Detection

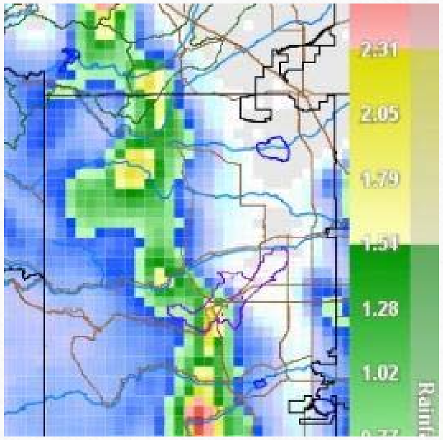
GARR and Gauges over the UDFCD Region

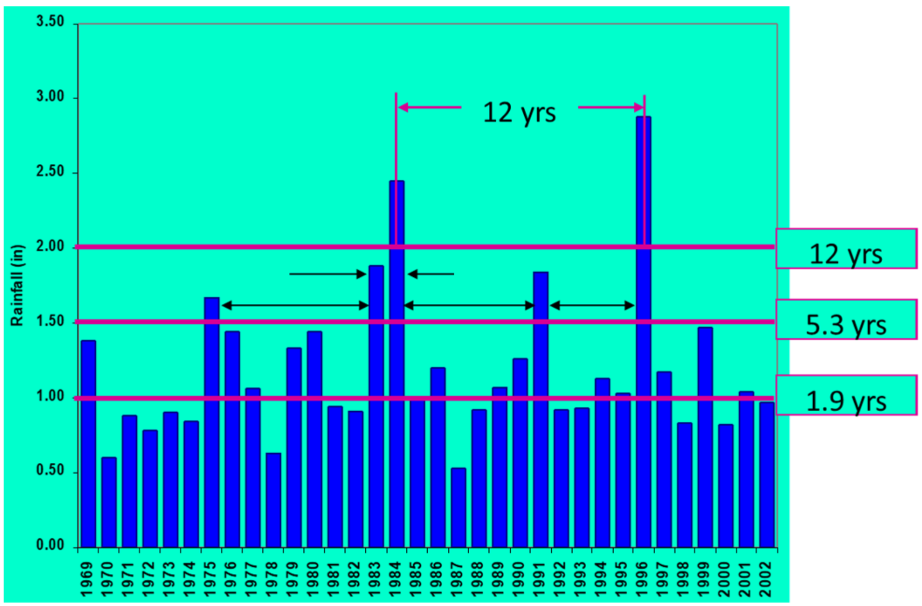
Detecting Extreme Rainfall

- Real-time rainfall is needed for flood alert decisions in support of the Urban Drainage and Flood Control District.
- UDFCD covers 1,608 mi^2 and parts of 6 counties along the Colorado Front Range
- FCD operates 202 ALERT rain gauges with a mean spacing of 2.6 mi.
- Gauge-adjusted radar rainfall (GARR) is a combination of weather radar and these gauges that fills in between the gauges.

Tools for today's analysis

- GARR
  - Radar spatial patterns at high resolution
  - Rain gauge point measurements
- Better than either system alone at producing accurate high resolution rainfall everywhere…'between the gauges'



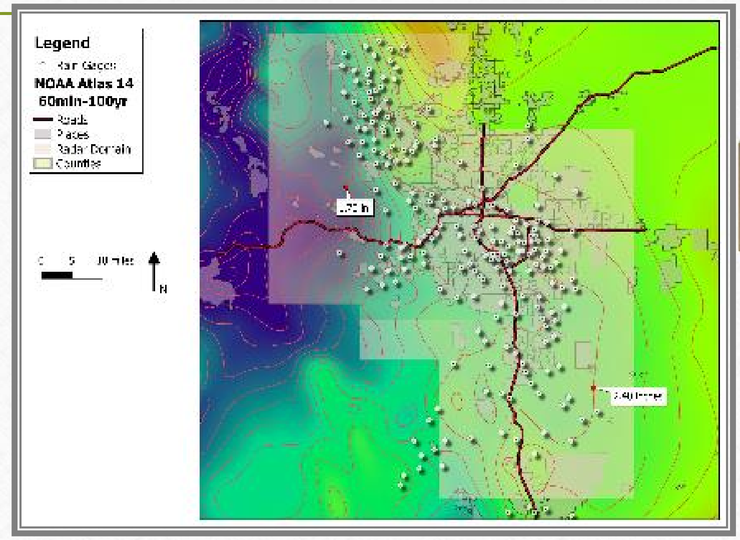


Return Period

- Defined as: "Average time between events larger than a given threshold"
- Used to categorize precipitation frequency.
- 100-yr event = 1 event in 100 years

NWS NOAA Atlas 14 Precipitation Probabilities

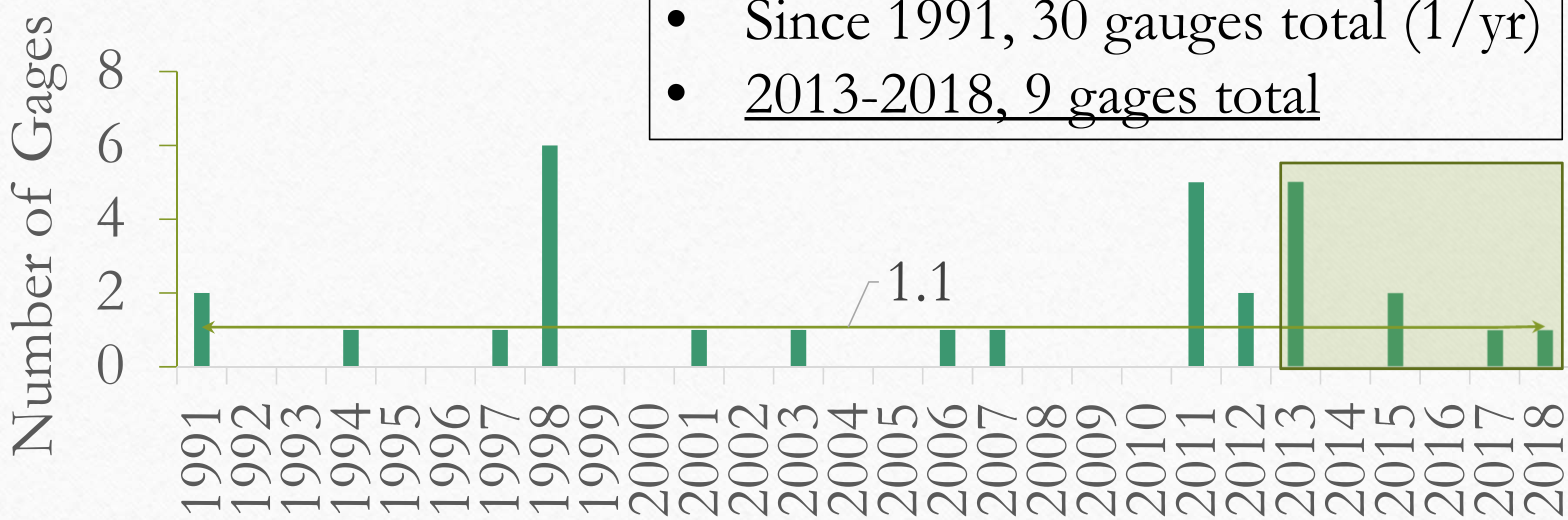
- Statistically at each of the 202 rain gauges there should be:
- One 100yr event occurs on average once every 100 years,
- Any one gauge has a 1% chance any given year
- Over 5 years, one gauge has 4.8% chance of a 100-yr event, Risk=$(1-1/T)^n$



Bedient, Huber, and Vieux (2018) Hydrology and Floodplain Analysis

100yr-60min Events Detected by Rain Gauges

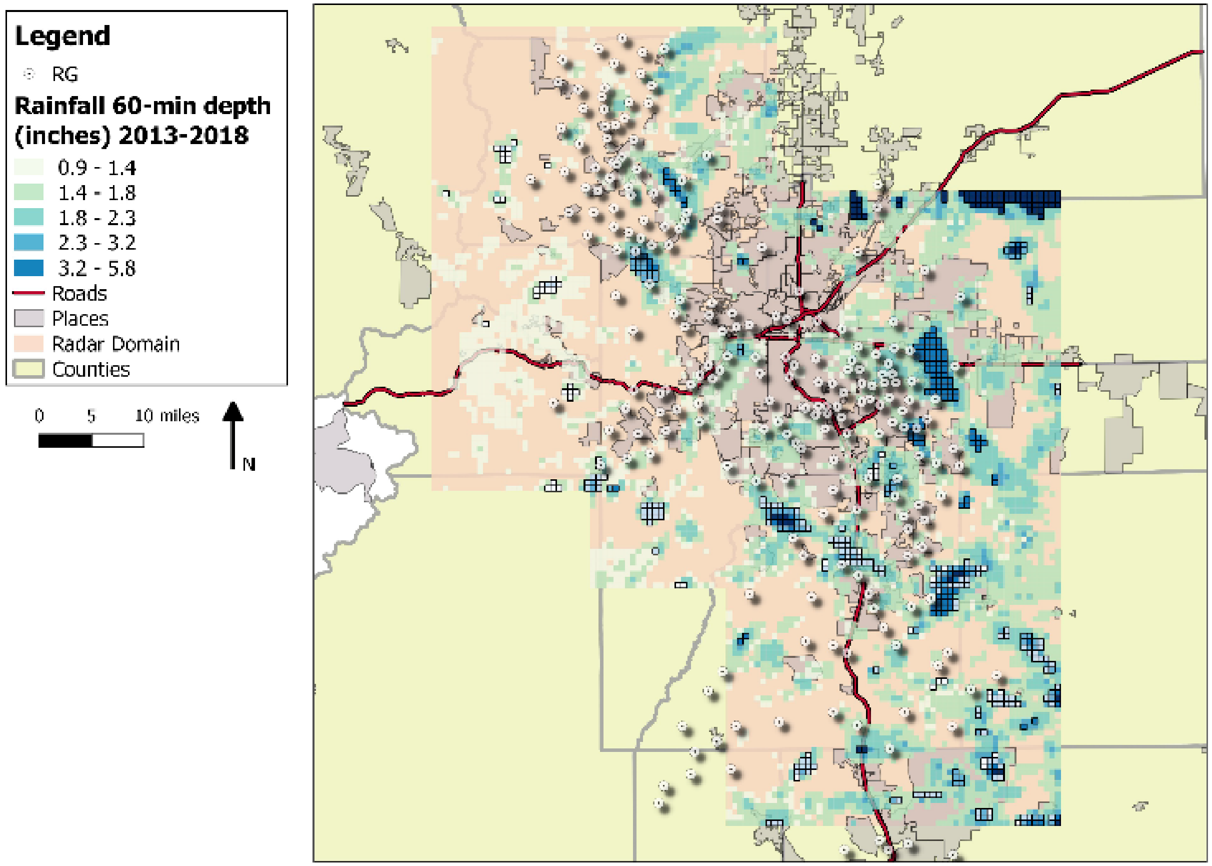
- Since 1991, 30 gauges total (1/yr)
- 2013-2018, 9 gages total

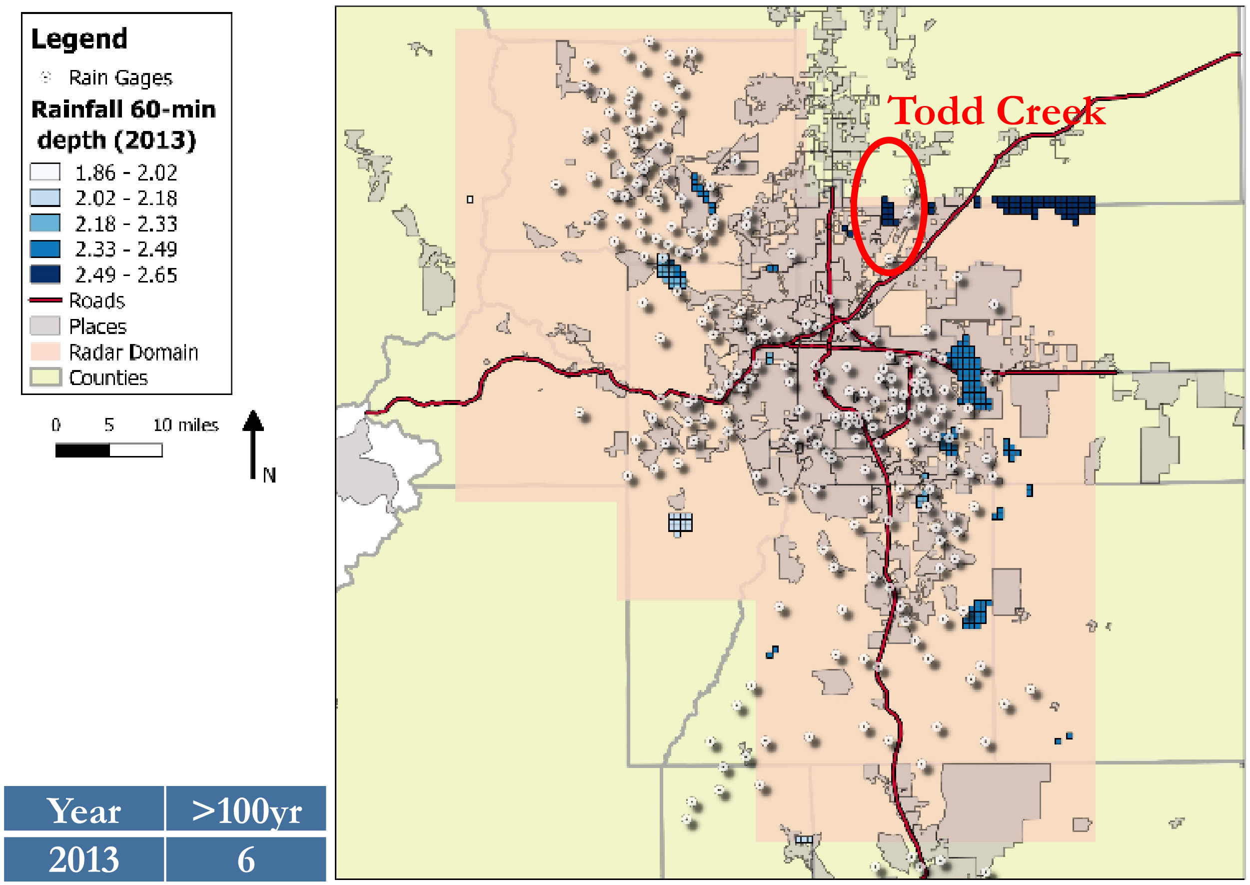


GARR Events

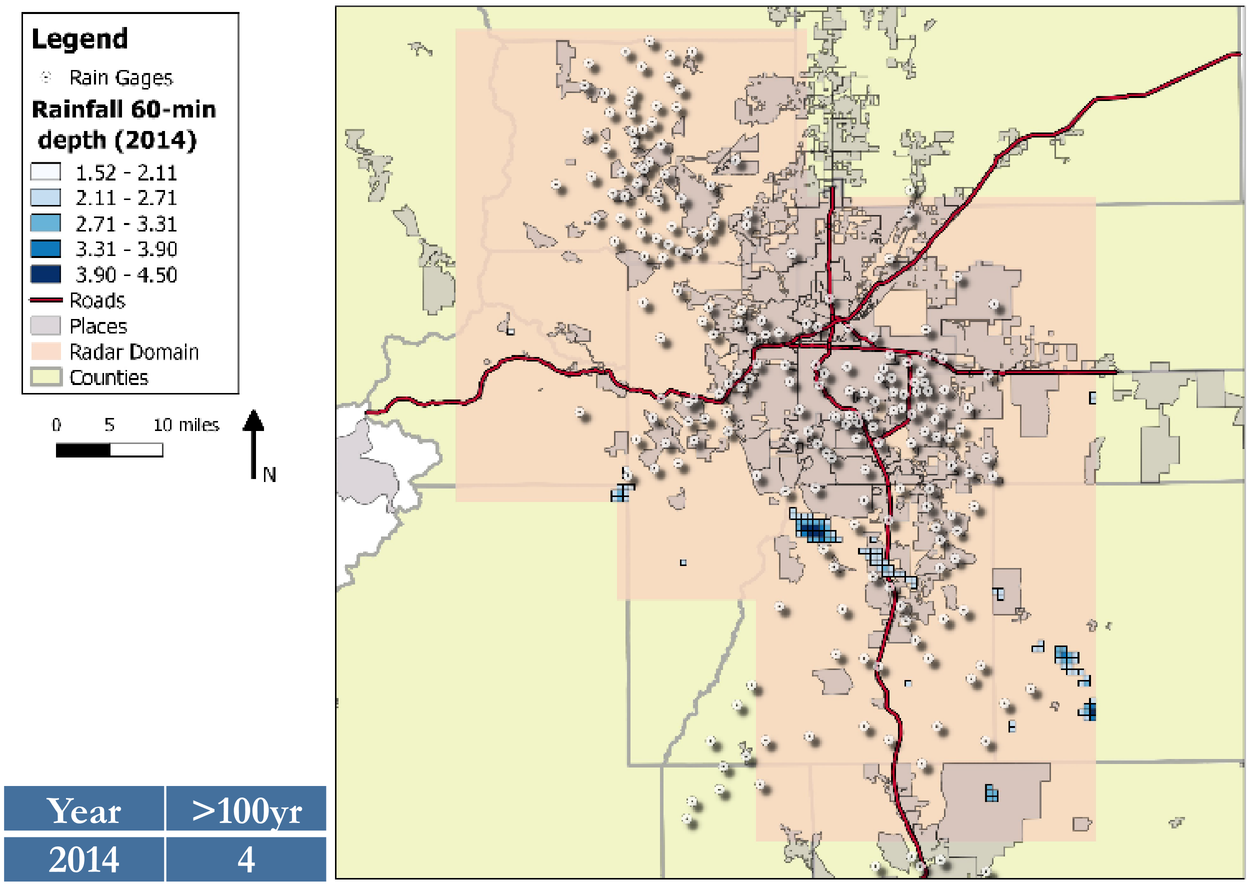
Year	>100yr
2013	6
2014	4
2015	3
2016	1
2017	12
2018	1
Total	26
Average	**5.2**

- **26 pixel events 5 per year**
- **9 gage events, 1 per year**

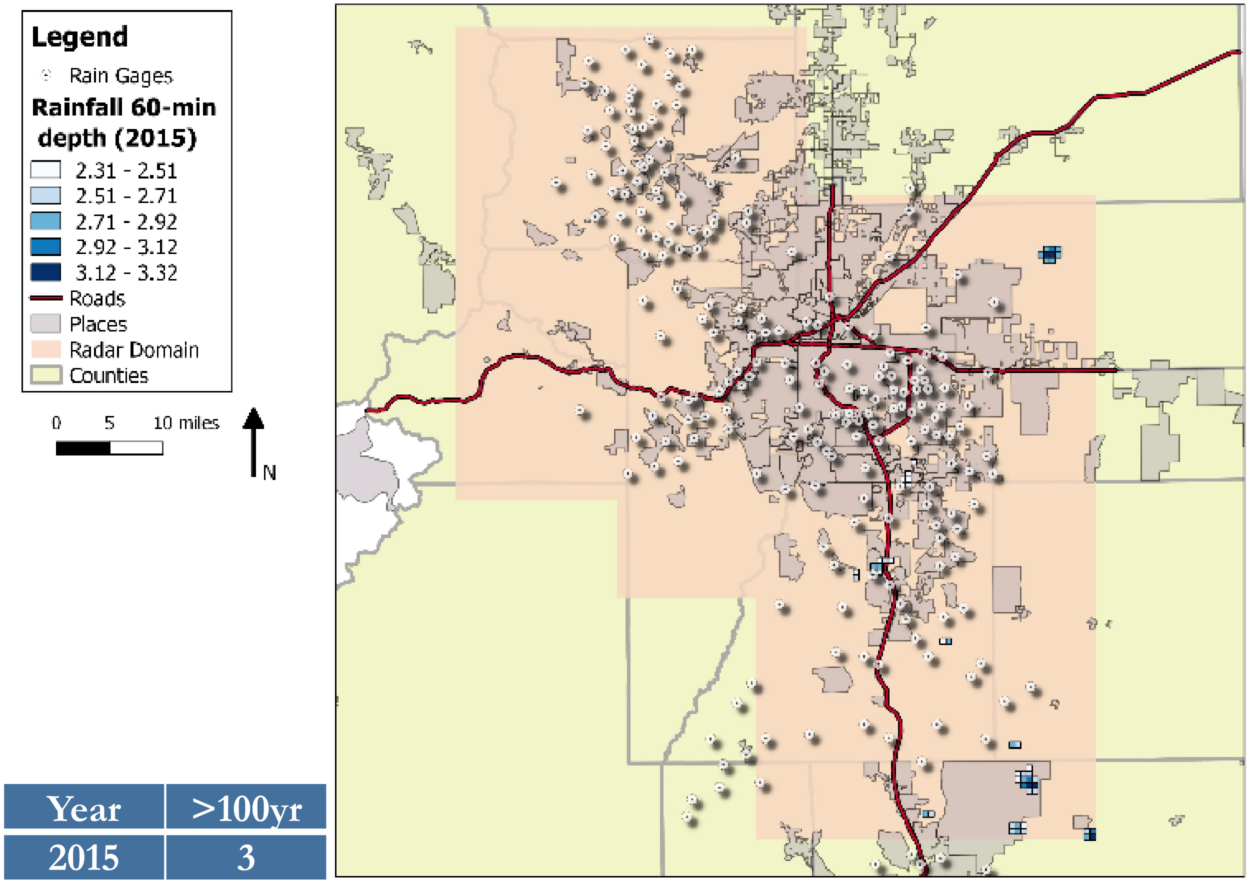




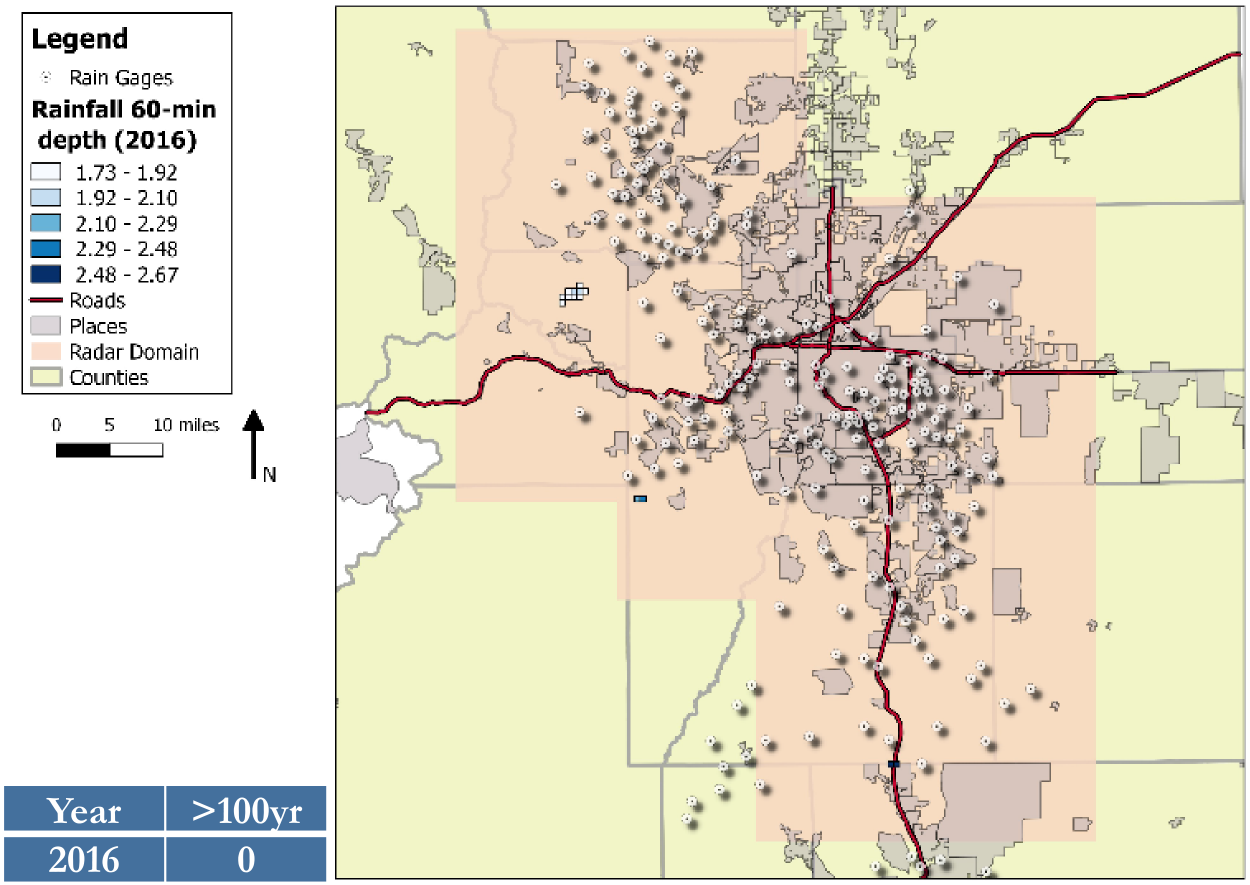
Year	>100yr
2013	6



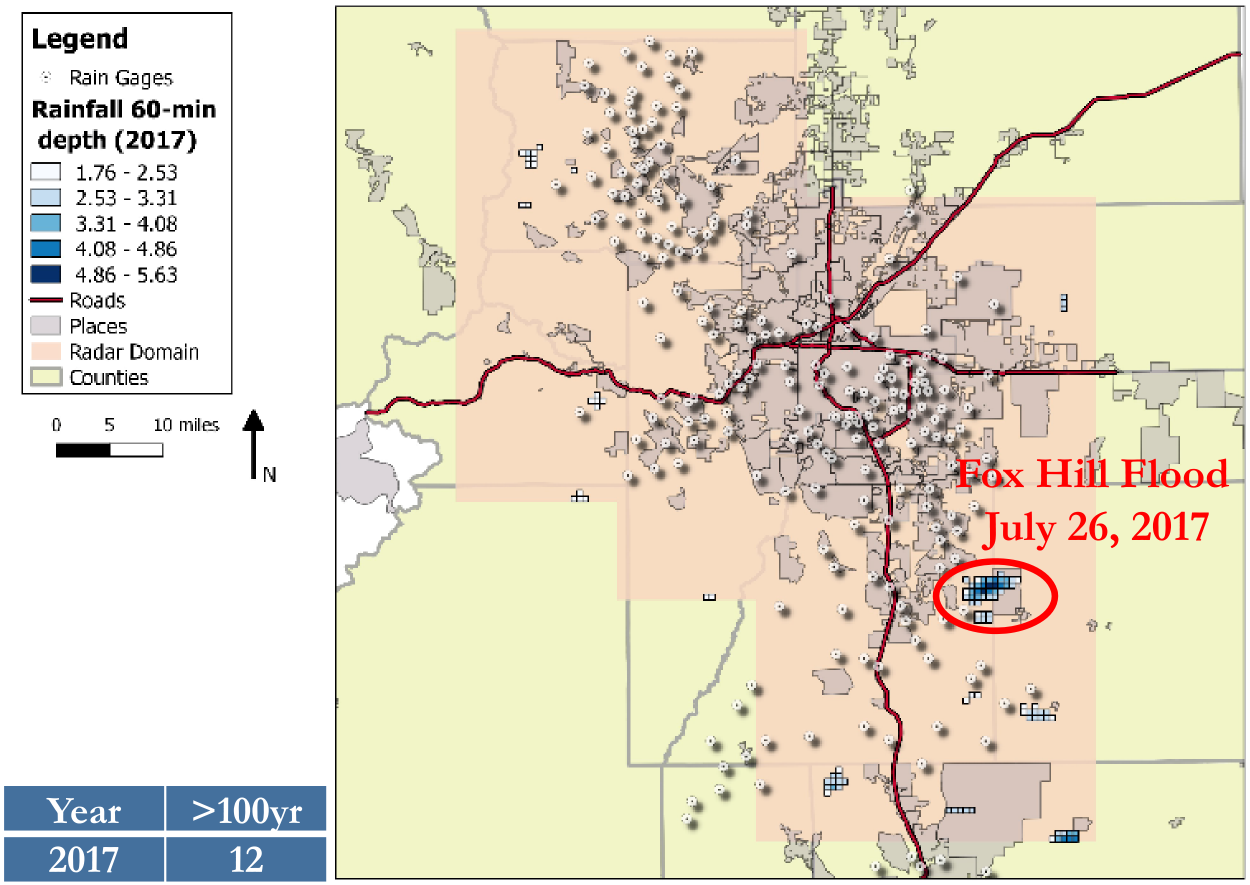
Year	>100yr
2014	4



Year	>100yr
2015	3



Year	>100yr
2016	0



Year	>100yr
2017	12

Summary

- "Rare" events are not that rare when considering the UDFCD region
- 100-yr events happen frequently
- How much did we find and how much did we miss?

<u>100yr-60min (2013-2018)</u>

9 gage events, 1 per year

26 pixel events, 5 per year

Structure-Level Risk Assessment Using 2D Probabilistic Modeling

CASFM 2018 – Snowmass, CO

Geoff Uhlemann - AECOM

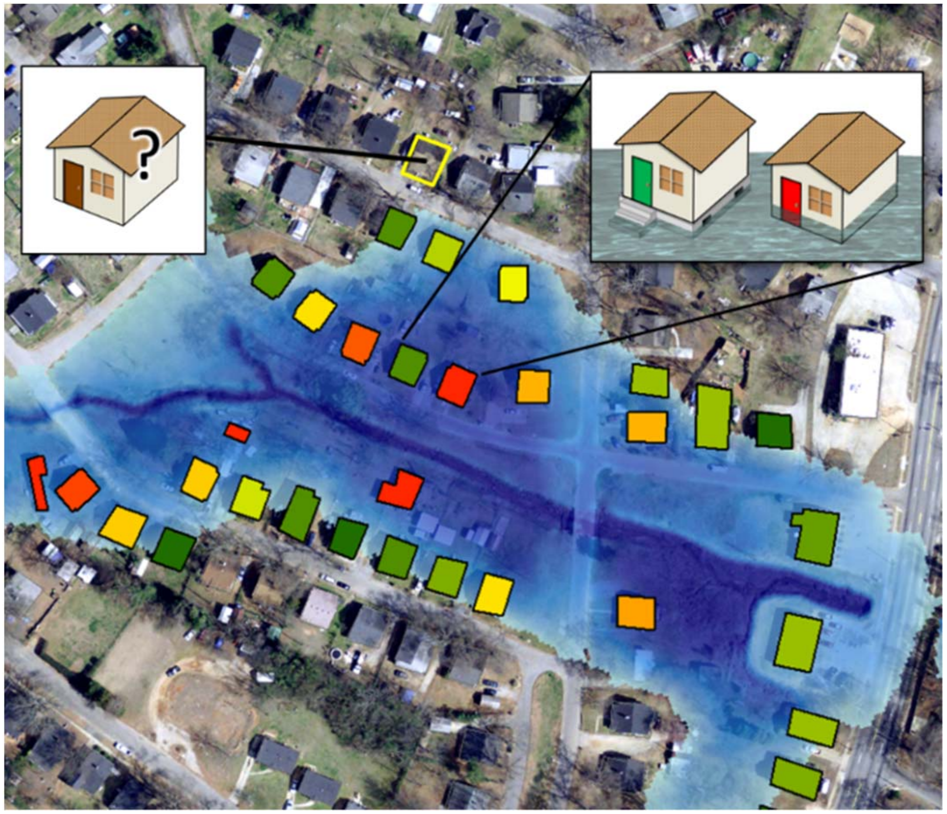
FEMA

compass
Identify, Interpret, Integrate

Reasons for a New Approach

Improved Accuracy & Resolution

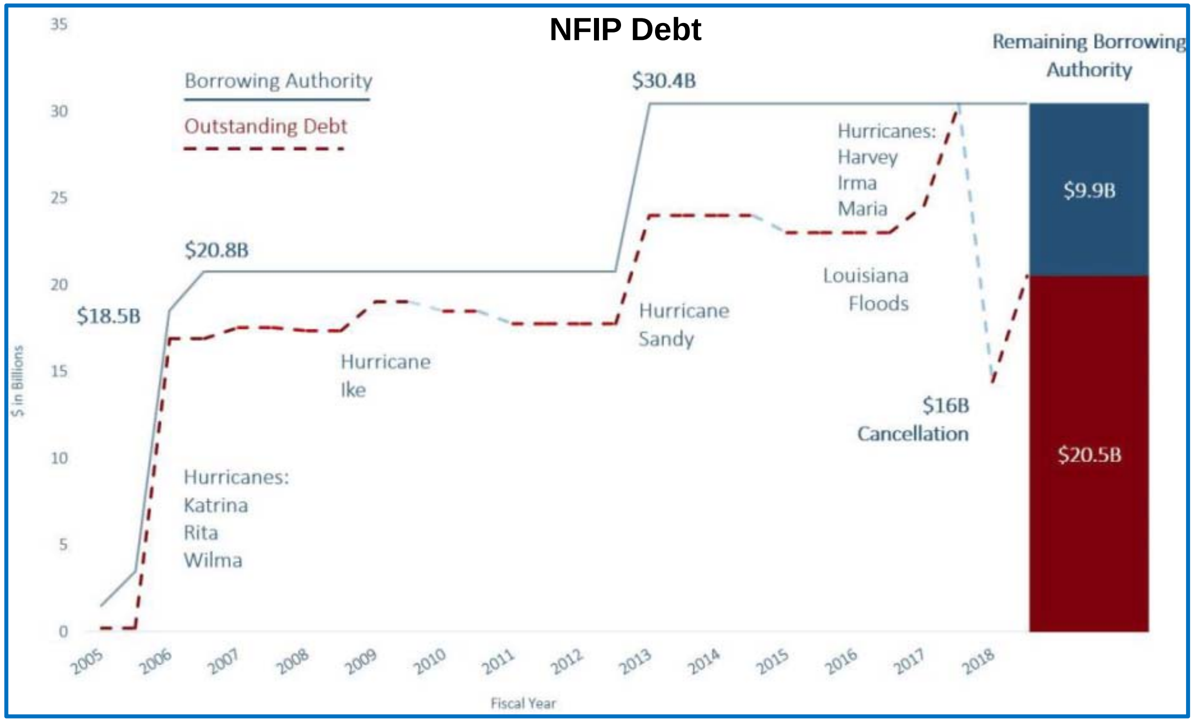
- To account for uncertainty
- Model future conditions
- >25% NFIP claims are structures outside SFHA (about 60% of losses)
- To capture more extreme events
- Show graduated risk within the 0.2% floodplain
- Include residual and pluvial risk
- Evaluate specific homes



Reasons for a New Approach

Enhanced End Products/Application

- To provide structure-level risk assessment
- To discretize flood insurance
- Communicate location-specific risk
- Evaluate risk behind levees
- CBA & performance-based levee analysis
- Risk-informed decision making process
- Depict total flood risk (fluvial + pluvial)
- Information on wide range of events, esp frequent (2 yr)
- Byproducts are grids for any recurrence interval

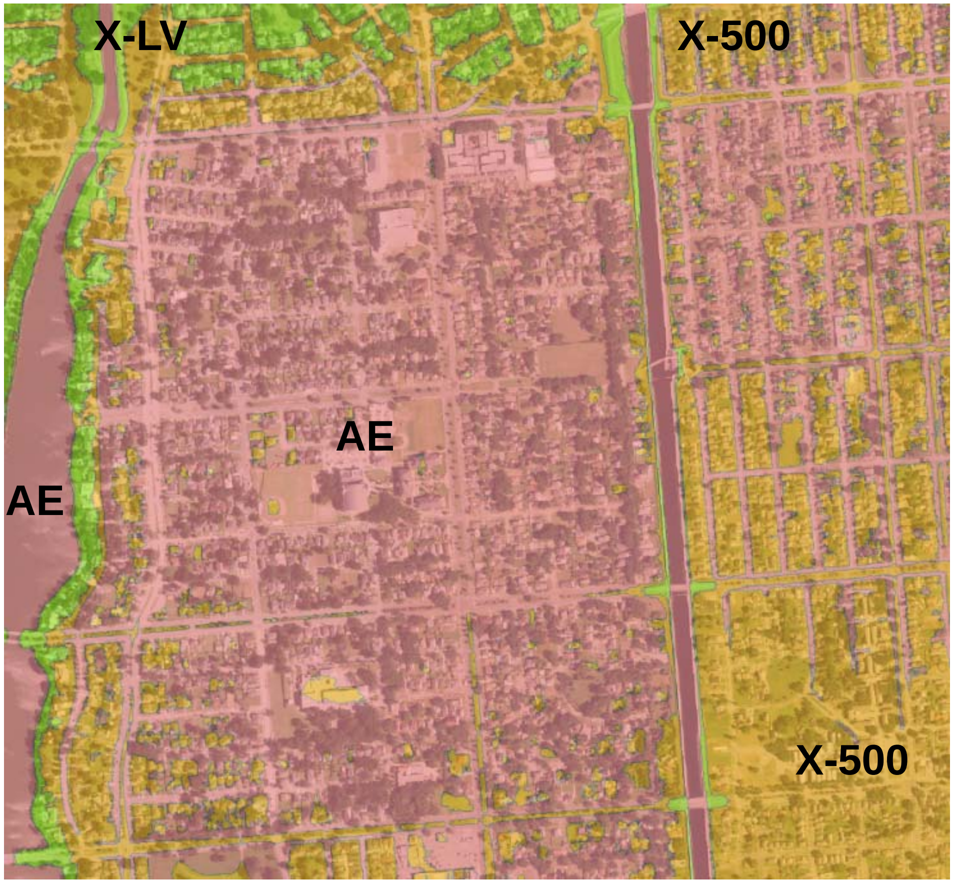


Potential NFIP Implications
From Zones to Graduated Risk

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

Potential NFIP Implications
Insurance Premiums

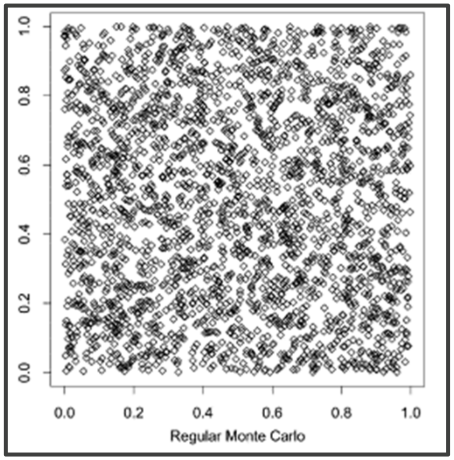
- Spatially varied insurance premiums (homes, neighborhoods, census blocks, zip codes) based on average annualized loss (AAL) relative to structure value/policy amount
- Can vary behind levees then & account for pluvial



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

Concept of Probabilistic Modeling
Overview

- Monte Carlo distribution & importance sampling
- Fluvial Hydrology
  - Differing flood durations, confidence limits, hydrographs
- Pluvial Hydrology
  - Differing durations, confidence limits, quartiles, hyetographs
- Batch Hydraulics - thousands of runs
  - Differing land cover, breach locations & dimensions
  - All 2D model based – exports max WSEL grids
  - Create AEP grids
- Risk Assessment (at structure level)
  - Extract WSELs from all runs at each structure
  - Damage calcs with varying FFEs
  - AALs



Concept of Probabilistic Modeling
Existing Approach Comparison

ANNUAL EXCEEDANCE PROBABILITY	BULL.17B ESTIMATE	SYSTEMATIC RECORD	<-- FOR BULLETIN 17B ESTIMATES --> VARIANCE OF EST.	95% CONFIDENCE INTERVALS LOWER	UPPER
0.9950	487.6	579.5	----	363.4	618.7
0.9900	548.4	631.7	----	4[illegible]4.5	6[illegible]8.5
0.9500	786.7	840.3	----	62[illegible].2	[illegible]58.5
0.9000	978.2	1011.	----	789.2	[illegible]173.0
0.8000	1305.	1306.	----	1082.[illegible]	1538.0
0.6667	1753.	1719.	----	1485.0	2042.0
0.5000	2455.	2380.	----	2110.0	2849.0
0.4292	2846.	2755.	----	2452.0	3311.0
0.2000	5157.	5062.	----	4386.0	6198.0
0.1000	7960.	8023.	----	6592.0	9969.0
0.0400	13110.	13810.	----	10420.[illegible]	[illegible]7390.0
0.0200	[illegible]	20210.	----	14230.0	2[illegible]570.0
0.0100	25490.	29040.	----	190[illegible]0.0	36[illegible]90.0
0.0050	[illegible]	41150.	----	25[illegible]70.0	520[illegible]0.0
0.0020	50940.	64180.	----	35440.0	80760.0

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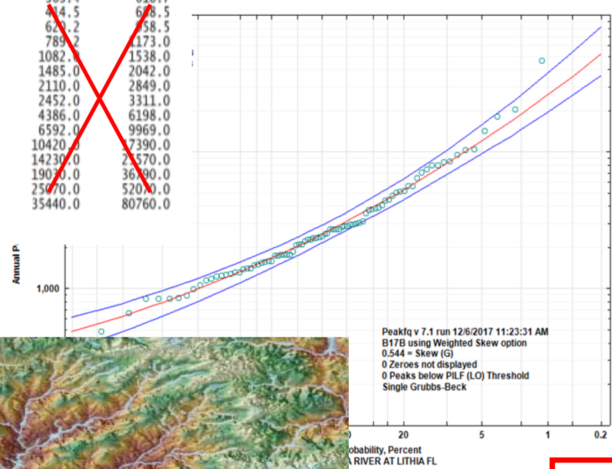
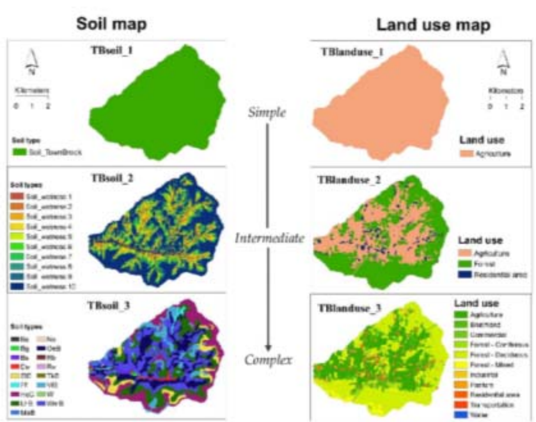
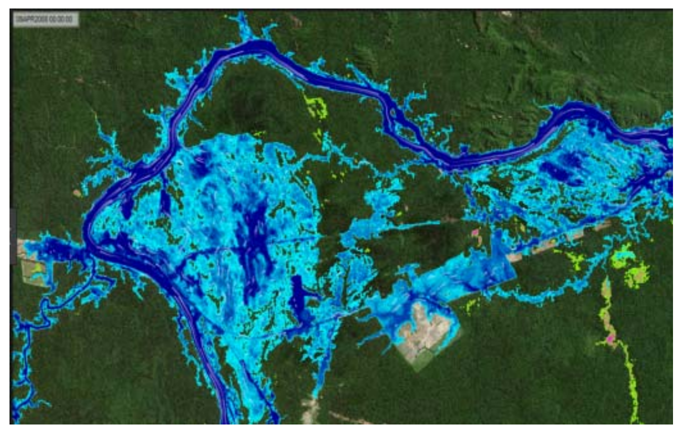
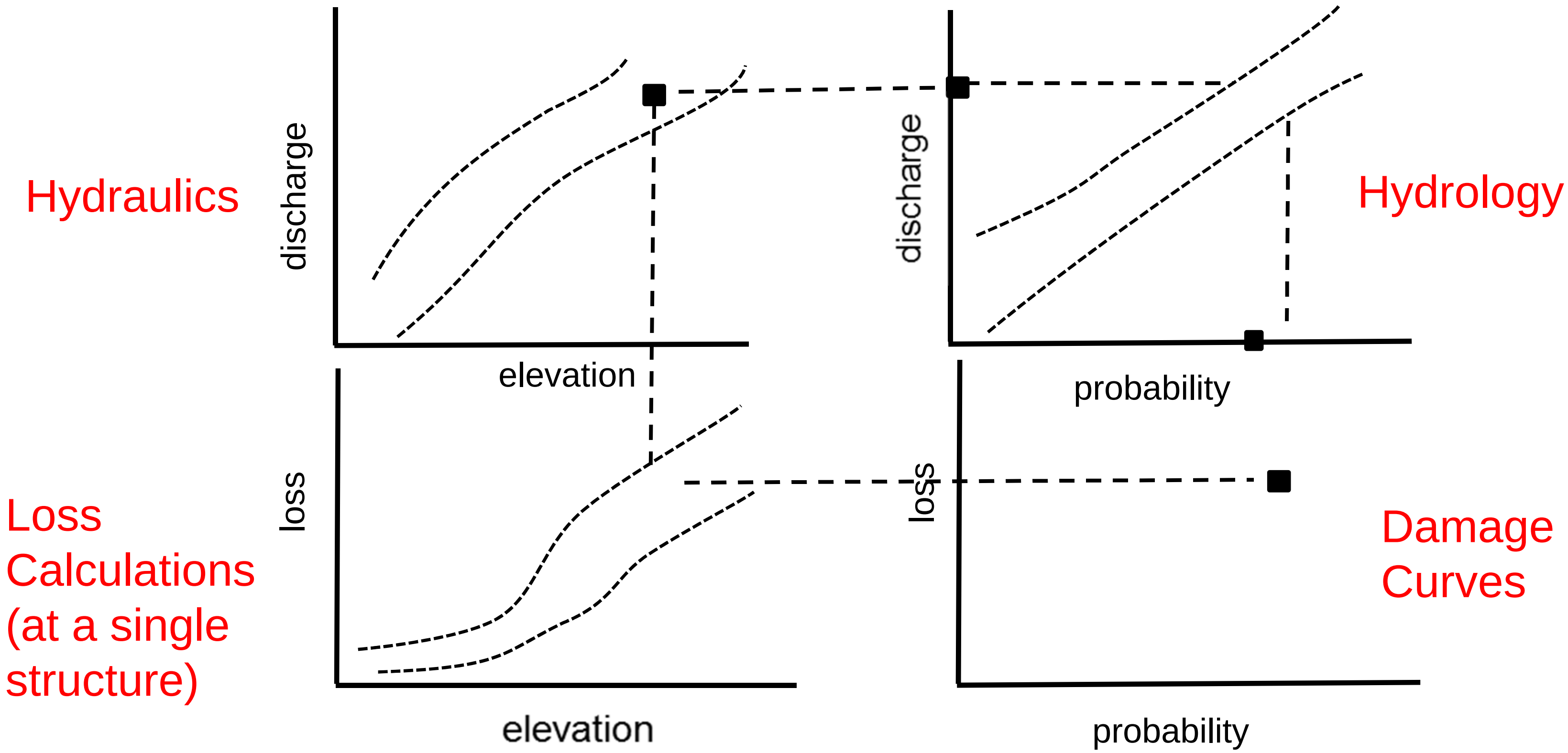




1D or 2D Hydraulic Modeling

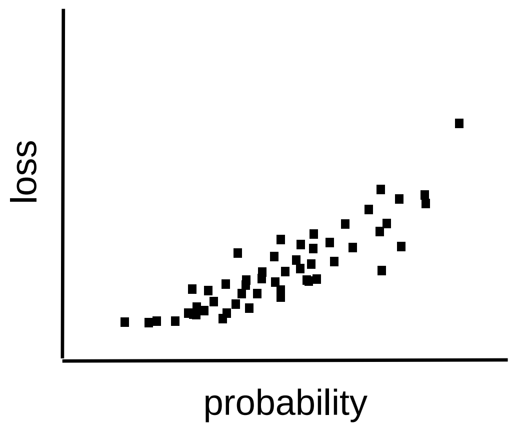


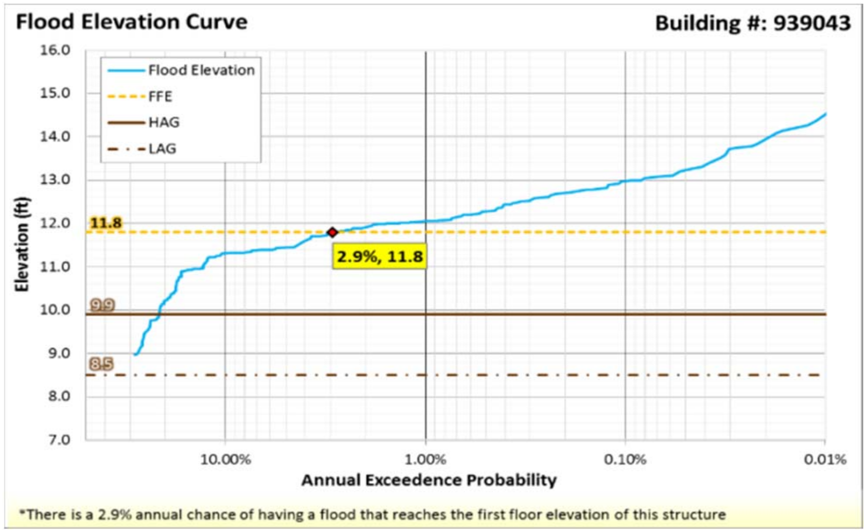
Concept of Probabilistic Modeling
Random Sampling Methodology

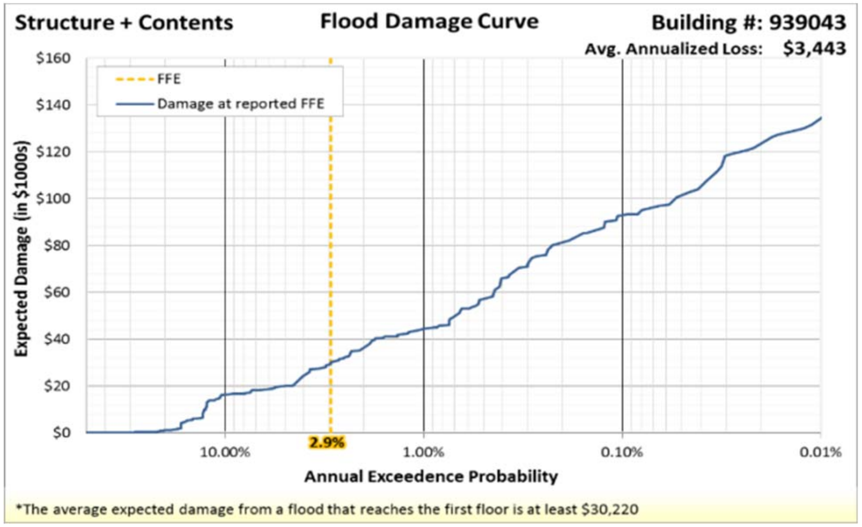


Concept of Probabilistic Modeling
Risk Assessment

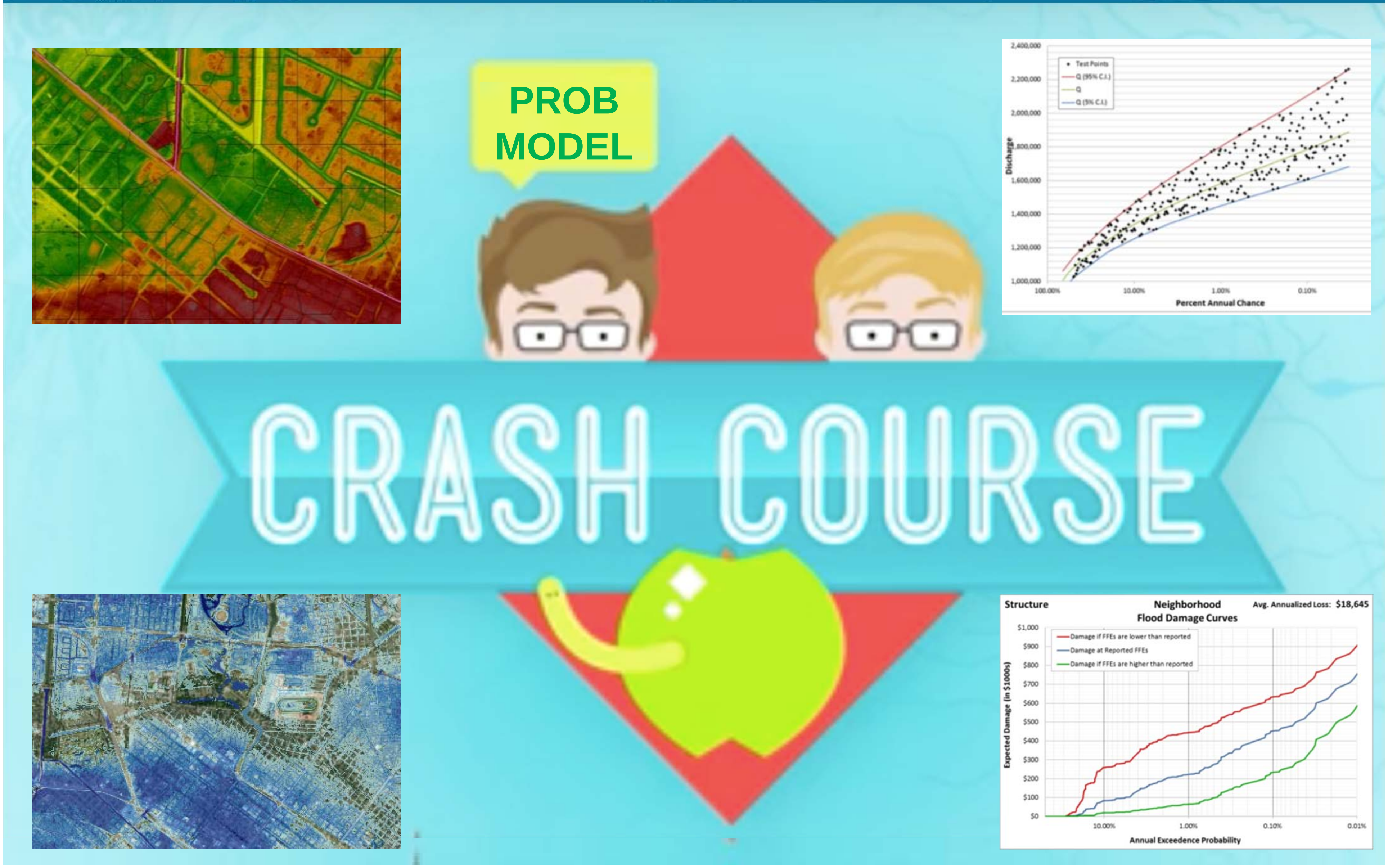
- **Individual model results plotted out to produce various curves**





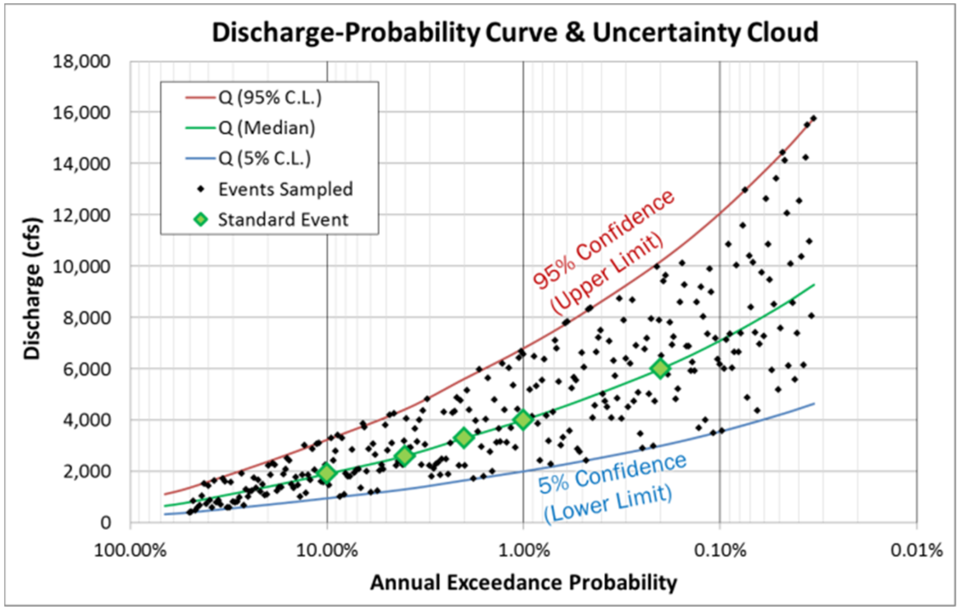


Crash Course of Probabilistic Approach



Crash Course of Probabilistic Approach
Fluvial Hydrology

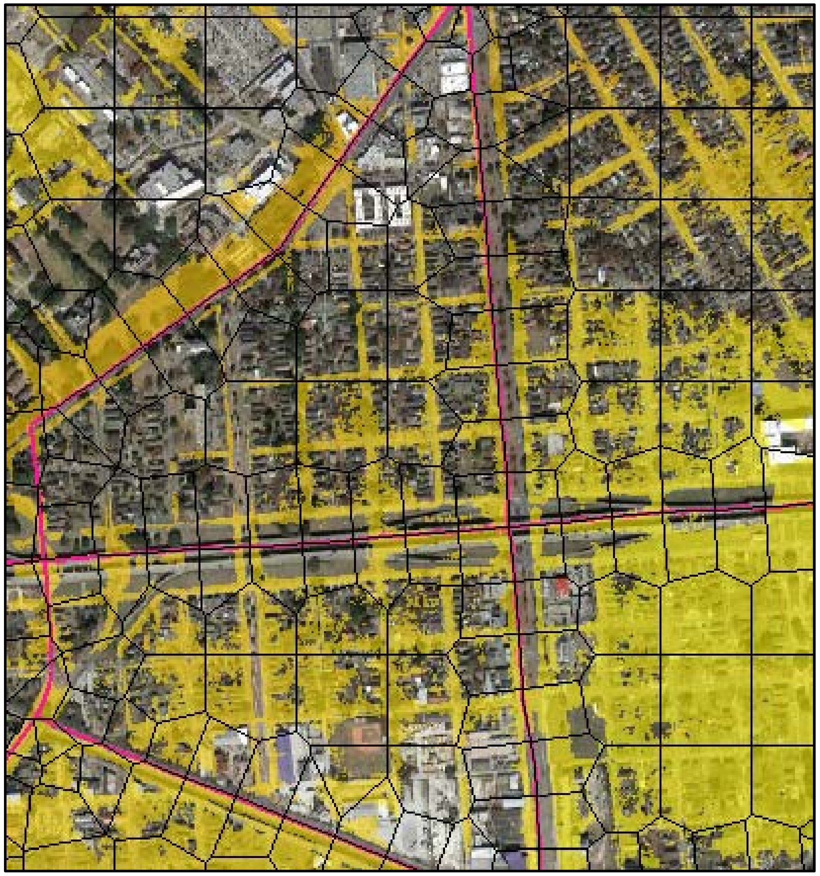
- **Rather than selecting the 5 typical discharges along the median line, 300 discharges are randomly sampled between the 5% and 95% confidence limits for a large number of probabilities, from the 50% (2-yr) to the 0.033% (3000-yr) or beyond annual-chance probability**



