Reconnaissance RSR Meeting

NHERI GSC

Lessons learned from Hurricane Otis

January 17, 2024
12:00 pm CT

Dr. Juan Antonio Balderrama

NSF | NHERI GSC Graduate Student Council

Speaker Introduction

Dr. Juan Antonio Balderrama

Associate Professor of Instruction

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NHERI GSC
Graduate Student Council

Hurricane Otis Post-Disaster Assessment

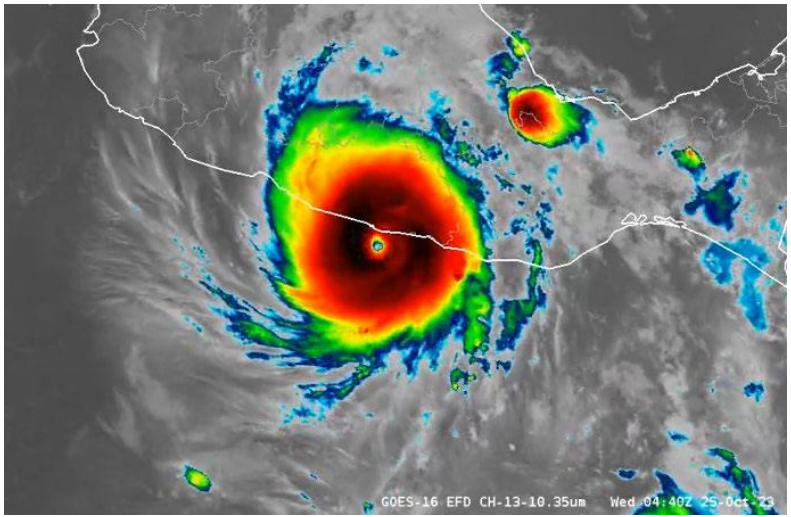
NHERI GSC January 17, 2025, Virtual Meeting

Juan Antonio Balderrama Garcia Mendez, PhD, PE
Associate Professor of Instruction
The University of Texas at Arlington

Presentation Agenda

1. Overview of Hurricane Otis
2. Acapulco Jurisdiction Design Aspects (Hazards)
3. Establishing Questions to Inform the FAST Strategy
4. Reconnaissance Survey Strategy
5. Areas Surveyed
6. Data Collection Methodology
7. Key Observations
8. Logistic Challenges
9. Lessons from Otis
10. Acknowledgements

Overview of Hurricane Otis (October 2023)



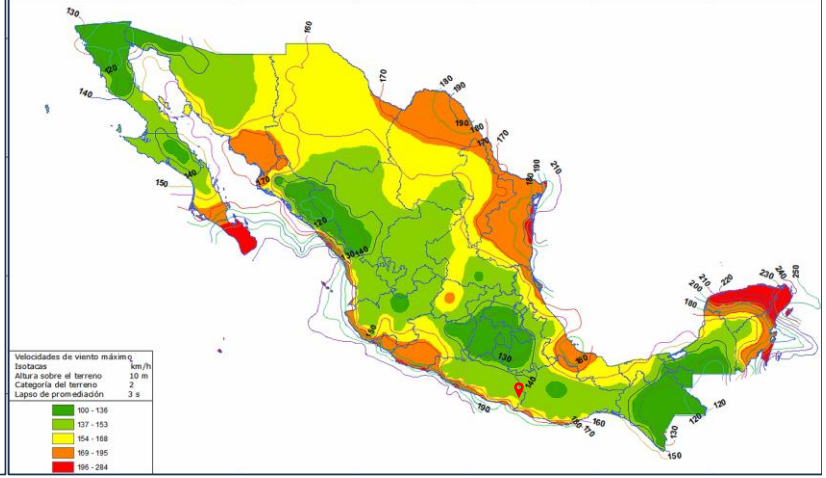
Rapid intensification from Category 1 to 5 in 18 hrs.

Acapulco Jurisdiction Design Aspects (Hazards)

2015 CFE Manual Seismic Design Criteria

Site specific seismic spectra per ASCE 7 2016 criteria from a previous design bid in Playa Diamante were higher than California spectra

2020 CFE Manual Wind Design Criteria



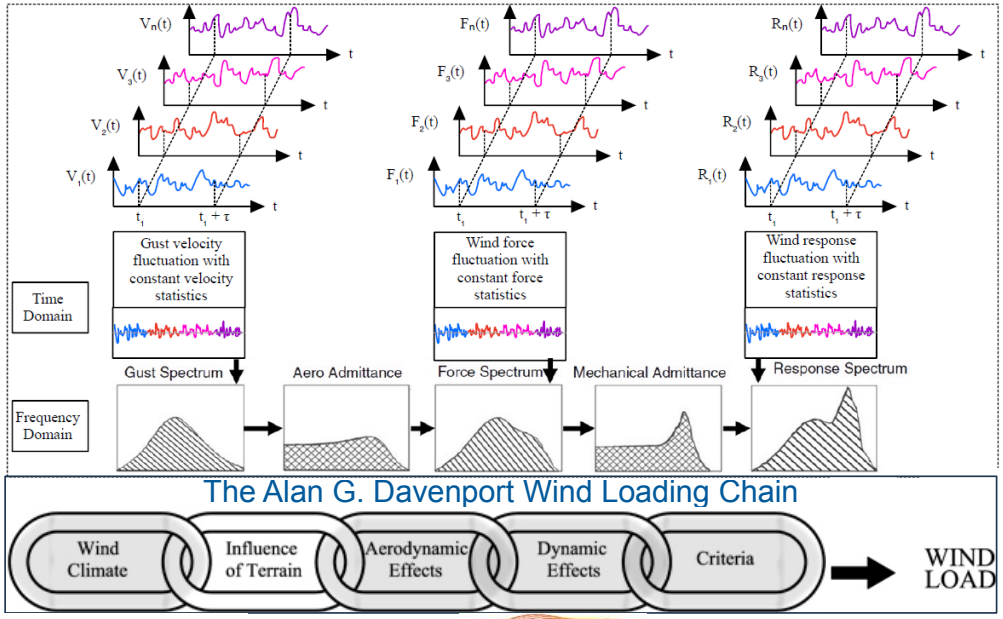
Basic Wind Speeds (3 s gust open terrain)

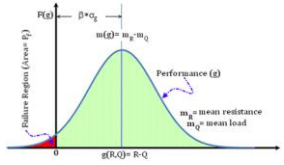
- 141 km/hr for 050 yr. return period
- 164 km/hr for 200 yr. return period

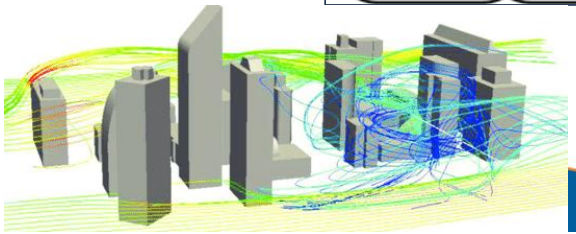
2023 Hurricane Otis Peak Gust

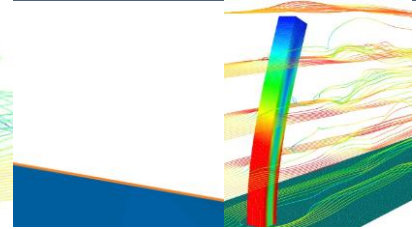
- 330 km/hr (5 meter height on a dock, open water)

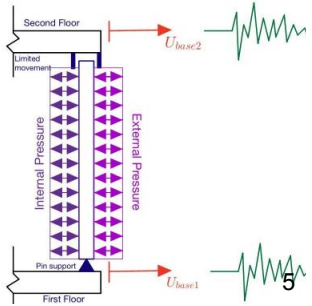
Establishing Questions to Inform the FAST Strategy





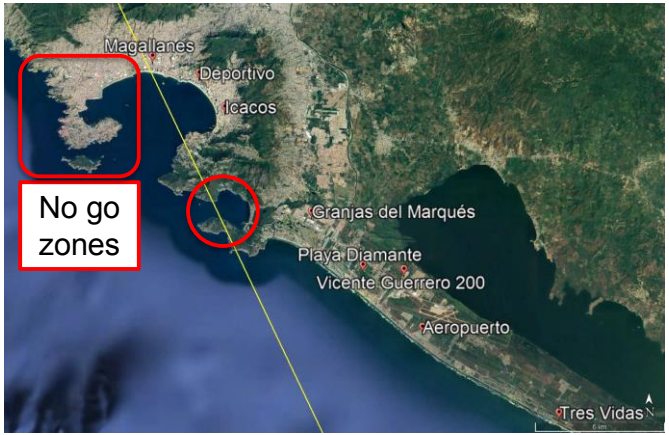






Reconnaissance Survey Strategy

Security concerns to define reconnaissance trajectory



CFE recommended: stay near the beach (tourist areas), avoid inland areas (mountains).

PVRR damage photos & questions to define strategy

1. No access to buildings
2. Systematic failures to building envelopes

Strategy: focus on building envelopes and roofs for as many high rise buildings as possible and capture data for low and mid-rise buildings encountered along the way for comparison (split the team in two to capture damage from the beach and damage from the street).

Areas Surveyed

Main Acapulco Bay (day 1 prior to teacher union strikes)

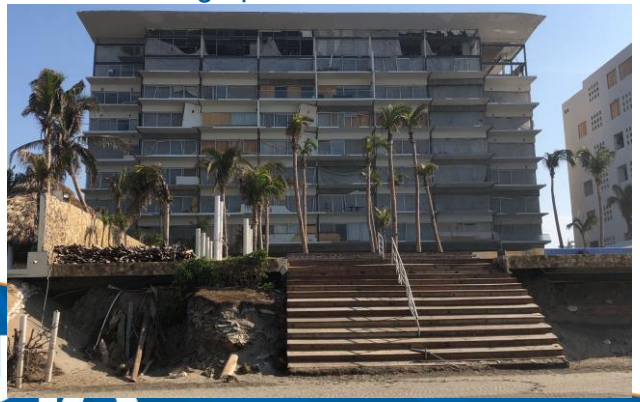
Playa Diamante (days 2 & 3, safer feeling)

8 colonias (neighborhoods) covered, grouped buildings in 20 clusters

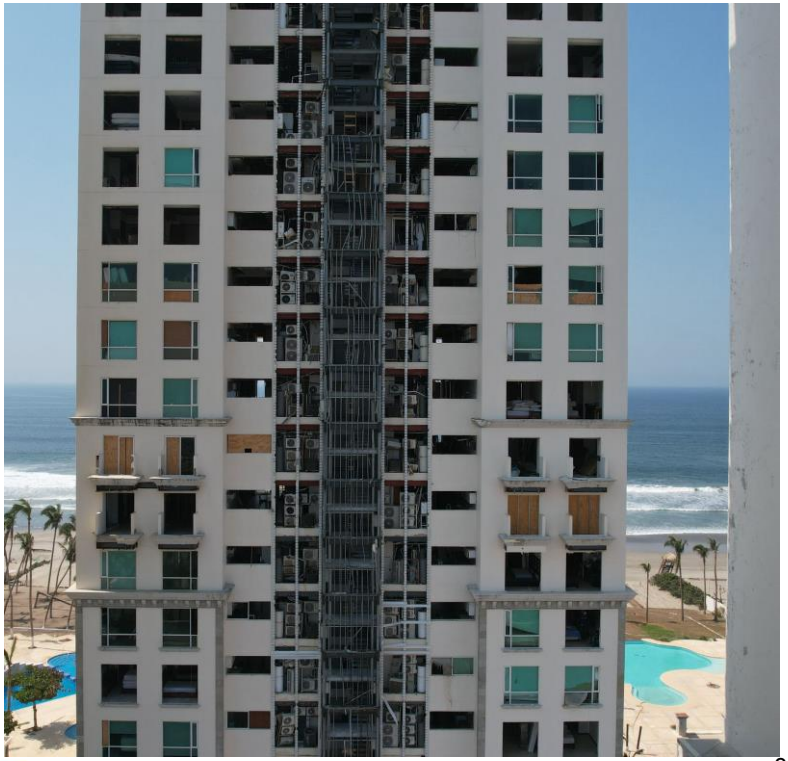
Data Collection Methodology

UAS Higher Flight Survey of Building Cluster

Cell Phone Photographs from Ground & Fulcrum App



UAS Panoramas Wrapping Vertically Up Select Buildings

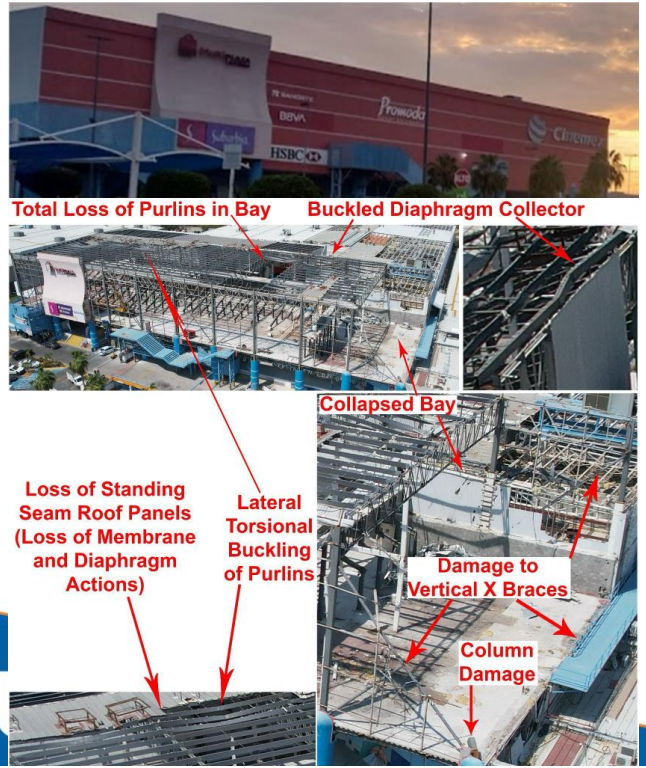


Key Observations High Rise Buildings

- Most assessed buildings were in the high-end architecture market sector (ambitious views) and combined the use of veneer walls, curtain walls, and infill walls as their wall cladding system.
- Lattice metallic panels, louvers, and cement board veneers were implemented as ventilated facades and enclosures of utilities shaft.
- These were all systematically damaged, regardless of the element type.

