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GEER Association
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2021 Marshall Fire
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May 2022

The 2021 Marshall Fire, Boulder County, Colorado

Geotechnical Extreme Events Reconnaissance Association
Version 1.0
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1.0 INTRODUCTION

On December 30, 2021, the Marshall Fire ignited as a small grass fire at approximately 11:00 AM. It began near the intersection of Colorado 93 and Marshall Road in Boulder County, Colorado (Bontke, 2022). Hurricane force wind gusts, ranging 80 - 100 miles per hour (mph) and sustained winds of 50 - 60 mph intensified the fire and accelerated the fire spread through the area (US Department of Commerce, 2022). A particularly wet 2021 spring, followed by an unusually dry 2021 summer and fall (see Section 4.1) exacerbated conditions and provided an abundance of fuel for the fire (Stavros, 2022). The fire traveled in an eastern direction, beginning in unincorporated Boulder County outside the town of Marshall. The fire reached the town of Superior at approximately 12:00 PM and Louisville by 1:00 PM. Snowfall on December 31st allowed fire fighters to gain control of the fire and its perimeter was considered fully contained by January 4th, 2022. In total, the Marshall Fire burned more than 6200 acres, with over 6000 of those acres burned in a 24-hour span (Boulder County, 2022(a)). Though the Marshall fire burned significantly less area than previous Colorado wildfires, it is the most destructive wildfire in Colorado to date in terms of housing damage (Rose, 2021).

As the fire progressed through the area, a series of evacuation orders were issued by Boulder County, Superior, and Louisville which helped to minimize injuries and loss of life in the communities. The first evacuation notice was sent out approximately 45 minutes after the fire's ignition to those just NE of the area of origin. Approximately an hour after the first evacuation notice, the Rock Creek area in Superior issued an evacuation notice, and approximately ten minutes after Rock Creek the whole town of Superior received notice to evacuate. By 2:30 PM all of Louisville was instructed to evacuate by Louisville Fire. In total, the Marshall fire destroyed 1,091 structures and damaged an additional 179 across unincorporated Boulder County, Louisville, and Superior. Of those destroyed and damaged, 97% were residential structures. Across the three jurisdictions, the total residential damage exceeded an estimated $500 million. At this time, the commercial damage assessment has not been completed (Boulder County, 2022(b)). The fire also impacted the water distribution systems of the three jurisdictions. The fire's burn area encompassed two of Louisville's treatment plants, Superior's only treatment plant, and the water distribution system established in unincorporated Boulder County. Due to the fire, Superior's treatment plants as well as Louisville's south treatment plant lost power. To meet firefighting demand, raw water was introduced into Louisville's water distribution system (Reinke, 2022). The GEER team mobilized an interdisciplinary team to investigate the geotechnical, lifelines, and housing impacts of the December 2021 Marshall Fire. During this phase of the reconnaissance, the team collected data and observations on:

- Governmental structure throughout the impacted communities
- Fire impacts on slopes throughout the impacted region
- Fire impacts on infrastructure (housing, foundations, retaining walls, roads)
- Fire impacts on lifelines (water, electricity, natural gas, telecommunications, transportation)

The goal of this version of the GEER report is to summarize the preliminary findings of the team from the collaborative investigation and establish a basis for future wildfire investigations.

2.0 TEAM STRUCTURE AND DATA COLLECTION APPROACH

The GEER team was comprised of experts in wildfires, geotechnical engineering, structural engineering, lifelines, environmental engineering, water quality, and decision making during and after disasters. The team was co-led by Brad Wham of the University of Colorado Boulder (CU) and Erica Fischer of Oregon State University (OSU). The team consisted of Andrew Whelton of Purdue University (PU), Abbie Liel of University of Colorado Boulder (CU), Amy Javernick-Will of University of Colorado Boulder (CU), Shideh Dashti (CU), Amy Metz of Oregon State University (OSU), Dae Kun Kang of Oregon State University (OSU), Nicolas Berty (CU), Jacob Klingaman (CU), Jessica Ramos (CU), and Hailey-Rae Rose (CU).

The NHERI RAPID team on the ground included Jaqueline Zdebski, Karen Dedinsky, Michael Grilliot, and Jamie Vickery; and were supported remotely by Karen Dedinsky, Andrew Lyda, Jeffrey Berman, and Joseph Wartman.

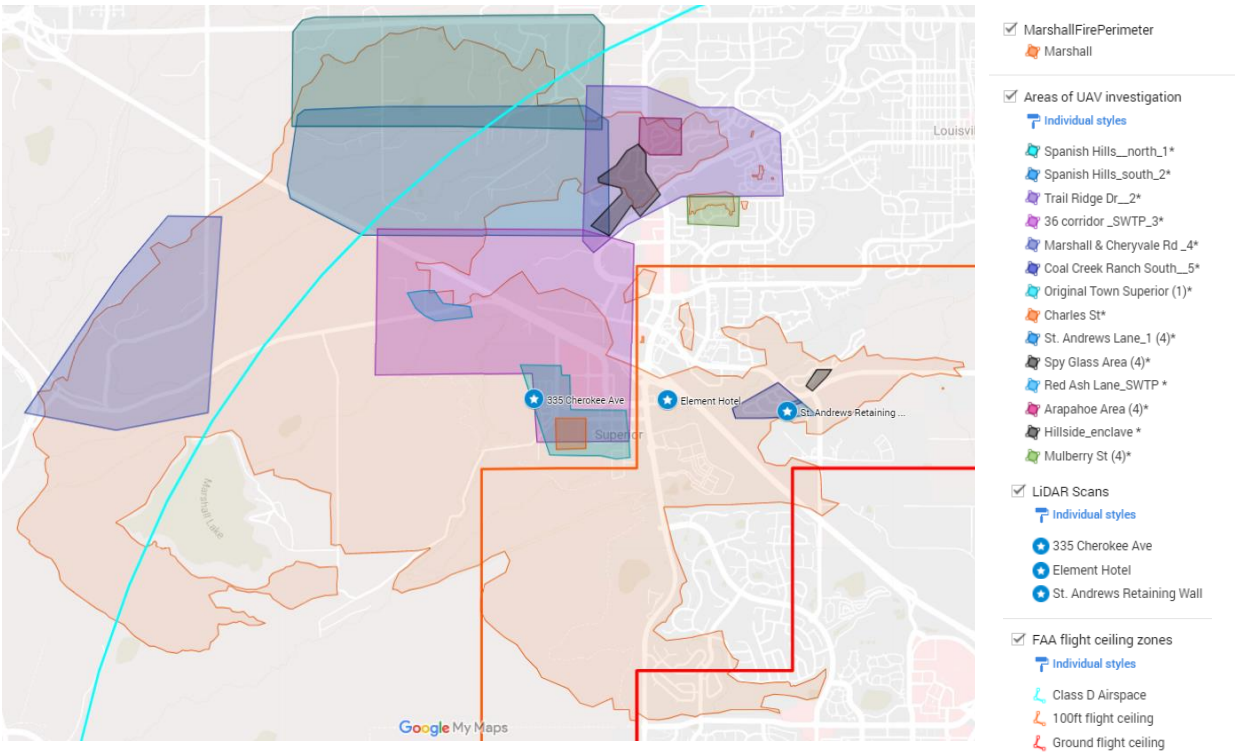
Preliminary reconnaissance started the day of the fire by team members that were directly impacted. Primary field activities occurred from 24 – 29 January 2022. Snow fall and cover significantly impacted the progress and collection of field data. Throughout this report, photos will show the amount of snow that accumulated on the ground while the GEER team was in the field. As a result, NHERI RAPID team members returned to the impacted regions for additional drone flights 13 – 16 February. However, even during these days, snowfall impeded progress on data collection. Other activities by various team members contributed to the enclosed report, as outlined below:

- 31 Dec. 2021: Preliminary visit to heavily impacted areas (Wham)
- 6–8 Jan. 2022: Visit with Public Works Departments on Water Quality Concerns (Fischer, Wham, Whelton)
- 20-21 Jan. 2022: Preliminary flights by RAPID facility (Grilliot, Vickery, Wham)
- 23 Jan. 2022: Team members arrive from OSU, Purdue, UW
- 24-28 Jan. 2022: Field reconnaissance occurs
    - Monday, January 24:
        - Ground building surveys in Mulberry, Vista Lane, Cherrywood, Original Town Superior
        - Drone flights in Mulberry, Cherrywood, and Original Town Superior
        - Slope surveying
        - Visit with Town of Superior Public Works Department on Water Quality Concerns
        - Visit with East Boulder County Water District on Water Quality Concerns
    - Tuesday, January 25 (snow)
        - Discussions with Louisville Open Space
        - Drone flight planning
    - Wednesday, January 26
        - Foundation surveys in Mulberry, Vista Lane, Cherrywood, Original Town Superior
        - Planning and LiDAR training on Element Hotel
        - Discussion with Louisville Public Works on timeline of events on the day of the fire
    - Thursday, January 27
        - Visit Louisville South Water Treatment Plant

        - On the ground surveys and retaining wall surveys in St. Andrews and Spyglass
    - Friday, January 28
        - On the ground surveys in Unincorporated Boulder County (media)
        - LiDAR scans – Element hotel and 335 Cherokee
        - Discussions with West Metro Fire Department
        - Discussions with Boulder County Health Department
- 29-30 Jan. 2022: Additional meetings and data collection by RAPID (Zdebski, Berty, Fischer, Wham)
    - Saturday, January 29
        - Discussions with Louisville Fire Department
        - On the ground surveys of St. Andrews neighborhood housing and retaining wall structures
        - UAV flights of Arapahoe Circle, Trail Ridge Dr., Summit Neighborhood
    - Sunday, January 30
        - Drone flights of St. Andrews and Spyglass neighborhood retaining walls and Red Ash Ln (SWTP)
        - LiDAR scans of St. Andrews
        - Discussions with Element hotel
- 13-16 Feb. 2022 RAPID Faculty returns for additional flights (Dedinsky, Grilliot, Wham)
    - Sunday, 13 Feb – flight planning and equipment prep
    - Monday, 14 Feb. – flights
        - Spanish Hills North, Unincorporated Boulder (South of S. Boulder Rd)
        - Spanish Hills South, Unincorporated Boulder (Spanish Hills Neighborhood)
    - Tuesday, 15 Feb. – flights
        - 36 Corridor, Southwest Louisville and North Superior
        - Marshall and Cherry Vale Rd. (Marshall, CO)
        - St. Andrews Ln. Coal Creek Ranch South, Louisville, CO
    - Wednesday, 16 Feb. – snow fall
- 25-27 Apr. 2022 RAPID Faculty returns for additional flights (Grilliot, Lyda, Wham)
    - Monday, 25 Apr. – travel, flight planning, equipment prep
    - Tuesday, 26 Apr. – flights
    - Wednesday, 27 Apr. – shipping gear, travel
- Additional field data collection and communication with impacted entities occurred throughout report preparation timeline.

2.1 Remote Sensing Methods

Several techniques for data collection were utilized during the reconnaissance. Large areas were surveyed using high resolution images captured by Uncrewed Aerial Vehicles (UCAVs). Specific locations of interests were also scanned using Light Detection and Ranging (LiDAR) equipment. Additional terrestrial methods included ground surveys and camera images (e.g., using the app Theodolite). All captured data has been posted to Design-Safe under the project: “GEER – Marshall Fire, Colorado” and Project ID: PRJ-3379. Methods of accessing the data are provided in Appendix A. An overview of collected data is provided in Figure 2-1.



https://www.google.com/maps/d/u/0/edit?mid=1G83LCZoWe3HvbXYUxJ-Y_qG6tQ-x5fIo&usp=sharing

Figure 2-1. Map of UAV flight coverage and LiDAR scan locations collected during this GEER reconnaissance (click to access) (39°57'15.7" N, 105°11'38.4" W)

2.1.1 Uncrewed Aerial Vehicle (UCAV)

Several unmanned aerial vehicles were used to capture low-altitude imagery from sites across the impacted region. The NHERI RAPID Facility made available two fixed wing aircraft and two quadcopters for the mission. An overview of the instruments is provided in Table 2-1

Table 2-1. Overview of remote sensing instruments

Device	Description	Notes/Links
DJI Mavic II Pro	Small, lightweight quad-copter UAS for scouting and damage assessments.	
DJI Matrice 210 V2 RTK with X5S Camera	Medium-sized, industrial, weather-proof quad-copter UAS system for damage assessment and SfM imagery collection	X5S Camera RTK GNSS
Sensefly eBee X	Lightweight, fixed wing, RTK UAS system. Up to 60 min flight time with 20 MP 3D camera for SFM imagery.	https://www.sensefly.com/drone/ebee-x-fixed-wing-drone/
Quantum Systems Trinity F90+	Fixed Wing eVTOL UAS system capable of 90 min flight time, vertical takeoff, and PPK positioning with 42 MP camera.	https://www.quantum-systems.com/project/trinityf90plus-mapping-drone/

Areas where UCAVs were flow are shown in Figure 2-1 and listed by date and equipment below:

- 20 Jan 2022 (Thurs)
  - Unincorporated Boulder, test flights [Trinity]
- 21 Jan 2022 (Fri)
  - Arapahoe_area_test: Arapahoe Circle, West of McCaslin, Louisville [Matrice 210 OG] [Altum-multispec] {note: may be listed as 20220222 on DesignSafe}
- 24 Jan 2022 (Mon)
  - Mulberry: Cherrywood II & Heritage Park Neighborhoods, [Matrice 210 RTK]
    - Cherrywood Ln., Mulberry St., Vista Ln., Louisville
  - Superior: Original_Town & St. Charles, South Superior [Matrice 210 RTK]
- 25 Jan 2022 (Tues) – Snow – flight planning
- 26 Jan 2022 (Wed)
  - Hillside-enclave, Louisville, [Matrice]
- 28 Jan 2022 (Fri)
  - Original Town Superior, Sagamore, snow cover [eBee]
- 29 Jan 2022 (Sat)
  - Araphahoe_2: Trail Ridge Dr., Summit Neighborhood, Louisville [Matrice 210 RTK]
  - Arapahoe_2B: The Grove at Harper Lake (south of Harper Lake), Louisville [Matrice 210 RTK]
- 30 Jan 2022 (Sun)
  - Spyglass Cir., RS2, Coal Creek Ranch, Louisville, [Matrice 210 RTK]
  - St. Andrews Ln. RS1, Coal Creek Ranch South, Louisville [Matrice 210 RTK]
  - WaterTreatment: Red Ash Lane, SWTP, [Matrice 210 RTK]
- 14 Feb. 2022 (Mon)
  - Spanish_Hills_North: Unincorporated Boulder (South of S. Boulder Rd) [Trinity]
  - Spanish_Hills_South: Unincorporated Boulder (Spanish Hills Neighborhood) [Trinity]
    - Support imagery, cell tower [Mavic 2 Pro]
  - Arapahoe: Trail Ridge Dr. Area, south of Harper Lake [Trinity]
- 15 Feb. 2022 (Tues)
  - Old_Town_Superior: 36 Corridor, South-west Louisville and North Superior [Trinity]
    - Sagamore Neighborhood, video [Mavic 2 Pro]
  - Marshall: Town of Marshall and Cherry Vale Rd. (aka “Ridge”) (Marshall, CO) [Trinity]
    - Support imagery [Mavic 2 Pro]
  - Coal_Creek: St. Andrews Ln. Coal Creek Ranch South, Louisville, CO (remainder of neighborhood [Matrice 210 RTK]
- 26 Apr. 2022 (Tues) [No snow cover]
  - OldTown_20220426: Original Town Superior and Sagamore Neighborhood [Trinity]
  - Arapahoe_20220426: Enclave, Trailridge Dr. Northwest Louisville [Trinity] Marshall2_20220426: Town of Marshall and location of fire ignition [Trinity]
  - SpanishHillsSouth2_20220426: Unincorporated Boulder County (Spanish Hills Neighborhood) [Trinity]

UCAVs were equipped with fully autonomous mapping capability that allows for pre-programmed flight. The small footprints of the quadcopters made them ideal for transport to various sites of interest and flying near damaged structures without the risk of causing significant damage or harm in the event of a malfunction. The fixed winged aircraft had the advantage of longer flight times and more coverage area at higher altitudes. The eBee X did require some additional open space for take-off and landing. The vertical take-off and landing capability of the Trinity 90x was a noted advantage in more densely populated areas where homes are closer together and open space may not be available for launch areas.

The UCAVs were equipped with fully autonomous 3D autopilot that can fly an entire mission with little or no operator input. The operator was able to monitor the UCAV from the ground using a wireless telemetry link connected to a laptop computer. This telemetry link showed the real-time GPS location of the UCAV as well as critical flight instruments such as heading, velocity, and artificial horizon. Along with the telemetry link, the operator always maintained a separate radio control link.

Several camera systems were used to take vertical and oblique images during the mission. Three-dimensional point cloud and textured models were developed from the aerial images captured with the cameras. Structure from Motion (SfM) computer vision technology was used to develop the 3D models. Finalized dense point clouds were exported, scaled, edited, and analyzed in point cloud manipulation software *CloudCompare 2.6.1*. Examples of the resulting orthomosaics are shown in Figure 2-2 and were made immediately available to impacted municipalities to support assessment and recovery planning.

https://ucboulder.maps.arcgis.com/apps/mapviewer/index.html?webmap=c912400c8c6840f1b086094e3d48cd16

Figure 2-2. Orthomosaics from UCAV flights hosted on ArcGIS online (view) (39°57'15.7" N, 105°11'38.4" W)

2.1.2 Light Detection and Ranging (LIDAR)

Terrestrial LIDAR scanning (3D laser scanning) consists of developing a three-dimensional point cloud of coordinates by sending laser pulses toward a surface and measuring the time it takes for the pulse to be received. The time of travel for a single pulse reflection is measured along a known trajectory such that the distance from the laser, and consequently the position of a point of interest, is computed. This methodology allows the collection 50,000 – 150,000 points per second to generate a detailed 3D model.

This reconnaissance utilized two different scanners: Leica RTC360 (short range scanner) and the Leica ScanStation P50 (long range scanner). The terrestrial LIDAR technique (3D laser scanning) consists of sending and receiving laser pulses to build a point file of three-dimensional coordinates of the scanned surface.

LIDAR data was collected at the following locations:

- St. Andrews Ln. Coal Creek Ranch South, Retaining Wall (RS1) [RCT360]
- 336 Cherokee Ln. Sagamore Subdivision, Superior, CO [RCT360]
- Element Hotel, Superior, CO [P50] [RCT360]

A total of 3 terrestrial LiDAR scanning (TLS) sites were developed during our reconnaissance (Figure 2-1 and Figure 2-3) over a total of 53 individual scans (Table 2-2). Scans were typically collected at a nominal point spacing of 43mm at 100m, to facilitate coverage of several sites over highly detailed scanning of individual features. Individual lidar scans for only the Coal Creek Ranch South retaining structure were merged into a composite point cloud using Maptek's I-suite software. Resultant merged point cloud models, and raw data as .e57 and .las files, are available via DesignSafe. Users should note noise due to passing vehicles or individuals, incidental returns from rain, or other spurious points have not been removed to provide raw and unaltered data to those wishing to perform their own registration or analyses. The remainder of the TLS data will be merged into a singular point cloud data over the coming months to evaluate the structural performance of both a single-family home and commercial structure during a fire.

Figure 2-3. Map of location for each terrestrial lidar scan (336 Cherokee Ln: 39°57'20.6" N, 105°10'40.7" W; Element Hotel: 39°57'19.4" N, 105°09'47.2" W; Coal Creek Retaining Wall: 39°57'17.0" N, 105°09'0.30" W)

Table 2-2. Summary of terrestrial lidar scans from the GEER reconnaissance. All models and data can be found at 'Designsafe'.

Name (ID)	# of Scans	Key Features	Notes
336 Cherokee Lane	13	Geometry and damage state of destroyed house and property	Scan of a destroyed home within the Sagamore neighborhood of Superior to capture the final damage state of a house impacted by fire
Element Hotel	28	Damaged steel-timber composite hotel	Scans of a damaged hotel to capture the final damage state of an engineered building impacted by fire. Timber beams and columns were severely charred and significant deformation of the steel members occurred.
Coal Creek Ranch South Retaining Structure (RS1)	12	Significant charring of timber retaining structure	Scans of timber retaining structure impacted by the fire. Retaining structures are on significant slopes.

2.1.3 Satellite Imagery

Satellite imagery was used to plan data collection and provide an overview of the impacted area before, during, and after the event. Maxar Technologies (2022) provided access to a variety of valuable images taken on 24hr intervals; examples are provided in Figure 2-4. Figure 2-5 shows images of the Sagamore Neighborhood taken before, during, and after, demonstrating potential detail available through satellite imagery. Images taken at 2 PM during the fire provided in (Figure 4-6). Summary images and a brief summary of each TLS model are described below.

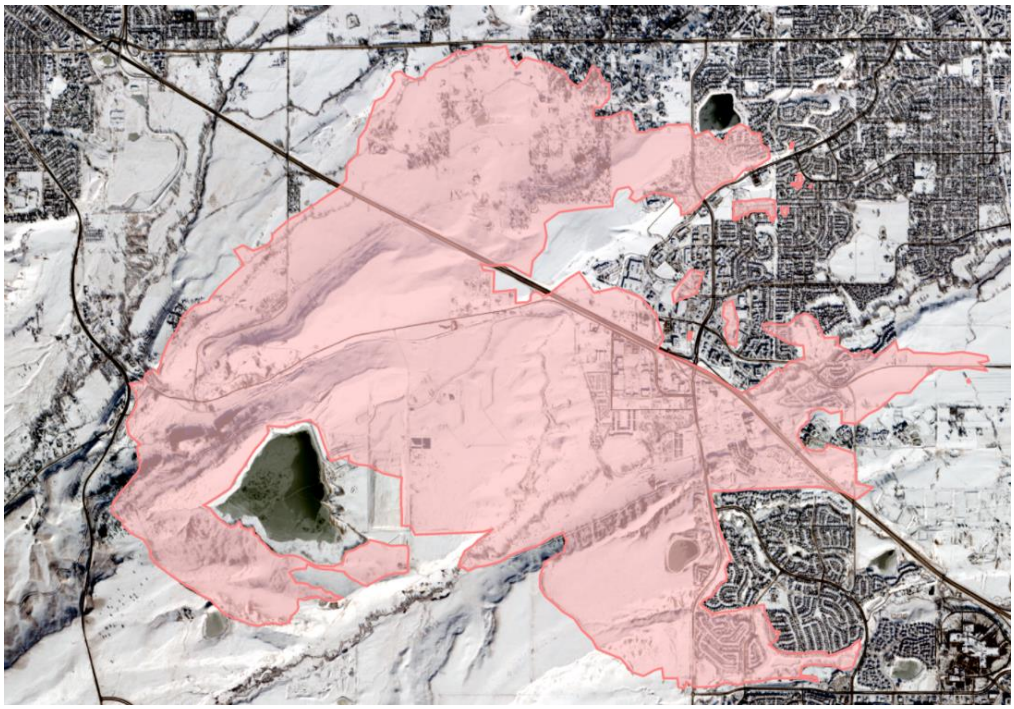


Figure 2-4. Comparison of before and after imagery available from Satellite imagery (2 Jan. 2022) (Maxar Technologies, 2022) (39°57'15.7" N, 105°11'38.4" W)


(a)


(b)


(c)

Figure 2-5. Examples of satellite imagery to evaluate spatial features: (a) before, (b) during (2 PM MST), and (c) after (2 Jan. 2022, vexcel 7.4 cm) in Sagamore Neighborhood (39°57’25.7” N, 105°10’41.5” W)

2.2 Geotagged Datasets

The reconnaissance team merged the GPS data, site logs, and digital photos into a common database. Following the reconnaissance, a Google Earth KML file was generated to display the observations on dynamic digital maps. All pictures and maps will be available on DesignSafe.

The primary tools of the reconnaissance effort were smartphone (iPhones and Android) devices that are essentially handheld computers, phones, cameras, GPS units, and dictation devices. These devices integrate all the basic functions previously performed by individual pieces of equipment.

All recorded information, photographs, and data observations were located with latitude and longitude coordinates, either through onscreen functions utilizing the reconnaissance app “Theodolite” or as part of standard smart phone meta data. All observations were recorded and reported as ellipsoid heights in the World Geodetic System of 1984 (WGS84).

2.3 Building Survey Approaches

On-the-ground surveys of damaged, destroyed, and standing homes were performed for over 200 homes throughout Louisville, Superior, and Unincorporated Boulder County. The surveys were executed through a google form developed by the team prior to entering into the field and adjusted throughout the week to fit the objectives of the study. The specific data that was collected through the survey are:

- Street address of the house
- Type of structure (freestanding home, apartment building, townhome)
- Damage state of the house (Damaged, partial collapse; Damaged, visible boarding up of windows or damage on outside of house (yellow tag); Destroyed; Standing, undamaged)
- The color of the foundation if the house is destroyed using color cards developed from the research by Hager (2014)
- Type of pipes connected to the hot water heater
- Number of stories above ground
- Type of damage visible throughout the property
- If there is a destroyed structure neighboring the house (including damaged out buildings)
- Characteristics of the neighboring homes including the distance between each of the homes
- Characteristics of retaining walls close to the home

The survey instrument provides space for additional comments by the user. Some additional notes that were made throughout the survey were damage patterns to concrete foundations and the type of foundation that each home had (matt, basement, rubble, etc.)

2.3.1 Temperature of foundation

The temperature of the foundation was determined by comparing the colors of concrete provided in Hager (2014) to the foundation itself (Figure 2-6). The temperature range investigated by Hager (2014) was 300ºC – 900ºC. Temperature ranges of the foundation were noted in groupings of:

- Below 300ºC
- 300 – 400ºC
- 500 – 600ºC
- 700 – 800ºC
- 900ºC

Figure 2-6. Comparing concrete colors from Hager (2014) to foundation colors in the field (39°58’20.0” N, 105°09’22.2” W)

3.0 REGIONAL WILDFIRE RISK

The wildland urban interface (WUI) is where structures or other human development meet vegetative or wildland fuels (ICC, 2021). In the state of Colorado about half of the population lives in a WUI. In Boulder County, about 18% of the population lives in a moderate or higher risk to WUI fires. The map in Figure 3-1 shows the history of WUI fires within Boulder County. These have mainly occurred west of Boulder. Figure 3-1 shows the mountainous forested life zones overlaid with the locations of where most of the past Colorado wildfires have occurred. These life zones and fire boundaries show that most of the wildfires in Colorado's past have occurred west of Boulder in the forested landscape. There are both forested and grassland WUI within Boulder County, which can threaten both life and property. From the years 2011 - 2015, there were 61,900 grass, brush, and forest fires in the western U.S. About 39% of these fires were grass fires and during these years a total of 6,200 structures were destroyed (Ahrens, 2018).

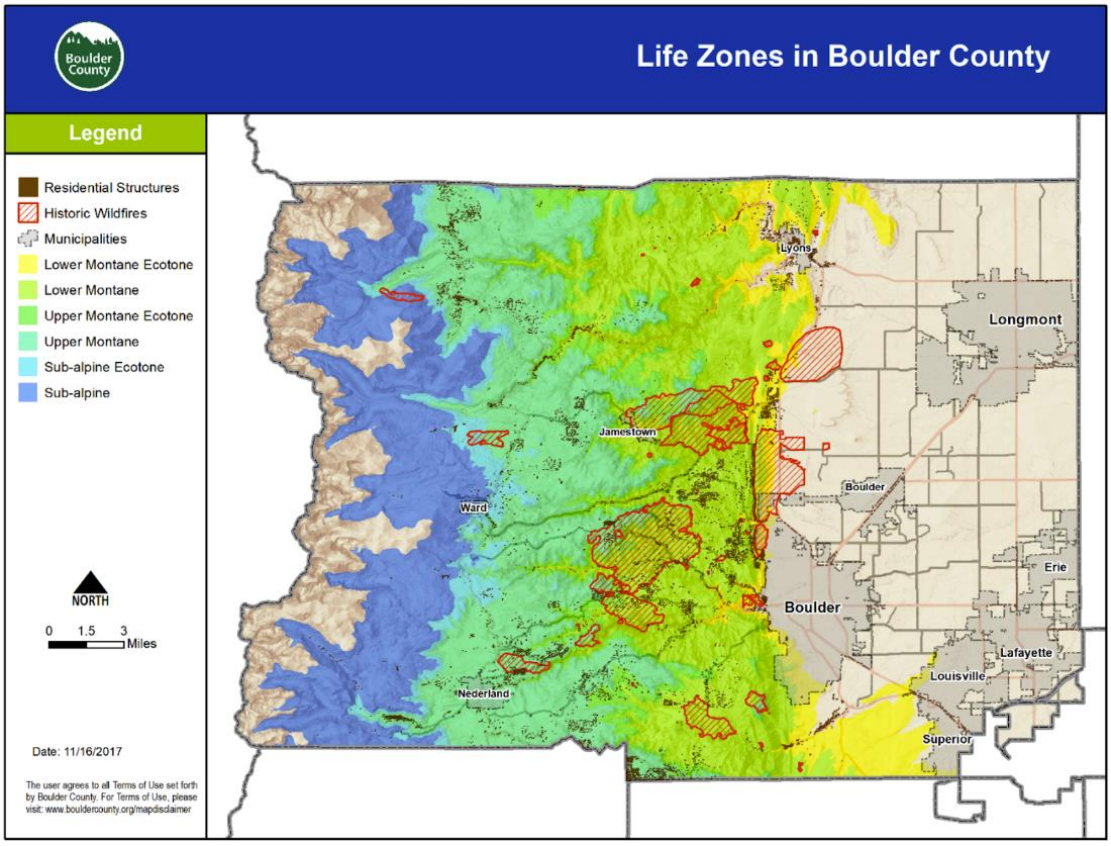


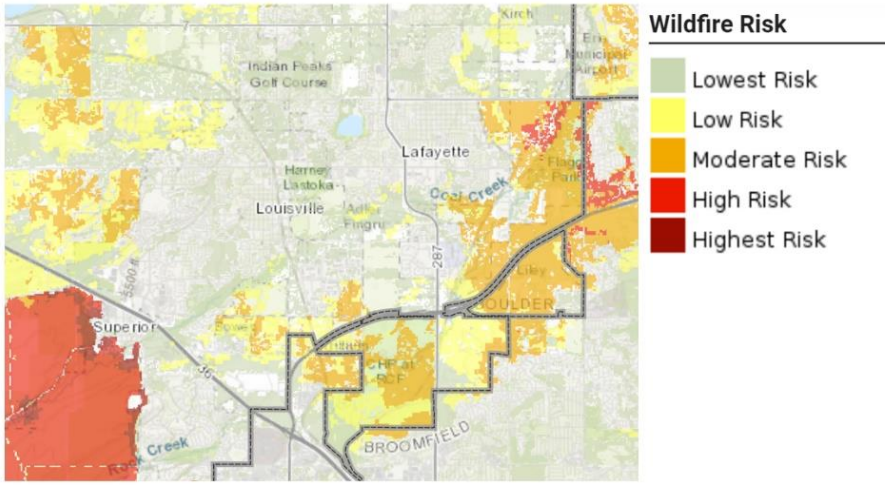
Figure 3-1. History of WUI fires within Boulder County, Colorado

Figure 3-2 shows a map of Boulder County with data from the Colorado Forest Atlas. The Colorado Forest Atlas is a mapping tool, developed in 2017, that maps the wildfire risk throughout the state and the implications of that risk at 30-meter resolution. Figure 3-2a shows the wildfire risk in and around Louisville and Superior, Colorado calculated as a combination of the risk rating at each point in the map and the burn probability at that point. This map shows that the majority of the town of Louisville is in the lowest area of wildfire risk. Northwest Louisville has low wildfire risk and southeast Louisville has low and moderate wildfire risk. The western portion of Superior has high wildfire risk.

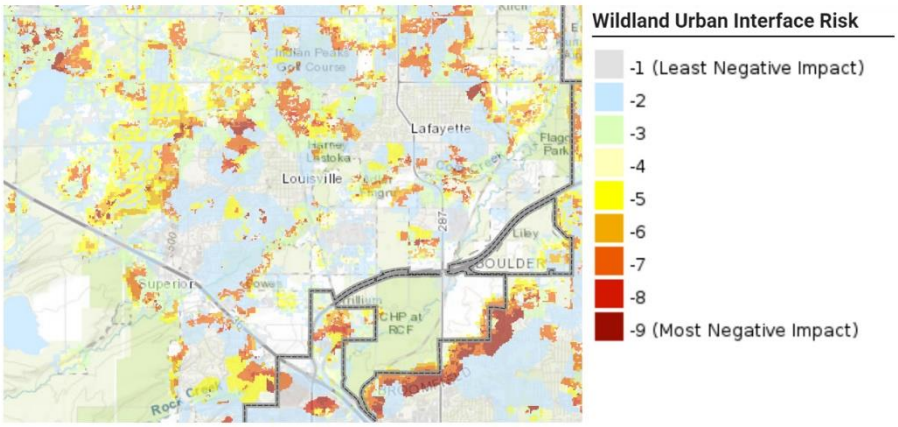
Figure 3-2b shows a map of Louisville and Superior's wildland urban interface risk. The WUI risk map portrays the potential impact of wildfire on the community population and homes and is dependent upon housing density and potential flame length of a fire in the region. The red shades on the map represent the areas of Louisville and Superior where the most negative impacts of a wildfire would occur. These areas are to the north, northwest of Louisville as well as a band the runs from the southwest to northeast of Louisville. The town of Superior has the most negative impacts on the western side of the town corresponding to where the highest wildfire risk occurs, as shown in Figure 3-2a.