- **Applied as inflow hydrograph**
  - Vary flood durations & hydrographs

Crash Course of Probabilistic Approach
Pluvial Flooding

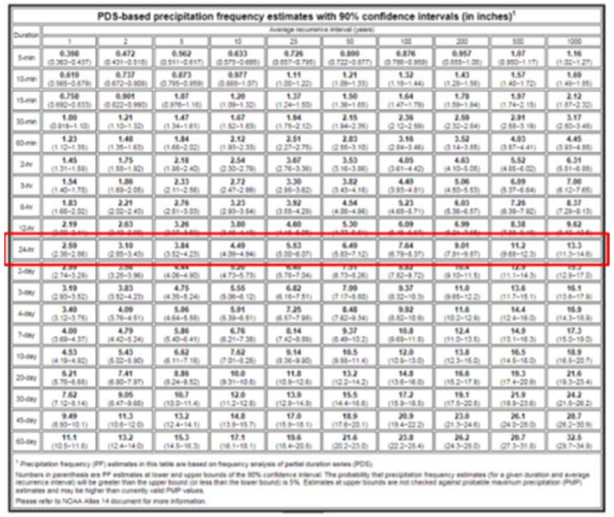
- **Evaluates runoff – applied as excess precip to 2D area**
- **Major contributor to the residual risk in leveed areas**
- **Currently not mapped on FIRMs or any of the existing flood products**
- **Catastrophic models used by private insurance companies capture pluvial hazard**
- **One reason structures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



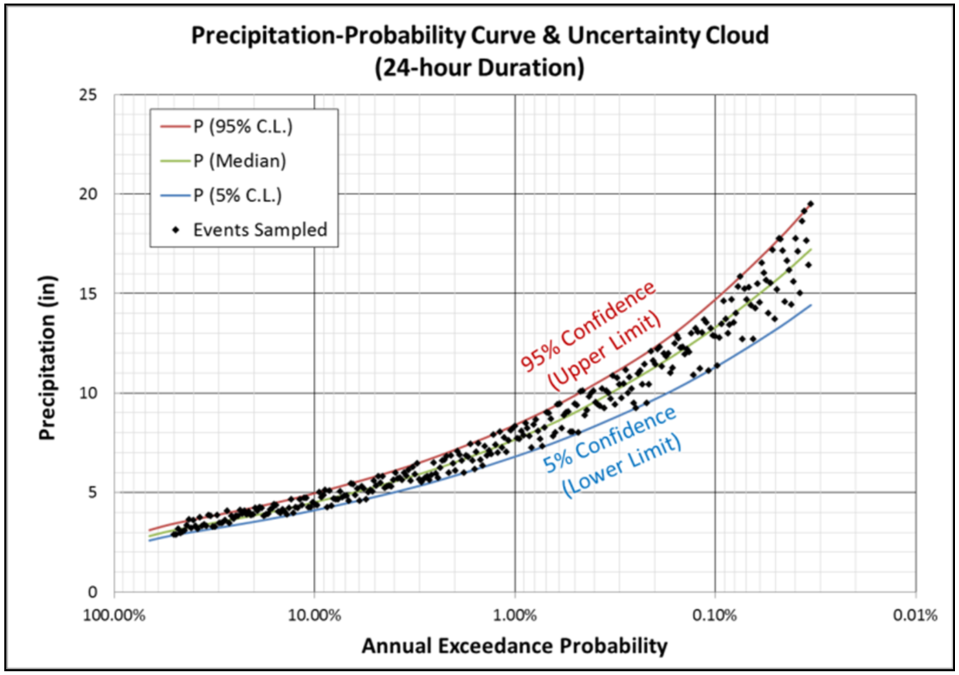
Crash Course of Probabilistic Approach

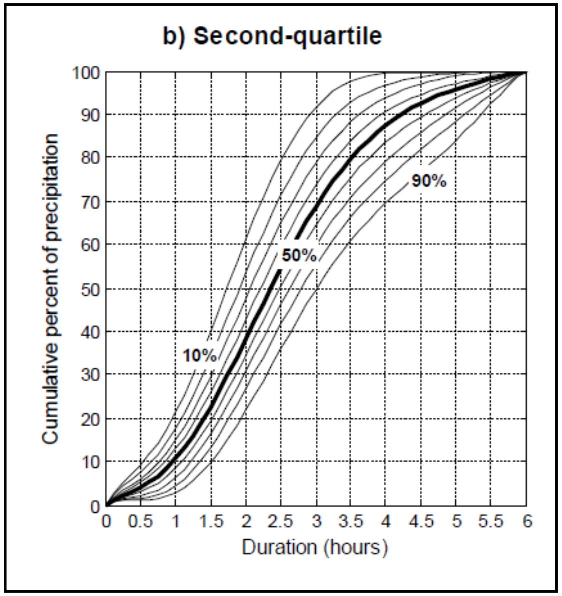
Pluvial Hydrology

- **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**
- **75 depths for 16 different unique storm duration (6-, 12-, 24-, and 96-hr) vs. temporal distribution (1st, 2nd, 3rd, or 4th quartile) scenarios are analyzed**



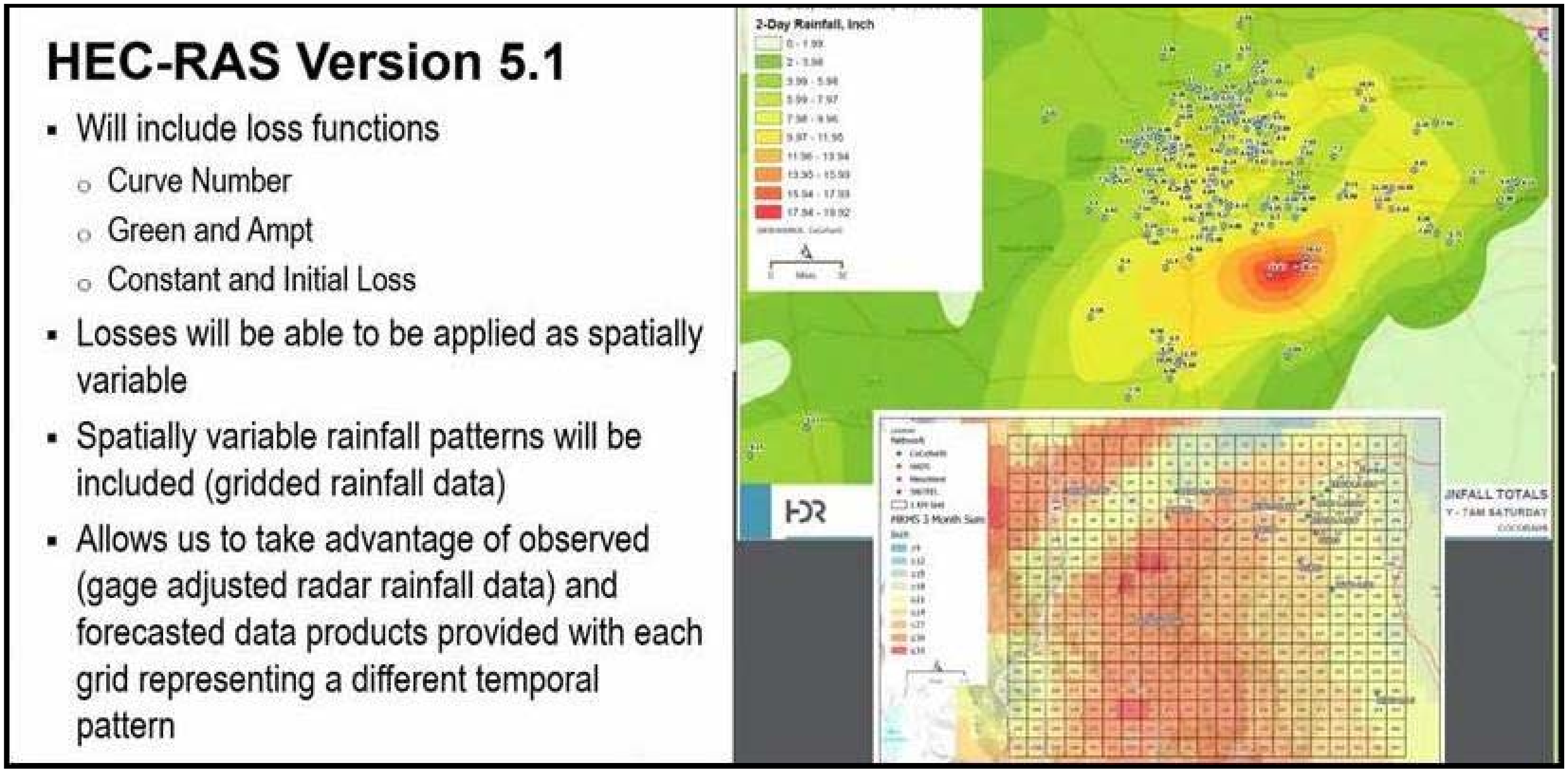
From NOAA Atlas 14 Precipitation Frequency Data Server





Crash Course of Probabilistic Approach
Pluvial Hydrology

- **Curve Number variation is considered and randomly selected in between +/- one standard deviation**
- **HEC-HMS generated 1,200 hyetographs that were then used in HEC-RAS to map the excess rainfall on the grid**
- **But going forward…**

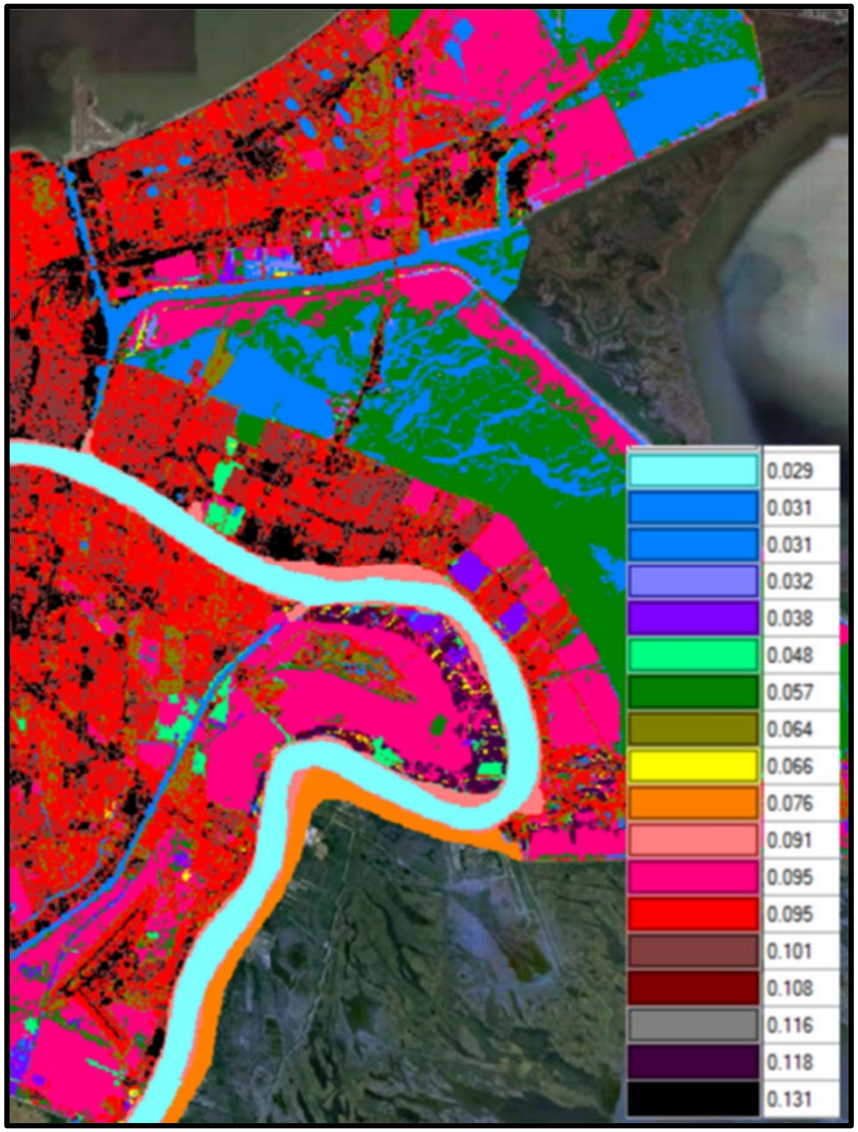


Crash Course of Probabilistic Approach

Hydraulics – Land Cover

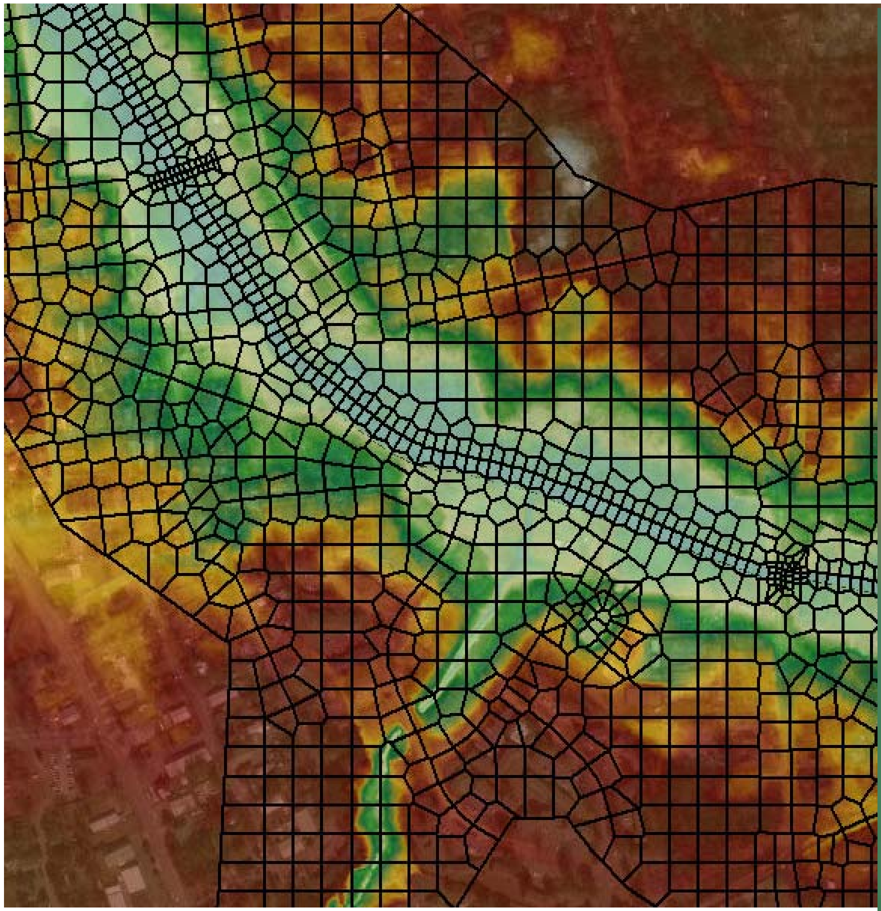
Uncertainty in Manning's n-values are factored into models – 10 land use layers

NLCD Classification	Assigned Manning's Roughness		
	Minimum	Normal	Maximum
Open Water	0.025	0.03	0.033
Developed, Open Space	0.035	0.055	0.095
Developed, Low Intensity	0.085	0.095	0.11
Developed, Medium Intensity	0.09	0.115	0.13
Developed, High Intensity	0.1	0.13	0.16
Barren Land	0.03	0.033	0.036
Deciduous Forest	0.1	0.12	0.16
Evergreen Forest	0.085	0.115	0.14
Mixed Forest	0.09	0.115	0.15
Scrub/Shrub	0.05	0.075	0.09
Grassland Herbaceous	0.028	0.03	0.035
Pasture/Hay	0.038	0.045	0.055
Cultivated Crops	0.035	0.042	0.048
Woody Wetlands	0.08	0.095	0.12
Emergent Wetland	0.04	0.065	0.1
River Channel	0.026	0.028	0.03

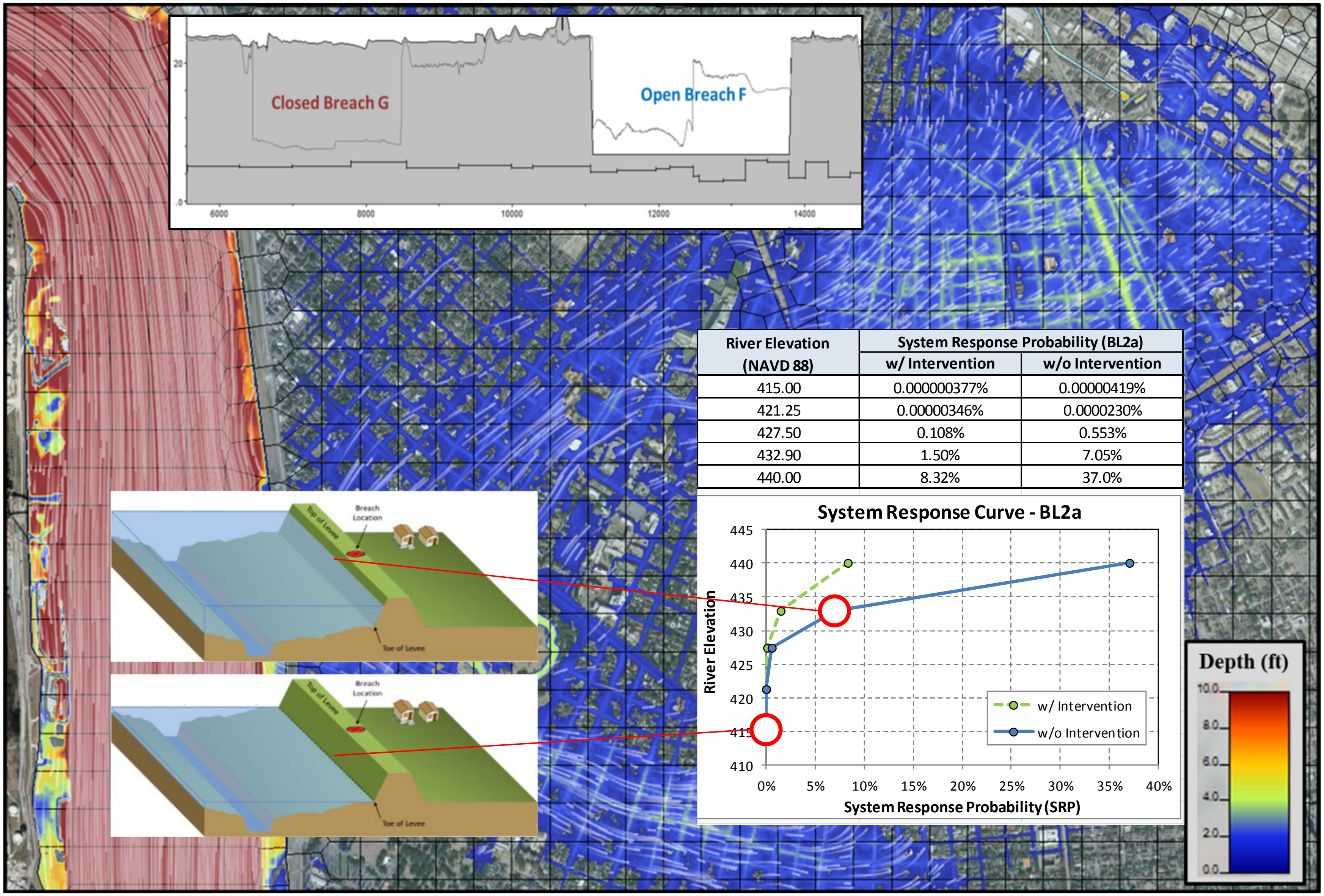


Crash Course of Probabilistic Approach
Hydraulics – Simulations

- **2D model scenarios are run in a batch, automated process**
- **30 fluvial/land set; 120 pluvial/land set**



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%

Results

WSEL, depth, depth * velocity grids

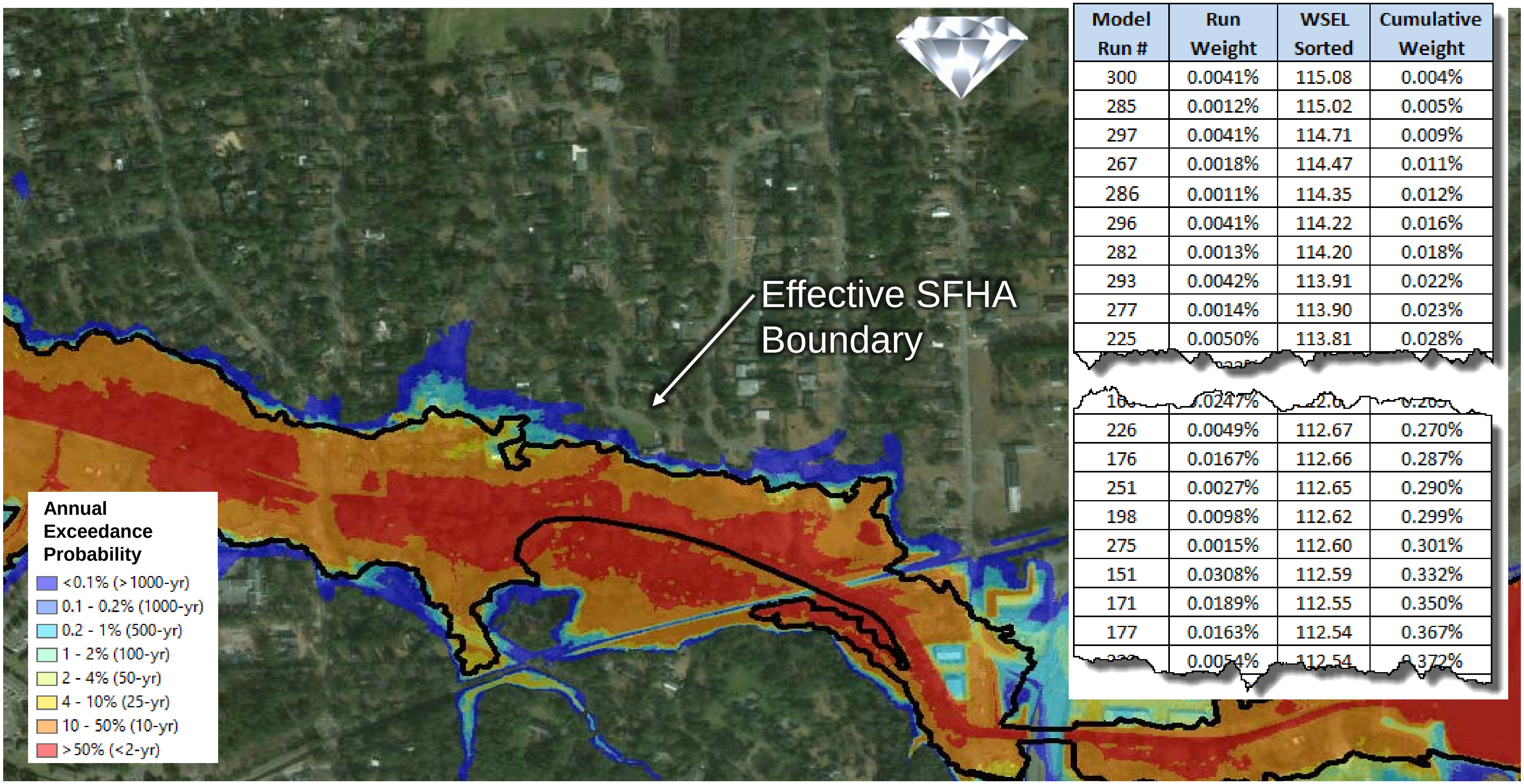
Annual Exceedance Probability (AEP) grids

Damage curves at any structure

Average Annualized Loss (AAL) for any structure or area

Annual Exceedance Probability Grid

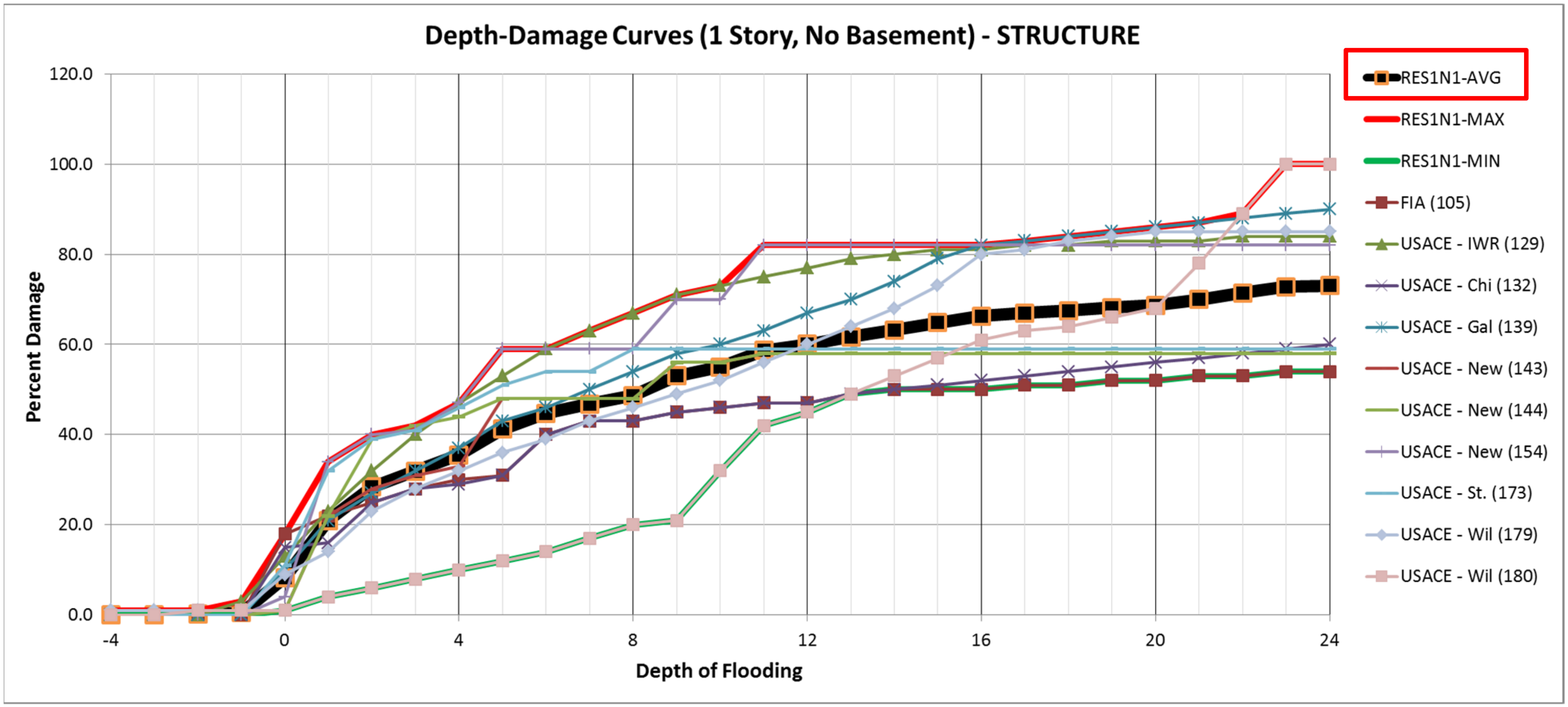
- **Using the results and probabilities from each model run, a probability grid is generated**



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]
[illegible]	.0247%	[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%

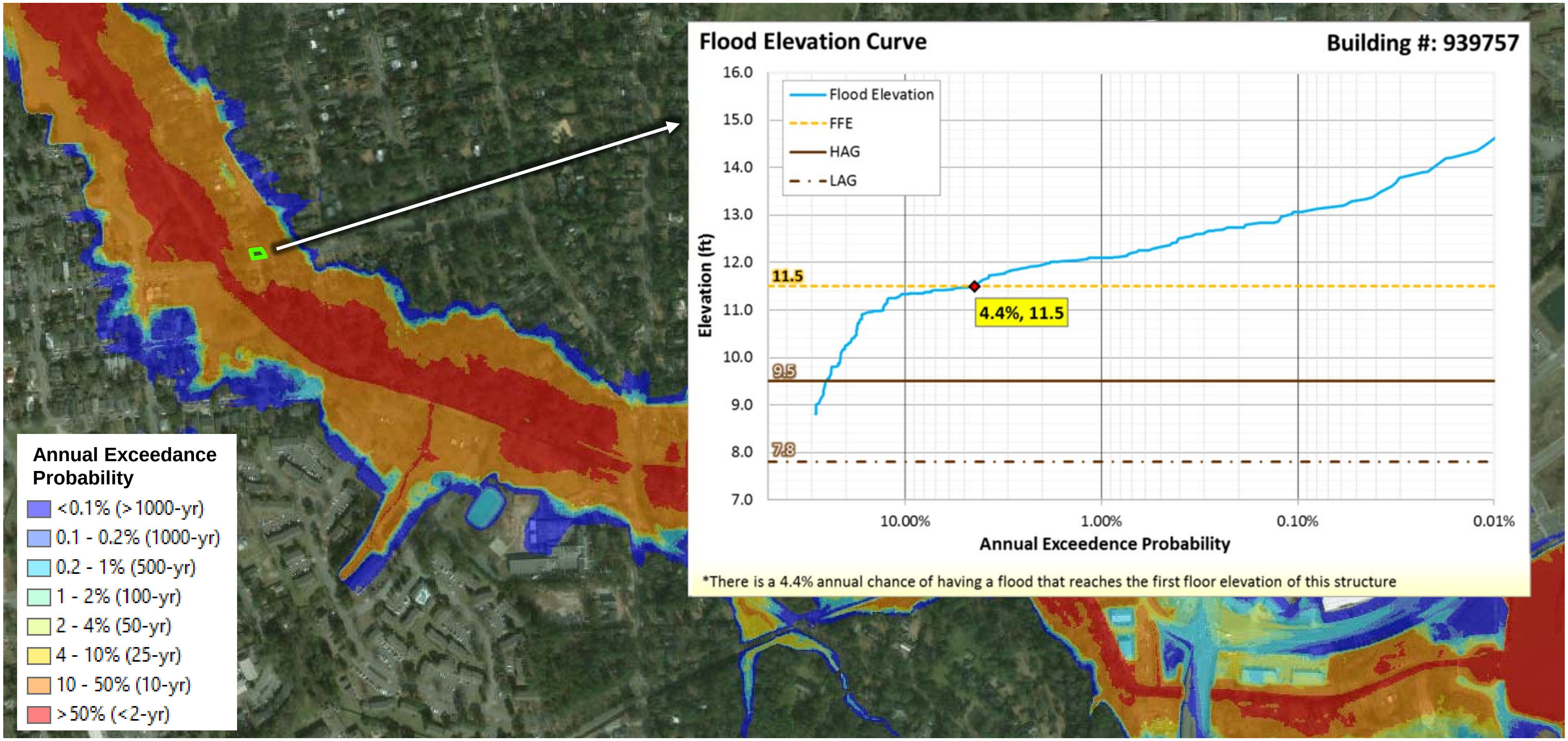
Depth-Damage Functions used in Risk Assessments

- **Composite Depth-Damage curves for each structure type were used based on available curves from Hazus**



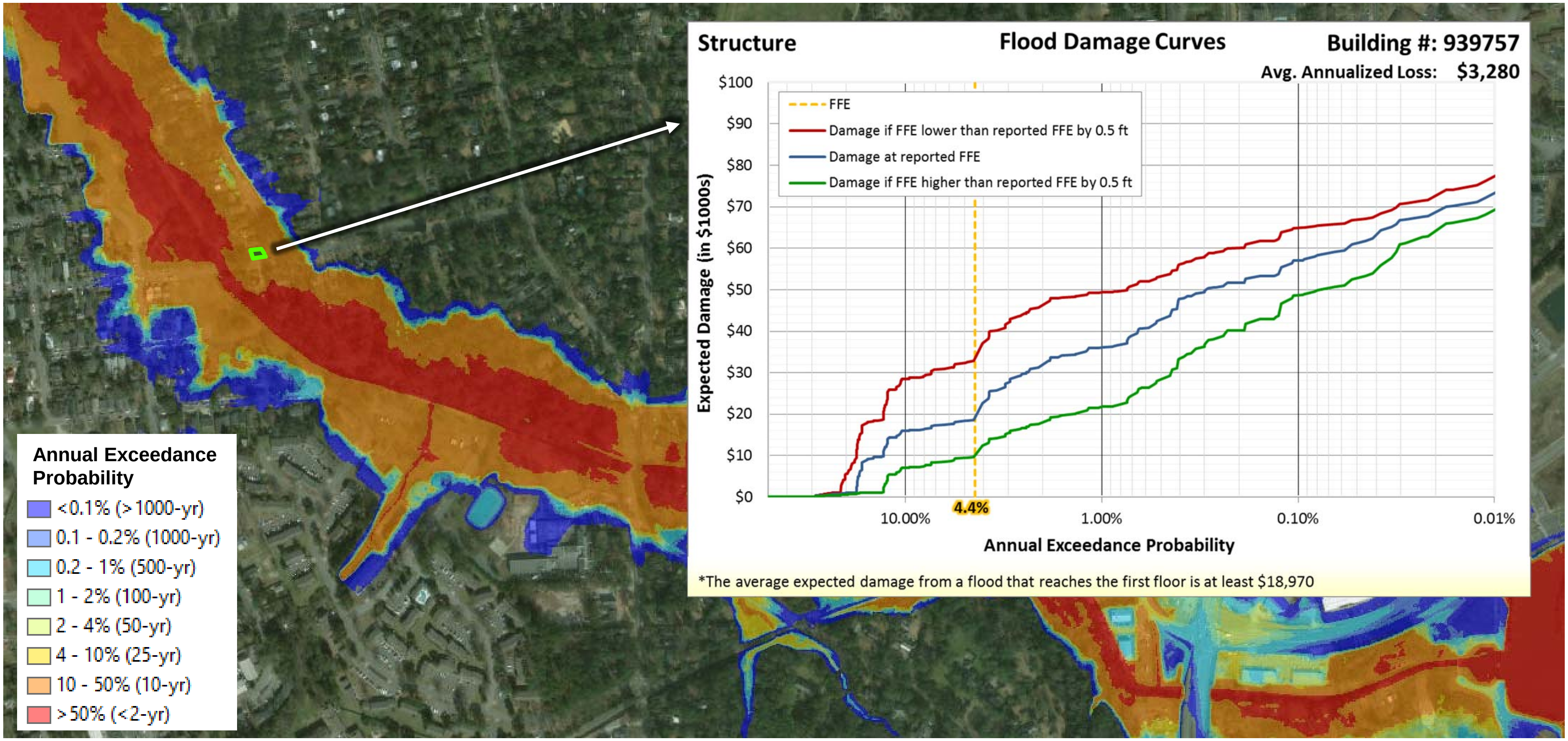
Structure-Level Risk

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



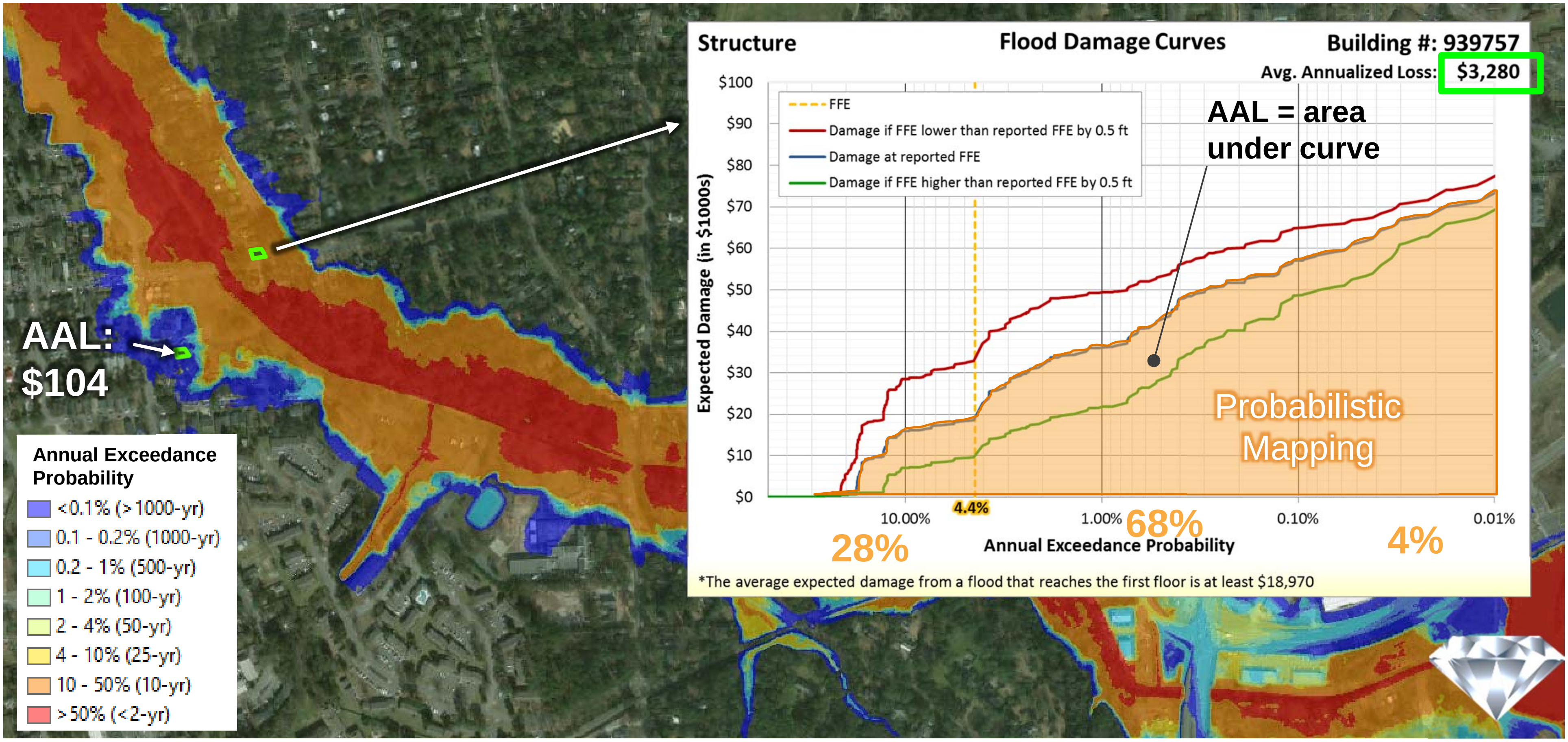
Structure-Level Risk

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



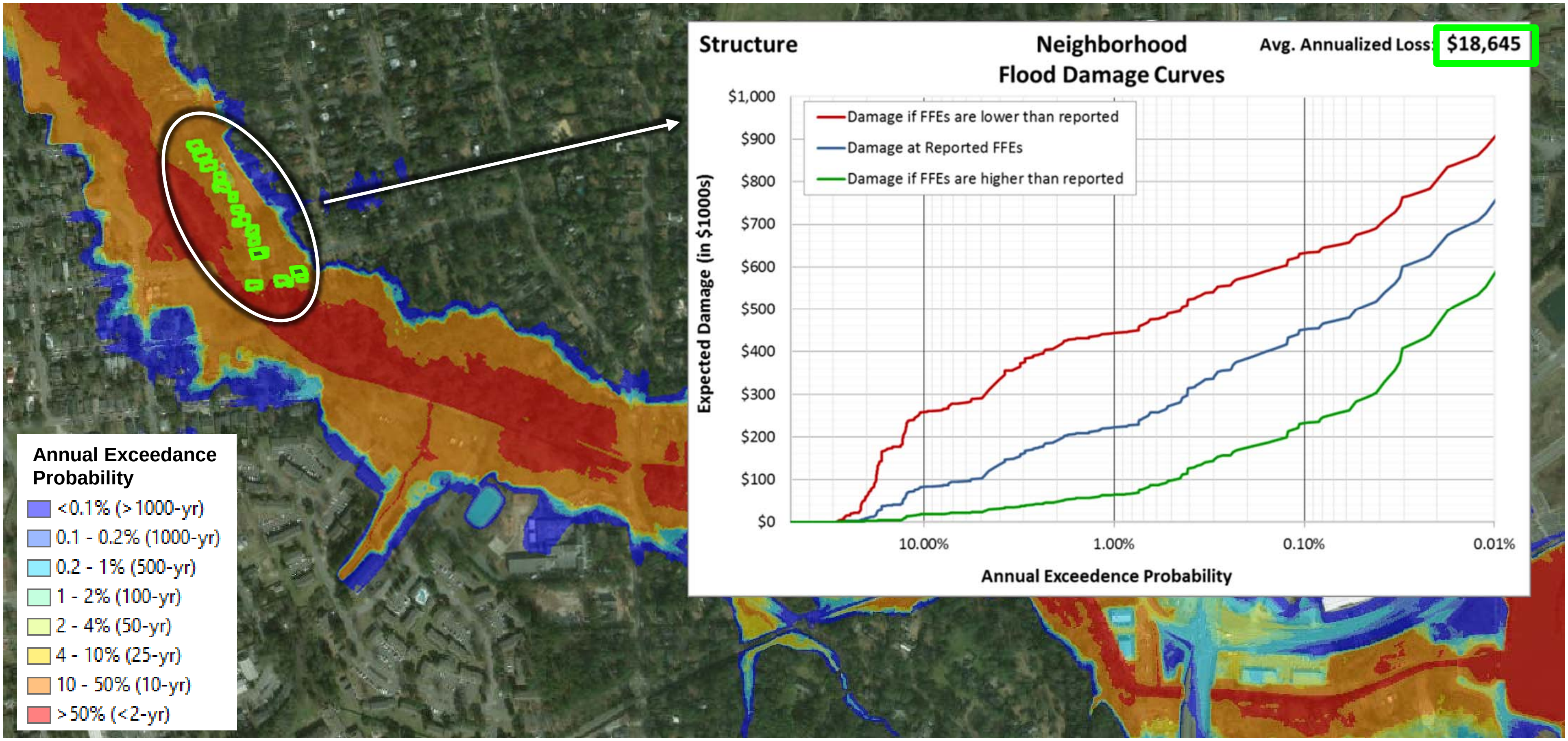
Structure-Level Risk

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



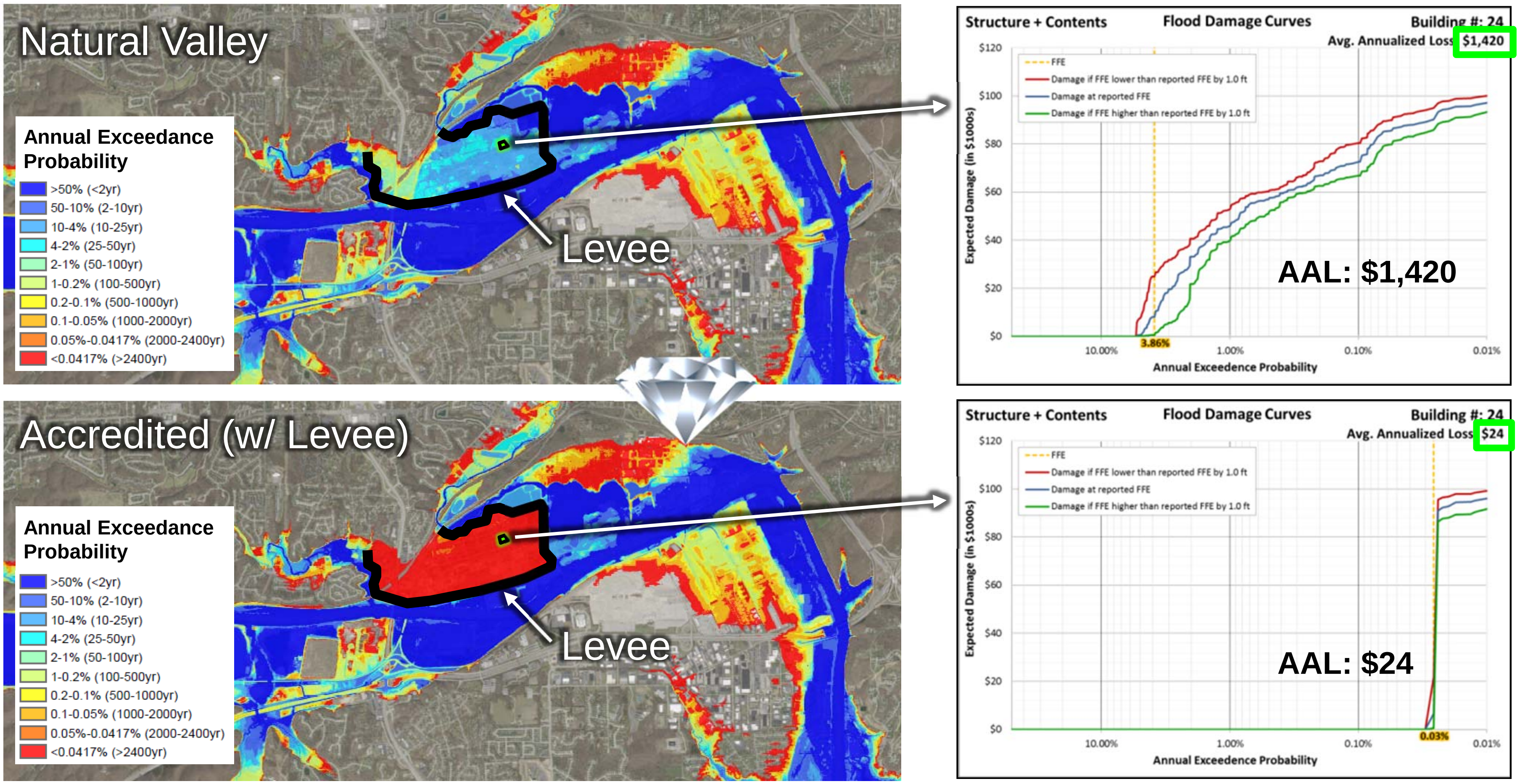
Structure-Level Risk

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

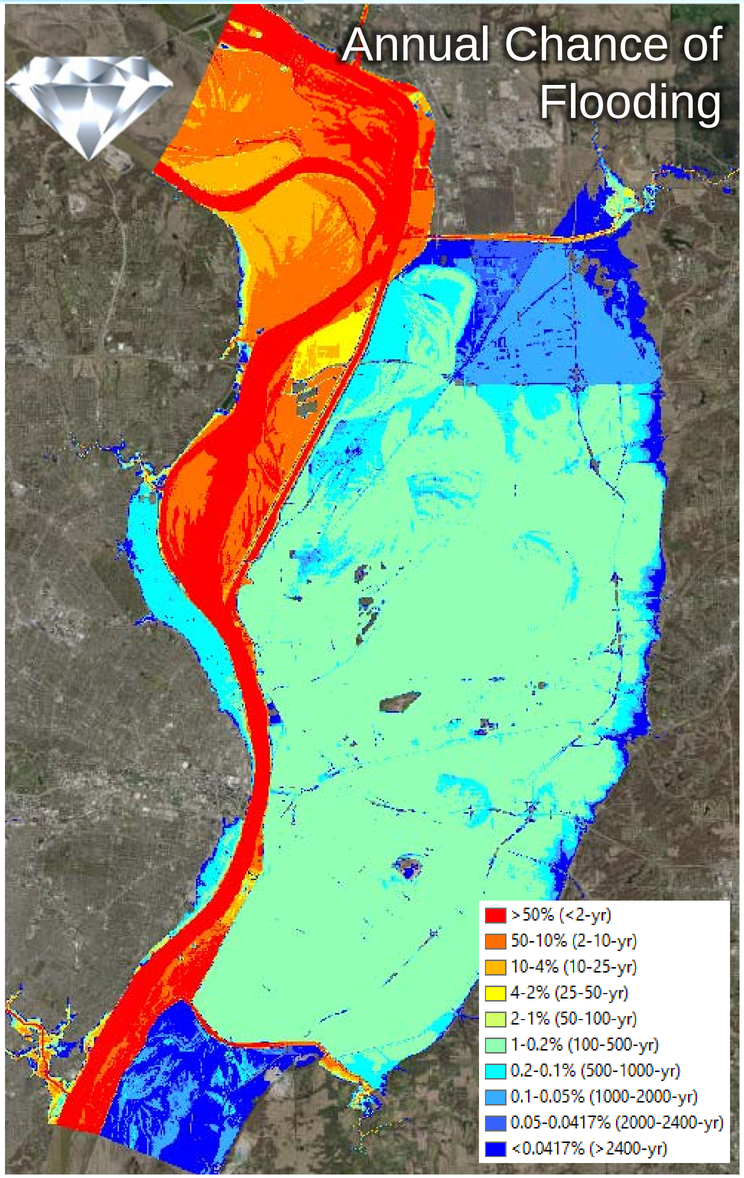


Cost Benefit Analysis for Levees

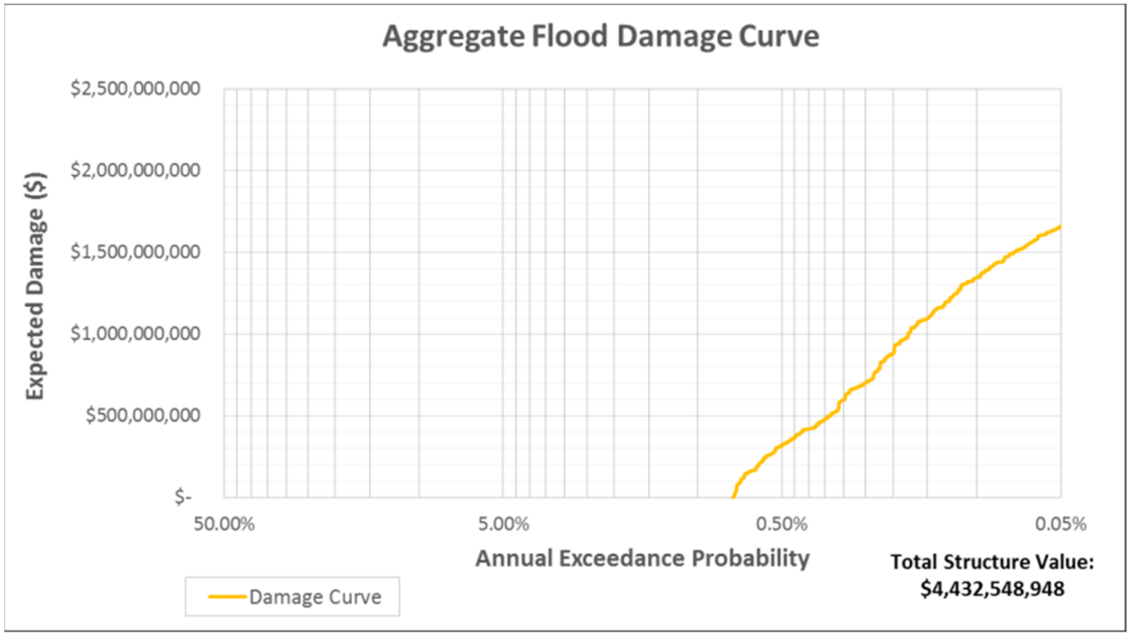
- **Probabilistic approach can consider accredited, breaching, and natural valley levee scenarios (each w/ associated probabilities)**



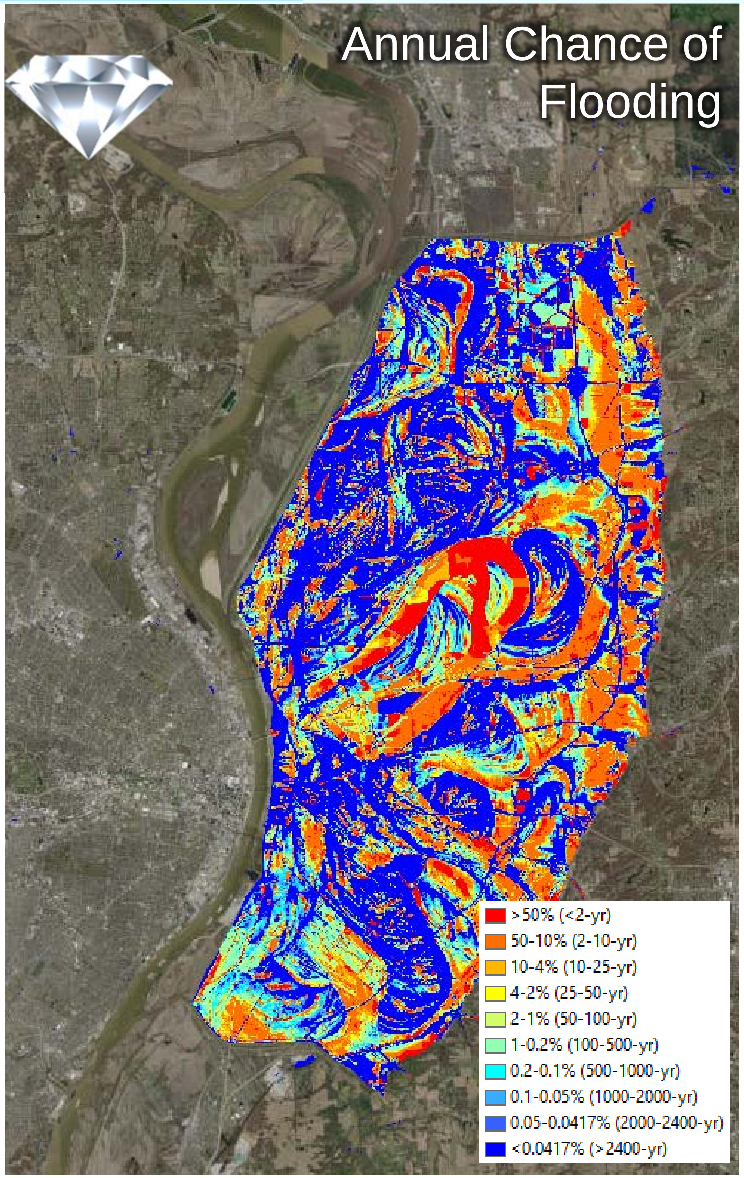
Fluvial (Riverine) Results: Aggregate



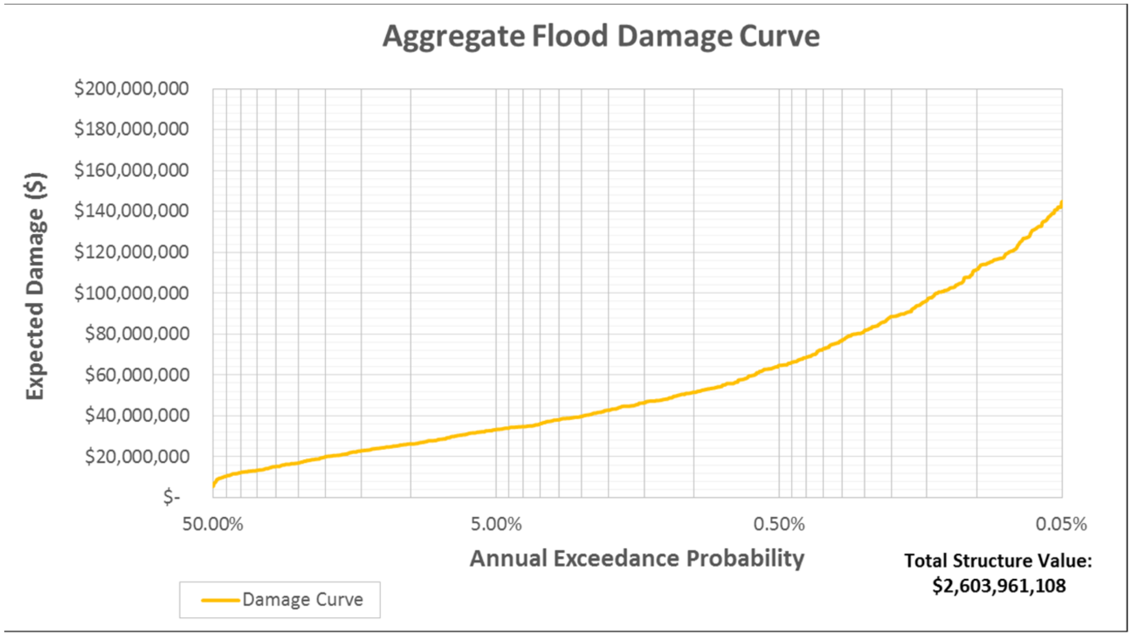
# Structures with Damage	35,197 of 35,236 (99.9%)
Avg. Annualized Loss (AAL)	$4,848,716



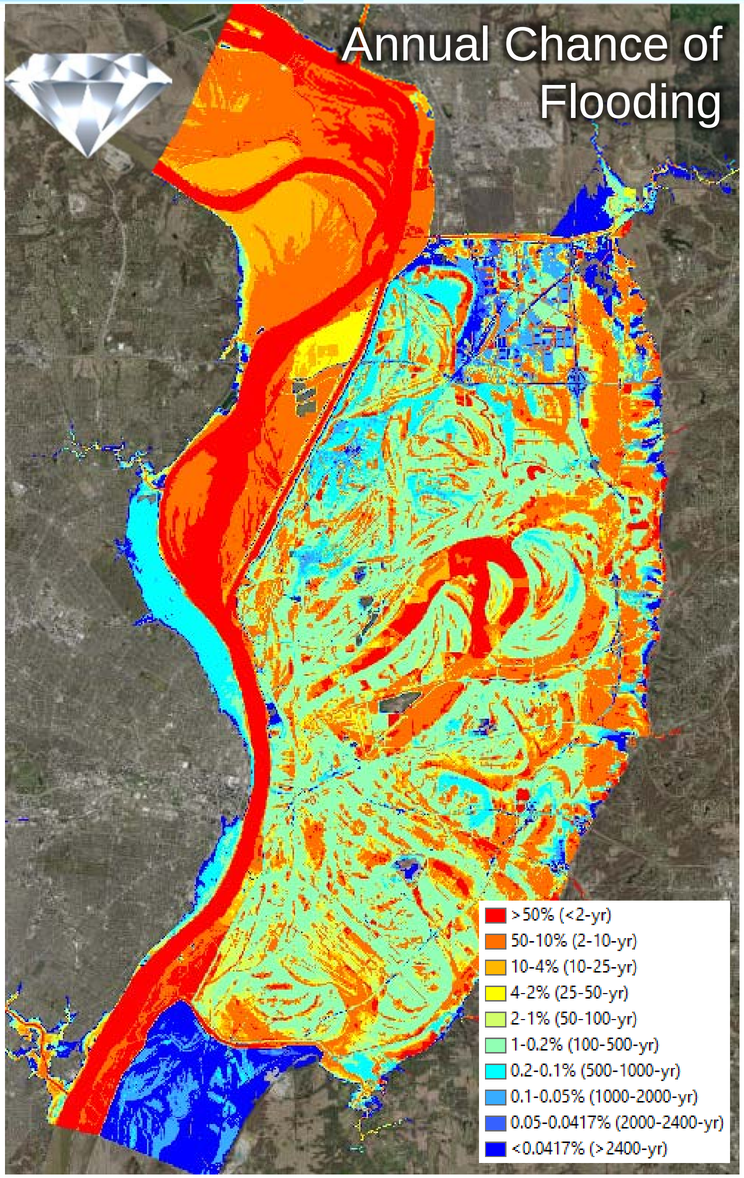
Pluvial (Rainfall) Results: Aggregate



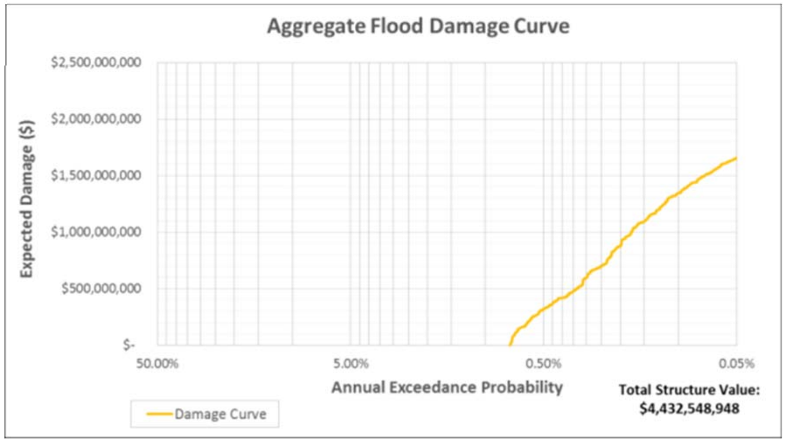
# Structures with Damage	21,491 of 35,236 (61%)
Avg. Annualized Loss (AAL)	$10,179,415