Key Observations Low Rise Commercial Buildings

Car dealerships, wholesale stores (e.g., WalMart, HomeDepot), distribution centers, and other lightweight steel buildings sustained heavy damaged to their building envelope and MWFRS



Logistics Challenges

- **Restricted Zones:** Army and navy facilities, as well as airport areas, were designated as no-fly zones or had restricted flight elevations
- **Bird Hazards:** Drone operators had to remain vigilant for birds of prey, which tended to follow the drone
- **Complex Aerodynamics:** Turbulent flow features around buildings affected drone flight stability
- **Glare:** Extremely difficult to direct the drone operator in real time due to the screen glare
- **Limited Access:** Beach areas and the four sides of buildings were heavily restricted and made highlighting the need for specialized drones capable of surveying from both beach and street perspectives
- **Signal Interference and Limited Access Points:** Widely spaced beach access points and building interference with the drone's line of sight disrupted control, complicating efforts to survey all four elevations in a single operation (we had to survey several buildings from the street first and then from the beach; could have brought more drones)
- **Traffic Hazards in the Main Acapulco Bay**

Lessons from Otis

From the assessment we cannot identify the exact causes of the widespread damage in Acapulco. However, we can identify knowledge gaps in the wind-to-damage chain from our observations and our understanding of the hypothetical basis behind the design codes and standards adopted for structural engineering in Acapulco:

- Effects of recent extreme weather patterns on hurricane risks
- Flow within urban canopies
- Wind-induced dynamic response of buildings and effects on lateral force resisting systems (LFRS) and components and cladding (C&C)
- Wind design and retrofit considerations of predominantly seismically-designed buildings
- Risk consistency evaluations of building design provisions for sites without clear governing lateral load hazards

Acknowledgements

- This disaster assessment was made possible by NSF StEER and by the support and guidance provided by StEER's leadership:
  - Mohammad S. Alam, University of Hawai'i at Manoa
  - Tracy Kijewski-Correa, University of Notre Dame
  - David O. Prevatt, University of Florida
  - Ian Robertson, University of Hawai'i at Manoa
  - David Roueche, Auburn University
- The event was coordinated by:
  - Keegan Wolohan, University of Notre Dame
- The drone operator, Jorge Hernandez Toral

Questions?

Speaker Introduction

Dr. Brad Wham
Assistant Professor

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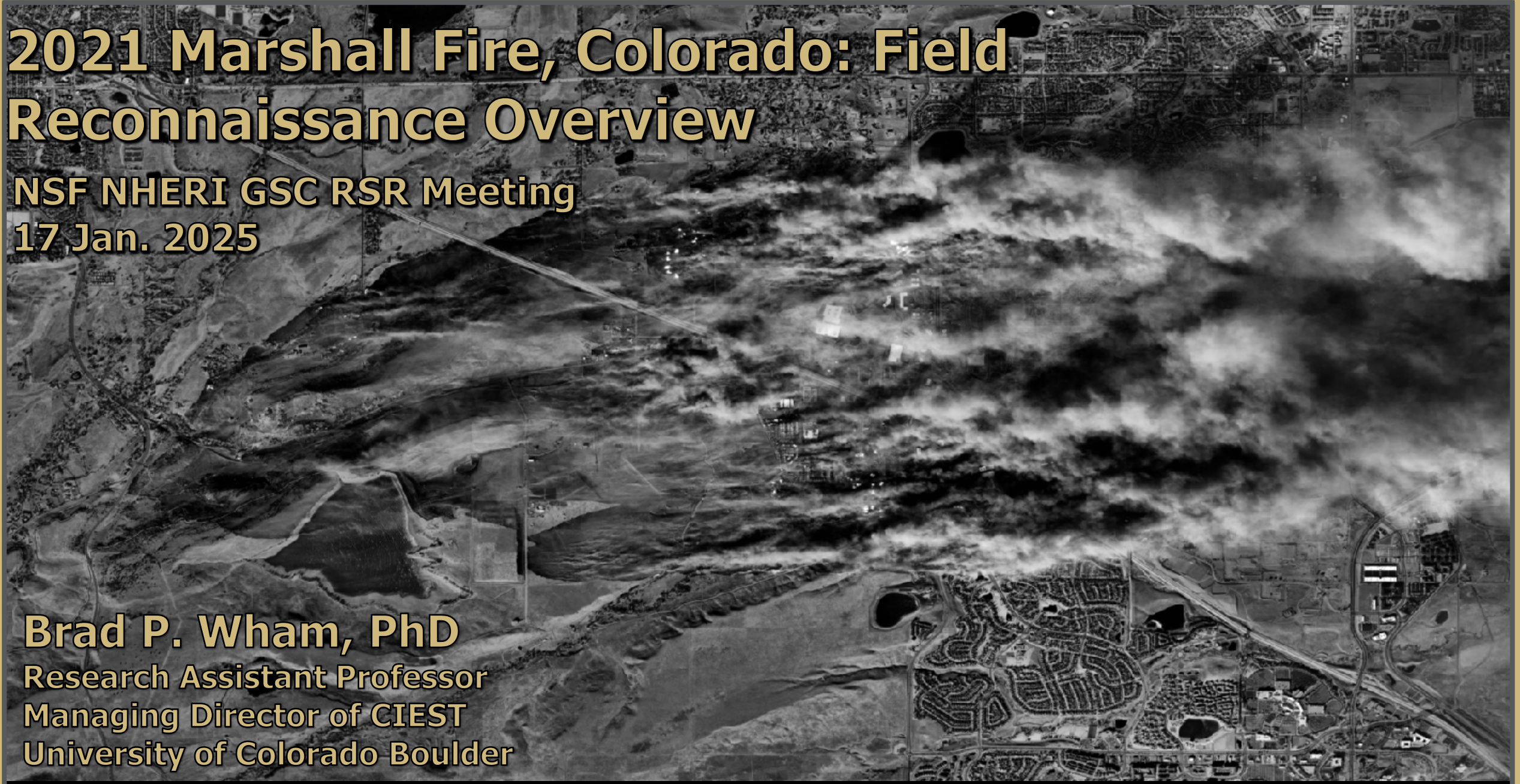
2021 Marshall Fire, Colorado: Field Reconnaissance Overview

NSF NHERI GSC RSR Meeting
17 Jan. 2025



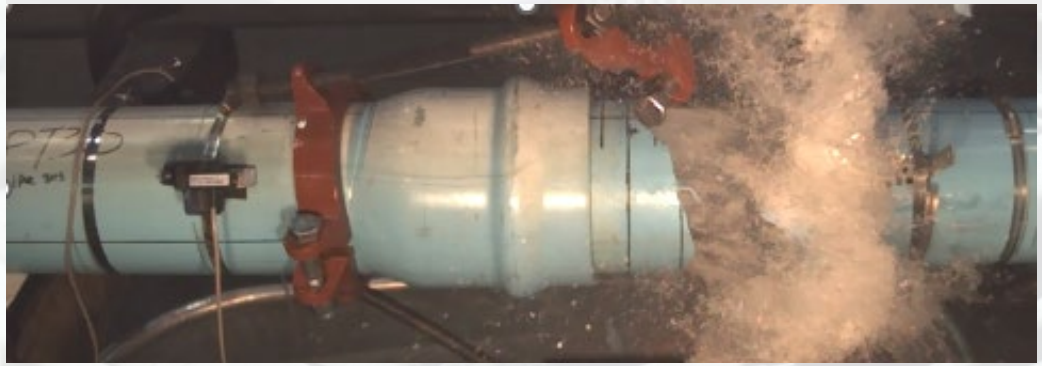
Brad P. Wham, PhD
Research Assistant Professor
Managing Director of CIEST
University of Colorado Boulder

Background

Earthquake Reconnaissance:
- Christchurch, New Zealand (2013)
- Kumamoto, Japan (2017)
- Hokkaido, Japan (2018)
- Kahramanmaraş, Turkey (2023)

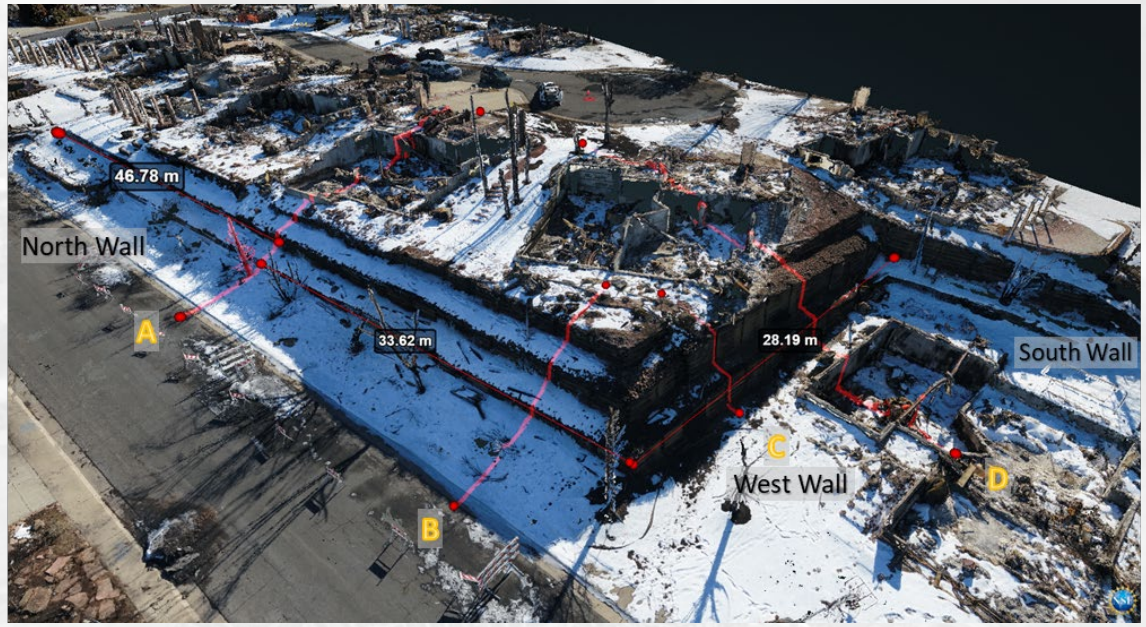
Brad P. Wham, PhD
Assistant Research Professor
Managing Director of CIEST
Civil, Environmental, and Architectural Engineering

Center for Infrastructure, Energy, and Space Testing
UNIVERSITY OF COLORADO **BOULDER**



Outline

- **Marshall Fire Overview**
  - **Event overview**
  - **Initial Response (Water Utility)**
- **Field Reconnaissance (GEER)**
  - **Planning**
  - **Example data sets**
  - **Housing**
- **Topics not Discussed**
  - **Lifeline system interdependencies**
  - **Wildfire impacts on Water quality**
  - **Team Water Quality Response**