Figure 3-2c is a map of the likelihood of burning within the towns of Louisville and Superior. This map was derived based on historical ignition patterns throughout the state of Colorado, including burning on both federal and non-federal lands. This map shows many highest likelihoods of burning scattered throughout the town of Louisville indicating high risk of home ignition throughout the town.

The Marshall Fire is the first large wildfire west of Boulder within Boulder County (Figure 3-3). Other wildfires have been west of Boulder where more forested areas are present. In 2011 Boulder County developed the *Boulder County Community Wildfire Protection Plan* (CWPP) as a collaborative effort between Boulder County residents, stakeholders, and staff of bounder county (Boulder County, 2021). This plan was voluntary for residents to implement on their own properties. Figure 3-4 shows the locations where the Boulder County CWPP has been implemented on private property.



(a)



(b)

(c)

Figure 3-2. a) Wildfire Risk, and (b) Wildland Urban Interface Risk, and (c) Likelihood of a wildfire starting (Colorado Forest Atlas)

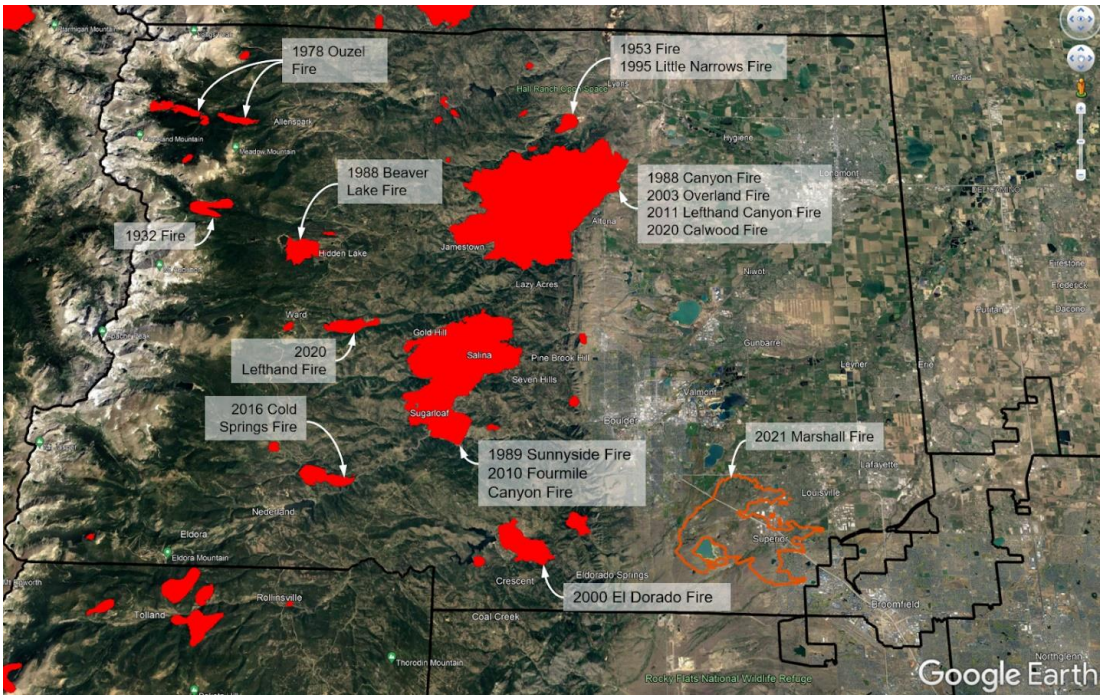


Figure 3-3. Historical wildfires within Boulder County in relation to the Marshall Fire

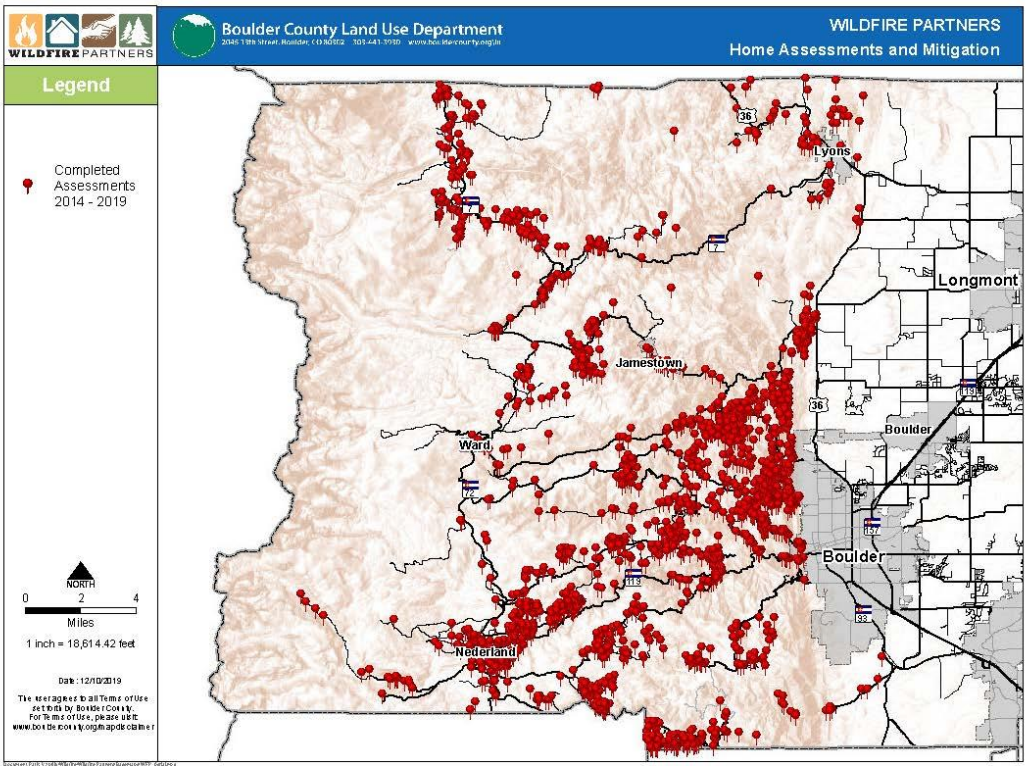


Figure 3-4. Locations of homes mitigated per Boulder County Wildfire Partners Home Assessments and Mitigation (Wildfire Partners, 2022)

4.0 OVERVIEW OF THE MARSHALL FIRE

The Marshall Fire started at 11 am on December 30, 2021 near South Foothills Highway and Marshall Road. The same morning, two other fires were reported in Boulder County, shown in Figure 4-1. The first bush fire was quickly extinguished. The second, called the Middle Fork Fire, was reported around 10:30 am near North Foothills Highway and Middle Fork Road. The Middle Fork Fire was contained within a few hours (Boulder County Office of Emergency Management, 2021).

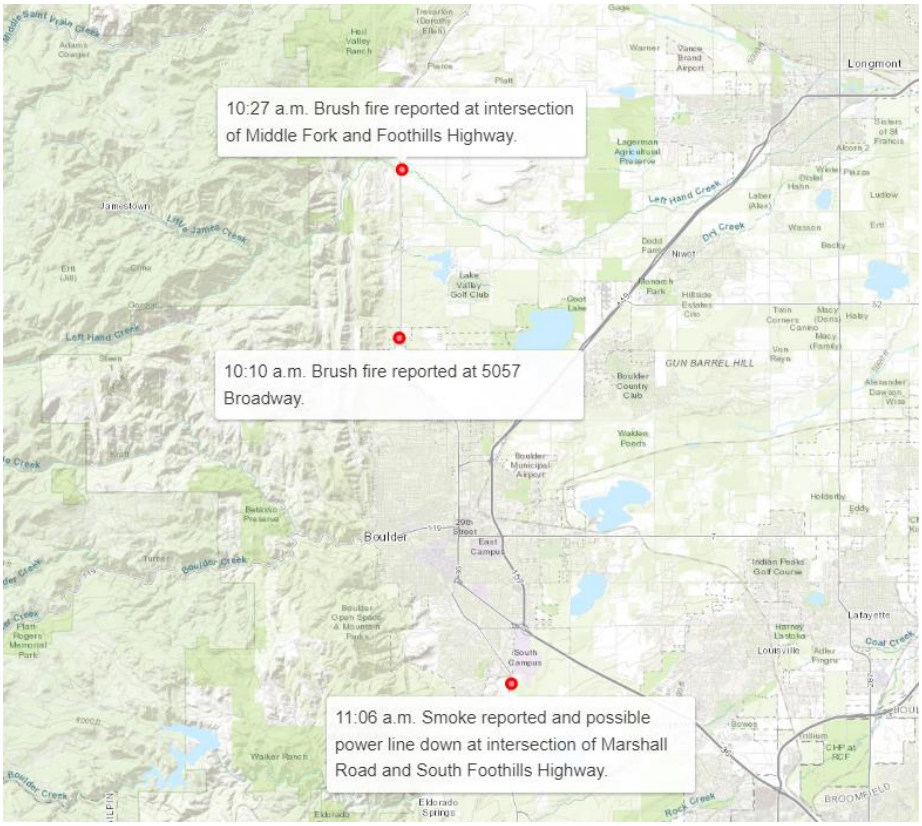


Figure 4-1. Approximate locations of three reported fires during morning of 30 Dec. 2021 in Boulder County (Markus, 2022) (Middle Fork and Foothills: 40°07’45.6” N, 105°16’56.5” W; 5057 Broadway: 40°04’03.7” N, 105°16’55.9” W; Marshall Rd and S. Foothills: 39°57’13.1” N, 105°13’55.2” W)

4.1 Weather and Environmental Conditions

On December 30, there was a windstorm within the region of the Marshall Fire. Atmospheric pressures on the east side of the Rockies dropped abruptly and strong downslope winds followed shortly after. Wind gusts of up to 100 miles per hour were recorded in the foothills west of Denver (Figure 4-2). These wind gust helped push the fire front to move at approximately 8-9 miles per hour (Scott, 2022). The high winds also grounded aerial support firefighting planes and tankers; which were available in the region to drop fire retardant from the air but unable to fly safely.

```
...Boulder County...
1 NE Crisman                    102 MPH    1120 AM 12/30
3 NW Marshall                   90 MPH     0125 PM 12/30
Boulder                         75 MPH     0215 PM 12/30
036e03750rws1rp1 At Baseline    73 MPH     1123 AM 12/30
Wondervu                        72 MPH     0956 AM 12/30
Atoc - Univ. Colorado Campus    71 MPH     1050 AM 12/30
Lafayette                       70 MPH     1001 AM 12/30
Lyons 3W                        70 MPH     1042 AM 12/30
Longmont                        68 MPH     1147 AM 12/30
Louisville                      68 MPH     0200 PM 12/30
Nederland                       66 MPH     0900 AM 12/30
Nederland                       65 MPH     0938 AM 12/30
Boulder                         64 MPH     1117 AM 12/30
Boulder                         64 MPH     0325 PM 12/30
Boulder                         63 MPH     1116 AM 12/30
Boulder                         62 MPH     0223 PM 12/30
Boulder                         61 MPH     1042 AM 12/30
Ward                            60 MPH     0833 AM 12/30
```

Highest wind gusts reported in Boulder County, Dec. 30, 2021. (Each line is a separate weather station.)

Figure 4-2. Highest wind gusts reported at weather stations across Boulder County on 30 Dec. 2021 (Gabbert, 2021)

Boulder County experienced significant rains during Spring 2021, providing the opportunity for plant growth throughout the grass lands and front range. These rains were followed by an unusually dry summer and fall. Figure 4-3 shows the precipitation in inches throughout 2021 near Boulder, Colorado along with the normal precipitation levels (Scott, 2022). During the months of March, April, and May, rainfall was higher than the normal precipitation levels; however, for June – December, precipitation levels were significantly lower than normal. In Denver, Colorado, there was 1.92 inches of precipitation recorded between June 1 and December 30, which is the lowest precipitation levels since 1939 (US Department of Commerce NOAA, 2022).

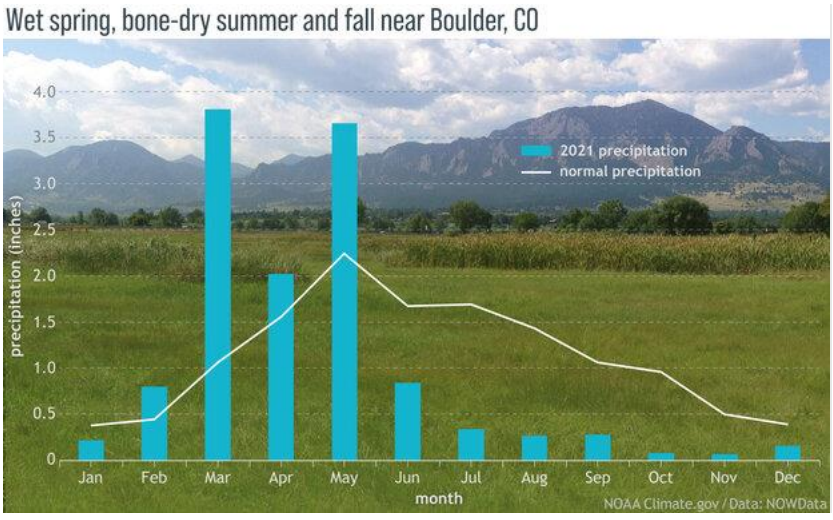


Figure 4-3. Average precipitation per month near Boulder, CO for Jan. – Dec., 2021 (Scott, 2022)

These low precipitation levels were coupled with higher-than-normal temperatures. Figure 4-4 shows the difference in average temperatures in Boulder throughout the month of December. The red bars represent the difference in temperature above the average temperature and the blue bars

represent the difference in temperature below the average temperature. In the region specifically impacted by the Marshall Fire, the lack of precipitation caused drought conditions beginning in October 2021 and by December 2021, drought conditions were characterized as extreme (Scott, 2022).

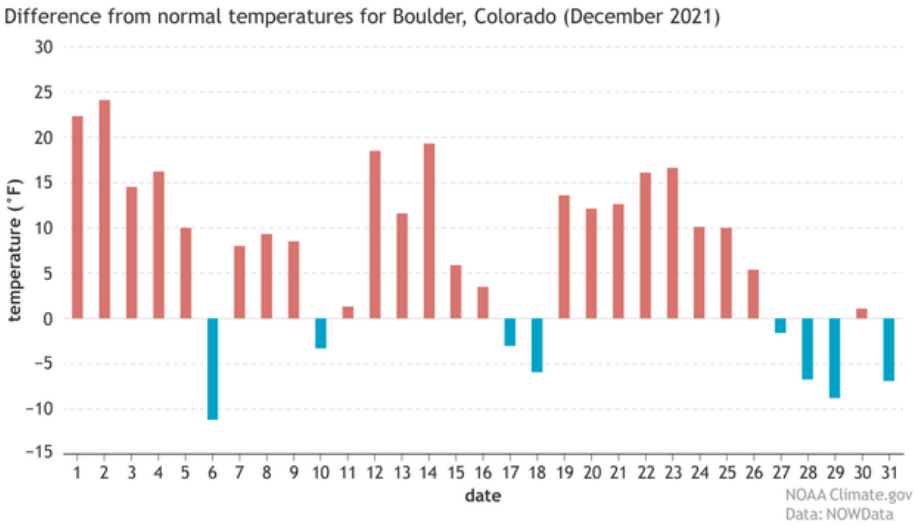


Figure 4-4. Difference from average temperatures for Boulder, CO for Dec. 2021 (Scott, 2022)

4.2 Impacts and Extent

On the day of the fire, there was a windstorm and atmospheric pressure dropped sharply east of the Rockies, followed by strong downslope winds. At the base of the foothills west of Denver, wind gusts reached 100 miles per hour. This wind spread embers and flames north and east of the fire towards Superior, Louisville, and Unincorporated Boulder County (Scott, 2022). The fire impacted 6,219 acres, destroying 1,084 residential and 7 commercial structures, and damaging 149 homes and 30 commercial structures (Figure 4-5) (Boulder County, 2022(b)). A summary of housing damage is shown in Table 4-1 for each impacted area(Superior, Louisville, and Unincorporated Boulder County).

Figure 4-6a shows a satellite image taken at 2:00 PM on the day of the fire and Figure 4-6b includes an overlay of the approximate fire perimeter (Maxar, 2021). At the time of this writing, the source of the fire is still being investigated. While several potential sources have been speculated (Vaughan, 2022), Figure 4-7 provide a possible ignition point based on burn area shape and prevailing winds, overlayed on the magnified satellite imagery from 30 Dec. with updated 2 PM fire perimeter.

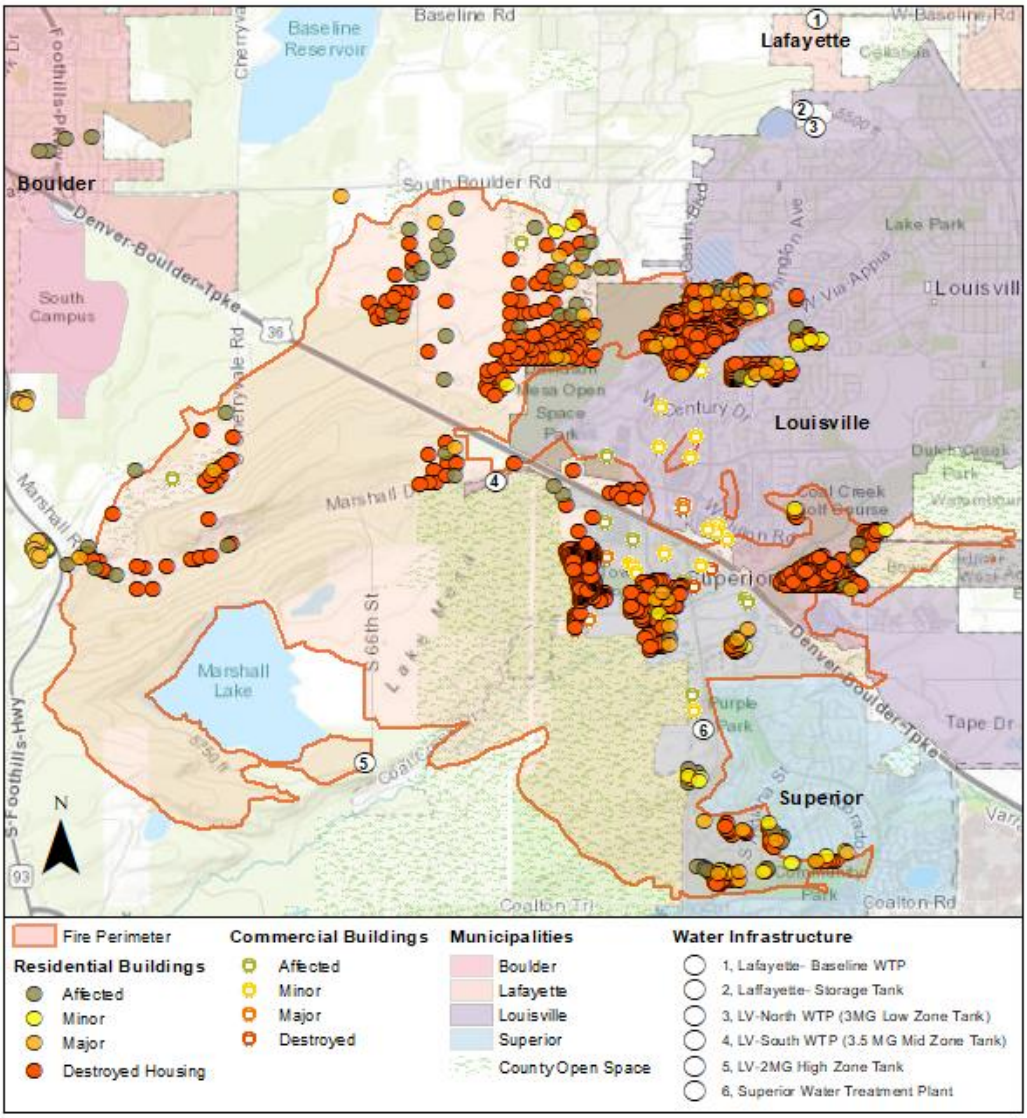


Figure 4-5. Approximate extents of the Marshall Fire (M3)

Table 4-1. Breakdown of Marshall Fire impacts by community (Boulder County, 2022(b))

Community	Residential Structures				Commercial Structures		Total Destroyed
	Destroyed	Damaged	Total	Approx. value	Destroyed	Damaged	
Superior	378	58	436	$152,757,462	3	14	381
Louisville	550	43	593	$229,199,184	4	14	554
Unincorporated Boulder Co.	156	48	204	$131,255,944	-	2	156
Totals	**1084**	**149**	**1228**	**$513,212,590**	**7**	**30**	**1091**

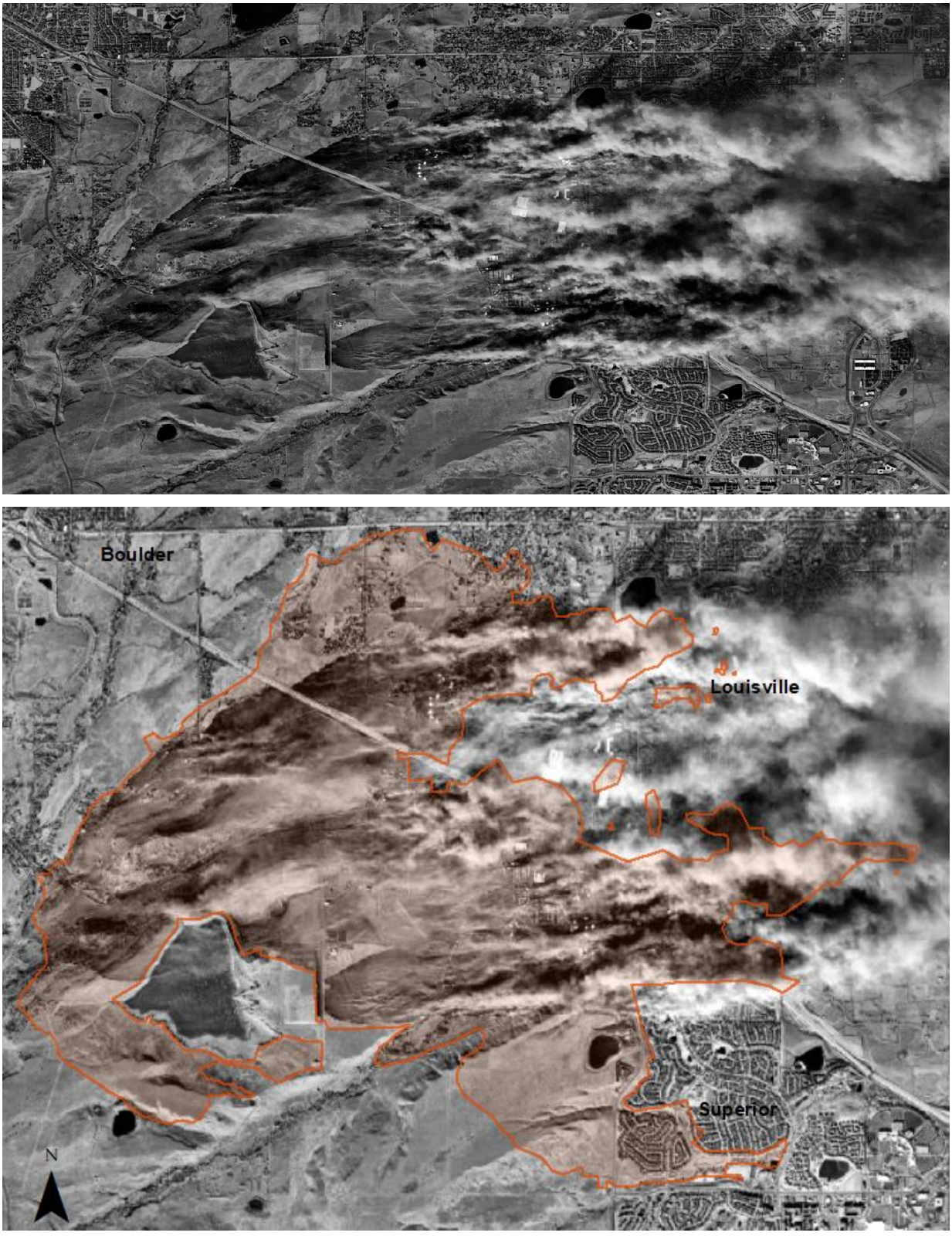


Figure 4-6. Satellite image of Marshall Fire, 2021-12-30 21:00:33 Zulu (2:00 PM MT) (Maxar, 2022) (39°57'15.7" N, 105°11'38.4" W)

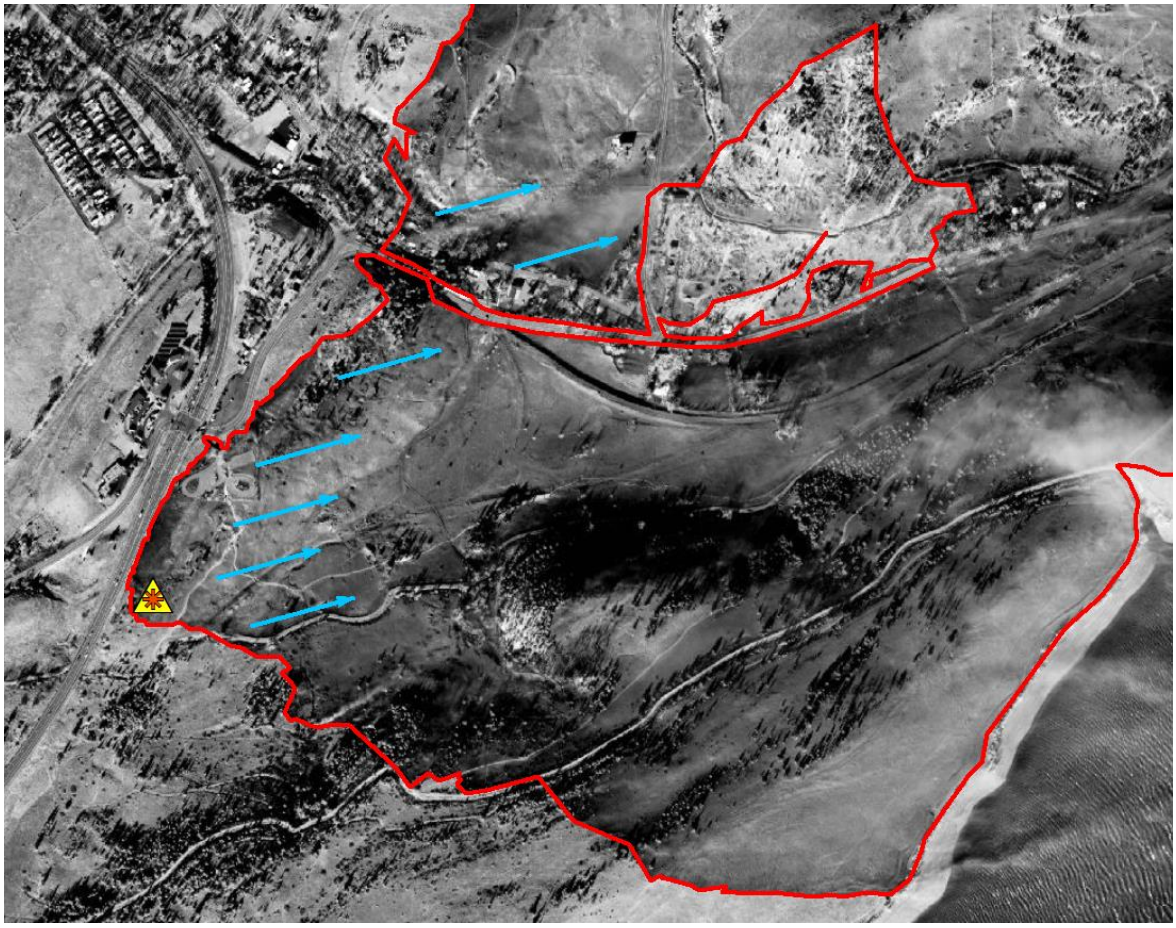


Figure 4-7. Possible ignition location, 2 PM fire perimeter, and prevailing wind direction (blue) at intersection of Highway 93 and Eldorado Springs Dr. in Marshall. (39°57’13.3” N, 105°13’56.0” W)

Figure 4-8. Possible location of fire ignition, UCAV capture imagery near intersection of Highway 93 and Eldorado Springs Dr. in Marshall. (39°57’13.3” N, 105°13’56.0” W)

4.3 Marshall Fire Timeline

An overview of key events occurring during the Marshal Fire and shortly after are provided in Table 4-2. The timeline has been assembled from interviews, public notices, emergency dispatch records, and other sources. While timelines pertaining to specific topics (e.g., Lifelines) are provided in the following sections, this overview provides some insight toward the progression, speed, and complexity of the event.

Table 4-2. Timeline of Marshall Fire Events

Approx. Time	Event	Agency/Area
30 December 2021		
11:06 AM (MST)	Reported start of the Marshall Fire, near intersection of Route 93 and Marshall Rd. in Boulder County, CO	Emergency Dispatch
11:30 AM	Centennial Peaks Hospital calls Louisville Fire Protection District (LFPD) to ask if they should evacuate	LFPD
11:33 AM	Firefighters reported at least one structure is compromised.	Fire Radio Dispatch
11:47 AM	Evacuation order issued for Highway 93 and Marshall	BC-OEM
12:10 PM	Shoppers evacuated from SUP Costco, Whole Foods, etc.	*Colorado Sun*
12:15 PM	- Evacuation order issued for western portions of Superior - Flames reported in backyard of Sagamore neighborhood	BC-OEM, Dispatch
12:30 PM	Louisville notifies all city employees to evacuate	LV-PW

Approx. Time	Event	Agency/Area
12:40 PM	Mountain View Fire Department abandons Sagamore neighborhood (SUP) because fire has overtaken community.	Radio Dispatch: *From Colorado Sun article*
12:46 PM	Evacuation order issued for additional areas of Superior up to Highway 36	BC-OEM
12:47 PM	LV Police Department tweets “The City of Louisville is not under an evacuation order at this time. Please avoid travel in the area, and take safety precautions.”	Louisville Police Department
12:50 PM	Caller reports fire has jumped US 36 into Louisville	Dispatch
1:00 PM	LFPD clears overlook near Key Bank of fire onlookers	LFPD
1:00 PM	Fire front has reached Home Depot in Louisville	LFPD *Chief Wilson*
1:00 PM	LV-PW turned North plant to maximum capacity (8 MGD)	LV-PW
1:08 PM	Evacuation order issued for southern parts of Louisville, McCaslin, and east of Highway 36	BC-OEM
2:00 PM	**Maxar Satellite Photo taken of region [Figure 4-6]** - **Sagamore community only has five standing homes**	**Satellite image (Maxar Inc.)**
2:08 PM	B.P. Wham evacuates 603 Ridgeview Drive, Louisville	Pers. Com.
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 – 3:00 PM	Cherrywood col-de-sac burns and West Metro fire begins taking down fence between Cherrywood homes and Cypress Lane homes to protect Cypress Lane. Louisville community south of Harper Lake begins to burn.	West Metro Fire
2 – 3:00 PM	XCel Energy calls LV-PW to ask how they can help. LV-PW asks XCel Energy to prioritize getting power back to water treatment plants low on water.	LV-PW
2:30 PM	East Boulder Water loses internet/electric (they had data up to that point)	EBCWD
2:51 PM	Evacuation order issued for all of Louisville	BC-OEM
3 – 4:00 PM	City of Louisville loses electricity and natural gas including at the Louisville Fire Station. Fire station begins to run natural gas generator to power station.	LFPD
3:45 PM	Boulder Incident Management Team took operational management of the fire	BC-OEM
4:00 PM	Louisville south water treatment plant (SWTP) opens interconnect with Superior water distribution system	LV-PW
4:00 PM	Some patients evacuated from Avista Adventist Hospital, 5 PM entire facility is evacuated.	LV
5:00 PM	Fire impacted area estimated to be 1,600 acres	BC-OEM[1]
5:00 PM	Tango Division of firefighting is fighting fires in the Mulberry neighborhood, Trail Ridge, and Owl Drive	
5:00 PM	LV-PW drives to mid-zone tank and high-zone tanks to check water levels. There is only 2 ft of water left in tanks. When they return to mid-zone tank, the tank is empty.	LV-PW
6:00 PM	LV-PW staff manually open raw water valve to allow untreated water into the water distribution system to maintain pressure and provide water for firefighting	LV-PW

Approx. Time	Event	Agency/Area
6:00 PM	LV-PW calls LFPD 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
6:18 PM	2-phase power available. Treated water flow restarted at 2000 GPM, increased to 3300 GPM by 10 PM.	SUP (WTP) REC
6 – 7:00 PM	Fiber connection between Superior and Louisville water plants is damaged through the splice connection melting	LV-PW
7 – 8:00 PM	LFPD is given permission to draft water out of Harper Lake. They never need to do this.	LFPD
7:50 PM	Boil water advisory issued by CDPHE to LV, SUP, EAS, EBCWD, & SSMHP	Boulder Co.
9 - 10:00 PM	XCel Energy drives natural gas tanks to LV SWTP. Natural gas line is cut and hooked up to the tanks to bring power back to the plant. Both south and north water treatment plants in Louisville 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 for the Marshall Fire, approving the state's Fire Management Assistance Grant request earlier in the afternoon. The authorization allows for FEMA funding to cover 75% of the state's firefighting costs.	FEMA
11:14 PM	Westminster says the Meadow View neighborhood is no longer under evacuation status. Only Boulder County areas remain under evacuation orders.	Westminster
11:55 PM	Broomfield lifts evacuation orders	Broomfield
31 December		
12:00 AM	Chief Wilson takes over fire operations within Louisville. LFPD has control of the fire. Department of Fire Prevention and Control took operational control	LFPD BC-OEM
12 – 1:00 AM	Louisville storage tanks water levels are still dropping	LV-PW
1 – 7:00 AM	LV-PW shuts off water to each home that was destroyed either at curb stop or at the entrance to the neighborhood to maintain water pressure within the system	LV-PW
8 – 9:00 AM	Water levels in storage tanks began rising within the Louisville WTP	LV-PW
10:00 AM	Fire impacted area estimated to be 6,219 acres	BC-OEM[2]
mid-day	Water levels within water storage tanks in Louisville are back to normal levels	LV-PW
12/31 - 1/01	Louisville makes a plan to flush the entire water distribution system within a four-day time period by working collaboratively with neighboring municipalities	LV-PW
1/1, 6 AM	Federal Incident Management Team take operational control	BC-OEM
1/1 (2)	President Biden issues federal disaster declaration	BoCo
1/7, 7 PM	Incident turned back over to local control administrators	BC-OEM

BC-OEM = Boulder County Office of Emergency Management; FEMA = Federal Emergency Management Agency; LV-PW = Louisville Public Works and Utilities; LFPD Louisville Fire Protection District; SUP = Town of Superior; ; SUP-PW = Superior Public Works & Utilities Department

[1] (Boulder Office of Emergency Management, 2021(a))

[2] (Boulder Office of Emergency Management, 2021(b))

(Broomfield PD, 2021)

5.0 OVERVIEW OF REGIONS IMPACTED BY THE MARSHALL FIRE

This section will provide an overview of the impacted regions before the fire. The information in this section provides a perspective and a basis for the damage that is presented in the subsequent sections.