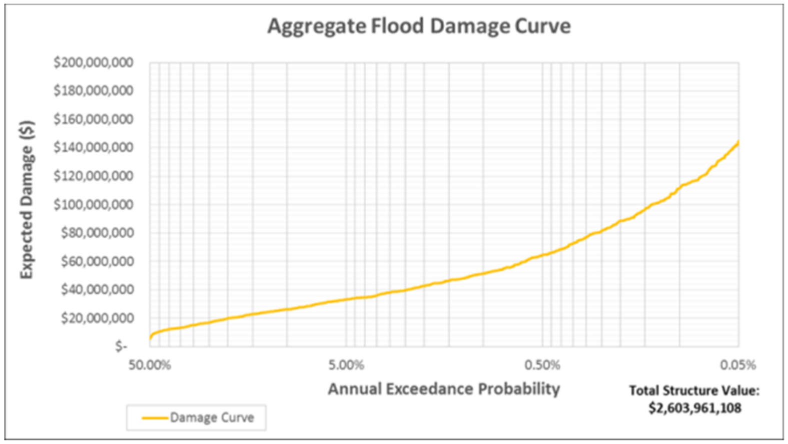
Combined Fluvial & Pluvial: Aggregate



AAL (Fluvial): $4,848,716



AAL (Pluvial): $10,179,415

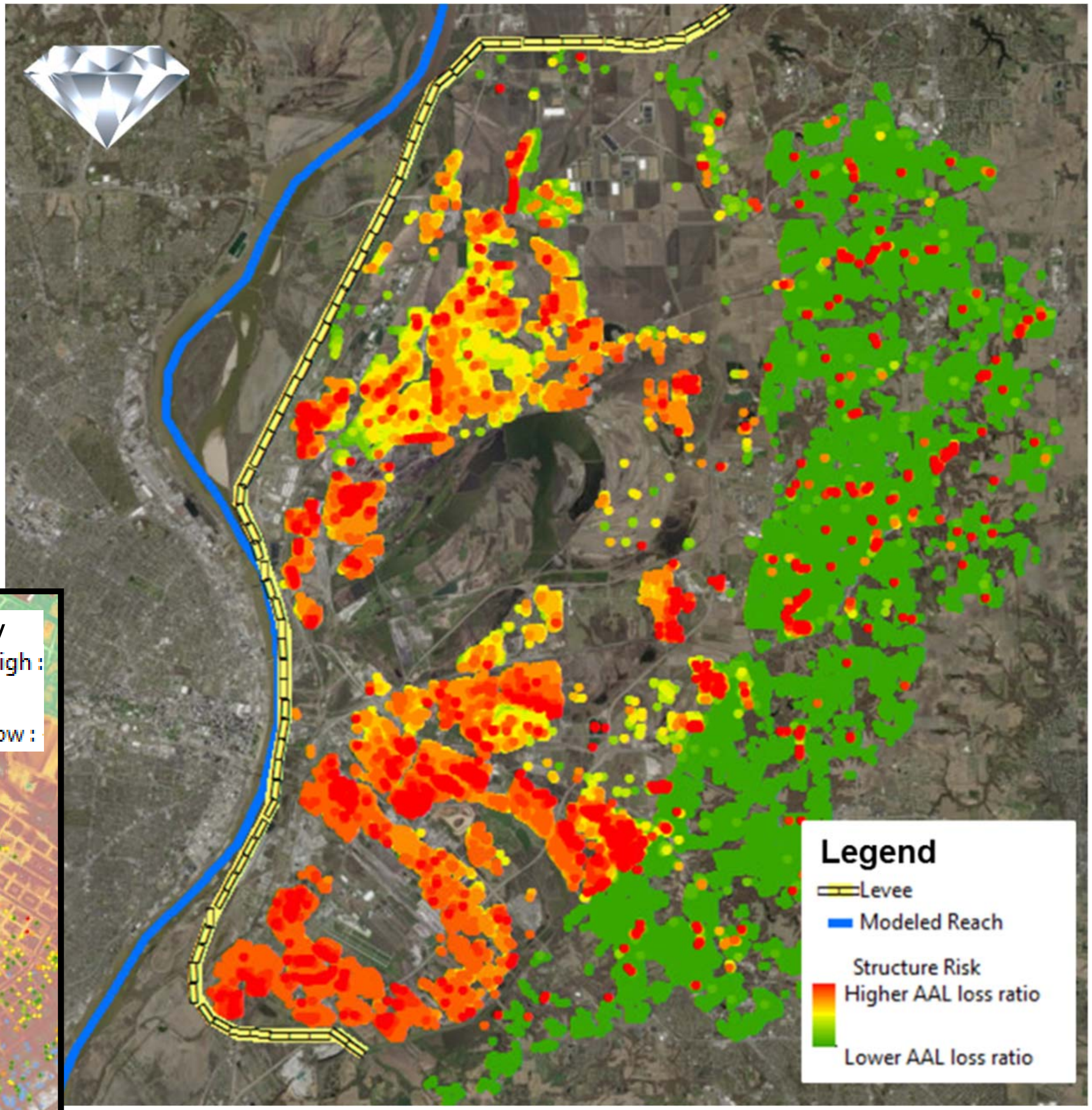


Total AAL
$15,028,131

Hot Spot Map of AAL Loss Ratio (Combined Fluvial and Pluvial)

AAL Loss Ratio = $\frac{AAL}{Structure\ Value}$

High AALs were primarily due to pluvial flooding within low-lying topographic areas

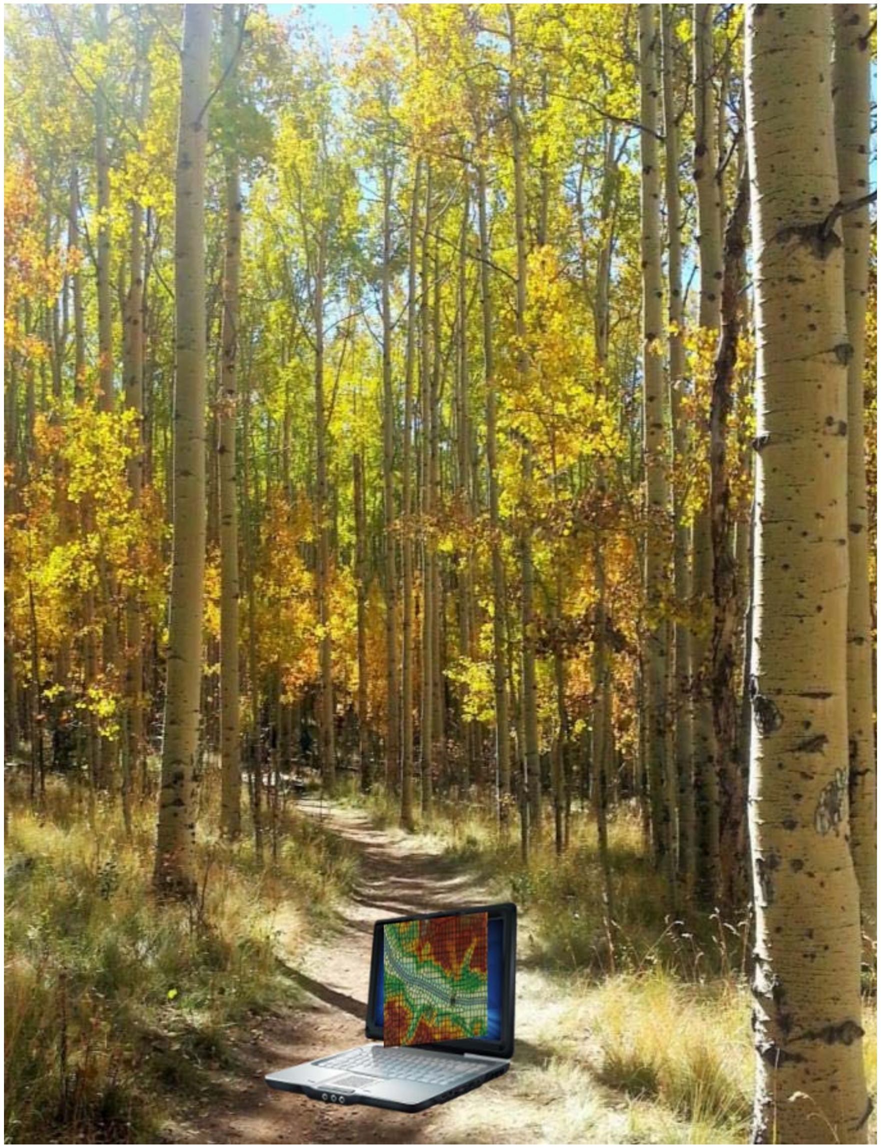


Probabilistic Mapping – Benefits

- **More comprehensive analysis of the flood hazard – from the 50% (2-yr) to the 0.033% (3000-yr) annual chance**
- **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**
- **Enhanced outreach and awareness**

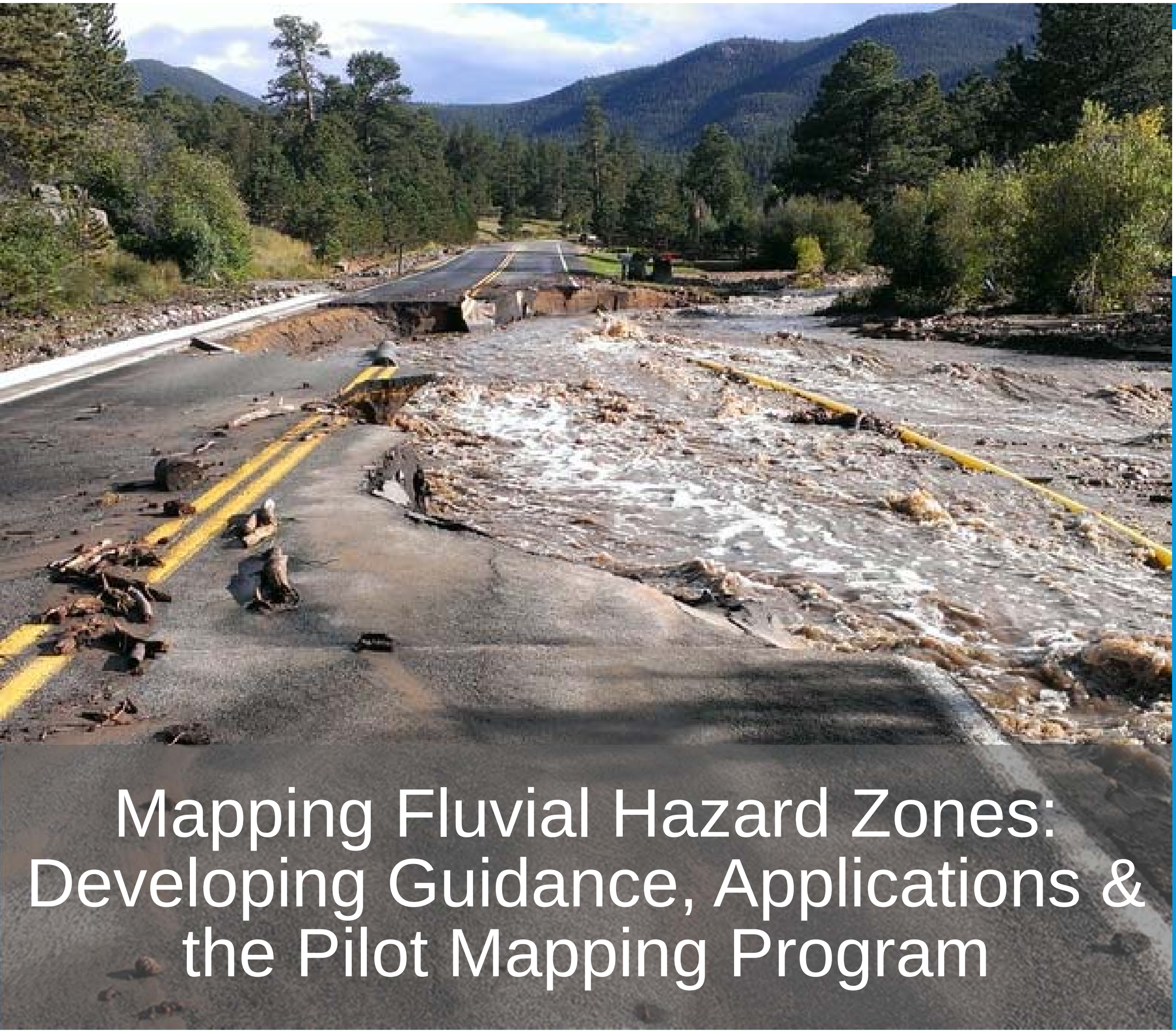
Next Steps

- **Performing additional pilots now**
- **Methodology and approach being refined based on continued lessons learned**
- **Development of guidelines and/or best practices (App C)**
- **Results to inform insurance premium adjustments in areas, particularly behind levees**
- **Time will tell…**



If you have any questions, please visit below!
https://aecom.jobs/

Geoff Uhlemann
geoffrey.uhlemann@aecom.com
303.796.4783



Mapping Fluvial Hazard Zones: Developing Guidance, Applications & the Pilot Mapping Program

COLORADO
Colorado Water Conservation Board
Department of Natural Resources

Stephanie DiBettito, CFM
Colorado Water Conservation Board

Joel Sholtes, PhD, PE
USBR Sedimentation and River Hydraulics

Michael Blazewicz
Round River Design

Katie Jagt, PE, CFM
Watershed Science + Design, PLLC

September 27, 2018 2:30pm
CASFM Snowmass
Emergency Preparedness

FLUVIAL HAZARD ZONE DEFINITION

"The Fluvial Hazard Zone (FHZ) is the area a stream has occupied in recent history, could occupy, or could physically influence as it stores and transports sediment and debris. The objective of a mapped FHZ is to identify lands most vulnerable to fluvial hazards in the near term."

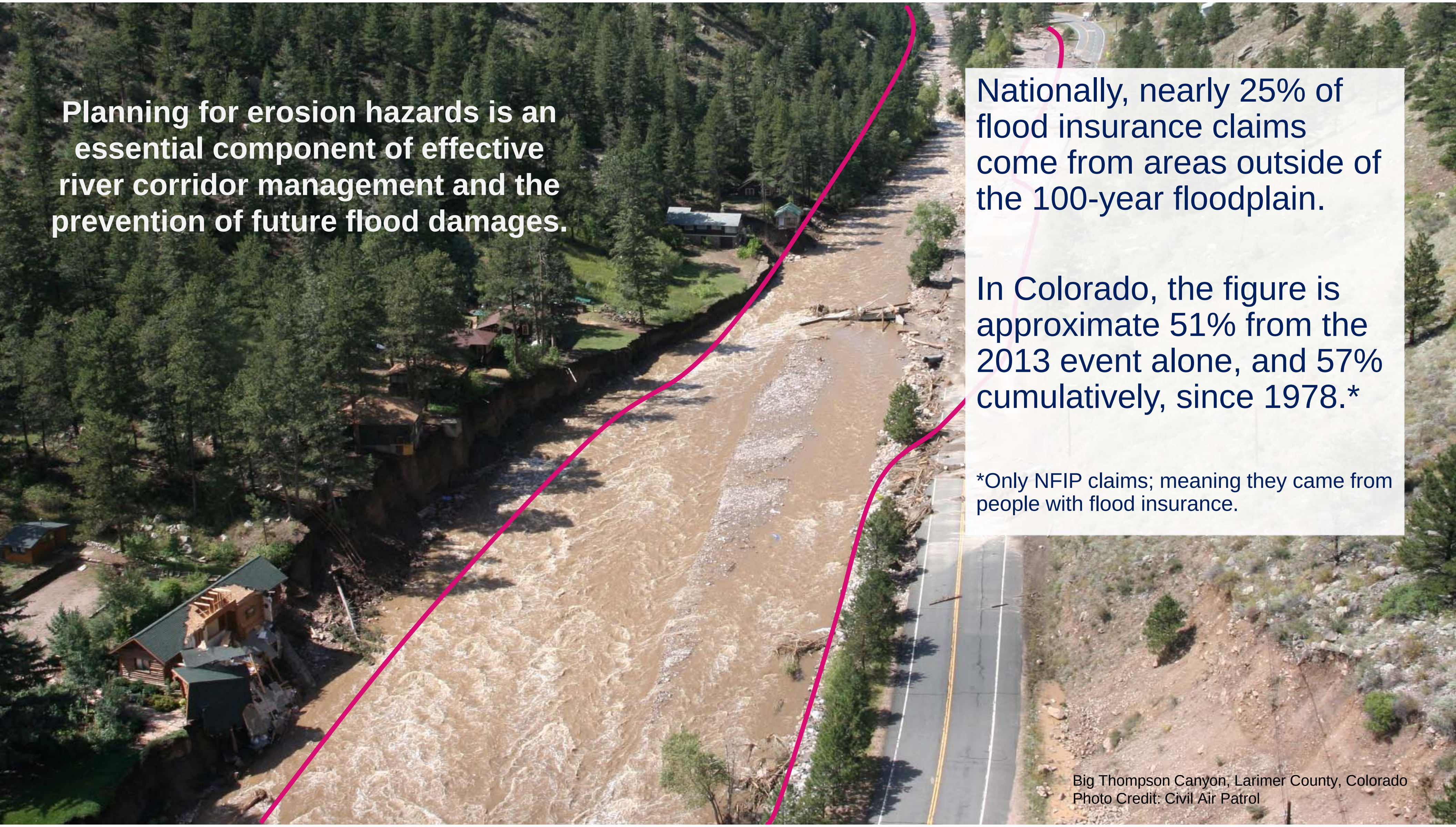
Estes Park, Larimer County, Colorado
Photo Credit: Town of Estes Park

Planning for erosion hazards is an essential component of effective river corridor management and the prevention of future flood damages.

Nationally, nearly 25% of flood insurance claims come from areas outside of the 100-year floodplain.

In Colorado, the figure is approximate 51% from the 2013 event alone, and 57% cumulatively, since 1978.*

*Only NFIP claims; meaning they came from people with flood insurance.



Big Thompson Canyon, Larimer County, Colorado
Photo Credit: Civil Air Patrol

State of Colorado's Perspective

The Colorado Water Conservation Board (CWCB) is the state coordinating agency for the National Flood Insurance Program (NFIP). **Floodplains are a matter of statewide importance** and the CWCB has been given the authority to prevent flood damages, regulate and designate floodplains, and ensure proper regulation of floodplains. The CWCB has Rules and Regulations for regulatory floodplains that set higher standards for floodplain management for communities in the state.

The Fluvial Hazard Mapping Program will develop and implement a program for mapping fluvial hazard areas, which will help strengthen the CWCB's role in **preventing flood damages**, regulate and designate floodplains, and ensure proper regulation of floodplains. The CWCB will **provide technical standards,** conduct studies for communities requesting mapping, and provide **regulatory guidance** for communities interested in **voluntarily** adopting map products.

FHZ PROGRAM GOALS

Goal 1. Develop a scientifically defensible set of standards for Colorado.

Goal 2. Implement fluvial hazard mapping throughout Colorado.

Goal 3: Reduce damage from future flood events by increasing awareness of fluvial (river-related) hazards thereby leading to better land use decisions.

STATE PROGRAMS AND TAC

- Vermont River Corridor Planning and Protection Program
  - Mike Kline
- Washington State Channel Migration Zone Program
  - Patricia Olson
  - Tim Abbe
- Montana Channel Migration Easement Program
  - Karin Boyd
  - Tony Thatcher

FLUVIAL HAZARD ZONE MAPPING TIMELINE

Front Range Flood

CWCB Executes Erosion Hazard Mapping Preliminary Study/Proof of Concept

CWCB Completes Fluvial Hazard Zone Pilot Mapping Program

2013

2014

2015

2017

2019

CWCB's Flood Recovery Master Planning delineates preliminary Channel Migration Zones for Estes Valley and St. Vrain Creek

CWCB Executes Fluvial Hazard Zone Pilot Mapping Program

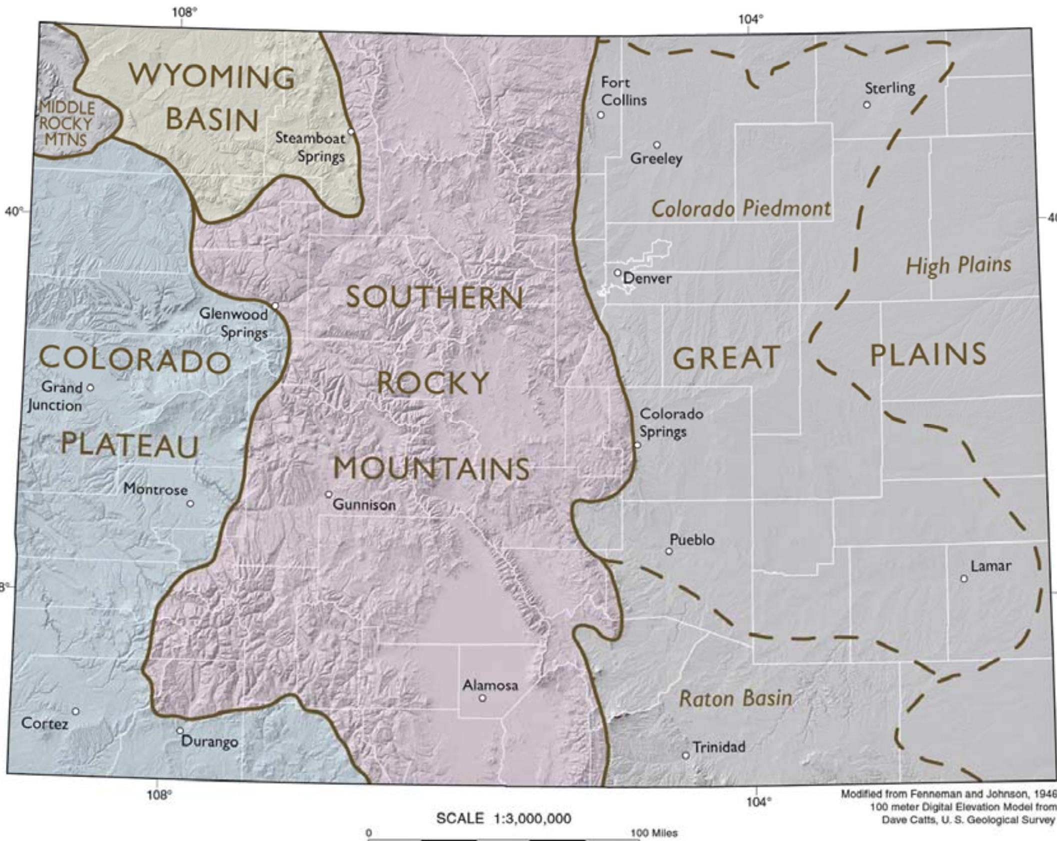
WHY NOT "EROSION" HAZARD MAPPING

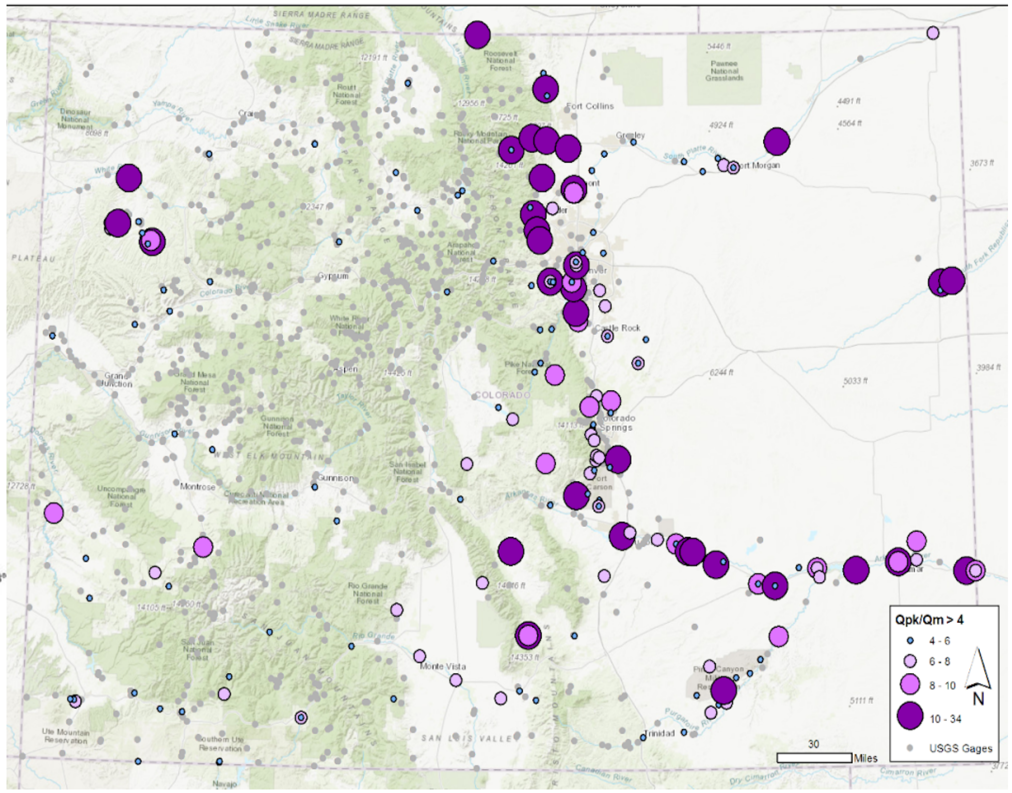
Erosion is just one of the geomorphic hazards associated with rivers. Simply measuring, modeling, or calculating erosion or bank retreat is insufficient to capture all hazards in a river corridor. Other geomorphic hazards include deposition, avulsion, and fan processes. This program identifies areas susceptible to erosion but also includes areas where these other geomorphic hazards present risk.

GOAL 1. DEVELOP A SCIENTIFICALLY DEFENSIBLE SET OF STANDARDS FOR COLORADO

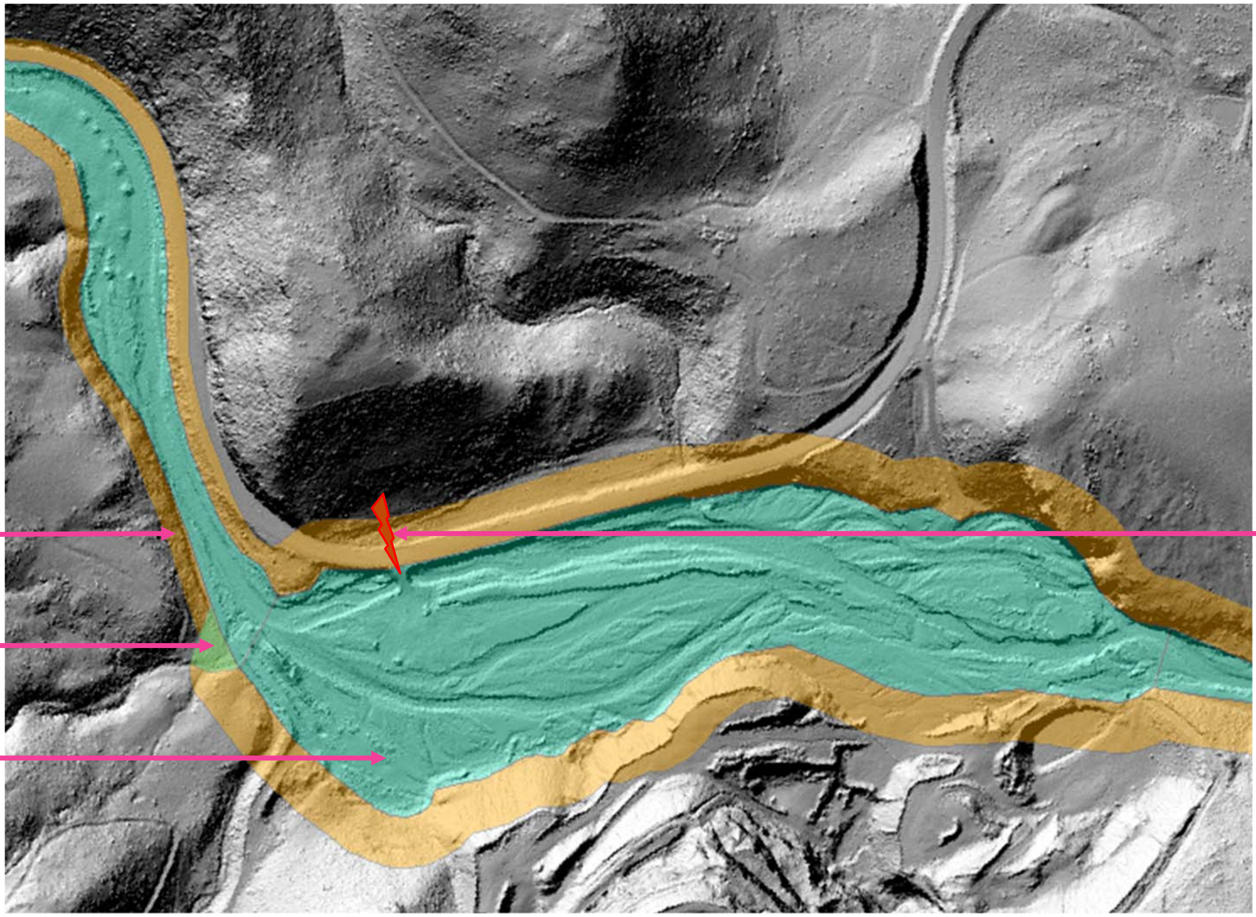
FHZ PROTOCOL DEVELOPMENT

PHYSIOGRAPHIC, GEOLOGIC, AND HYDROLOGIC CONTEXT





FLUVIAL HAZARD ZONE MAP COMPONENTS



Not Shown:

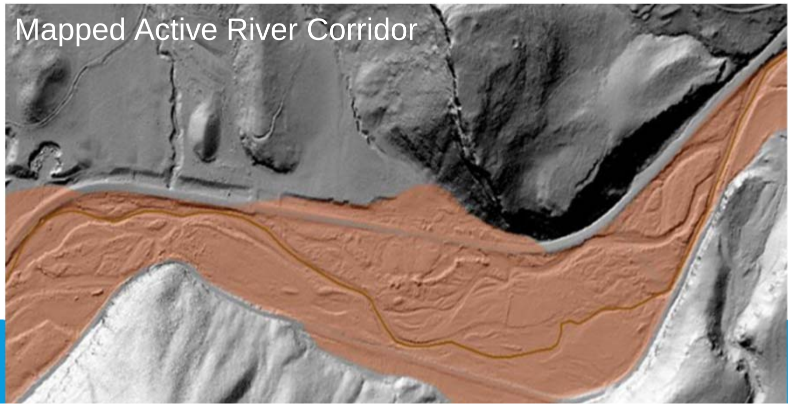
- Avulsion Zones (AHZ)
- Disconnected Active River Corridor (D-ARC)

__Active River Corridor (ARC)__:

Where the river has occupied in the past or is likely to occupy in the future.

Four Methods to Delineate an ARC:

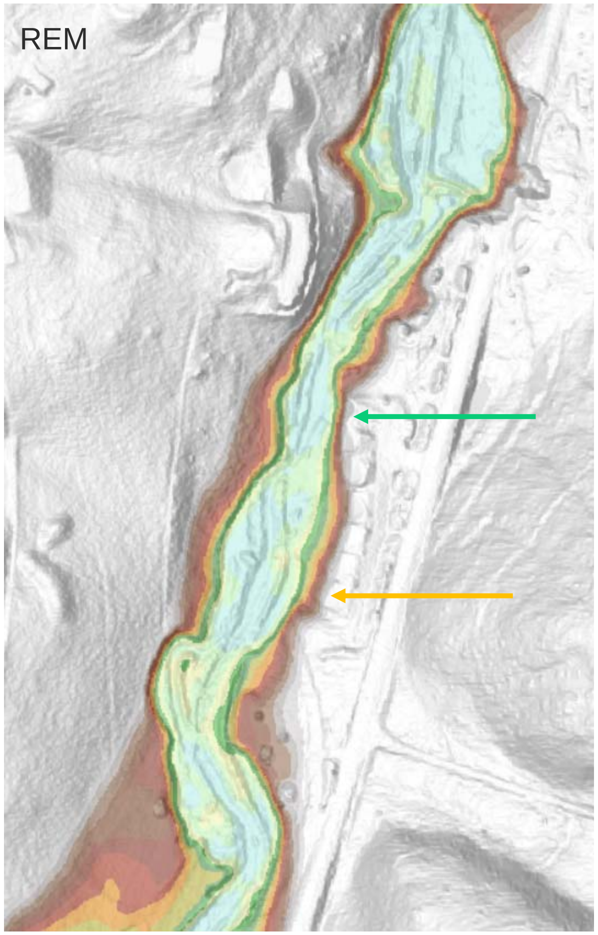
- **Headwater**: In steep headwater reaches
- **Fluvial Signature**: In streams with steeper slope or streams that are confined and partially confined by their valley walls or terraces
- **Meander Belt-Width**: In low-sloped streams that are unconfined by the valley margin or terraces
- **Urban**: In urbanized and heavily modified stream corridors also assesses the Disconnected-ARC.



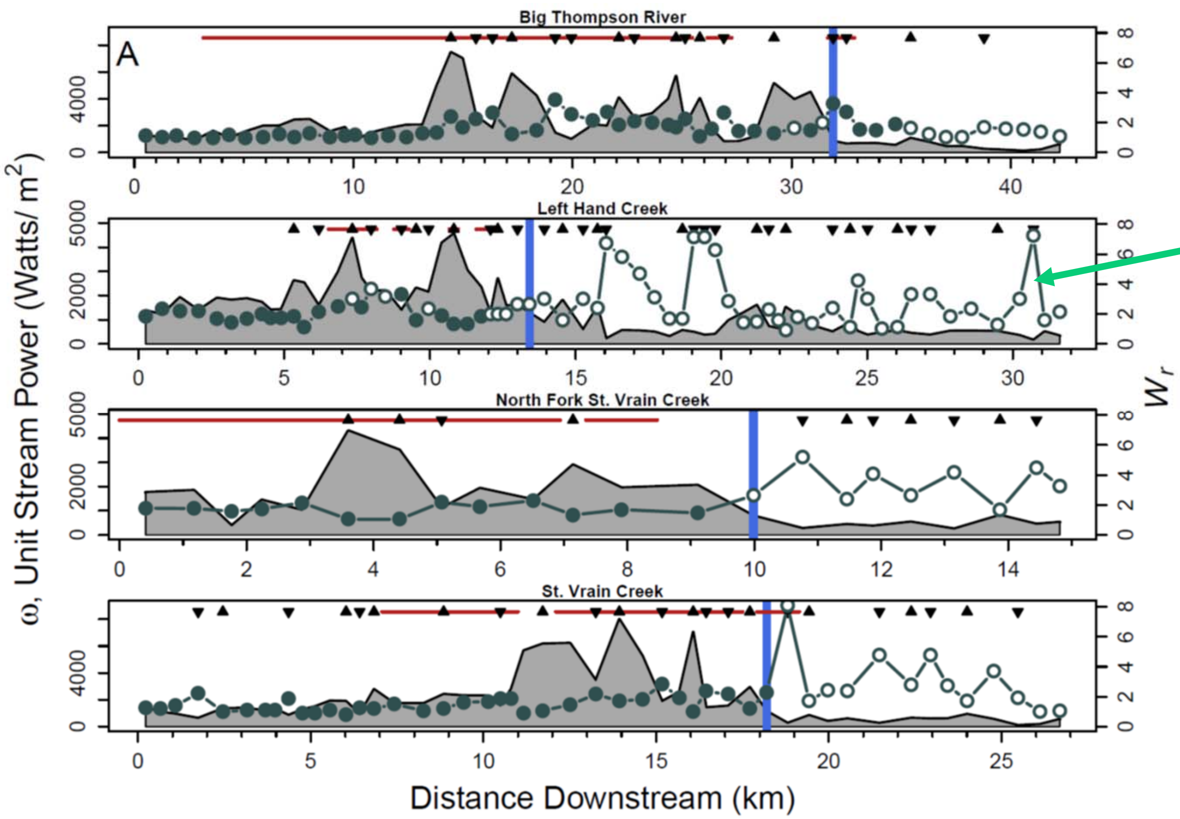
FLUVIAL SIGNATURE METHOD: ARC DELINEATIONS USING AN REM

- The ARC is mapped based on expert identification of the features that compose an active, geomorphic floodplain.
- We refer to these features as “fluvial signatures” and define them as landforms that are created by the deposition of sediment or erosion of sediment or bedrock. More than 17 of these out-of-channel geomorphic features have been described by Wheaton et al. 2015, and Brierley and Fryirs 2012.

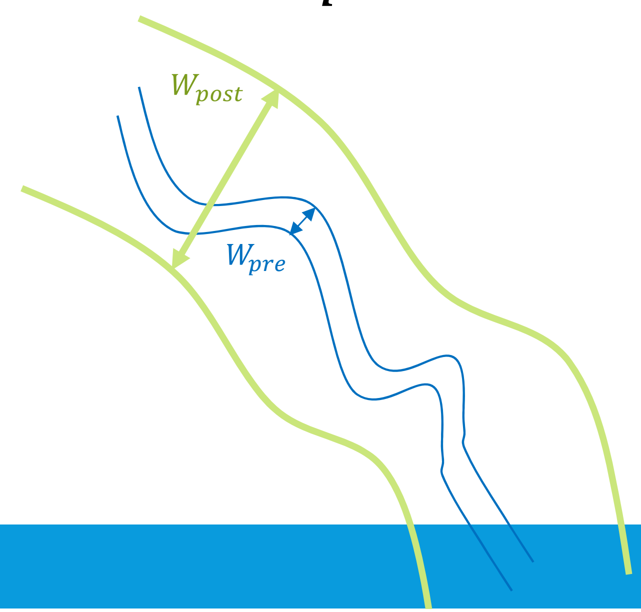
FLUVIAL SIGNATURE METHOD: ARC DELINEATIONS USING AN REM



FLUVIAL SIGNATURE METHOD: FLUVIAL SIGNATURE DATA AND OBSERVATIONS

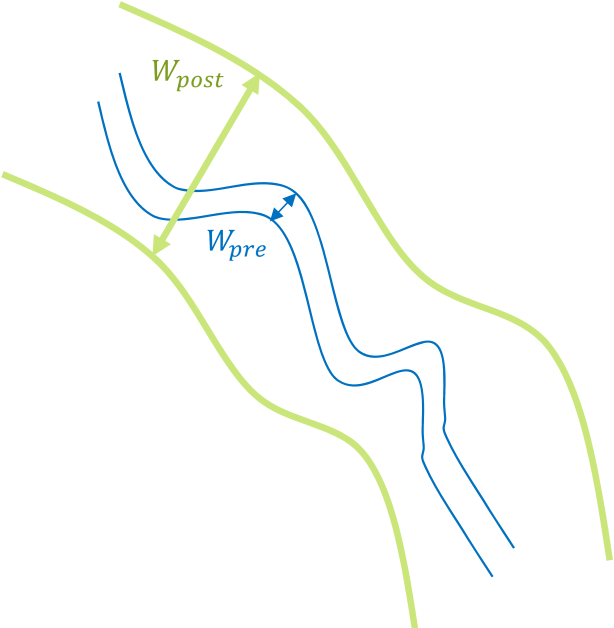


$$W_r = \frac{W_{post}}{W_{pre}}$$



FLUVIAL SIGNATURE METHOD: FLUVIAL SIGNATURE DATA AND OBSERVATIONS

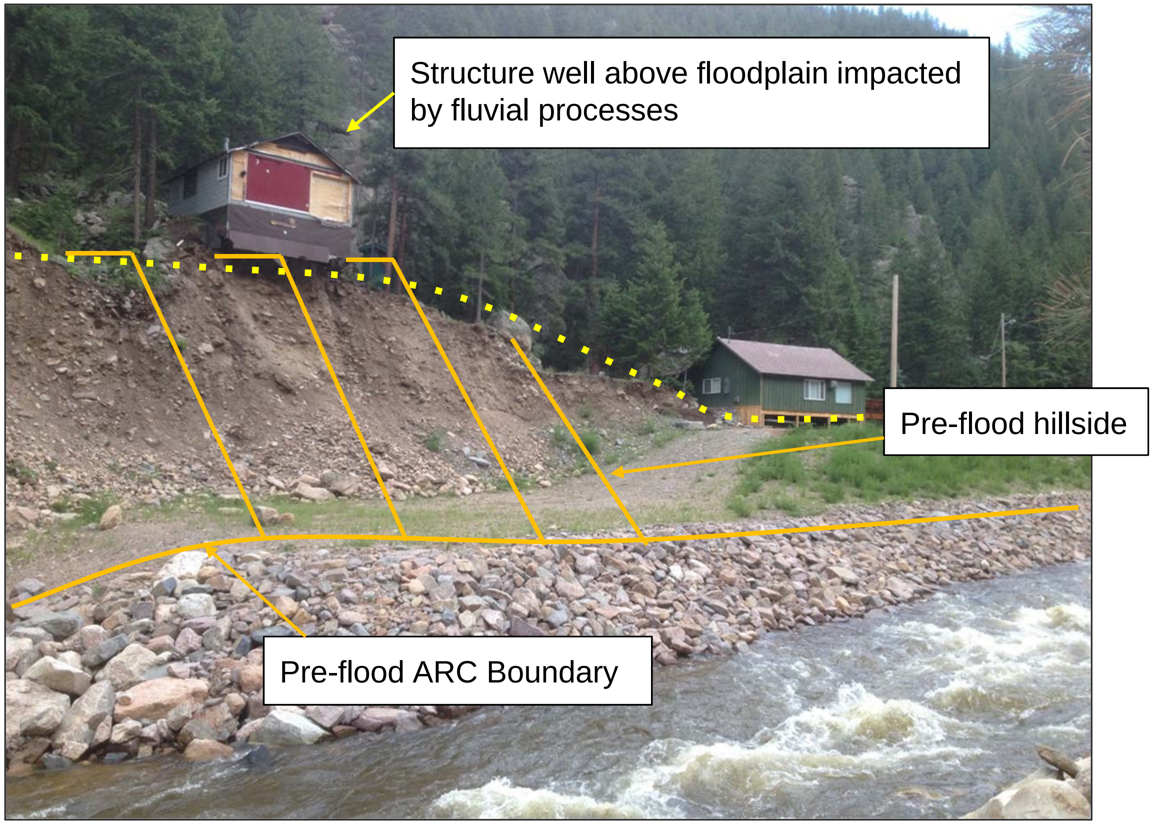
$$W_r = \frac{W_{post}}{W_{pre}}$$

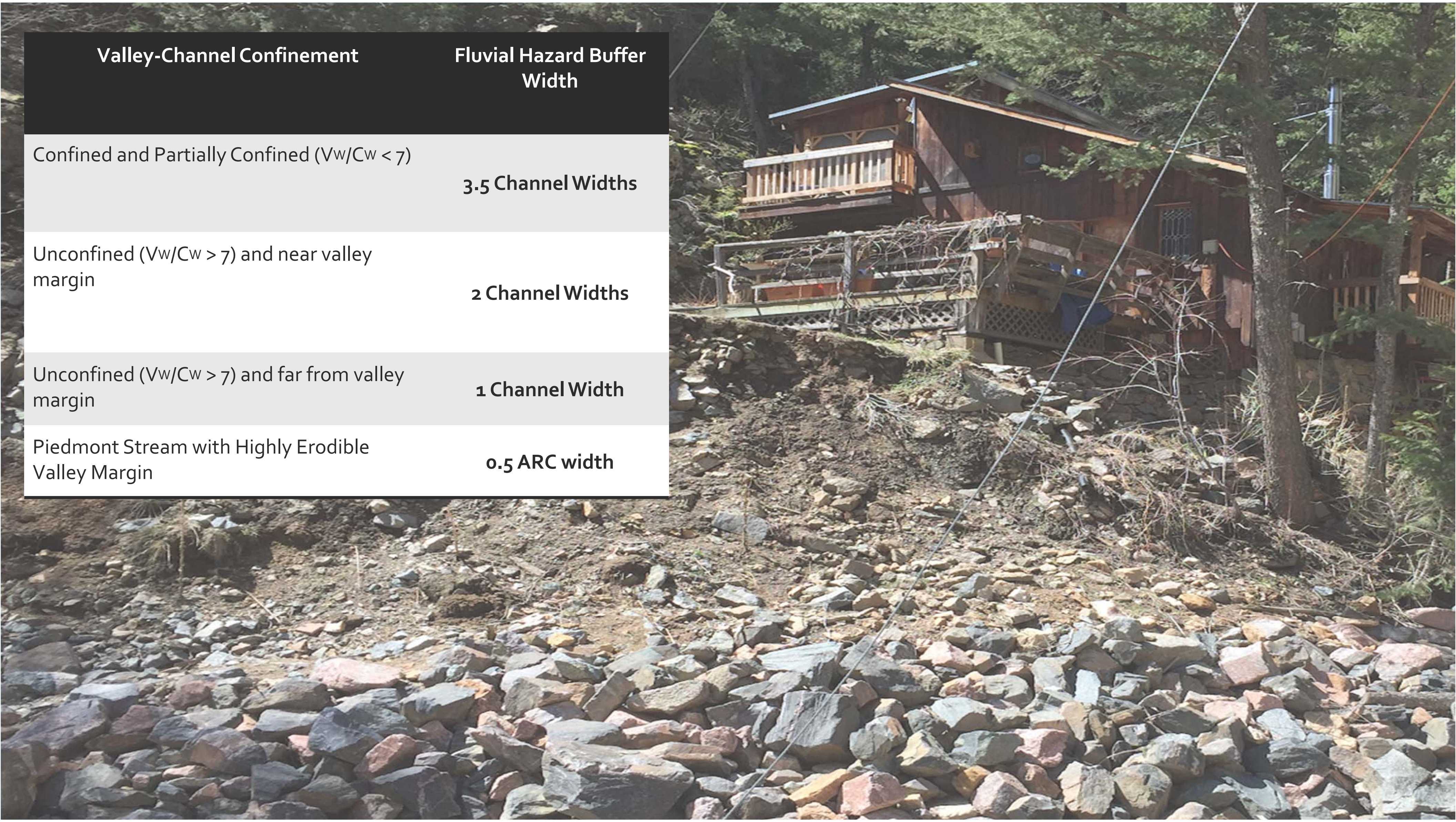


Big Thompson Canyon, Larimer County, Colorado
Photo Credit: Civil Air Patrol

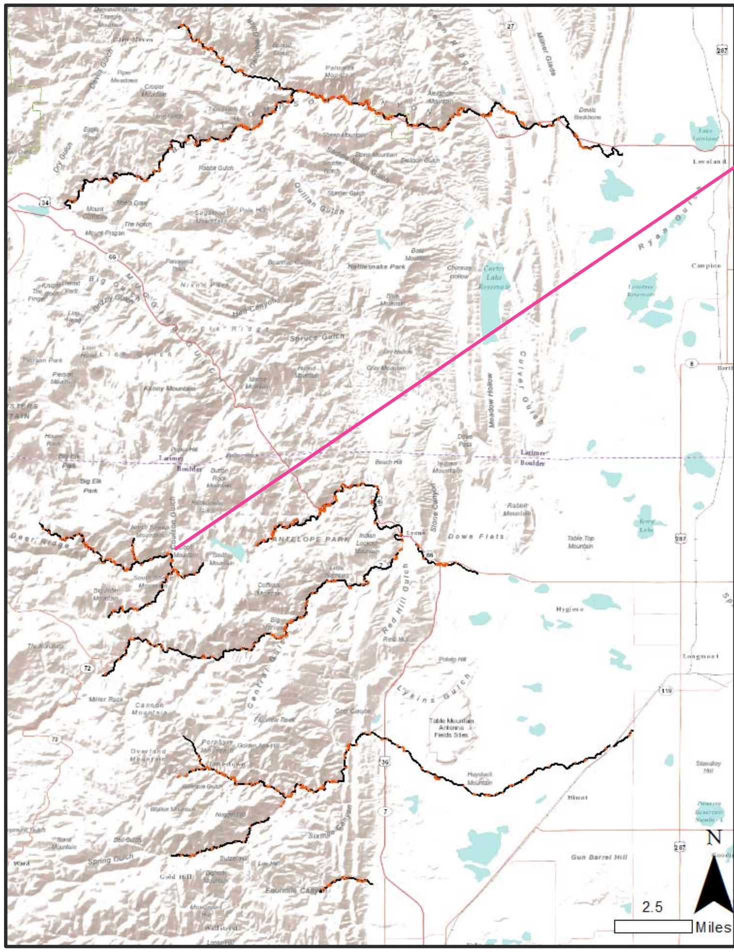
Fluvial Hazard Buffer (FHB):

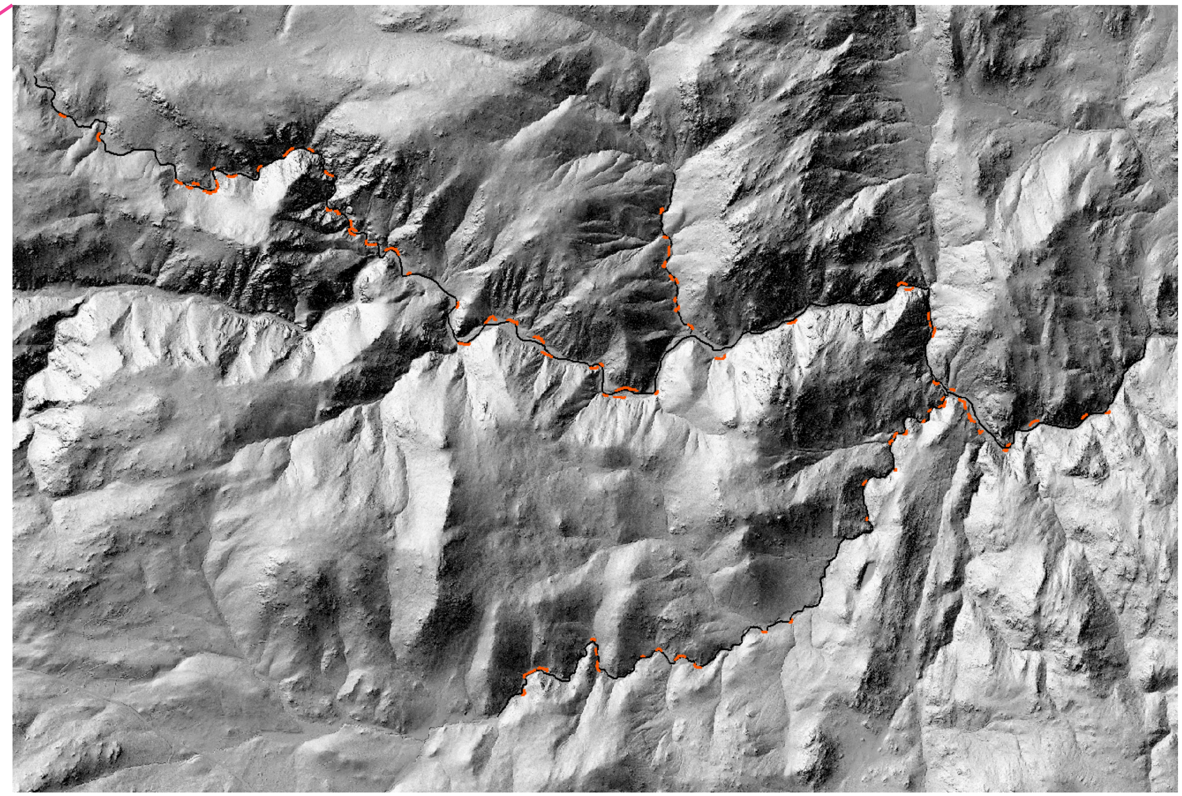
Regions, such as terraces or hillsides, that extend outward beyond the ARC and may be susceptible to erosion and mass wasting induced by lateral migration, widening, and incision of the river channel.



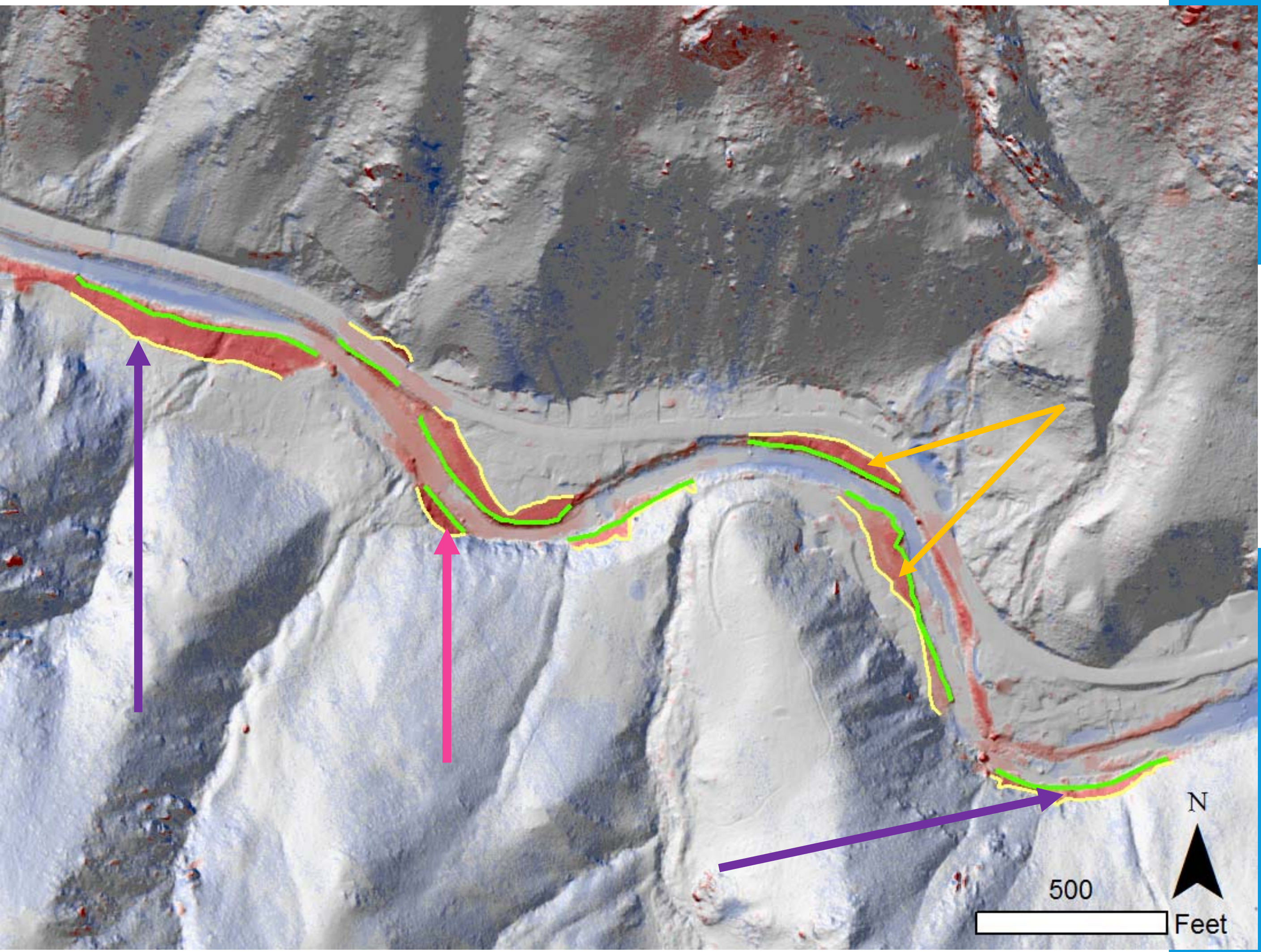


Valley-Channel Confinement	Fluvial Hazard Buffer Width
Confined and Partially Confined ($V_W/C_W < 7$)	**3.5 Channel Widths**
Unconfined ($V_W/C_W > 7$) and near valley margin	**2 Channel Widths**
Unconfined ($V_W/C_W > 7$) and far from valley margin	**1 Channel Width**
Piedmont Stream with Highly Erodible Valley Margin	**0.5 ARC width**





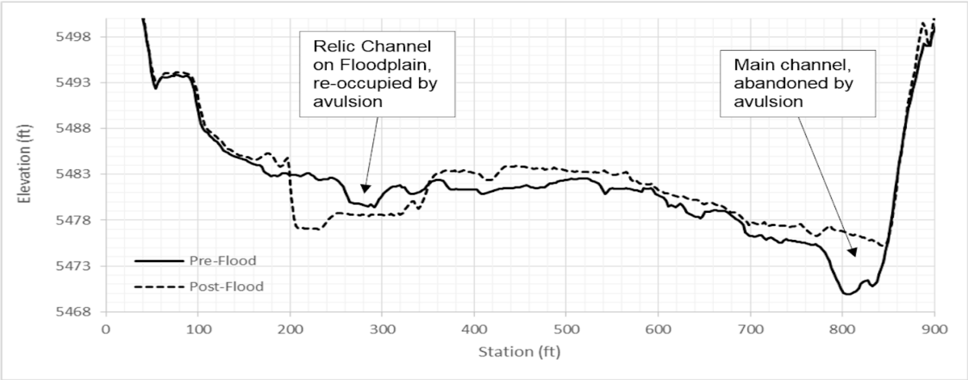
HILLSLOPE EROSION – 2013 FRONT RANGE FLOOD



MEASURING HILLSLOPE FAILURE

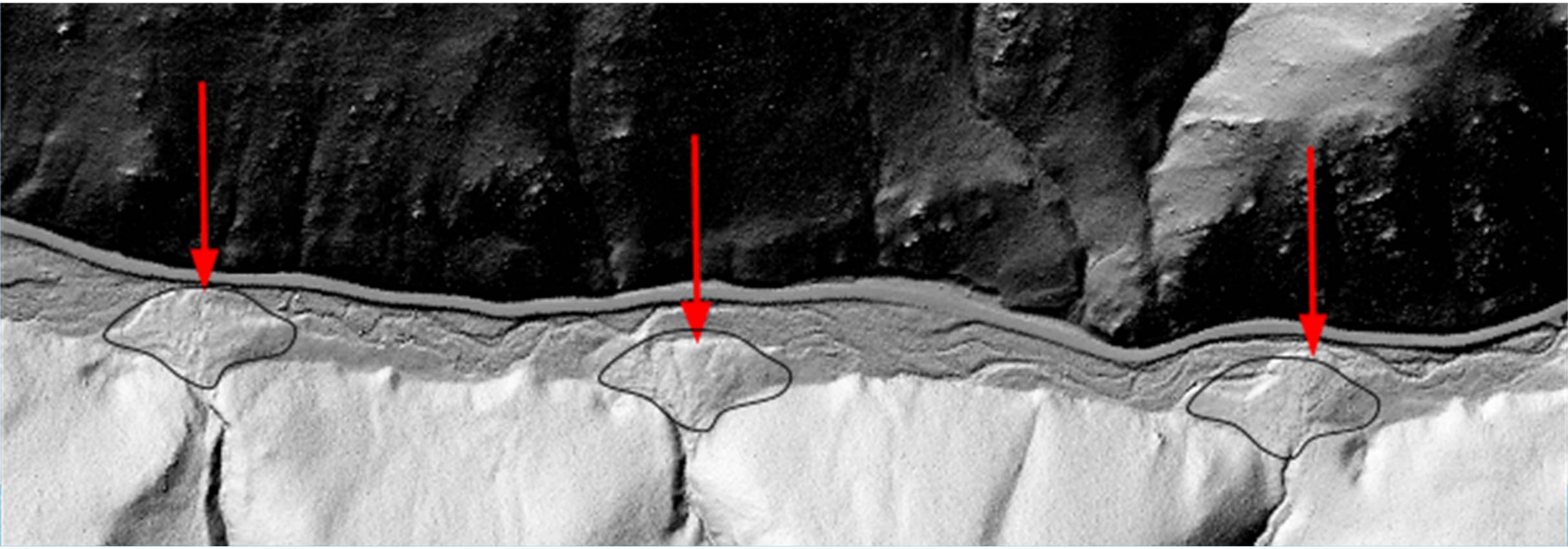
Avulsion Hazard Zone:

Areas a channel might occupy during a flood event due to a wholesale shift in channel position on the valley floor.