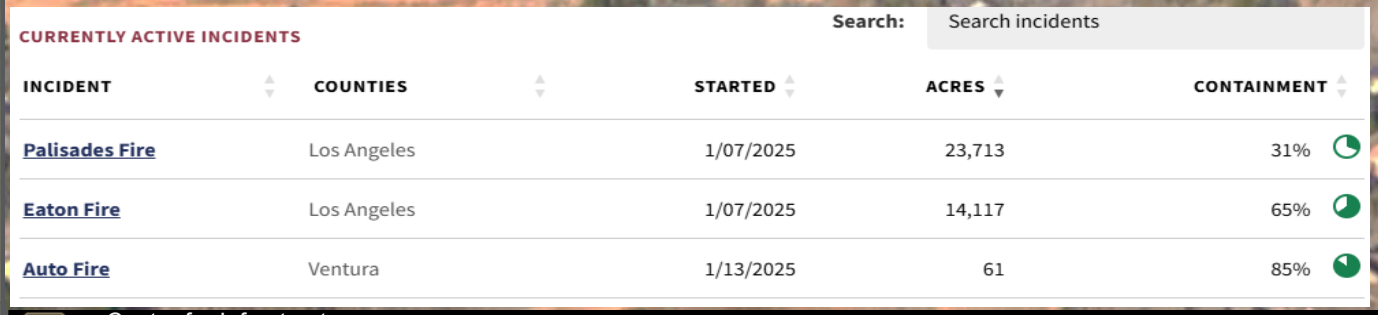


The Marshall Fire, December 30, 2021

- Most destructive in Colorado history in terms of the number of homes and businesses destroyed (>1,000 buildings in Boulder County, Louisville, and Superior).
- >**$1 Billion** in damages per NOAA, 6,000+ ac, 40,000+ evacuated

- Heavy Spring rains
- Bone dry summer and fall (no snow)
- 70 mph sustained winds, Gusts >100 mph

Parameter	2021 U.S.	2021 Marshall Fire	2018 Camp Fire
Median income	$62,843	$127,292	$51,566
Mean home value	$217,500	$576,800	$49,000
B.S. degree+	32.1%	76.3%	26.0%

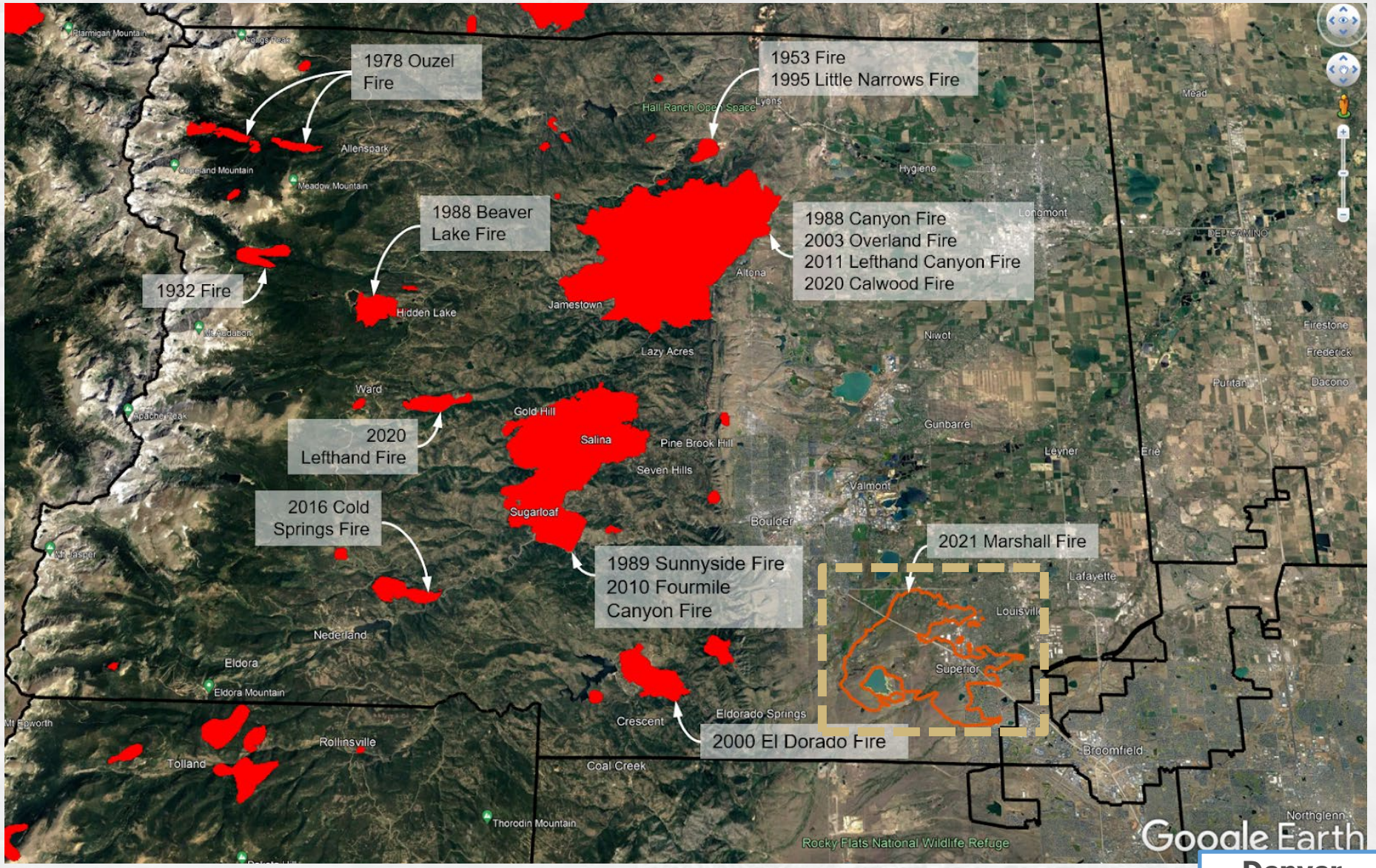


CURRENTLY ACTIVE INCIDENTS

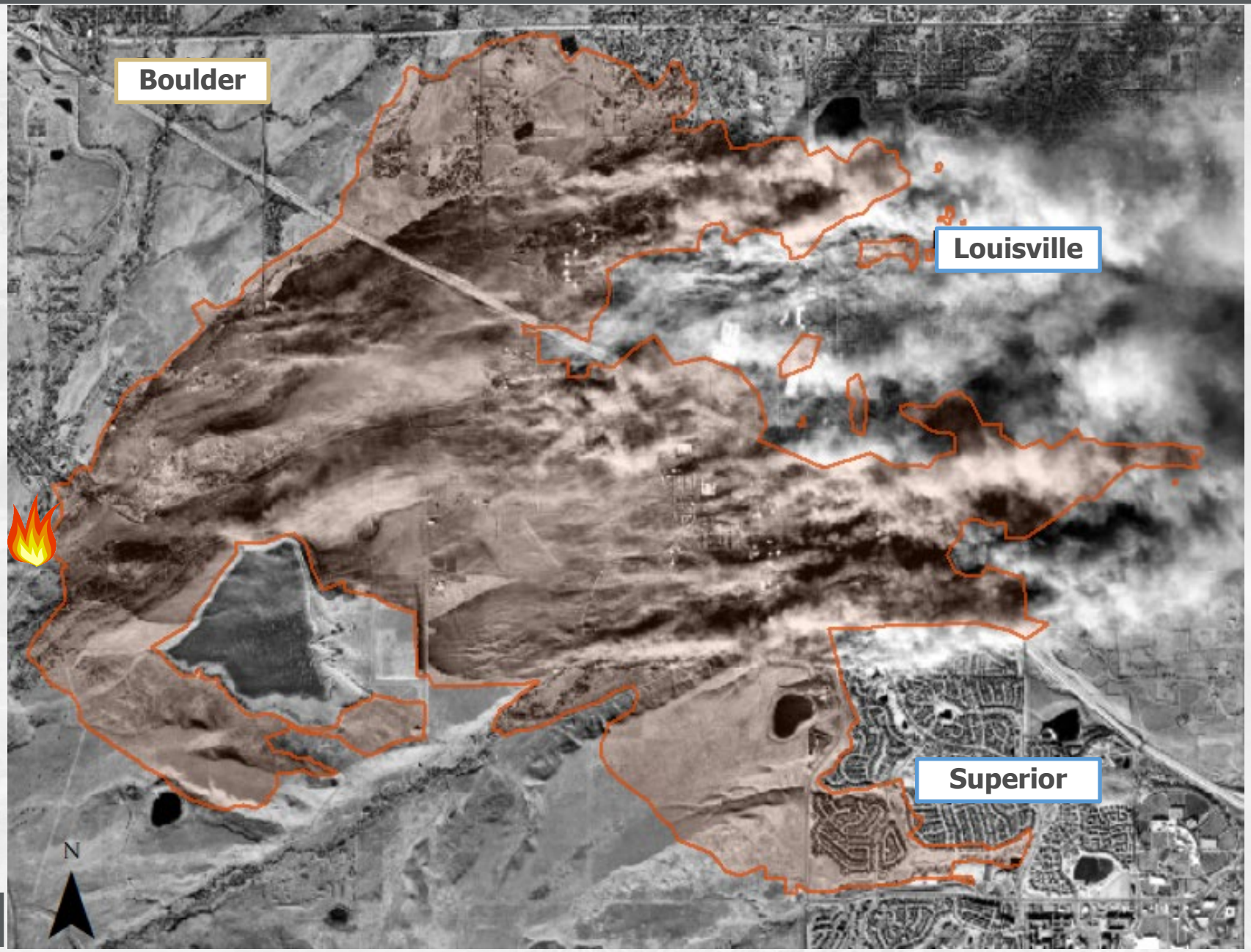
Search: Search incidents

INCIDENT	COUNTIES	STARTED	ACRES	CONTAINMENT
Palisades Fire	Los Angeles	1/07/2025	23,713	31%
Eaton Fire	Los Angeles	1/07/2025	14,117	65%
Auto Fire	Ventura	1/13/2025	61	85%

Historic Fires in Colorado



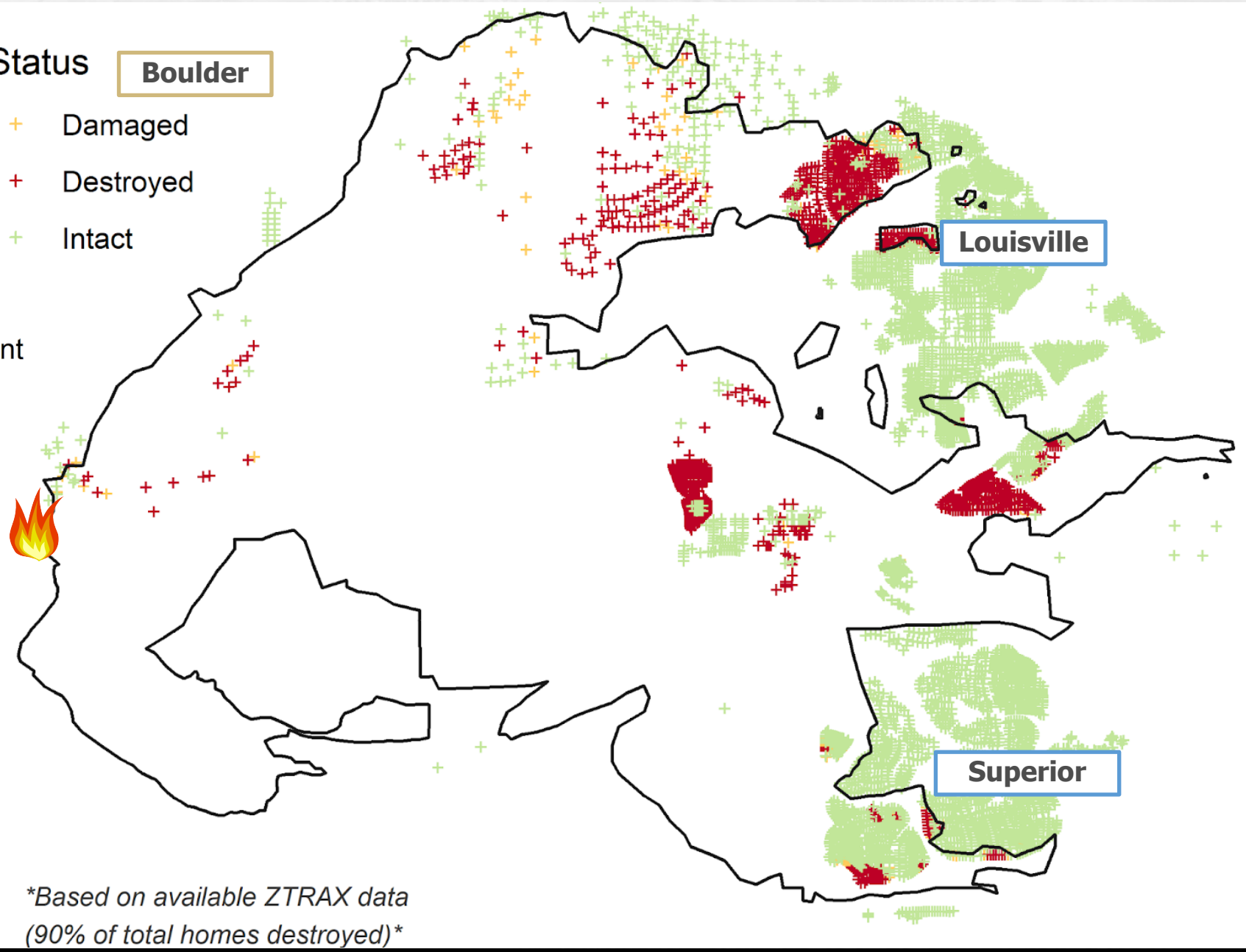
Marshall Fire Overview



(Maxar, 2021)