5.1 Socioeconomic demographics

The three impacted regions - Louisville, Superior, and Unincorporated Boulder County - have different socioeconomic demographics from previous wildfire-impacted regions in California and Oregon. Table 5-1 provides and overview of the impacted communities relative to the state of Colorado. All data is from US Census Data, based upon 2019 American Community Survey estimates.

Boulder County has a population of 330,758. The population grew in the county by 12.3% from April 1, 2010, to April 1, 2020. The median household income is $88,535, the employment rate is 69.1%, and the poverty rate is 11.7%. The County is highly educated, with 62.1% of those 25 and older holding a bachelor's degree or higher, compared to 40.9% of the State of Colorado. Boulder County has 140,848 housing units, with a vacancy rate of 6.4% and a homeownership rate of 61.6%, below the rate in the State of Colorado at 65.2%. The mean monthly Gross Rent is $1,637. 40.7% of housing units were built after 1990 (United States Census Bureau, 2019). According to Boulder County voter registration statistics, as of October 2, 2017, 44% of active voters were Democratic, 37.3% were Unaffiliated, 16.7% were Republican, and the remaining were other (Boulder County, 2017).

21,226 people reside in the City of Louisville. 69.9% of residents hold a Bachelor’s Degree or higher. The median household income is $103,017, the employment rate is 72.5%, and the poverty rate is 5.9%. The homeownership rate was 70.6%. There are 8,929 housing units, of which 4.2% were vacant. The median property value is $587,000 and monthly gross rent is $1,607. 42.9% of housing units were built after 1990 (United States Census Bureau, 2019).

The Town of Superior has 13,094 residents. 76.3% of those 25 and older hold a bachelor’s degree or higher. The median household income is above Boulder County (as a whole) and Louisville, at $127,292. The employment rate in Superior is also higher, at 76.8%, and the poverty rate of 4.2% is less than Louisville or Boulder County. There are 5,025 housing units, and there is a 2.2% vacancy rate, the lowest of the three. The homeownership rate is 58.2%, with a median home value of $576,800, and a monthly gross rent is $1,922. 91.9% of housing units were built after 1990, over twice the rate of the City of Louisville and Boulder County (United States Census Bureau, 2019).

5.2 Background on Local Geology and Water Resources

According to the Colorado Geologic Survey, annual precipitation in Boulder County averages 18.6 inches, producing 840,000 acre-feet of water. About 247,000 acre-feet of this precipitation flows from the mountains to the plains, streamflow, and basin diversions (Hall et al. 1980)). Boulder County includes fractured and unconsolidated rock aquifers above sedimentary and crystalline rock aquifers in the eastern and western parts, respectively (see Figure 5-1, Figure 5-2, and Figure 5-3). The regional direction of water movement in the aquifers is mainly to the east. Ground water is stored in the fractures and pores of these rock formations. Sources other than groundwater are

necessary for large scale developments and irrigation that have taken place in the area, particularly since the 1980s. The rapid increase in regional population in addition to a historic drought in 2021 and early 2022 (see Figure 5-4) contributed to an increase in the risk of fire in Boulder County.

The shallower surficial geology of the county includes soils that are described in characteristic and extend in Table 5-2 and Table 5-3. In general, a significant component of surficial soils in Boulder County includes highly plastic clayey soils (fine montmorillonite) that have a strong potential for expansion during the wetting seasons or shrinking during drought conditions. These soils are a major geotechnical hazard in the area for foundations, basement walls, and retaining structures, and were likely responsible for a large number of cracks in basement walls or foundation slabs prior to the fire if not properly mitigated by the geotechnical engineer.

Table 5-1. Overview of Impacted regions

	State of Colorado	**Boulder County**	**Town of Superior**	**City of Louisville**
Population	5,773,714	330,758	13,094	21,226
Housing Units (2020 Decennial Census)	2,491,404	140,848	5,025	8,929
Households (2019 ACS, 5-year estimates)	2,148,994	127,415	4,596	8,318
Vacant Housing Unit Rate (2020 Decennial Census)	9.4%	6.4%	2.2%	4.2%
Median Income (2019 ACS, 5-year estimates)	$77,127	$88,535	$127,292	$103,017
Median Gross Rent (2019 ACS, 5-year estimates)	$1,271	$1,637	$1,922	$1,607
Median home value, own-occupied units (2019, ACS, 5-year estimates)	$343,300	$592,000	$576,800	$587,000
% of housing units built after 1990 (2019, ACS, 5-year, Built 1990 or later/ total housing units)	41%	40.7%	91.9%	42.9%
Homeownership Rate (2019, ACS< 5-year estimate, owner-occupied/occupied housing units)	65.2%	61.6%	58.2%	70.6%
Employment Rate (2019, ACS, 5-year, Employment Status, (Population in labor force / population 16 years and over)	68.4%	69.1%	76.8%	72.5%
Poverty Rate (2019 ACS 5-year (Estimate below poverty level / population for whom poverty status is determined)	10.3%	11.7%	4.2%	5.9%
BS Degree or Higher (2019 ACS, 5-year, Bachelor's degree or higher/Population 25 years and over)	40.9%	62.1%	76.3%	69.9%

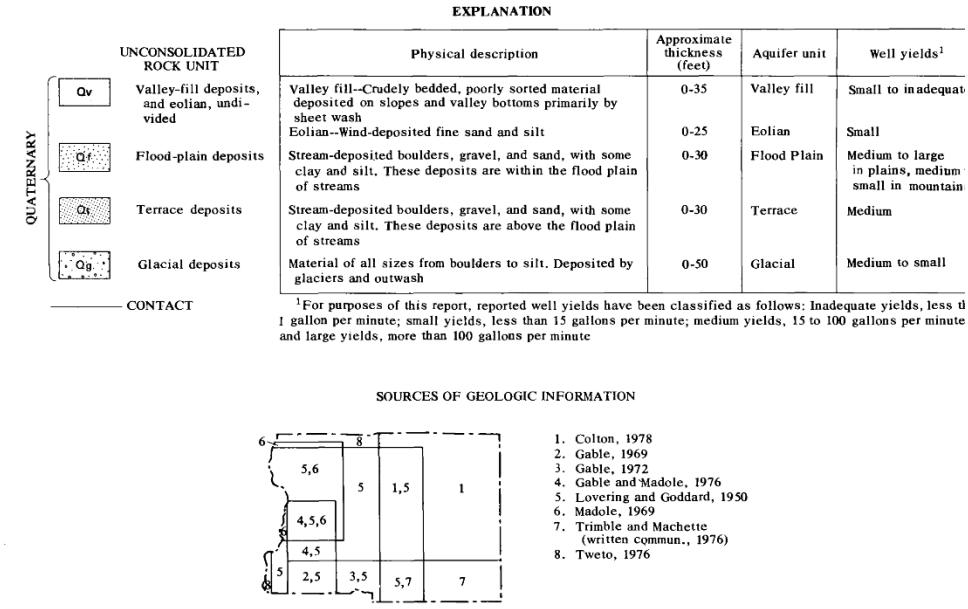


Figure 5-1. Description of unconsolidated rock aquifers in Boulder County, Colorado (after Hall et al., 1980).

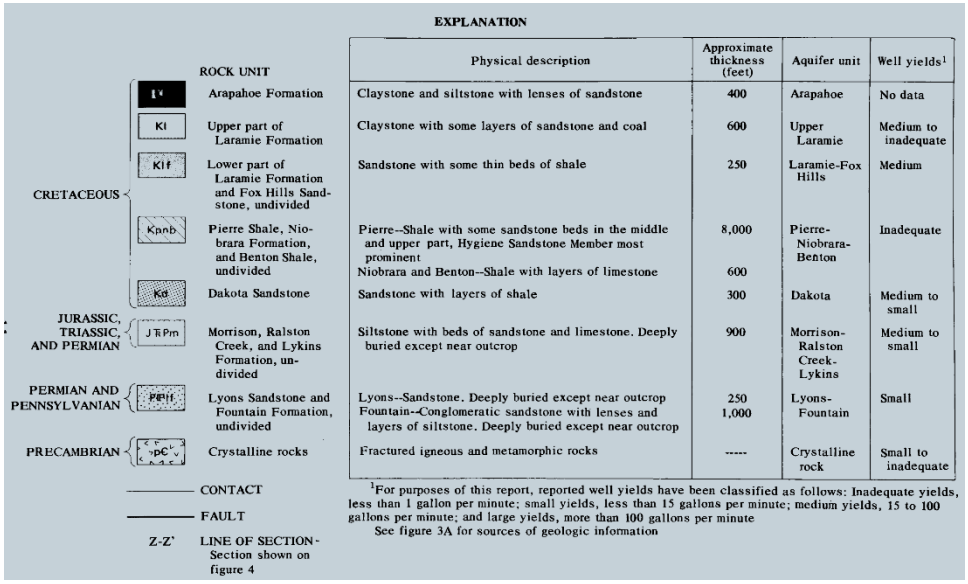


Figure 5-2. Description of sedimentary and crystalline rock aquifers in Boulder County, CO (Hall et al., 1980).

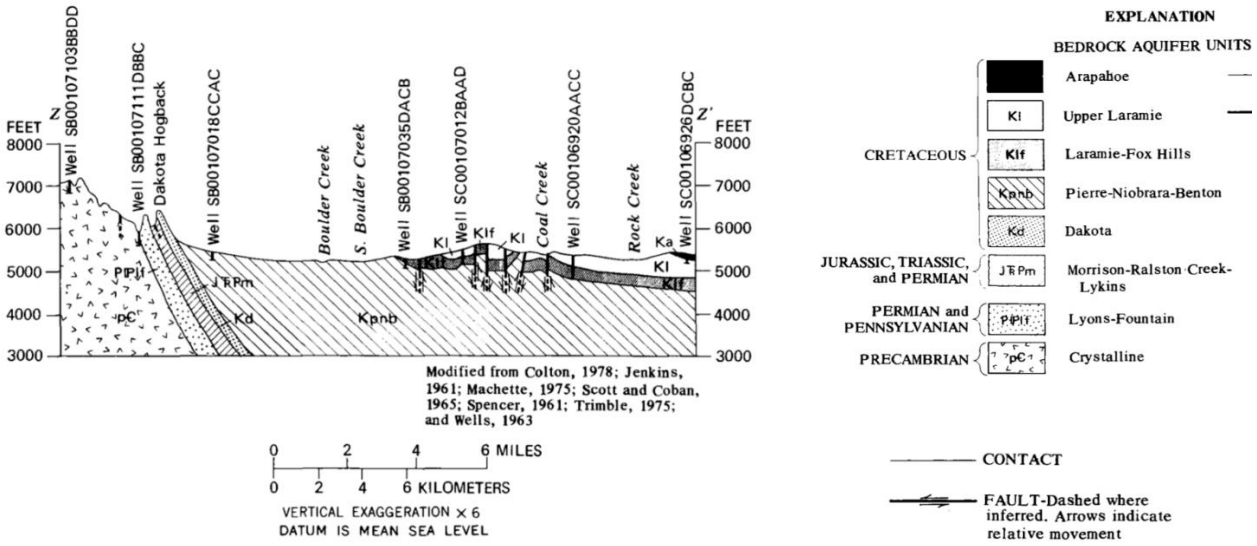


Figure 5-3. Generalized section of bedrock aquifers in Boulder Co., CO (Hall et al., 1980).

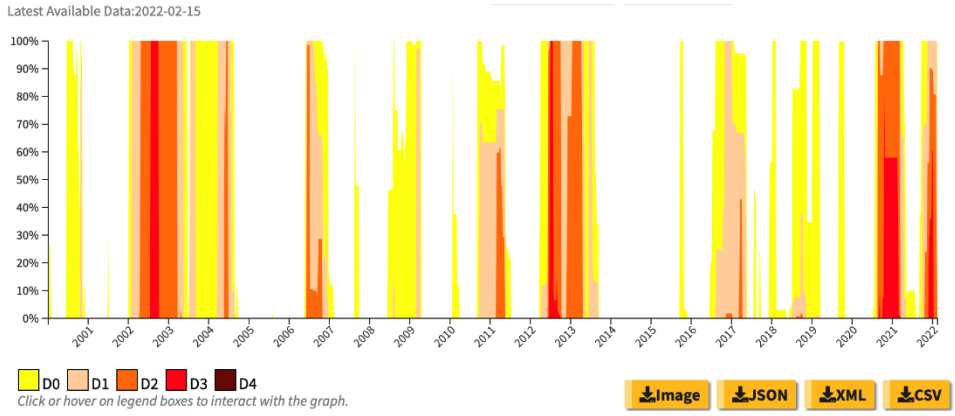


Figure 5-4. History of drought level (classified as D0 through D4, based on severity) in Boulder County, Colorado from 2001 to 2022 (NOAA NIDIS, last retrieved Feb. 17, 2022).

Table 5-2. Approximate range and description of different soil types in Boulder County, CO (USDA, 1975)

Soil	Area	Extent	Soil	Area	Extent
	Acres	*Percent*		*Acres*	*Percent*
Ascalon sandy loam, 0 to 1 percent slopes	1, 300	0. 5	McClave clay loam	2, 300	1. 0
Ascalon sandy loam, 1 to 3 percent slopes	11, 000	4. 5	Nederland very cobbly sandy loam, 1 to 12 percent slopes	11, 700	4. 8
Ascalon sandy loam, 3 to 5 percent slopes	4, 800	2. 0	Niwot soils	9, 100	3. 8
Ascalon sandy loam, 5 to 9 percent slopes	900	. 4	Nunn sandy clay loam, 0 to 1 percent slopes	1, 700	. 7
Ascalon-Otero complex, 0 to 3 percent slopes	1, 200	. 5	Nunn sandy clay loam, 1 to 3 percent slopes	3, 400	1. 4
Ascalon-Otero complex, 3 to 5 percent slopes	2, 600	1. 0	Nunn clay loam, 0 to 1 percent slopes	6, 800	2. 8
Ascalon-Otero complex, 5 to 9 percent slopes	2, 400	1. 0	Nunn clay loam, 1 to 3 percent slopes	15, 300	6. 3
Ascalon-Otero complex, 9 to 20 percent slopes	1, 700	. 7	Nunn clay loam, 3 to 5 percent slopes	5, 300	2. 2
Baller stony sandy loam, 9 to 35 percent slopes	7, 700	3. 2	Nunn clay loam, 5 to 9 percent slopes	1, 100	. 5
Calkins sandy loam, 0 to 1 percent slopes	1, 600	. 7	Nunn-Kim complex	2, 600	1. 0
Calkins sandy loam, 1 to 3 percent slopes	1, 700	. 7	Peyton-Juget very gravelly loamy sands, 5 to 20 percent slopes	2, 300	1. 0
Colby silty clay loam, 1 to 3 percent slopes	4, 300	1. 8	Pinata-Rock outcrop complex, 5 to 55 percent slopes	5, 200	2. 1
Colby silty clay loam, 3 to 5 percent slopes	2, 200	. 9	Renohill loam, 3 to 9 percent slopes	1, 300	. 5
Colby silty clay loam, 5 to 9 percent slopes	1, 000	. 4	Renohill silty clay loam, 1 to 3 percent slopes	1, 100	. 5
Colby silty clay loam, wet, 0 to 3 percent slopes	600	. 2	Renohill silty clay loam, 3 to 9 percent slopes	2, 200	. 9
Colby-Gaynor association	1, 100	. 5	Rock outcrop	6, 500	2. 7
Colluvial land	5, 800	2. 4	Samsil clay, 3 to 12 percent slopes	2, 600	1. 0
Fern Cliff-Allens Park-Rock outcrop complex, 15 to 60 percent slopes	12, 700	5. 2	Samsil-Shingle complex, 5 to 25 percent slopes	5, 800	2. 4
Gaynor silty clay loam, 1 to 3 percent slopes	400	. 2	Shingle-Gaynor complex, 3 to 20 percent slopes	1, 100	. 5
Gaynor silty clay loam, 3 to 9 percent slopes	900	. 4	Sixmile stony loam, 10 to 50 percent slopes	3, 100	1. 3
Goldvale-Rock outcrop complex, 9 to 55 percent slopes	2, 900	1. 2	Terrace escarpments	8, 300	3. 4
Hargreave fine sandy loam, 1 to 3 percent slopes	1, 100	. 5	Valmont clay loam, 1 to 3 percent slopes	5, 200	2. 1
Hargreave fine sandy loam, 3 to 9 percent slopes	900	. 4	Valmont clay loam, 3 to 5 percent slopes	1, 200	. 5
Heldt clay, 0 to 3 percent slopes	4, 700	1. 9	Valmont cobbly clay loam, 1 to 5 percent slopes	5, 500	2. 3
Heldt clay, 3 to 5 percent slopes	2, 000	. 8	Valmont cobbly clay loam, 5 to 25 percent slopes	1, 600	. 7
Juget-Rock outcrop complex, 9 to 55 percent slopes	20, 700	8. 5	Weld loamy sand, 1 to 4 percent slopes	220	. 1
Kutch clay loam, 3 to 9 percent slopes	2, 600	1. 0	Weld fine sandy loam, 1 to 3 percent slopes	1, 400	. 6
Laporte very fine sandy loam, 5 to 20 percent slopes	1, 200	. 5	Weld loam, 0 to 1 percent slopes	500	. 2
Longmont clay, 0 to 3 percent slopes	2, 800	1. 2	Weld loam, 1 to 3 percent slopes	3, 400	1. 4
Loveland soils	4, 500	1. 9	Weld-Colby complex, 0 to 3 percent slopes	1, 900	. 8
Made land	200	. 1	Weld-Colby complex, 3 to 5 percent slopes	500	. 2
Manter sandy loam, 0 to 1 percent slopes	400	. 2	Gravel pits and Mine dumps	700	. 3
Manter sandy loam, 1 to 3 percent slopes	2, 100	. 9	Water	5, 900	2. 4
Manter sandy loam, 3 to 9 percent slopes	1, 000	. 4	Total	241, 920	100. 0
Manvel loam	2, 100	. 9			

Table 5-3. Classification of soils in Boulder County, CO (USDA 1975)

Series	Current classification system		
	Family	Subgroup	Order
Allens Park	Fine-loamy, mixed	Typic Eutroboralfs	Alfisols.
Ascalon	Fine-loamy, mixed, mesic	Aridic Argiustolls	Mollisols.
Baller	Loamy-skeletal, mixed, mesic	Lithic Haplustolls	Mollisols.
Calkins	Coarse-loamy, mixed, mesic	Cumulic Haplaquolls	Mollisols.
Colby [1]	Fine-silty, mixed, (calcareous), mesic	Ustic Torriorthents	Entisols.
Fern Cliff	Fine-loamy, mixed	Psammentic Eutroboralfs	Alfisols.
Gaynor	Fine, montmorillonitic, (calcareous), mesic	Ustic Torriorthents	Entisols.
Goldvale	Fine, montmorillonitic	Typic Eutroboralfs	Alfisols.
Hargreave	Fine-loamy, mixed, mesic	Aridic Arguistolls	Mollisols.
Heldt	Fine, montmorillonitic, mesic	Ustertic Camborthids	Aridisols.
Juget	Sandy-skeletal, mixed	Lithic Haploborolls	Mollisols.
Kim	Fine-loamy, mixed, (calcareous), mesic	Ustic Torriorthents	Entisols.
Kutch	Fine, montmorillonitic, mesic	Torrertic Arguistolls	Mollisols.
Laporte	Loamy, mized, mesic	Lithic Haplustolls	Mollisols.
Longmont	Fine, montmorillonitic, (calcareous), mesic	Aeric Halaquepts	Inceptisols.
Loveland	Fine-loamy over sandy or sandy-skeletal, mixed, (calcareous), mesic.	Typic Haplaquolls	Mollisols.
Manter	Coarse-loamy, mixed, mesic	Aridic Argiustolls	Mollisols.
Manvel	Fine-silty, mixed, (calcareous), mesic	Ustic Torriorthents	Entisols.
McClave	Fine-loamy, mixed, mesic	Cumulic Haplaquolls	Mollisols.
Nederland	Loamy-skeletal, mixed, mesic	Aridic Argiustolls	Mollisols.
Niwot	Fine-loamy over sandy or sandy-skeletal, mixed, mesic	Typic Haplaquolls	Mollisols.
Nunn	Fine, montmorillonitic, mesic	Aridic Argiustolls	Mollisols.
Otero	Coarse-loamy, mixed, (calcareous), mesic	Uatic Torriorthents	Entisols.
Peyton	Fine-loamy, mixed	Aridic Argiborolls	Mollisols.
Pinata	Clayey-skeletal, mixed	Typic Eutroboralfs	Alfisols.
Renohill [2]	Fine, montmorillonitic, mesic	Ustollic Haplargids	Aridisols.
Samsil	Clayey, montmorillonitic, (calcareous), mesic, shallow	Ustic Torriorthents	Entisols.
Shingle	Loamy, mixed, (calcareous), mesic, shallow	Ustic Torriorthents	Entisols.
Sixmile	Fine-loamy, mixed, (calcareous), mesic	Ustic Torriorthents	Entisols.
Valmont	Clayey over loamy-skeletal, montmorillonitic, mesic	Aridic Argiustolls	Mollisols.
Weld	Fine, montmorillonitic, mesic	Aridic Paleustolls	Mollisols.

[1] Colby, wet (*CsB*) is a taxadjunct to the Colby series.

[2] Renohill loam (*EeD*) is a taxadjunct to the series as a paralithic contact is present at a depth of 10 to 20 inches.

5.3 Governmental structure

5.3.1 Louisville

The Louisville governmental structure consists of four parts: city council, boards and commissions, the city manager's office, and city departments and services. The City Council consists of the Mayor and six council members. There are two city council members that are elected from each of the city's three wards. The boards and commissions have specific responsibilities, which are detailed in the Municipal Code and City Charter. The City Council appoints people to Louisville's boards and commissions. The City Manager is the chief executive officer for the City of Louisville and is appointed by and reports directly to the City Council. The Building Safety Department oversees all building and construction in Louisville, issuing building permits and contractor's licenses, and conducting inspections. The Planning Department administers land use regulations in the City, including zoning, development review, historic preservation, and long-range planning, handling updates to and implementation of the City's Comprehensive Plan.

5.3.2 Superior

The Town of Superior is a statutory town that has a trustee-manager government. Superior's Board of Trustees adopts Ordinances and Resolutions, appropriates funds to conduct Town business, and provides policy direction for the Town governance through both Town Staff and Advisory Groups rather than boards and commissions. The Board of Trustees includes the elected Mayor and six Trustees that are elected by the residents of the town for up to two, four-year terms. Superior has a Town Manager appointed by the Board of Trustees, who implements policies approved by the Board. The Building Department oversees review of plans and the issuance of building permits, and

is responsible for inspections, building safety, and variances. The building department is managed and supported by staff at SAFEbuilt. The Planning Department works to implement the goals of the Board of Trustees, including managing development opportunities and reconciling public and private interests to achieve the Town's long-term vision.

5.3.3 Unincorporated Boulder County

Unincorporated Boulder County is governed by ordinances and regulations adopted by the Board of County Commissioners. The Board of County Commissioners includes three Commissioners that are elected at –large by the voters of Boulder County to serve four-year terms. They represent the county as a whole.

5.4 Previous hazards

The 2013 Colorado Floods impacted Colorado's Front Range. Rainfall within Boulder County over the span of five days exceeded the county's annual average. In Louisville, County Road was closed for over three years after the flood and a bridge in the city was heavily damaged due to the flood. First responders in Louisville helped residents evacuate during the flood, and there are members of the Louisville departments and services that were employees of the city during the flood and were familiar with disaster response and recovery, including working with FEMA. In 2018, Boulder County was impacted by one of the worst hail storms they have ever experienced. Superior reported 3-in. diameter hail while Louisville residents reported 2-in. diameter hail. The result of this hail storm was roof damage throughout Louisville and Superior. Those residents that replaced their roofs, replaced roofs with asphalt shingles. The US was impacted by the 2020 COVID-19 pandemic. Boulder County, specifically has experienced 347 deaths from COVID-19 and 57,181 cases. At the time of the Marshall fire, the omicron surge was beginning in the county; the seven-day PCR positivity was less than 10% until the end of January when it was about 17% (Boulder County, 2022(c)).

6.0 RETAINING WALLS AND SLOPES

Previous research has shown that homes within close proximity to slopes or elevation changes have a higher probability of destruction (Duff and Penman, 2021). The rate of fire spread increases on slopes. As more unburned material is heated through convective heat transfer, hot gases are produced. These hot gases increase the rate of heat transfer to unburned material, which then produces more hot gases. This process continues, accelerating the rate of fire spread.

This section will summarize the damage to the retaining structures in the Coal Creek Ranch South (St. Andrews Ln.), designated RS1 and Coal Creek Ranch (Spyglass Circle), designated RS2. It includes additional retaining potential instabilities observed and the slope along W. Century Dr. All locations are shown in Figure 6-1.

6.1 Retaining wall case studies

The fire impacted a number of soil retaining structures throughout the burn area. Impacted walls were constructed by a variety of materials, including stone, concrete block, and timber/wood. Some damage (movement or dislodgement) of stone walls was observed, likely due to heavy water flow during firefighting efforts (water displacing individual elements).

Timber retaining walls suffered the most damage. In several locations, wall facings were completely consumed, lateral timber supports were dislodged or completely consumed, and members embedded in the soil were fully chard at various embedment depths.

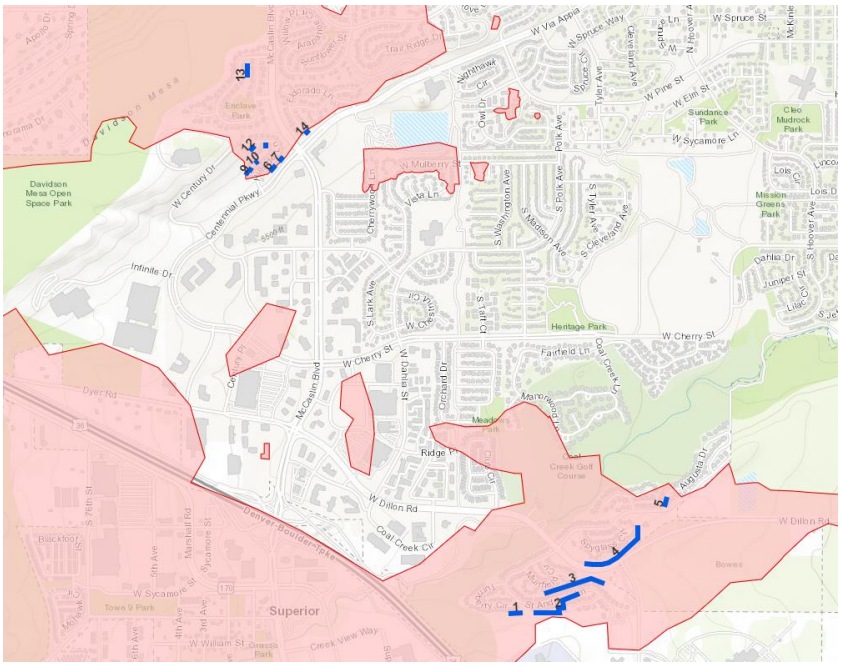


Figure 6-1. Locations of impacted retaining walls in Louisville, CO (Walls 1-5: 39°57’21.0” N, 105°09’01.3” W; Walls 6-14: 39°58’27.3” N, 105°09’56.6” W)

6.1.1 Retaining Structure 1 (RS1): Coal Creek Ranch South (St. Andrews)

The retaining structure in the Coal Creek Ranch South (St. Andrews Ln.) neighborhood (RS1) consisted for three walls, identified as North, West and South (Figure 6-2). The location was ground surveyed, imaged via UCAV (Figure 6-3), and scanned by multiple LiDAR setups. UCAV images were used to develop a Structure from Motion (SfM) model, from which measurements were taking using DesignSAFE's HazMapper online software; data accessibility described in greater detail in Appendix A and publicly available at the following link: https://hazmapper.tacc.utexas.edu/hazmapper/project-public/473bc0e5-0da4-492c-afe1-0b0d99d463b3

The North Wall, along St. Andrews Ln. consisted of three tiers, each ranging from 3 – 7 ft in height, with an approximately 4 – 5.5 ft horizontal offset between the tiers. The length of each of the timber tiers is 203, 264, and 202 ft, (61.9, 80.5, and 61.6m) for the bottom, middle, and top tiers, respectively. The east end of the bottom tier was extended by a concrete block wall an additional 61 ft (18.6m) as the height of retained soil decreased.

Figure 6-2. SfM model of Coal Creek Ranch South, RS1, showing three walls and four profile cross-sections (39°57'17.0" N, 105°09'0.30" W)

As shown in Figure 6-4 (Profile C), soil previously retained by timber components is free-standing nearly vertical and some localized vertical/horizontal displacements, or sloughing, are visible. Most of the face of the retaining structures was charred due to the fire. Timber tie backs had char depths that ranged from 6 – 35 in.

Profile A provides an example cross-section of the North Wall extending from the surface of St. Andrews Ln. up the wall, through the foundation of the destroyed home and to the concrete driveway. A total vertical change from start to end of profile is nearly 24 ft (7.25m) over a distance of 100 ft (30m). Locally, a vertical change of 13 ft (4m) is accommodated over a 22 ft (6.7m) horizontal distance.

At Profile B (Figure 6-6a), along the North Wall closer to the corner, the total wall height of 15.4 ft (4.7m) exceeds the horizontal offset from toe to top [12.5 ft (3.8m)].