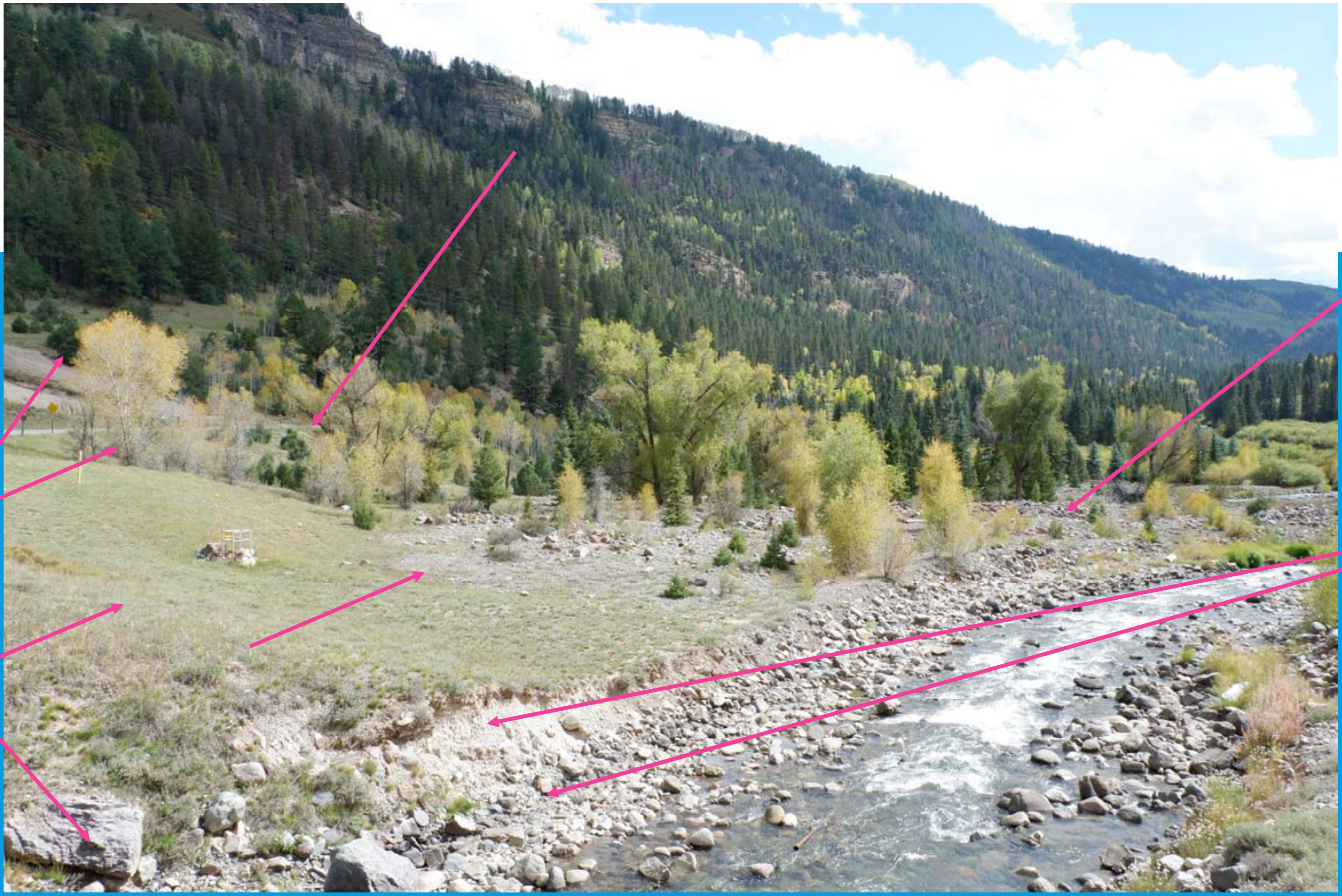
Fans:

Fans are triangular-shaped depositional features that generally form where steep transport reaches meet an unconfined, relatively flat river valley and a reduction in sediment and debris transport capacity causes material to deposit.



GO IN THE FIELD!

Estes Park and Telluride, Colorado
Photo Credit: Katie Jagt and Steph DiBettito



FIELD VERIFY—WHY?

Telluride, Colorado
Photo Credit: Katie Jagt

GOAL 2. IMPLEMENT FLUVIAL HAZARD MAPPING THROUGHOUT COLORADO

FHZ PILOT MAPPING PROGRAM

FHZ PILOT PROGRAM

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- Vdq#P ljxho#Frxqw|
- Vdjxdfkh#Frxqw|
- Hdjoh#Frxqw|
- Wrzq#ri#Hvwhv#Sdun
- Flw|#ri#Ghowd
- Flw|#ri#Fdvwoh#Urfn
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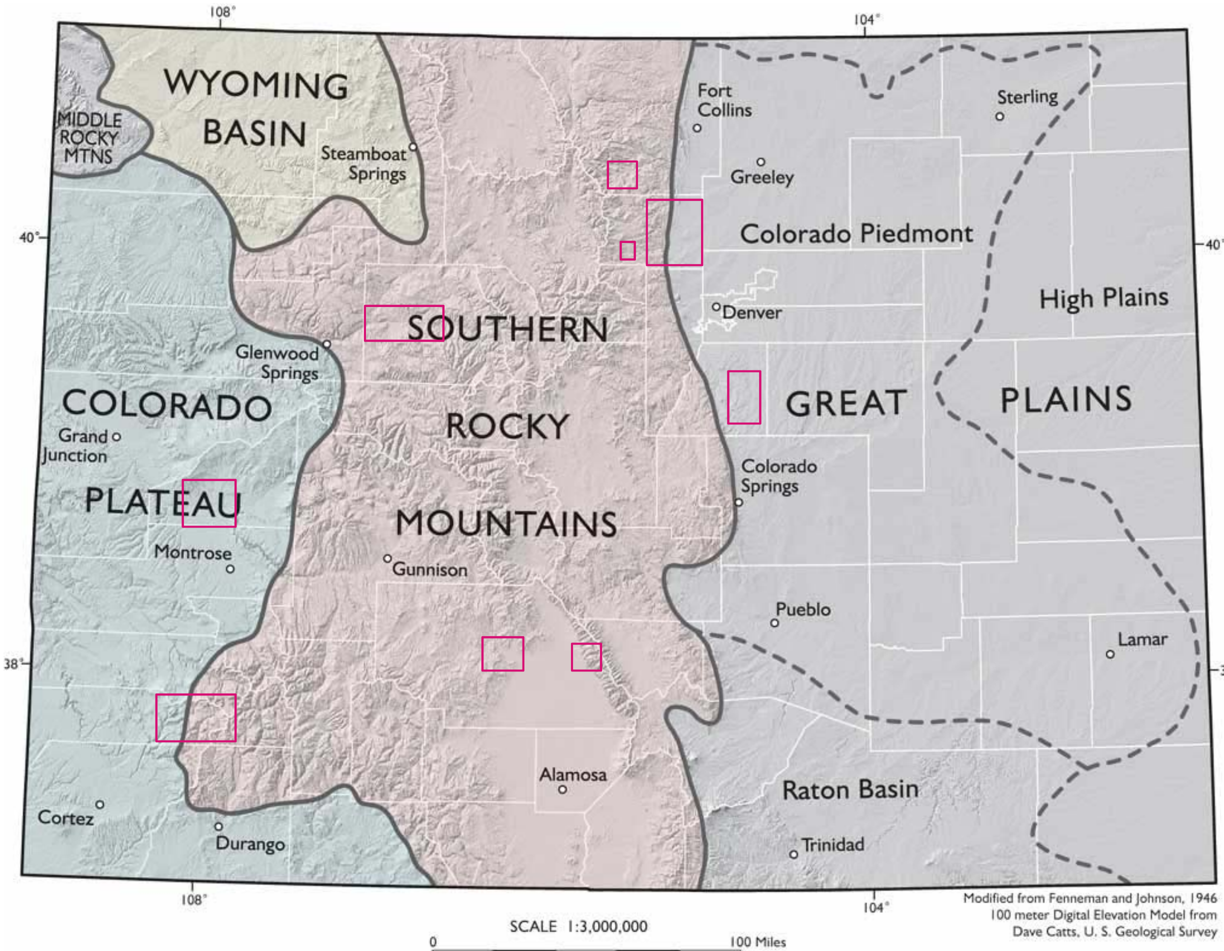

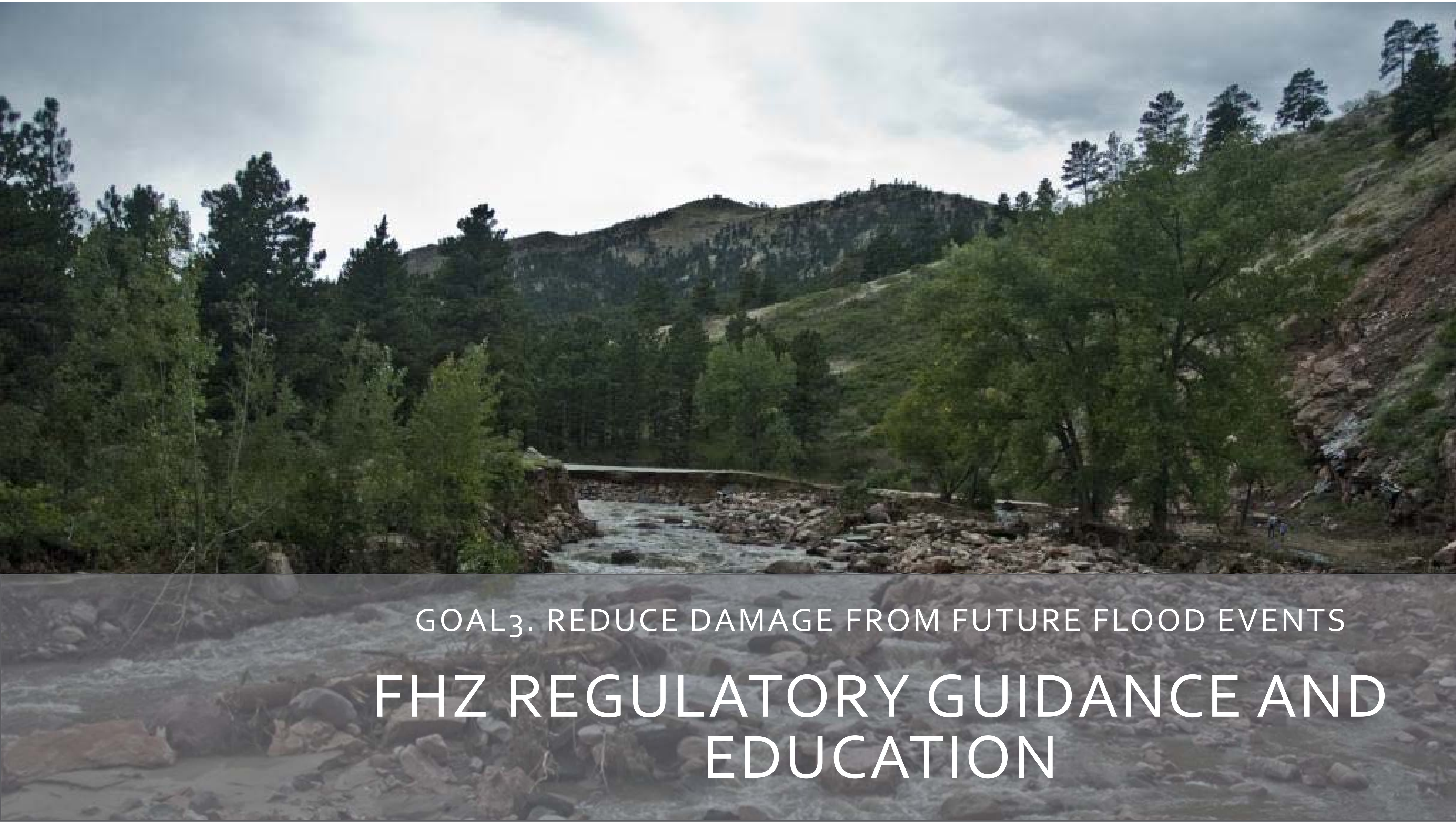

GOAL3. REDUCE DAMAGE FROM FUTURE FLOOD EVENTS

FHZ REGULATORY GUIDANCE AND EDUCATION

Krz#Pdsv#Pljkw#eh#Xvhg

- Suhyhqw#frppxqlw|#iurp#lqyhvwlqj#vhuylfhv# +h1j1/#vfkrrov/#iluh2uhvfxh#vwdwlrqv/#zdwhu# vdqlwdwlrq/#hwf1,#lq#fulwlfdo#yxoqhudeoh#duhdv1##
- Suryigh#lqirupdwlrq#wr#odqgrzqhuv#derxw# h{lvwlqj#ulvn
- Dvvlvw#lq#wudqvsruwdwlrq#ghflvlrqv#zkhuh# urdgv2ulyhuv#lqwhudfw
- Lqirup#odqg#frqvhuydwlrq#sodqqlqj
- Ryhudo|#lq#odqgxvh#ru#}rqlqj#

Jamestown, Colorado
Top: 2013 Flood, Civil Air Patrol
Bottom: 1969 Flood, Carnegie Branch Library/Boulder Historical Society


Drake, Colorado
Left: 2013 Flood, Civil Air Patrol
Right: 1976 Flood
Bill Sptiz

LIMITATIONS

Wkrxjk#wklv#surfhvv#
frqvwlwxwhv#d#vljqlilfdqw#
lp suryhp hqw#wr#
xqghuvwdqglqj#iorrg#
kd}dugv/#lw#lv#xqghuvwrrg#
wkh#surjudp #grhv#qrw#dqg#
zloo#qrw#surylgh#devroxwh#
vdihw| ru#hqfrp sdvv#doo#
iorrg/#jhrp ruskif/#dqg#
ulyhu0uhodwhg#kd}dugv1

Fourmile Canyon, Boulder, Colorado
Photo Credit: FMFPD

COLORADO
Colorado Water Conservation Board
Department of Natural Resources

Vwhskdqh#G1#Ehwwr
Z dwhuvkhg#) #Iorrg#Surwhfwlrq#Vhfwlrq/#FZ FE
Frp p xqlw|#Dvvlvwdqfh#Surjudp #Frruglqdwru
vwhskdqh1ehwwrCvwdwh1fr1xv
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Ndwh#Mdjw/#SH/#FIP
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ndwhmdjwCzdwhuvkhgvflhqfhdqgghvljq1frp
:530859065355

WATERSHED
SCIENCE + DESIGN

1935 Memorial Day Flood Fountain and Monument Creeks
Image Source: Pikes Peak Library Digital Collection

Evacuation Planning for Extreme Events: Failure of the Cherry Creek Dam

Presented by:
Jeffrey Brislawn, CFM / Wood
Kyle Karsjen, Wood

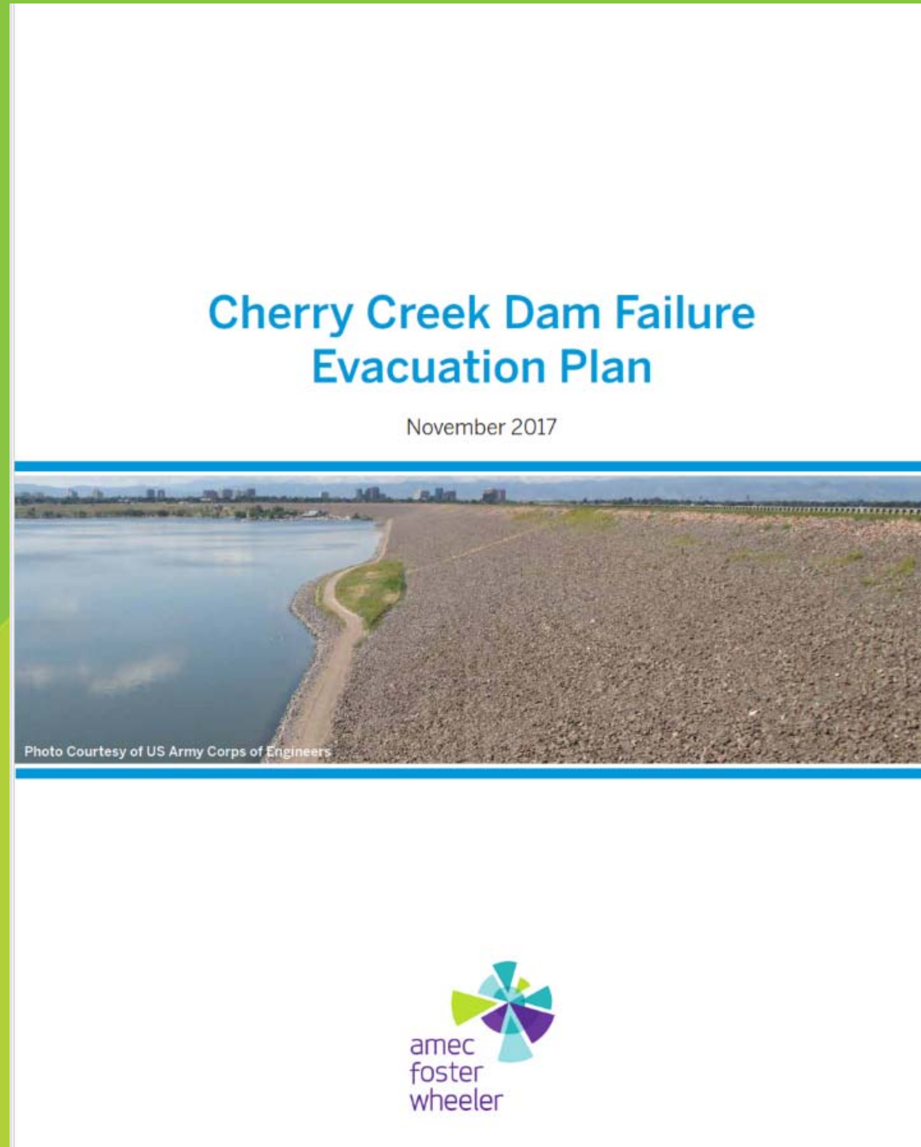
2018 Annual CASFM Conference
Snowmass, CO: "*Tackling the Impossible*"

woodplc.com

Presentation overview

- Project background
- Planning Situation and Probable Maximum Flood Risk
- Planning Process
- Multi-jurisdictional considerations
- Plan Elements
- Summary/Lessons Learned

Project Background


Cherry Creek Dam Failure Evacuation Plan

November 2017

Photo Courtesy of US Army Corps of Engineers

amec foster wheeler

Purpose

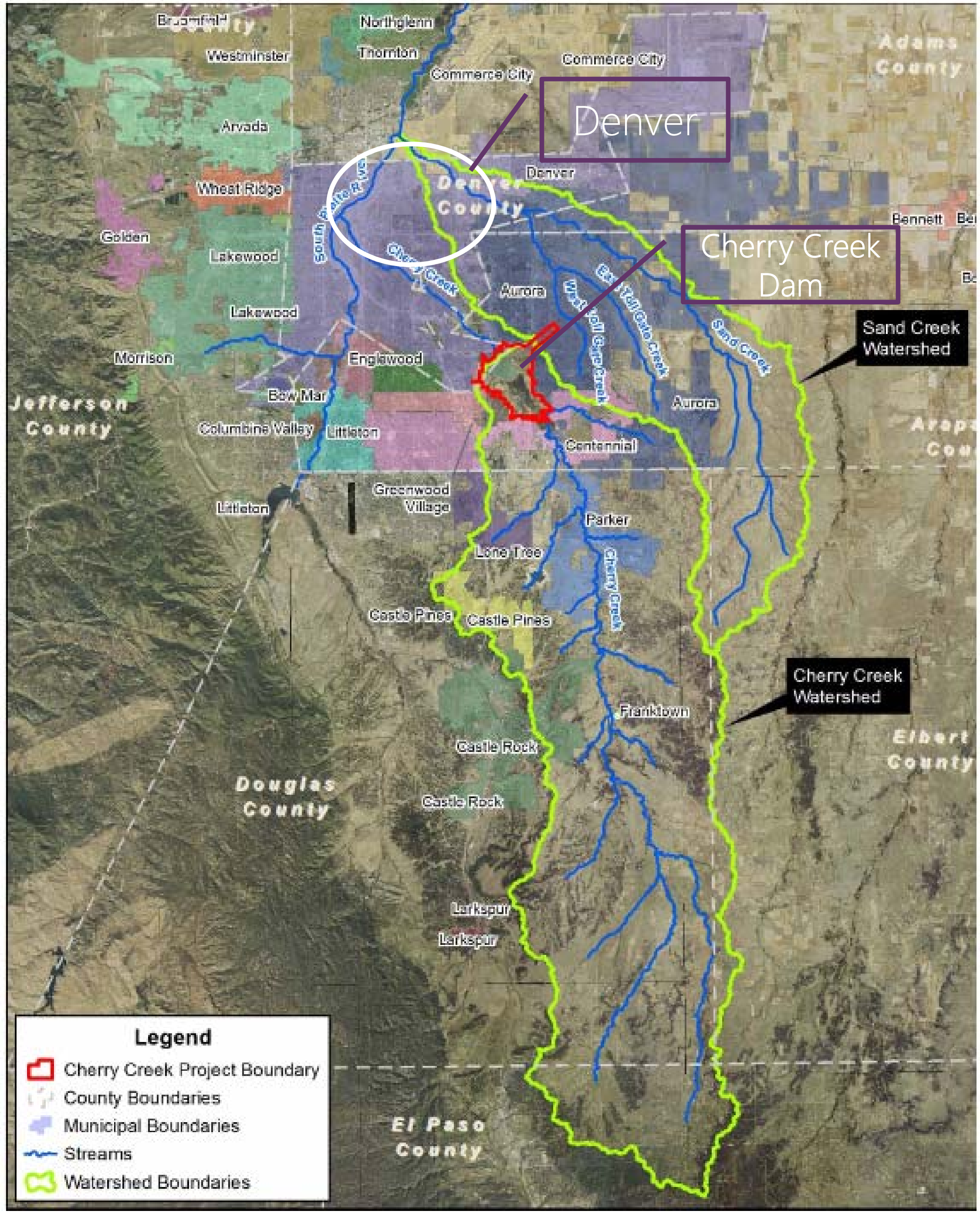
- *The goal of the Evacuation Plan is to provide a coordinated strategy to evacuate large numbers of persons from an area of high flood risk within the Cherry Creek Dam protected region to an adjoining area of reduced risk prior to, during and after a dam incident or failure.*

In other words:

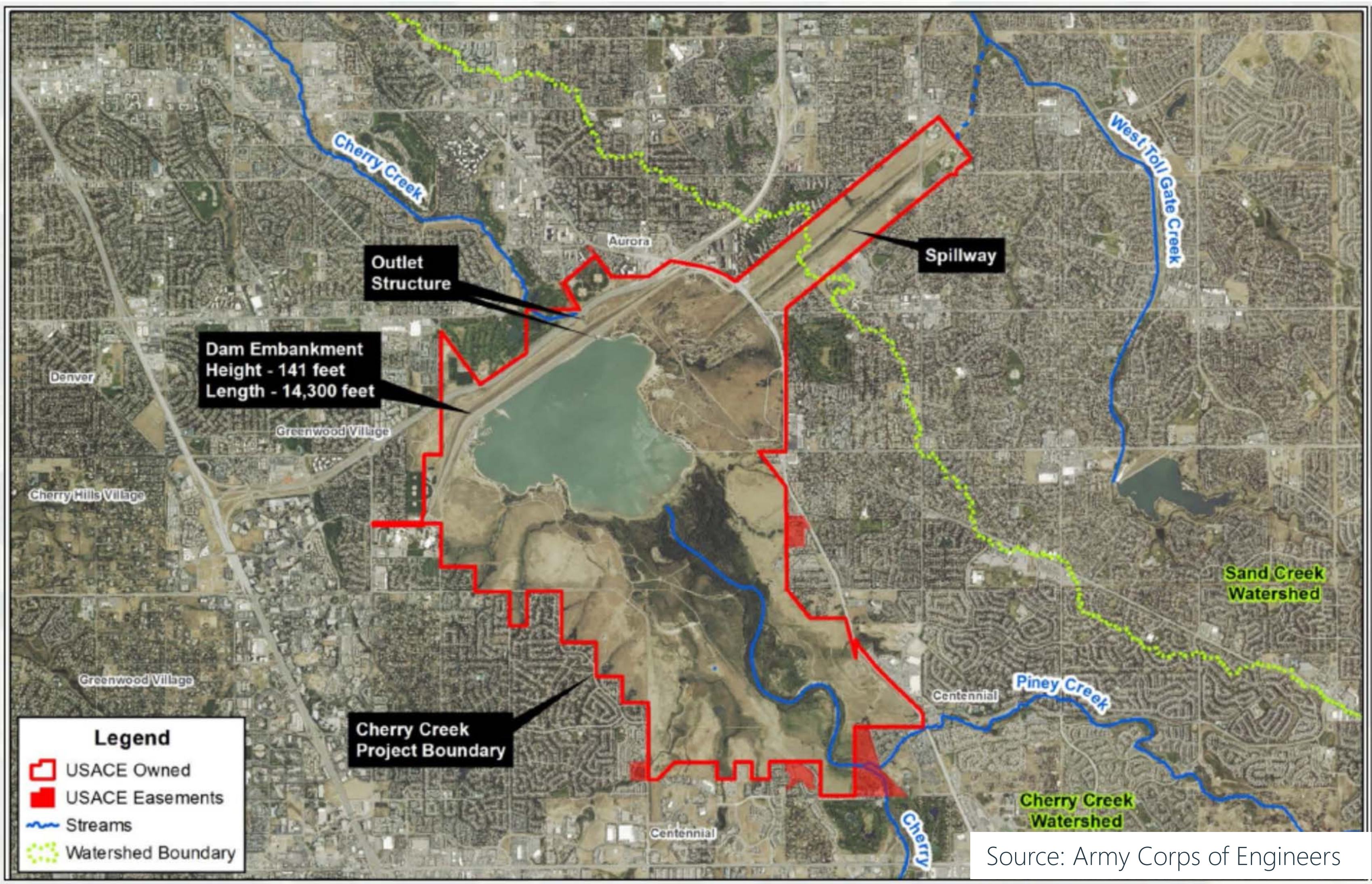
1. There are a lot of people in the inundation area
2. There is a lot of water coming
3. How do our communities work together to get people out efficiently and effectively?

Watershed and Planning Area

- Cherry Creek Dam completed in 1950
- Managed in conjunction with Chatfield and Bear Creek dams to mitigate flood risk in the Denver area.
- 2017 Army Corps of Engineers Water Control Plan Modification and Dam Safety Modification study identified concerns and mitigation options



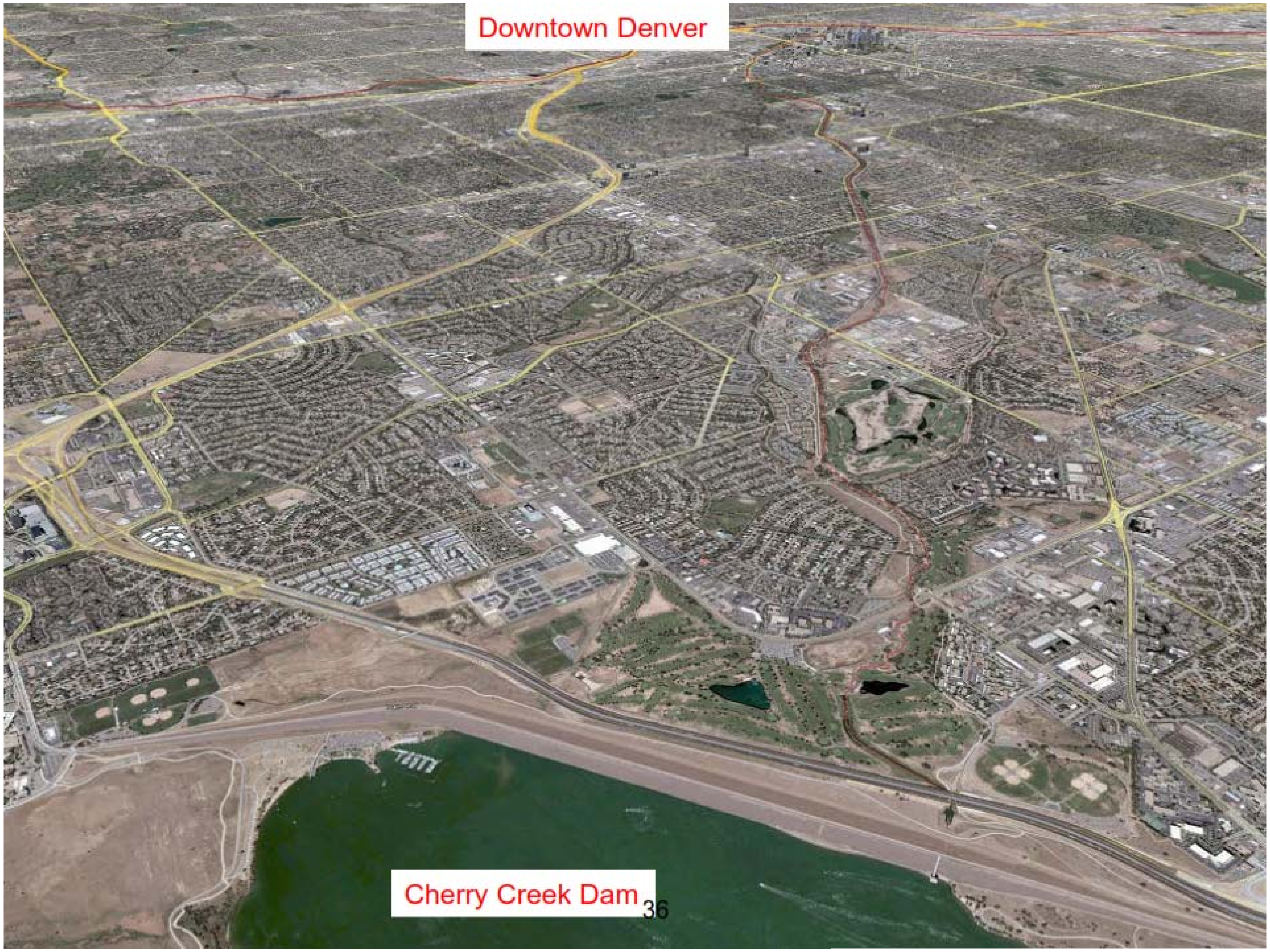
Cherry Creek Dam and Reservoir



Source: Army Corps of Engineers

Cherry Creek Dam and Reservoir – Perspective View

Perspective View Towards Denver

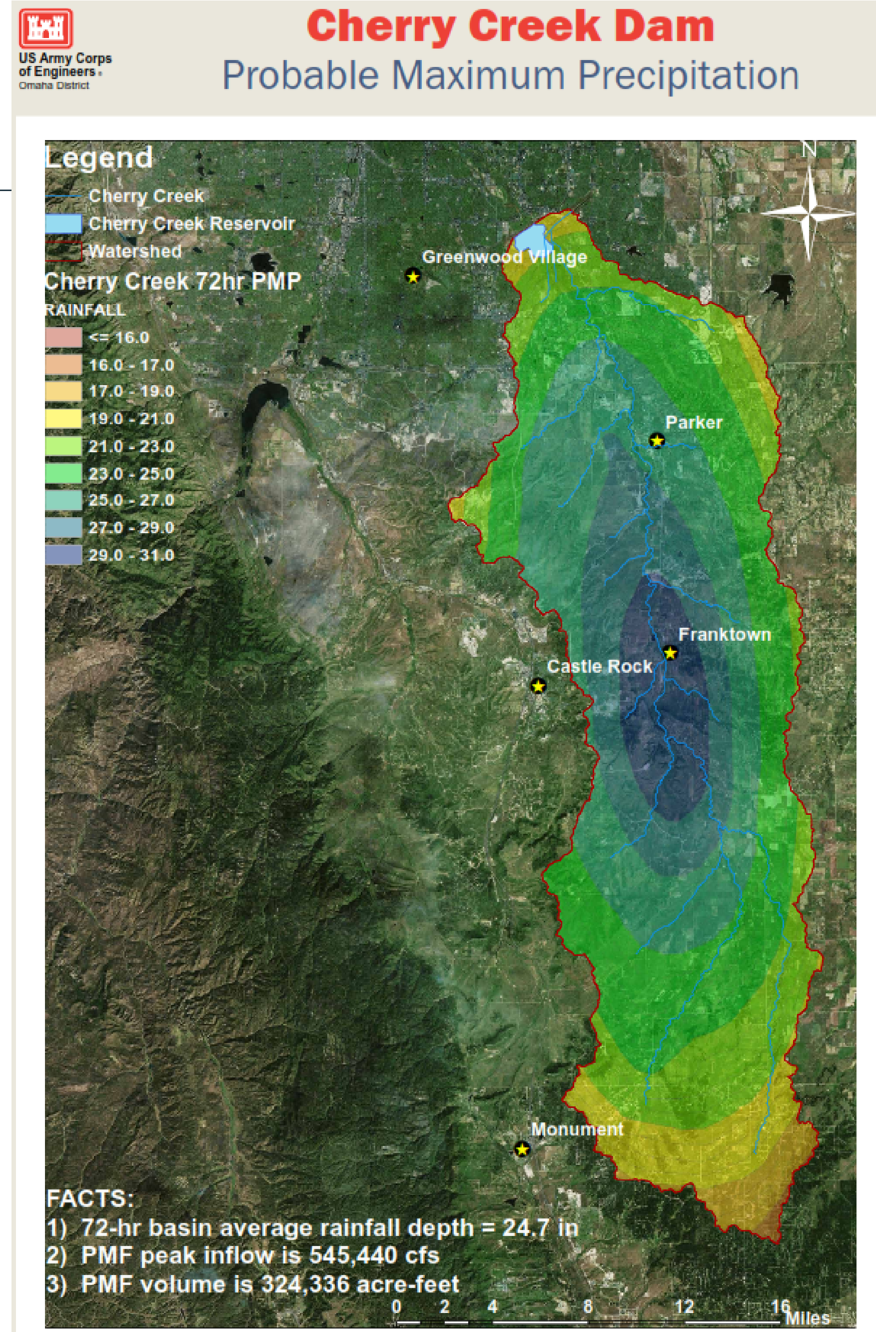


Source: Army Corps of Engineers

Planning Situation and Probable Maximum Flood Risk

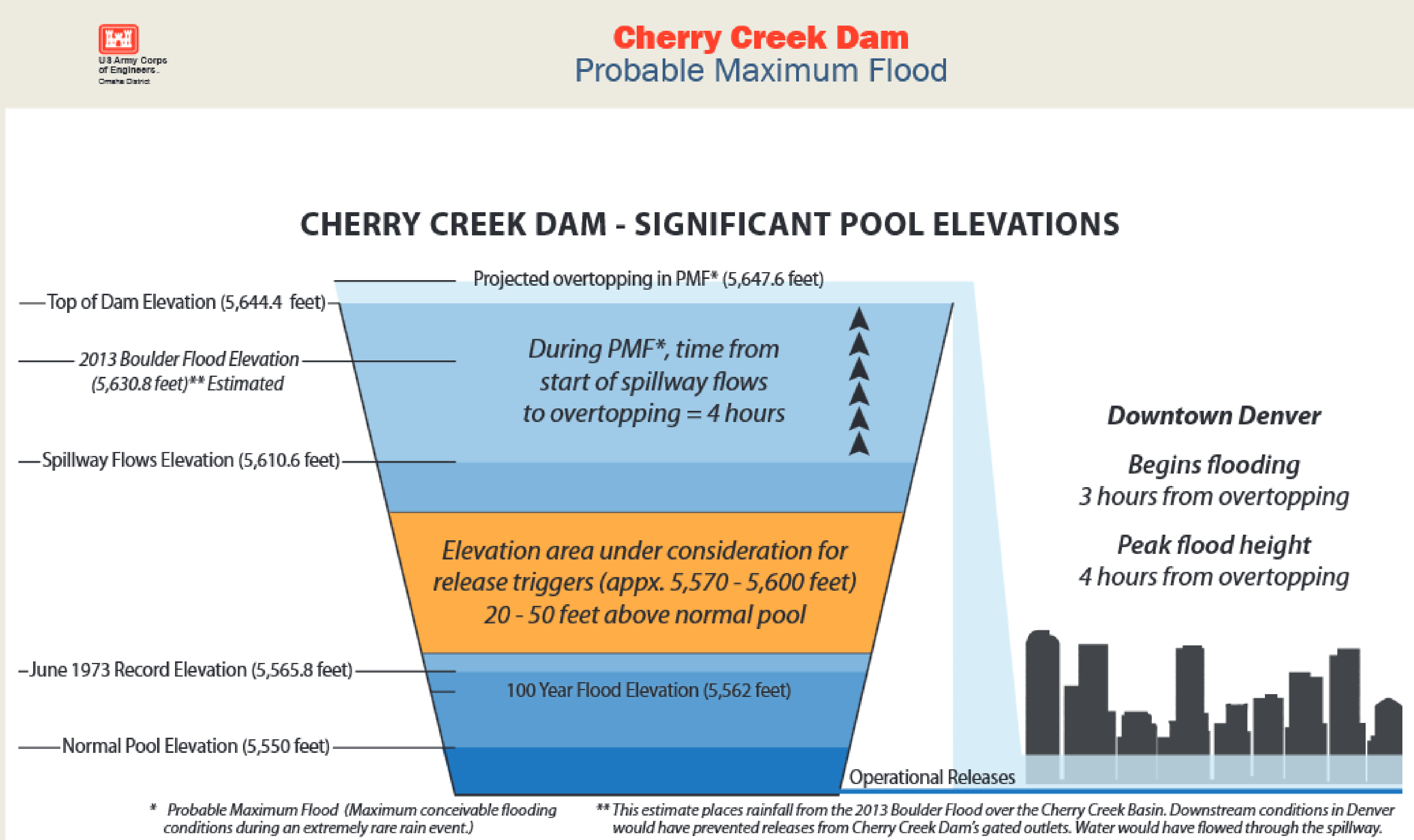
Probable Maximum Precipitation and Flood

- 24.7" in 72 hrs in watershed upstream of Dam
- The PMF produces uncontrolled drainage flooding peak flows of 27,000 cfs at the Cherry Creek gage and 109,000 cfs at the South Platte River at Denver stream gage.
- It would take 40 days to empty the flood water stored in the reservoir and the spillway would flow for about 8 days.
- Assumed that the weather forecast would allow a warning and planning time of approximately 24-72 hours.



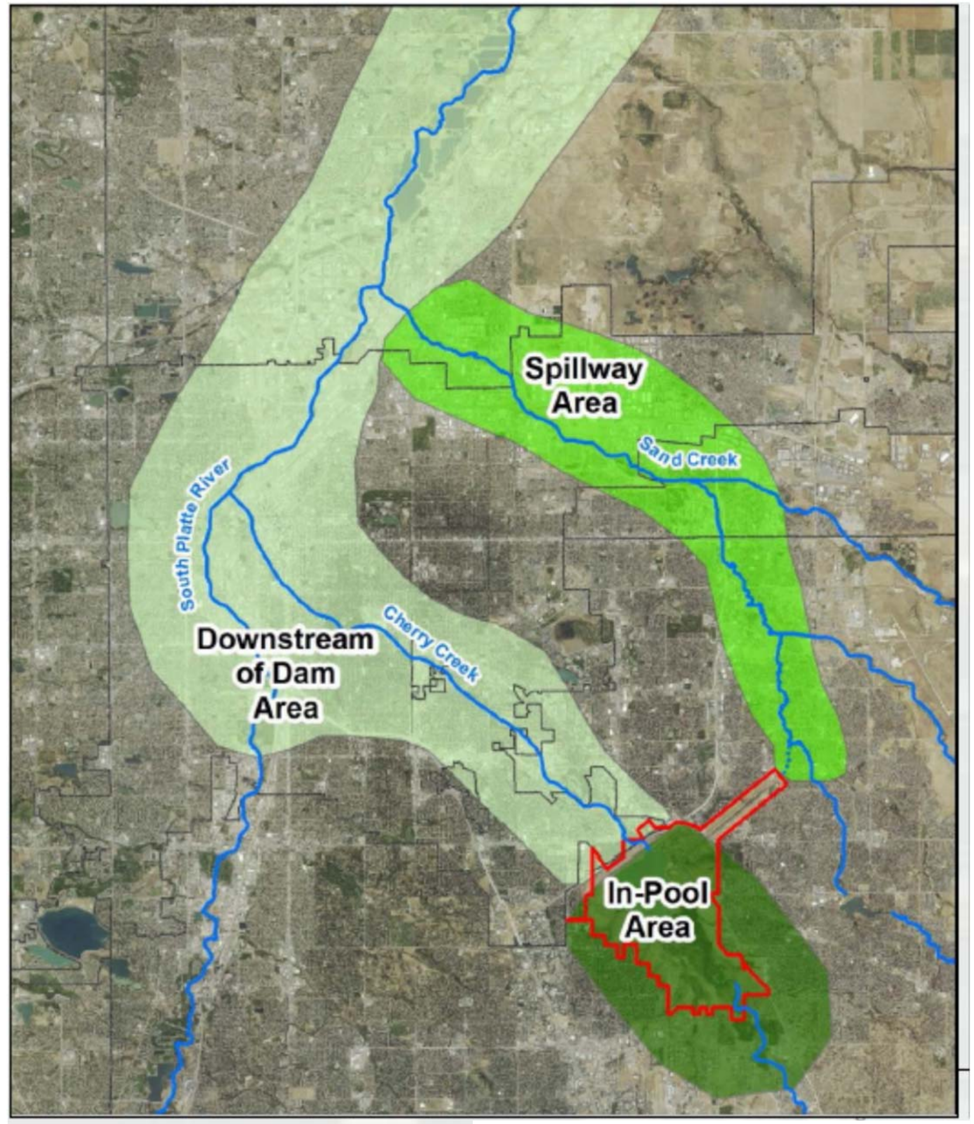
Cherry Creek Dam
72 Hour Probable Maximum Precipitation (PMP)

Probable Maximum Flood Risk



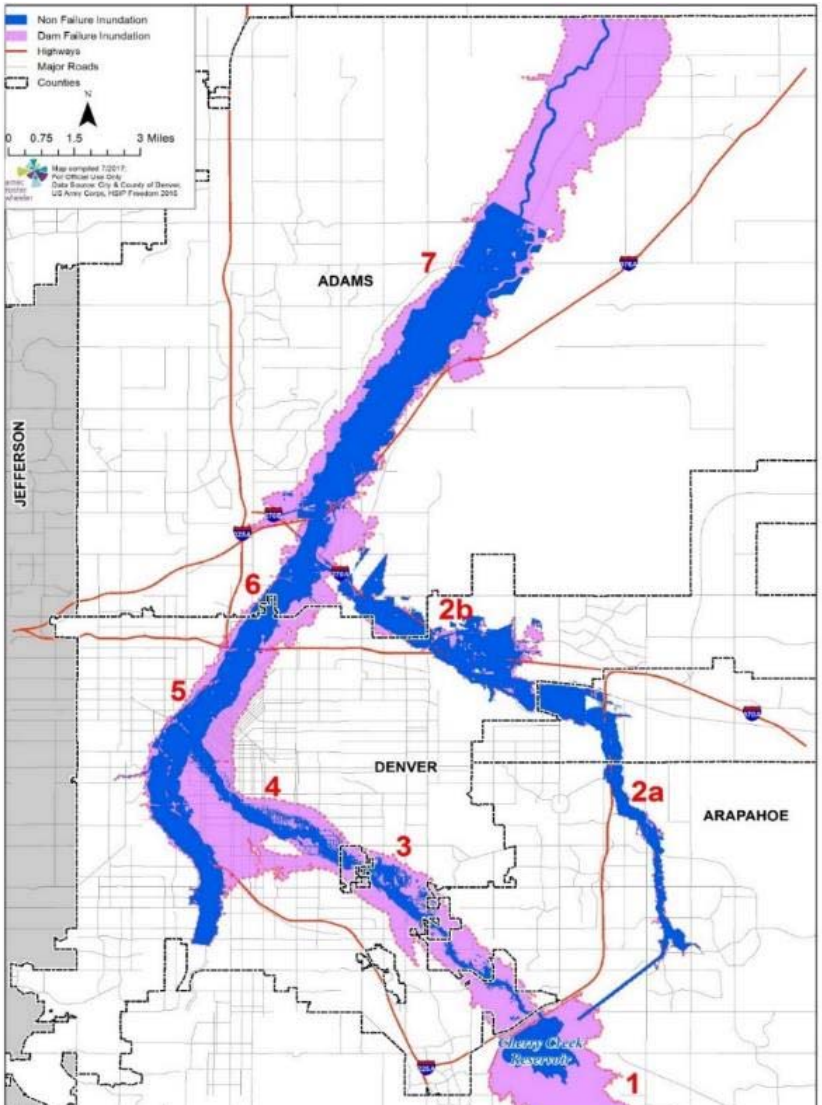
Consequence Impact Areas

- In- Pool Area
- Downstream of Spillway
- Downstream of Dam

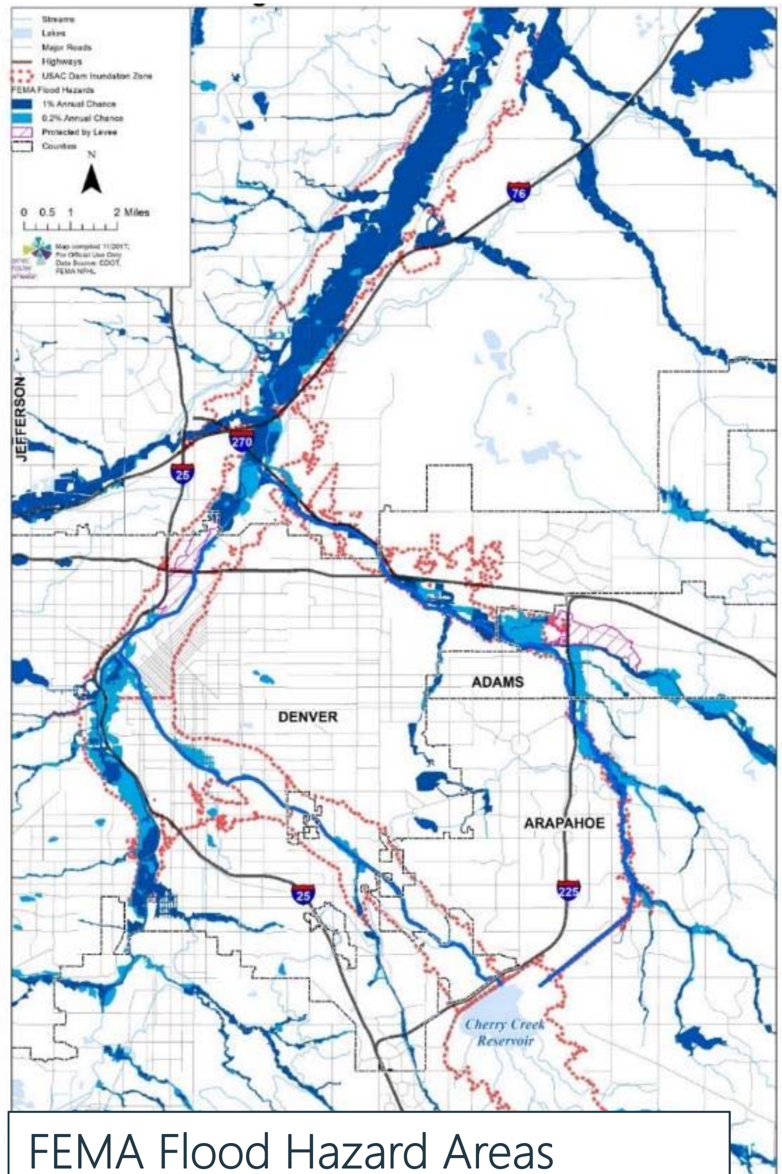


Source: Army Corps of Engineers

Regional Inundation



Controlled Release (Blue) and Failure (Pink)



FEMA Flood Hazard Areas

Consequences/Planning Situation

- Population at Risk: approximately 300,000 in the inundation area
- Critical facilities, bridges and other infrastructure
- 25,000 buildings impacted
- Hospitals, nursing homes, schools

Planning Process

Evacuation Planning Committee and Working Groups

Developed with input from subject matter experts, stakeholders and local emergency managers

- Steering Committee
  - Arapahoe County Emergency Management
  - City and County of Denver Emergency Management
  - City of Aurora Emergency Management
  - Adams County Emergency Management
- Evacuation Planning Team (EPT)
  - Regional stakeholders and subject matter experts
    - Army Corps of Engineers
    - Urban Drainage and Flood Control District
    - CO Division of Homeland Security and Emergency Management
    - Regional Transportation District
    - CDOT
    - Colorado State Patrol

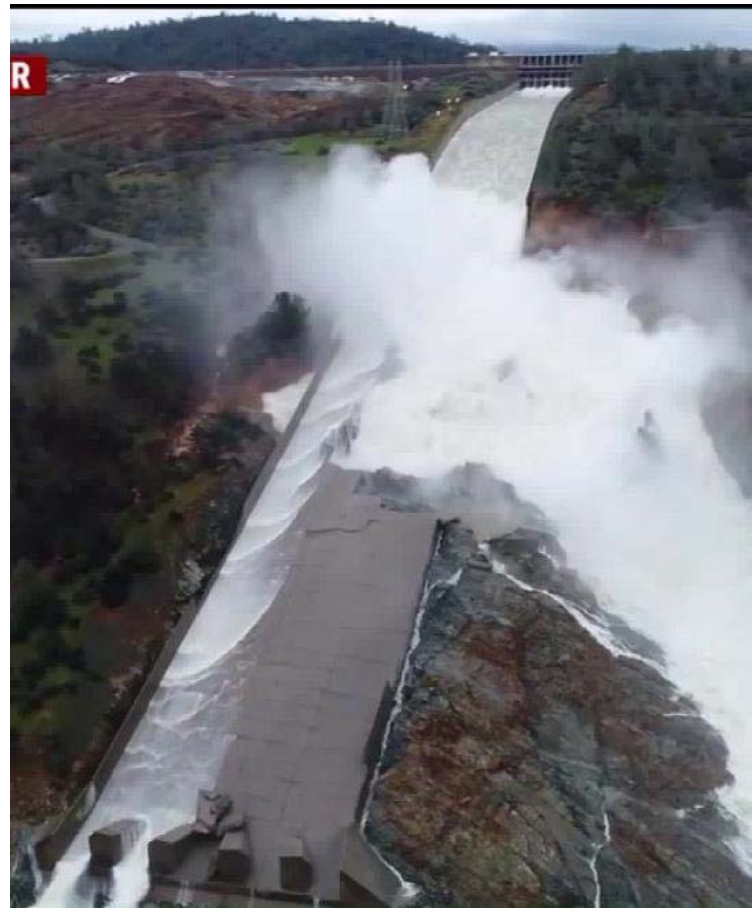
Planning Process and Timeline

- Working groups for functional areas: Transportation, Communications and Warning, Access and Functional Needs, Animal Protection, Reunification and Re-entry
- Two large group Evacuation Planning Team meetings
  - Kickoff (April 12, 2017)
  - Plan Rollout (October 2017)
- Two working group sessions
  - 2 half-day sessions for each working group in May/June and August
- Monthly coordination calls and additional meetings with Steering Committee
- Initial Draft provided to Steering Committee October 10th, 2017

Planning Process

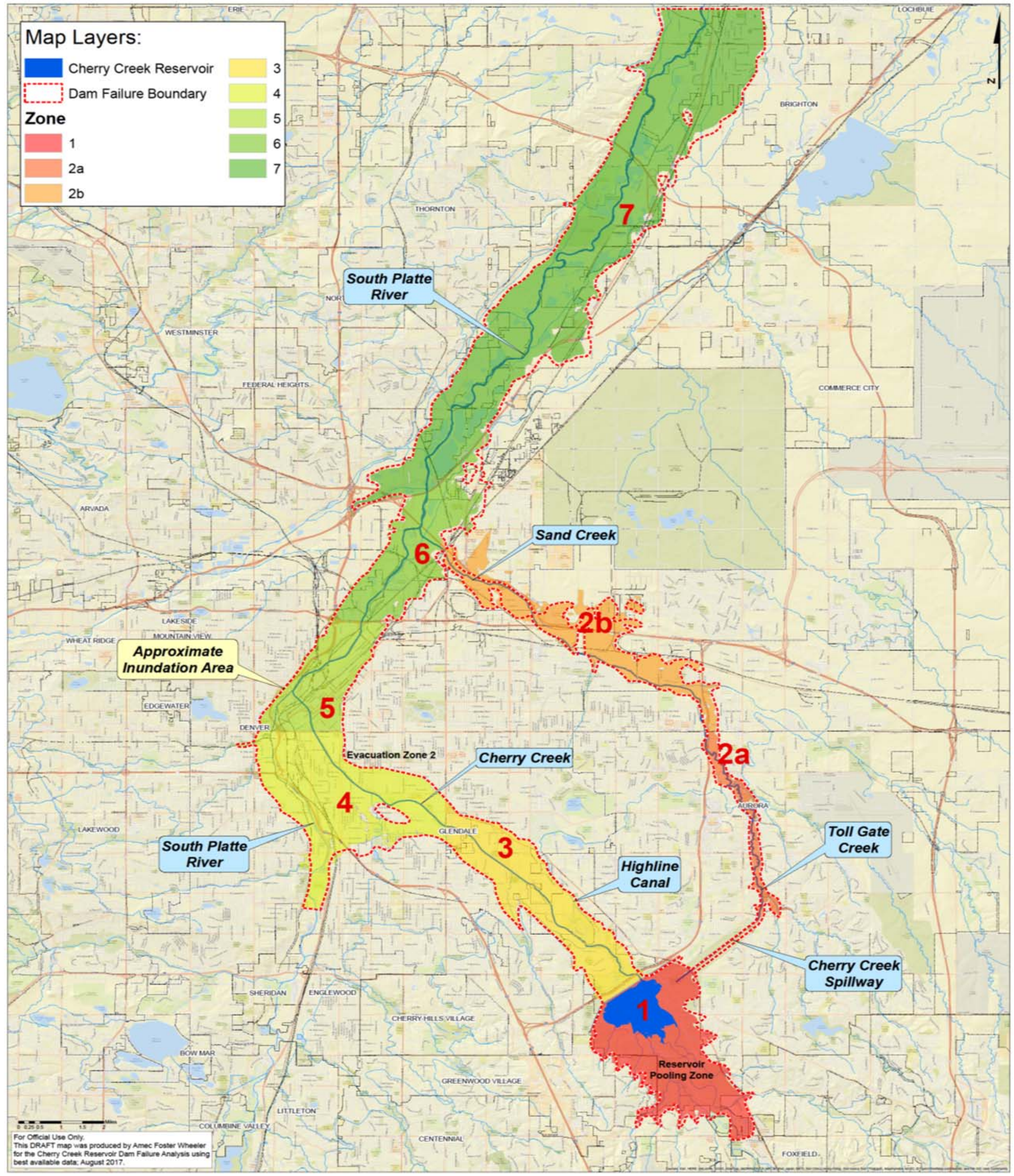
Planning Considerations from the 2017 Oroville Dam Incident Used to Inform Plan

- Notifications, evacuation warnings and orders
- Transportation of Evacuees
- Shelters and Shelter Operations
- Security of the Evacuated Area
- Diversion, Inundation, and Debris
- Decision support and decision-making
- Intergovernmental Relations and Coordination



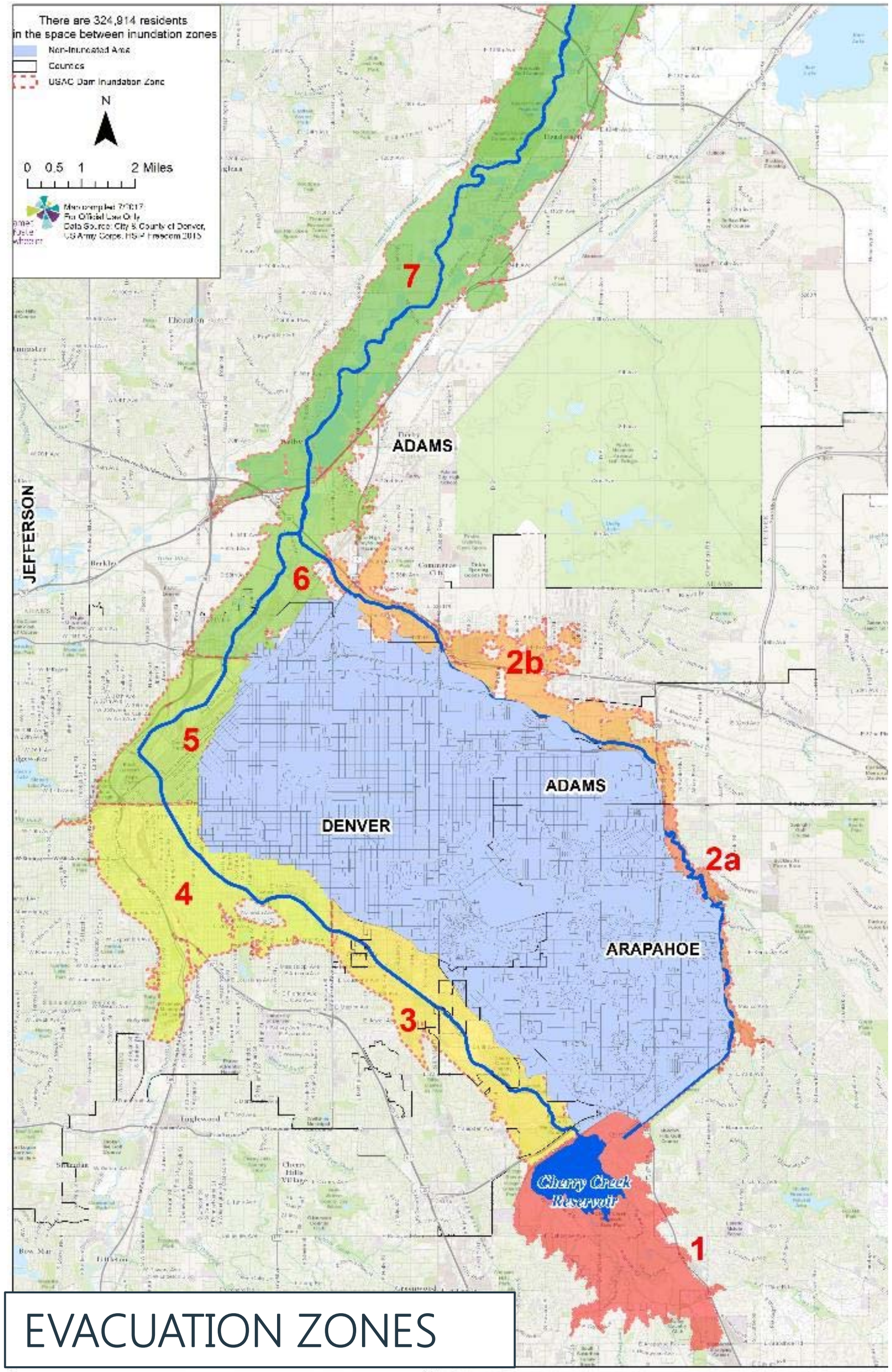
Evacuation Zones

- Zones for internal management of incident
- Determined Early on for planning purposes
- In- Pool Area (1)
- Downstream of Spillway (2)
- Downstream of Dam (3-7)