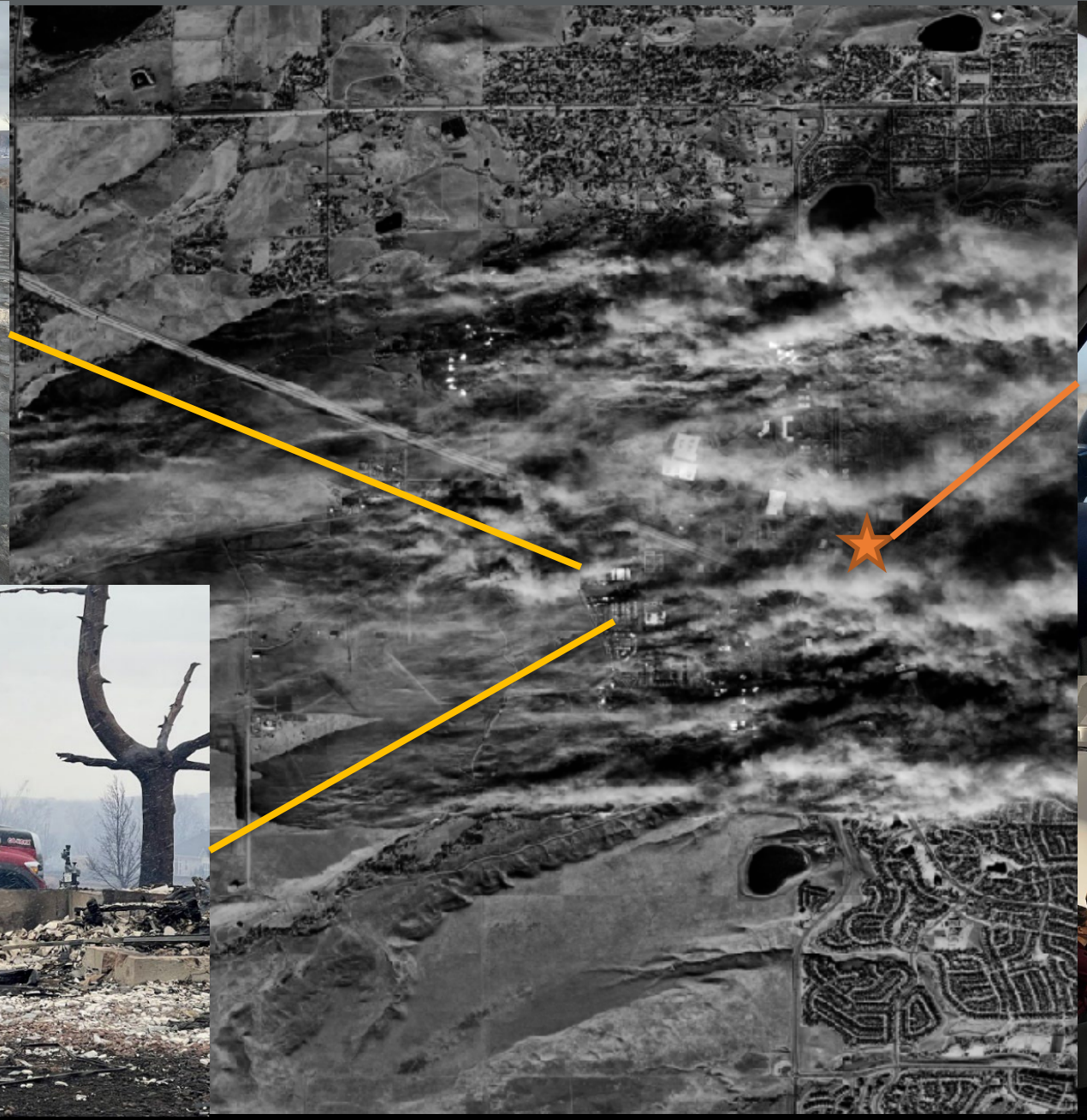
Marshall Fire Overview

Marshall Fire, CO (2021) Damage Assessment

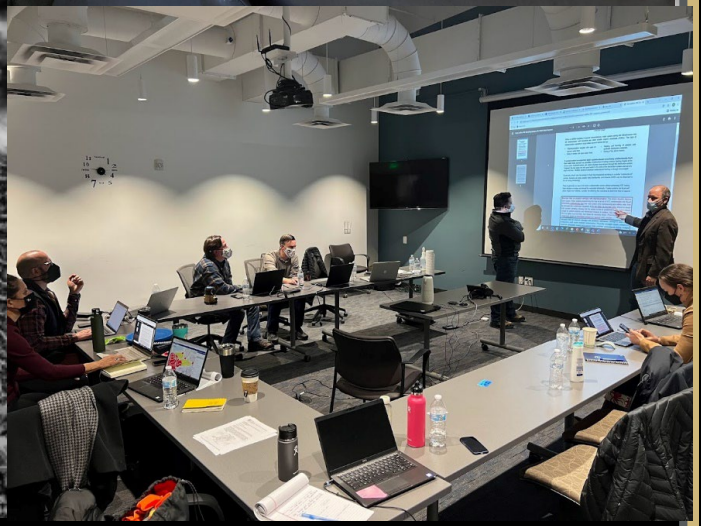


Data Sources:
Boulder County Sheriff's Office,
Zillow Transaction and Assessment Database (ZTRAX),
NIFC Current Fire Perimeters

Figures by Maxwell Cook, Johannes Uhl, Jennifer Balch, Stefan Leyk; Data source: ZTRAX




TIM ERLINE
PROTECTION
DISTRICT

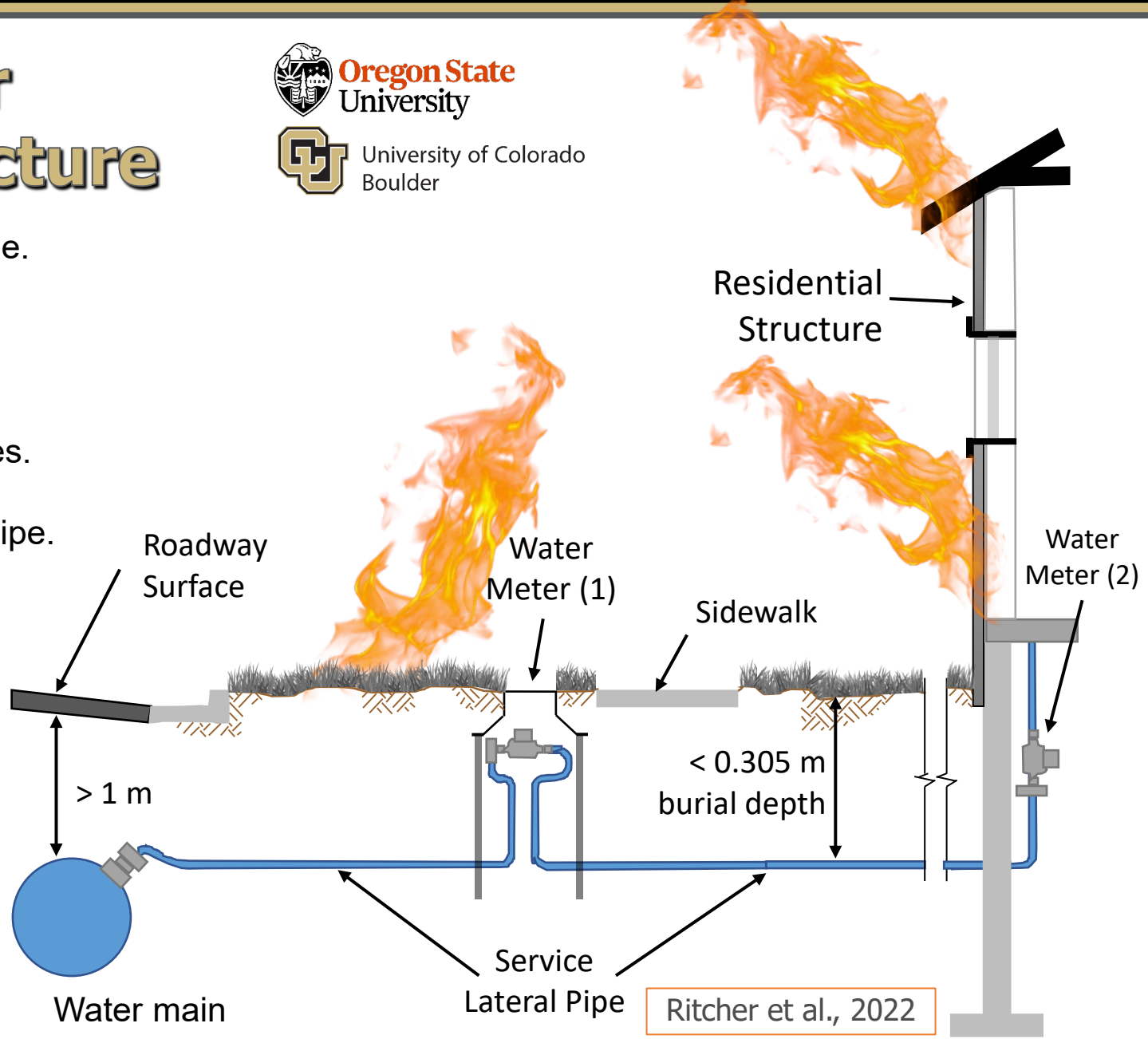


Fire Impacts on Water Distribution Infrastructure

Oregon State University

University of Colorado Boulder

- Burning homes **release chemicals**, like benzene. They also act as a fuel source, heating **service lines beneath the ground**.
- Increased water usage during a fire creates decompression and backflow in waterlines.
- Vacuum draws these chemicals into the pipelines. Service lines are heated/damaged.
- Contaminants may absorb into or adsorb onto pipe. Damaged service lines will need to be replaced.



Field Resonance

http://www.geerassociation.org/

University of Colorado
Boulder

GEER Team

- *Erica Fischer (structures, fire) [co-lead]*
- *Brad Wham (lifelines, geotech, structures) [co-lead]*
- *Abbie Liel (structures, risk)*
- *Shideh Dashti (geotechnical)*
- *Amy Javernick-Will (construction engineering)*
- *Andrew Welton (environmental engineering)*

PURDUE
UNIVERSITY

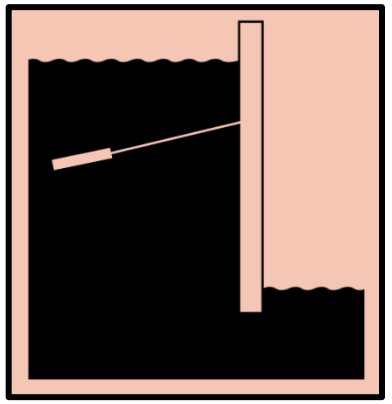
https://rapid.designsafe-ci.org/

Rapid Team

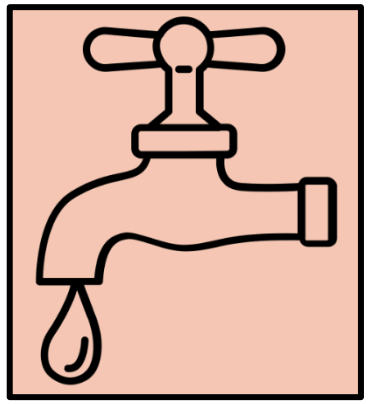
- *Jaqueline Zdebski*
- *Michael Grilliot*
- *Karen Dedinsky*
- *Jamie Vickery*
- *And Jeff and Joe of course*

Overview of GEER mission

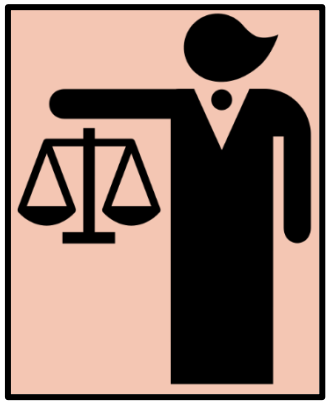
Characteristics of homes that influenced survivability



Performance of slopes and retaining structures



Behavior of lifelines and the role of utilities throughout and during the response to the fire



Changes in policies immediately after the fire

In-field data collection January 23 – 30
Additional drone flights February 12 – 14, March xx-xx