Figure 6-3. UCAV imgage of RS1 (39°57’17.0” N, 105°09’0.30” W)

(a) West Wall (b) Deck peir at top of Profile B

Figure 6-4. Photos of RS1 in Coal Creek Ranch South (39°57’17.0” N, 105°09’0.30” W)

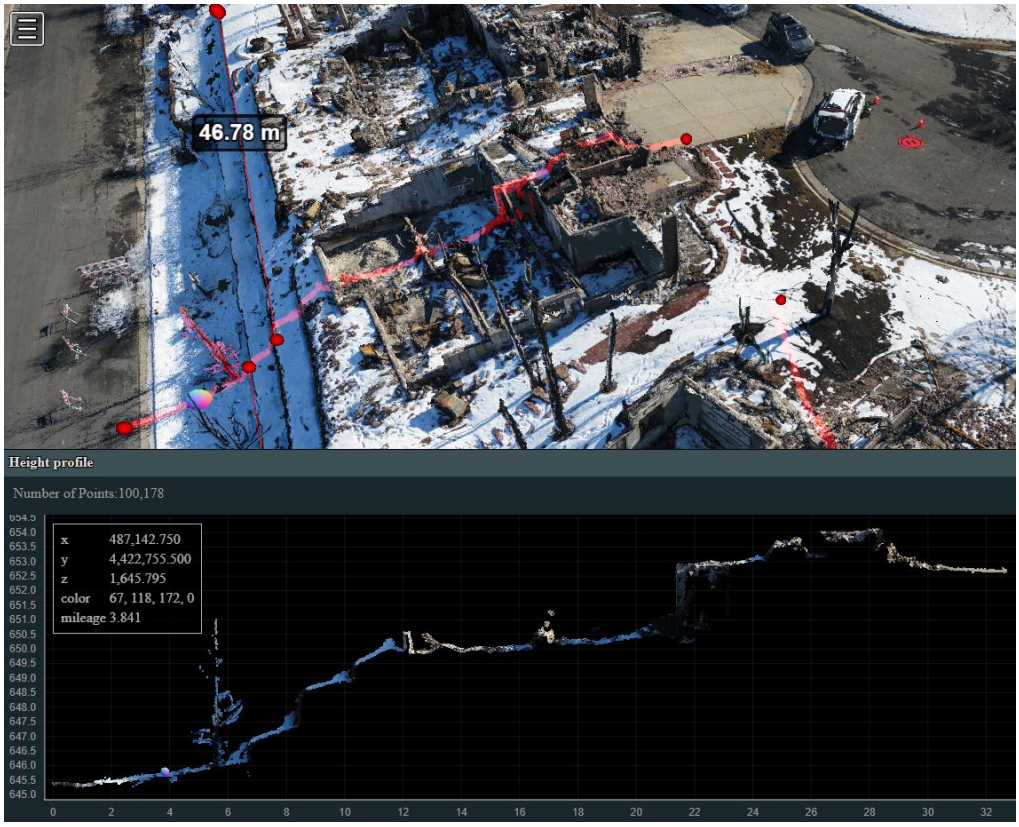


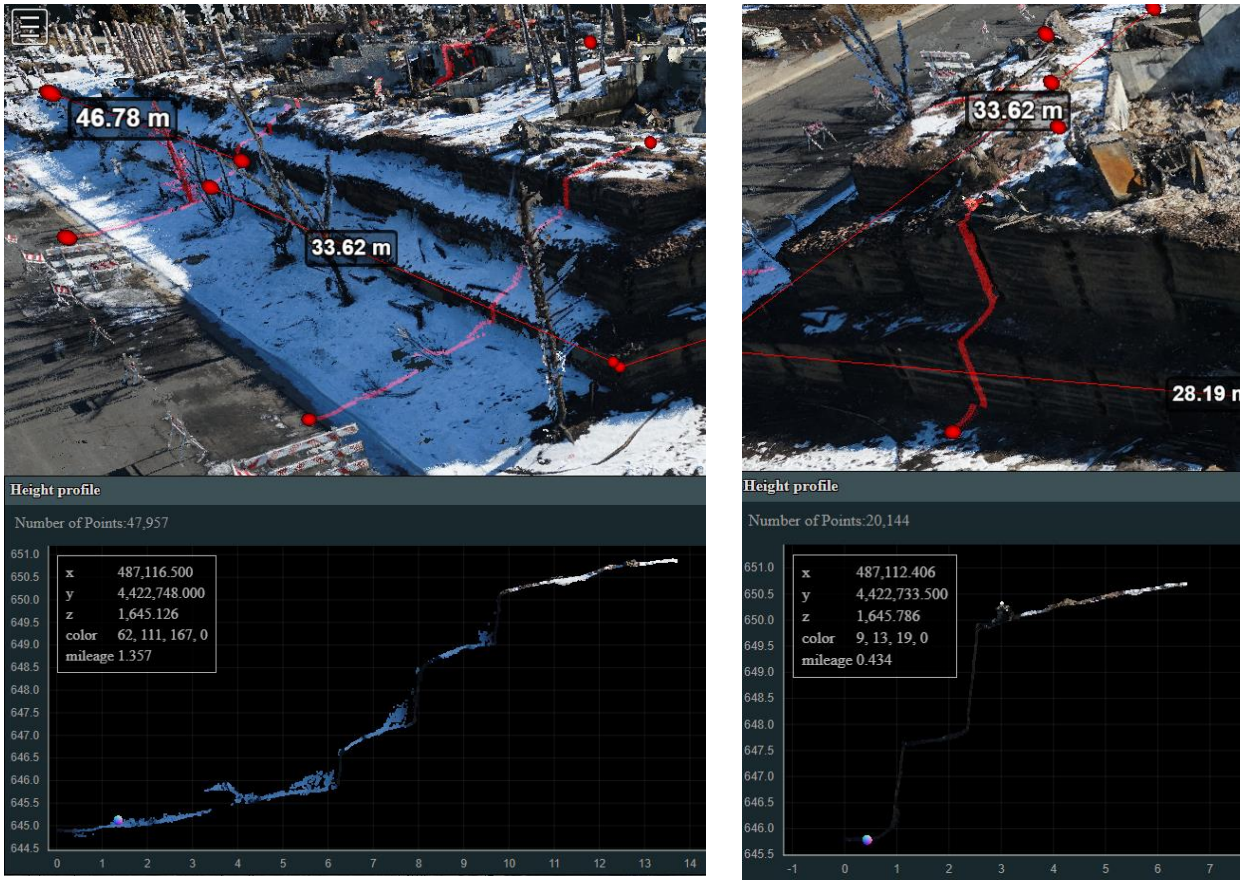
Figure 6-5. RS1 Profile A, section of North Wall extending from St. Andrews Lane to the RAPID mobile equipment vehicle on Troon Ct. (39°57'16.4" N, 105°09'01.4" W)

The West wall consists of 2-3 teir over an approximate length of 92 ft (28m) (Figure 6-3). Tiebacks were chared to distances ranging from 4 to 64 in. into the soil mass. Profile C (Figure 6-6b), shows a local wall height of 13.5 ft (4.1m), which exceeds its horizontal setback of 6.6 ft (2m) by more than 2:1. Beyond the top of the wall, sloping backfill and the diagonllly positions foundation provide additional surcharge loads.

The maximum extents of Profile D (Figure 6-7) extend from the bottom of the basement at the low house (1) up to ground level beyond the elevated house (4). From the figure, the gross elevation change is measured to be 32 ft (9.8m) over a horizontal distance of 57 ft (17.5m). The local vertical offset of the wall, from point (1) to point (2) is 20 ft (6.1m) over an offset of 13.8 ft (4.2m).

The tie backs had char depths that ranged from 6 – 35 in. and 4 – 64 in. for the North and West Wall, respectively. According to US codes and standards, timber chars at a constant rate of nominally 1.5 in./hour, regardless of the species (AWC, 2018). In highly turbulent environments, this char rate could be upwards of 2.6 in./hour (Schmid et al., 2020). Because of the presence of high winds throughout the fire, areas impacted by the Marshall Fire can be considered highly turbulent. These char rates indicate that the retaining structure could have been burning for 2.7 – 43 hours with a char rate of 1.5 in./hour and 1.5 – 27 hours with a char rate of 2.6 in./hour. This burning does not have to correspond to visual combustion, rather could include smoldering behavior of the timber retaining walls; however, it demonstrates the severity and length of burning that can be expected in communities impacted by a wildfire.

Given the absence of structural support members and loss of tieback support, local or global movement of these walls is possible, particularly with repeated moisture from snow and rain. Recognizing the potential safety concern, the town of Louisville put up traffic barriers to keep cars and pedestrians away from the north wall, along St. Andrews Ln. Stability will also need to be addressed to all three walls before reconstruction of lots at the top and bottom of the slopes.



(a) North Wall (b) West Wall

Figure 6-6. RS1 profiles (a) Profile B extending from St. Andrews Lane to elevated foundation (39°57’16.3” N, 105°09’02.2” W) and (b) Profile C the RAPID mobile equipment vehicle (39°57’15.8” N, 105°09’02.1” W)

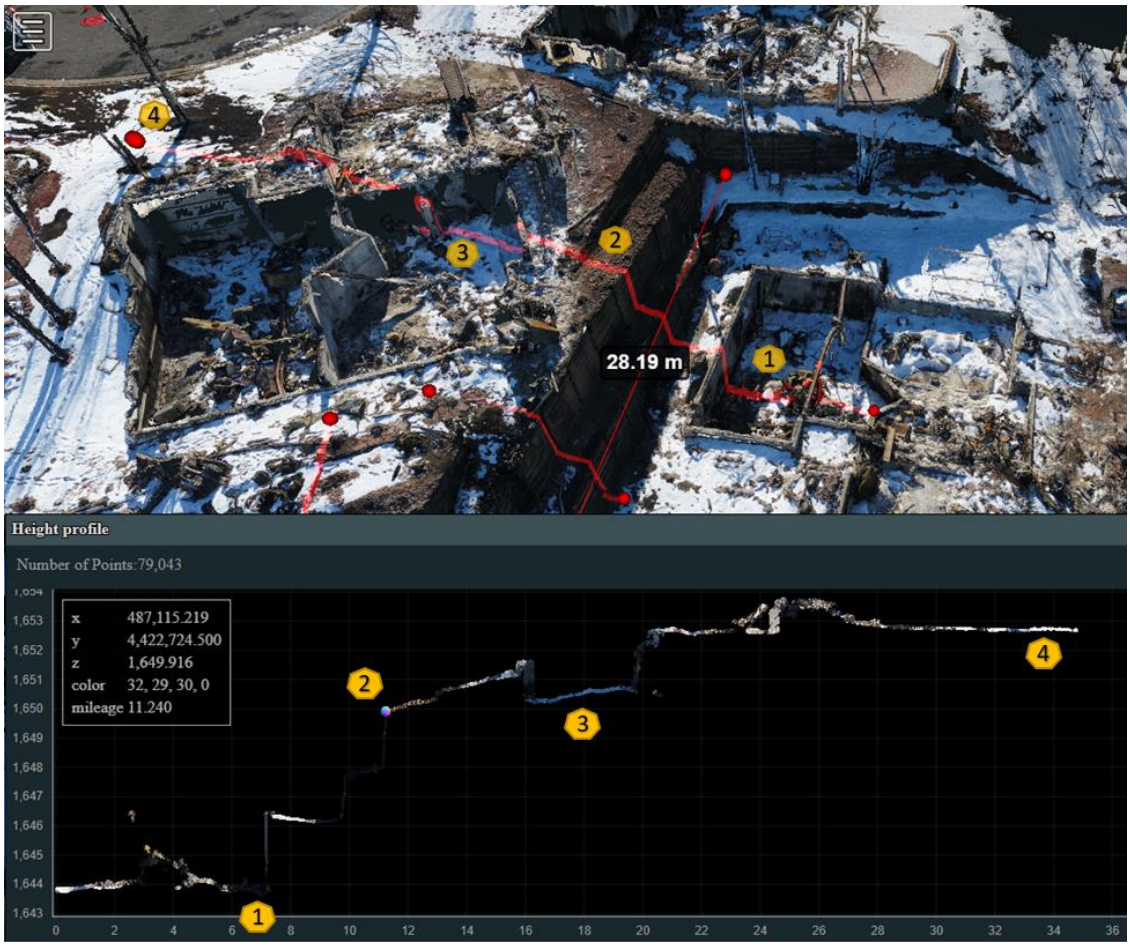


Figure 6-7. RS1 Profiles D (39°57’16.3” N, 105°09’02.2” W) showing (1) basement elevation, (2) top of retaining wall, (3) upper house basement level, and (4) upper ground level

6.1.2 Retaining Structure 2 (RS2): Coal Creek Ranch North (Spyglass Cir.)

The retaining structure in the Coal Creek Ranch North neighborhood (located between Spyglass Circle and Dillion Rd) consisted of two primary wall sections (Wall A and Wall B-D), each with two tiers, shown before (google earth) and after (SfM model) the fire in Figure 6-8. Each tier was 4 – 5 ft in height with a ~5 ft horizontal offset between the tiers. The length of the bottom tier, consumed by fire, was 143 and 254 ft for Wall A and B-D, respectively. Most of the face of the bottom tier of the retaining structure was charred due to the fire. Similar to RS1, the wall was constructed of 8 x 8 in. square timbers, staked in an alternating pattern of face and tieback (embedded in soil mass) members, secured by iron nails (Figure 6-9a). Behind the horizontal face members was a think (3/4 in.) wood sheathing, so limit soil erosion through structural components.

(a)

(b)

Figure 6-8. Coal Creek Ranch (Spyglass Cir.) Retaining Structure (a) Google earth before fire and (b) SfM model with cross-sections identified (39°57’24.4” N, 105°08’51.0” W)

The tie backs had char depths that ranged from 4 – 36 inches. According to US codes and standards, timber chars at a constant rate of nominally 1.5 inch/hour, regardless of the species (AWC 2018). In highly turbulent environments, this char rate could be upwards of 2.6 inch/hour (Schmid et al. 2020). Because of the presence of high winds throughout the fire, areas impacted by the Marshall Fire can be considered highly turbulent. These char rates indicate that the retaining structure could have been burning for 2.7 – 24 hours with a char rate of 1.5 inch/hour and 1.5 – 13.8 hours with a char rate of 2.6 inch/hour. This burning does not have to correspond to visual combustion, rather could include smoldering behavior of the timber retaining walls; however, demonstrates the severity and length of burning that can be expected in communities impacted by a wildfire.

(a) Near Profile D (b) Near Profile B

Figure 6-9. RS2 (a) comparison of damaged (lower) and undamaged (upper) wall (39°57’23.5” N, 105°08’52.7” W) and (b) consumed section of RS2 wall near Profile B (39°57’25.7” N, 105°08’49.5” W)

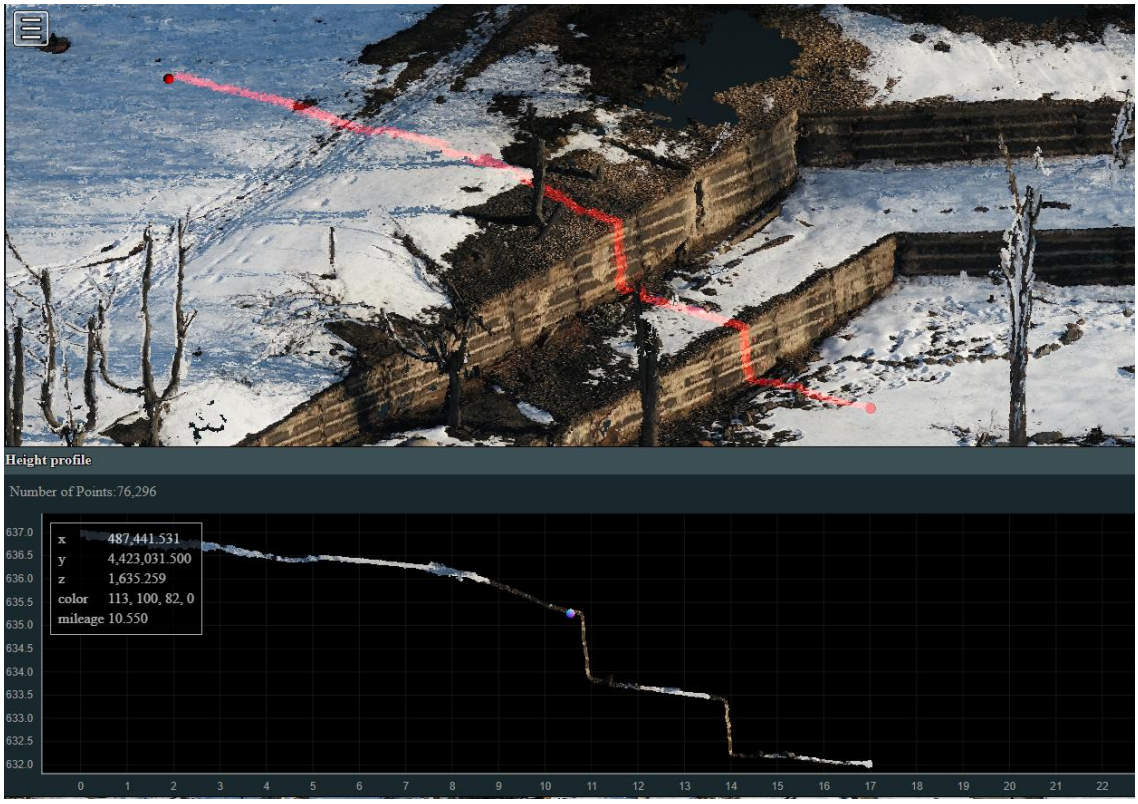
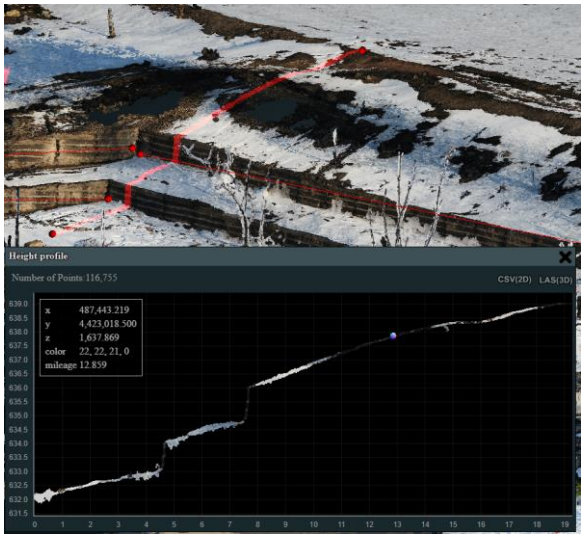
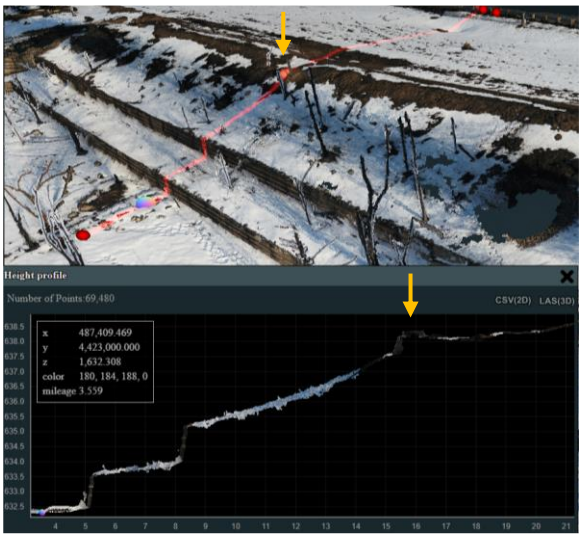


Figure 6-10. Coal Creek Ranch North, Spyglass Ln. (RS2): cross-section A (39°57’27.5” N, 105°08’49.3” W)

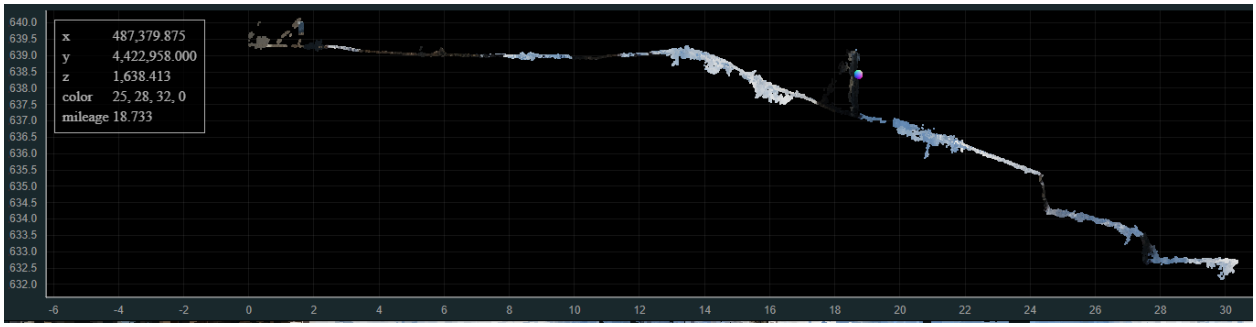
Figure 6-10 shows Profile A shows an elevation view of the retaining wall along Wall A while Figure 6-11 shows profiles along Wall B-D. Of particular note is a the storm sewar along the top tier of Wall B-D, a manhole of which is show at a purple indicator in Figure 6-11c, which is located approximately 30 ft from the top of the wall. This buried infrastructure could be damaged if the slope were to become unstable. Wall stability is aided at this presents of trees, and their roots, positioned along the top of the wall (Figure 6-9b). While some trees were lost due to burn damage, survival of the remaining trees may impact wall stability over time.



(a) Section B (39°57’25.7” N, 105°08’49.5” W)



(b) Section C (arrow indicated Storm and Drainageway Manhole) (39°57’25.5” N, 105°08’52.3” W)



(c) cross-section D (39°57’23.5” N, 105°08’52.7” W)

Figure 6-11. Coal Creek Ranch (Spyglass) retaining all sections (meters)

6.1.3 Other Retaining Structures

Several additional retaining structures were surveyed during reconnaissance. Figure 6-12 shows a series of backyard walls along S. Centennial Pkwy. As this location, a mixture of concrete block, stone, and timber walls performed to various levels. The cementitious walls remained relatively undamaged while the timber walls were completely lost. Another example is provided in Figure 6-13 where masonry block walls were mostly undamaged adjacent to fully compromised timber walls.

(a) SfM overview

(b) Block wall

(c) Timber wall

Figure 6-12. Backyard retaining structures in the Hillside neighborhood, along S. Centennial Pkwy (39°58’20.4” N, 105°09’54.4” W)

Figure 6-13. Backyard retaining walls behind houses along the north side of St. Andrews Ln showing good performance of masonry block wall (foreground) relative to fully burned tiers in the background and below (39°57'18.1" N, 105°09'06.3" W)

Two block retaining walls located along Via Appia Way shown in Figure 6-14. While fire damage was not noted beyond cosmetic damage (Figure 6-14b), excess water from firefighting efforts did dislodge blocks or otherwise displace wall sections, which may have long-term impacts on wall stability.

Reinforced concrete walls appeared to perform well in all instances inspected. Besides cosmetic impacts, the retaining wall located in Marshal, where the fire initiated, was mostly unaffected (Figure 6-15) despite erosion initiated by snow melt.

(a) Dislodgment at McCaslin and Via Appia (39°58’22.7” N, 105°09’52.5” W)

(b) Displaced blocks at Via Appia and Eldorado Ln (39°58’27.8” N, 105°09’41.9” W)

Figure 6-14. Stone retaining structures in Louisville, along Via Appia Way

Figure 6-15. Reinforced concrete wall at corner of Marshall Rd and Eldorado Springs Dr. (39°57’22.3” N, 105°13’46.4” W)

6.2 Slope damage

Many slopes existed within the fire perimeter. Homes constructed in the Spanish Hills neighborhood (Unincorporated Boulder) are built on sloping ground of various pitch. Significant sloping ground is present throughout the burned open space areas. Erosion concerns were abundant due to ash deposits and loss of vegetation (USDA, 2022). Erosion protection measures were implemented within a couple of weeks following the fire, particularly at stormwater intakes and at critical surface runoff locations to accommodate reoccurring snow melt and eventual precipitation (Figure 6-16). To reduce air quality concerns due to wind-blown ash and soot throughout the area, the municipalities covered burned homes, slopes, and burn areas adjacent to water ways with hydro-mulch.

Figure 6-16. Example of stormwater erosion protection (39°57’28.4” N, 105°09’51.7” W)

One slope of interest is located to the northwest of W. Century Blvd. Figure 6-18 shows and overview of the area, which is a commercial property that is impacting public infrastructure. Loss of vegetation and deposits of ash contributed to soil erosion at the toe of the slope, shown in Figure 6-17. The figure also shows deposits made by a street sweeping truck working around the clock to remove eroded soil from the road surface. Measurement of the profile shown in Figure 6-18 indicate slopes of 21 deg at the toe (1-13m), 13 deg along the long constant region (13 to 50m), and 22 deg at the steeper section at the top of the profile.

Figure 6-17. Images of soil erosion along Century Blvd. (39°58’12.4” N, 105°10’16.1” W)

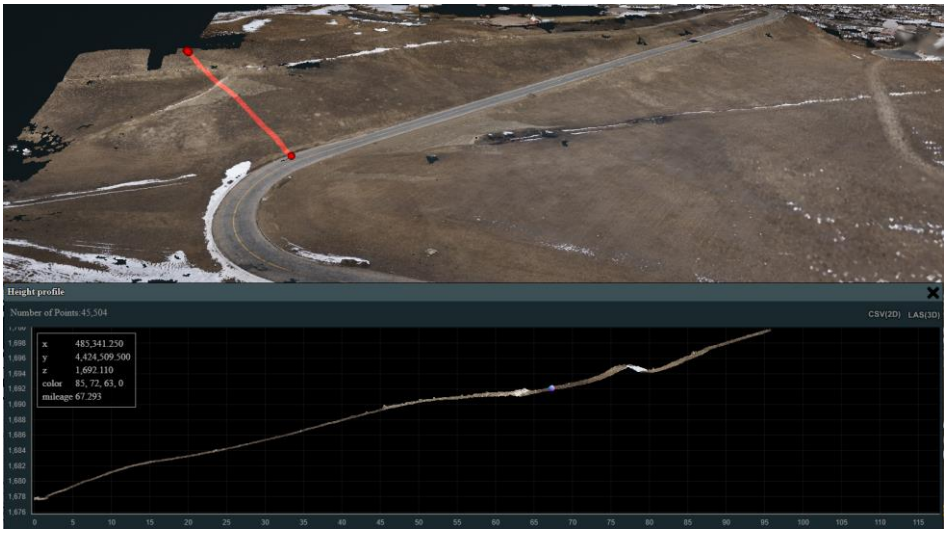


Figure 6-18. Slope along Century Blvd. in Louisville, CO (39°58’12.4” N, 105°10’16.1” W)

6.3 Concerns and remediation by Louisville Department of Parks, Recreation, and Open Space

The wildfire significantly impacted open spaces throughout Louisville. The GEER team met with a representative from the Louisville Department of Parks, Recreation, and Open Space to further understand how they approach wildfire mitigation and impacts. A total of six properties were impacted within Louisville: three of the properties impacted were grass lands where the entire property burned, a trail corridor near the golf course was burned, and a trail network through Davidson Mesa was significantly impacted. The Department was planning for wildfire mitigation in the form of prescribed burns during Spring 2022 in Davidson Mesa since there was a significant amount of invasive species and overgrowth. The department also lost a lot of fences around their properties.

The documented perimeter of the wildfire was not correct and the Department was looking to use UCAVs to document the actual perimeter. The published perimeter showed that only about 15% of Davidson Mesa burned; however, in actuality over 90% of the open space Davidson Mesa burned.

Due to the burning of the Hillside open space near the Louisville Recreation Center, the Department was concerned about erosion and settlement of the soil onto the sidewalk. To mitigate these potential impacts, the Department will be implementing mitigation throughout the spring until vegetation regrows and stabilizes the soil.

Additional concerns were raised about soil contamination from burning structures. The City requested soil testing to help determine the depth of potential contamination. This information was of interest to determine the depth of surface soil that needed to be removed during debris removal. To reduce airborne ash and air quality concerns over the months following the fire, hydro-mulch was deposited over destroyed structures, slopes, and other locations across the impacted area (Figure 6-19).

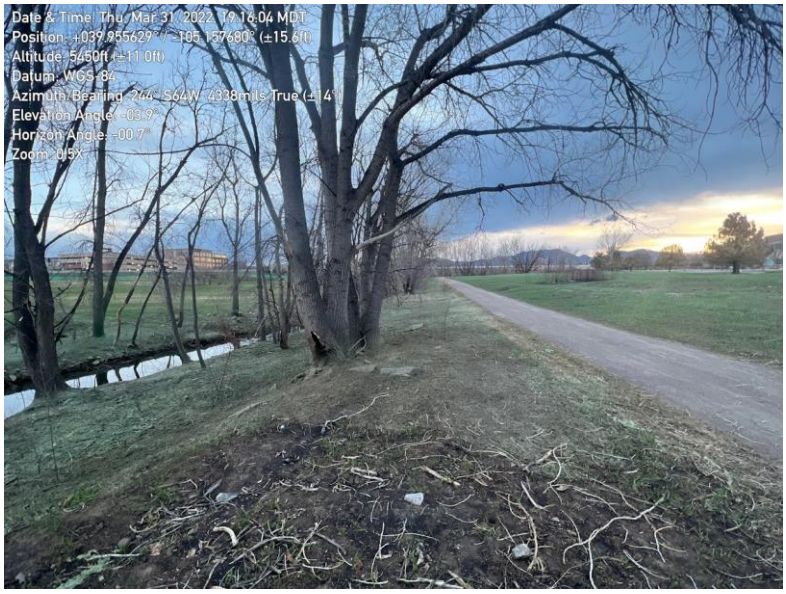


Figure 6-19. Example of hydro-mulch placed at burned areas along waterways; adjacent Coal Creek Golf Course (39°57’20.3” N, 105°09’27.6” W)

7.0 LIFELINES

7.1 Water utilities

There were several public water systems impacted by the fire directly and indirectly. These included the City of Louisville (LV), Town of Superior (SUP), City of Lafayette (LAF), East Boulder County Water District (EBCWD), Sans Souci Mobile Home Park (SSMHP), and Eldorado Artesian Springs (EAS). The largest utilities (Louisville, Superior, and Lafayette) served more than 66,000 people while the three other systems combined served less than 1,000 people. The City of Lafayette, East Boulder County Water District, and Sans Souci Mobile Home Park provided water to customers impacted in unincorporated Boulder County. System characteristics and the impact of the fire on their infrastructure and customer properties is described below and this information was provided by the water systems. Table 7-1 provides a timeline of major events relative to the impacted water utilities during the first ~24 from the start of the fire. Locations of major water infrastructure components are provided in Figure 7–1 and characteristics of the water systems are provided in Table 7–2.

Table 7-1. Timeline of water utility events during first 24 hours of fire (30 Dec. 2021)

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 (on backup power)	LFPD

Time (MST)	Event/notice/advisory	Org/ Area
3 – 4 PM	LV–PW arrive at interconnect, still no power at SWTP	LV–PW (SWTP)
3:45 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)
~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, ~1 ft from empty.	LV–PW
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)
6:45 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 – 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 via emergency generators	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 request earlier in the afternoon.	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 (temporary natural gas), chem pumps on, 5 MGD flow, Alum at 40 ppm, flow observed in clear well	LV–PW (SWTP)
~1 AM[1]	LV Operations Staff convene to discuss dangerously low water system pressure. Storage tanks still low.	LV–PW (SWTP)

Time (MST)	Event/notice/advisory	Org/ Area
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; below freezing temperatures for several days	Boulder County
12/30 – 31	LAF WTP loses power intermittently	LAF
All Day	SSMHP experiences wind damage and structure leaking	Marshall

BC = Boulder County; LV = City of Louisville; SUP = Town of Superior; SUP–PW = Superior Public Works & Utilities Department; REC = Ramey Environmental Compliance; LAF = City of Lafayette Public Works Department; EBCWD = East Boulder County Water District; EAS = Eldorado Artesian Spring; SSMHP = Sans Souci Mobile Home Park; CoB = City of Boulder; LFPD= Louisville Fire Protection District; CDPHE = Colorado Department of Public Health and Environment; CEC = Corona Environmental Consulting.