Dam Failure Flood Evacuation Zones and “Island”

- “Island” blue area on map between spillway and Cherry Creek/S Platte may need to be evacuated
  - 324,914 residents
  - Reduced flood risk, but potentially isolated from services should a failure occur

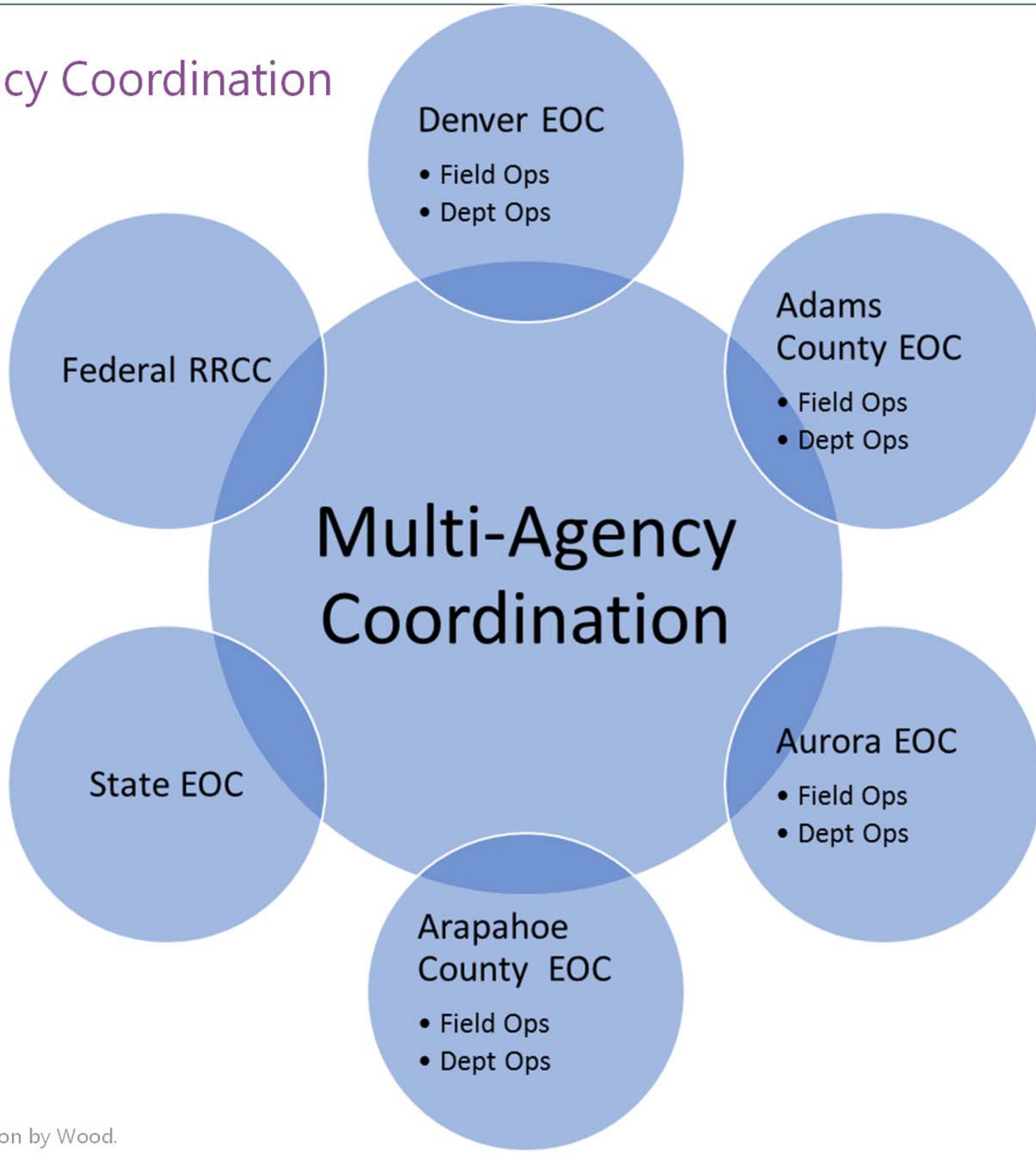


EVACUATION ZONES

Multi-Jurisdictional Considerations

Multi-Jurisdictional Considerations

Multi-Agency Coordination



Evacuation Plan Crosswalk with Local Emergency Operations Plans

Coordination with existing planning mechanisms and emergency procedures

Evacuation Components/Annexes	Relevant Emergency Support Function	Relevant Function
Base Plan	• Emergency Management	• Direction and Control • Evacuation
Communications and Warning	• Communications • External Affairs	• Communications and Warning • Emergency Public Information • Evacuation
Transportation	• Transportation • Public Works and Engineering • Public Safety and Security	• Transportation and Resources • Evacuation
Access and Functional Needs	• Mass Care	• Sheltering and Mass Care • Evacuation
Animal Protection	• Agriculture and Natural Resources	• Sheltering and Mass Care • Evacuation
Reunion and Reunification	• Mass Care	• Sheltering and Mass Care

Plan Elements

Base Plan - Overview

- Situation/overview of hazard
- Relationship to existing plans
- Concept of operations
- Direction, Control and Coordination
- Multi-Agency Coordination System
- Evacuation Decision Making and Authorities
- Roles and Responsibilities
- Plan maintenance and exercising recommendations

Tiered Activation Stages

Evacuation Plan – Stages and Phases
Stage 1 Evacuation – Controlled release flooding on Cherry Creek, spillway flooding and uncontrolled drainage flooding; the dam is still structurally sound and functioning
Evacuation Area: Evacuation zones should be evacuated depending on projected release flows with priority on Zones 3, 4, 5, 6 and 7; Spillway flows will necessitate evacuation of Zones 1 and 2 **Phase 1: Evacuation Watch**: immediate preparation for a full-scale evacuation. **Phase 2: Evacuation Warning:** evacuate
Stage 2 Evacuation – Potential Dam Failure Situation
Evacuation Area: All evacuation zones should be evacuated with priority on Zones 1, 2, 3, 4, and 5; Evacuation of Denver in areas ringed by I-25, I-225 and I-270 as second priority. **Phase 1: Evacuation Watch** **Phase 2: Evacuation Warning**
Stage 3 – Dam Failure
Evacuation Area: Continued evacuation of all inundation zones excluding the Interstate Ring
Preparedness/Blue Sky Activities: Building partnerships, exercise, training, personal perparednes

Functional Annexes

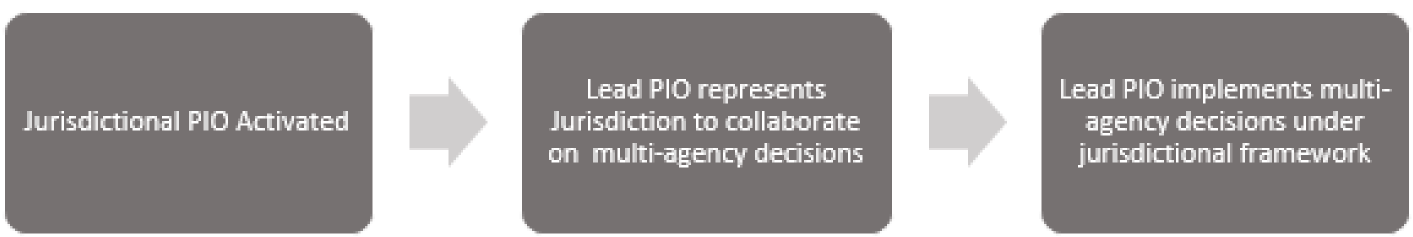
- Focused on specific areas of the response requiring jurisdictional coordination
  - Transportation
  - Communications and Warning
  - Access and Functional Needs
  - Family Reunification and Re-entry
  - Animal Protection
- Developed with input from working groups
- Functional considerations as communities execute the response based on jurisdictional response plans
  - Watch vs. Warning phase considerations
- Annexes do not supersede jurisdictional operations

Communications and Warning

Key Elements

- Joint Information Centers (JICs) – Local jurisdictions
- Multi-jurisdictional/multi-agency coordination on communication through Joint Information System (JIS)
  - Unified decisions regarding:
    - What messages will be released – Watch vs Warning
    - When the messages will be released
    - Sample message text edits
    - Coordinated messaging

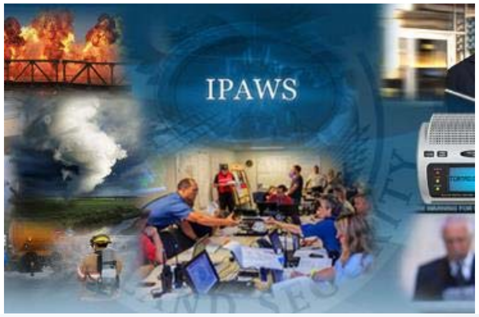
Lead PIO/Multi-Agency Coordination Flow Chart



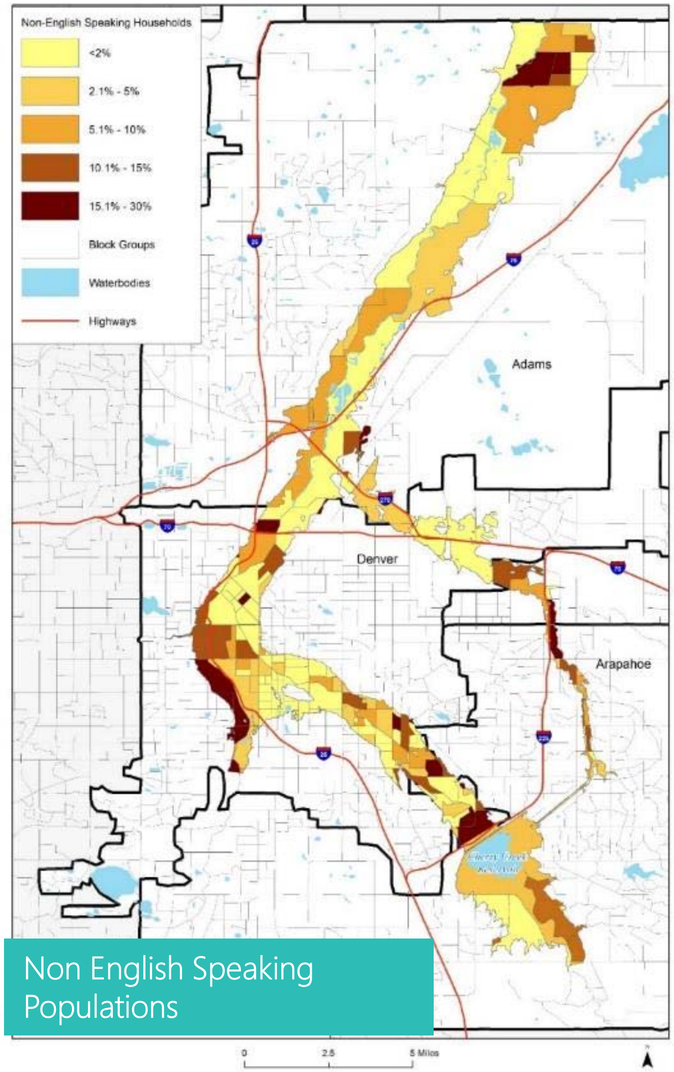
Communications and Warning

Messaging Dissemination Channels and Tools

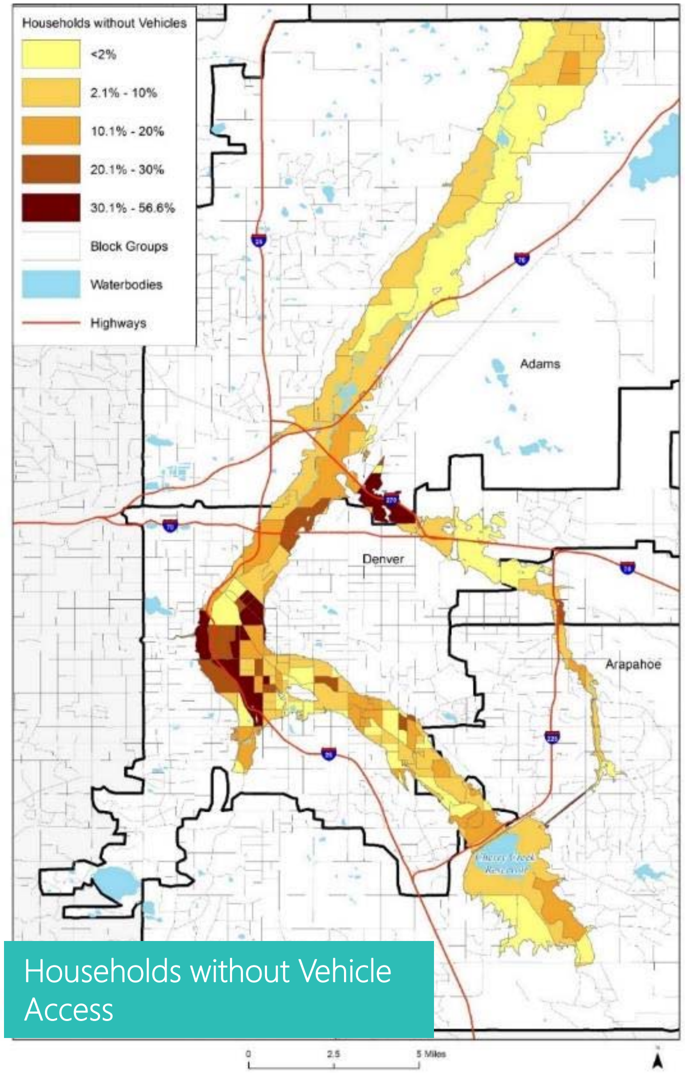
- IPAWS
- Wireless Emergency Alerts (WEA)
- Wireless Communications
- Radio
- Variable Message Signs
- Television broadcast and message scrolls
- NOAA WX radio
- UDFCD Alert
- Social Media
- Sample Message Templates
- Sample Evacuation Order



Social Vulnerability Considerations



Non English Speaking Populations



Households without Vehicle Access

Transportation Annex

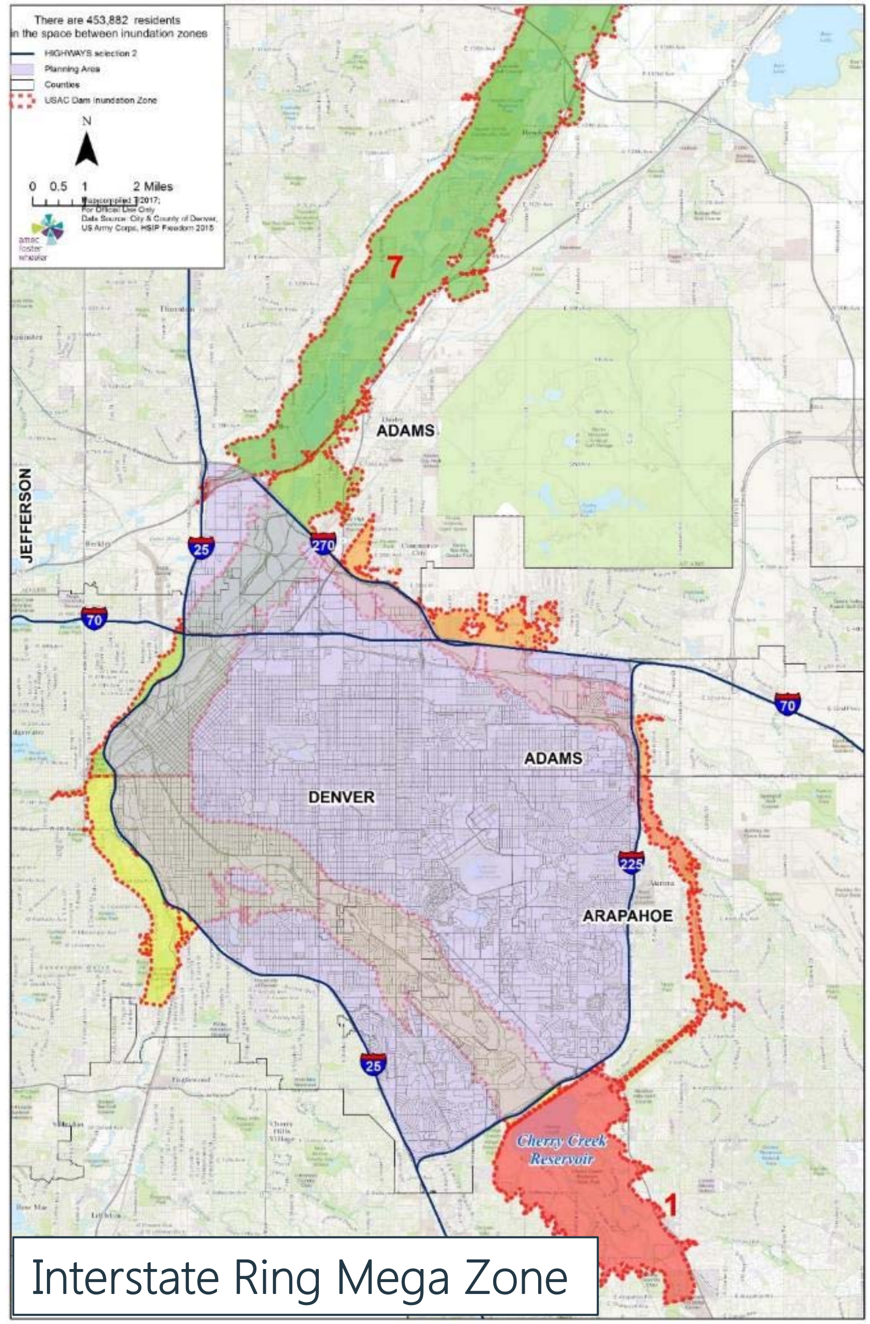
- Table 3: Evacuation Zones, Jurisdictions and Primary Transportation Options

Table 3: Evacuation Zones, Jurisdictions and Primary Transportation Options

Zone number and name	Boundaries/Description	Primary Jurisdictions Involved	Primary Transportation Options	Flood Arrival Time (hrs)
Zone 1 Reservoir pool	Reservoir pool area- areas adjacent to reservoir and State Park	Arapahoe, Aurora, Greenwood Village, Cherry Creek State Park	Motor vehicle	0-1
Zone 2a Spillway South	West Tollgate Creek to Colfax Blvd	Arapahoe, Aurora	Motor vehicle RTD - bus	0-1
Zone 2b Spillway North	West Tollgate Creek from Colfax Blvd, junction with Sand Creek to confluence of South Platte River	Aurora, Adams, Denver, Commerce City	Motor vehicle RTD - bus	1-2
Zone 3 Arapahoe-Glendale	Cherry Creek Dam to South Colorado Boulevard	Arapahoe, Denver, Glendale	Motor vehicle Foot RTD - bus	1-2
Zone 4 Denver South	South Colorado Boulevard to W Colfax Ave	Denver	Motor vehicle Foot RTD – bus and light rail	2-3
Zone 5 Denver Downtown	W Colfax Ave to I-70	Denver	Motor vehicle Foot RTD – bus and light rail, Amtrak	3-4
Zone 6 Commerce City	I-70 to I-76	Denver, Adams, Commerce City	Motor vehicle RTD - bus	4-5
Zone 7 Adams County	I-76 to the E 168th Avenue (Adams-Weld County line)	Adams, Brighton	Motor vehicle RTD - bus	5.5

Transportation Appendix

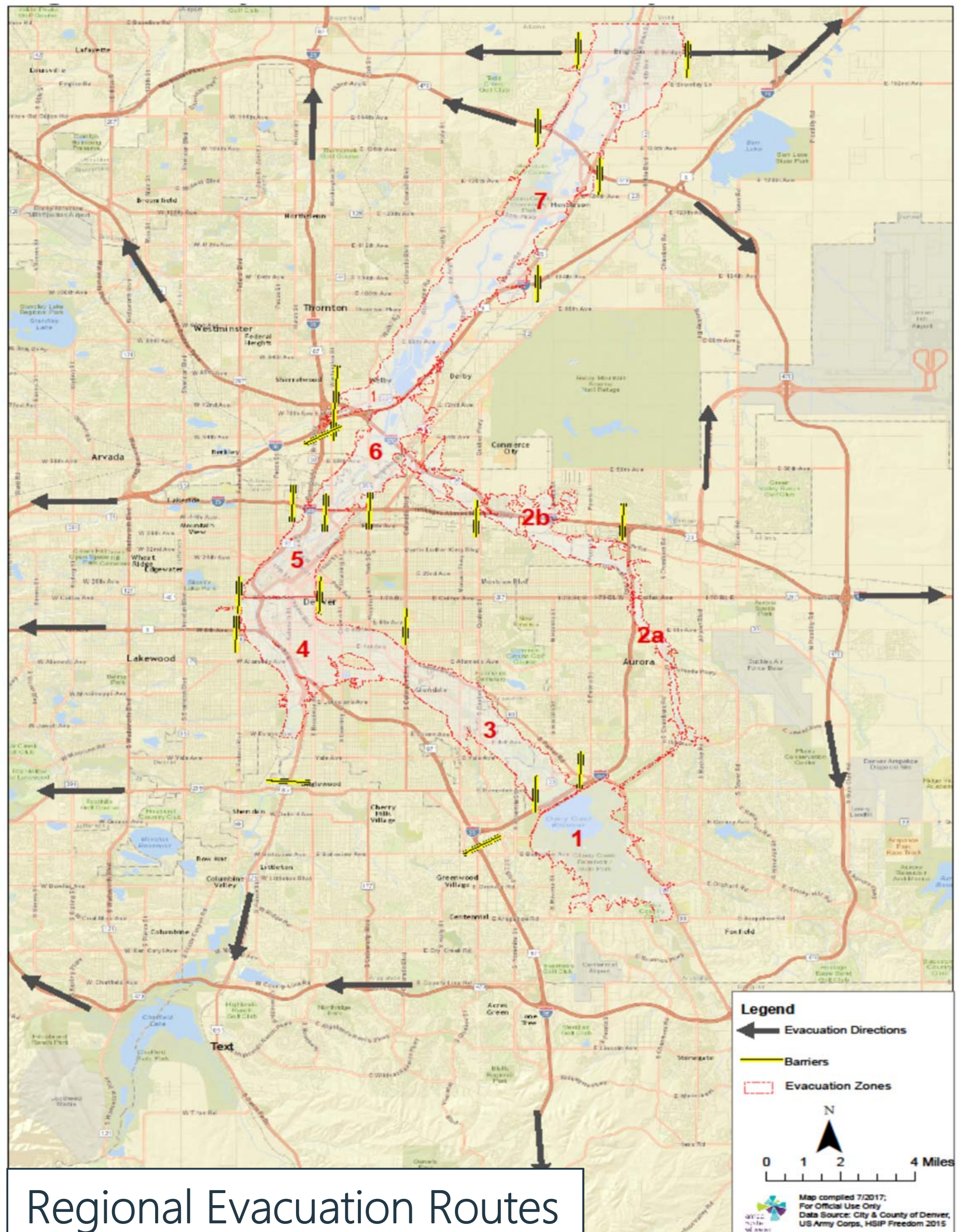
- Supporting maps and statistics
- Interstate Ring ‘Mega Zone’
  - I 25
  - I 225
  - I 270



Interstate Ring Mega Zone

Evacuation Routes

- Regional Routes and Barricades
  - I 25
  - I 225
  - I 270
- Detailed maps with critical facilities for each zone for emergency managers
- Simple messages for the public that vary based on watch vs warning



Regional Evacuation Routes

Summary / Lessons Learned

Summary / Lessons Learned

- Consequence analysis spurred action and informed planning process
- Emergency managers want to plan for controlled release scenarios, not just dam failure
- Communities want autonomy but recognize the value of working together in a common framework
- Coordination and cross referencing existing jurisdictional plans and procedures key in a multi-jurisdictional effort.
- Drawing the line between evacuation of dangerous areas versus isolated areas
- Overall scope of regional mass evacuation would require additional planning e.g. regional mass care, regional mass evacuation
- Continuity of operations would be challenging due to widespread impacts

Acknowledgements

Acknowledgements

Thanks to everyone that contributed to this effort!

- Arapahoe County
- Denver City and County
- Aurora
- Adams County
- US Army Corps of Engineers
- Working group and Evacuation Planning Team members
- Wood project team

Questions?

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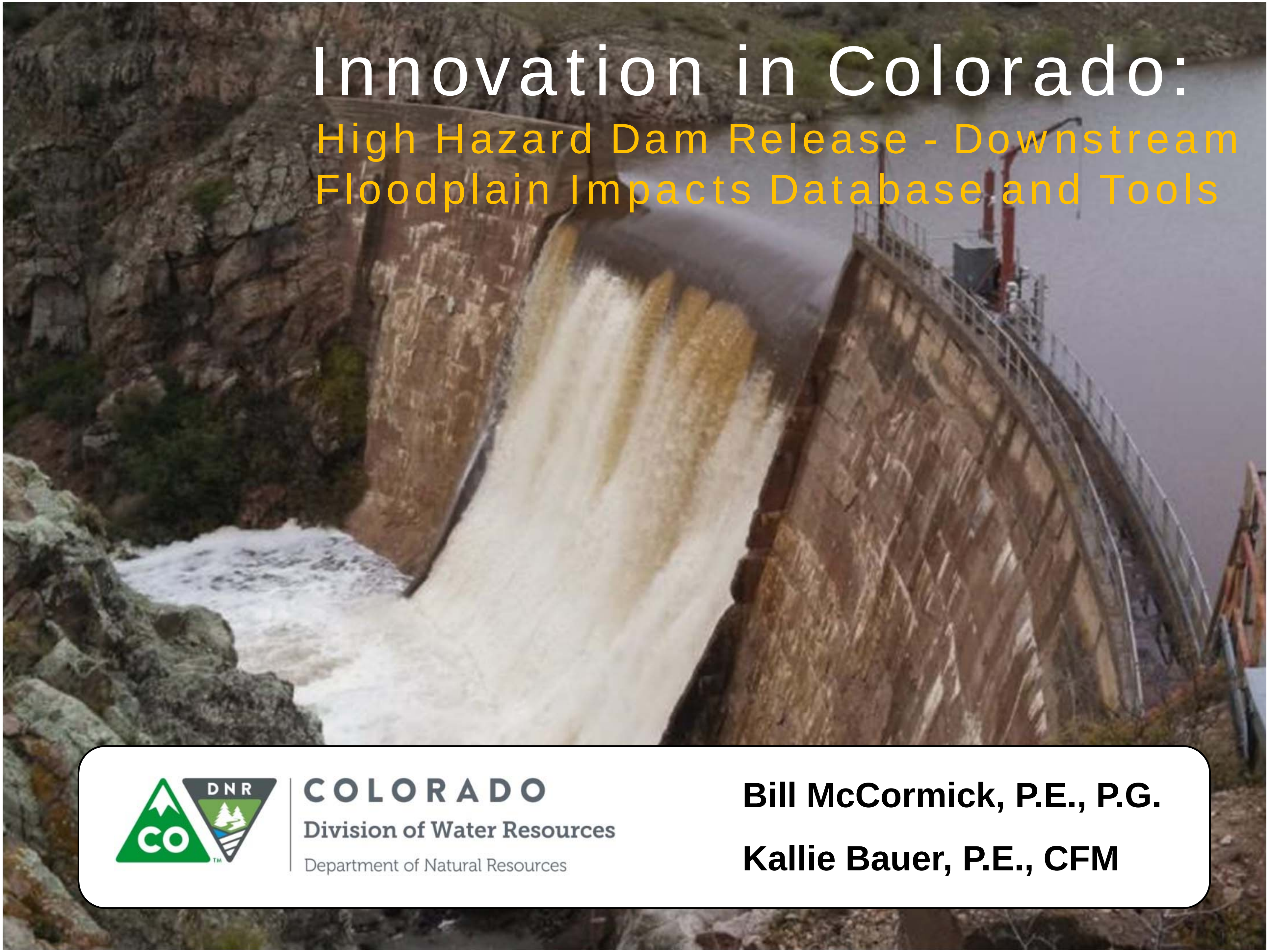
Innovation in Colorado:

High Hazard Dam Release - Downstream Floodplain Impacts Database and Tools



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Department of Natural Resources

Bill McCormick, P.E., P.G.

Kallie Bauer, P.E., CFM

Outline

- Why we did this project
- How we did this project
- How the project turned out
- What we Learned
- Where we go from here

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Colorado Dam Safety Mission

- Prevent loss of life and property damage from dam failures
- Maximize *Safe* storage of water
- Technical liaison between dam owners and emergency and floodplain managers

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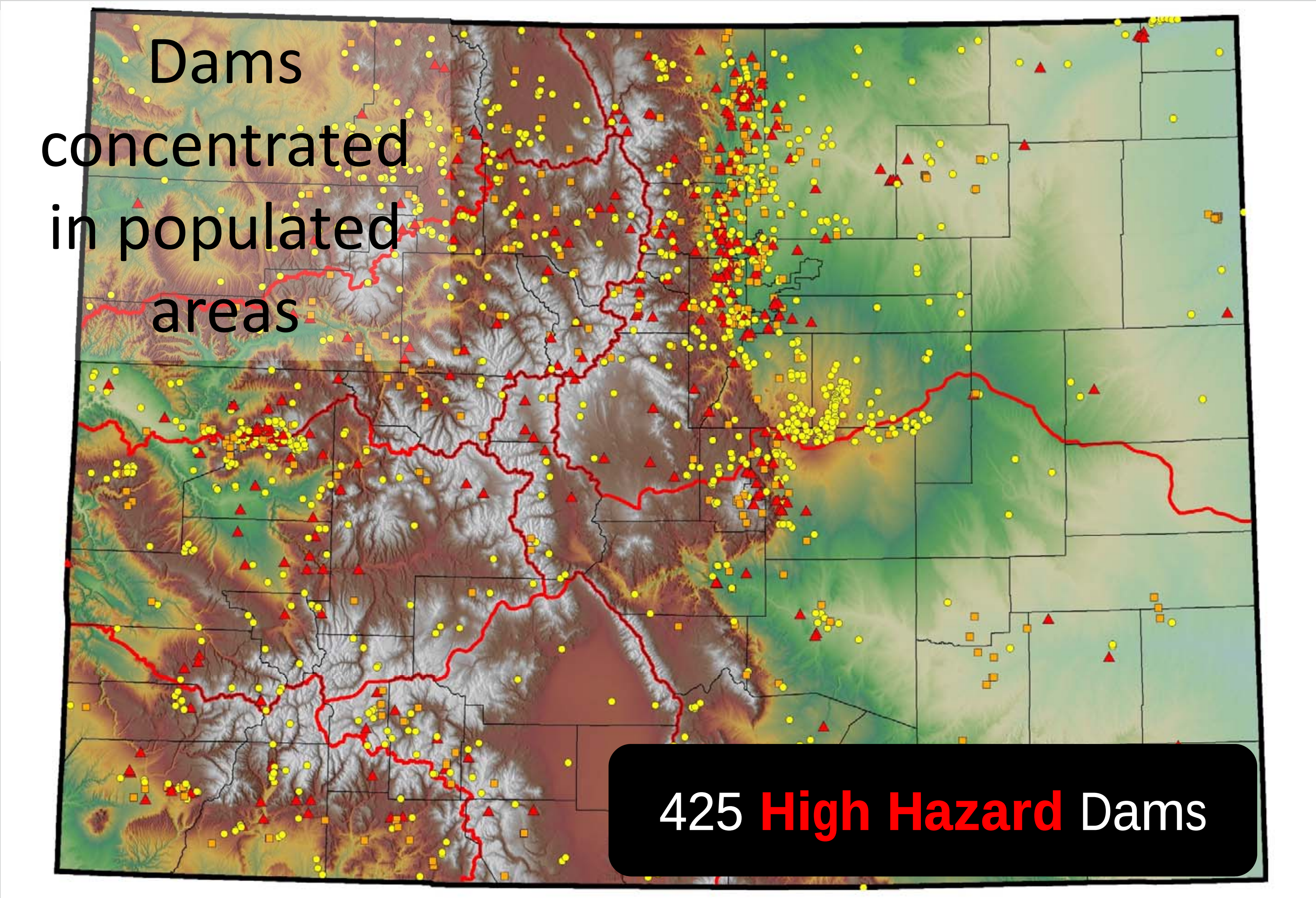
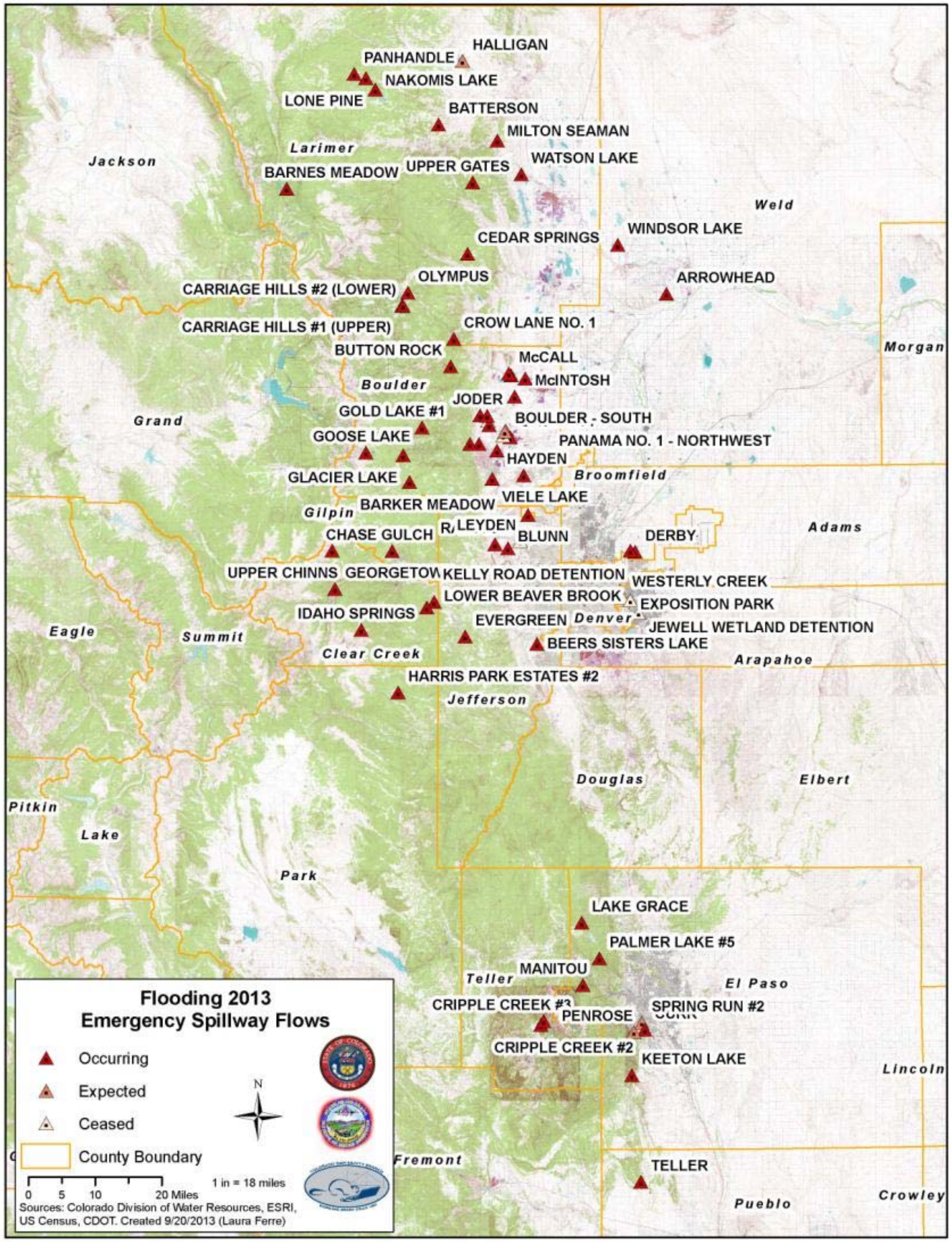
1750ish Program Dams





Spillway Flows 9/20/13

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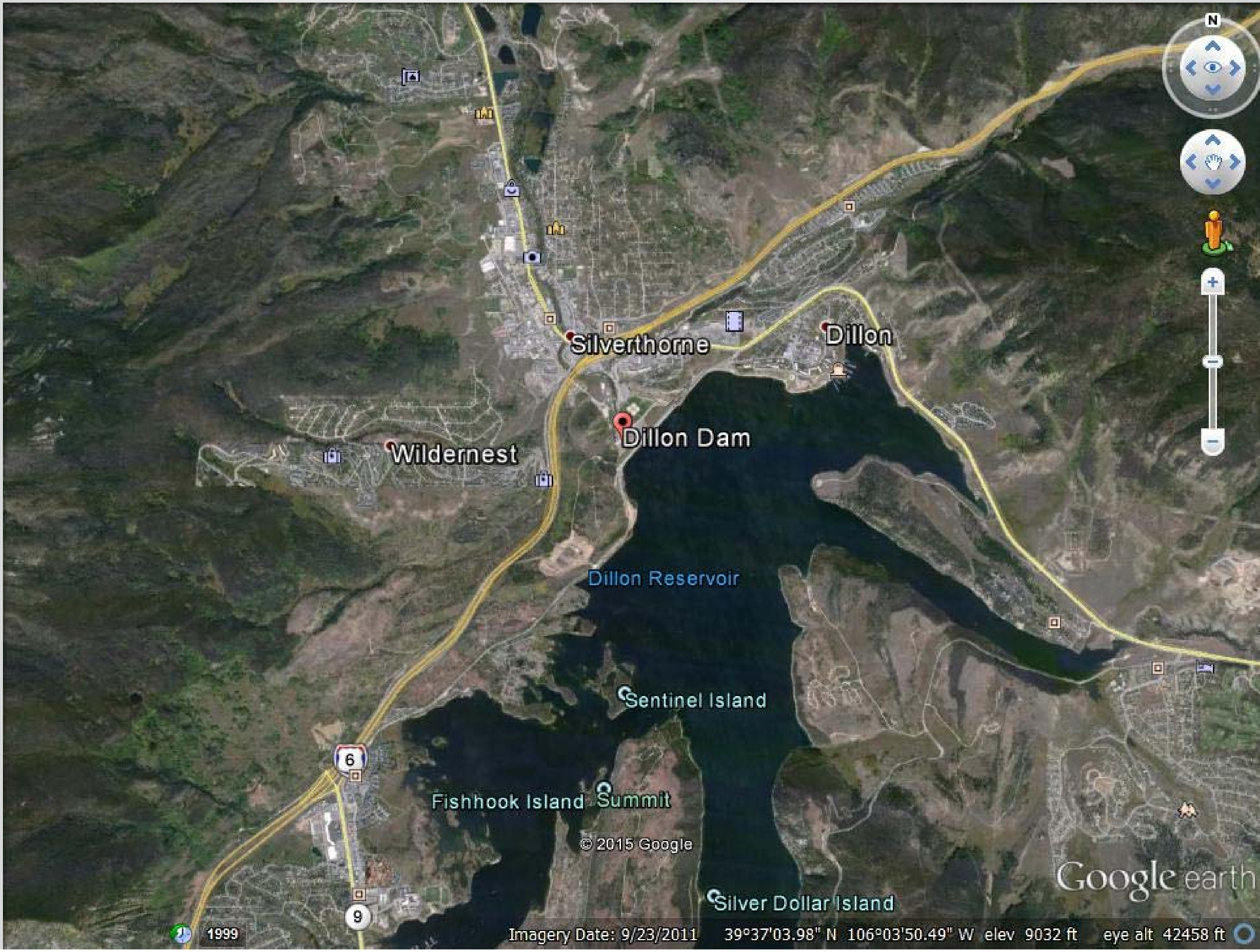
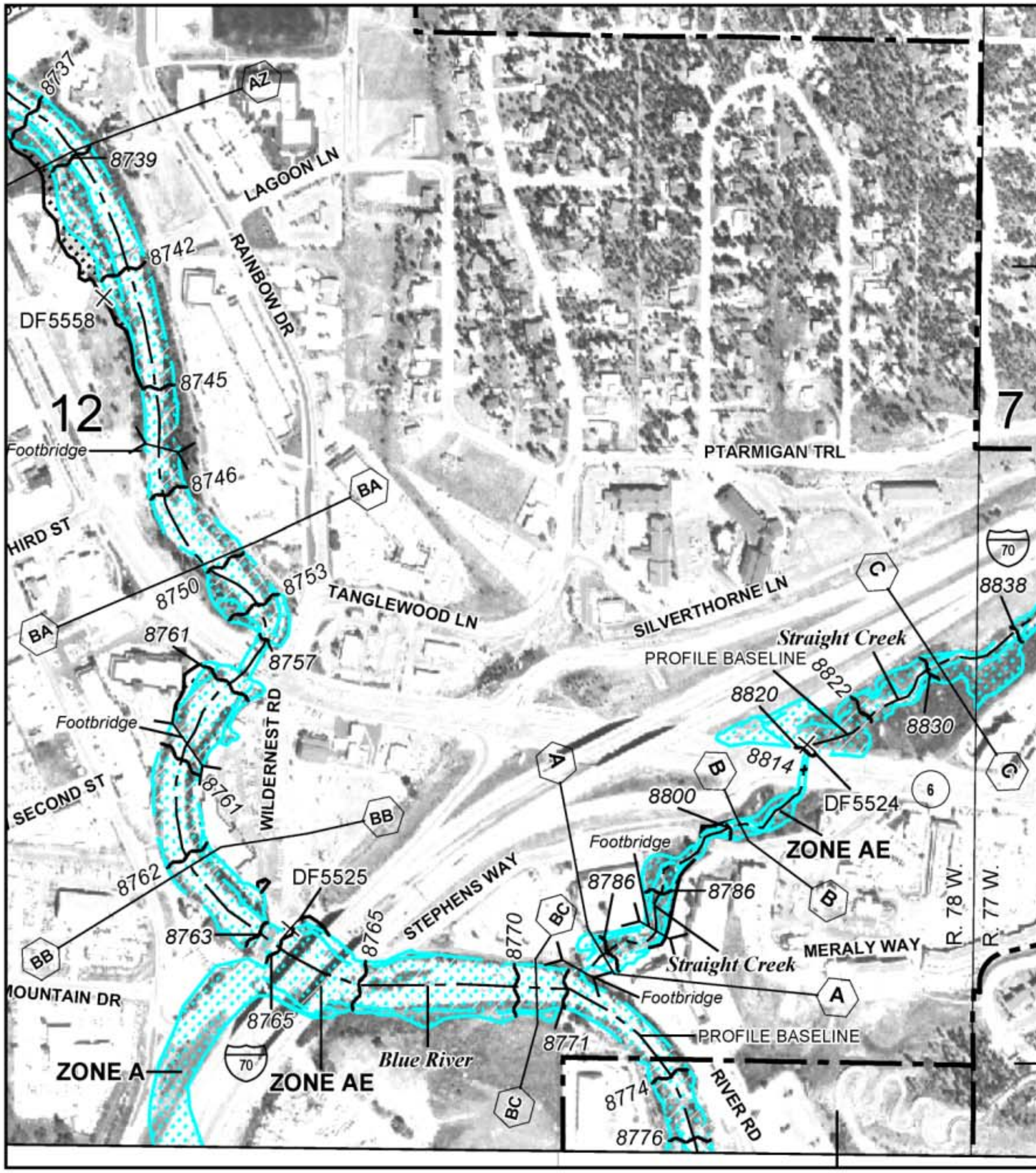
Outlet Releases - Dillon Dam





MAP SCALE 1" = 500'

250 0 500 1000 FEET

METERS

NFIP

NATIONAL FLOOD INSURANCE PROGRAM

PANEL 0239E

FIRM

FLOOD INSURANCE RATE MAP

SUMMIT COUNTY, COLORADO

AND INCORPORATED AREAS

PANEL 239 OF 575

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

CONTAINS:

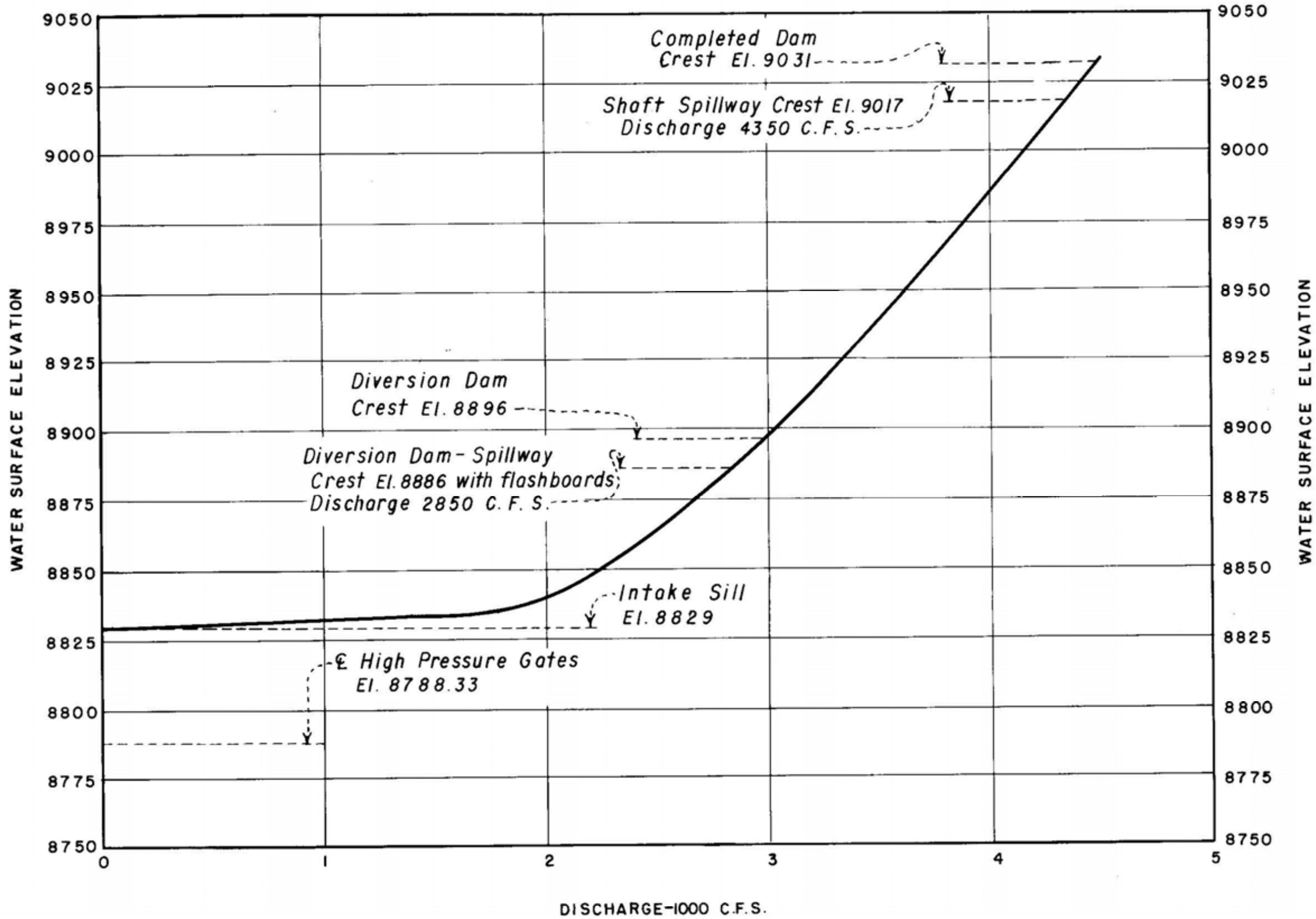
COMMUNITY	NUMBER	PANEL	SUFFIX
DILLON, TOWN OF	080237	0239	E
SILVERTHORNE, TOWN OF	080201	0239	E
SUMMIT COUNTY, Unincorporated Areas	080290	0239	E

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

MAP NUMBER
08117C0239E

EFFECTIVE DATE
NOVEMBER 16, 2011

Federal Emergency Management Agency



DISCHARGE CURVE-OUTLET WORKS

2 - 4'-0" x 5'-0" HIGH PRESSURE GATES

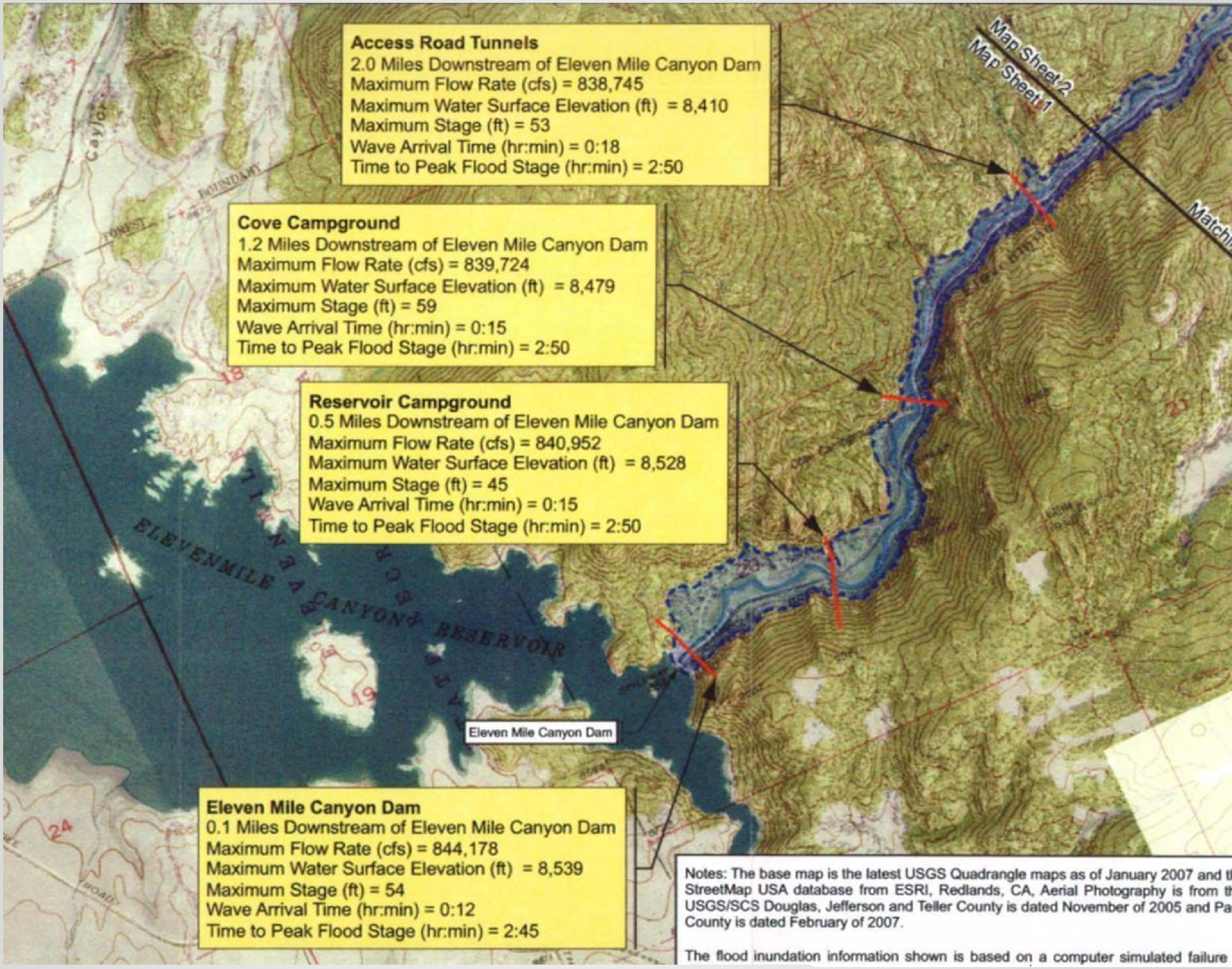
1 - 2'-3" x 2'-3" HIGH PRESSURE GATE

Outlet Releases – EAP Activations 2015 - Eleven Mile Canyon Dam

Outlet channel

Spillway channel

Eleven Mile Inundation Map



esources
ources

Project to highlight the Gap?

- $95,000 project, Funded by NDSP States Grants ($45K) and Colorado Water Conservation Board grant ($50k)
- Created a High Hazard Dam Release - Downstream Floodplain Impacts Database and Ranking Tool
- “Controlled Releases” only
- Safe Channel Capacity Comparisons
- Promote and share information, database and tools with floodplain and emergency managers

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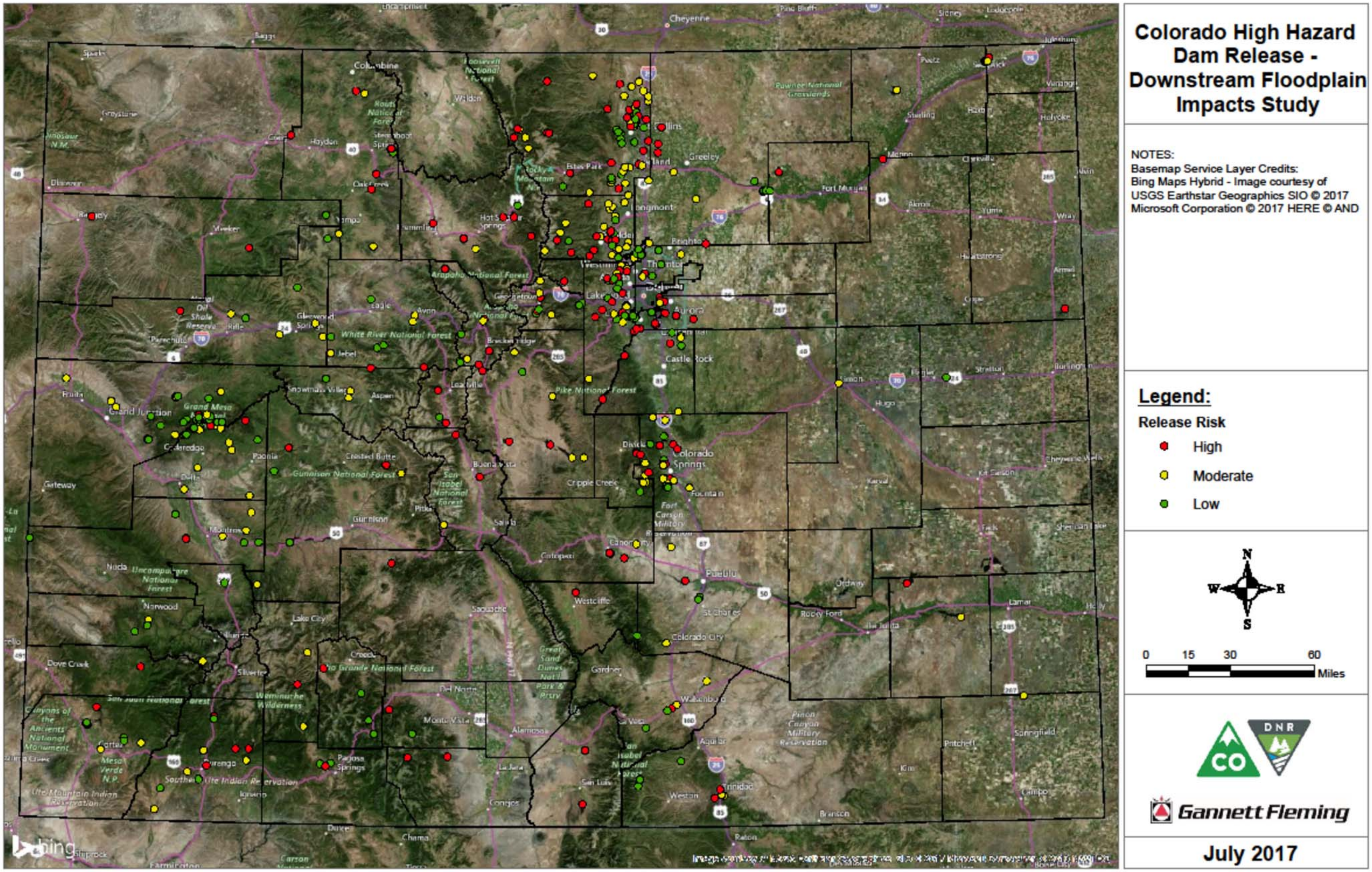
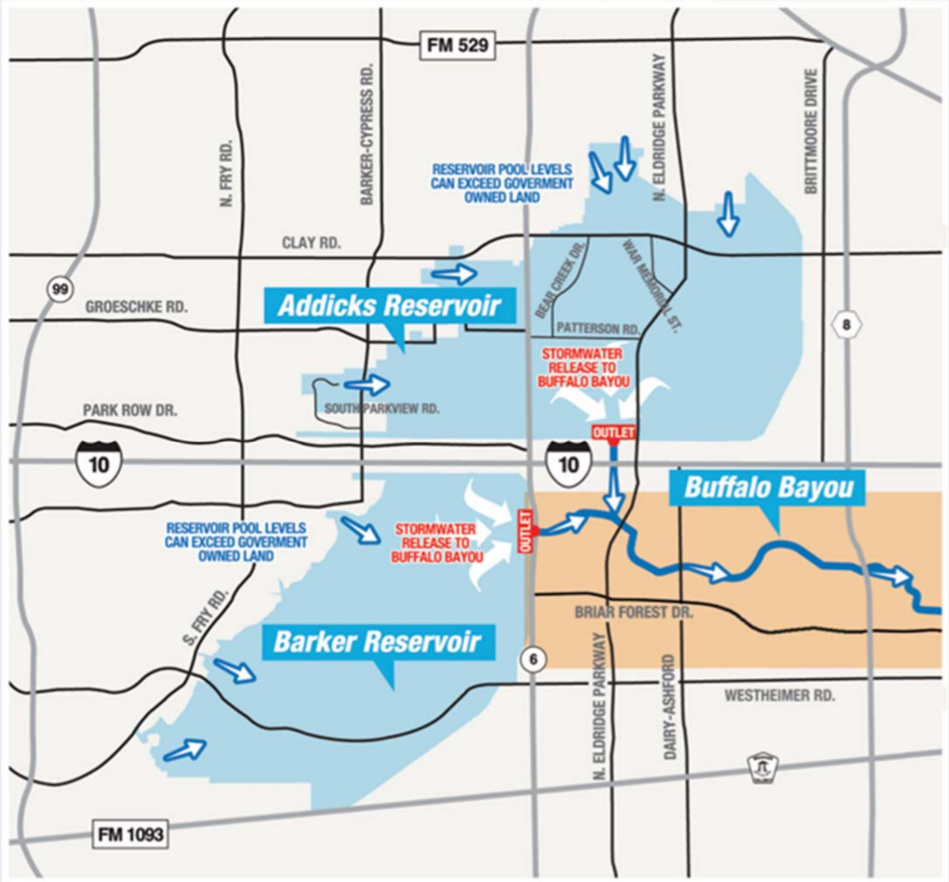
Ranked Dams - Statewide



Aug 2017 - Barker and Addicks Dams

- Flood control dams built in 1940
- Water surface in reservoir rising at ½ ft per hour
- Record high elevation
- Outlets opened, releasing 4,000 cfs each



Neighborhoods around Barker and Addicks Reservoir

What Did We Learn?