Oregon State University

University of Colorado Boulder

PURDUE UNIVERSITY

GEER

NSF

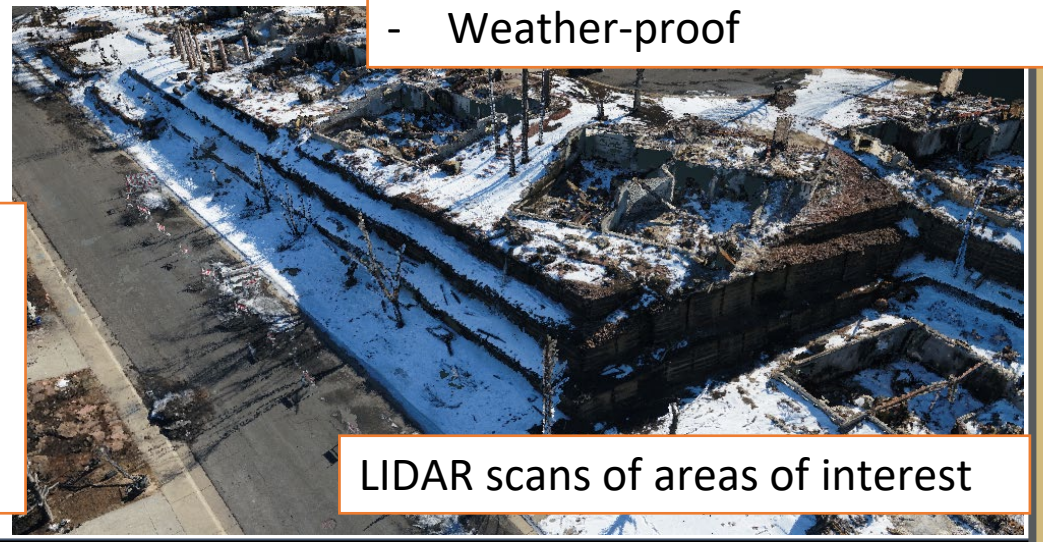
UAV Aircraft

RAPID NHERI
Natural Hazards Reconnaissance

Fixed wing:
eBee X
- Accuracy: 1.4 cm (0.6 in.)
- 90 min flight time
- Max. Coverage: 550 Acres

Quadcopter:
DJI Matrice 210 w/ X4S Camera
- Weather-proof

Fixed wing:
Trinity F90+
- 90 min flight time
- Max. Coverage: 1720 Acres
- Max. altitude 14,000 ft



LIDAR scans of areas of interest

UAV Flights

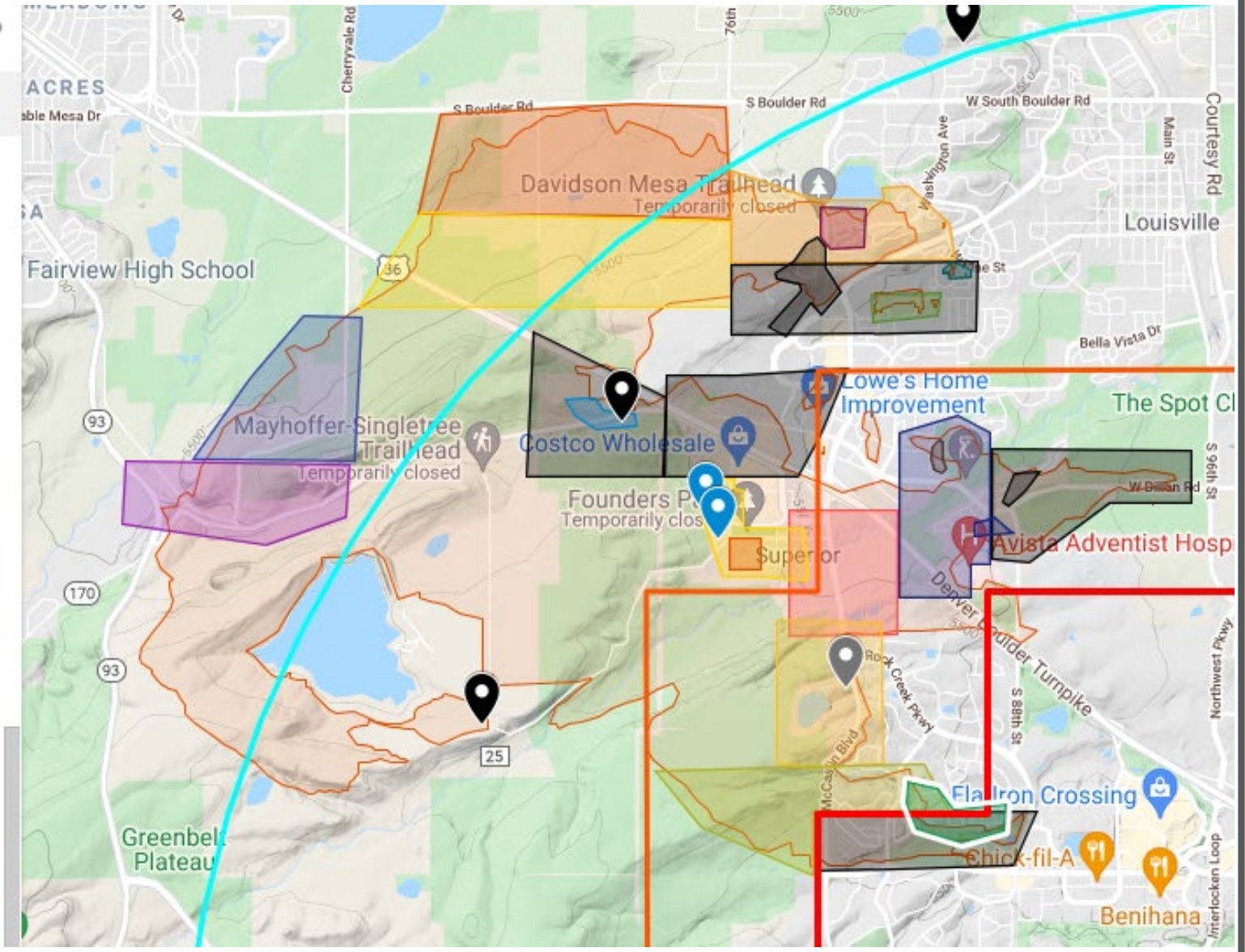
https://www.google.com/maps/d/u/0/edit?mid=1G83LCZoWe3HvbXYUxJ-Y_qG6tQ-x5flo&ll=39.96440432249915%2C-105.21959304862702&z=14

Last edit was seconds ago

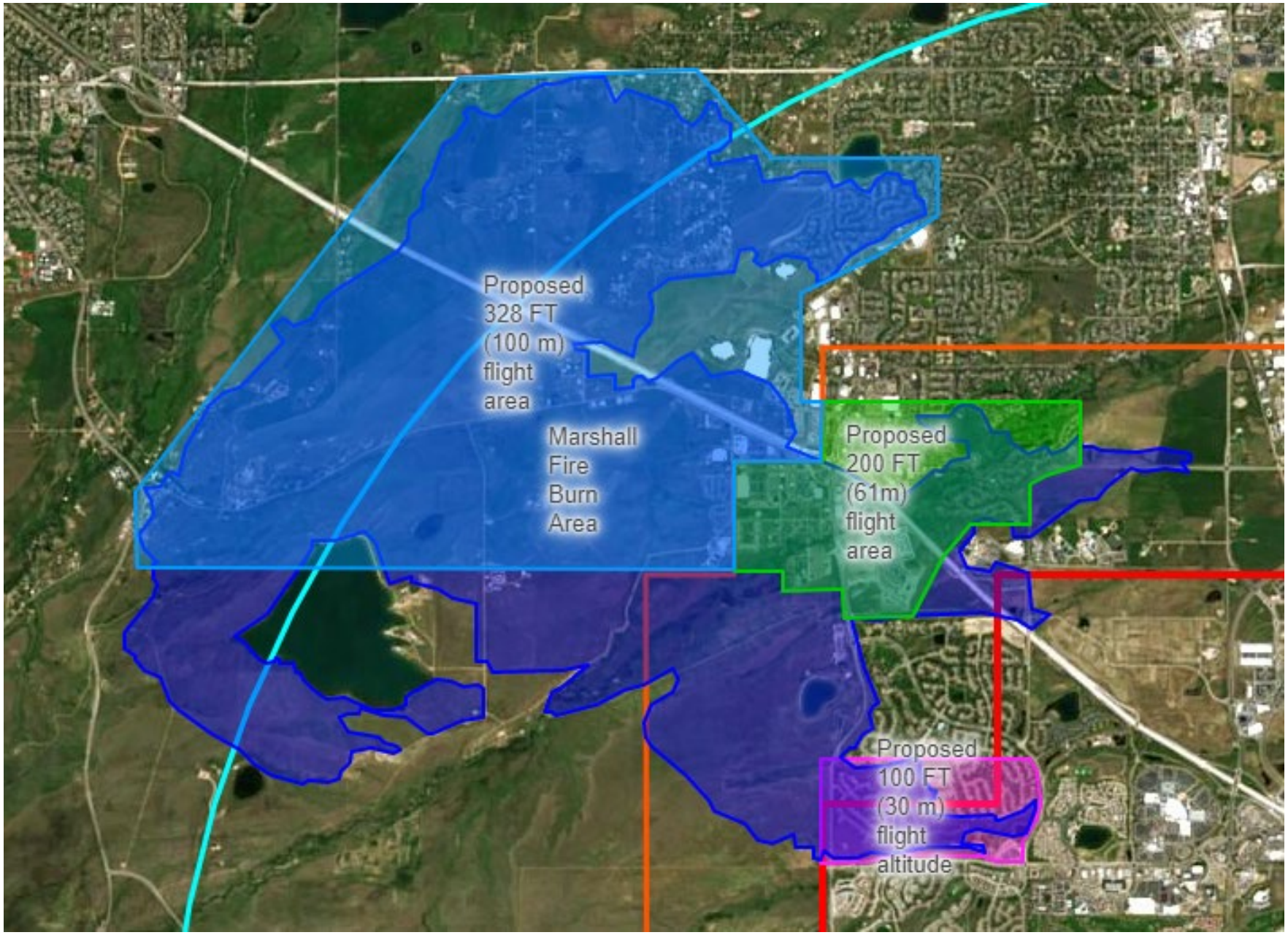
Add layer | Share | Preview

- Club Circle (low)
- Eldorado Drive
- 335 Cherokee Ave
- 162 Mohawk Cir
- Town of Marshall__4

- [ ] Local Access Points
- [x] FAA flight ceiling zones
  - Individual styles
  - Class D Airspace
  - 100ft flight ceiling
  - Ground flight ceiling
- [ ] destroyed_housing
- [ ] damaged_housing
- [ ] 220213_commercial



FAA Proposed Flight Area



2D Imagery (Orthomosaic)

https://www.arcgis.com/home/webmap/viewer.html?layers=6be1ef0adf93486abe65d2066893cf9c

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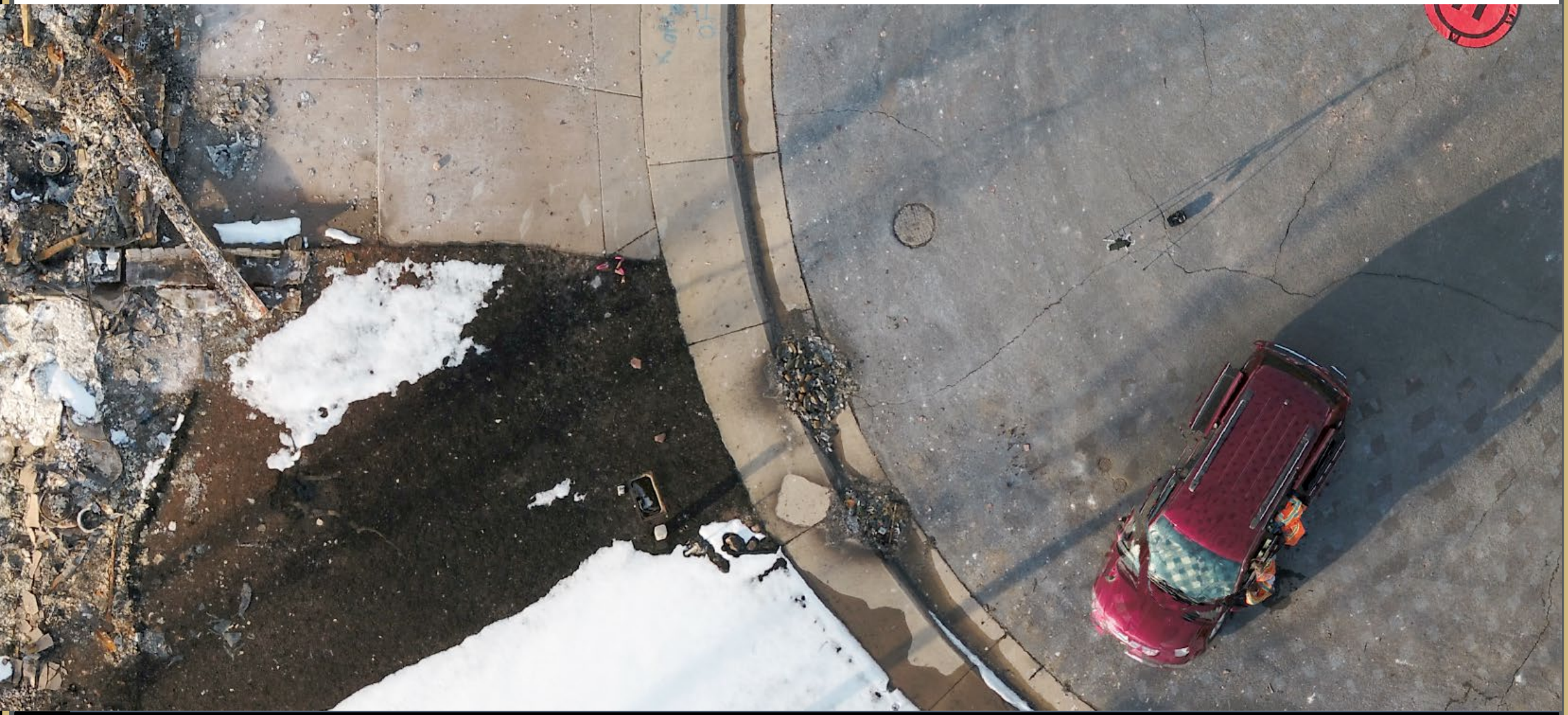
https://www.arcgis.com/home/webmap/viewer.html?layers=6be1ef0adf93486abe65d2066893cf9c