[1](City of Louisville, 2022)

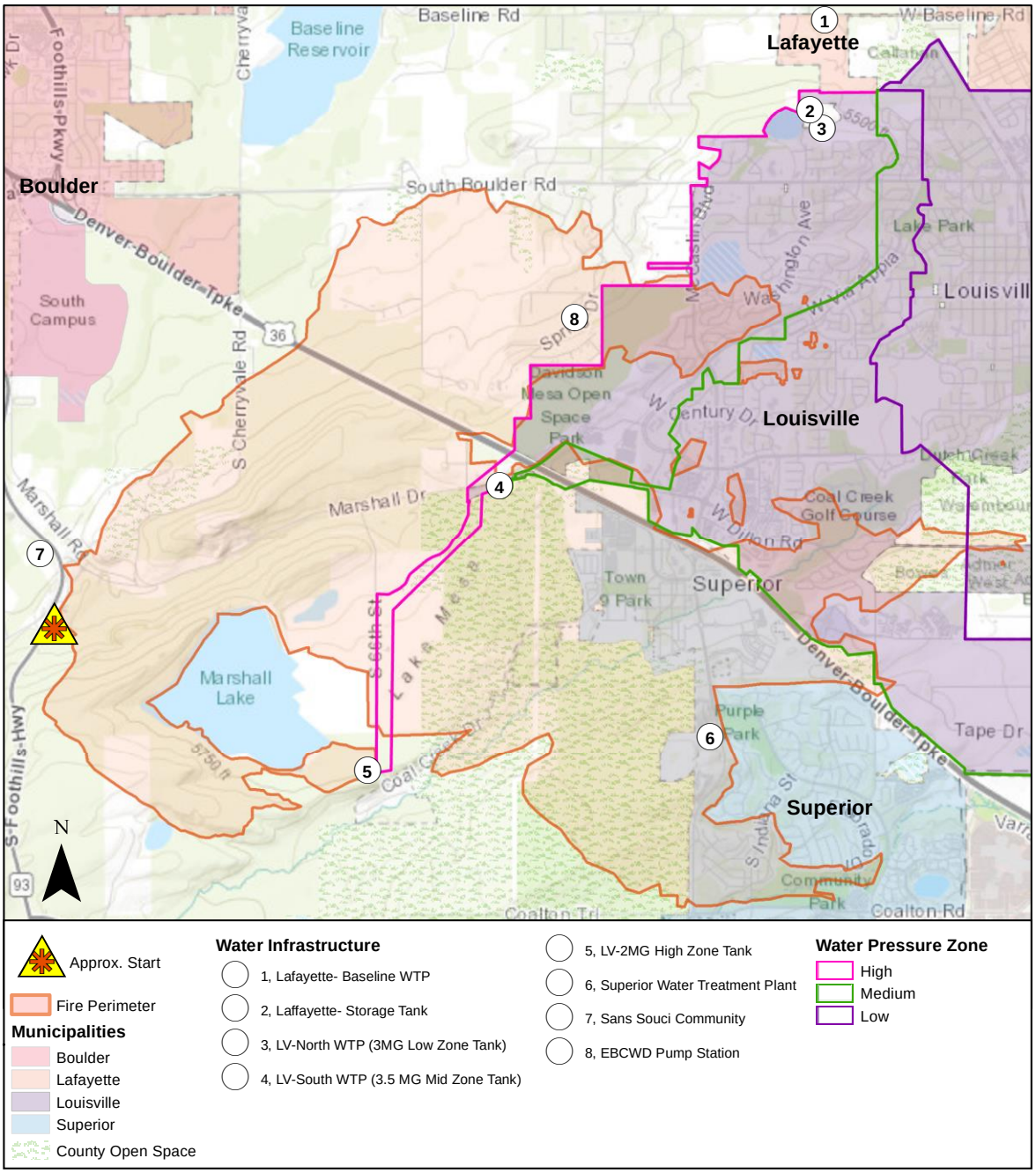


Figure 7–1. Overview of water utilities and related infrastructure. Red outline indicates the approximate Marshall Fire burn area (M8)

Table 7–2. Overview of water utilities

	Louisville	Superior	Lafayette	EBCWD	S.S Mobile Home Park
Service Population	20,139	17,170	28,700	300	150
Damaged & Destroyed Properties[1]	611 of 7,339	453 of 3,650	18 of 9,700	72 of 137	3 of 61
Water Mains (mi)	120	50	177	8	<1
Hydrants	1,200	430	900	40	0
Total Finished Water Storage (MGD)	8.5	3.4	14	0.1	0
Raw Water Source	Surface	Surface	Surface	–	1 Well
Water Treatment Plant(s)	2	1	1	0	0
Elevations of Water Treatment Plants	NWTP: 1700m SWTP: 1729m	1727m	1660m	–	–
Physical Fire/Heat Damage to Assets?	Yes	Yes	Yes	Yes	No
Physical Wind Damage to Assets?	Yes	Yes	Yes	Yes	Yes
Residual Disinfectant:	Free Available Chlorine	Free Available Chlorine	Free Avail. Chlorine	Free Available Chlorine	Free Available Chlorine
Contamination?	Yes	Yes	No	Yes	Not Tested
Contamination Source:	Water Distribution System	Reservoir	–	Water Distribution System	–
Contamination Type:	VOC & SVOC's indicative of past wildfire contamination	VOC's from ash and debris entering reservoir surface	–	VOC & SVOC's indicative of past wildfire contamination	–

[1]includes sum of all destroyed and damaged residential and commercial properties relative to approximate number of total properties that are served by the water utility

7.1.1 Louisville Public Works and Utilities (LV-PW)

The Louisville water distribution system serves a population of over 20,000 residents. Utility details are provided in Table 7–2. Louisville sources its water from 6 locations: South Boulder Creek, Marshall Lake, Harper Lake, Louisville Reservoir, Gross Reservoir and Carter Lake. Louisville's system consists of two water treatment plants at elevations of 1729 m and 1700 m, three pressure zones, and three primary finished storage tanks with a total storage capacity of 8.5MG (Figure 7–1). The south water treatment plant (SWTP), mid zone tank, and high zone tank are located west of the City, within the burn zone. The South WTP was offline for winter/low demand conditions on the morning of the fire.

On the day of the fire, the SWTP staff evacuated the facility around 11:30 AM, shortly before the fire reached the property (Table 7-1). Shortly after this evacuation (sometime between noon and 1 pm), the fire enters the region of the SWTP and the water treatment plant loses power. At this time, water pressure is decreasing and LV-PW staff drive into the fire area to check on the SWTP. Around the

same time, to accommodate for dropping levels of water at the SWTP, the North plant is set to maximum capacity (8 MGD).

Midafternoon (sometime between 2 – 3 pm) on December 30, Louisville Public Works talks to Xcel Energy and asks them to prioritize getting power back on to the SWTP such that remote instruments can work because the plants are low on water. Between 3 – 4 pm on December 30, Louisville Public Works arrives at the interconnect between Louisville and Superior and opens the interconnect to provide Superior with water. At this time, there is still no power at the SWTP in Louisville. By 4 pm on December 30, water is flowing through the interconnect between Louisville and Superior at about 1 MGD.

Around 5 pm, Louisville Public Works staff drive back into the burn area to the mid-zone and high-zone tanks to check the water level manually and find the levels in the tank are very low (only 2 feet left). When the staff returns to the mid-zone tank, the tank was at ~1ft remaining. To maintain pressure within the system for firefighting efforts, LV-PW staff open the raw water valved at the SWTP Figure 7–2(a), which was flowing by 6:45 PM. The interconnect with Superior was closed in parallel. Around the same time (~6 PM) the fiber optic cable between the north and south WTPs was damaged by fire (Figure 7–3), contributing to lack of communication between critical facilities. In part due to the introduction of untreated water into the system, CDPHE and Louisville issue a boil water notice to this community between 7 and 8 PM.

Between 9 – 10 pm Xcel Energy drives natural gas tanker trucks through the burn area to the Louisville SWTP to provide temporary power to the treatment plant to restart the plant and begin getting potable water production back on-line (the plant had been offline for winter). The location of the temporary hook-up is shown in Figure 7–2(b). After power is restored, both plants begin running at full capacity (13 MGD or 9,000 GPM). Power was restored via the temporary natural gas splice to the SWTP emergency backup generator at 10:50 PM after an approximately 11 hour outage. Utility power was restored on January 2nd at approximately 6 PM.

(a) (b)

Figure 7–2. Louisville South WTP (a) Tour of lower-level infrastructure and (b) location of temporary natural gas hookup (39°57’45.3” N, 105°11’17.0” W)

At 1 am on December 31, Louisville Public Works Operations Staff meet to discuss dangerously low pressure within the water distribution system and that the tanks are still low. To accommodate this low pressure, staff shuts off curb stops to destroyed properties or at the entrance of neighborhoods with significant numbers of damaged properties. This task occurs from 1 – 7 am on December 31. By 5:35 AM the SWTP was producing fully compliant potable drinking water. By 8 – 9 am on December 31, water levels in the tanks at the Louisville Water Treatment Plants begin to rise, by mid-day on December 31 these levels are back to normal levels.

Figure 7–3. Damaged fiber optic cable linking Louisville water treatment plants (approximate location: 39°58'30.6"N 105°09'57.7"W)

7.1.2 Superior Public Works and Utilities

The Superior water distribution system serves a population of over 17,000 residents. Utility specifics are detailed in Table 7–2. Superior sources its water from 2 locations: Marshall Lake and Carter Lake. Superior's system consists of one water treatment plant at an elevation of 1727m (Figure 7–1), one pressure zone, and three primary finished storage tanks (1.4 MG, 0.5 MG, 1.5 MG) with a total capacity of 3.4 MG. At the time of the fire, the Superior's water treatment plant was operated by Ramey Environmental Compliance (REC). Before the fire, the Town had set into motion an operator change that had been previously scheduled for the end of 2021, one day after the fire.

Superior's sole Water Treatment Plan (WTP) suffered damage due to the fire and taste/odor concerns due to ash deposits in their primary storage facility, Terminal Reservoir (Figure 7–1). A timeline of events relative to Superior's water supply are provided in blue in Table 7-1. At 11:45 AM REC staff were notified about the fire and additional staff shortly arrived to prepare the plant for emergency protocols and potential evacuation, including increasing water production (650 to 1200 GPM) and increasing turbidity shutdown setpoints (from 0.3 NTU to 0.7 NTU).

Figure 7–4a shows an overview of the WTP and Figure 7–4b shows the location of the fire at 2 PM. Shortly after this satellite image was taken, staff was forced to evacuate as smoke and fire moved through the plant. At around the same time (2:25 PM) the plant lost both electric power and natural gas supply, resulting in a total power loss. The plant was not producing treated water for a period of approximately 4 hours (2:25 to 6:18 PM).

When staff returned to the WTP at ~4:15PM, it was found that power surges caused catastrophic failure of the automatic transfer switch which resulted in only half of the WTP to be with power. During this time Xcel Energy was able to get 2-phase power to the plant, which allowed some equipment to operate, but the plant needed 3-phase for proper operation of much of its equipment. REC staff took damage inventory which included loss of all flow meters, chlorine/fluoride/caustic feed pumps, surface wash pumps, clarifloculator drives, SCADA computers and remote site communications. Figure 7–5 shows pictures of the destroyed backup generator which was located at the northeast of the plant Figure 7–4(a). Significant efforts were made by REC staff to get filters operating manually, contact tanks dosed, and switches closed; however, power was still out to various parts of the plant.

Due to the multiple failures of the Superior WTP and inability to keep up with water demand at approximately 3:45 PM Louisville opened the interconnect station between the towns' water systems to feed the Town of Superior with 1 MGD of flow to keep up with system demand and allow for the Town of Superior tanks to recover.

Superior was fortunate to get power back relatively quickly and, shortly after 6 PM, was able to restarted the flow of treated water at a rate of 2000 GPM, which was increased over the following hours. Several groups contributed to bringing the WTP's supervisory control and data acquisition (SCADA) system back online to improve operations. They data system reported that storage tanks were down to 15% of their capacity, which were at 90% capacity before the system went down just 5 hours earlier (1:53 PM).

While the plan was producing at near maximum capacity under manual operation at ~8:15 PM, water usage was extraordinarily high and tanks were not refilling. Around this time, Superior Public Works staff started looking for water loss, shutting fire hydrants (abandoned by firefighters) and curb stops (destroyed homes) across the system. One significant loss was occurring at a rupture of the 6 in. diameter fire suppression system that serves Target; taking several hours to address with aid of firefighters.

Power supply remained an issue at the WTP until around 9:45 PM when Xcel Energy was able to repair the on-site transformer and reestablish 3-phase power; restoring full functionality of process equipment and instrumentation. Due to system pressure loss, a boil water notice was issued to this community by CDPHE.

(a) (b)

Figure 7–4. Superior WTP overhead (a) google earth image showing location of destroyed backup generator and (b) at 2 PM 12/30 with fire to the north (39°56’33.8” N, 105°09’50.2” W)

(a) Post–fire (a) Salvageable foundation structure

Figure 7–5. Destroyed backup generator at Superior Water Treatment Plant (39°56’33.8” N, 105°09’50.2” W)

7.1.3 Lafayette Public Works Department

The Lafayette water distribution system serves a population of nearly 29,000 residents. Utility details are provided Table 7–2. Lafayette sources its water from 2 locations: Baseline Reservoir and Goosehaven Reservoir. The Lafayette system consists of one water treatment plant at an elevation of 1660m and four primary finished storage tanks (4 MG, 4 MG, 4 MG, 2 MG) with 14 MG of total storage capacity. As shown in the top right of Figure 7–1, the fire perimeter did not enter the city limits of Lafayette. However, 22 properties were destroyed in Unincorporated Boulder that were provided water by Lafayette Public Works.

7.1.4 East Boulder County Water District (EBCWD)

The East Boulder County Water District does not have its own water treatment plant and instead receives water from the Lafayette Water District. The EBCWD has one pump house and one primary finished water storage tank with a capacity of 0.1 MG which serve the community's 300 residents through eight miles of pipelines and 40 hydrants. The pump station and corresponding storage tank are shown in Figure 7–6. Description of EBCWD characteristics and fire damage are provided in Table 7–2.

EBCWD had 72 homes damaged or destroyed, representing nearly half of their total customers. Their system as fairly significant elevation changes and at least some portions lost pressure during the fire. A boil water notice was issued to this community by CDPHE.

Figure 7–6. EBCWD Pump house with buried storage water tank in the foreground, adjacent to destroyed home (39°58'33.2" N, 105°10'40.8" W))

7.1.5 Sans Souci Mobile Home Park (SSMHP)

SSMHP services 150 people through one on–site well. Figure 7–7 shows an image of their well house and out–of–service storage tank. While this neighborhood was located just west of the fire perimeter (Figure 7–1) high winds caused damage to many of the homes and impacted the water supply system. A boil water notice was issued to this community by CDPHE.

Figure 7–7. Sans Souci Mobile home park water station (39°57’24.8” N, 105°13’56.3” W))

7.1.6 Eldorado Artesian Springs

The springs are located 10 miles west of Louisville, outside of the fire perimeter, and serves a population of 259 sourced by 2 wells and 1 spring. They were issued a boiling water advisory by the state because they have a water bottling facility at the business center in southeast Louisville.

7.1.7 Fire Impacts on Water Quality

A timeline of events related to water utilities in the days following the fire are outlined in Table 7–3. To protect the public from exposure to disease causing organisms that may have entered the piping network during the fire, all public water systems were issued a boil water advisory by the Colorado Department of Public Health and Environment (CDPHE). CDPHE is the State of Colorado’s Safe Drinking Water Act primacy agency responsible for regulating all public water systems. During low or no pressure events, pathogens may enter water distribution networks. After bacteriological testing by the water systems, CDPHE lifted the advisories. No bacteriological contamination was identified after flushing.

Chemically contaminated water however was found in three systems: Louisville, East Boulder County Water District, and Superior. Louisville found volatile (VOC) and semi–volatile organic compound (SVOC) contaminated drinking water in a hydraulically isolated part of their distribution system. There, benzene was detected at 221 parts per billion (ppb) along with other VOCs such as styrene, and more. Results indicated that water use posed an acute health risk. For example, California OEHAA determined 26 ppb of benzene posed a short–term risk to children’s health. The USEPA’s 1–day health advisory for a 10 kg child is 200 ppb, while the federal maximum contaminant level (long–term drinking water exposure limit) is 5 ppb. At this distribution system location all benzene health–based thresholds were exceeded. Contamination found in Louisville was similar to the type found in distribution systems after fires in California and Oregon (Odimayomi et al., 2021, Proctor et al., 2020). Sources include debris, particulates, and vapors drawn into depressurized water systems and thermal degradation of plastic infrastructure materials (Draper et al., 2022; EPA, 2021; Isaacson et al., 2021). However, when contamination was found in Louisville no water was being used in the affected area because pressure had been shutoff.

Table 7–3. Timeline of water quality and utility events following the fire

Date(days since fire)	Org	Event/notice/advisory	Area
12/31 (1)	–	Cold front moves in, snow starts, building pipes freeze	All
12/31 (1)	LV	25 Chlorine residual samples collected	Louisville
12/31 – 1/1	LAF	Flushed hydrants near destroyed properties	Lafayette
1/1 (2)	POTUS	President issues federal disaster declaration	Boulder County
1/1 (2)	LV	18 Bacterial and chlorine residual samples collected	Louisville
1/1 (2)	SUP	SUP–PW begins flushing hydrants	Superior
1/2 (3)	LV	5 VOC samples collected	Louisville
1/2 (3)	LV–PW	Began flushing the entire system (120 miles, 1,200 hydrants) Sunday morning. Estimated to take 6–8 days. Completed in 4 days utilizing collaboration with neighboring municipalities	Louisville
1/4 (5)	CDPHE	Boil water advisory lifted for EAS residents outside of closed areas[1]	Eldorado Artesian Spring
1/5 (6)	LV	17 Bacterial and chlorine residual samples collected	Louisville
1/5 (6)	CDPHE	Boil water advisory lifted for EBCWD residents outside of closed areas[1]	EBCWD
1/6 (7)	CDPHE	Boil water advisory lifted for residents outside of closed areas[1]	LV, SUP, SSMHP
1/6 (7)	CoB, LV	8 VOC samples from water mains collected by City of Boulder (524.2)	Louisville
1/7 (8)	CDPHE	CDPHE provides more guidance for residents on flushing in homes and businesses	LV & SUP
1/7 (8)	CoB, LV, SUP	CoB collects VOC samples from water mains at 12 and 13 property locations in LV and SUP, respectively (524.2)	LV & SUP
1/10 (11)	LV	Experts draft plan and standard operating procedures for the water system sampling and recovery approach	Louisville
11 – 12, Jan.	LV	LV–PW and CEC staff collect VOC and SVOC samples of closed water mains with standing structures via isolated hydrants	Louisville
1/12 (13)	SUP	Public meeting with town, CDPHE, and CEC to discuss 300 drinking water odor concerns	Superior
1/13	LV	LV–PW holds public meeting to discuss customers without water service	Louisville
1/14	LV	LV–PW emails customers about Do Not Drink water guidance in areas shutoff from water and progression to test and restore water service	Louisville

BC = Boulder County; LV = City of Louisville; LV–PW = Louisville Public Works and Utilities; LAF = City of Lafayette Public Works Department; SUP = Town of Superior; SUP–PW = Superior Public Works & Utilities Department; EBCWD = East Boulder County Water District; EAS = Eldorado Artesian Spring; SSMHP = Sans Souci Mobile Home Park; CoB = City of Boulder; CDPHE = Colorado Department of Public Health and Environment; CEC = Corona Environmental Consulting.

[1](Boulder Office of Emergency Management, 2022)

Over the course of several weeks, Louisville conducted testing, followed by water main flushing, and repeated follow–up testing to track removal of the contamination. This procedure required 72-hour stagnation intervals between flushing and follow–up sampling to increase the chance that Louisville would find any present contamination. This 72 hour 'stagnation' procedure was initiated in 2017 after the Tubbs Fire and has been applied in California and Oregon ever since. The EBCWD also found VOC contamination in their system, including benzene and other chemicals indicative of wildfire caused damage. Although, EBCWD testing was conducted about 1 month after the fire occurred and water had been being used by customers before testing without restriction. Contaminant levels found in this system did not exceed levels that would present acute drinking water health risks per CDPHE. Superior did not find VOCs indicative of this acute contamination, but did discover ash and fire debris chemicals that caused the drinking water to have off–tastes and odors. The contaminated water was found to be originating from a reservoir, was unaffected by the water treatment plant, and residual disinfectant. The drinking water had smoky, ash tray, and chemical–like flavor characteristics. A map showing the water sampling activities of the Louisville and Superior can be found in Figure 7–8**.**

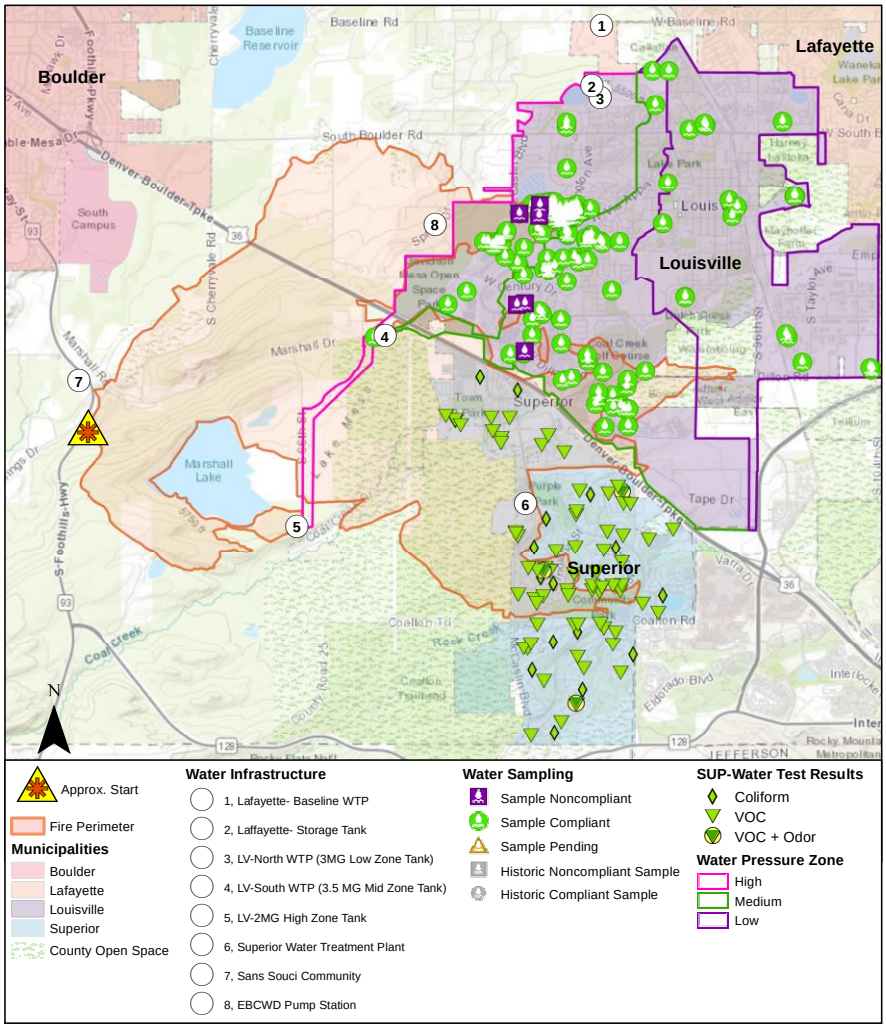


Figure 7–8. Water sampling locations in the City of Louisville and Town of Superior following the Marshall Fire. Red outline indicates the Marshall Fire burn area (M7)

7.2 Energy—Natural gas and electricity

Natural gas and electric services in the Louisville and Superior areas are primarily provided by XcelEnergy® (Xcel Energy Colorado, n.d.). Xcel Energy is the largest energy provider in Colorado with approximately 1.5 million electric customers. Nearly 17% of homes within Colorado are in areas considered to be at high and extreme risk for wildfires. At the time of the fire, Xcel Energy had invested in a $597M wildfire mitigation program across the state of Colorado and had reported spending $13.5M to track and mitigate fire risks within Boulder County in 2020 (Osher, 2022).

Before the Marshall fire had been named on December 30th, Xcel Energy already had many customers in the area experiencing outages due to high winds (Xcel Energy Colorado, n.d.)—when the Marshall fire reached populated areas, that number grew. During the Marshall fire, Xcel Energy was asked to shut down natural gas and electric services in the Louisville and Superior areas by public authorities (personal correspondence). By the end of the day on the 30th, all Xcel Energy natural gas services in Superior and Louisville were shut off (Warwick, 2021). Within 24–48 hours of the fire, Xcel Energy had lost all access to the burn area (personal correspondence).

On the 31st of December, 13,000 natural gas customers and 5,500 electric customers were reported to be without service (Svaldi, 2021). Following the Marshall fire, temperatures dropped below freezing, introducing the risk of frozen water pipes. Xcel Energy dispatched 500 employees and contractors to focus on restoring lost services (Svaldi, 2021). In addition, Xcel Energy provided portable heaters to help customers heat portions of their homes and plumbing.

The following message is an approximate transcript of a voicemail sent to Xcel customers via a robo call on 31 Dec. 2021 (12:33 PM): *At the request of public safety officials, gas and electric was shut off to Louisville and Superior to minimize safety concerns. 150 employees and contractors are working today to assess damage. Restoration is likely to take several days as crews will need to go house–by–house and building–by–building to restore natural gas. Once public safety officials allow crews into the burn area, residents will see contractor in the neighborhood. Due to winter weather concerns, we are providing electric heaters, at one location now, a second to come*.

Table 7-4 provides a timeline of events related to the electrical and natural gas power systems. The majority of events were pulled from publicly available information as the incident report has not yet been made available.

7.2.1 Natural Gas

As the Marshall fire grew, Xcel Energy implemented rolling blackouts (shutoffs) in the surrounding areas to reduce demand on the natural gas system (Ivy et al., 2021). As blackouts ended, Xcel Energy asked its customers to continue conserving natural gas (Xcel Energy Colorado, n.d.). By 11:44 p.m. on the 30th, all natural gas services provided by Xcel Energy had been shut off indefinitely (Warwick, 2021) to the impacted area. For example, Figure 7–9 shows the approximate area over which natural gas was shut off with in the City of Louisville, corresponding with city boundaries to the west and south of the City.

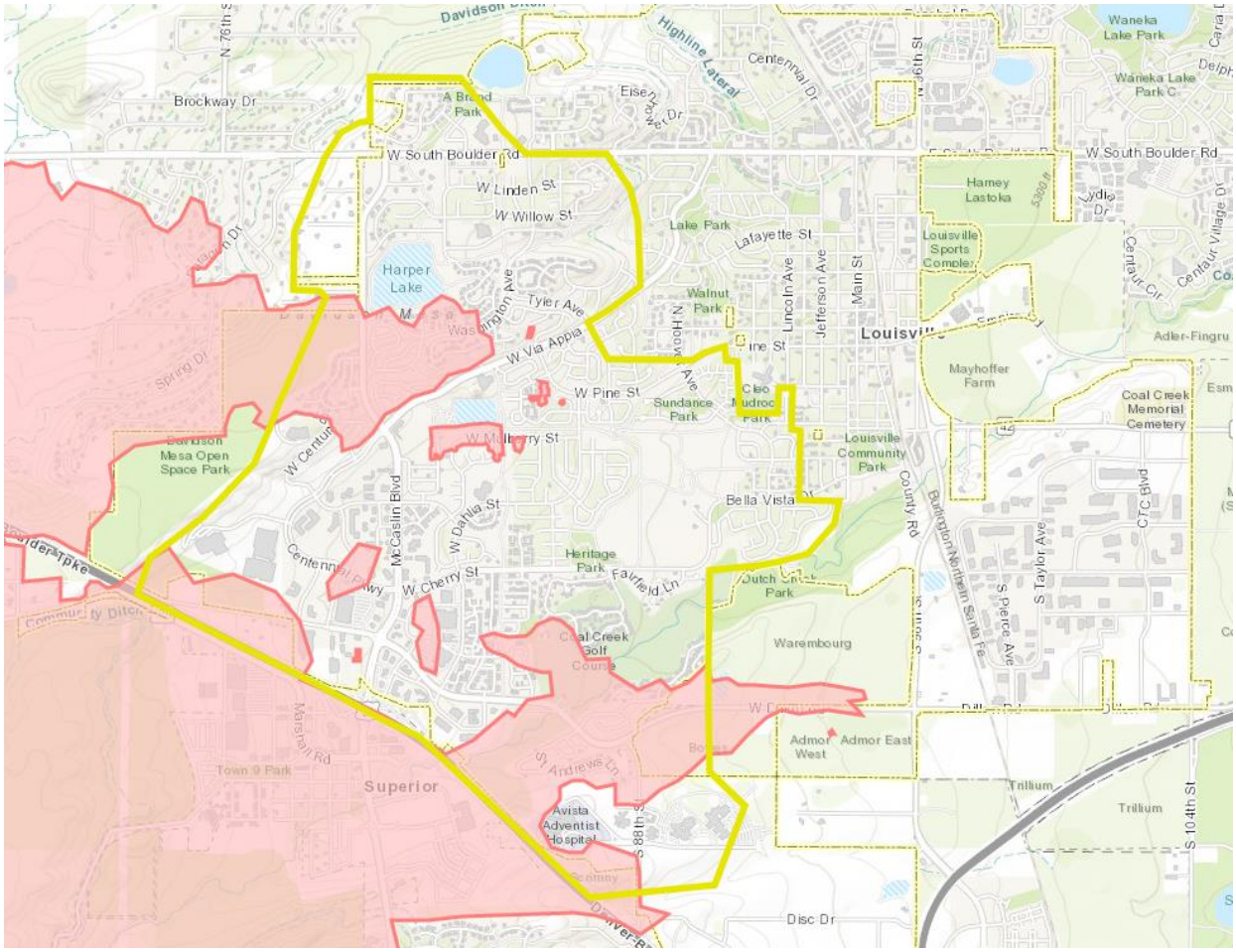


Figure 7–9. Approximate area of natural gas shut off (solid yellow) in Louisville, CO (city boundary in dashed yellow) and fire perimeter (pink)

On the 31st, approximately 13,000 customers were without natural gas service (Svaldi, 2021). Over the next several days, recovery of the natural gas system occurred (Figure 7-10). Recovery involved three steps:

1. Manually cutting off gas service
2. Re-pressurizing the natural gas systems to ensure the integrity of the infrastructure
3. Reigniting pilot lights at each connection/household (Mulholland, 2022)

After performing the first two steps, approximately 150 employees and contractors were dispatched to reestablish natural gas service to all homes for which it was safe to do so (Svaldi, 2021). Customers were instructed not to call in for service restoration, but that service would be restored without a request as quickly as possible (Xcel Energy Colorado, n.d.).

By January 1st a few hundred service connections had already been restored (Garrison, 2022), and Xcel expected that all customers that were able to receive service would have service restored by January 4th (Xcel Energy Colorado, n.d.). Short-term repairs remained to be made to the system as service was restored. Around 7 p.m. on January 2nd, service had been restored to an estimated 1,800 customers and it was reported that crews were working from 7 a.m. to 11 p.m. each day to relight pilot lights (KUSA Staff, 2021).

By 6:32 p.m. on the 3rd, gas had been restored to approximately 6,000 customers (Xcel Energy Colorado, n.d.). By 2 p.m. on January 4th, natural gas service had been restored to approximately 10,000 of the 13,000 original customers without service (Xcel Energy Colorado, n.d.). At 6:35 p.m. on January 5th it was reported that service had been restored to all customers that could receive it. Permanent repairs remained to be made to the system, and all customers still without service were instructed to contact Xcel Energy to have their service restored (Xcel Energy Colorado, n.d.).