- Colorado in 2013 and 2015, Texas 2017 show dams operating as designed but still cause dangerous flooding downstream

- Dam Emergency Action Plans have maps for dam failure inundation – of no use in operational release flooding scenarios

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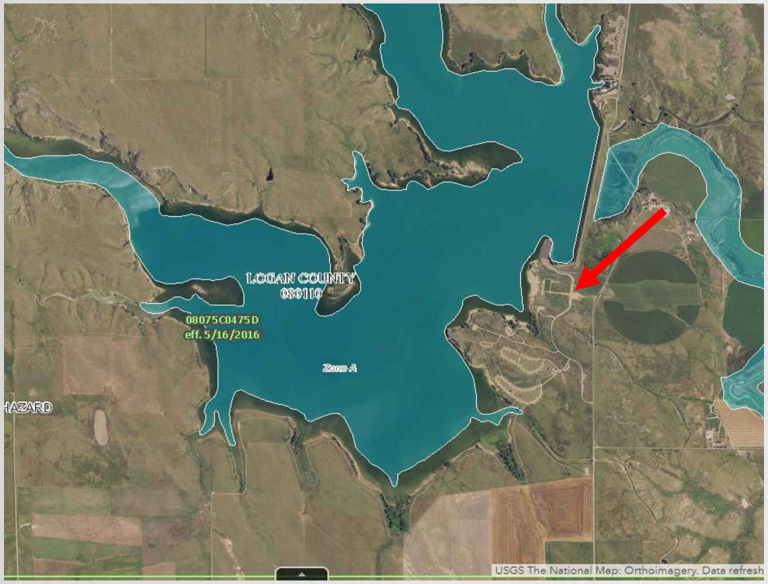
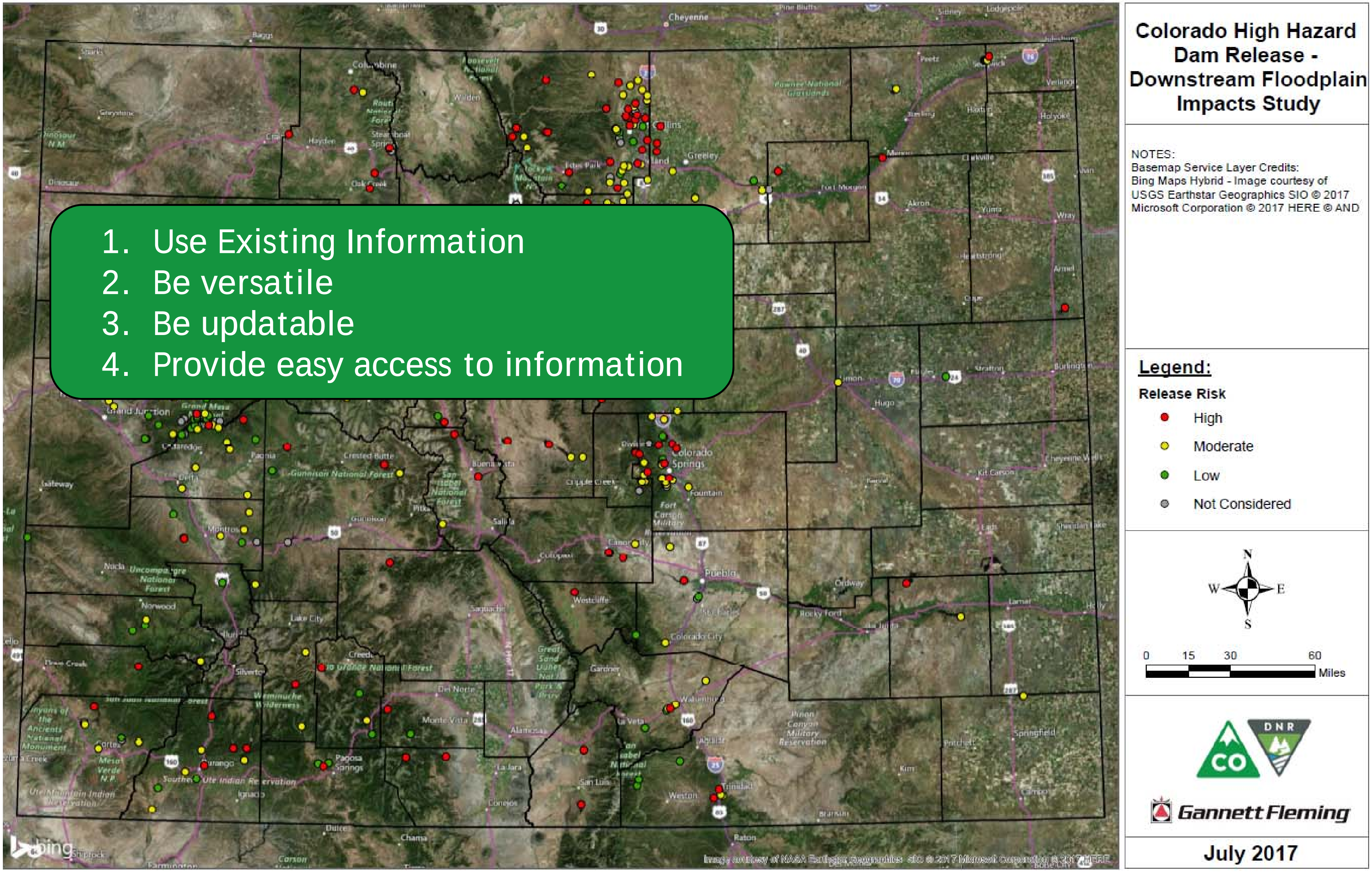
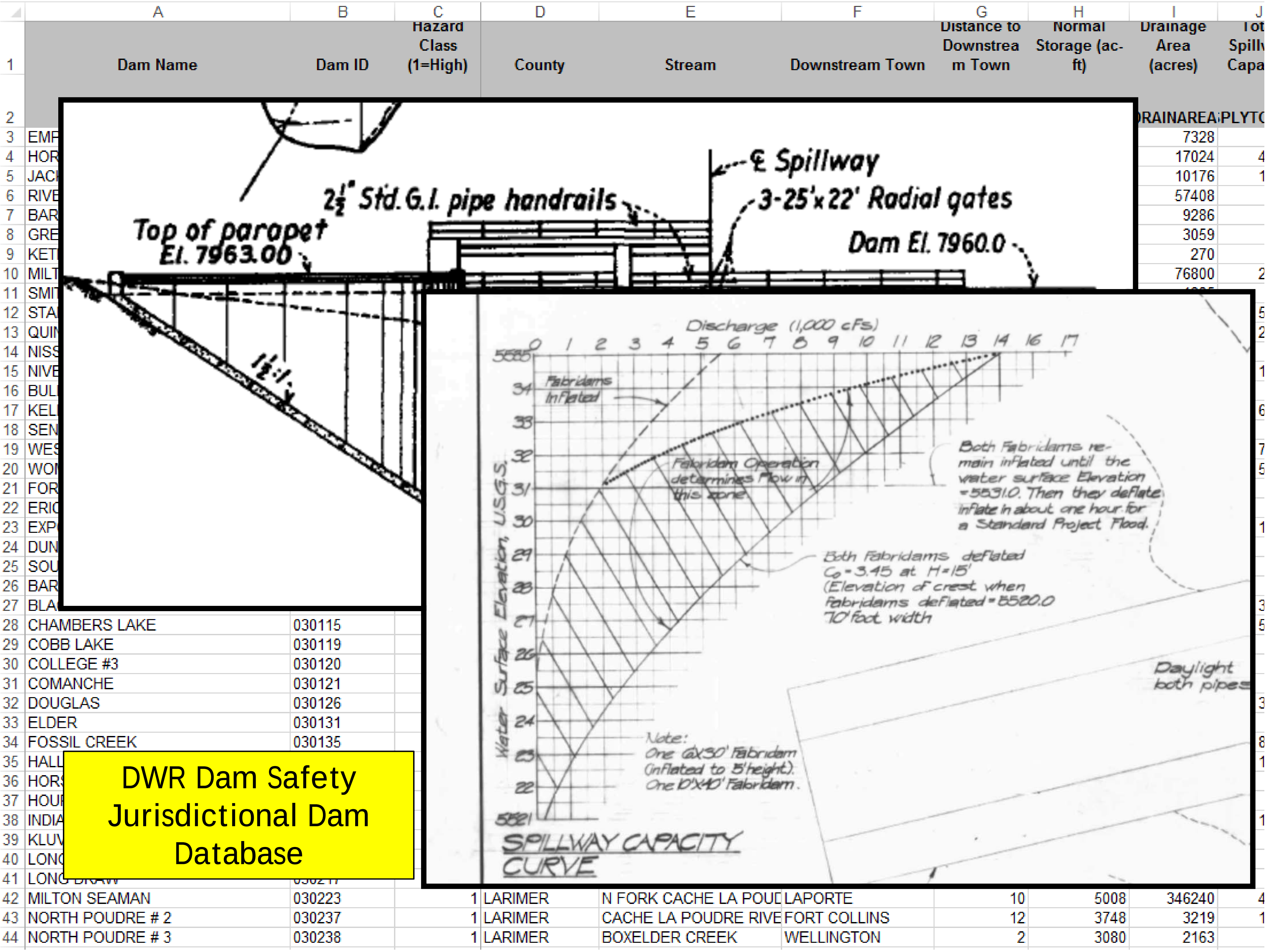
Why should Floodplain Managers care about Dams

- Not all dams provide flood control
- FEMA maps don't show spillway flows or outlet releases
- Dam releases impact floodplain management

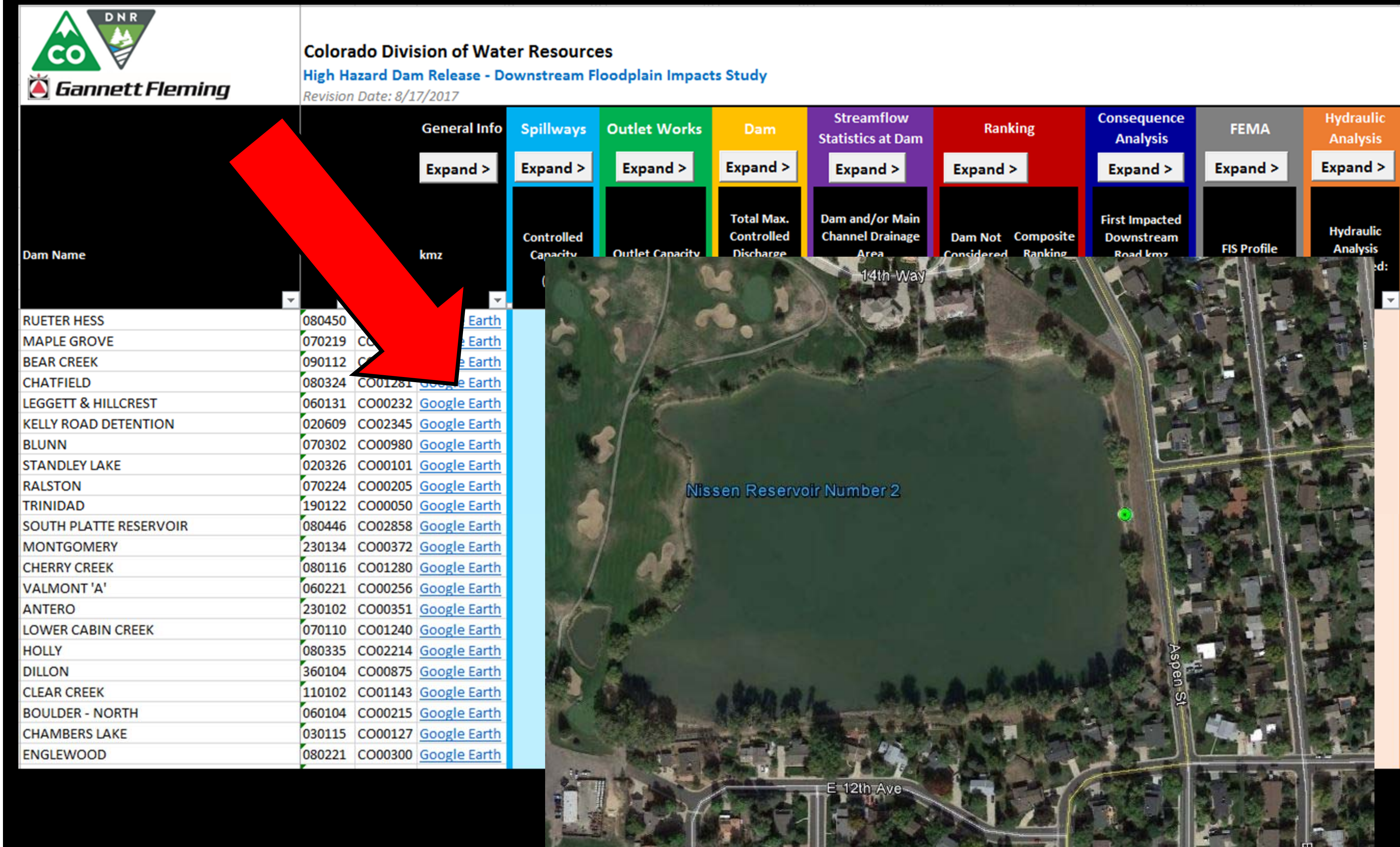


1. Use Existing Information
2. Be versatile
3. Be updatable
4. Provide easy access to information




DWR Dam Safety Jurisdictional Dam Database
Dam Name
Dam ID
Hazard Class (1=High)
County
Stream
Downstream Town
Distance to Downstream Town
Normal Storage (ac-ft)
Drainage Area (acres)
MILTON SEAMAN 030223 1 LARIMER N FORK CACHE LA POUD LAPORTE 10 5008 346240
NORTH POUDRE # 2 030237 1 LARIMER CACHE LA POUDRE RIVE FORT COLLINS 12 3748 3219
NORTH POUDRE # 3 030238 1 LARIMER BOXELDER CREEK WELLINGTON 2 3080 2163
℄ Spillway
3-25'x22' Radial gates
2½" Std. G.I. pipe handrails
Top of parapet El. 7963.00
Dam El. 7960.0
SPILLWAY CAPACITY CURVE
Discharge (1,000 cfs)
Water Surface Elevation, U.S.G.S.
Fabridams Inflated
Fabridam Operation determines Flow in this zone
Both Fabridams remain inflated until the water surface Elevation =5531.0. Then they deflate inflate in about one hour for a Standard Project Flood.
Both Fabridams deflated
Note:
One 6'X30' Fabridam (inflated to 5' height).
One 10'X40' Fabridam.

Colorado High Hazard Dams Release Database



CO High Hazard Dams Release Database – General Information

General Information

- Dam Name
- Dam ID
- NID ID
- Latitude
- Longitude
- County
- Stream
- CO Database Drainage Area

Spillways

- Controlled Capacity
- Total Capacity

Links!
Sorting!
Views!

Outlet Works

- Outlet Capacity
- Outlet Description

Dam

- Total Maximum Controlled Discharge
- Type
- Off Channel
- PAR
- Social Vulnerability
- Distance to Downstream Town
- Height
- Length
- Dam Safety Engineer
- Owner Type
- Owner

Streamflow Statistics at Dam

- Drainage Area
- Elevation
- Basin Slope
- EL7500
- Precip
- 16HR100YR
- PK2
- PK5
- PK10
- PK25
- PK50
- PK100
- PK200
- PK500

CO High Hazard Dams Release Database – Initial Ranking

Gannett Fleming

ts Study

Dam Name	Dam: Total Max. Controlled Discharge (cfs)	Streamflow Statistics at Dam: Dam and/or Main Channel Drainage Area (mi²)	Ranking: Dam Not Considered	Ranking 1 Drainage Area/Total Max. Controlled Discharge* Value	Ranking 1 Rank	Ranking 2 Q100/Total Max. Controlled Discharge* Value	Ranking 2 Rank	Ranking 3 Distance to Downstream Town** Value	Ranking 3 Rank	Ranking 4 Q100/Total Spillway Capacity Value	Ranking 4 Rank	Ranking 5 1/Total Max. Controlled Discharge Value	Ranking 5 Rank	Ranking 6 1/Total Spillway Capacity Value	Ranking 6 Rank	Total Score	Composite Ranking
Weight==>				1		1		1		1		1		1			
RUETER HESS	1242.7	10.52		0.00847	30	1.36799	52	0.1	1	0.06739	85	0.00080	38	0.00004	47	253	1
MAPLE GROVE	13467.0	10.40		0.00077	4	0.17599	3	0.1	1	0.17733	174	0.00007	3	0.00007	76	261	2
BEAR CREEK	2000.0	235.67		0.11784	142	1.56500	65	1.0	74	0.01385	13	0.00050	25	0.00000	3	322	3
CHATFIELD	8300.0	3020.77		0.36395	171	1.63855	67	0.1	1	0.07234	90	0.00012	5	0.00001	5	339	4
LEGGETT & HILLCREST	385.0	1.52		0.00394	15	1.06494	37	0.1	1	0.06072	75	0.00260	91	0.00015	122	341	5
KELLY ROAD DETENTION	690.0	10.65		0.01543	52	6.15942	127	0.1	1	0.07083	88	0.00145	61	0.00002	16	345	6
BLUNN	420.0	48.29		0.11497	140	2.47619	86	0.0	1	0.01625	17	0.00238	87	0.00002	15	346	7
STANDLEY LAKE	700.0	15.95		0.02279	69	5.55714	122	0.1	1	0.07125	89	0.00143	60	0.00002	20	361	8
RALSTON	650.0	46.41		0.07139	119	1.35692	51	1.0	74	0.02352	29	0.00154	62	0.00003	34	369	9
TRINIDAD	5500.0	671.86		0.12216	143	2.78182	96	1.0	74	0.03338	46	0.00018	10	0.00000	2	371	10
SOUTH PLATTE RESERVOIR	110.0	0.30		0.00276	10	2.48182	87	0.0	1	0.02093	26	0.00909	180	0.00008	78	382	11
MONTGOMERY	1243.0	7.84		0.00631	24	0.25744	8	5.0	174	0.04430	57	0.00080	37	0.00014	119	419	12
CHERRY CREEK	8100.0	385.67		0.04761	104	1.80247	71	0.1	1	0.25933	219	0.00012	6	0.00002	19	420	13
VALMONT 'A'	210.0	1.52		0.00721	27	1.95238	75	0.1	1	0.06072	75	0.00476	121	0.00015	122	421	14
ANTERO	1800.0	190.91		0.10606	138	0.82778	27	5.0	174	0.03311	45	0.00056	27	0.00002	26	437	15
LOWER CABIN CREEK	549.0	13.65		0.02486	75	0.57013	18	3.0	142	0.02833	36	0.00182	73	0.00009	94	438	16
HOLLY	195.0	2.05		0.01050	43	5.69231	124	0.1	1	0.07923	97	0.00513	126	0.00007	75	466	17
DILLON	4400.0	334.09		0.07593	122	0.86591	28	0.1	1	0.32414	236	0.00023	12	0.00009	89	488	18
CLEAR CREEK	2145.0	68.77		0.03206	88	0.58275	19	15.0	294	0.02976	39	0.00047	23	0.00002	29	492	19
BOULDER - NORTH	940.0	11.60		0.01234	45	4.85106	114	1.0	74	0.17882	175	0.00106	47	0.00004	45	500	20
CHAMBERS LAKE	1700.0	31.93		0.01878	56	0.67647	21	43.0	357	0.02114	27	0.00059	28	0.00002	21	510	21

Ranking Dams

What makes a "risky" dam?

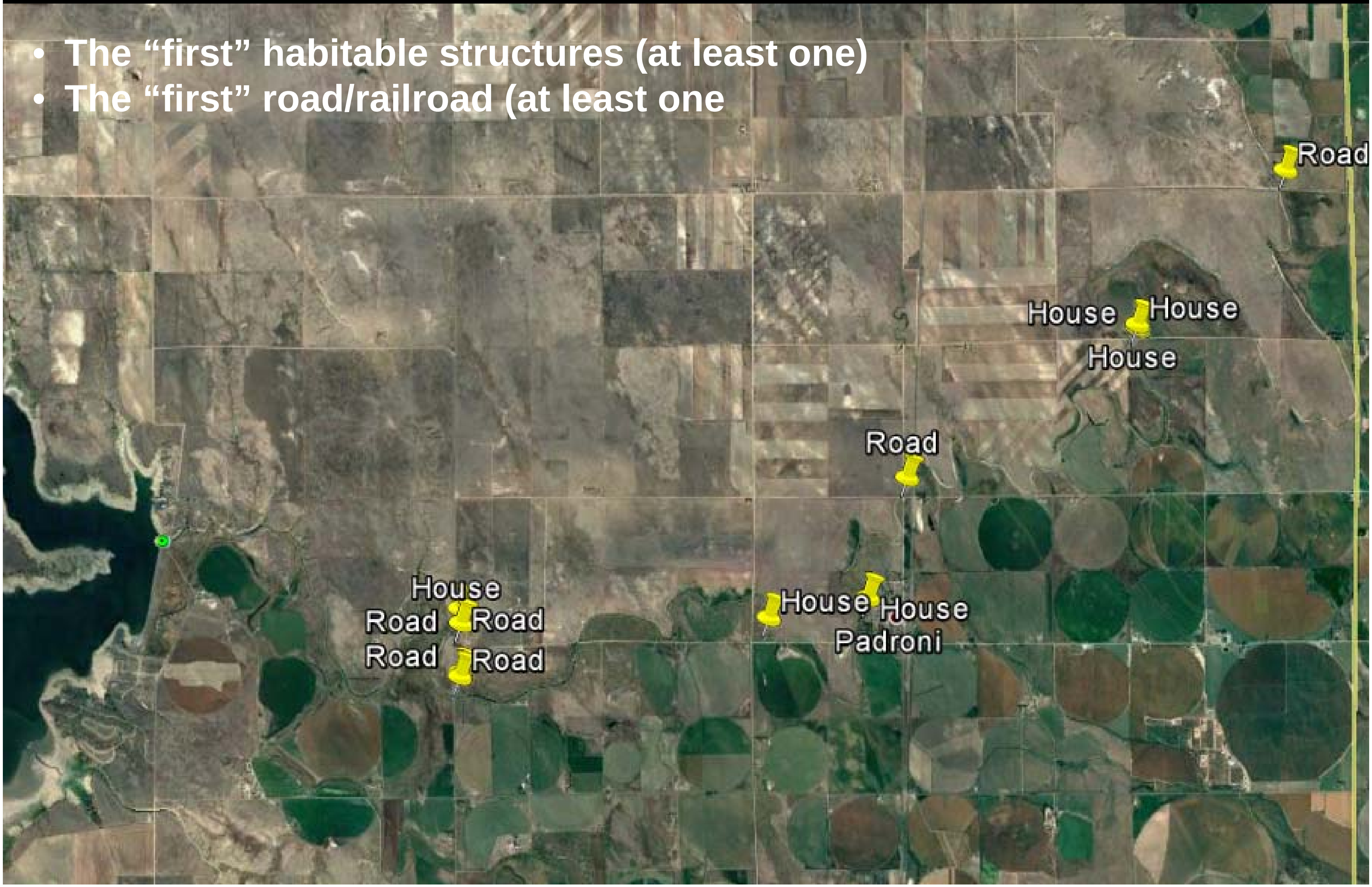
- Ability to release "large" discharges relative to drainage area
- Large spillways
- Proximity to population

Ranking Relationships

- Drainage area/Total Maximum Controlled Discharge
- Q100/Total Maximum Controlled Discharge
- Distance to Downstream Town
- Q100/Total Spillway Capacity
- 1/Total Maximum Controlled Discharge
- 1/Total Spillway Capacity

Downstream Consequences

- The “first” habitable structures (at least one)
- The “first” road/railroad (at least one



CO High Hazard Dams Release Database
Potential Downstream Impacts Ranking

Gannett Fleming

Colorado Division of Water Resources

High Hazard Dam Release - Downstream Floodplain Impacts Study

Revision Date: 7/17/2017

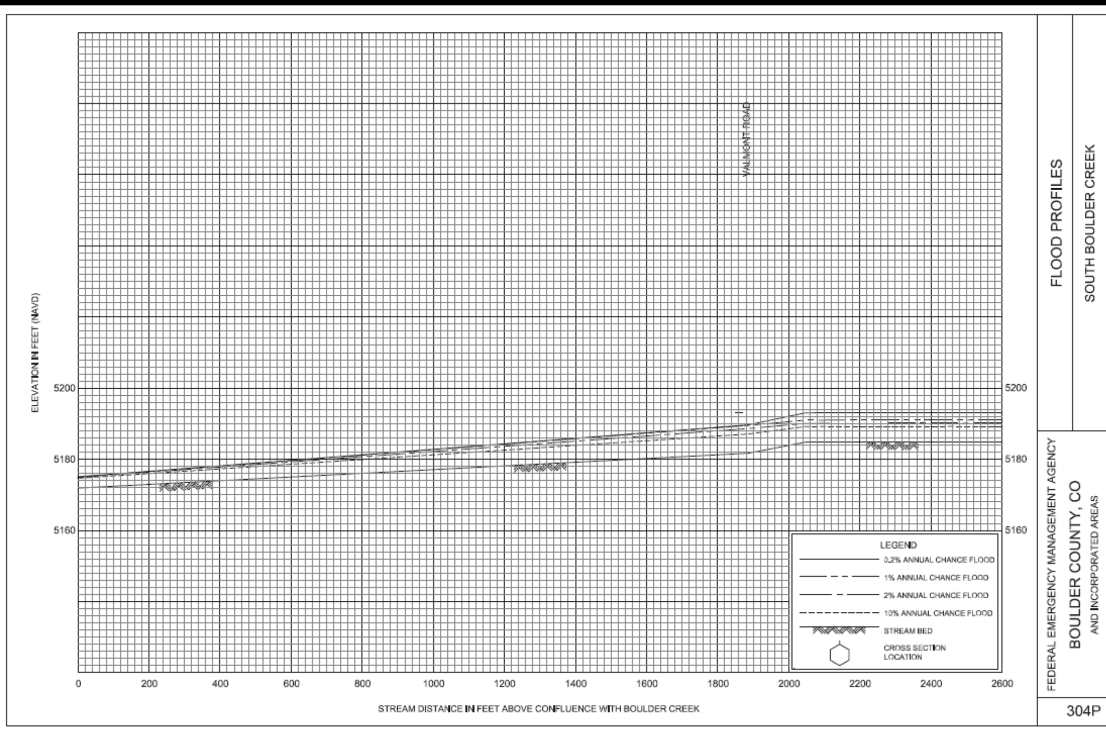
			General Info	Spillways	Outlet Works	Dam	Streamflow Statistics at Dam	Initial Ranking		Consequence Analysis			
			Expand >	Expand >	Expand >	Expand >	Expand >	Expand >		< Hide			
Dam Name	**Dam ID**	**NID ID**	**kmz**	**Controlled Capacity (cfs)**	**Outlet Capacity (cfs)**	**Total Max. Controlled Discharge (cfs)**	**Dam and/or Main Channel Drainage Area (mi^2)**	**Dam Not Considered**	**Initial Ranking by Total**	**First Impacted Downstream Road kmz**	**First Impacted Downstream Road Drainage Area (mi^2)**	**First Impacted Downstream Structure kmz**	**First Impacted Downstream Structure Drainage Area (mi^2)**
RUETER HESS	080450	CO02949	Google Earth	648	594.7	1242.7	10.52		1	Google Earth	10.78	Google Earth	11.18
MAPLE GROVE	070219	CO00203	Google Earth	13365	102.0	13467.0	10.40		2	Google Earth	10.87	Google Earth	10.86
BEAR CREEK	090112	CO00004	Google Earth	0	2000.0	2000.0	235.67		3	Google Earth	255.00	Google Earth	238.51
CHATFIELD	080324	CO01281	Google Earth		8300.0	8300.0	3020.77		4	Google Earth	3100.00	Google Earth	3040.00
LEGGETT & HILLCREST	060131	CO00232	Google Earth		385.0	385.0	1.52		5	Google Earth	131.52	Google Earth	131.51
KELLY ROAD DETENTION	020609	CO02345	Google Earth		690.0	690.0	10.65		6	Google Earth	10.66	Google Earth	10.67
BLUNN	070302	CO00980	Google Earth		420.0	420.0	48.29		7	Google Earth	49.30	Google Earth	49.30
STANDLEY LAKE	020326	CO00101	Google Earth		700.0	700.0	15.95		8	Google Earth	18.45	Google Earth	17.05
RALSTON	070224	CO00205	Google Earth		650.0	650.0	46.41		9	Google Earth	47.04	N/A	N/A
TRINIDAD	190122	CO00050	Google Earth		5500.0	5500.0	671.86		10	Google Earth	749.38	Google Earth	749.48
SOUTH PLATTE RESERVOIR	080446	CO02858	Google Earth	0	110.0	110.0	0.30		11	Google Earth	3.12	N/A	N/A
MONTGOMERY	230134	CO00372	Google Earth		1243.0	1243.0	7.84		12	Google Earth	9.44	Google Earth	31.67
CHERRY CREEK	080116	CO01280	Google Earth		8100.0	8100.0	385.67		13	Google Earth	410.00	Google Earth	410.00
VALMONT 'A'	060221	CO00256	Google Earth		210.0	210.0	1.52		14	Google Earth	1.56	Google Earth	1.53
ANTERO	230102	CO00351	Google Earth		1800.0	1800.0	190.91		15	Google Earth	215.57	Google Earth	400.37
LOWER CABIN CREEK	070110	CO01240	Google Earth		549.0	549.0	13.65		16	Google Earth	15.19	Google Earth	29.65
HOLLY	080335	CO02214	Google Earth		195.0	195.0	2.05		17	Google Earth	2.07	Google Earth	2.07
DILLON	360104	CO00875	Google Earth		4400.0	4400.0	334.09		18	Google Earth		Google Earth	
CLEAR CREEK	110102	CO01143	Google Earth	1500	645.0	2145.0	68.77		19	Google Earth	549.05	Google Earth	553.06
BOULDER - NORTH	060104	CO00215	Google Earth		940.0	940.0	11.60		20	Google Earth	26.60	Google Earth	26.60
CHAMBERS LAKE	030115	CO00127	Google Earth		1700.0	1700.0	31.93		21	Google Earth	35.20	Google Earth	138.17
ENGLEWOOD	080221	CO00300	Google Earth		210.0	210.0	9.39		22	Google Earth	9.71	Google Earth	9.68
LEYDEN	070209	CO01216	Google Earth		193.0	193.0	8.87		23	Google Earth	9.80	Google Earth	9.80
TROUT CREEK	110233	CO02813	Google Earth		304.0	304.0	60.84		24	Google Earth	60.95	Google Earth	62.40
EXPOSITION PARK	020643	CO02816	Google Earth		109.0	109.0	5.00		25	Google Earth		Google Earth	
GROSS	060211	CO00247	Google Earth		1385.0	1385.0	92.96		26	Google Earth	93.35	Google Earth	95.75

CO High Hazard Dams Release Database – FEMA

er Resources

ownstream Floodplain Impacts Study

Dam Name	Spillways: Controlled Capacity (cfs)	Outlet Works: Outlet Capacity (cfs)	Dam: Total Max. Controlled Discharge (cfs)	Streamflow Statistics at Dam: Dam and/or Main Channel Drainage Area (mi^2)	Initial Ranking: Dam Not Considered	Initial Ranking: Initial Ranking by Total	Consequence Analysis: First Impacted Downstream Road kmz	FEMA: FIS Profile	FEMA: Flooding Source and Location	FEMA: Drainage Area (mi^2)	Peak Discharges (cfs): 10-Percent Annual Chance	Peak Discharges (cfs): 2-Percent Annual Chance	Peak Discharges (cfs): 1-Percent Annual Chance	Peak Discharges (cfs): 0.2-Percent Annual Chance
RUETER HESS	648	594.7	1242.7	10.52		1	Google Earth	FIS Profile	At West Parker Road	11.8	1890	3450	4590	7920
MAPLE GROVE	13365	102.0	13467.0	10.40		2	Google Earth	FIS Profile	At U.S Highway 6	3.68	1000	1800	2200	3300
BEAR CREEK	0	2000.0	2000.0	235.67		3	Google Earth	FIS Profile	Below Mt.Carbon Dam	239	500	1000	1000	2000
CHATFIELD		8300.0	8300.0	3020.77		4	Google Earth	FIS Profile	At downstream limit of study	2018	2950	4600	5400	7700
LEGGETT & HILLCREST									reek		1570	3180	4980	7750
KELLY ROAD DETENTION									enue	N/A	570	870	1000	1320
BLUNN									per CK.		4091	7932	9700	13200
STANDLEY LAKE										11.4	2370	4800	6460	13260
RALSTON									am					
TRINIDAD										N/A	N/A	N/A	N/A	N/A
SOUTH PLATTE RESERVOIR									h Creek		1300	2200	2700	4000
MONTGOMERY														
CHERRY CREEK									dy	340	10300	31000	51000	150000
VALMONT 'A'										N/A	N/A	N/A	N/A	N/A
ANTERO														
LOWER CABIN CREEK									eek	30.7	420	580	640	790
HOLLY										2.07	1183	2413	3076	4330
DILLON										N/A	N/A	N/A	N/A	N/A
CLEAR CREEK										N/A	N/A	N/A	N/A	N/A
BOULDER - NORTH									am					
CHAMBERS LAKE										N/A	N/A	N/A	N/A	N/A
ENGLEWOOD											3410	7000	9010	12140
LEYDEN										9	850	1150	2200	3400
TROUT CREEK										N/A	N/A	N/A	N/A	N/A
EXPOSITION PARK										10.8	2700	4200	5000	6800
GROSS											1310	2640	4340	7400



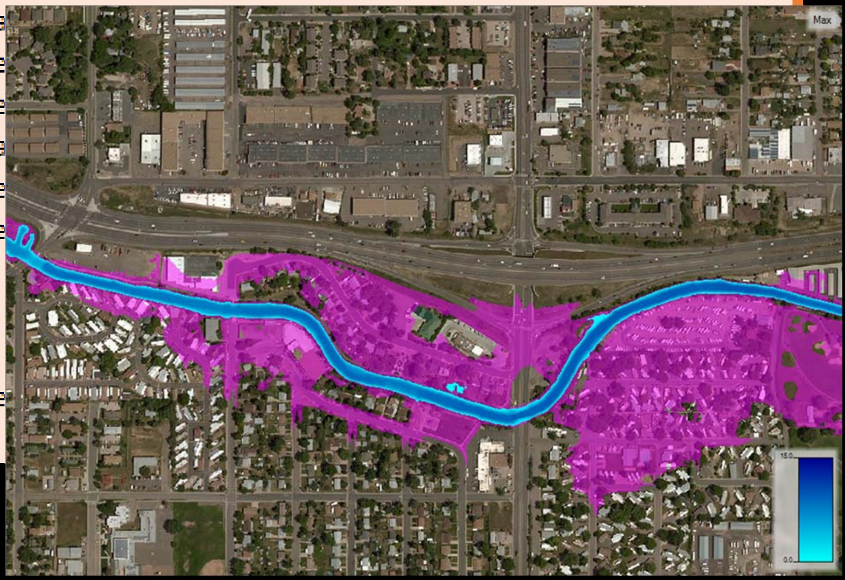
Hydraulic Analysis

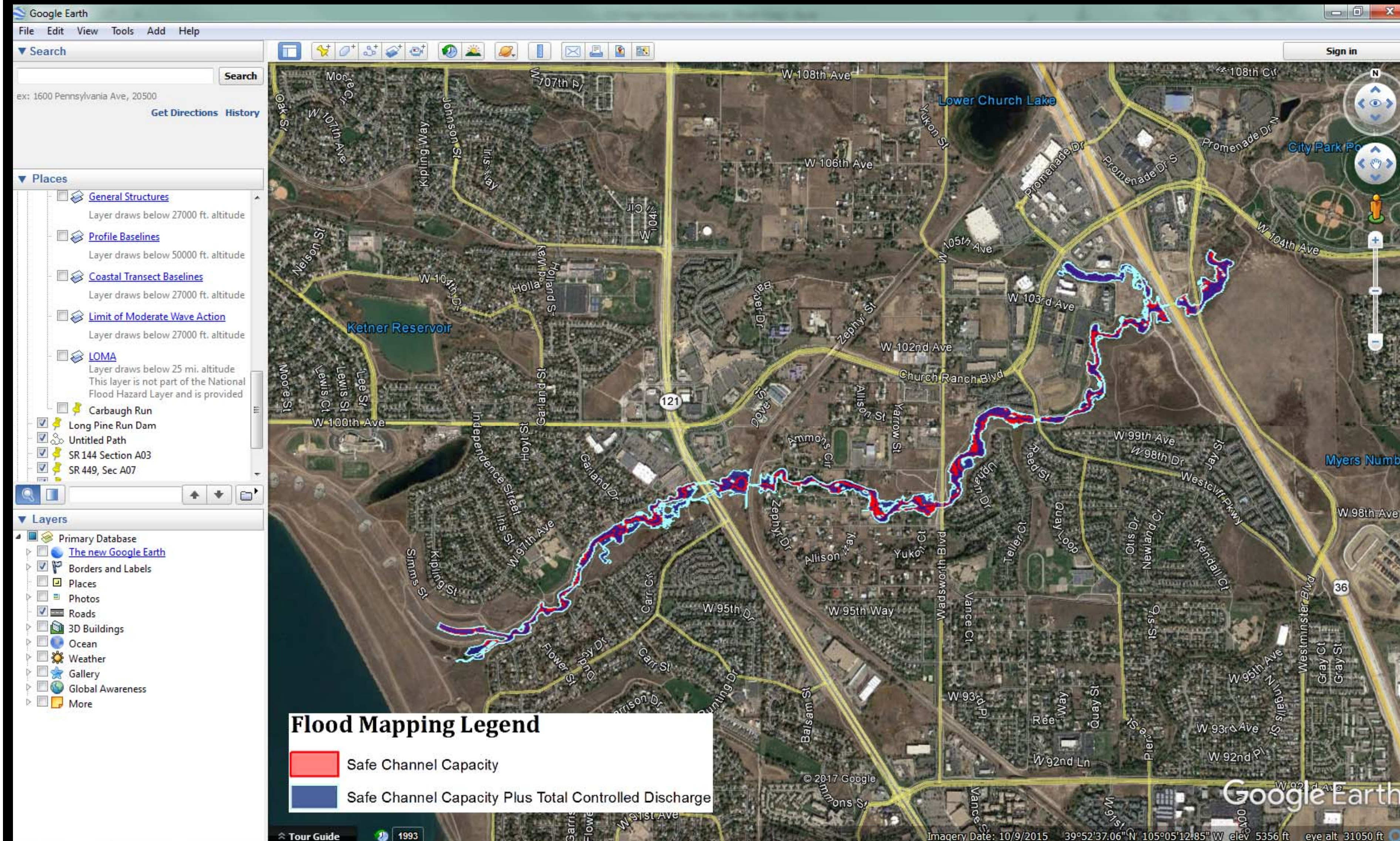
More than 20 completed

Safe Channel Capacity – just before impacts

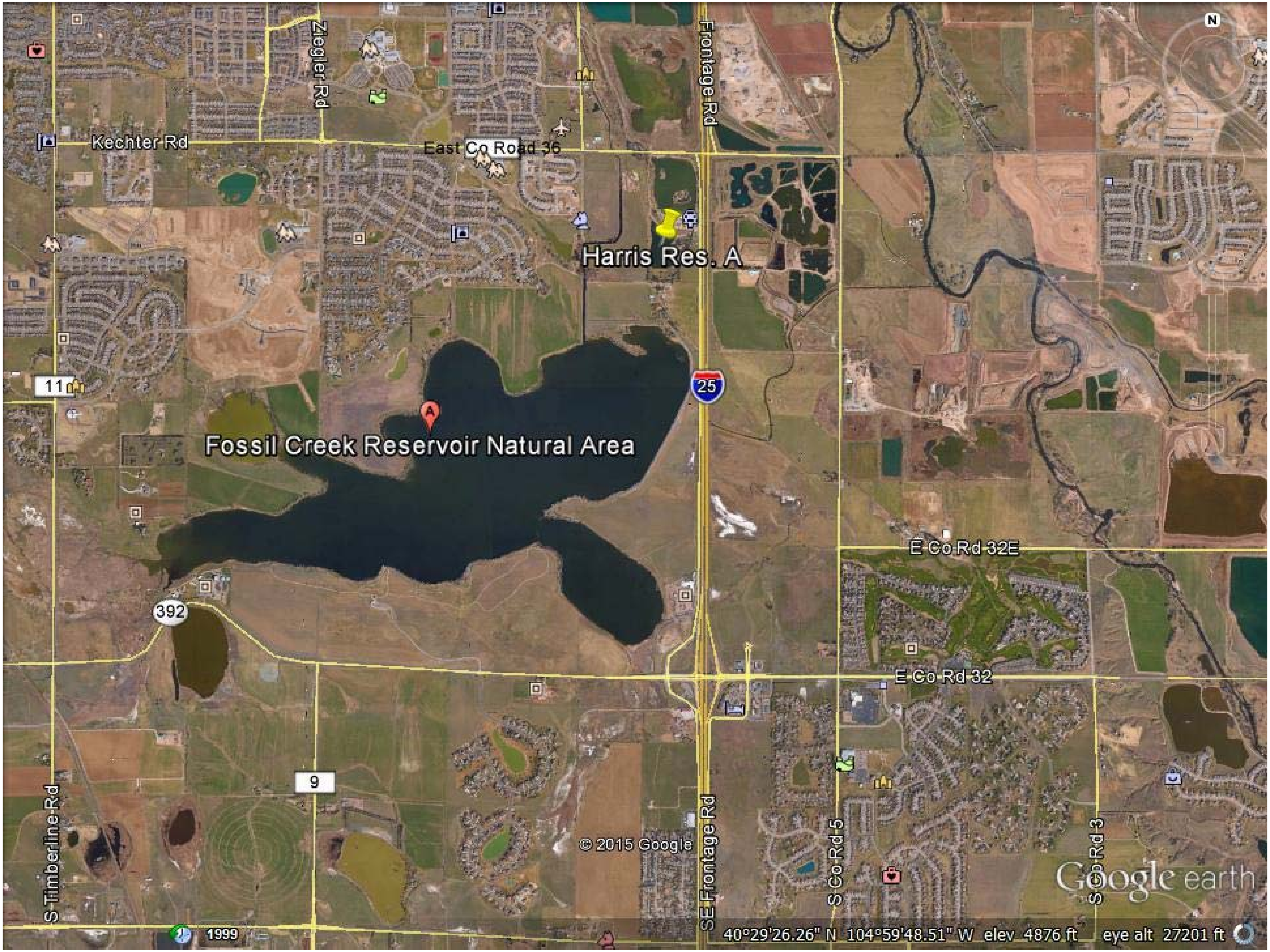
Hydraulic Analysis

Hydraulic Analysis Performed by:	Safe Channel Capacity (cfs)	Safe Channel plus Total Max. Controlled Discharge (cfs)	Reference Flow 1 (cfs)	Reference Flow 1 Frequency and Source	Reference Flow 2 (cfs)	Reference Flow 2 Frequency and Source	Reference Flow 3 (cfs)	Reference Flow 3 Frequency and Source	Flood Mapping kmz
AJL		1242.7							
YW	350	13817.0	1000	10-year (FEMA	2200	100-year (FEMA)			
YW	1350	3350.0	730	2-yea					
YW	13700	22000.0	10300	50-ye					
WCH	2052	2742.0	668	25-ye					
YW	50	470.0	211	2-yea					
YW	380	1080.0	1130	10-ye					
YW	6040	6690.0	3052	50-ye					
YW		5500.0							
YW	4638	12738.0	2892	10-ye					
WCH		210.0							




Flood Mapping Legend
Safe Channel Capacity
Safe Channel Capacity Plus Total Controlled Discharge
© 2017 Google
Google Earth
Imagery Date: 10/9/2015 39°52'37.06" N 105°05'12.85" W elev 5356 ft eye alt 31050 ft

Video Instruction



Ziegler Rd
Frontage Rd
Kechter Rd
East Co Road 36
Harris Res. A
11
25
Fossil Creek Reservoir Natural Area
E Co Rd 32E
392
E Co Rd 32
9
S Timberline Rd
© 2015 Google
SE Frontage Rd
S Co Rd 5
S Co Rd 3
Google earth
1999
40°29'26.26" N 104°59'48.51" W elev 4876 ft eye alt 27201 ft

Example – Fossil Creek Dam

Colorado Division of Water Resources
High Hazard Dam Release
Downstream Floodplain Impacts Study

Gannett Fleming

FOSSIL CREEK

DAM ID	030135		Go to Google Earth
NID ID	CO01165	**Latitude**	40.492
County	LARIMER	**Longitude**	-104.994
Stream	FOSSIL CREEK		

Dam Drainage Area, DA (mi^2)	29.09	Outlet Works Capacity (cfs)	393
100-Yr StreamStats Discharge (Q_{100}) (cfs)	14900	Total Maximum Controlled Discharge, Q_{cont} (cfs)	393
Total Spillway Capacity, Q_{SW} (cfs)	88100		

Ranking Summary

R1: DA/Q_{cont}	120	R4: Q_{100}/Q_{SW}	166
R2: Q_{100}/Q_{cont}	191	R5: $1/Q_{cont}$	89
R3: Dist. To DS Town	142	R6: $1/Q_{SW}$	10

Composite Ranking **74** HIGH *Rankings reported out of 416 total dams*

Consequence Analysis

Population at Risk (PAR) N/A
Social Vulnerability Index (SVI) N/A

Estimated first impacted downstream road [View in Google Earth]
Estimated first impacted downstream structure [View in Google Earth]

	LOW		MODERATE			HIGH	
SVI	LESS THAN	-4.7	-4.7	TO	0.4	GREATER THAN	0.4
TOTAL RANKING	GREATER THAN	278	139	TO	278	LESS THAN	139

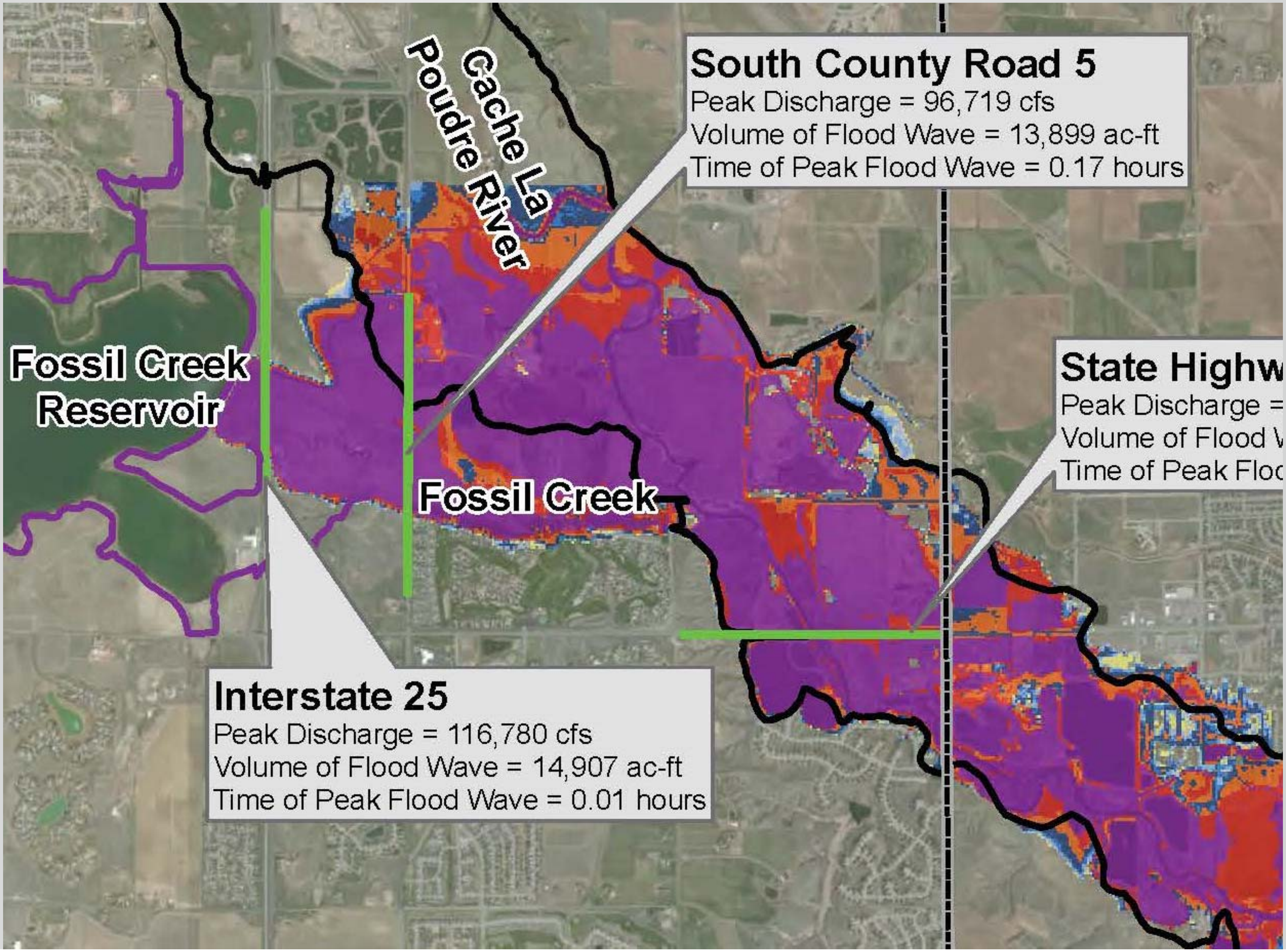
Hydraulic Analysis Summary

Dam Name	FOSSIL CREEK
Dam ID	030135
Safe Channel Capacity (cfs)	616
Safe Channel plus Total Max. Controlled Discharge Qcont (cfs)	1009
	Safe Channel Capacity Mapping in Google Earth
Reference Flow 1 (cfs)	516
Reference Flow 1 Frequency and Source	2-year (SS)
Reference Flow 2 (cfs)	3450
Reference Flow 2 Frequency and Source	10-year (SS)

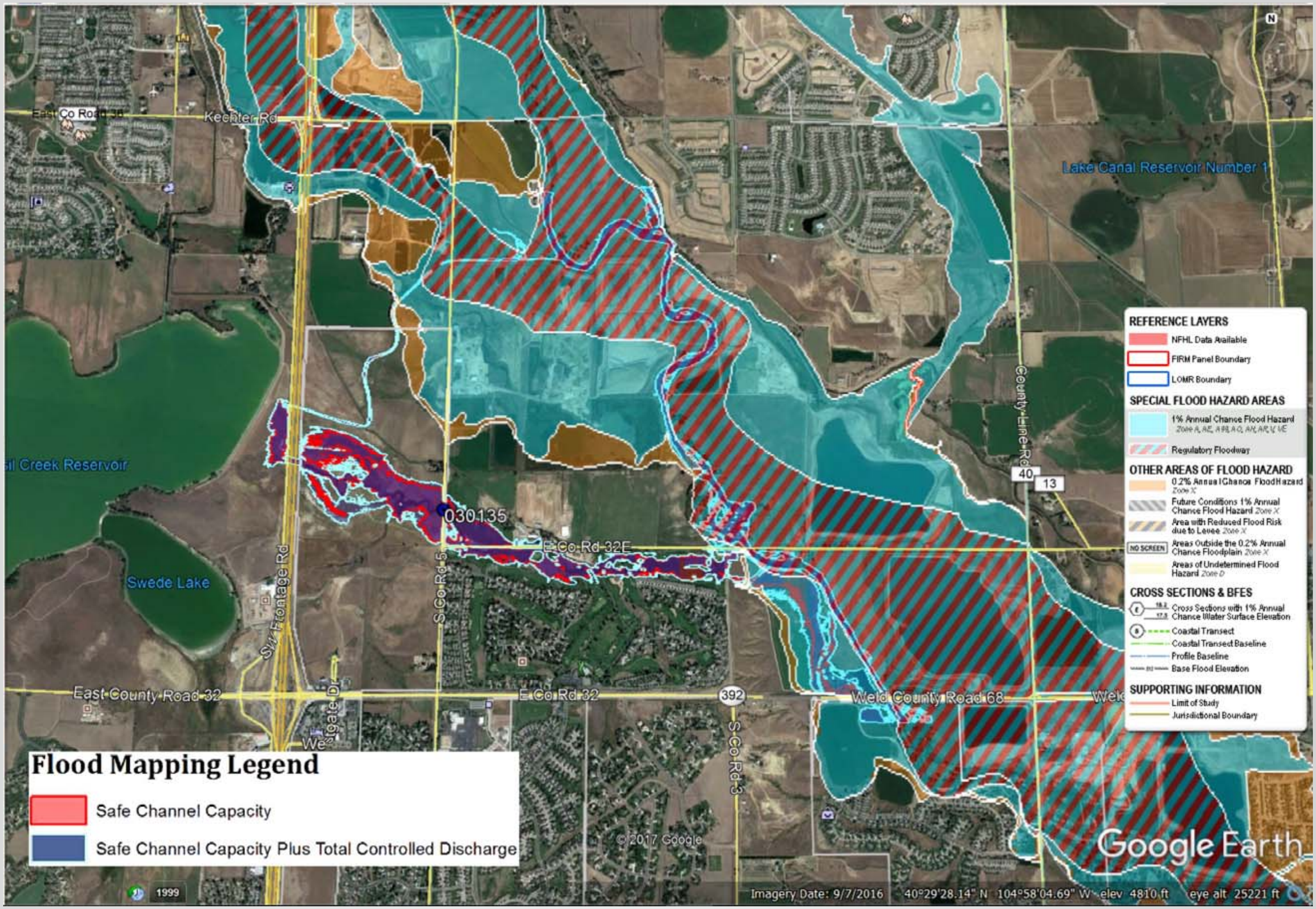
Hydraulic Analysis Findings

The safe channel capacity of the reach downstream of Fossil Creek Dam is estimated to be 616 cfs. The maximum controlled discharge is 393 cfs. For comparison, the 2-year peak discharge estimated by StreamStats is 516 cfs; the 10-year peak discharge estimated by StreamStats is 3450 cfs. The downstream impact area is rural. The first impacted roads downstream of the dam are South County Road 5, South County Road 3, and County Road 32 East. The roads may be overtopped at a peak discharge of approximately 616 cfs. The first impacted structure downstream of the dam is located at the end of Watson Drive. The residential house may be flooded at a peak discharge of approximately 616 cfs.

Fossil Creek Dam – Inundation Map



Fossil Creek Dam – Outlet Release



Message for Floodplain Managers

- We know the Risk exists
- Flooding can happen downstream of a dam because of operations
- Know what you don't know
  - Database can sort by county
  - Information for all high hazard dams
- You might be surprised by the number of dams that can impact your floodplains
- Work together to manage floodplains below dams

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Department of Natural Resources

Next Steps

- Sharing the database
- Pilot study with Fort Collins:
  - Map outlet flows
  - Analyze data
  - guidelines

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Department of Natural Resources

Questions?

Sunday SEPTEMBER 15, 2013 • DENVERPOST.COM • THE DENVER POST ★★ SECTION B

DENVER & THE WEST

DONATE: Contribute to flood-relief efforts. »2B

FORECAST: More rain expected Sunday. »16B

Front Range Flooding

"Normal has changed"

Fifth person presumed dead while authorities work to get hundreds to safety

Jon Cook drives down Hygiene Road with his father, Bob, while looking over flooding of neighboring properties Saturday in Hygiene. Resident of the town helped one another salvage personal belongings from flooded homes. *Craig F. Walker, The Denver Post*

Image Source: Denver Post

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Division of Water Resources
Department of Natural Resources

SHOWCASING THE PILOT BOULDER COUNTY FLOOD RISK INFORMATION SYSTEM (FRIS)

HOLISTIC FLOOD RISK COMMUNICATION

Thuy Patton

COLORADO
Colorado Water
Conservation Board
Department of Natural Resources

Madeline Kelley

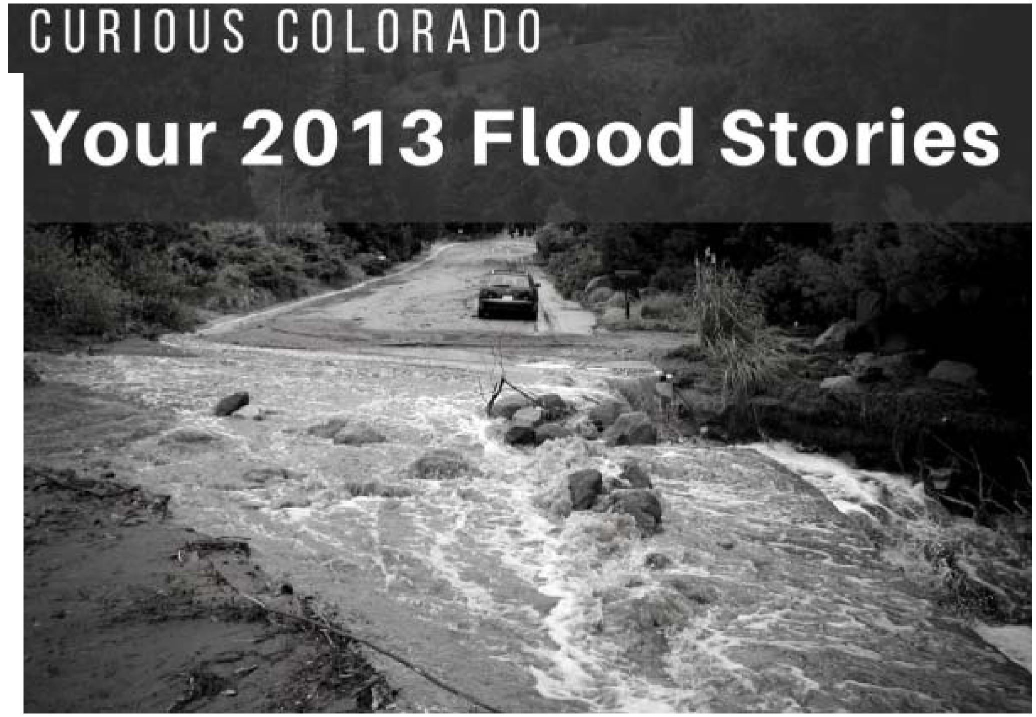
UNIVERSITY of DENVER

COLORADO'S 5-YEAR FLOOD ANNIVERSARY

DATE: Monday, September 10, 2018
TIME: 10:00AM-11:30AM
LOCATION: Bohn Park
199 2nd Avenue Lyons, CO 80540

When the rains of September 2013 poured down on Colorado and caused flooding, the town of Lyons was severely impacted. Today, however, Lyons is flourishing.

Please join Gov. Hickenlooper and leaders from across the state in commemorating Colorado's 5-year anniversary of the 2013 floods, and in celebrating the resilience of Colorado communities.



5 years later, Colorado communities continue to rebuild after devastating floods

Five year anniversary of catastrophic floods

BY: Russell Haythorn
POSTED: 4:46 PM, Sep 10, 2018
UPDATED: 7:01 PM, Sep 10, 2018

TAG: colorado flooding anniversary | 2013 floods | floods in colorado | 5 year anniversary | 5 year anniversary of floods

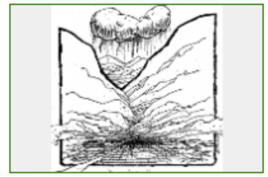
TECHNICAL MAPPING ADVISORY COUNCIL

TMAC

BOCO FRIS

Tags

BOCO FRIS



1. Understanding and Exploring Your Flood Risk Information System

Web Mapping Application

An online system to access and share flood information for your Boulder County community.