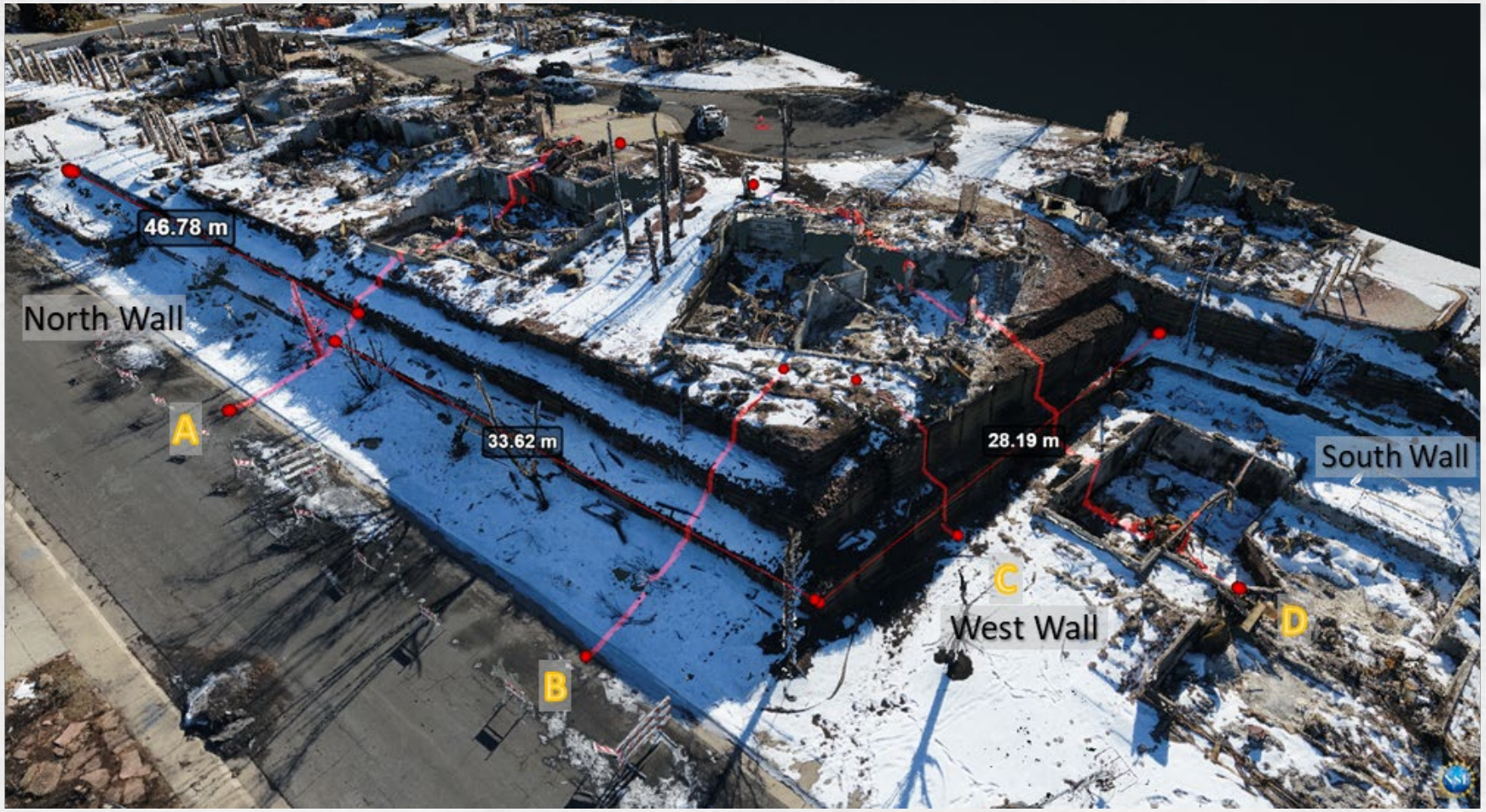


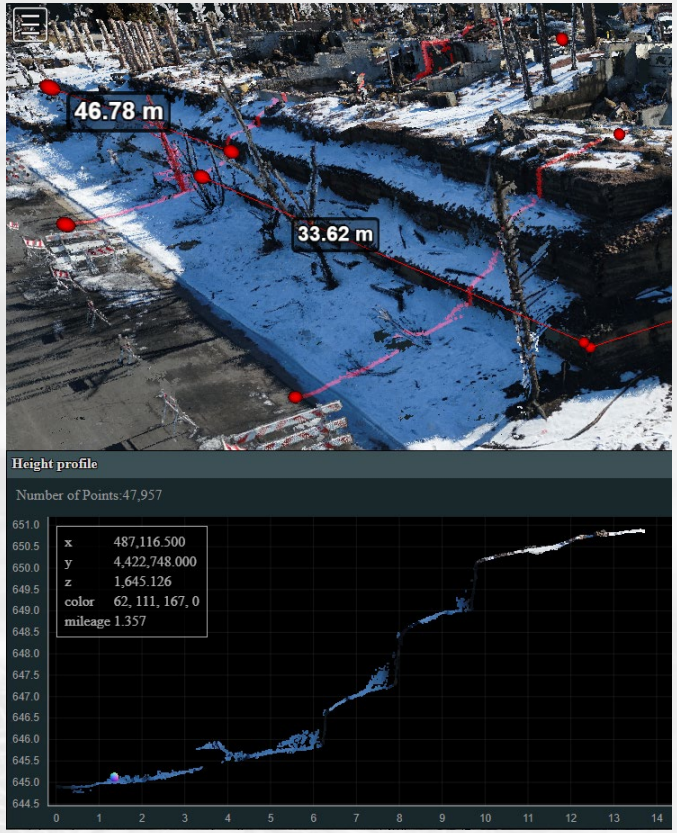
Structure from Motion Modeling

https://hazmapper.tacc.utexas.edu/hazmapper/project-public/473bc0e5-0da4-492c-afe1-0b0d99d463b3

Structure from Motion Modeling

https://hazmapper.tacc.utexas.edu/hazmapper/project-public/473bc0e5-0da4-492c-afe1-0b0d99d463b3





Ground Surveys

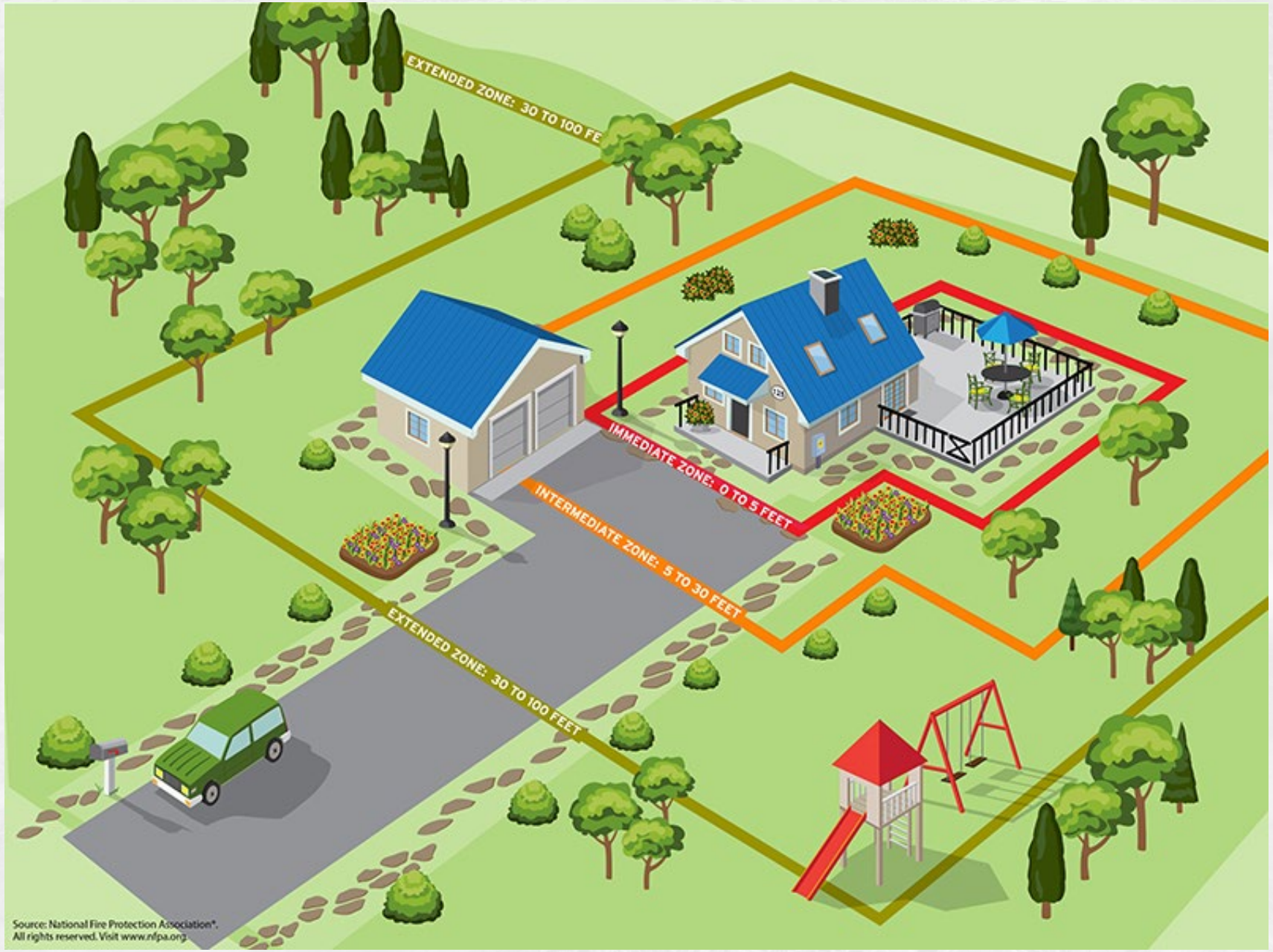
Damage state of homes

Proximity of homes to other damaged homes

Proximity of homes to one another

Proximity of homes to open space

WUI Code Recommendations



Preliminary Findings

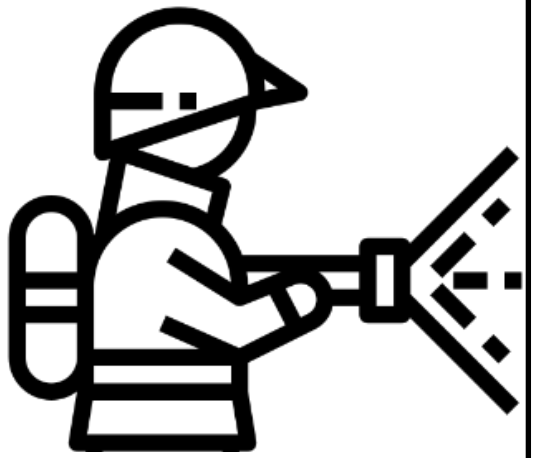
Closely spaced houses

High intensity of fire (high temperatures)

No protection on vents

Fences touching homes/Burnt fences

Proximity to open space



Firefighting strategies

(Ellery et al., 2023)

How the data has been used

- **Sharing data with Municipalities to aid recovery and decision making**
- **Follow on grants**
  - **NSF Rapids (e.g., Housing & Policies)**
  - **WRF Grant on Utility response**
- **Data has been used for:**
  - **Fire Initiation Assessment**
  - **Water contamination studies (e.g., Whelton et al. 2023)**
  - **Open space assessment**
  - **Pavement assessment**
  - **Rebuilding efforts**
  - **FEMA MAT Team**
  - **Social Science Survey Teams**
  - **Others….**

Acknowledgements

Local municipalities

City of Louisville

Town of Superior

West Metro Fire

Louisville Fire

Student support

Amy Metz (OSU)

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Nicholas Berty (CU)

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Jessica Ramos (CU)

Hailey Rae Rose (CU)