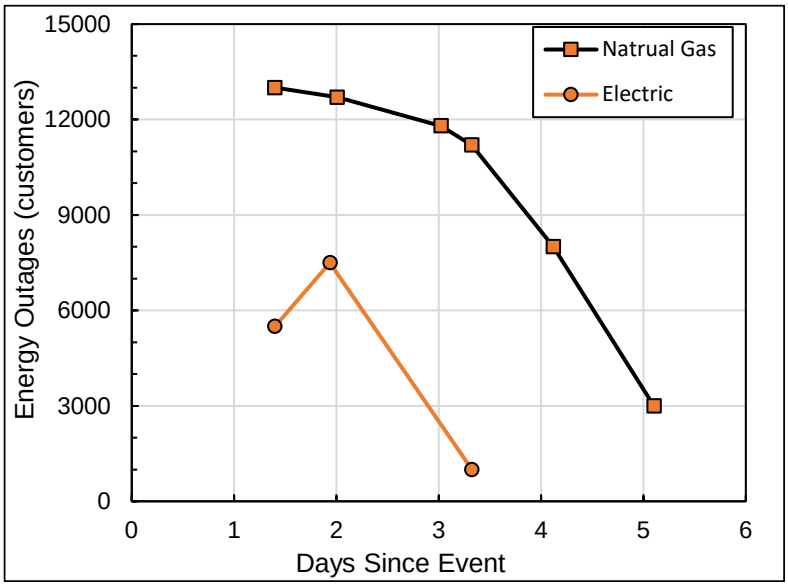


Figure 7-10. Natural Gas and Electric Outages

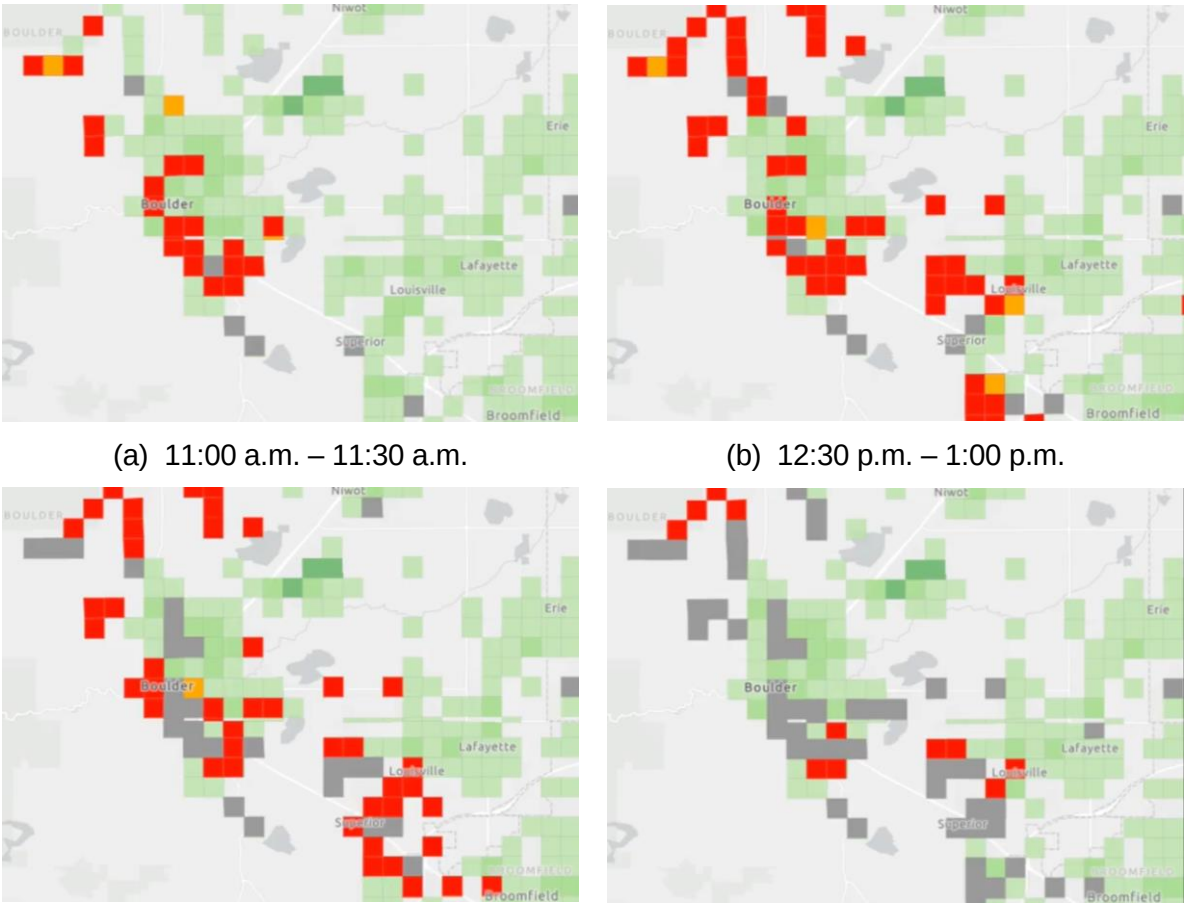
7.2.2 Electricity

Power outages due to high winds prior to the fire meant crews were already working around the clock to restore power that had been lost in the Boulder area (Xcel Energy Colorado, n.d.). As the fire grew on the 30th, the South Boulder Recreation Center was designated as an evacuation center. Within a few hours, the South Boulder Recreation Center lost power (even though it was not in the burn area). This required evacuees and resources to be relocated to a newly designated evacuation center (Ivy et al., 2021).

On the 31st, an estimated 5,500 customers in the Boulder were without electric power and Xcel Energy dispatched approximately 350 employees and contractors to focus on restoring electric service (Svaldi, 2021). Over the next few days recovery of the electric system occurred (Figure 7-10). On the morning of January 1st, Xcel Energy estimated that 7,500 customers in the Boulder area were without electric service (Garrison, 2022). At 1:20 p.m. on the 1st, Xcel Energy expected that all customers who had lost electric service would have it restored within the day (Xcel Energy Colorado, n.d.).

At 7:16 p.m. on January 2nd, an estimated 1,000 customers in the fire area and 600 outside of the fire zone remained without power (KUSA Staff, 2021). At 6:31 p.m. on January 3rd, Xcel Energy reported electric restoration to be “nearly complete” (Xcel Energy Colorado, n.d.). At 6:35 p.m. on January 5th, permanent repairs remained to be made to the electric system, and all customers still without service were instructed to contact Xcel Energy to have their service restored. Statewide, an estimated 100,000 customers had lost service due to the fire and extreme wind events (Xcel Energy Colorado, n.d.).

Gridmetrics™ provides real time power outage data using a Power Event Notification System (PENS). Data was logged and mapped in a 1 km by 1 km grid of the Boulder area from 6 a.m. to 6 p.m. on December 30th, 2021 (Figure 7-11). Images from the (PENS) illustrate the outages experienced in Boulder due to high winds before the Marshall Fire caused any outages (Figure 7-11a), outages increasing in the Superior and Louisville areas as the fire grew (Figure 7-11b,c), and the system losing access to the data as the fire continued to grow throughout the day (Figure 7-11d). An example of wind/fire damage to power infrastructure is provided in Figure 7-12, where a downed power pole is shown within the fire perimeter during the snowstorm that followed the fire.



(a) 11:00 a.m. – 11:30 a.m.

(b) 12:30 p.m. – 1:00 p.m.

(c) 2:00 p.m. – 2:30 p.m.

(d) 3:30 p.m. – 4:00 p.m.

Figure 7-11. Map of Approximate Electric Outages, 1 x 1 km grid points (Gridmetrics, 2022) (39°57’15.7” N, 105°11’38.4” W)

(a) (39.97543, -105.1786) (b) 39.94957, -105.16125

Figure 7-12. Damage to electrical power: (a) Down power pole due to wind and/or fire damage (https://co.my.xcelenergy.com/s/controlled-electric-outages-notice) and (b) Plastic vs. steel components

Table 7-4. Timeline Electrical Power (E) and Natural Gas (G) Events

Time	Electric or Gas	Event	Agency/Reference
12/30/2021			
Before 11:30 a.m.	Electric (E)	Two fires reported; 105 mph wind recorded; Xcel reports 48 power outages affecting about 4,700 customers (statewide assumed)	KVDR News (Ivy et al., 2021)
1:31 p.m.	Electric	Crews working to safely restore power in Boulder due to high winds. Working around the clock to restore power to Boulder	Xcel Energy Colorado twitter account
2:25 PM	E & G	Natural gas shut off, generator quit, total power loss at SUP WTP, staff evacuate	SUP (WTP)/ REC
2 – 3 PM	Electric	LV–PW asks XCel Energy to prioritize getting power back to water treatment plants low on water.	LV–PW
3:52 p.m.	Electric	Power outage at South Boulder Rec Center (evacuation center) and LF Fire Station	KVDR News (Ivy et al., 2021) & LV (LFPD)
4:20 p.m.	Electric	25,000 customers without power in Boulder, Superior, Louisville, and Arvada areas.	KVDR News (Ivy et al., 2021)
5 PM	Electric	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
9 – 10 PM	Gas	Xcel 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.	Xcel Energy & LV–PW

Time	Electric or Gas	Event	Agency/Reference
9:45 PM	Electric	By this time, Xcel has completed repairs to onsite transformer and reestablished 3-phase power; full function of process equipment & instrumentation	SUP (WTP) REC
10:15 p.m.	E & G	Xcel expects to end outages overnight; blackouts were used to reduce the demand on the natural gas system while the Marshall fire was fought.	KVDR News (Ivy et al., 2021)
10:29 p.m.	E & G	Some controlled outages ending throughout Colorado. Customers asked to "continue conserving natural gas."	Xcel Energy Colorado twitter account
11:44 p.m.	Gas	No Xcel natural gas service in Superior and Louisville—service out indefinitely	Warwick, 2021
12/31/2021 11:43 a.m.	E & G	15,00 customers without electricity or natural gas service; 500 workers and contractors working to restore service.	https://www.denverpost.com/2021/12/31/marshall-fire-power-outages-xcel-energy/
12/31/2021; 12:33 PM	E&G	Robo calls circulated to customers' cell phones	B. Wham (personal communication)
12/31/2021 1:18 p.m.	Electric	Boulder OEM issues statement contradicting early reports that downed power lines ignited the fire. Xcel found downed communication lines, not power.	Mullen & Klamann, 2022
12/31/2021 9:04 p.m.	E & G	5,500 customers in Boulder area without electric service; 13,000 customers without natural gas service. About 350 Xcel employees focused on restoring electricity; 150 focused on restoring natural gas.	https://www.denverpost.com/2021/12/31/marshall-fire-power-outages-xcel-energy/
12/31/2021 2:19 p.m.	E & G	Xcel encouraged its customers in Louisville and Superior to protect their plumbing amidst dropping temperatures.	Xcel Energy Colorado twitter account
12/31/2021 10:42 p.m.	Gas	Xcel informed customers not to call in for service restoration—service will be restored, when possible, without a request.	Xcel Energy Colorado twitter account
01/01/2022, morning	Electric	Xcel said about 7,500 customers in the Boulder area are still without electric service as of Saturday morning	Dickey, 2022
01/01/2022, morning	Gas	utility company said crews have restored natural gas service to a few hundred of the 13,000 customers in Superior and Louisville who are without service, as repairs to the system continue. However, Xcel said the process will take several days before gas service is completely restored.	Dickey, 2022
01/01/2022 1:20 p.m.	Electric	All customers who can accept service are expected to have their power restored within the day. About 13,000 customers to have service restored in the next several days.	Xcel Energy Colorado twitter account

Time	Electric or Gas	Event	Agency/Reference
01/01/2022 4:31 p.m.	Gas	All customers who can accept service are expected to have their gas restored by Tuesday (January 4th).	Xcel Energy Colorado twitter account
01/01/2022 5:08 p.m.	Gas	Customers without gas service can pick up electric heaters.	Xcel Energy Colorado twitter account
01/02/2022 12:02 p.m.	Gas	About 1,200 customers in the Superior and Louisville area have had gas restored.	Xcel Energy Colorado twitter account
01/02/2022 1:26 p.m.	Gas	Stocking shortage of electric heaters, expected to last 2-6 p.m.	Xcel Energy Colorado twitter account
01/02/2022 7:02 p.m.	Gas	Repairs being performed on the gas system in Superior and Louisville to allow restoration of the entire system.	Xcel Energy Colorado twitter account
01/02/2022 7:16 p.m.	Gas	About 1,800 customers out of 13,000 have had gas restored. Crews working 7 a.m. to 11 p.m. going door to door to relight	KUSA Staff, 2022
01/02/2022 7:16 p.m.	Electric	About 1,000 customers in the fire area remain without power—some customers unable to accept service. About 600 customers outside the fire zone remain without power.	KUSA Staff, 2022
01/03/2022 2:23 p.m.	Gas	Gas service restored to 5,000 of about 13,000 customers. Crews go door to door to relight pilot lights.	Xcel Energy Colorado twitter account
01/03/2022 6:31 p.m.	E & G	Electric restoration “nearly complete”, gas restored to 6,000 customers	Xcel Energy Colorado twitter account
01/04/2022 12:21 p.m.	E & G	Warning of scammers contacting Xcel customers.	Xcel Energy Colorado twitter account
01/04/2022 2:00 p.m.	Gas	Gas service restored to 10,000 customers.	Xcel Energy Colorado twitter account
01/05/2022 6:35 p.m.	E & G	Electric and gas service restored to 100,000+ (was 100,000 statewide?) customers. Permanent repairs remain to be made to both systems before all customers have service restored.	Xcel Energy Colorado twitter account
01/05/2022 6:35 p.m.	E & G	Customers who still have not had service restored need to contact Xcel to have power/gas restored.	Xcel Energy Colorado twitter account
01/05/2022	E & G	Due to fires, wind, and freezing temperatures, more than 100,000 customers lost electricity and gas service was turned off for about 13,000 customers as a safety precaution in the Louisville and Superior areas.	https://co.my.xcelenergy.com/s/controlled-electric-outages-notice

7.3 Telecommunications

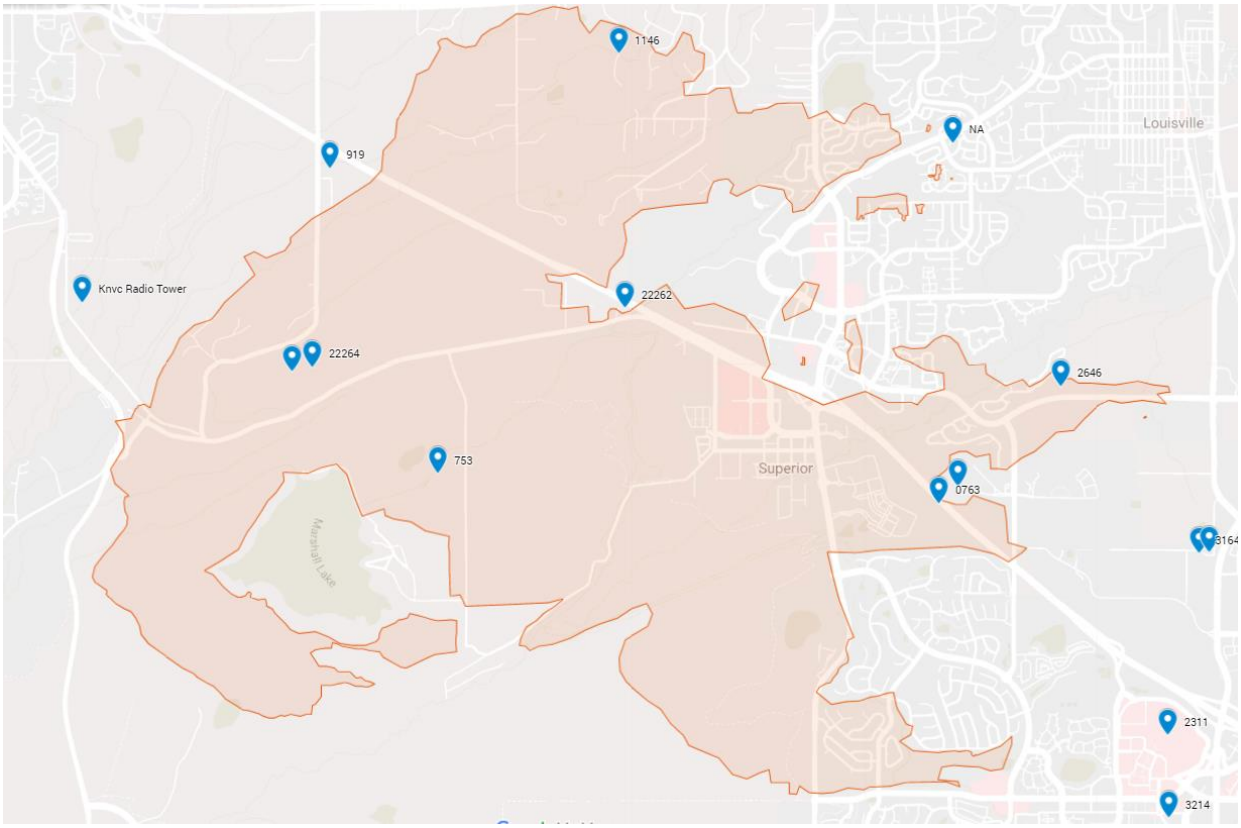
Telecommunication systems are essential during a disaster to provide communication and disaster information such as evacuation procedures to victims and relief efforts alike. Damage to these systems can cause significant distress to effected communities, which was the case during the 2021 Marshall Fire where regional power failures and damage to telecommunication faculties resulted in limited internet and cell services throughout the fire region.

The primary internet service provider for the Louisville and Superior communities is Xfinity by Comcast. Xfinity serves over 1 million Colorado residents and per HighSpeedInternet.com is the largest internet provider in the state. During the Marshall Fire more than 13,000 residential customers and 660 businesses lost service, of which approximately 95% of outages were restored by January 7th 2022. The first recognition of services affected by the Marshall Fire from Comcast came from the Colorado Comcast Twitter account (@ComcastColo) at 4:53 PM on December 31st 2021 indicating Xfinity was aware of the affects the fire may have on their service. Comcast created a Marshall Fire update page on their Colorado Comcast site to provide information about service reconnections (Comcast Updates) in the community. A detailed timeline of internet services restoration is listed in Table 7-5 below.

Table 7-5. Timeline of Telecommunications and Internet Service Restoration (Comcast)

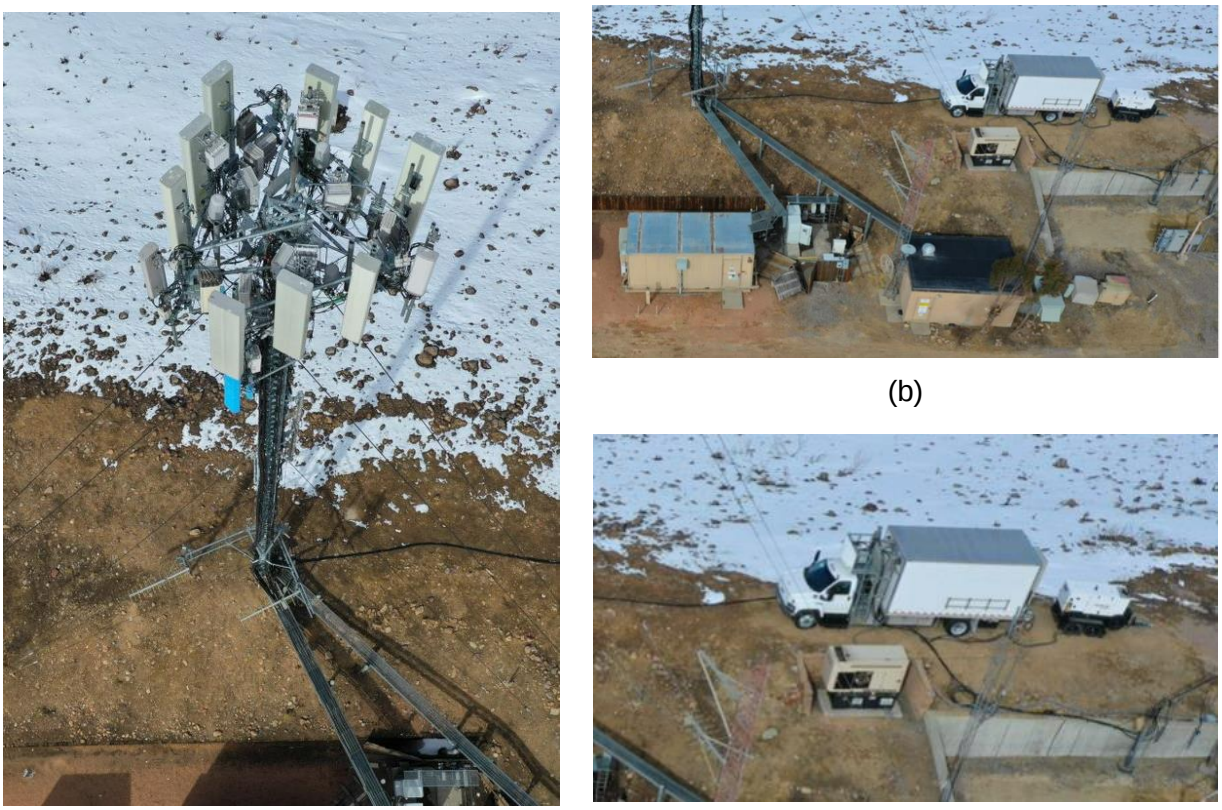
Date	Time	Event	Source
12/30/21	~3:00 PM	Phone and text message capability down for ~30 min. during evacuation (Cherry Rd., Louisville)	Pers. Comm.
12/30/21	4:53PM	First Contact from Xfinity about services affected by Marshall Fire via Twitter	Twitter
1/2/22	5:00PM	Granted access to affected areas and 40% of affected customers restored	Comcast
1/3/22	10:00AM	First update to customers affected by fires information page	Comcast
1/3/22	3:16PM	Communication to customers about Comcast Update Information Page via Twitter	Twitter
1/3/22	8:00PM	Update financial contribution to Boulder County Foundation on 12/30	Comcast
1/4/22	12:00PM	Service restored for ~85% of affected customers	Comcast
1/4/22	unknown	Comcast crews going property to property to assess damage and restore service	Comcast
1/5/22	unknown	Service restored in Broomfield, Boulder, and Lafayette ~89% of those affected by fires.	Comcast
1/5/22	unknown	Completed Fiber Optic restoration to: Properties near McCaslin & Marshall Properties near McCaslin & Coal Creek Properties near the 100 Superior Plaza	Comcast
1/6/22	12:00PM	Service restored to ~93% of residential customers and 90% of business customers	Comcast
1/7/22	unknown	Service restored to 95% of residential and business customers	Comcast

Approximate cell tower locations within the impacted area were obtained through antennasearch.com. As shown in Figure 7-13, a total of 5 cell towers were impacted by the Marshall Fire. Figure 7-14 shows a typical cell tower facility within the burn area. Preliminary inspections and reports suggest minimal damage to cell provider utilities. However, cell service and cell tower facilities were impacted during the fire by commercial power failures and damaged fiber optic cables (City of Louisville, 2022). While no significant loss of communication was reported during or after the fire, it is important to understand how damaged lifeline systems can impact one another during a disaster event such as the Marshal Fire.



https://www.google.com/maps/d/u/0/edit?mid=1lDruZ5kSmIF88rb8DeeGA6ydY8ulbb2T&ll=39.95916579591598%2C-105.20738071989838&z=14

Figure 7-13. Cell Tower Locations (available)



(a) (b) (c)

Figure 7-14. UCAV images of cell tower (ID:22264) in burn area (39°57'36.3" N, 105°12'48.4" W)

7.4 Transportation

7.4.1 Evacuation Notice

Nearly 30,000 residents were evacuated during the Marshall Fire and there was one confirmed death as a result of the wildfire (Camero, 2021; Zialcita, 2022). Although the evacuation efforts seem successful, in terms of how many residents were able to safely leave the area within a few hours, many community members felt that Boulder County, including the City of Louisville and Town of Superior, failed in their ability to notify warnings and evacuation orders (Najmabadi & Prentzel, 2022). Some community members in the Sagamore neighborhood claimed that there were "no sirens or notifications" when they decided to evacuate their home (Allen, 2022).

Boulder County's Wireless Emergency Alert (WEA) system is through Everbridge, and residents must be registered through Everbridge to receive emergency notifications (Phillips, 2022). Residence must be registered through Everbridge for notification services. Over 24,000 notifications were sent out between 11:45am – 3:00pm, however, less than 1/5 of residents received notifications, and most evacuation notices were done via neighbors, word-to-mouth, and personal choice based on proximity of the smoke (Najmabadi & Prentzel, 2022). Table 7-6 provides a detailed timeline of when emergency notifications were issued, and the area these notifications were issued for. The evacuation zones and order of notifications are provided by the Boulder OEM and are

illustrated in Figure 7-15 below. Figure 7-16 shows a snap shot of distributed evacuation orders as of 3:30 PM on the day of the fire.

As can be expected based on the rapidly changing conditions, due to high winds and rapidly moving fire front, some confusion existed throughout the transportation and evacuation routes. Hundreds of police and firefighters setup road blocks and re-routed traffic to safe areas. An example is provided in Figure 7-17, where east/south bound traffic on Highway 36 was turned around before reaching the McCaslin exit, to orient traffic away from the area where the fire had jumped across the highway.

Table 7-6. Timeline of evacuation progression

Time	Event	Location
1105	Fire starts	Marshall
1147	1st evacuation order; 215 contacts	Near CO 93 & Marshall Road
1215	2nd order: 2588 contacts; Zone 2A	East of Cherryvale Rd along Marshall Rd into Original Superior and Sagamore neighborhood
1215	3rd Order: Zone 2B	
1246	4th 254 contacts sent orders Zone 3A & 3b	East of McCaslin Blvd and S US 36
1249	4173 contacts sent warnings “Leave if you feel unsafe” Zone 4	Rock Creek and SE Original Superior
1308	Mandatory evacuations ordered Zone 5A & B [10,000 contacts between 1308 and 1325]	South of Cherry St. and East of McCaslin [Most of Louisville & S Boulder Rd]
1315	Mandatory evacuations ordered; Zone 6A & B	Cherryvale Rd to McCaslin
1325	Mandatory evacuation ordered; Zone 7	McCaslin and South Boulder Road
1314	Westminster says the Meadow View neighborhood is no longer under evacuation status. Only Boulder Co. areas remain under evacuation orders	Meadow View neighborhood, Westminster
1451	2,200 contacts told to prepare for evacuation: Zone 8	E McCaslin Blvd & North of West Cherry St.
1458	Evacuation warning; Zone 9	North of South Boulder Road
1437 [12/31/21]	By this time, US Highway 36 was reopened (Mullen & Klamann, 2022)	Boundary between Superior and Louisville

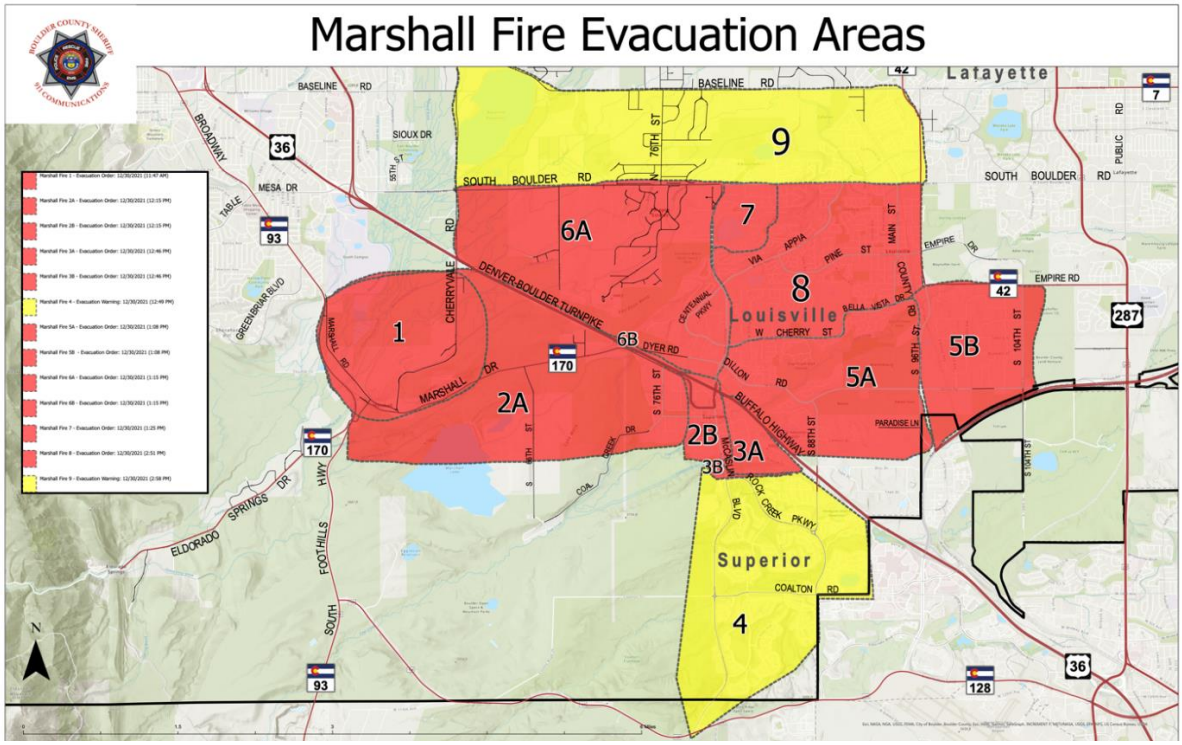


Figure 7-15. Boulder OEM Evacuation Areas for the Marshall Fire

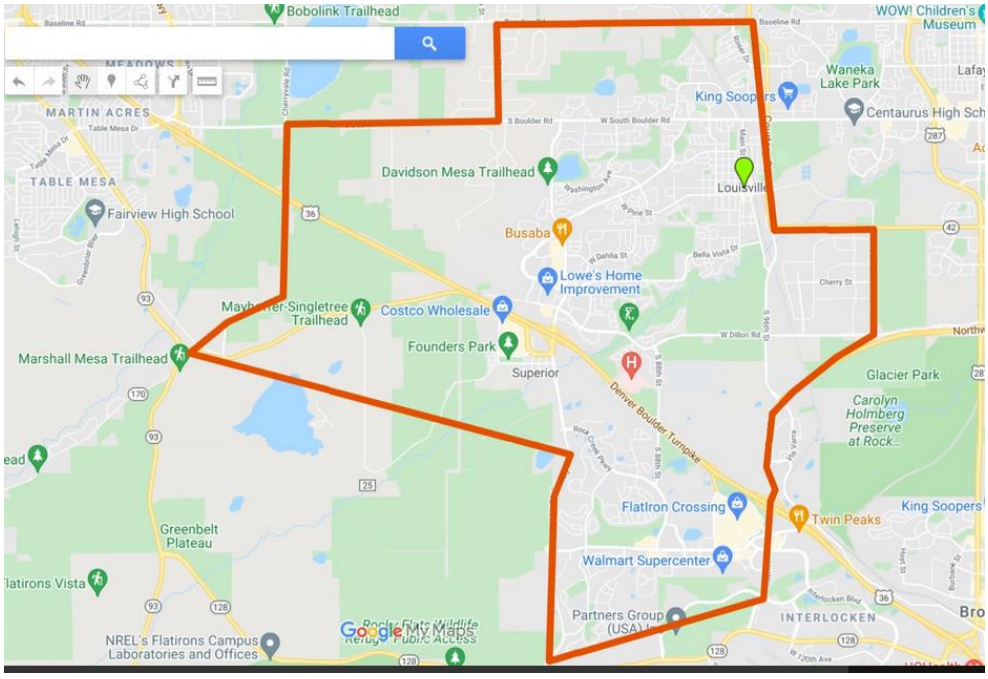


Figure 7-16. Boulder OEM evacuation orders as of 3:30 PM 30 Dec. 2021 (Boulder County OEM, 2021)

Marshall Fire, posted at 1 p.m. Dec. 30, 2021 by @BouldeJeff.

Figure 7-17. Image of Highway 36 looking southeast, showing eastbound traffic lanes heading west (Gabbert, 2021) (39°57’50.8” N, 105°10’55.3” W)

7.4.2 Pavement Damage

A roadway and pavement investigation for neighbors heavily impacted by the fire was conducted by RockSol Consulting Group, Inc. at the request of Louisville Public Works Department (Nettleton, 2022). The report relied on visual condition assessments and core samples of effected areas throughout the City of Louisville. Visual assessments were done in destroyed neighborhoods, characterized by destroyed structures, melted cars, and burned trash bins. 10 sample cores were bored from one neighborhood, with a sample core diameter of 4 in. and depths of cores ranging from 6 – 12 in. A general outline of the various types of damage and their properties is provided in Table 7-7 below, and pictures corresponding to the types of damage is show in Figure 7-18.

RockSol provides a few rehabilitation recommendations for the various types of roadway damage observed. All burned asphalt area should be milled to their relative depth of damage (micro-milling for ASD areas, about 0.5 in. deep and ADD areas milled to 2.5 in. deep). The shallower areas should be overlayed with a new wearing surface and sealed over the entire roadway, both length and widths for best/most consistent results. The ADD areas should be overlayed with HMA consisting of SX(75)(PG64-28) material, per RockSol Consulting recommendations. Curb panel replacement is advised for MSGD areas, and surface cleaning for smoke stains if deemed necessary.

Table 7-7. Assessment of Pavement Damage from Marshall Fire (RockSol, 2022)

Name	Location & Burned Area	Characteristics	Typical Damage Size
Asphalt Shallow Damage: ASD	Relatively further distances from localized major heat sources	Streak-like marks on pavement. Sometime downwind from burned structures	Long length of road, less than 0.5 in. deep
Asphalt Deep Damage: ADD	Close to major heat sources	Asphalt binder burning and surface cracking	12x40 ft rectangular area of road around burned vehicles, no more than 2.5 in. deep
Monolithic Sidewalk and Gutter Damage: MSGD	Very close to major heat sources on sidewalk and gutters	Sidewalk spalling, cracking and smoke stains, sampling showed no signs of deep damage	Sidewalk panels about 10 ft long, relatively shallow damage
Manholes and Valve Boxes:	Manhole and valve box covers	Valve box seal damage and concrete spalling	Immediately around openings

(a) ASD

(b) ADD

(c) MSDG

(d) ADD and MSGD

Figure 7-18. Examples of Roadway Damage, images from UCAV assembled orthomosaics along Arapahoe Cir. in Louisville, CO (39°58’37.452” N, 105°9’48.744” W)

8.0 HOUSING & STRUCTURES

A total of 1,084 houses were destroyed and 149 houses were damaged across Louisville, Superior, and Unincorporated Boulder County. A summary of housing damage per area is shown in Table 8-1 (Boulder County, 2022(b)). The distribution of damage across the affected region is shown in Figure 8-1.