2. Calculate Your Base Flood Risk

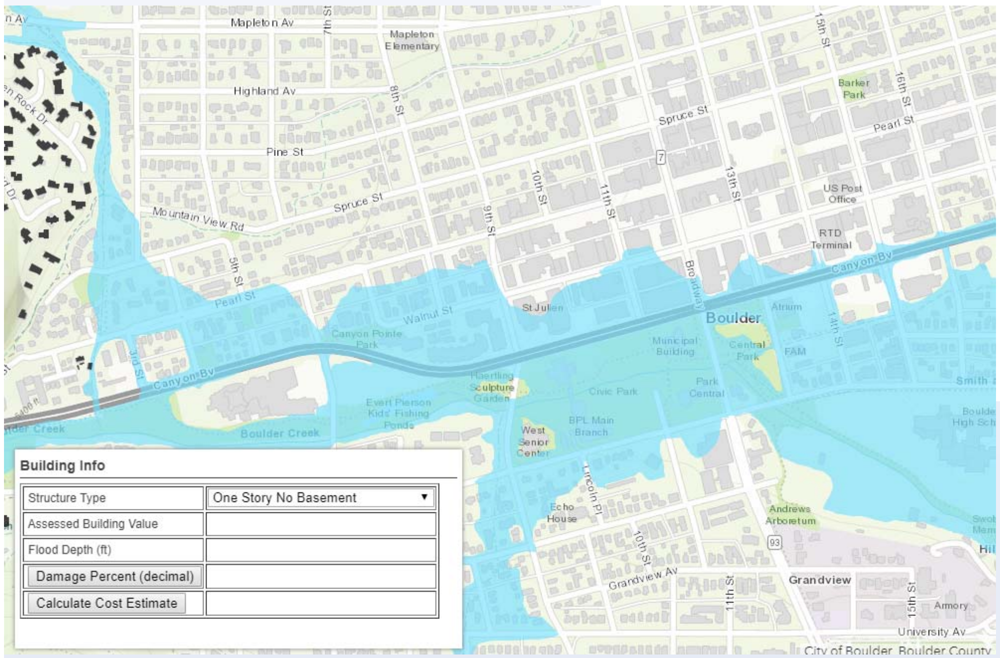
Web Mapping Application

3. Local's Knowledge

Web Mapping Application

4. Add Your Flood Knowledge

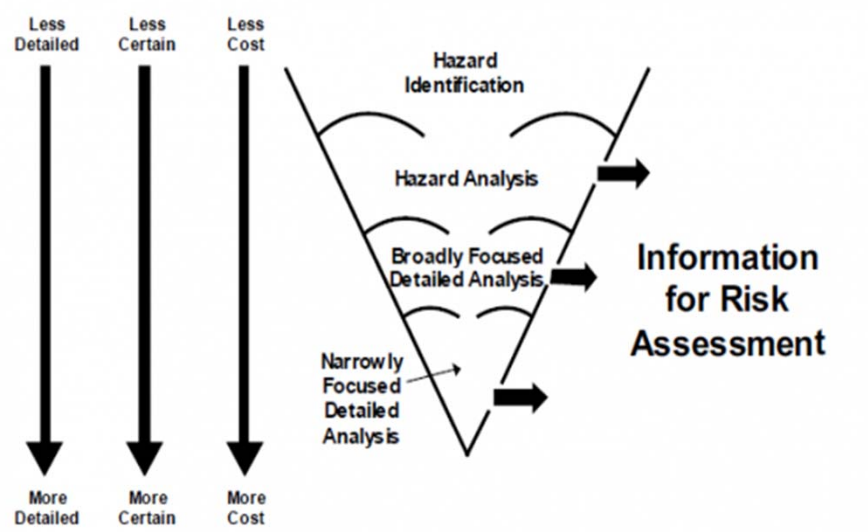
Web Mapping Application



Geographer and focused on the application of **geographic information science and remote sensing** to the *and science communication.* Interested in mixed methods and Participatory GIS

BA in Environmental Studies/GIS Certificate
University of Pittsburgh - 2014
MS in Geographic Information Science
University of Denver – 2018
PhD Geography Student
University of Arizona - current

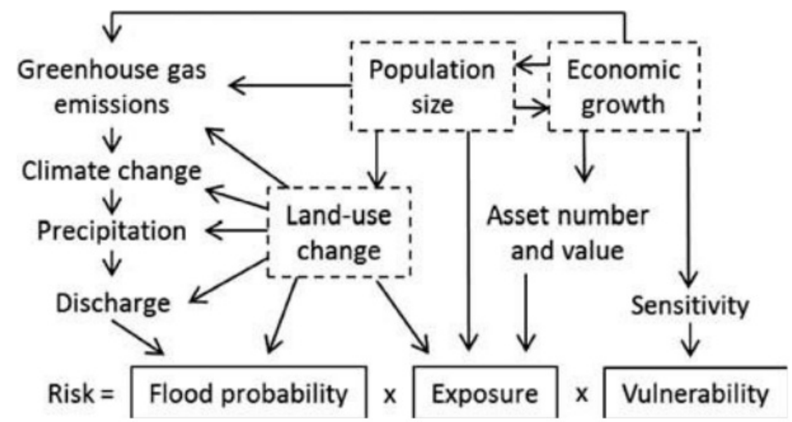
Flood risk communication is complicated

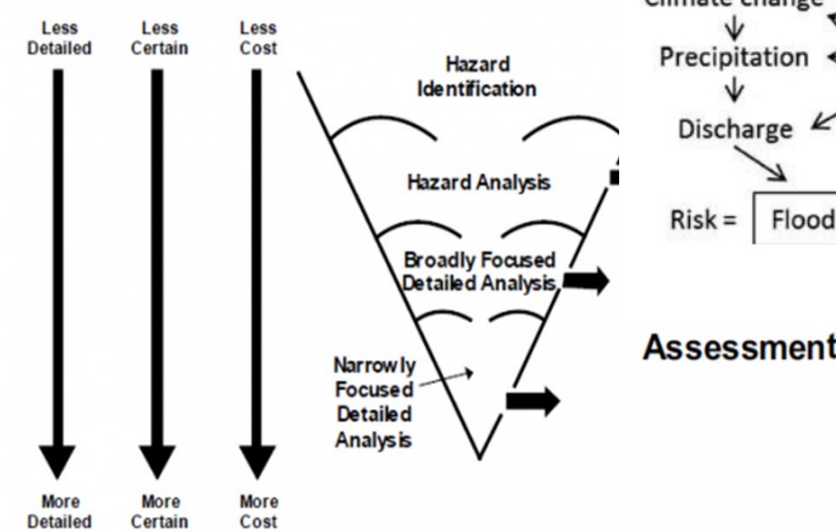


AIChE – CPS 2016 **FIGURE 9.1.** Levels of Hazard Evaluation and Risk Assessment

Flood risk communication is complicated

Source: Kundzewicz, Z. W.; Kanae, S.; Seneviratne, S. I.; et al., (2014) Flood risk and climate change: global and regional perspectives. Hydrol. Sci. J. 59(1), 1-28.





AIChE – CPS 2016

FIGURE 9.1. Levels of Hazard Evaluation and Risk Assessment

Flood risk communication is complicated

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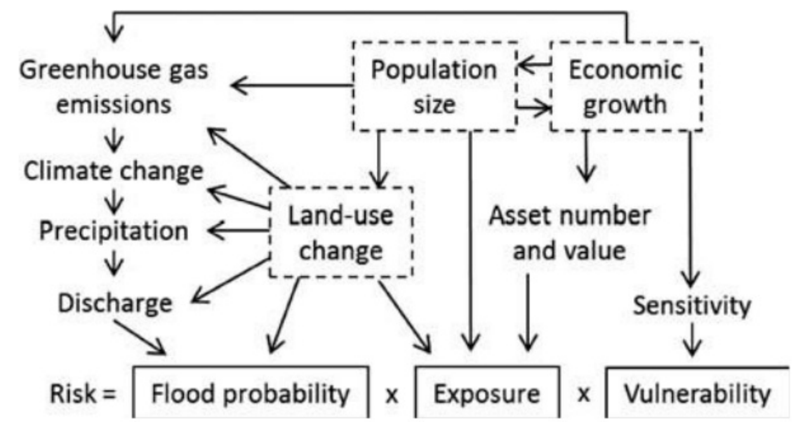
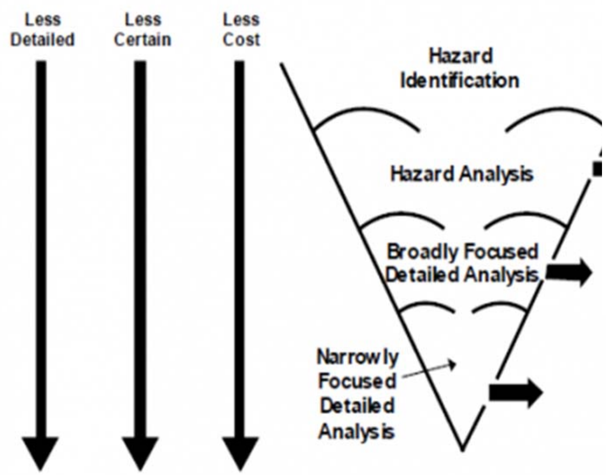
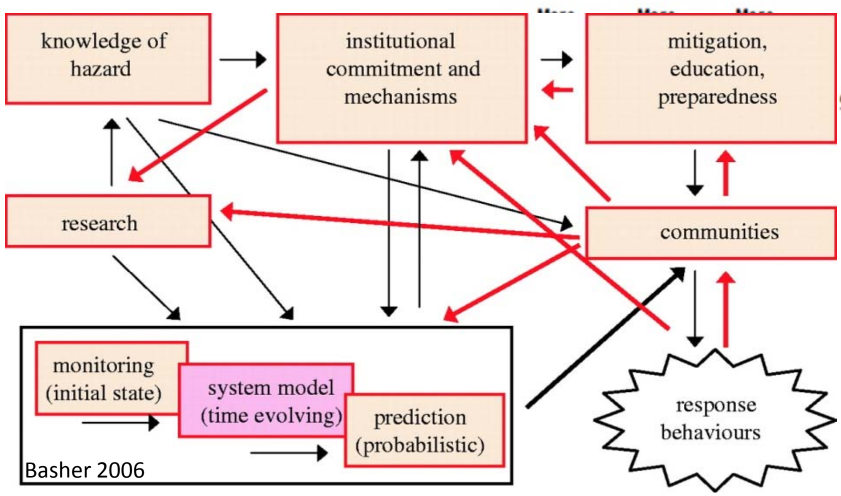


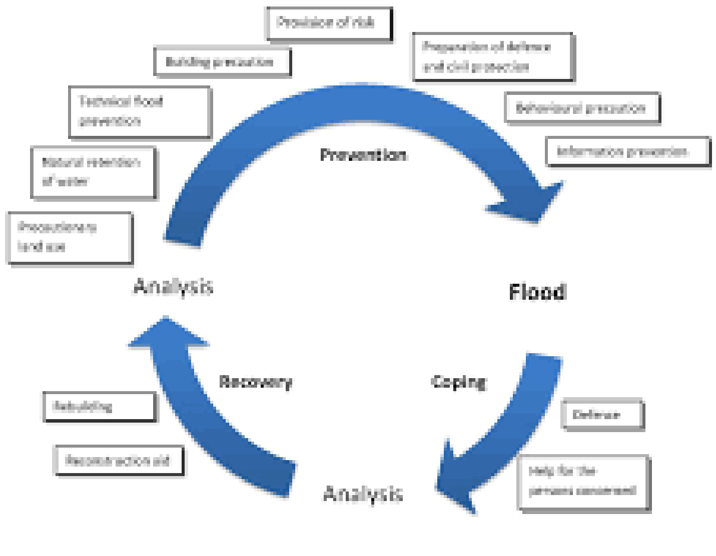


Assessment

9.1. Levels of Hazard Evaluation and Risk Assessment

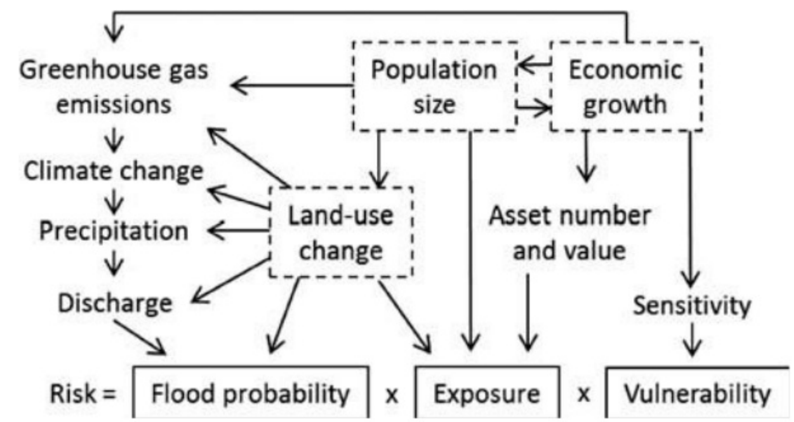


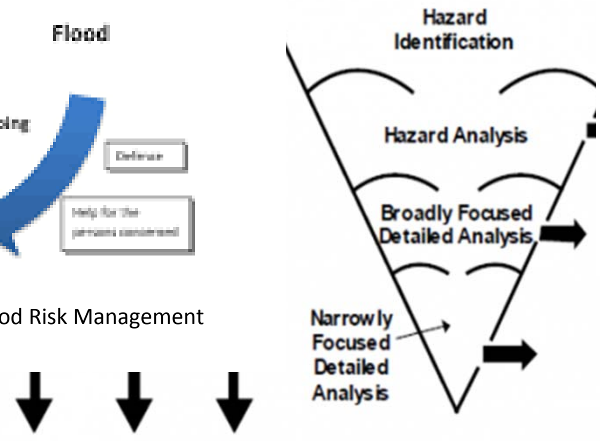
Flood risk communication is complicated



SECOM Flood Risk Management

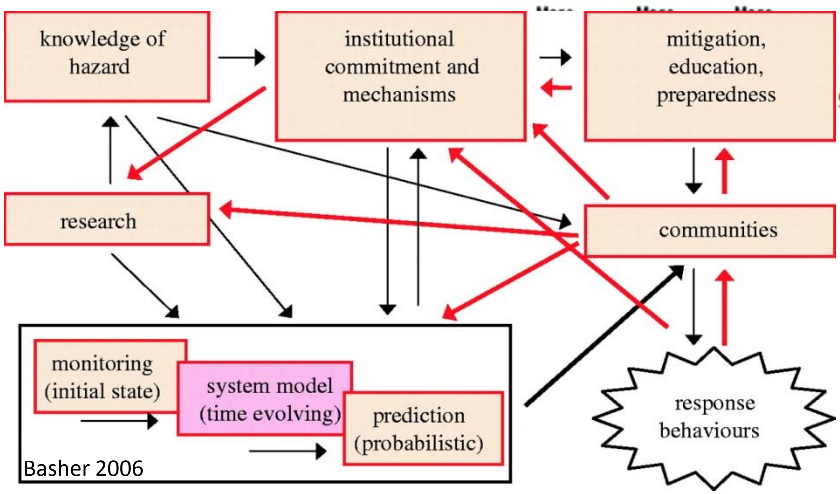
Source: Kundzewicz, Z. W.; Kanae, S.; Seneviratne, S. I.; et al., (2014) Flood risk and climate change: global and regional perspectives. Hydrol. Sci. J. 59(1), 1-28.





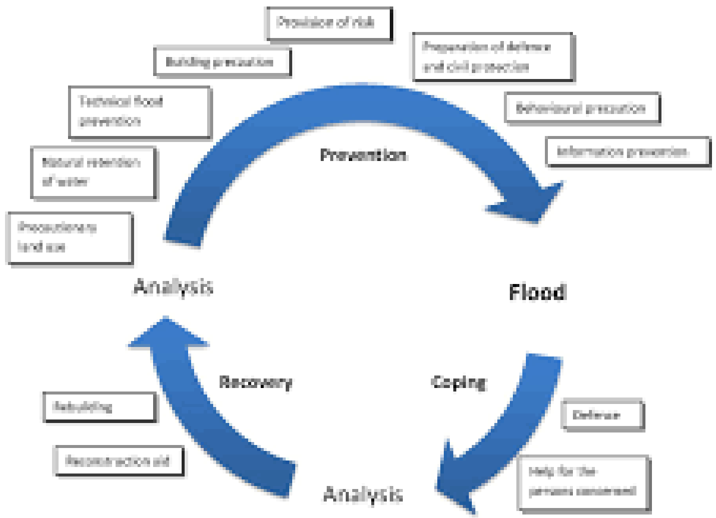
Assessment

9.1. Levels of Hazard Evaluation and Risk Assessment

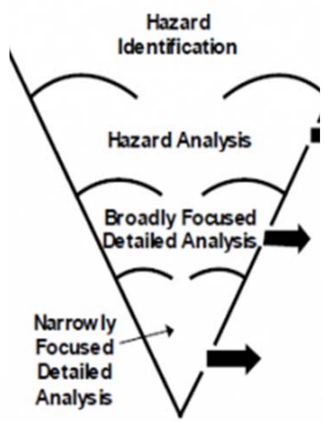


Basher 2006

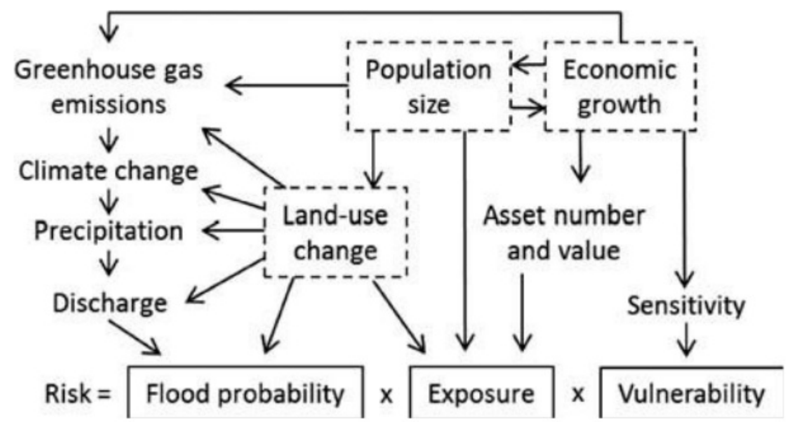
Flood risk communication is complicated



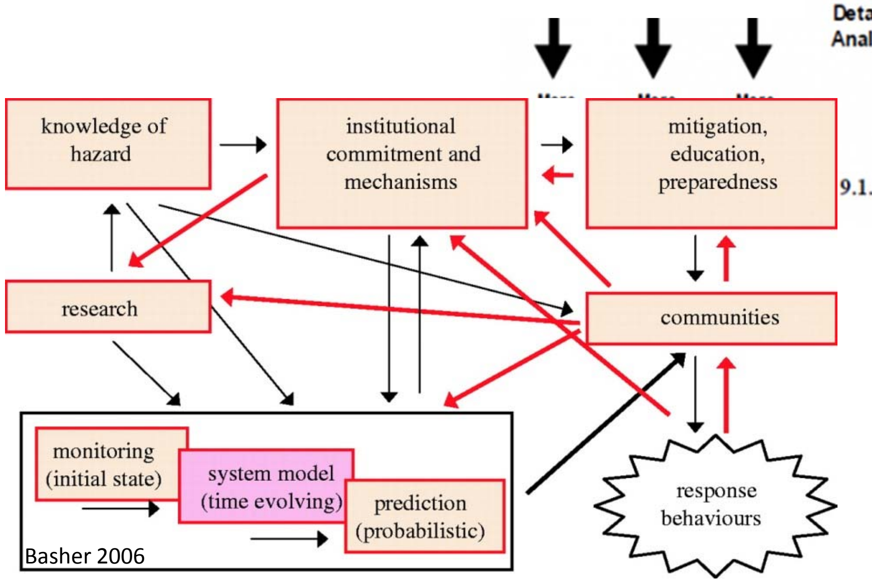
SECOM Flood Risk Management



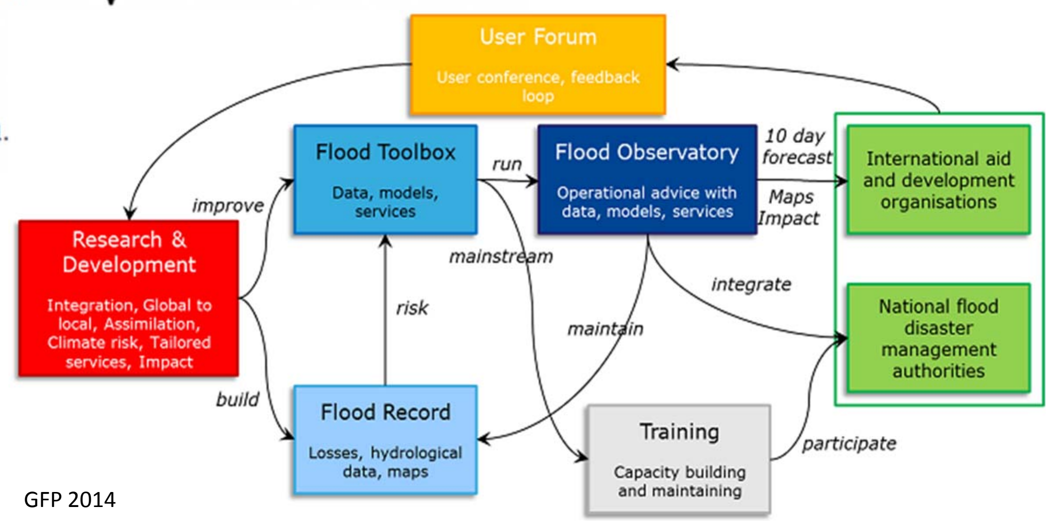
Source: Kundzewicz, Z. W.; Kanae, S.; Seneviratne, S. I.; et al., (2014) Flood risk and climate change: global and regional perspectives. Hydrol. Sci. J. 59(1), 1-28.



Assessment



Basher 2006



GFP 2014

NOTES TO USERS

This map is for use in administering the National Flood Insurance Program. It does not necessarily identify all areas subject to flooding, particularly from local drainage sources of small size. The **community map repository** should be consulted for possible updated or additional flood hazard information.

To obtain more detailed information in areas where **Base Flood Elevations** (BFEs) and/or **floodways** have been determined, users are encouraged to consult the Flood Profiles and Floodway Data and/or Summary of Stillwater Elevations tables contained within the Flood Insurance Study (FIS) Report that accompanies this FIRM. Users should be aware that BFEs shown on the FIRM represent rounded whole-foot elevations. These BFEs are intended for flood insurance rating purposes only and should not be used as the sole source of flood elevation information. Accordingly, flood elevation data presented in the FIS Report should be utilized in conjunction with the FIRM for purposes of construction and/or floodplain management.

Coastal Base Flood Elevations shown on this map apply only landward of 0.0 North American Vertical Datum of 1988 (NAVD 88). Users of this FIRM should be aware that coastal flood elevations are also provided in the Summary of Stillwater Elevations table in the Flood Insurance Study Report for this jurisdiction. Elevations shown in the Summary of Stillwater Elevations table should be used for construction and/or floodplain management purposes when they are higher than the elevations shown on this FIRM.

Boundaries of the **floodways** were computed at cross sections and interpolated between cross sections. The floodways were based on hydraulic considerations with regard to requirements of the National Flood Insurance Program. Floodway widths and other pertinent floodway data are provided in the Flood Insurance Study Report for this jurisdiction.

Certain areas not in Special Flood Hazard Areas may be protected by **flood control structures**. Refer to Section 2.4 "Flood Protection Measures" of the Flood Insurance Study Report for information on flood control structures for this jurisdiction.

The **projection** used in the preparation of this map was Universal Transverse Mercator (UTM) zone 13. The **horizontal datum** was NAD 83, GRS 1980 spheroid. Differences in datum, spheroid, projection or UTM zones used in the production of FIRMs for adjacent jurisdictions may result in slight positional differences in map features across jurisdiction boundaries. These differences do not affect the accuracy of this FIRM.

Flood elevations on this map are referenced to the North American Vertical Datum of 1988. These flood elevations must be compared to structure and ground elevations referenced to the **same vertical datum**. For information regarding conversion between the National Geodetic Vertical Datum of 1929 and the North American Vertical Datum of 1988, visit the National Geodetic Survey website at http://www.ngs.noaa.gov or contact the National Geodetic Survey at the following address:

NGS Information Services
NOAA, N/NGS12
National Geodetic Survey
SSMC-3, #9202
1315 East-West Highway
Silver Spring, Maryland 20910-3282
(301) 713-3242

To obtain current elevation, description, and/or location information for **bench marks** shown on this map, please contact the Information Services Branch of the National Geodetic Survey at **(301) 713-3242**, or visit its website at http://www.ngs.noaa.gov.

Base map information shown on this FIRM was provided by the FEMA Map Service Center and the Boulder Area Spatial Data Cooperative (BASIC). Additional input was provided by the Town of Erie and the City of Longmont. These data are current as of 2004.

This map reflects more detailed and up-to-date **stream channel configurations** than those shown on the previous FIRM for this jurisdiction. The floodplains and floodways that were transferred from the previous FIRM may have been adjusted to conform to these new stream channel configurations. As a result, the Flood Profiles and Floodway Data tables for multiple streams in the Flood Insurance Study Report (which contains authoritative hydraulic data) may reflect stream channel distances that differ from what is shown on this map.

Corporate limits shown on this map are based on the best data available at the time of publication. Because changes due to annexations or de-annexations may have occurred after this map was published, map users should contact appropriate community officials to verify current corporate limit locations.

Please refer to the separately printed **Map Index** for an overview map of the county showing the layout of map panels; community map repository addresses; and a Listing of Communities table containing National Flood Insurance Program dates for each community as well as a listing of the panels on which each community is located.

For information on available products associated with this FIRM visit the **Map Service Center (MSC)** website at http://msc.fema.gov. Available products may include previously issued Letters of Map Change, a Flood Insurance Study Report, and/or digital versions of this map. Many of these products can be ordered or obtained directly from the MSC website.

If you have **questions about this map**, how to order products, or the National Flood Insurance Program in general, please call the **FEMA Map Information eXchange (FMIX)** at **1-877-FEMA-MAP** (1-877-336-2627) or visit the FEMA website at http://www.fema.gov/business/nfip.

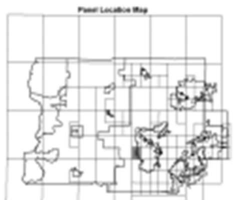
Provisionally Accredited Levee Notes to Users: Check with your local community to obtain more information, such as the estimated level of protection provided (which may exceed the 1-percent-annual-chance level) and Emergency Action Plan, on the levee system(s) shown as providing protection for areas on this panel. To maintain accreditation, the levee owner or community is required to submit the data and documentation necessary to comply with Section 65.10 of the NFIP regulation by September 23, 2011. If the community or owner does not provide the necessary data and documentation or if the data and documentation provided indicate the levee system does not comply with Section 65.10 requirements, FEMA will revise the flood hazard and risk information for this area to reflect de-accreditation of the levee system. To mitigate flood risk in residual risk areas, property owners and residents are encouraged to consider flood insurance and floodproofing or other protective measures. For more information on flood insurance, interested parties should visit the FEMA Website at http://fema.gov/business/nfip/index.shtm.

Boulder County Vertical Datum Offset Table

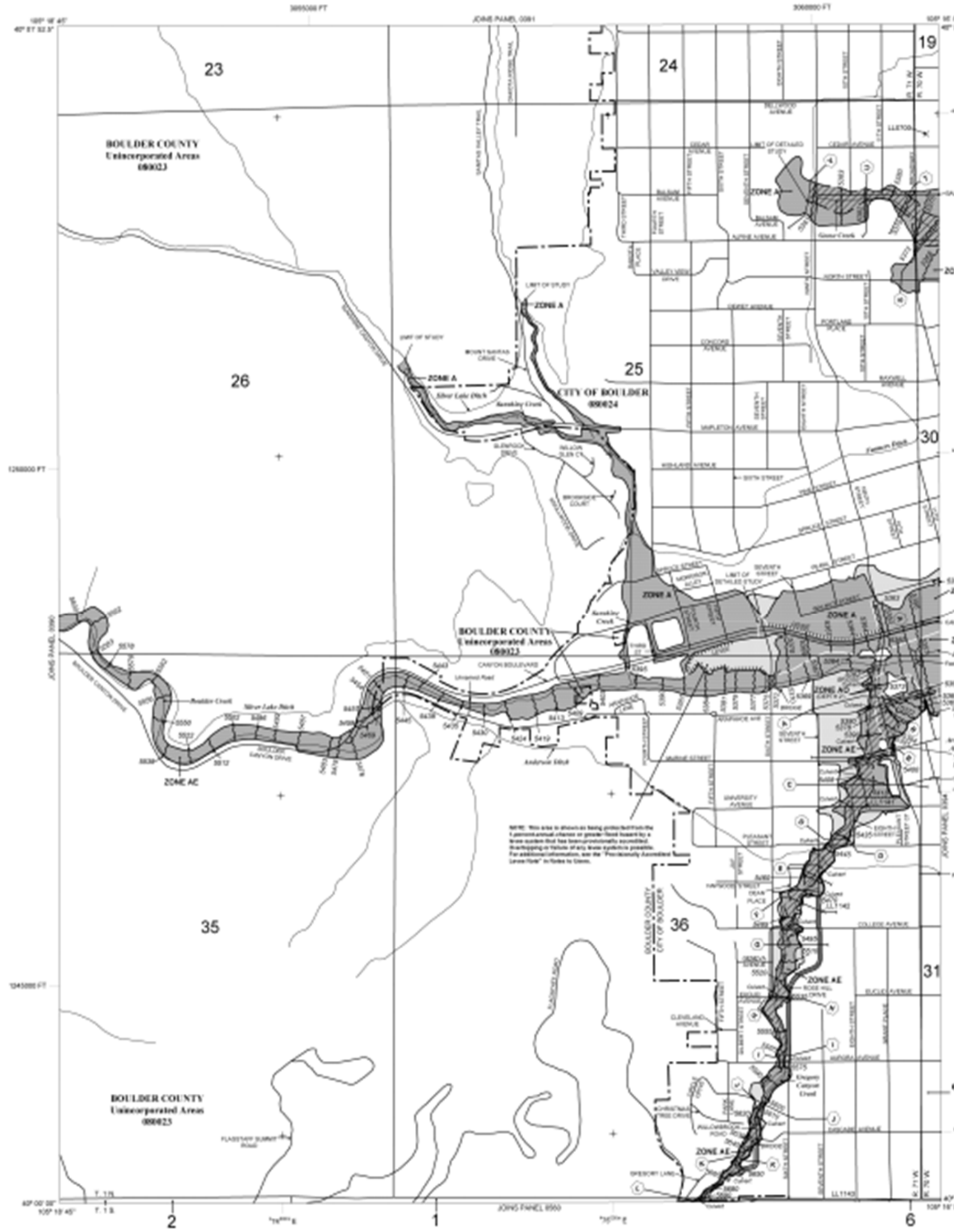
Flooding Source	Vertical Datum Offset (ft)	Flooding Source	Vertical Datum Offset (ft)
Goose Creek	3.3	Canyon Boulevard Overflow	3.3
Boulder Creek	4.2		

Example: To convert Goose Creek elevations to NAVD 88, 3.3 feet were added to the NGVD 29 elevations.

Panel Location Map



This digital Flood Insurance Rate Map (FIRM) was produced through a cooperative partnership between the State of Colorado Water Conservation Board, the Urban Drainage and Flood Control District and the Federal Emergency Management Agency (FEMA).



LEGEND

SPECIAL FLOOD HAZARD AREAS (SFHAs) SUBJECT TO INUNDATION BY THE 1% ANNUAL CHANCE FLOOD

ZONE A
ZONE AE
ZONE AH
ZONE AO
ZONE AR
ZONE A99
ZONE V
ZONE VE

FLOODWAY AREAS IN ZONE AE

OTHER FLOOD AREAS

ZONE X

OTHER AREAS

ZONE X
ZONE D

COASTAL BARRIER RESOURCES SYSTEM (CBRS) AREAS

OTHERWISE PROTECTED AREAS (OPAs)

MAP SCALE 1" = 500'

PANEL 0393J

FIRM

FLOOD INSURANCE RATE MAP

BOULDER COUNTY, COLORADO AND INCORPORATED AREAS

PANEL 393 OF 615

(SEE MAP INDEX FOR FIRM PANEL LAYOUT)

COMMUNITY	NUMBER	PANEL	SUFFIX
BOULDER, CITY OF	080024	0393	J
BOULDER COUNTY	080023	0393	J

Notice to User: The **Map Number** shown below should be used when placing map orders; the **Community Number** shown above should be used on insurance applications for the subject community.

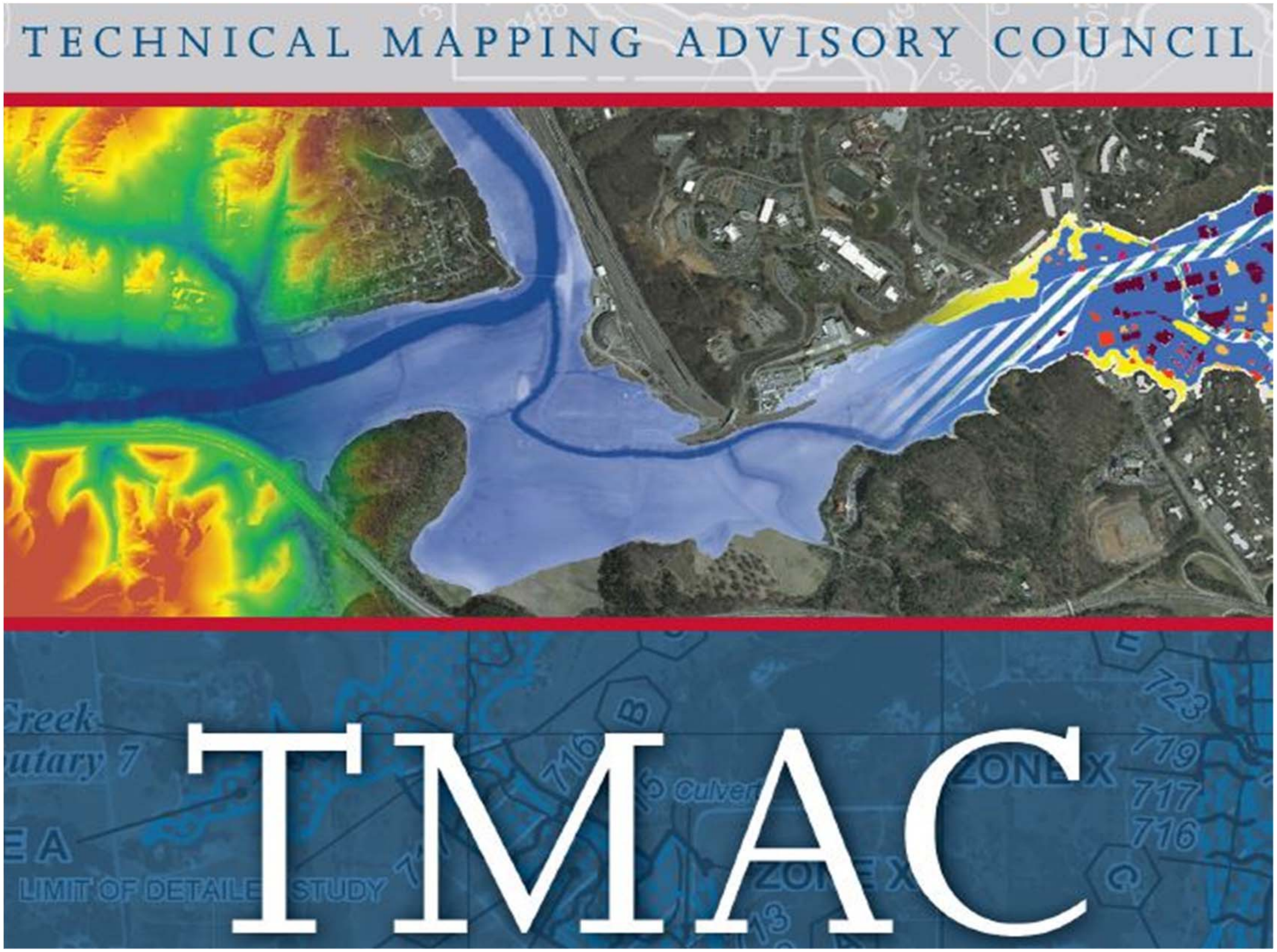
MAP NUMBER
08013C0393J

MAP REVISED
DECEMBER 18, 2012

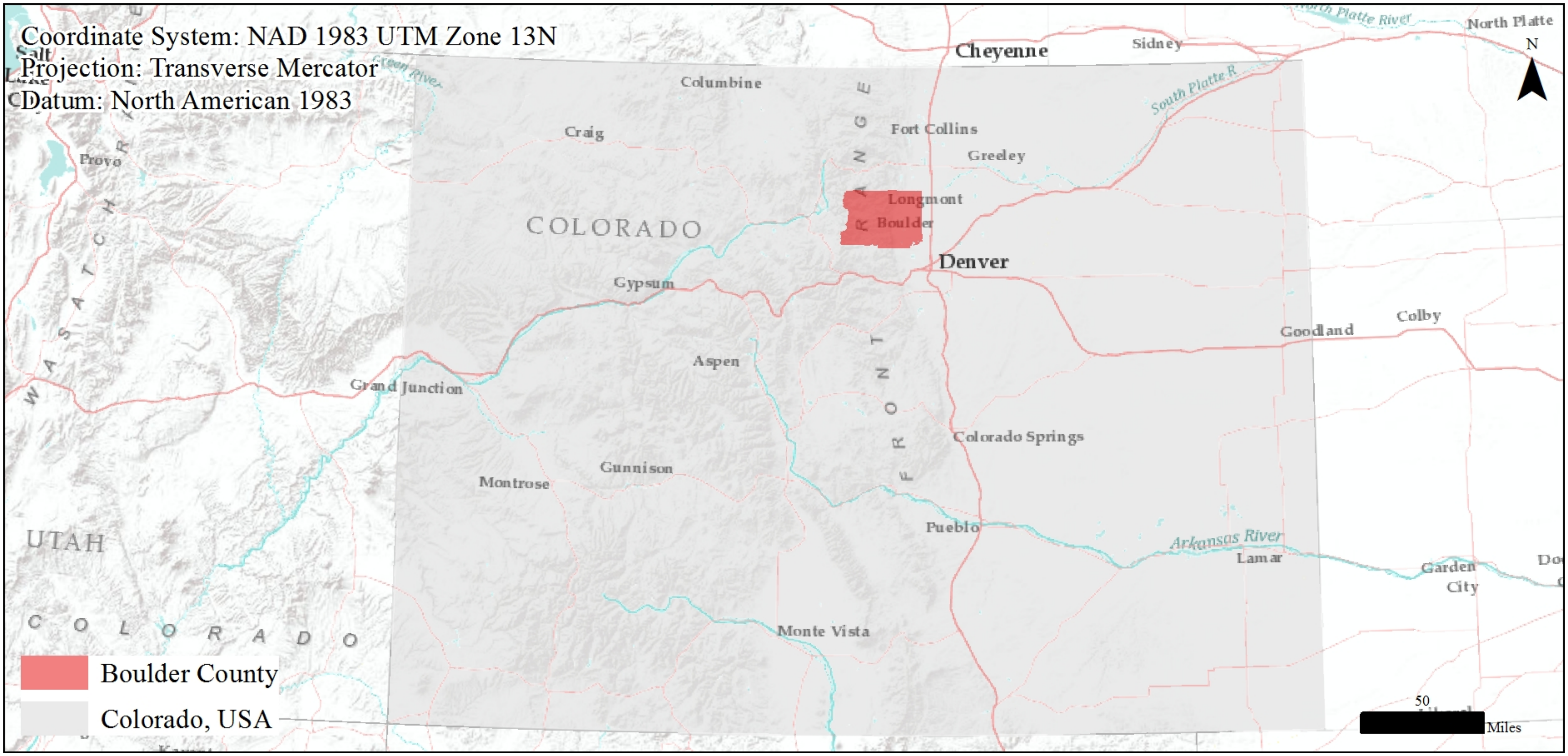
Federal Emergency Management Agency

NATIONAL FLOOD INSURANCE PROGRAM

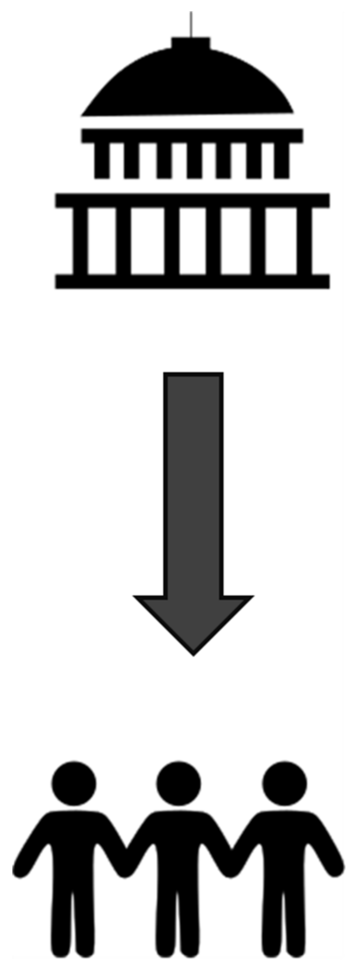
More detailed information



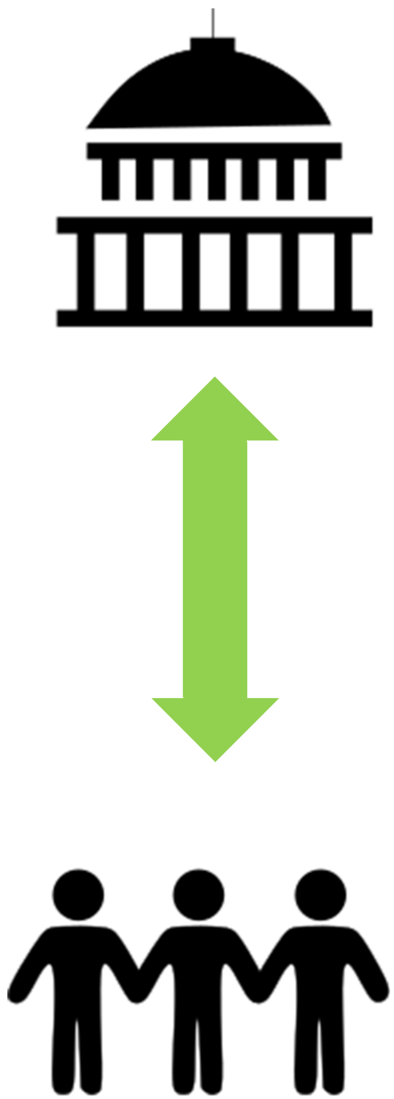
Case Study Location



Top-down, one-way flow of information



Two-way flow of information



Meyer's et. al (2012)

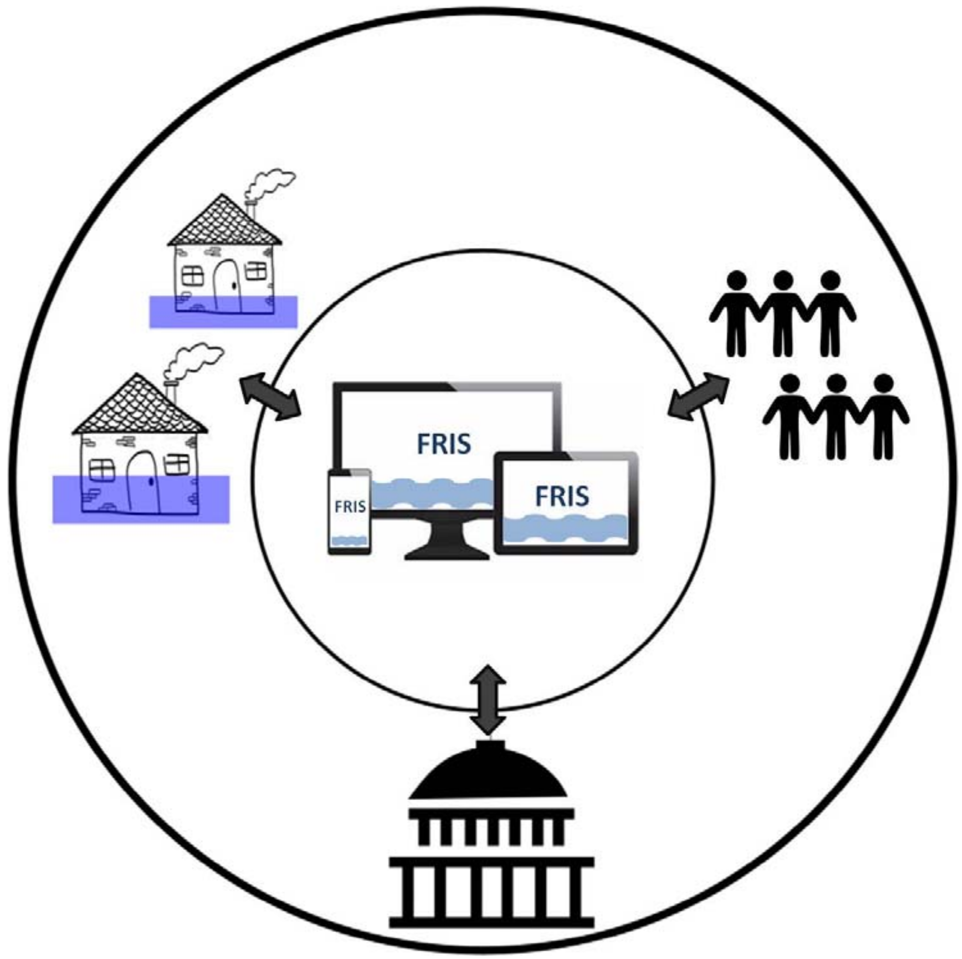
My Project

- Investigated the application of Geographic Information Science (GIS) to flood risk communication through a pilot project in Boulder County, Colorado

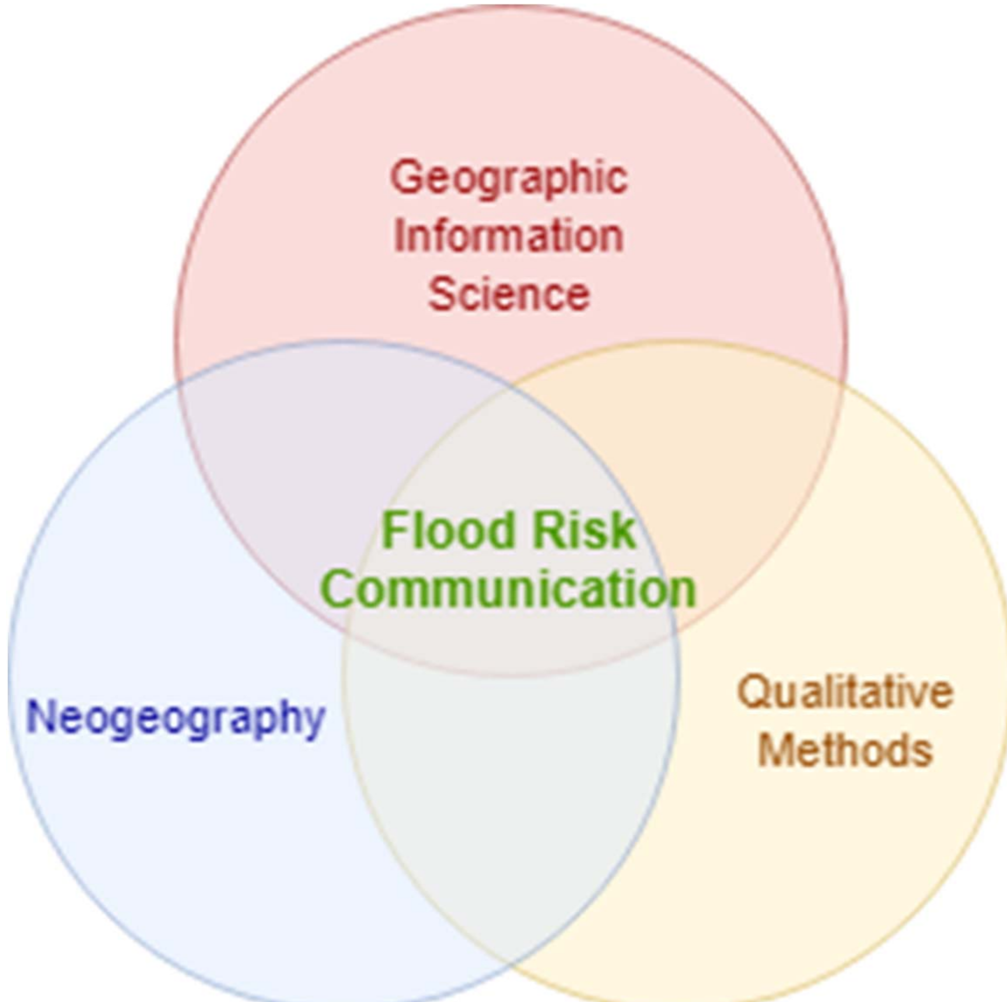
- Explored stakeholders’ preferences in flood risk communication

- Proposed novel products and data layers

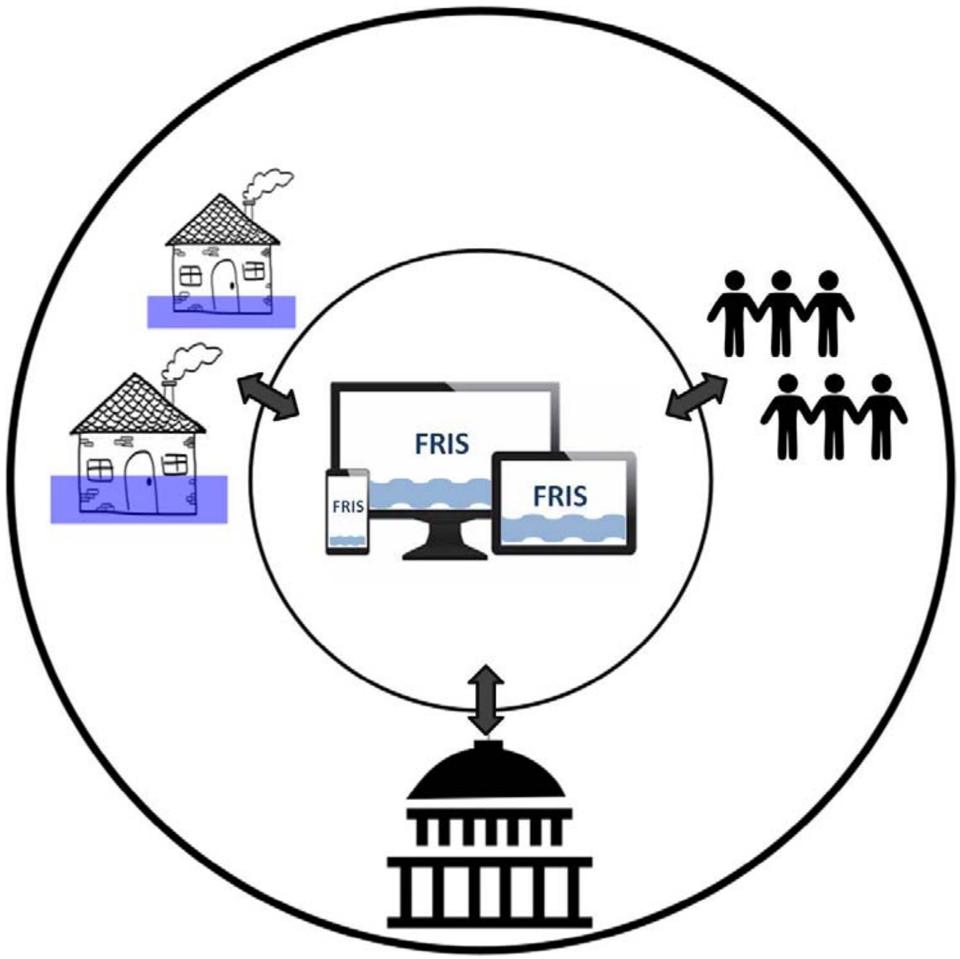
Proof-of-concept
New communication tool
Flood Risk Information System



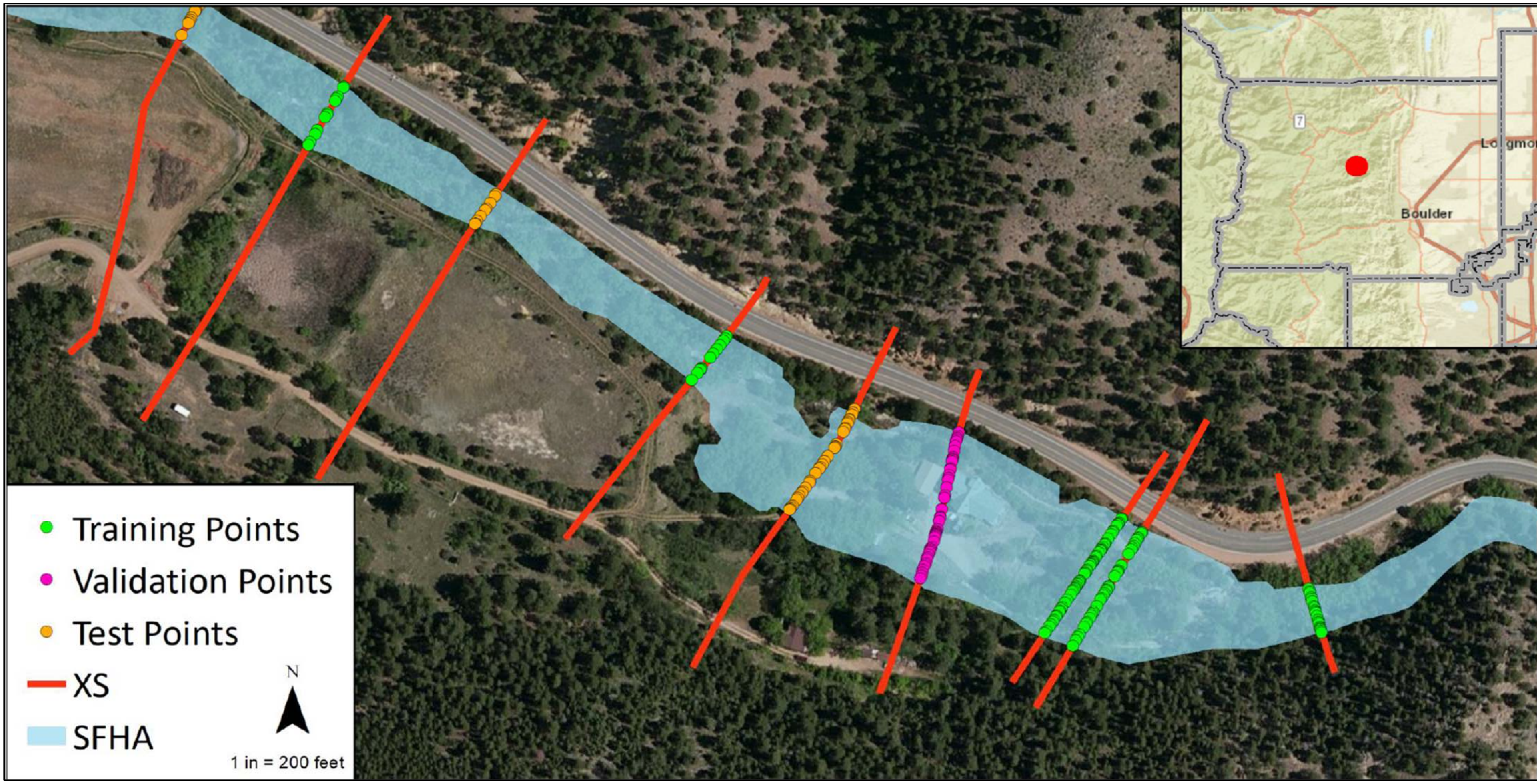
Theoretical framework



Structure-specific data

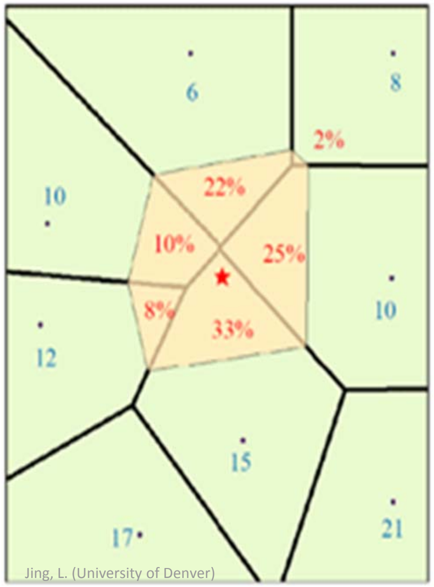


Public Data

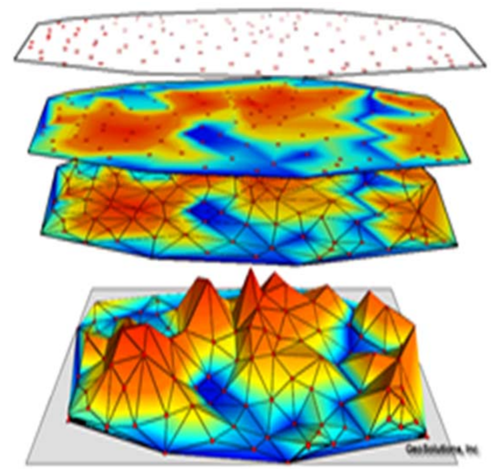


Training Points
Validation Points
Test Points
XS
SFHA
N
1 in = 200 feet
Boulder

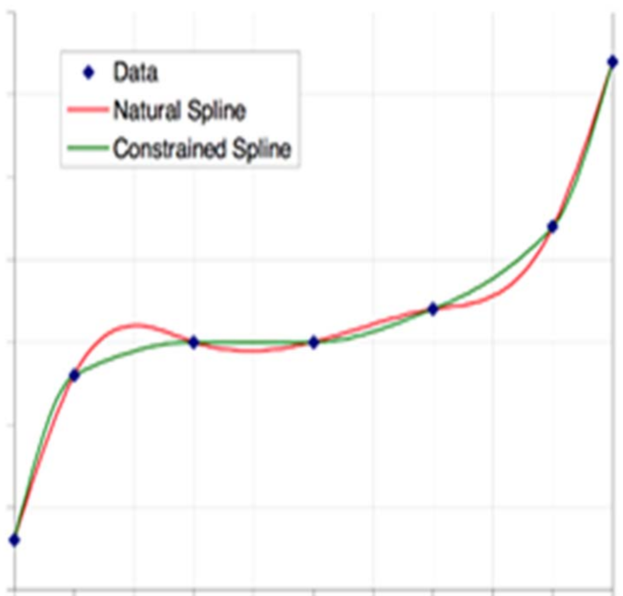
Natural Neighbor



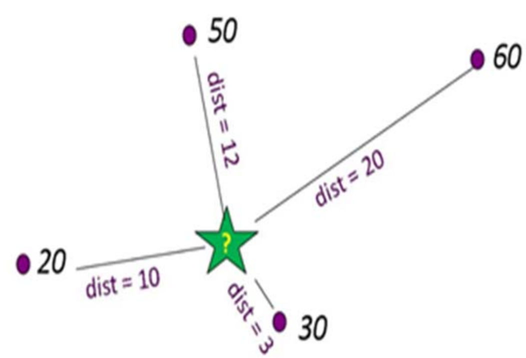
Triangular Irregular Networks (TIN)