NHERI Rapid Cente: Jaqueline Zdebski, Michael Grilliot, Karen Dedinsky

National Science Foundation (NSF) GEER

Water Research Foundation

Many others…

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Acknowledgements

Student GEER Team
Nicholas Berty (CU)
Jacob Klingaman (CU)
Jessica Ramos (CU)
Hailey Rae Rose (CU)
Amy Metz (OSU)
Dae Kun Kang (OSU)

GEER TEAM
Brad Wham (CU) [co-lead]
Erica Fischer (OSU) [co-lead]
Abbie Liel (CU)
Shideh Dashti (CU)
Amy Javernick-Will (CU)
Andrew Welton (Purdue)

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Local Agencies/Utilities
City of Louisville/ Louisville Fire
Town of Superior Public Works
West Metro Fire
East Boulder Water Utility
Boulder County (OEM)
CDHPE
Xcel Energy

NHERI Rapid Center:
Jaqueline Zdebski
Michael Grilliot
Karen Dedinsky
Jamie Vickery

National Science Foundation (NSF) GEER

Some References and Resources

- Fischer, E., Wham, B.P., Dashti, S., Javernick-Will, A., Liel, A.B., Whelton, A.J., Berty, N.W., Klingaman, J., Metz, A., Ramos, J., & Rose, H.-R. (2022). *The 2021 Marshall Fire, Boulder County, Colorado. Geotechnical Extreme Event Reconnaissance (GEER) Association.* https://doi.org/10.18118/G6KT04
- Wham, B.P., Fischer, E., Dedinsky, K., Zdebski, J., Grilliot, M., Lyda, A., Berty, N.W., Kang, D.K., Klingaman, J., Metz, A., Ramos, J., Rose, H.-R., Dashti, S., Javernick-Will, A., Liel, A.B., & Whelton, A.J. (2023). "Marshall Fire Reconnaissance - 2022". Designsafe-CI. https://doi.org/10.17603/DS2-GARB-1N48
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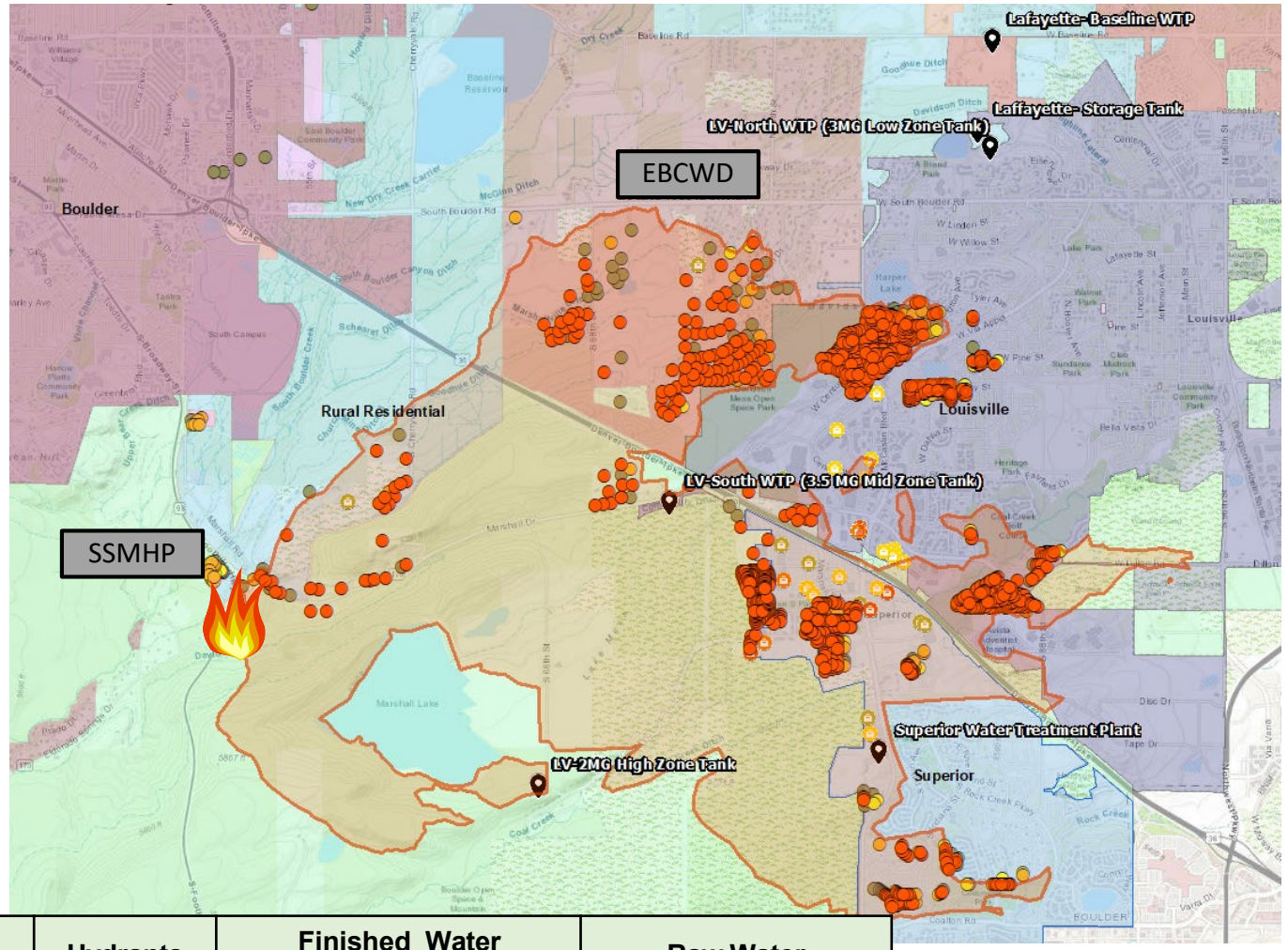
- **Water Research Foundation Reports**
- **CU CONVERGE Workshops:** https://docs.google.com/document/d/1IAMi4qXCfs8fTz2CAKm8Ee9rYTgRBdXqixN6D0Upfvs/edit

Marshall Fire Overview: Water Systems

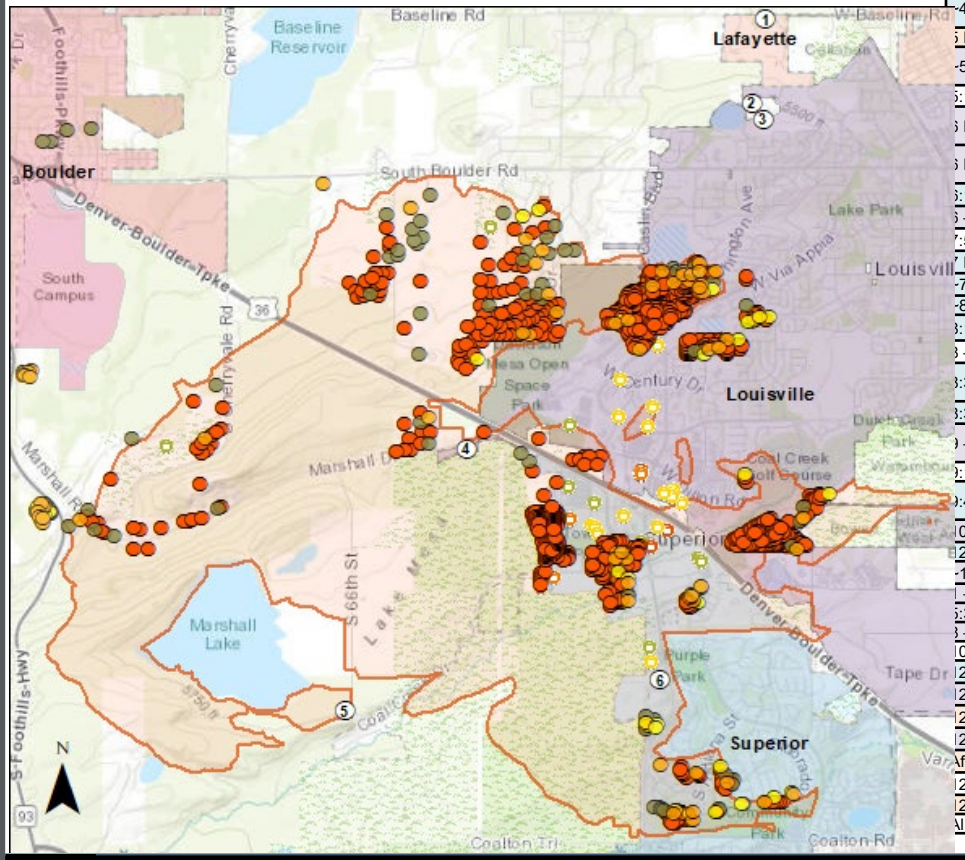


5 Public water systems were damaged affecting about 60,000 people

Public Water System (pop.)	Damaged/Destroyed Properties	Water Mains, miles	Hydrants	Finished Water Storage, MG	Raw Water
Louisville (20,319)	593 of 7,339	120	1,200	7.5	Surface water
Superior (17,170)	436 of tbd	50	430	3.4	Surface water
Lafayette (28,700)	22 of 9,700	177	900	14	Surface water
EBCWD (300)	72 of 137	8	40	0.1	Lafayette
S.S. Mobile Home Park (150)	3 of 61, wind	<1	None	None	1 Well

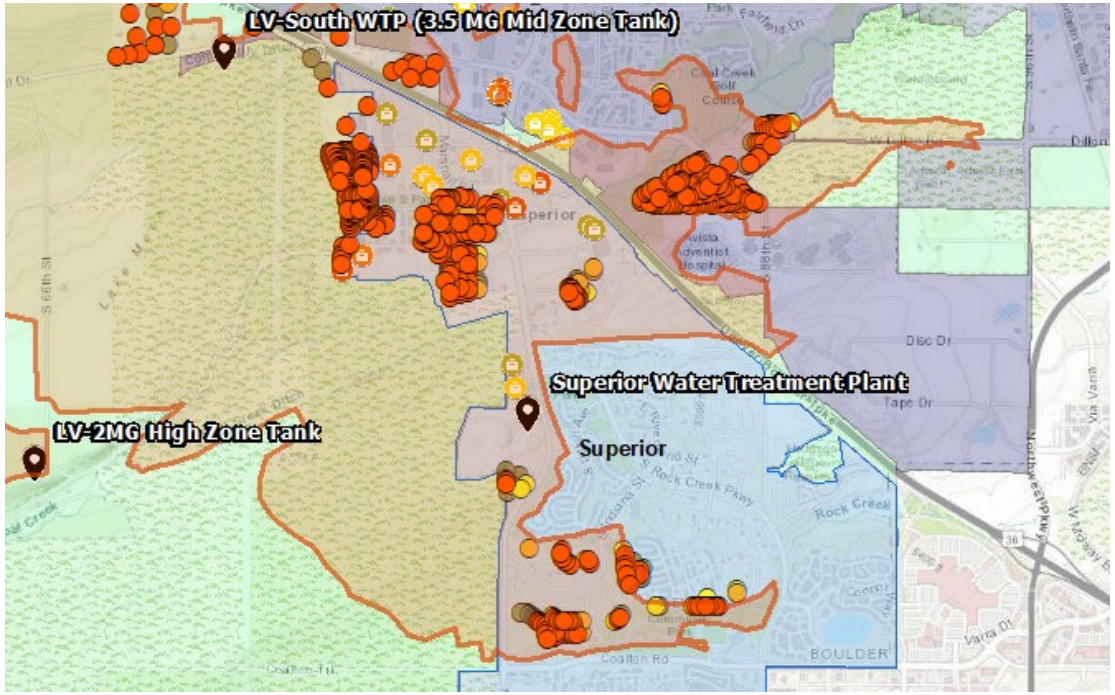
Eldorado Artesian Spring: 2 wells, one spring

Timeline (Water)