Table 8-1. Overview of housing damage by municipality

Municipality	Number of homes destroyed	Number of homes damaged	Approximate value of residential damage
Louisville	550	43	$229,200,000
Superior	378	58	$152,757,000
Unincorporated Bolder County	156	48	$131,256,000

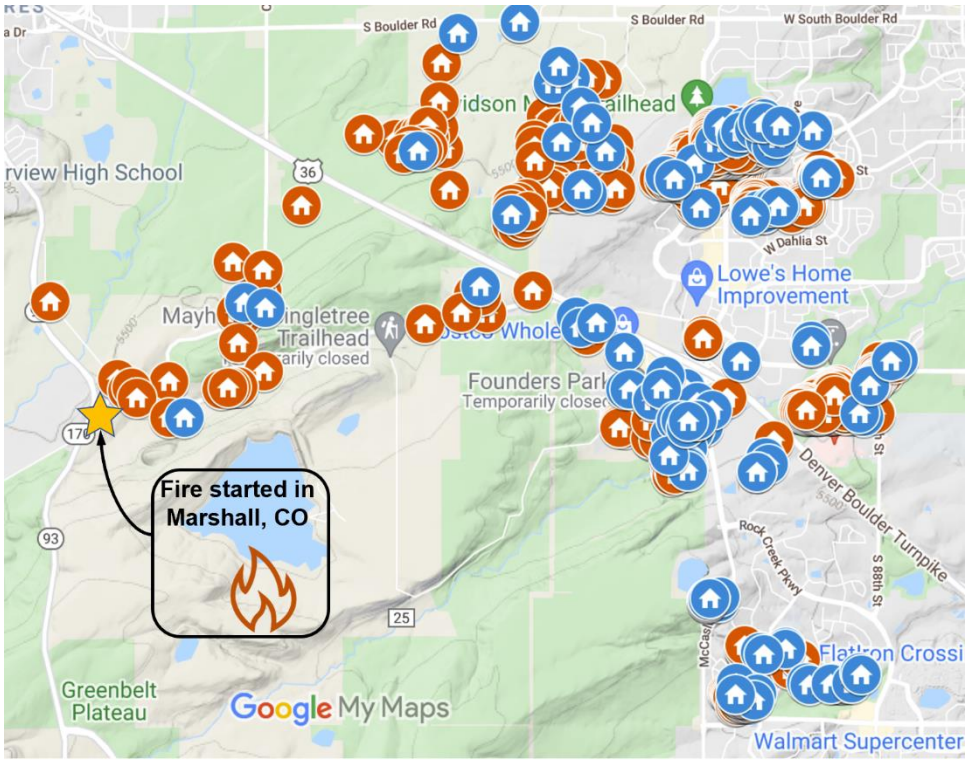


Figure 8-1. Map of damaged and destroyed homes due to the Marshall Fire. Red icons are destroyed homes and blue icons are damaged homes

To understand the housing damage further, and the characteristics of housing damage, the GEER team performed ground surveys of seven neighborhoods, five in Louisville and two in Superior. The goal of these on-the-ground surveys was to collect information about each of the affected homes to observe trends in the characteristics of damaged homes within the municipalities and across municipalities. Foundation temperature was measured by matching the foundation color of burned

homes to color cards developed based on Hager (2014). The highest temperature indicated by the foundation color was recorded. The GEER team also utilized Google Earth to observe trends among the homes before the fire (e.g., presence of a fence or vegetation close to the home). Lastly, the GEER team spoke with firefighting departments that were present on the ground to understand how the presence of firefighting efforts influenced survivability of homes in the areas that the team was performing surveys.

For the neighborhoods surveyed, the following characteristics were evaluated: year built (from permit data), square footage (from permit data), exterior cladding (from field surveys, permit data), home-to-home distance (from Google Earth, and groundtruthed with field measurements), fencing characteristics (from field surveys, Google Earth), decking characteristics (from field surveys, Google Earth), vegetation on the lot (from field surveys, Google Earth), proximity to open spaces (Google Earth), and the foundation temperature of the destroyed homes (from field surveys). These factors are known to affect the survival of homes. For example, the presence of wooden fencing, decking, and/or vegetation in close proximity of a home can increase the ignitability of the home and decrease home survivability.

Spacing is a key characteristic to evaluate because the International Residential Building Code (ICC, 2021) requires a minimum of 36 inches between homes for emergency vehicle access. Recent research and methodologies developed by the National Institute of Standards and Technology (NIST), Insurance Institute for Business and Home Safety (IBHS), and California Department of Forestry and Fire Protection (CAL Fire) note that high intensity fires in regions with high housing density has shown that 6 – 10 ft of housing spacing is not sufficient to prevent home-to-home fire spread (Maranghides et al., 2022). In addition, this report notes that even if houses have upwards of 30 ft of distance between them, if they are close or neighboring open spaces, this could put them at risk for wildfire and home hardening can reduce that risk (Maranghides et al., 2022).

High intensity fires can be indicated by elevated temperatures of the fire itself. Fire temperatures throughout the surveyed neighborhoods were determined by the color of concrete foundations and presence of concrete spalling. As concrete is exposed to elevated temperatures, the color of the concrete changes (Hager, 2014). Using previous research on this color change, the GEER team was able to determine the temperature range that the concrete foundations of destroyed homes was exposed to. The GEER team also looked for the presence of concrete spalling. Concrete begins to spall around 300^{o}C due to increasing pore pressure within the concrete itself. Concrete spalling of back patios, sidewalks, walkways, and concrete foundation walls was noted throughout the ground surveys.

Defensible space for wildfire mitigation removes ignitable material within various zones around the home (Figure 8-2) and provides room around homes to fight fire with firefighting equipment.

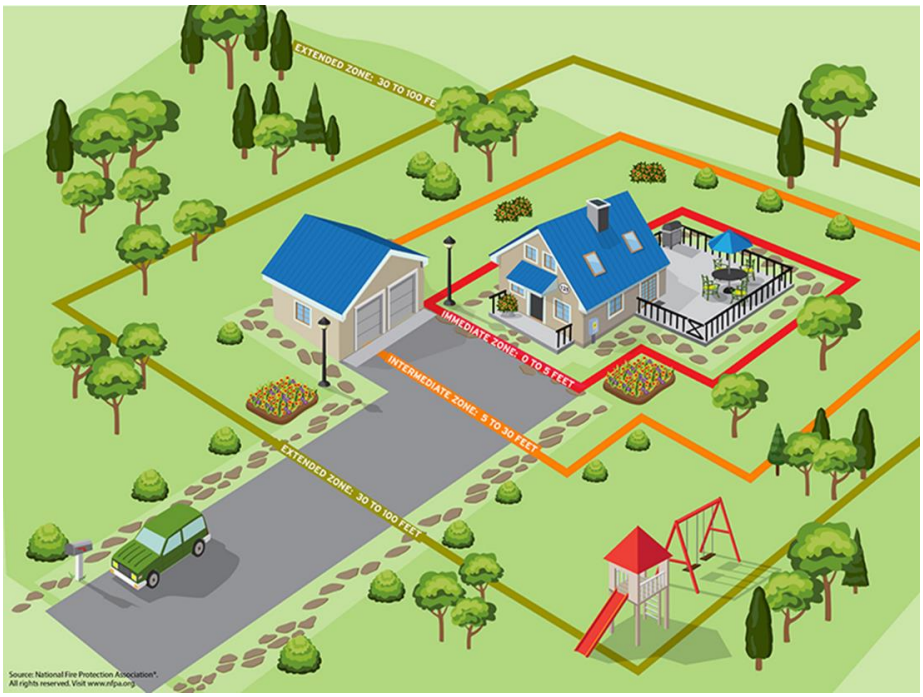
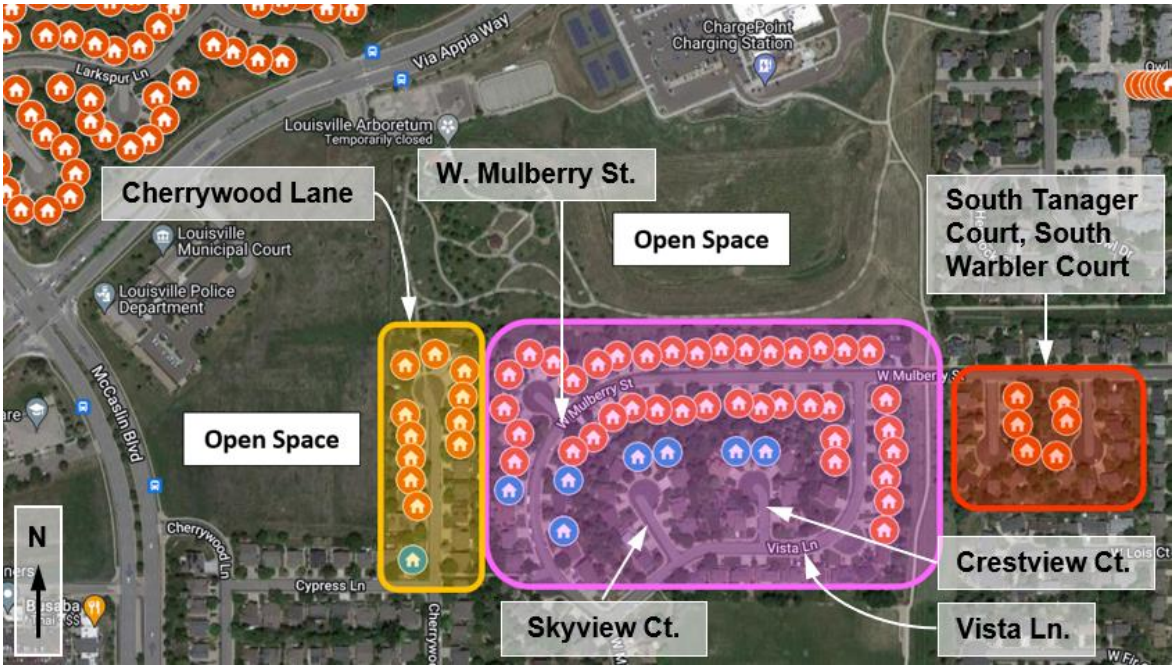


Figure 8-2. Defensible space zones for homes in the wildland urban interface per FireWise USA

8.1 Louisville

The GEER team surveyed portions of Cherrywood Lane, Mulberry Street, South Tanager Court, South Warbler Court, Vista Lane, Crestview Court, Skyview Court, and Coal Creek South in Louisville. All but the Coal Creek South neighborhood are located east of McCaslin Blvd and south of Via Appia Way. Cherrywood Lane ends in a cul-de-sac and South Tanager Court, South Warbler Court, Crestview Court, and Skyview Court are small cul-de-sacs. Cherrywood Lane is bordered by two open spaces and Mulberry Street is bordered by one. The Coal Creek South neighborhood is located on the south portion of Louisville near the hospital.

Figure 8-3 shows a map of the streets with Cherrywood Lane boxed in yellow, Mulberry Street, Vista Lane, Crestview Court, and Skyview Court in pink, and South Tanager Court and South Warbler Court in red. The data gathered for this neighborhood is described in detail before showing trends across all the communities in Louisville.



(a) Map of streets and areas surveyed in Louisville

(b) Orthomosaic from UCAV images

Figure 8-3. Map of damaged and destroyed homes due to Marshall Fire showing Cherrywood Lane and open spaces (a) google map view and (b) drone image view (Cherrywood: 39°58'16.5" N, 105°09'38.5" W; Mulberry: 39°58'18.2" N, 105°09'34.3" W; Skyview: 39°58'15.4" N, 105°09'31.3" W; Crestview: 39°58'16.3" N, 105°09'28.0" W; Tanager and Warbler: 39°58'17.7" N, 105°09'18.5" W)

On the portion of Cherrywood Lane evaluated, all of the homes were built in 1993 and the average square footage of the homes is 1975 ft^2 with a maximum of 2390 ft^2 and minimum of 1730 ft^2. Of the homes within the yellow box shown in Figure 8-3, 75% of the homes are 2-3 stories and 25% of homes are split level. None of the homes within the yellow box had siding renovations conducted

between the years 2016-2021. However, many of these homes had roof renovations that consisted of replacing roofs with asphalt shingles after a 2018 hail storm . Boulder County open space borders these properties to the west. There are no significant slopes in the open spaces.

Of the 17 homes surveyed on Cherrywood Lane, 12% of the homes had 11-15 ft spacing and only 6% of the homes had a spacing greater than 30 ft. The distribution of housing spacing for each of the neighborhoods surveyed in Louisville is shown in Figure 8-6. Of the 17 homes on Cherrywood Lane that were evaluated, 94% (16 homes) of the homes had wooden fences and of the homes that had wooden fences, 100% of them had the fence touching the home itself (Figure 8-4). All of the homes had large trees either directly in front of the house or directly behind the house. Lastly, about 52% (9 homes) of the homes had decks attached to the home that were constructed out of wood (Figure 8-5). All of these housing characteristics can increase the ignitability of the home and decrease home survivability.

(a)

(b)

Figure 8-4. Example of burnt fence touching an undamaged home (a) on Tanager Ct. and (b) on Cherrywood Lane. GPS coordinates provided on the figure.

(a) (b) 39°57’42.6” N, 105°09’29.8” W

Figure 8-5. (a)Wood porch attached to home on Cherrywood Lane (GPS coordinates shown) and (b) examples of embers from an unburned neighborhood (Townhomes at Coal Creek)

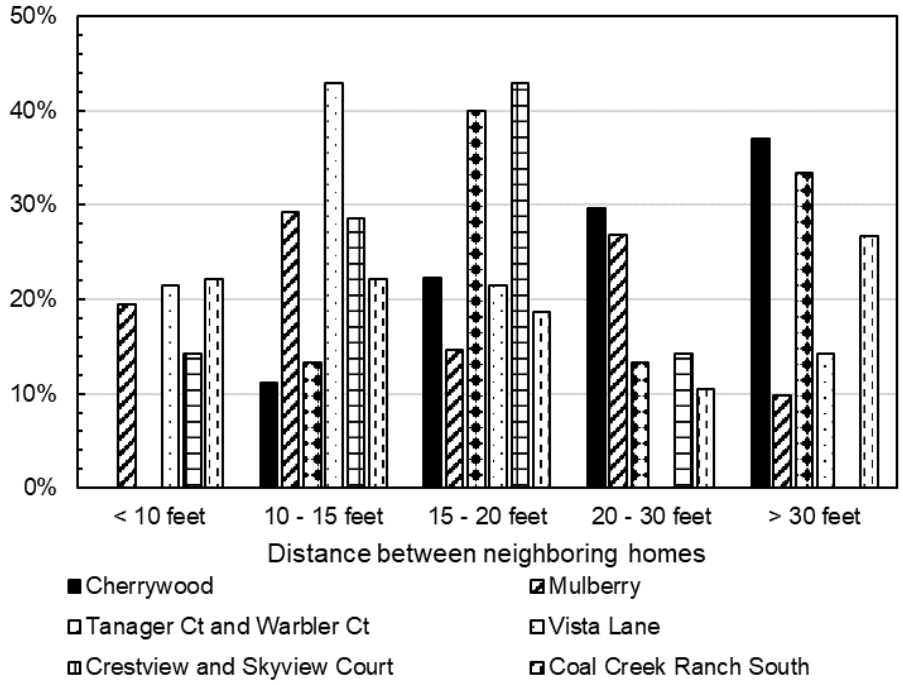


Figure 8-6. Distribution of housing within neighborhoods in Louisville

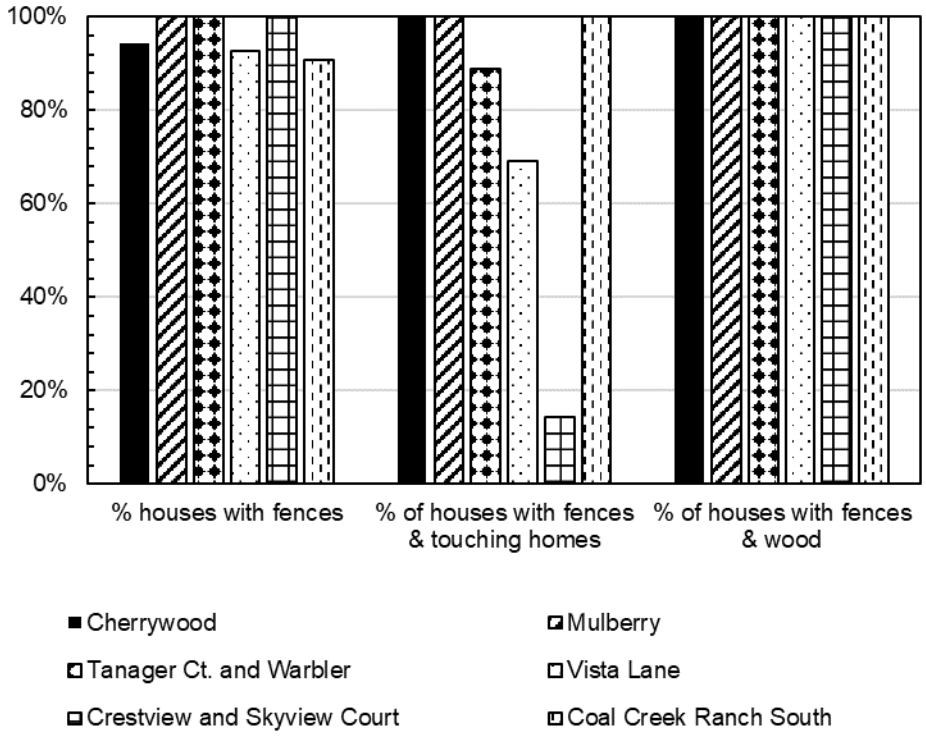


Figure 8-7. Details of fences at homes in various neighborhoods in Louisville

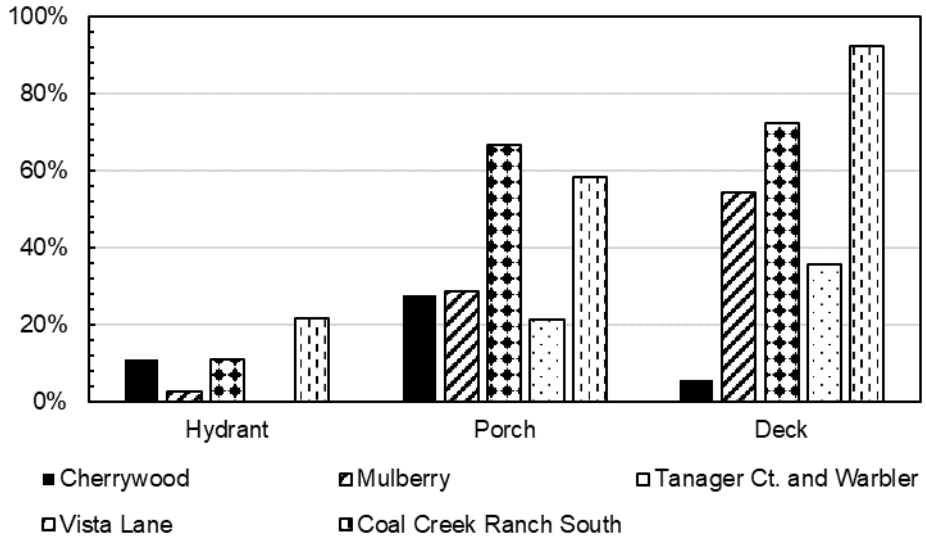


Figure 8-8. Details of housing characteristics in various neighborhoods in Louisville

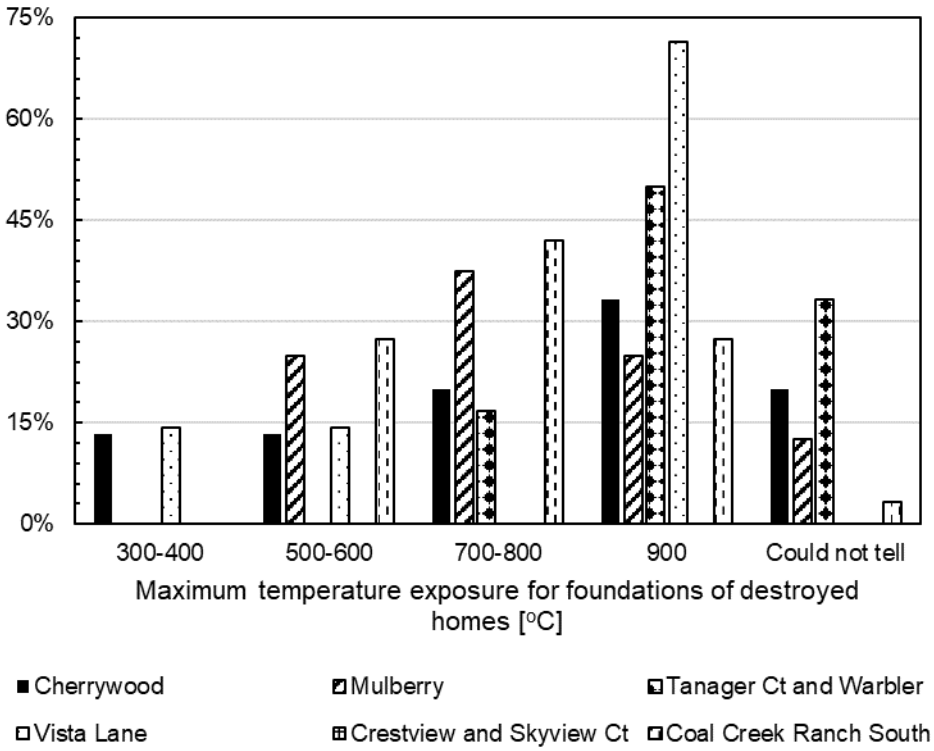
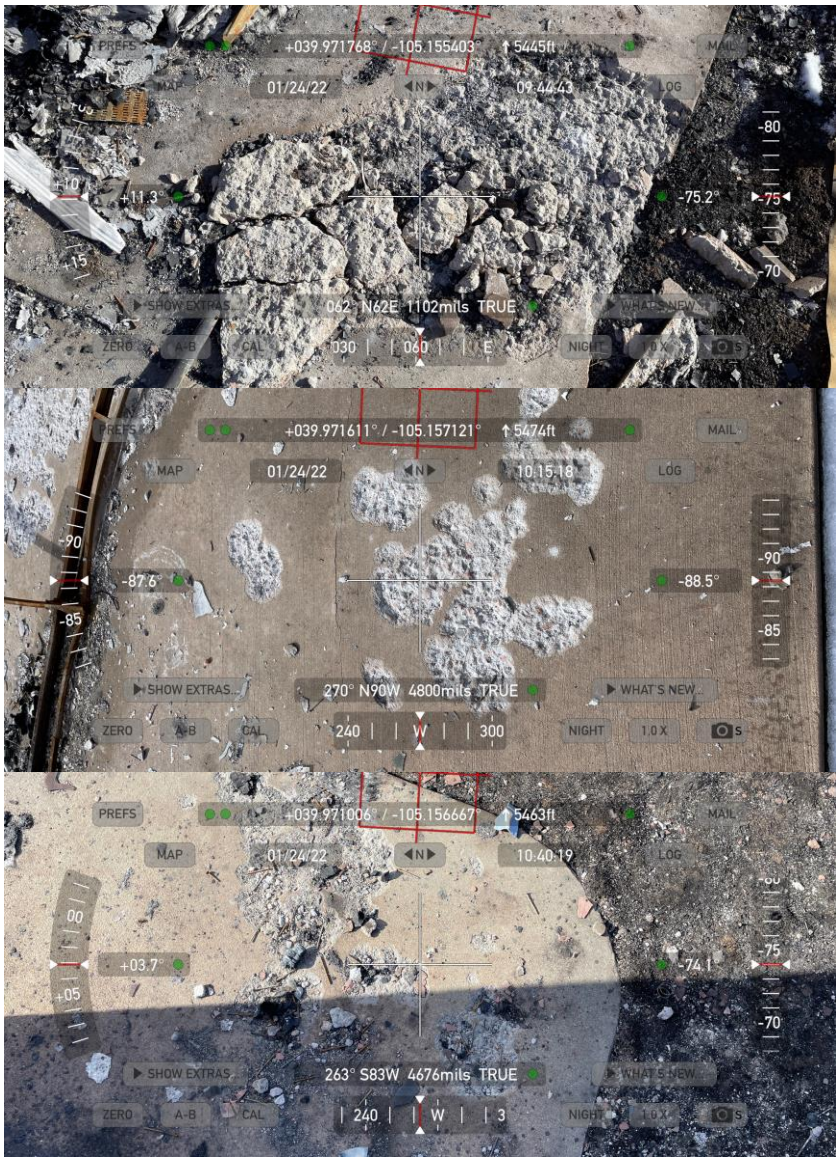


Figure 8-9. Distribution of temperature exposures to foundations of destroyed homes in neighborhoods in Louisville

On the Cherrywood Lane cul-de-sac, 88% (15 homes) were destroyed and 22% (2 homes) were standing with minimal damage. For the destroyed homes, the temperature they were exposed to was evaluated by examining the concrete foundations (Figure 8-6). From this the team determined

that the homes burned at temperatures ranging from 300°C to 900°C. The homes nearest to standing homes with minimal damage were exposed to temperatures at the lower end of the spectrum. Elevated temperatures throughout S. Tanager, S. Warbler Ct., and on Vista Lane was evident by the presence of spalling of the concrete walkways, as shown in Figure 8-10.



(39°58’18.4” N, 105°09’19.5” W)

(39°58’17.8” N, 105°09’25.6” W)

(39°58’15.6” N, 105°09’24.0” W)

Figure 8-10. Spalling of concrete on S. Tanager Ct, S. Warbler Ct, and W. Mulberry St. indicated temperatures in excess of 300ºC

Of the 56 homes in the pink box, 40 were evaluated on foot. On W. Mulberry Street, 16 homes were omitted from the in-person survey due to time restrictions. For the homes located off of Mulberry, all were built between the year of 1988 and 1992, with 86% of the homes being built in 1992. All of these homes were wood-frame construction. The average square footage of these homes is 2080 ft^2, with a maximum square footage of 2410 ft^2 and a minimum of 1650 ft^2. Of the 35 homes evaluated along W. Mulberry, 97% were 2-3 stories and all homes had wood frame construction. There were no documented siding renovations on any of these homes between 2016-2021. Open space borders 43% of these homes, there are no significant slopes in the open spaces. All of the

homes had wooden fences in contact with the home. Of these homes, 89% had shrubbery had vegetation such as tree and shrubbery within 5 ft of the home. Lastly, of the 35 homes surveyed on W. Mulberry Street, 18% of the homes were spaced at under 10ft away from each other and only 8% of the homes had a spacing greater than 30 ft (see Figure 8-4). In this neighborhood 22% of the homes had wooden decks attached (see Figure 8-6). All of these housing characteristics can increase the ignitability of the home and decrease home survivability.

Along Vista Lane, a total of 14 homes were evaluated. These homes were built in with 1991 (43%) or 1992 (57%) with wood frame construction. These homes have an average square footage of 2080 ft^2, with a maximum value of 2300 ft^2 and a minimum of 1720 ft^2. 86% of these homes are classified as 2-3 story, with the remaining 14% as split-level. No homes had documented siding renovations from 2016-2021. No open spaces border these homes. Wooden fencing was present at all homes and 64% of those wooden fences abutted the home. Of the 14 homes assessed on Vista Lane, 21% of the homes were spaced at under 10ft away from each other and only 14% of the homes had a spacing greater than 30 ft (Figure 8-4). Along this stretch of Vista Lane, 21% of the homes had wooden decks attached to them (Figure 8-6). Also, it was noted that 93% of these homes had shrubbery and trees within 5 ft of the home. Wooden fencing and decks, as well as the present of vegetation close to the home increase the probability of home ignition and decrease home survivability.

Along Crestview and Skyview Courts, a total of seven homes were evaluated. These homes were built in with 1991 (43%) or 1992 (57%) with wood frame construction. These homes have an average square footage of 2100 ft^2, with a maximum value of 2300 ft^2 and a minimum of 1900 ft^2. All of these homes are classified as 2-3 stories and none had documented siding renovations from 2016-2021. No open spaces border these homes. Fencing was present at all homes and all fences were wooden and in contact with the home. Of the seven homes evaluated, none of the homes had decks. Also, it was noted that 86% of these homes had shrubbery within 5 ft of the home and 71% had trees within 5 ft of the home. Wooden fencing as well as the present of vegetation close to the home increase the probability of home ignition and decrease home survivability. Lastly, of the 14 homes assessed on Vista Lane, 14% of the homes were spaced at under 10ft away from each other and no homes had a spacing greater than 30 ft.

Along W. Mulberry Street, Vista Lane, Crestview Court, and Skyview Court, the foundation temperatures of the destroyed homes were recorded. For these homes, the temperatures they were exposed to varied between 300 and 900°C. No homes on Crestview or Skyview Court were destroyed. Figure 8-9 shows the breakdown of foundation temperatures. The breakdown of destroyed, damaged, and standing homes that were surveyed in each neighborhood is shown in Figure 8-11.

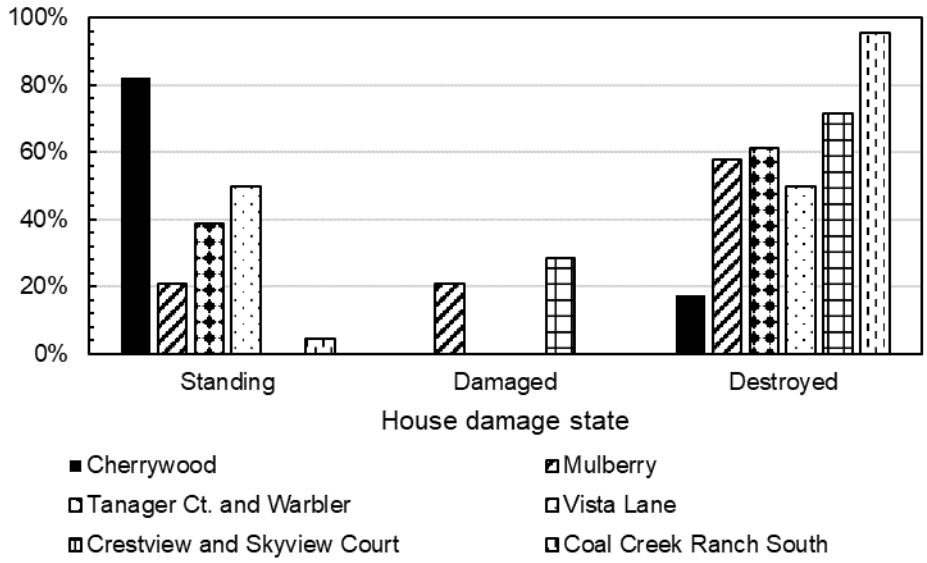


Figure 8-11**.** Breakdown of damaged, destroyed, and standing homes surveyed in each Louisville neighborhood

The two cul-de-sacs of South Tanager Court and South Warbler are off of an unburned portion of W. Mulberry Street and have houses abutting one another (shown in Figure 8-3). There was a total of 18 homes evaluated on these two streets. All homes were built in 1987 with wood frame construction with an average square footage of 1490 ft^2. The maximum square footage of these homes is 2065 ft^2 and the minimum is 1200 ft^2. The affected homes varied in height, with 11% falling under the 1-story ranch-style home category, 17% as split-level homes, and 72% and 2-3 story homes. None of these homes had siding renovations between the years of 2016 and 2021 and no open spaces bordered these homes. Wooden fencing was present at all homes. 89% of the wooden fences were in contact with the home (Figure 8-4). Of the 18 homes evaluated, 50% of the homes had decks attached to them that were of wood construction (see Figure 8-6). Also, it was noted that 100% of these homes had shrubbery within 5 ft of the home and 56% had trees within 5 ft of the home. Wooden fencing and decks, as well as the presence of vegetation close to the home increase the likelihood of home ignition and decrease survivability. Lastly, of the 18 homes assessed on Vista Lane, 13% of the homes were spaced 11 to 15 ft apart; however, 33% of the homes had a spacing greater than 30 ft. Figure 8-6 details the homes-to-home spacing on these cul-de-sacs. For the homes on Tanager and Warbler that had abutting back yards, all homes had a spacing of 30 ft or greater.