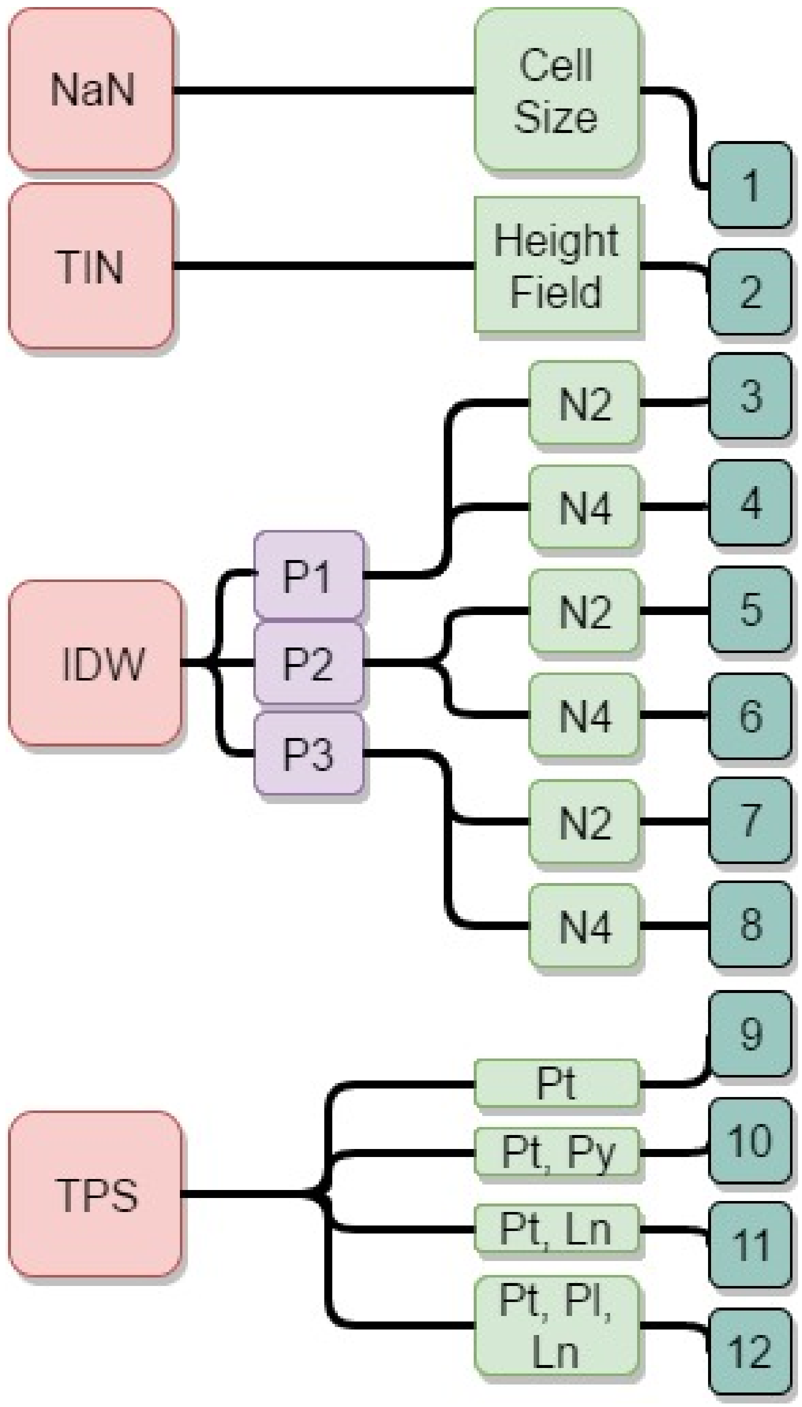
Topo to Raster



Inverse Distance Weighted (IDW)



August P., Wang Y (Coastal Institute in Kingston)



<u>Parameters</u>

Power (P)

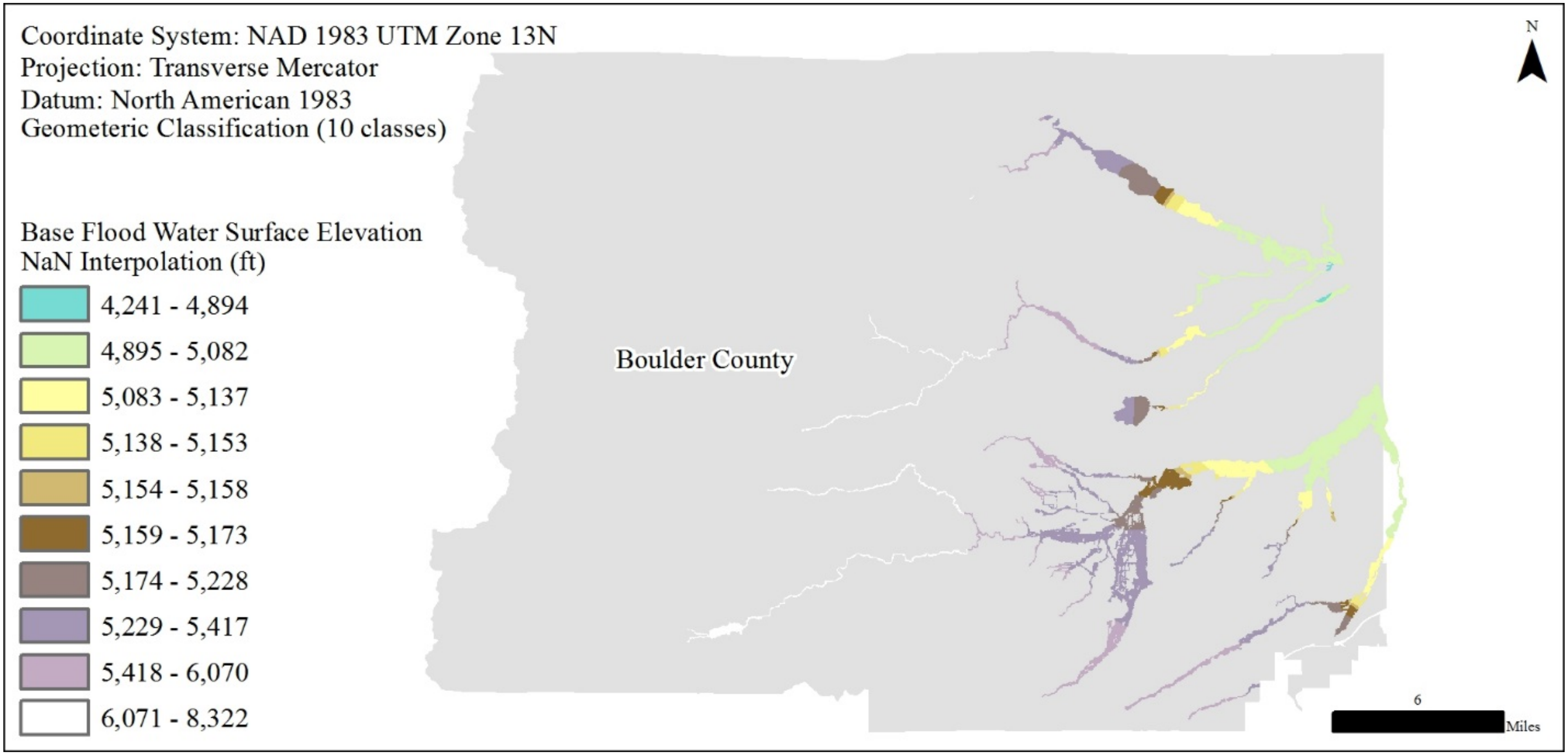
Number of points/search radius (N)

Point input (Pt)

Line input (Ln)

Polygon input (Py)

Output	Goodness of Fit	Error	
Validation			
	R^2	RMSE	MRE
NaN	0.9999	6.013	0.0018
TIN	0.9999	6.231	0.0019
IDW 3	0.9995	11.462	0.0034
IDW 4	0.9995	11.355	0.0034
IDW 5	0.9995	11.461	0.0034
IDW 6	0.9995	11.350	0.0034
IDW 7	0.9995	11.461	0.0034
IDW 8	0.9995	11.349	0.0034
TPS 9	0.9998	6.746	0.0020
TPS 10	0.9998	7.039	0.0021
TPS 11	0.9998	6.694	0.0020
TPS 12	0.9998	6.677	0.0020
Test			
	R^2	RMSE	MRE
NaN	0.9999	6.260	0.0019


Coordinate System: NAD 1983 UTM Zone 13N
Projection: Transverse Mercator
Datum: North American 1983
Geometeric Classification (10 classes)
Base Flood Water Surface Elevation
NaN Interpolation (ft)
4,241 - 4,894
4,895 - 5,082
5,083 - 5,137
5,138 - 5,153
5,154 - 5,158
5,159 - 5,173
5,174 - 5,228
5,229 - 5,417
5,418 - 6,070
6,071 - 8,322
Boulder County
N
6
Miles

5 ft Flood Depth

$80,0000 Damage

3 ft Flood Depth

$40,0000 Damage

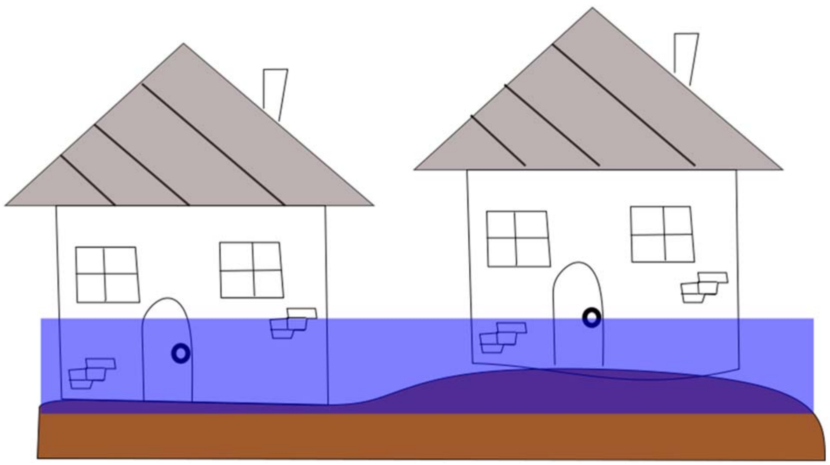
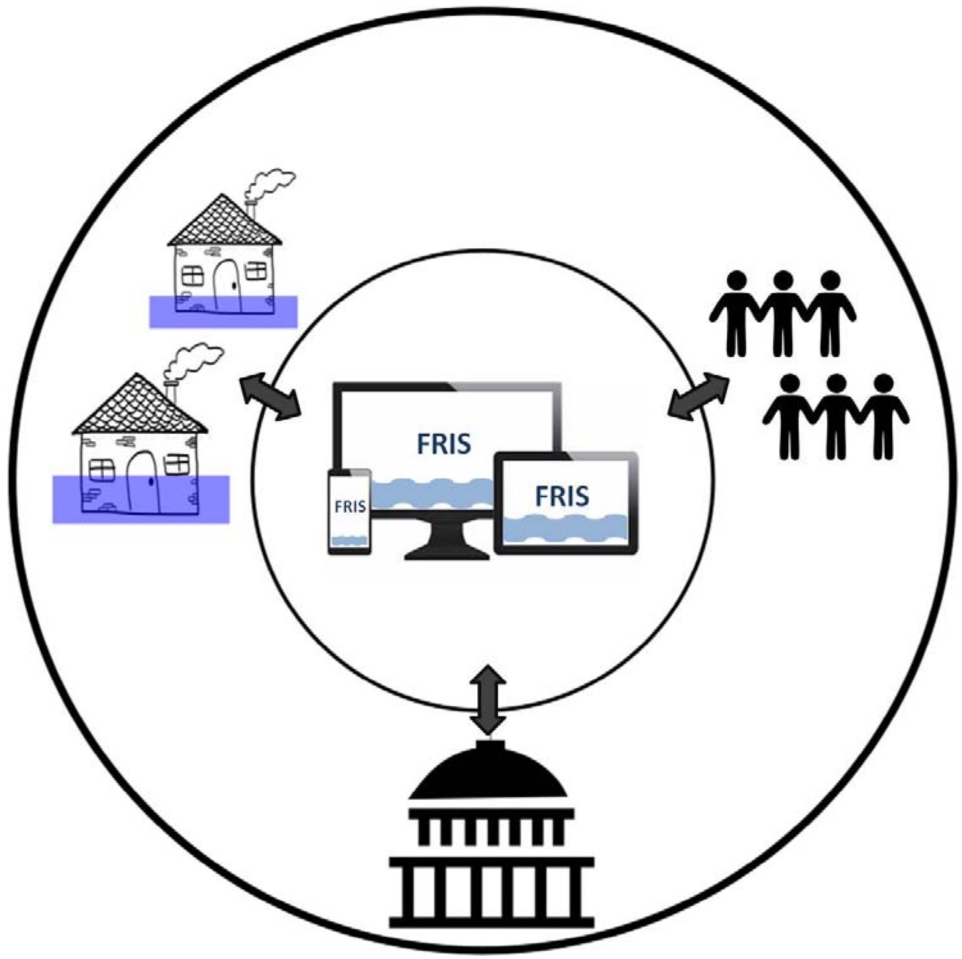


Table 2 **Structure** **Two or More Stories, With Basement**		
Depth	Mean of Damage	Standard Deviation of Damage
-8	1.7%	2.70
-7	1.7%	2.70
-6	1.9%	2.11
-5	2.9%	1.80
-4	4.7%	1.66
-3	7.2%	1.56
-2	10.2%	1.47
-1	13.9%	1.37
0	17.9%	1.32
1	22.3%	1.35
2	27.0%	1.50
3	31.9%	1.75
4	36.9%	2.04
5	41.9%	2.34
6	46.9%	2.63
7	51.8%	2.89
8	56.4%	3.13
9	60.8%	3.38
10	64.8%	3.71
11	68.4%	4.22
12	71.4%	5.02
13	73.7%	6.19
14	75.4%	7.79
15	76.4%	9.84
16	76.4%	12.36

US Army Corps Eng (EGM) 04-01 2003

Local Knowledge



Local Knowledge

Focus Groups:

- **Community Planners**: members/employees of the local, state, federal, or provate organizations
- **Community Members:** homeowners and renters in Boulder County

Event Tasks:

- Pre-survey
- Guided Group Discussion
- Post-survey

Community Members	**n=8**
Average Year Born	1957
Hispanic	100% - No
Race	100% - White
Gender	5 Female : 3 Male
Residence	100 % - Own Home
Time at current residence	<= 1 yr one: 2-4 yr two: 5-9 yr one: **>=10 four**
Current primary residence in a flood zone	*Response:* 1 Unsure: 4 No: 3 Yes *Reality:* 2 No : 6 Yes
Have you experienced a flooding event	100 % - Yes, personally

Focus Groups:

- **Community Planners**: members/employees of the local, state, federal, or provate organizations

Community Planners	n=8
Organization Type	LOCAL - 5 STATE - 1 FEDERAL - 1 PRIVATE - 1

- **Community Members:** homeowners and renters in Boulder County

Community Members	n=8
Average Year Born	1957
Hispanic	100% - No
Race	100% - White
Gender	5 Female : 3 Male
Residence	100 % - Own Home

Event Tasks:

- Pre-survey
- Guided Group Discussion
- Post-survey

Comparison of Static/Dynamic Product Formats				
Theme	**FG1**	**FG2**	**Total**	**Events**
Web map has more data/basemap provides context	**7**	**4**	**11**	**5**
Web map is interactive	**4**	**3**	**7**	**5**
Web map has color	1	3	4	4
Web map starts conversation	2	1	3	3
Web map is simple/understandable	1	1	2	2
Web map is more accessible	-	2	2	2
Static map is simple/understandable	**4**	**-**	**4**	**2**
Static map is more accessible	**1**	**3**	**4**	**3**
Static map has more data	2		2	2
Static map is more trustworthy	1	-	1	1

What are the pros and cons of structure-specific data?

Structure-Specific Data				
Theme	**FG1**	**FG2**	**Total**	**Events**
Provides more detailed risk info	**7**	**4**	**11**	**6**
Starts engagement	**2**	**1**	**3**	**3**
Simple/clear	2	-	2	2
Information is confusing	**3**	**3**	**6**	**5**
Provides too much info	**1**	**1**	**2**	**2**
Information not useful	-	2	2	2
A more general tool preferred	-	3	3	1

What are the pros and cons of incorporating local knowledge?

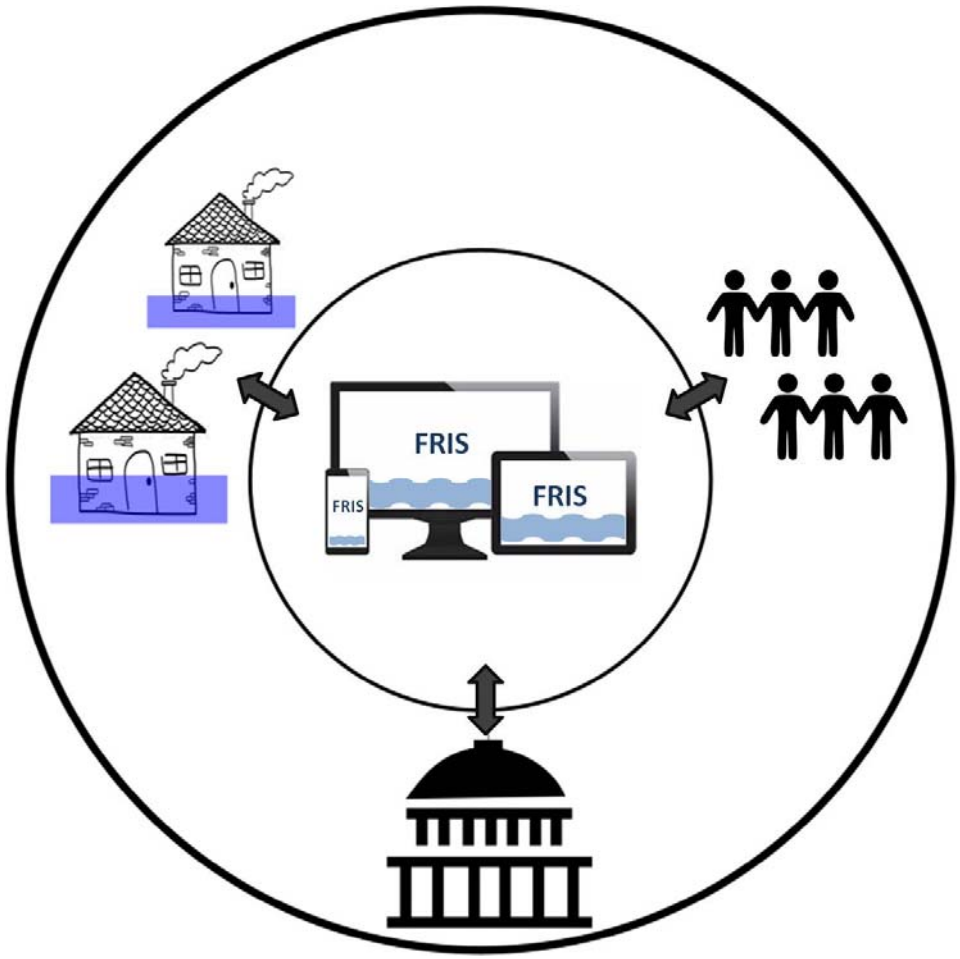
Local Knowledge				
Theme	**FG1**	**FG2**	**Total**	**Events**
Helpful format	**3**	**11**	**14**	**6**
Allows for contribution	**5**	**1**	**6**	**4**
Useful for mapping/other efforts	5	-	5	3
Impacts people quickly	2	1	3	3
Starts engagement	2	1	3	3
Provides too much information	**1**	**4**	**5**	**3**
Information purpose is confusing	**2**	**1**	**3**	**2**
Dislike data management requirement	2	-	2	1

What are the pros and cons of incorporating local knowledge?

Local Knowledge				
Theme	**FG1**	**FG2**	**Total**	**Events**
Helpful format	**3**	**11**	**14**	**6**
Allows for contribution	**5**	**1**	**6**	**4**
Useful for mapping/other efforts	5	-	5	3
Impacts people quickly	2	1	3	3
Starts engagement	2	1	3	3

What additional information or data would you like included in the FRIS?

Other Data/Information For FRIS				
Theme	**FG1**	**FG2**	**Total**	**Events**
Background, statistics, and information on flooding	**5**	**5**	**10**	**4**
Action information for during an event	**2**	**3**	**5**	**3**
Live flood data and warnings	**4**	**1**	**5**	**3**
Information for other types of local hazards	3	1	4	3
Information to protect/improve home	2	1	3	3
Characteristic of community relating to flooding and communication	2	1	3	2
Outreach information	-	2	2	2
Local insurance information	1	-	1	1


FRIS
FRIS
FRIS

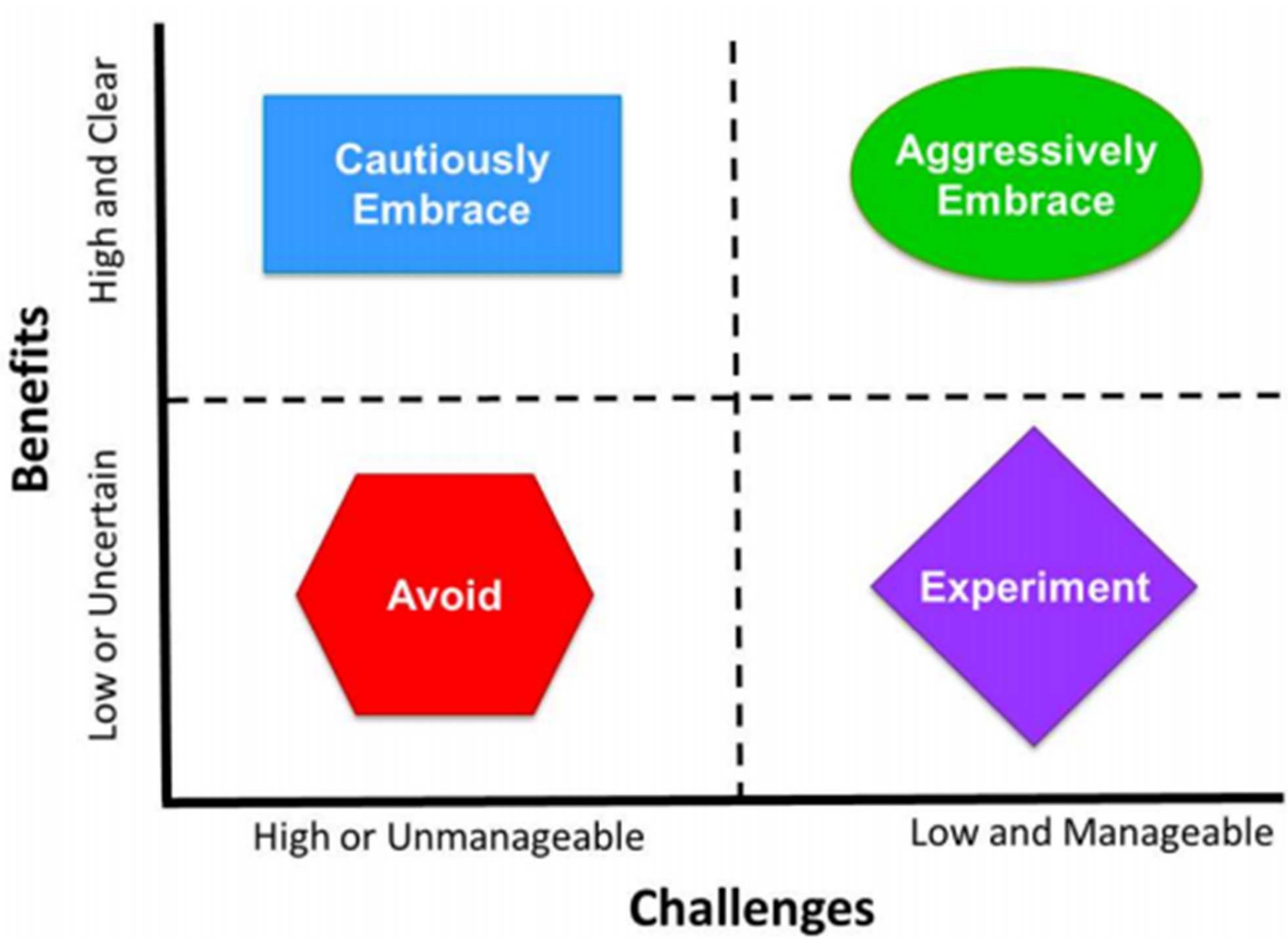
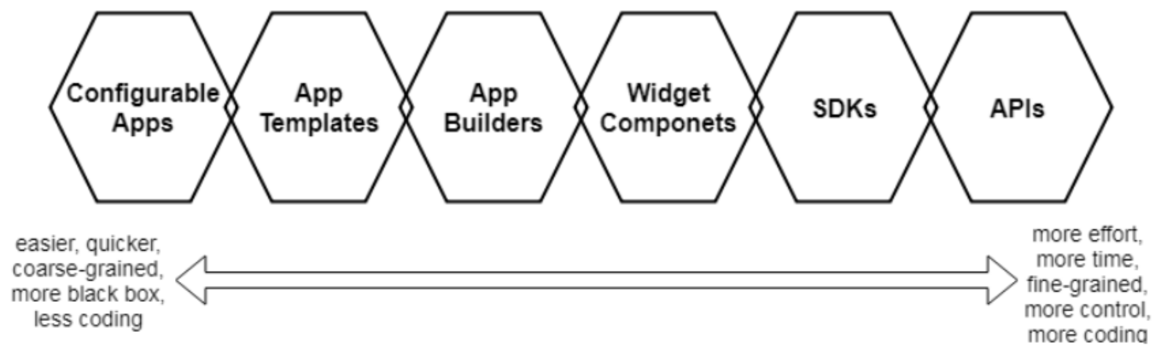
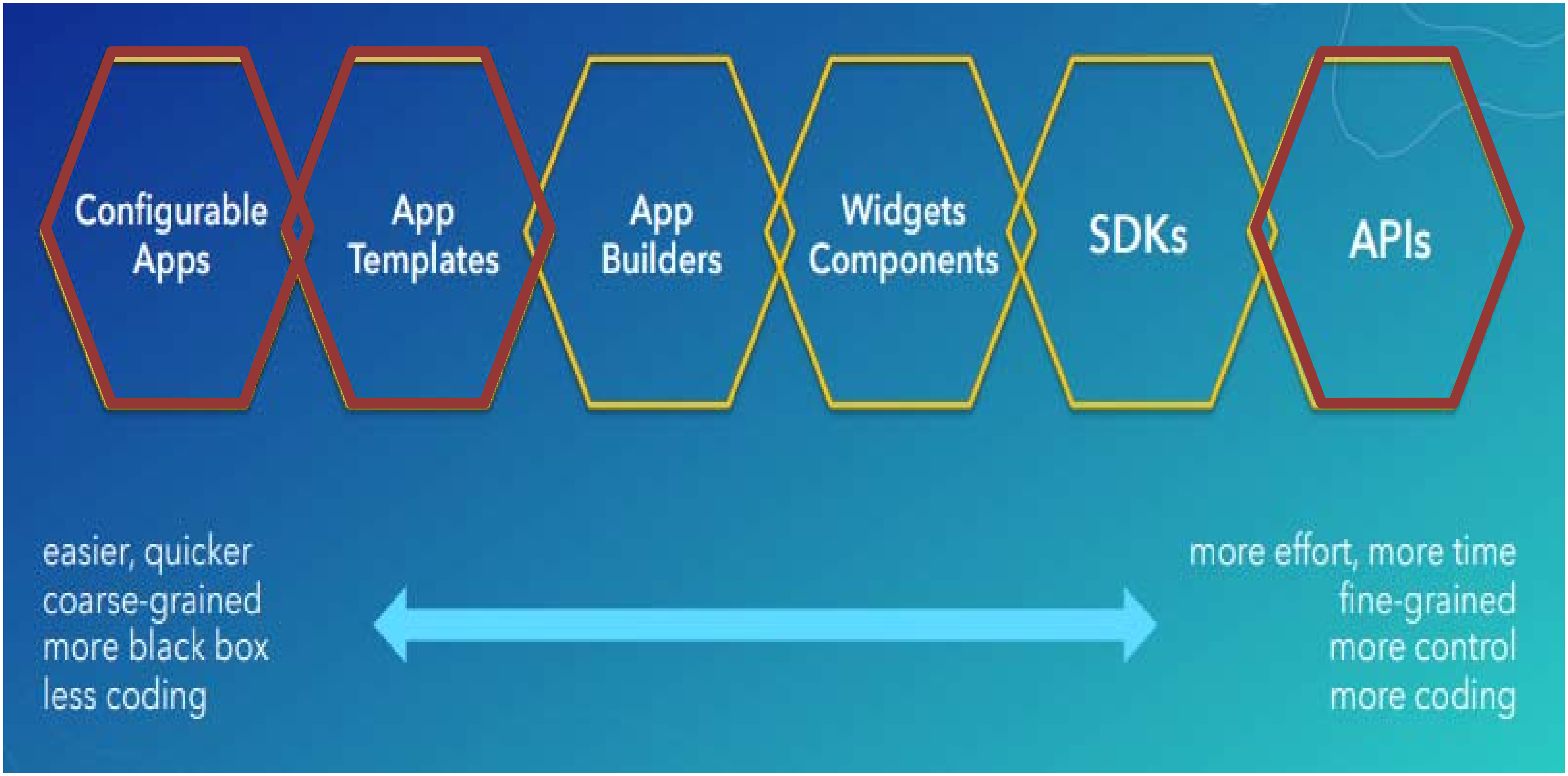


Figure 9: Project prioritization matrix evaluating benefits and challenges (Esri 2018)

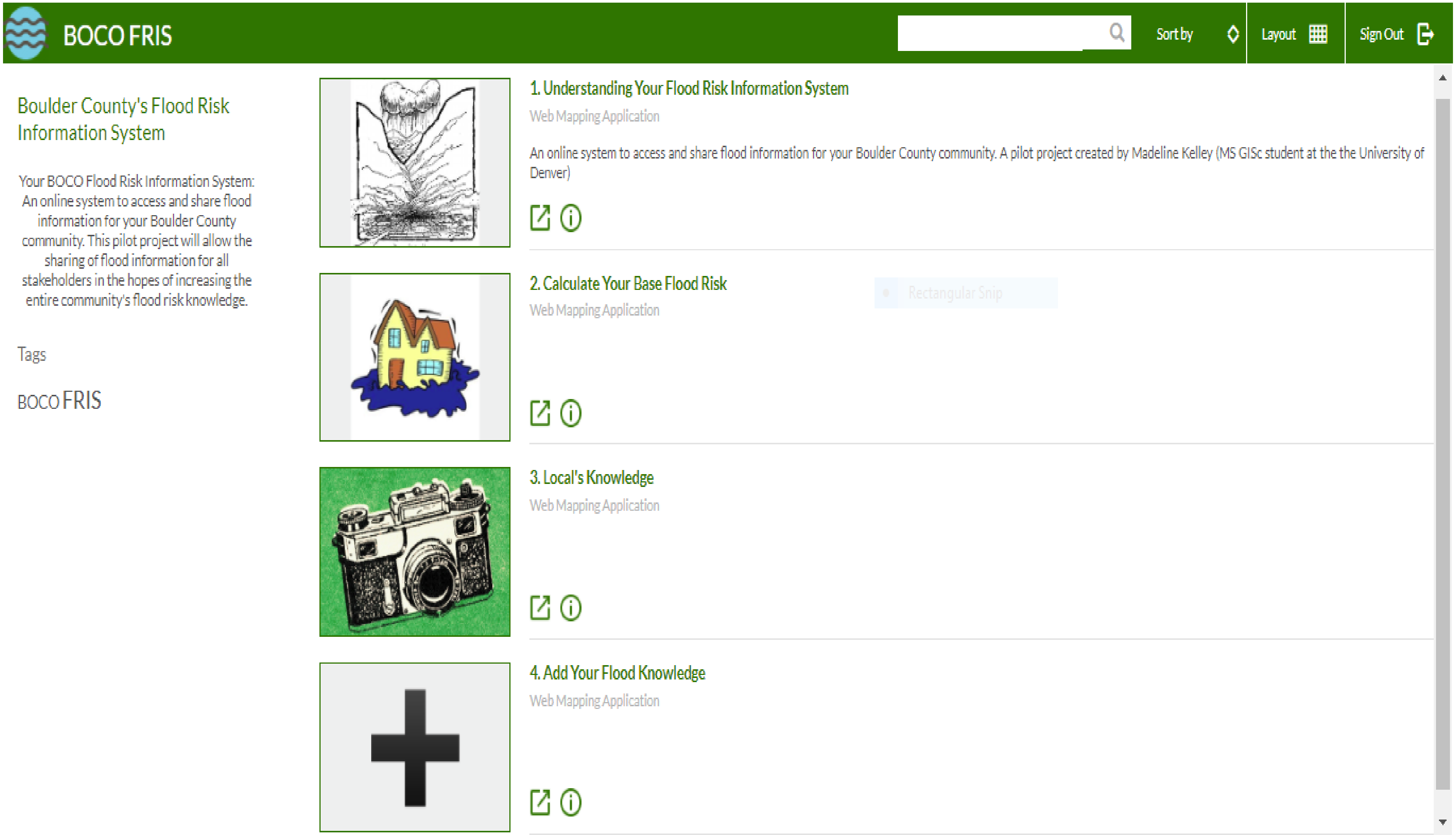
App Name	Description
FRIS App	An App of Apps. Organizes and displays other four applications
Understand Your Flood Risk Information System	A story map that provides background information on flooding and Boulder County
Calculate Your Base Flood Risk	Provides users with depth and cost estimates for structures
Local's Knowledge	Displays VGI and NFHL layers together
Add Your Flood Knowledge	Allows users to actively contribute to VGI layer





Configurable Apps
App Templates
App Builders
Widgets Components
SDKs
APIs
easier, quicker
coarse-grained
more black box
less coding
more effort, more time
fine-grained
more control
more coding

https://tinyurl.com/FRIS-CASFM




Cascade Builder
Cover
Flood Language
FEMA Terms
FRIS Elements
Organize
Understanding and Exploring Your Flood Risk Information System
An online system to access and share flood information for your Boulder County community. This pilot project allows the sharing of flood information for community stakeholders. Our hope is to increase the entire community's flood risk knowledge so appropriate, preventive action can be taken.

[redacted]

Online Community Flood Risk Products and Data

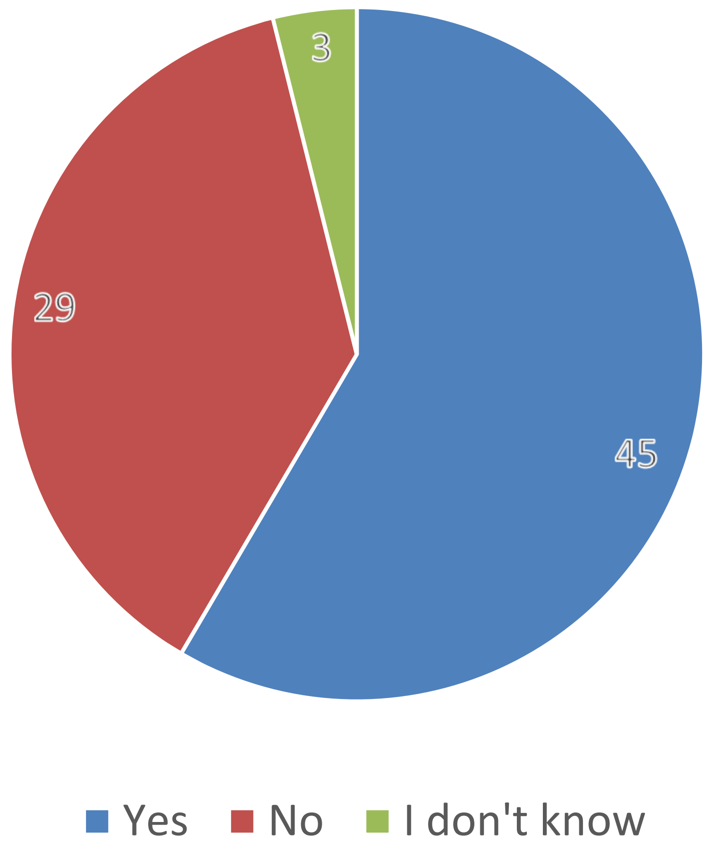
Electronic survey

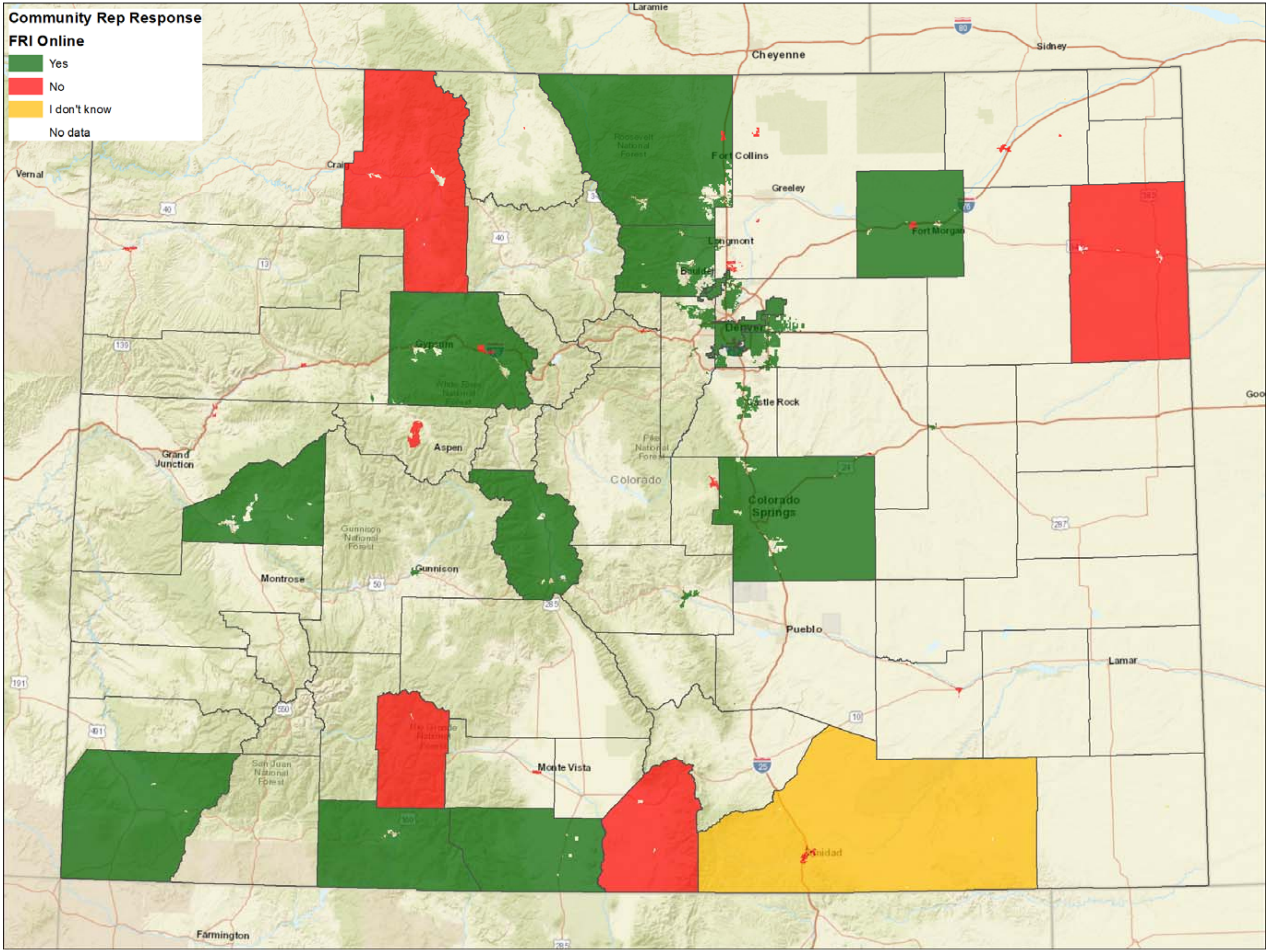
5 questions

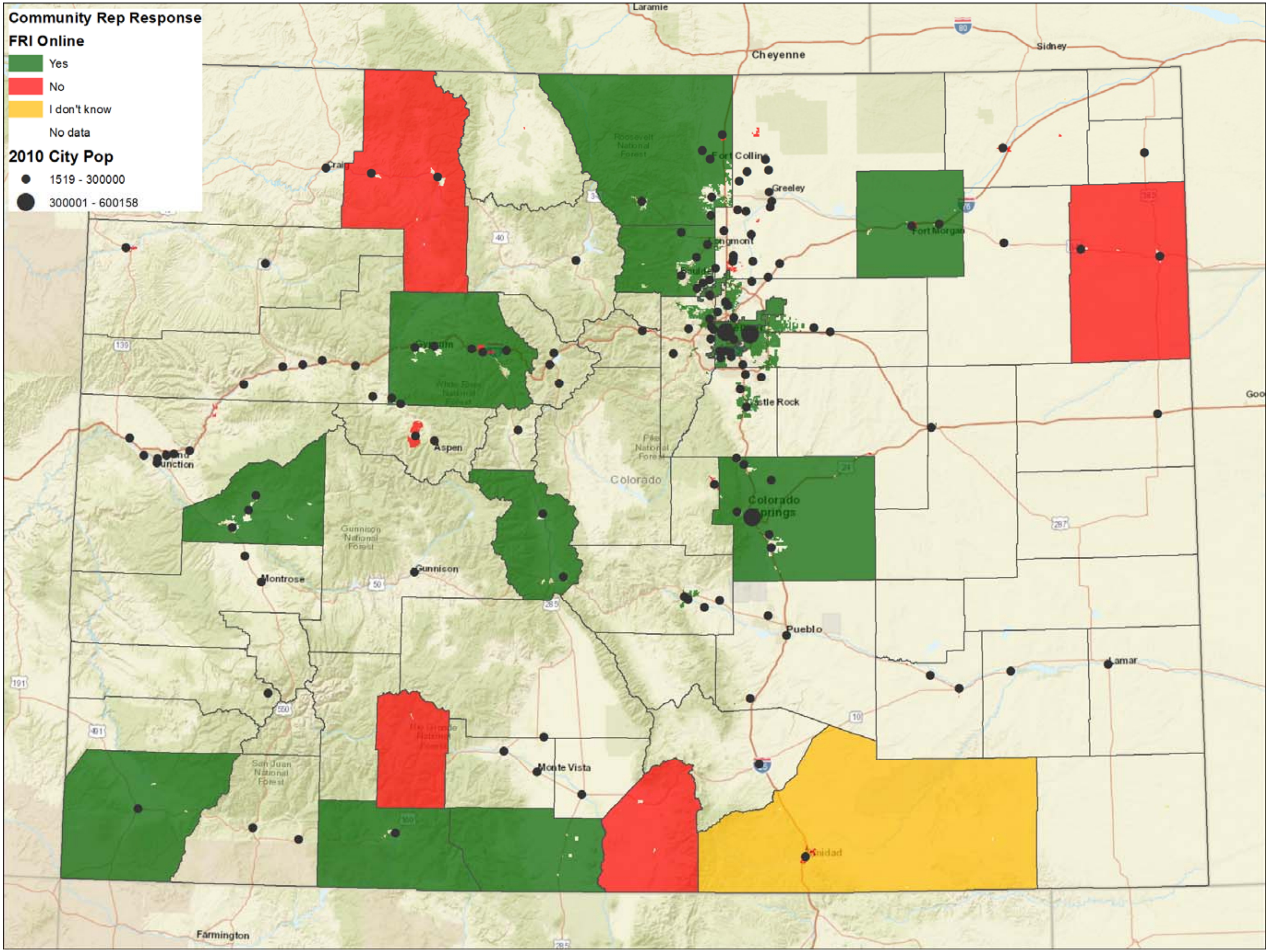
77 responses

65 different communities

Does your community have flood risk information available online?



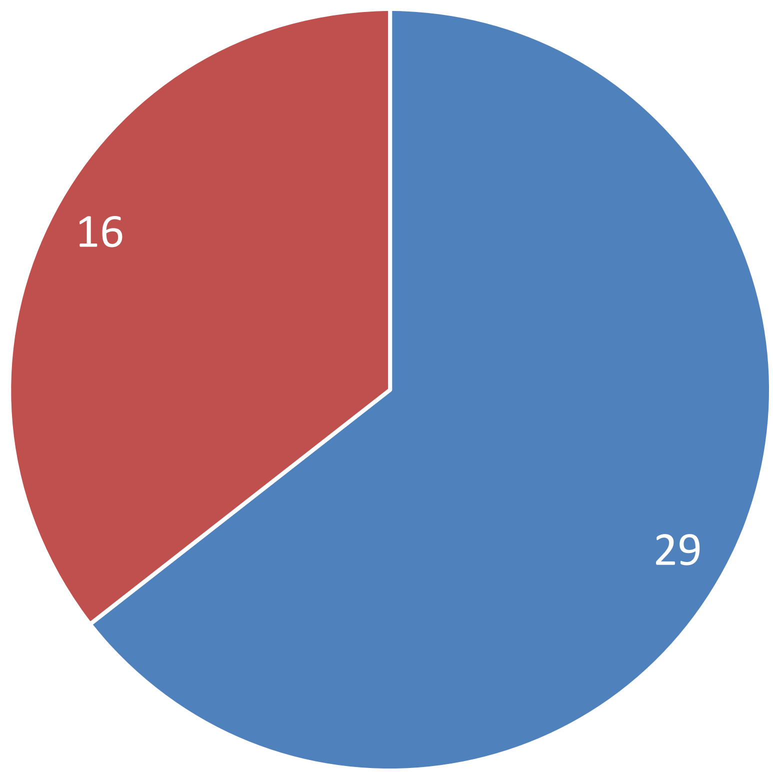

Community Rep Response
FRI Online
Yes
No
I don't know
No data
Laramie
Cheyenne
Sidney
Vernal
Craig
Fort Collins
Greeley
Longmont
Boulder
Fort Morgan
Denver
Gypsum
Castle Rock
Aspen
Grand Junction
Colorado
Colorado Springs
Gunnison
Montrose
Pueblo
Lamar
Monte Vista
Trinidad
Farmington

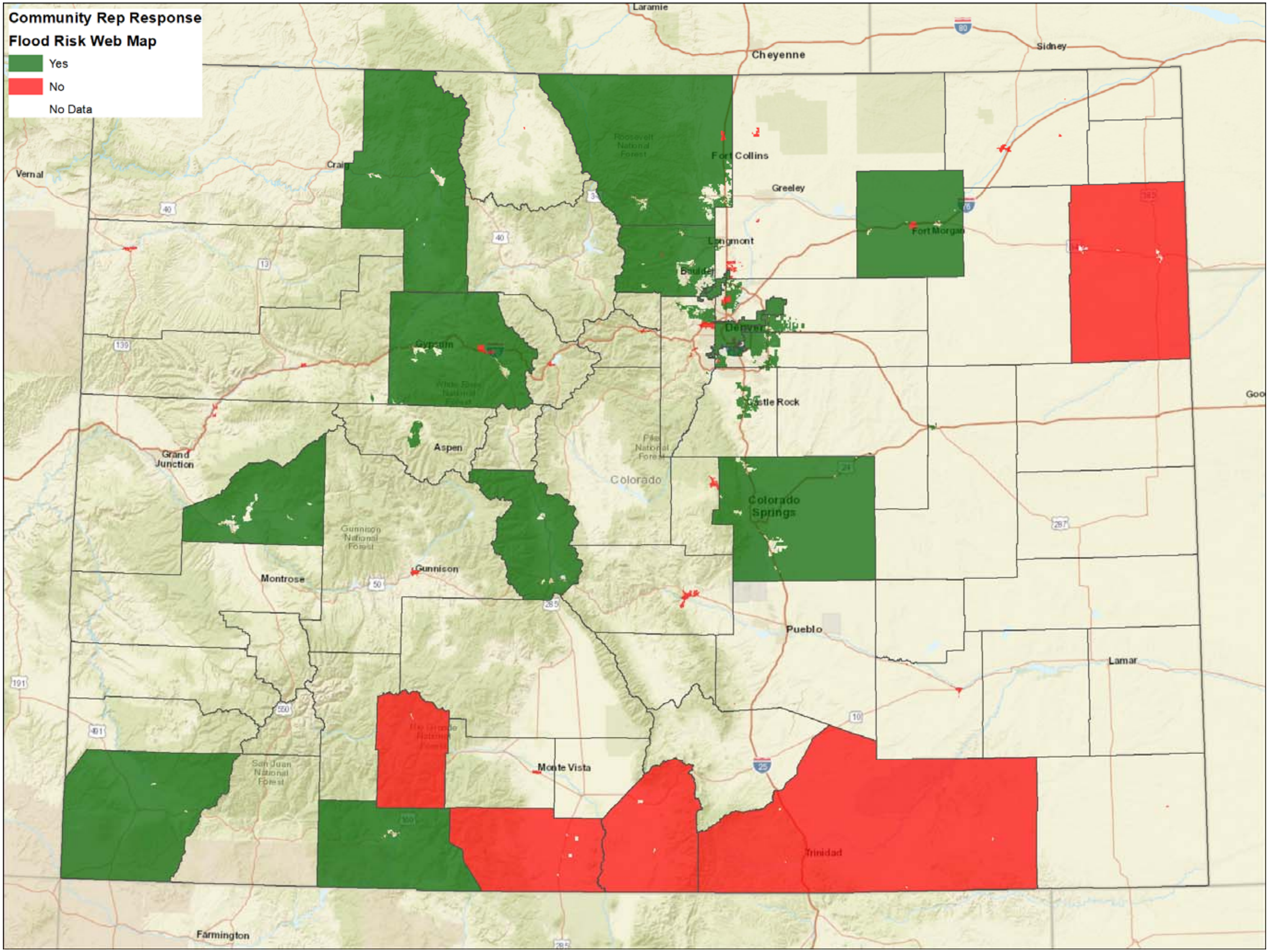


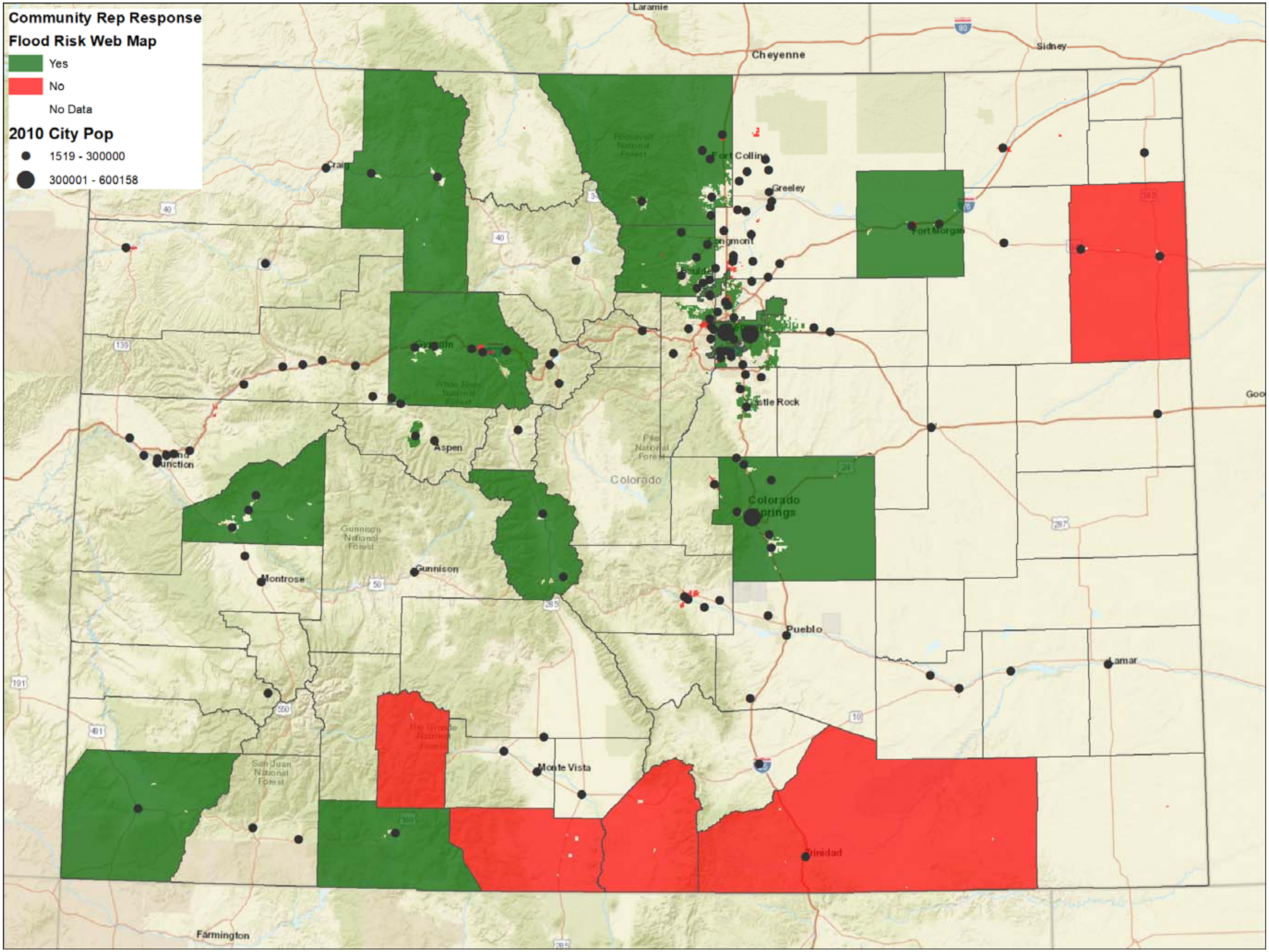
Community Rep Response
FRI Online
Yes
No
I don't know
No data
2010 City Pop
1519 - 300000
300001 - 600158
Laramie
Cheyenne
Sidney
Craig
Fort Collins
Greeley
Longmont
Boulder
Fort Morgan
Glenwood Springs
Castle Rock
Aspen
Grand Junction
Colorado
Colorado Springs
Montrose
Gunnison
Pueblo
Lamar
Monte Vista
Trinidad
Farmington

Does the community's website have an interactive, dynamic WebApp or WebMap?

N= 45
(45 responded
'Yes' to online FRI)

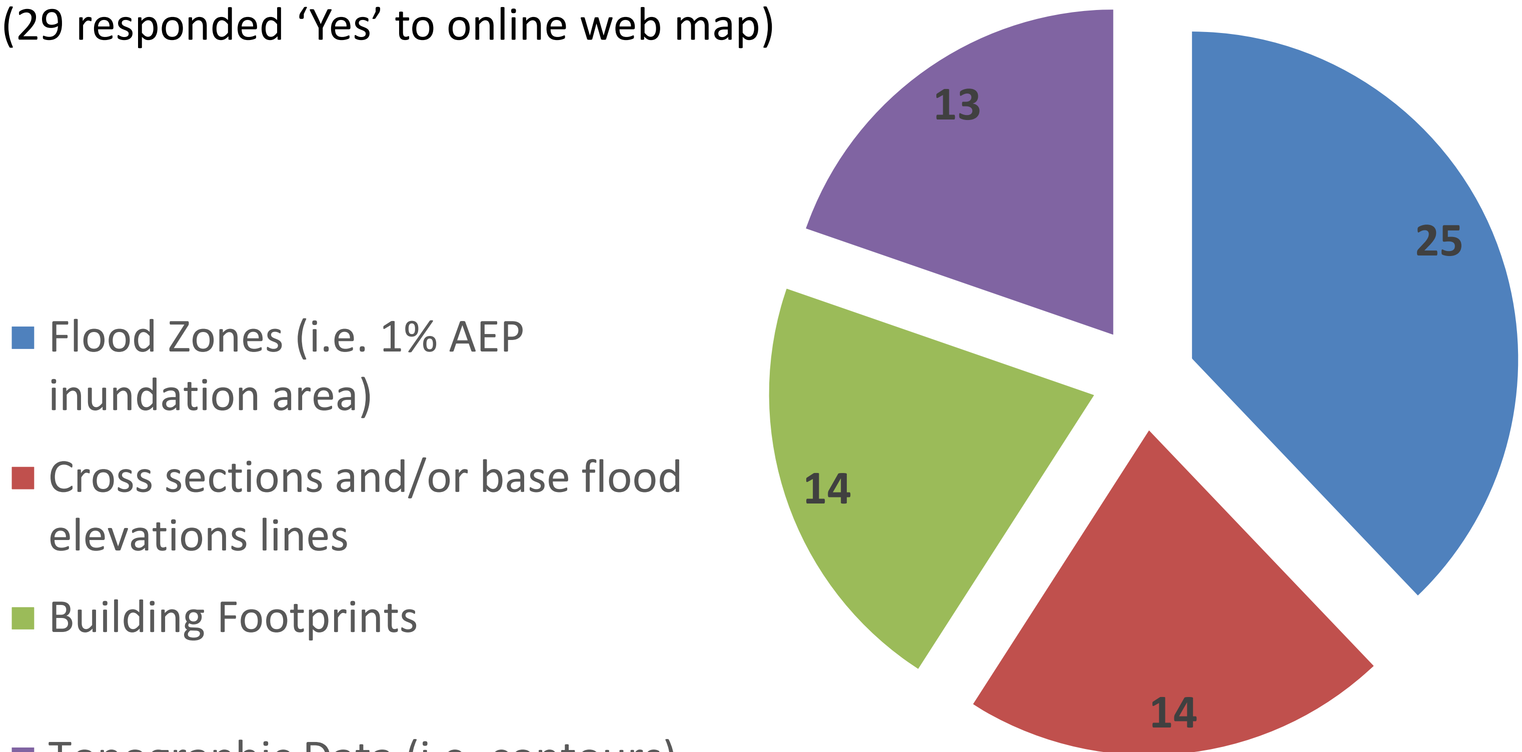



Community Rep Response
Flood Risk Web Map
Yes
No
No Data
Laramie
Cheyenne
Sidney
Vernal
Craig
Fort Collins
Greeley
Longmont
Fort Morgan
Boulder
Denver
Gypsum
Castle Rock
Aspen
Grand Junction
Colorado
Colorado Springs
Montrose
Gunnison
Pueblo
Lamar
Monte Vista
Trinidad
Farmington


Community Rep Response
Flood Risk Web Map
Yes
No
No Data
2010 City Pop
1519 - 300000
300001 - 600158
Laramie
Cheyenne
Sidney
Fort Collins
Greeley
Fort Morgan
Boulder
Castle Rock
Colorado
Colorado Springs
Aspen
Gunnison
Montrose
Pueblo
Lamar
Monte Vista
Trinidad
Farmington
Roosevelt National Forest
White River National Forest
Gunnison National Forest
San Juan National Forest
Pike National Forest
Rio Grande National Forest

Does the WebApp or WebMap have the following? (Select all that apply)

N= 27
(29 responded 'Yes' to online web map)



Discussion

•Set out to create a proof-of concept tool that promotes communication specifically the exchange of flood risk information.

•Limitations included, the FRIS was a successful proof-of-concept project that addresses the main gaps accentuated by government reports, academic literature, and the community feedback

•FRIS products are not “one size fits all” or static.

Future

- Incorporate new NFHL as it becomes effective
- Explore improvements for structure specific tool
- More focus groups to increase participants reprensentation of the community
- Product testing, implementation, improvemnt
- Use FRIS to adovate for more/new data (especially non-regulatory)

The University of Denver Geography and the Environment Department

DR. HILLARY B. HAMANN, DR. JING LI, DR. E. ERIC BOSCHMANN

Colorado Water and Conservation Board

THUY PATTON, STEPHANIE DIBETITTO, CAROLYN KEMP

Boulder County

ERIN COOPER, DAVE WATSON

The Urban Drainage and Flood Control District

TERRI FEAD, MORGAN LYNCH, KEVIN STEWART

The Army Corps of Engineers

PATRICK NOWAK

Funded by

Laurance C. Herold Fund

2017 GIS in the Rockies Scholarship

UNISDR ANNUAL REPORT 2012. *States News Service* 2013. May 31.
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Questions?