Time (MST)	Event/notice/advisory	Org/ Area
11 AM	Fire reported at 11:06 AM; Highway 93 and Marshall Rd	Marshall
11:47 AM – 2:51 PM	Boulder County Sheriff Office issues evacuation orders for >35k residence (see Section 7.4.1 for details)	Starting with Marshall and extending to LV
~11:30 AM	SWTP (South Water Treatment Plant) staff evacuated	LV–PW
12 – 1 PM	Fire enters South WTP, power loss	LV
~12:15 PM	Additional staff arrive to WTP, plant production increased from 650 to 1200 GPM, turbidity shutdown setpoint increased, staff prepared to evacuate	SUP (WTP) REC
1 PM	Fire visible from Terminal Reservoir (WTP)	SUP (WTP) REC
~1 PM	Water pressure begins to decrease, staff decides to drive into fire area to SWTP LV–PW turned North plant to maximum capacity (8 MGD)	LV–PW
1:53 PM	Recorded flow of treated water stopped, likely due to power loss/fluctuation; flow rate was 1200 GPM	SUP (WTP) REC
2:00 PM	**Maxar Satellite Picture taken**	**Maxar/BoCo**
2 PM	Fire had not yet entered WTP, approaching from North	SUP (WTP)
2 PM	Booster station lost communication near where the fire ultimately damaged properties	LAF
2:25 PM	- Natural gas shut off, generator quit, *total power loss* - staff evacuated due to smoke, closed influent valve to WTP, opened north hydrant to protect assets	SUP (WTP) REC
2 – 3 PM	LV–PW asks XCel Energy to prioritize getting power back to water treatment plants low on water.	LV–PW
2:30 PM	EBCWD losses power/internet (they had data up to that point)	EBCWD
3 PM	Water storage tanks were topped off. WTP evacuated.	LAF
~3 PM	WTP emergency generator destroyed by fire	SUP (WTP)
3 – 4 PM	LV loses electricity and natural gas at the Louisville Fire Station (backup power)	LFPD
3 – 4 PM	LV–PW arrive at interconnect, still no power at SWTP	LV–PW (SWTP)
~4 PM	REC contacts LV-SWTP about opening interconnect to SUP	LV–PW & SUP & REC
~4:15 PM	Staff returned to WTP, only 2-phase power had been restored (need 3-phase for proper function of much equipment), power surges caused failure of automatic transfer switch, only half of plant with power	SUP (WTP) REC
5 PM	Raw water pump stations at 2 reservoirs lost power for 15 min. 2 generators did not kick on, but 1 diesel generator turned on.	LAF
~5 PM	LV–PW drives to mid–zone & high–zone tanks to check water levels. Only 2 ft of water left in tanks. When LV staff returns to mid–zone tank, the tank is empty.	LV–PW
5:15 PM	LV-PW & SUP open interconnect station to feed 1 MGD to SUP due to multiple failures of SUP WTP and inability to keep up with water demand	SUP-PW, REC, LV-PW (SWTP)
6 PM (6–7 PM)	No power at LV SWTP; shut off interconnect to SUP; staff manually open raw water valve at SWTP to allow untreated water into system to maintain pressure (~6:45 PM) and provide water for firefighting	LV–PW (SWTP)
6 PM	LV–PW calls LV Fire to voice concern that water treatment plants are burning. LFPD confirms plants are not burning and prepares a strike team to deploy if necessary.	LFPD & LV–PW
6:18 PM	Treated water flow restarted at 2000 GPM, increased to 3300 GPM by 10 PM, and stayed at that rate for the next 29 hours	SUP (WTP)
6 – 7 PM	Fiber connection between Louisville water plants is damaged through the splice connection melting	LV–PW
7:50 PM	Boil water advisory issued by CDPHE to LV, SUP, EAS, EBCWD, & SSMHP	Boulder County
7 PM	Browns Hill Electric Controls arrives to begin diagnostic troubleshooting & repairs	SUP (WTP) REC
~7 PM	SCADA was restored, storage tanks at 15% full, down from 90% when fire shut down the WTP	SUP (WTP) REC
~8 PM	SUP–PW starts shutting curb stops to destroyed homes	SUP- PW
8:15 PM	By this time, all filters operated manually at max. production as well as chlorine pumps and both raw water trains	SUP (WTP) REC
8 – 9 PM	LAF connects hydrant to LV, provides 1.5 MGD through one–way valve to aid pressure loss	LAF & LV
8:30 PM	SUP-PW informs REC that many hydrants were left open by firefighters; 6 in. dia. fire suppression line in Target was ruptured/wide open, took several more hours to close	SUP (WTP) REC
8:30 PM	Xcel again contacted to ask to help restore full power to WTP	SUP (WTP) REC
9 – 10 PM	XCel Energy drives natural gas trucks to LV SWTP. Natural gas service line cut and hooked up to the tanks to bring power back to the plant. Both LV WTPs begin running at full capacity (13 MGD total).	Xcel Energy & LV–PW
9:11 PM	The FEMA authorized federal funds for use to help firefighting costs, approving the state's Fire Management Assistance Grant	FEMA
9:45 PM	By this time, Xcel has completed repairs to on-site transformer and reestablished 3-phase power; full function of process equipment & instrumentation	SUP (WTP) REC
10:50 PM	Power restored at SWTP, chem pumps on, 5 MGD flow, Alum at 40 ppm, flow observed in clear well	LV–PW (SWTP)
12:45 AM	LV-PW closed interconnect with SUP	SUP (WTP) REC
~1 AM[1]	LV Operations Staff convene to discuss dangerously low water system pressure. Storage tanks still low.	LV–PW (SWTP)
1 – 7 AM[1]	Staff shuts off curb stops to damaged/destroyed properties or at entrances to neighborhoods, aiding pressure concerns and firefighting	LV–PW/ Louisville
5:35 AM	By this time, SWTP producing compliant potable water	LV-PW (SWTP)
8 – 9 AM	Water levels in storage tanks began rising	LV–PW
10 AM	Fire impacted area estimated to be 6,219 acres	BC–OEM[2]
12/31	Pump, process, controllers and communication (SCADA) system checks.	SUP (WTP) REC
12/31 Mid–day	Water levels within water storage tanks in Louisville are back to normal levels	LV–PW
12 PM	Start removal of water meters at the 22 destroyed homes on cul–de–sacs	LAF
12/31 Morning	SUP on–site storage tank was re–filled	SUP–PW
Afternoon	Flushed hydrants near 22 destroyed homes on cul–de–sacs	LAF
12/31 Mid–day	Snow starts	Boulder County
12/30 – 31	LAF WTP loses power intermittently	LAF
All Day	SSMHP experiences wind damage and structure leaking	Marshall

Timeline (Superior)



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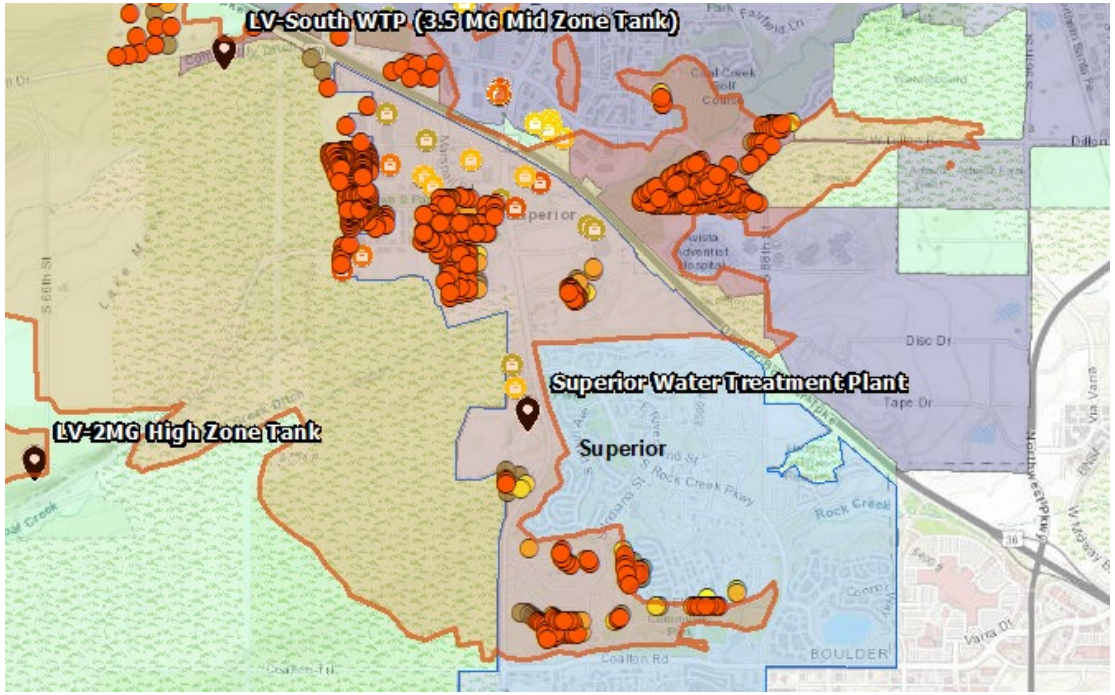
12/31	Pump, process, controllers and communication (SCADA) system checks.
12/31 Morning	SUP on–site storage tank was re–filled
12/31 Mid–day	Snow starts; Building plumbing pipes froze, broke, and leak

Timeline (Superior)



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Other Lifelines

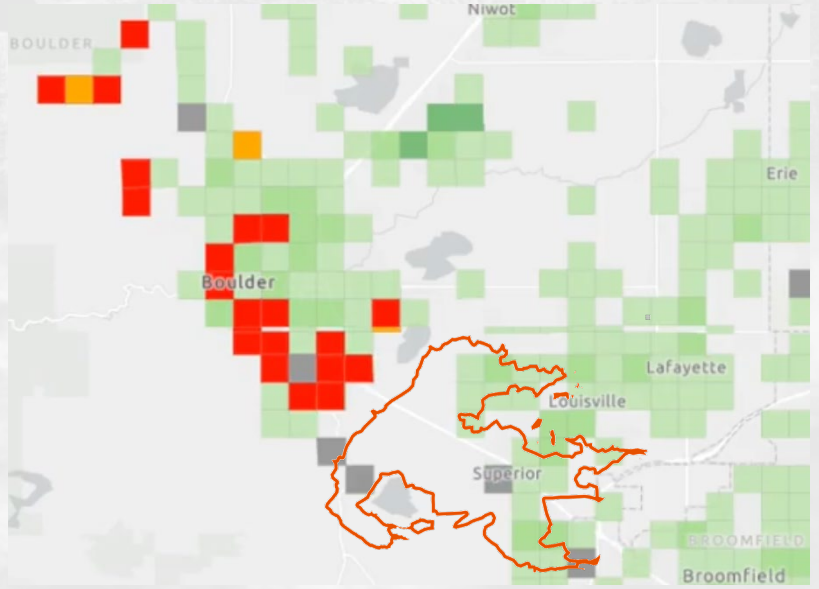
- Natural Gas
  - 13,000 customers with out gas
  - Xcel Energy dispatched 500 employees to help and provided thousands of portable heaters (freezing temperatures)
  - 6 Jan., most customer restored

- Electric
  - Statewide- 100,000 customers lost power (high winds impacted before fire)
  - Day after the fire, more than 5,500 without electricity
  - 3:52 PM- power our at evacuation center, facility relocated
  - 3 Jan. (4 days post fire) electric restoration “nearly complete”

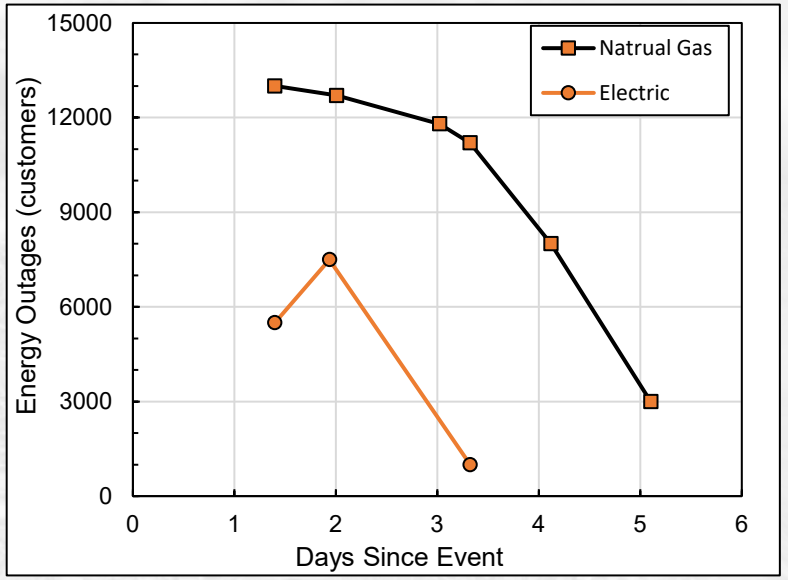
- Telecommunications
  - Xfinity- 8% of customers without connection one week after fire

- Wastewater- treatment challenges

- Transportation- evacuations, supplies notice



11 AM (12/30) (Gridmetrics, 2022)



Water Utility Response

- Internal leadership, exceptional staff, and requests for aide helped Louisville and Superior utilities stabilize

- **Mutual Aid:** Relationships between neighboring towns helped in asking for help during and after the fire.
  - Boulder, Ft. Collins, Erie, Westminster, South Adams County, Broomfield, Longmont, more…

- Lifeline interdependencies were critical to identify and react to; rapid communication among agencies

- Technology was important to Louisville and Superior in finding valves, isolating systems, flushing, and identifying sampling locations to restore service

- Transparent Public Communication

On December 31, boil water advisories were issued to the Louisville, Superior, Eldorado Artesian Spring, East Boulder Water District, and Sans Souci Mobile Home Park, and were rescinded between January 4 to 6 (CDPHE 2022a) with additional guidance issued for building owners (CDPHE, 2022b; CDPHE 2019). Almost one month after the fire, CDPHE issued a “bottled water advisory” to EBCWD, then rescinded it six days later (CDPHE 2022c).

Thank you!

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