For these two streets, the temperatures the homes were exposed to were assessed by checking the foundations of the destroyed homes. The temperatures observed ranged between 700 and 900°C for the seven destroyed structures; however, for three of the homes, the temperatures were unable to be determined due to the presence of debris and snow (Figure 8-9).

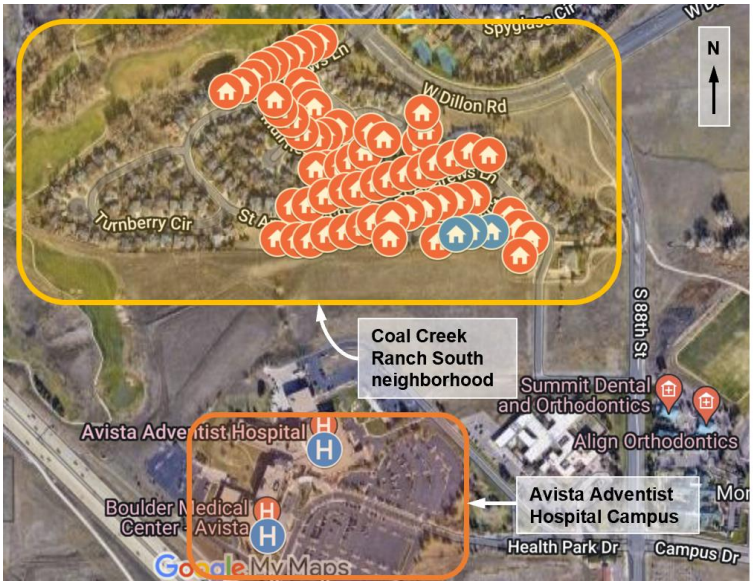


Figure 8-12. Map showing locations of surveyed homes in Coal Creek Ranch South neighborhood. Red icons indicate destroyed homes and blue icons indicate standing homes (Coal Creek: 39°57'23.9" N, 105°09'04.8" W; Avista: 39°57'05.4" N, 105°09'06.4" W)

Coal Creek Ranch South is located south of Dillon Road and north of the Avista Adventist Hospital Campus. As discussed in Section 6, significant slopes are present in this neighborhood with retaining structures throughout. 65 homes were surveyed throughout the neighborhood using on-the-ground survey tools and data collected through Google Maps. The homes were wood frame construction built between 1990 – 2000 with an average square footage of 2420 ft^2. The maximum square footage of these homes was 3350 ft^2 and the minimum was 1680 ft^2. The affected homes did not vary significantly in height with 95% of the homes being 2-3 stories. The remainder of the homes were split-level or 1 story ranch homes. According to permit records, only one house within this neighborhood had a siding renovation between the years of 2016 and 2021. That house was destroyed in the fire. 35% of the homes within the neighborhood bordered open space. 91% of the homes surveyed within the neighborhood had fences; however, of those that did have fences 100% of the fences touched the homes and were wood fences (Figure 8-7). Of the homes that were evaluated, 92% of the homes had decks (Figure 8-8) and of those that did have decks, 53% of them were constructed out of wood. It was noted that 100% of the homes surveyed had shrubbery and grass within 5 ft of the home and that 94% of the homes had trees within 5 ft of the home. Wooden fencing and decks, as well as the presence of vegetation close to the home increase the likelihood of home ignition and decrease survivability. Lastly, of the homes assessed in the Coal Creek Ranch South neighborhood, 22% of the homes were spaced less than 10 ft, 22% of the homes were spaced 11 to 15 ft apart, 19% of the homes were spaced 16 to 20 ft apart, and only 27% of the homes were spaced greater than 30 ft apart (Figure 8-6).

8.2 Superior

The GEER team surveyed 8th Avenue and a portion of West William Street in Original Town Superior. 8th Avenue is located to the East of W. Coal Creek Drive and South of Founders Park. The portion of West Williams Street surveyed stretched between South 1st Avenue and 4th Avenue. These areas are within two blocks of one another. Figure 8-8 shows the street view of each surveyed area. The 8th Avenue neighborhood is boxed in yellow. The portion of West William Street surveyed is boxed in pink.

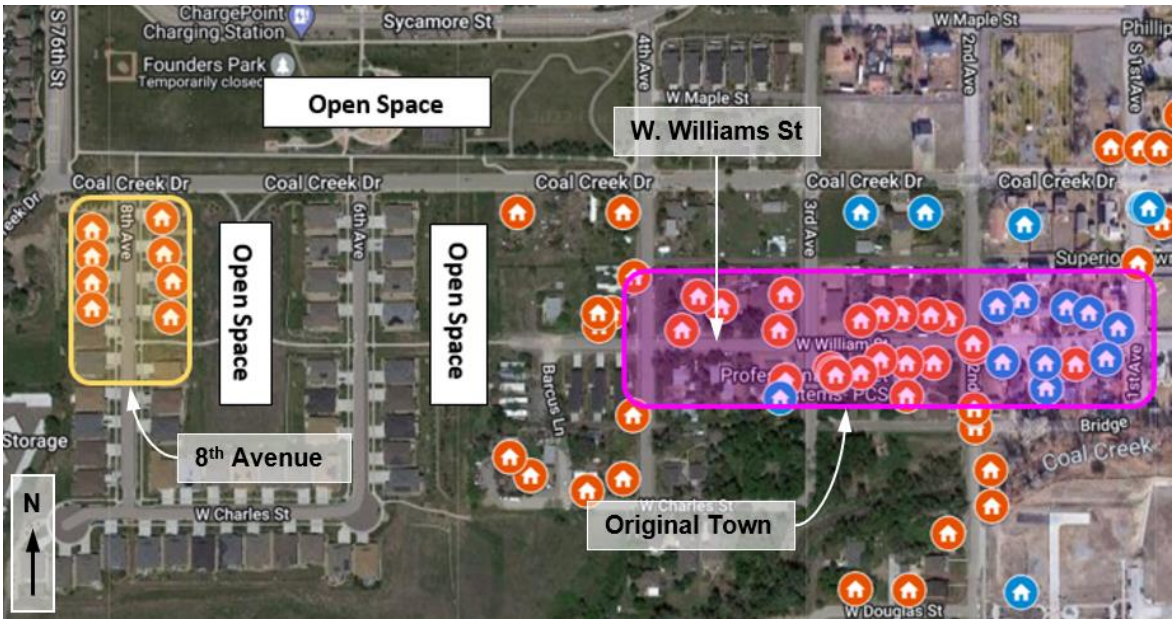


Figure 8-13. Map of damaged and destroyed homes due to Marshall Fire showing 8th Avenue, W. William Street, and the nearby open spaces google map view (8th Ave: 39°57'14.9" N, 105°10'29.1" W; W. Williams: 39°57'11.1" N, 105°10'07.1" W)

In the 8th Avenue neighborhood, there are eleven homes within the box. All of these homes were built in either 2015 (36%) or 2016 (64%) and have an average square footage of 2280 ft2 with a maximum of 3460 ft2 and a minimum of 2090 ft2. All homes surveyed in this neighborhood were one-story with full basements and wood frame construction. The neighborhood has open space to the north across Coal Creek Drive (see Figure 8-13) and bordering the neighborhood to the east. Each of the individual homes on the east side of 8th Avenue was designated to have open space on one side. There were no significant slopes in the open space. Also, it was noted that 100% of these homes had shrubbery within 5 ft of the home, but only 9% had trees within 5 ft of the home. Of the eleven homes on 8th Avenue, 45% are spaced under 10 feet apart and only 9% have a spacing of 30% or more. Figure 8-14 shows the full distribution of home spacing in this neighborhood. Fencing was present at 64% of the homes, with all of the fences being wooden and only 14% of those fences touching the home (Figure 8-15). Figure 8-16 shows the distribution of presence of characteristics such as decks, porches, and fire hydrants where over 80% of the homes surveyed on 8th Avenue in Superior had porches whereas none of them had decks. Wooden fencing and decks, as well as the presence of vegetation close to the home increase the likelihood of home ignition and decrease survivability.

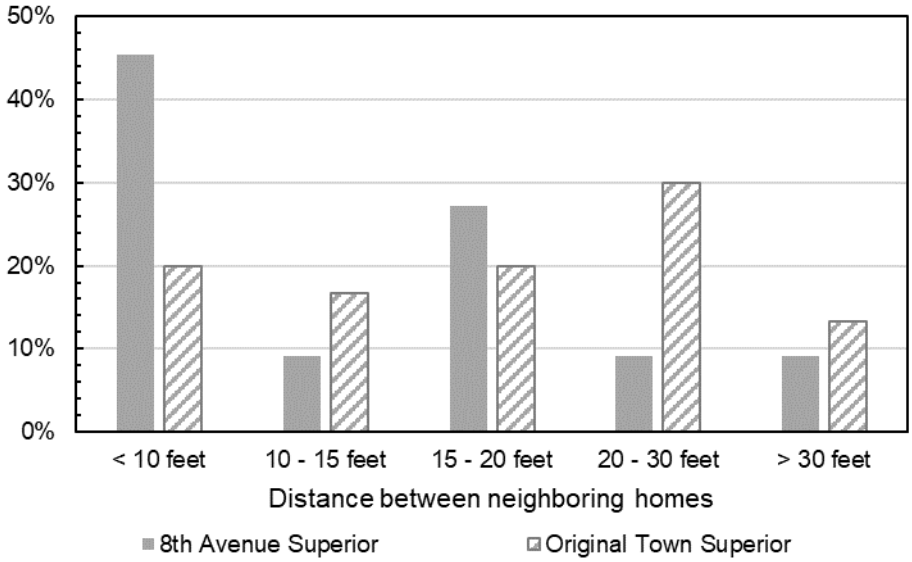


Figure 8-14. Distribution of housing spacing in Superior

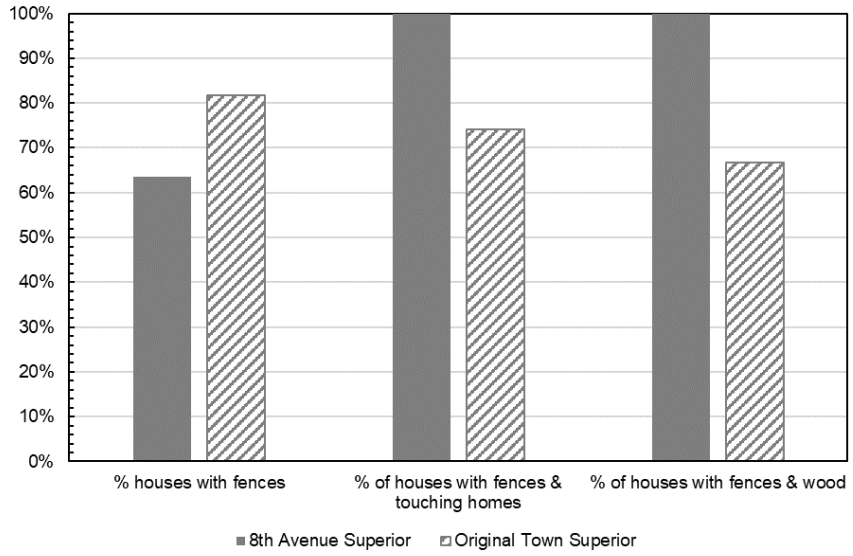


Figure 8-15. Details of fences at homes in various neighborhoods in Superior

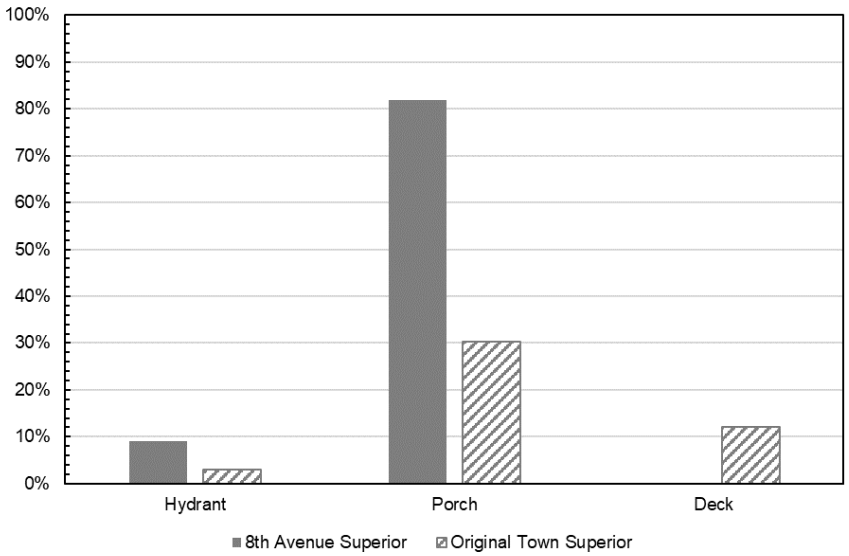


Figure 8-16. Details of housing characteristics in various neighborhoods in Superior

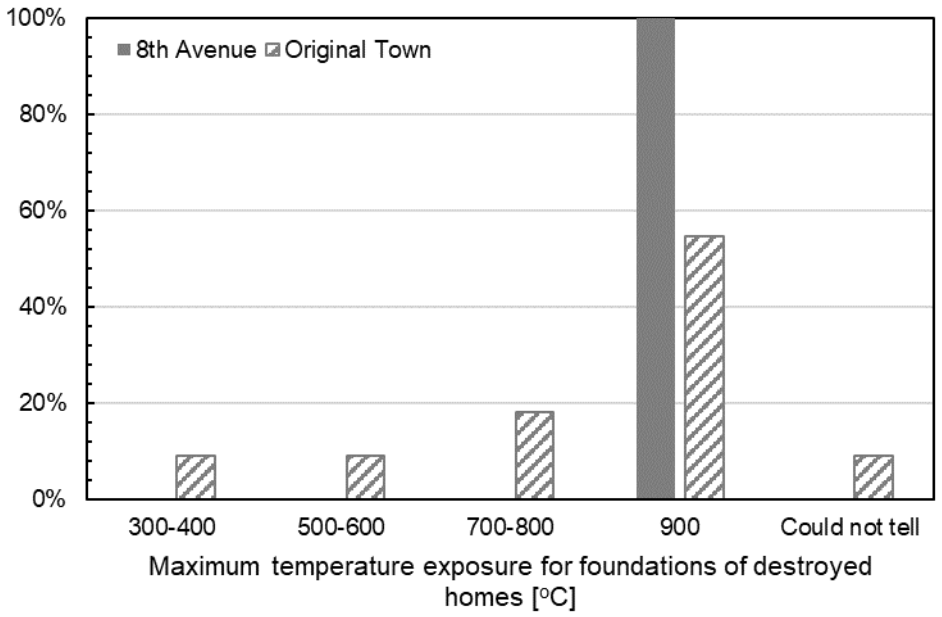


Figure 8-17. Distribution of temperature exposures to foundations of destroyed homes in neighborhoods in Superior

Figure 8-18. Evidence of elevated temperatures on 8th Avenue in Superior (a) concrete spalling, (b) and (c) pinkish foundations of houses

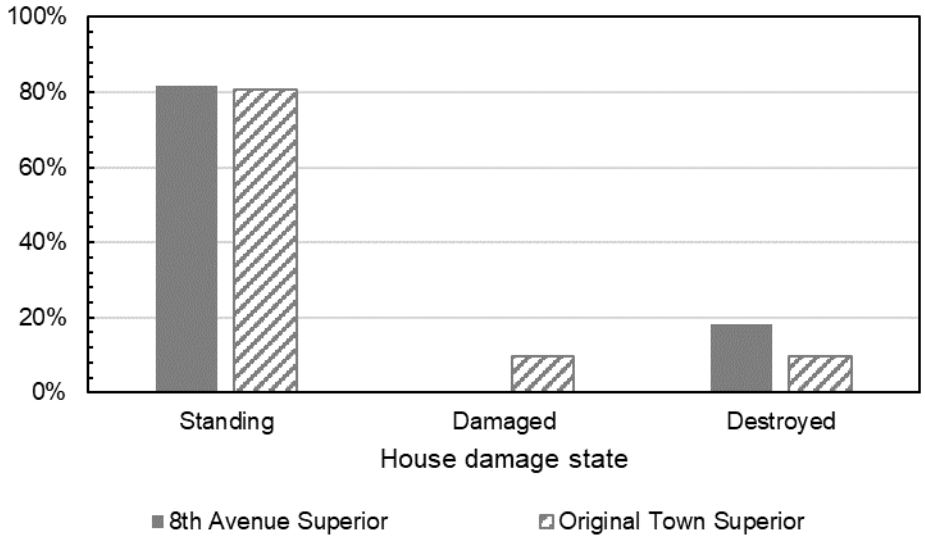


Figure 8-19. Distribution of standing, damaged, and destroyed homes surveyed in Superior

Looking at the foundations of the destroyed homes, the team was able to evaluate the temperatures at which the homes burned. The distribution of standing, damaged and destroyed homes that the team surveyed in Superior are shown in Figure 8-19. For 8th Avenue, all destroyed homes burned at a temperature of >900°C (Figure 8-17 and Figure 8-18). The presence of elevated temperatures is further demonstrated by the presence of spalling of the concrete driveways of the homes that were destroyed on 8th Avenue.

Along W. William Steet in Original Town Superior, 33 homes were evaluated. In this area of Superior, the neighbor is older and more established. This means that a variety of home ages were present. The construction years ranged from 1890 to 2012. Figure 8-20 breaks down the home age distribution. These homes have an average square footage of 1300 ft^2. The maximum square footage was 2800 ft^2 and the minimum was 580 ft^2, with a median of 1136 ft^2. Of the homes surveyed, 91% were one-story, 6% were two-story, and 3% were split level. 96% of the homes are wood frame construction.

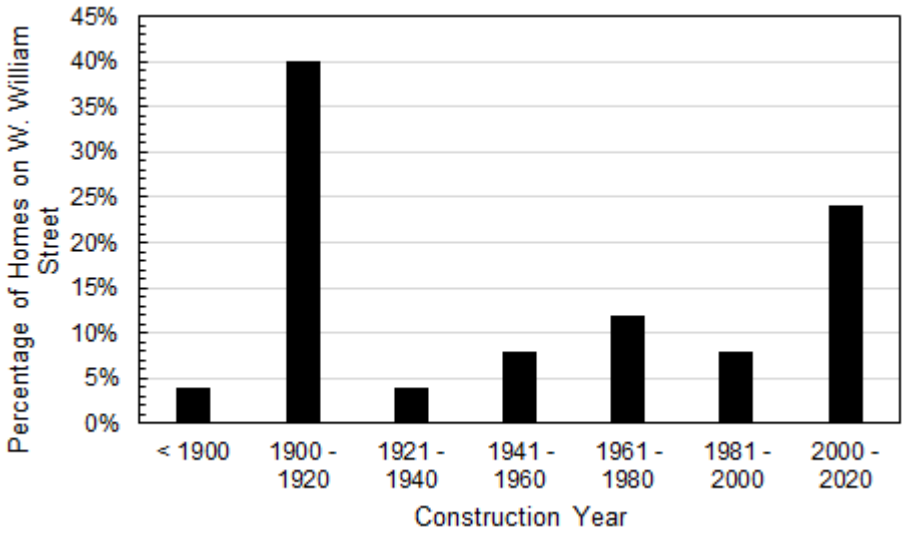


Figure 8-20. Distribution of home age on W. William Street in Original Town Superior

No open spaces border these homes. Fencing was present at 86% of the homes, with 57% of the fences being wooden; and of those wooden fences, 94% touched the home (Figure 8-16). An example of such fences are shown in Figure 8-21. 11% of the homes had wooden decks attached to them (Figure 8-16). Also, detached garages were very common in this neighborhood, with 63% of homes having them. It was noted that 88% of these homes had shrubbery within 5 ft of the home and 70% had trees within 5 ft of the home. Wooden fencing and decks, as well as the presence of vegetation close to the home increase the likelihood of home ignition and decrease survivability. In this neighborhood, the spacing between homes was less uniform than what was recorded on 8th Avenue. The minimum spacing was 2 feet while the maximum was 120 feet, with an average spacing of 25 feet (Figure 8-14).

Due to the age range of the homes in this neighborhood, there was a diverse type of foundations present, some of which include rubble, CMU block, brick, shotcrete, and reinforced concrete. Of the destroyed homes with reinforced concrete foundation, the team determined that the homes reached temperature between 300-900°C (Figure 8-17 and Figure 8-21).

(a) (b)

Figure 8-21. Housing characteristics in Original Town Superior (a) burnt fences touching homes and (b) spalling of concrete sidewalks (37°57'12.204" N, 105°10'4.368" W)

8.3 Unincorporated Boulder County

The GEER team surveyed houses on Benchmark Drive, Spring Drive, Spring Court, Panorama Drive, Skyway Drive, and Skyway Court in Unincorporated Boulder County. This region is located northwest of Louisville and Superior and borders the Davidson Mesa open space (Figure 8-22). A total of 29 homes were surveyed within this area. They are shown in the map of Figure 8-22. 52% of the homes surveyed were wood frame construction and 38% were masonry construction. The remainder of the home construction type was not indicated. The average square footage of the homes was 4240 ft^2 with the maximum square footage being 8700 ft^2 and the minimum square footage being 1100 ft^2. This range is significantly higher than the other neighborhoods within Louisville and Superior that were surveyed. The homes were built throughout a large time range with the oldest home being built in 1966 and the newest in 2013.

62% of the homes within the neighborhood bordered open space. 48% of the homes surveyed within the neighborhood had fences; however, of those that did have fences only 36% of the homes had a fence that touched the home. Those properties that had fences touching the house, the fence was wooden in 79% of these homes. For the remainder of homes, the material of the fence was not distinguishable.

Only one home that was surveyed had a hydrant in front of the house and it was across the street from the house. 79% of the homes surveyed had decks; however, only 17% of the homes surveyed had a porch. Of the homes that had a deck, 30% of these homes had a wooden deck and 48% of them had a concrete slab on grade patio. The remainder of the homes that had decks did not have a distinguishable material for the deck.

The vast majority of the homes surveyed had vegetation within 5 ft of the home. It was noted that 97% of the homes had grass within 5 ft of the home and 93% of the homes had shrubbery and trees

within 5 ft of the home. The homes assessed in Unincorporated Boulder County were spaced far apart with 93% of the homes spaced greater than 30 feet apart and the remainder 7% of the homes surveyed spaced 20 – 30 feet apart.

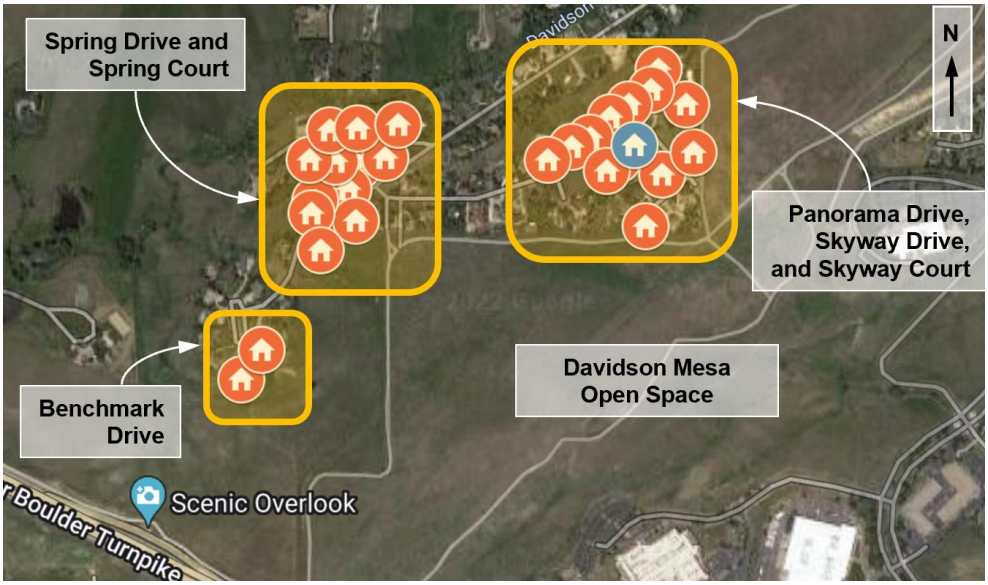


Figure 8-22. Map of surveyed houses in Unincorporated Boulder County. Red icons indicate destroyed home and blue icons indicate standing home (Benchmark: 39°58'14.7" N, 105°11'09.7" W; Spring Dr and Ct: 39°58'26.1" N, 105°10'53.6" W; Panorma and Skyway: 39°58'27.7" N, 105°10'36.0" W)

Due to snow cover on the day of the in-field surveys, foundation temperatures at 28% of the homes surveyed could not be concluded. The remainder of the homes had foundation temperatures that could be determined from the color of the concrete. These are summarized in Figure 8-23.

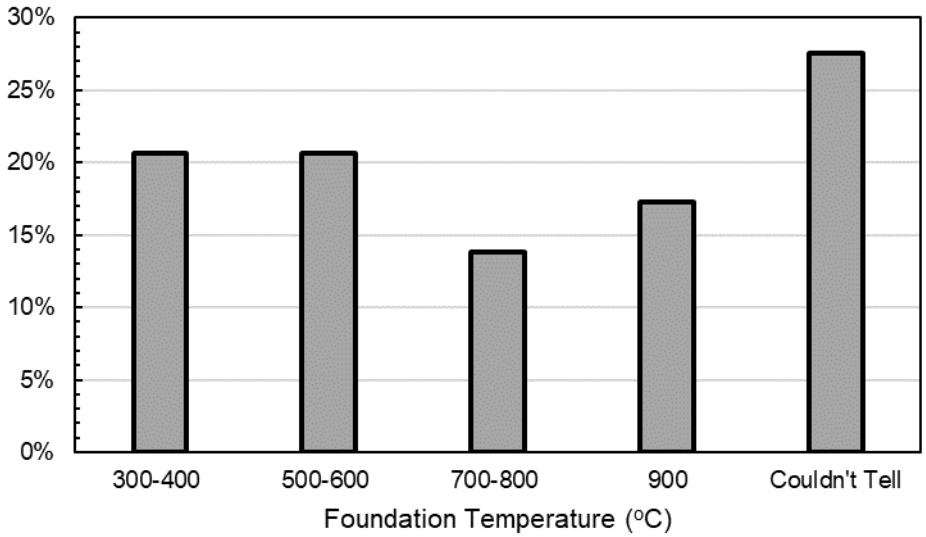


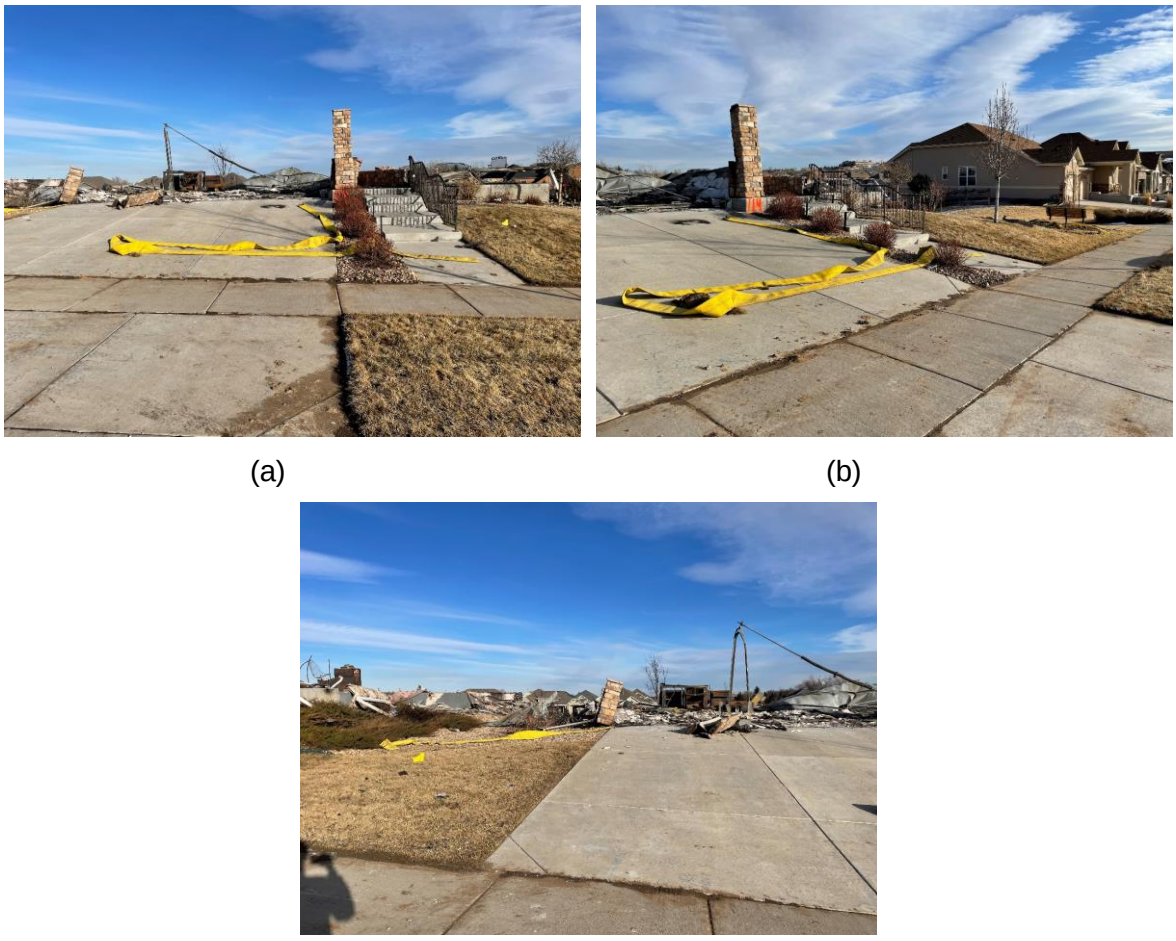
Figure 8-23. Distribution of foundation temperatures for homes surveyed in Unincorporated Boulder County

8.4 Role of firefighting strategies in saving homes

Firefighting efforts played a large role in survivability of housing during the Marshall Fire. Approximately 75 different fire departments were helping fight the fire throughout the Marshall Fire perimeter during the first two days and about 106 departments were helping during the first nine days of the response. Louisville Fire Department has 33 full-time career firefighters and 10 volunteer firefighters. The staff has basic training in wildland fire and wildland urban interface (WUI) firefighting.

West Metro Fire department fought homes on Cherrywood Lane and in the Mulberry community in Louisville with originally one strike team that included one Type 1 truck, one Type 3 truck (small truck for wildland fires), and two Type 6 trucks (brush trucks, small trucks with hoses). They arrived on the scene at around 2-3 pm. The wooden fence that bordered the open space behind the Cypress Lane homes was torn down to prevent the fire from spreading from Cherrywood and the open space to the homes on Cypress Lane. When the fire was controlled in this region, the strike team moved to Crestview and Skyview Ct and fought the fire along the bike path to prevent the fire from spreading from Vista Lane to homes on Warbler and Tanager Ct. The brush trucks were used to stage on the bike path and put out fires in vegetation that started due to embers. The team fought the fire for 30 hours in these neighborhoods. At one point there were 11 engines from West Metro Firefighting fire in this neighborhood.

If fires in a community are too intense and life safety is at risk, firefighters will leave the community quickly. However, these are extreme circumstances and it is not preferable for firefighters to leave equipment behind. In some instances, throughout the GEER team's work, we saw locations where fire hoses were left behind at houses (see Figure 8-24). This behavior indicates the fire was uncontrollable and it was no longer safe for firefighters to be present as they would have been trapped in the community. Figure 8-24 is 8th Avenue in Superior and shows a fire hose left in a driveway and burned through by the fire.



(a) (b)

(c)

Figure 8-24. Photos of firefighting hose left behind at a house on 8th Avenue in Superior (39°57'11.8" N, 105°10'28.9" W)

Figure 8-25. Initial signs of rebuilding, Original Town Superior, 9 January 2022 (39.95383, -105.16684)

8.5 Commercial Structures

The Marshall fire destroyed seven commercial buildings and damaged an additional 30 across Louisville, Superior, and unincorporated Boulder County. The following section will discuss the performance of three structures located within the burn zone.

The Element Hotel, operated by Marriott and Superior's first hotel, is an example of a destroyed structure (Figure 8-26). Completed around 2019, the four-story, LEED certified building was a component of Superior's community building project and new downtown facilities, including parks and business under the program "Coal Creek Enhancement". The gravity framing used hybrid construction. The first and second stories were steel-framed construction with infill beams made of LVLs. This allowed for transferring loads from the stories above to create an open lobby space. The upper floors of the building were constructed of timber with LVL beams and columns. The lateral force resisting system consisted of two concrete core wall clusters which housed the utility and elevators for the building.

The L-shaped geometry and orientation relative to the prevailing winds may have impacted its susceptibility, as several nearby buildings did not experience significant damage. The team identified this as an important structure for future evaluation and conducted detailed LiDAR scans of the property after safety fencing has been assembled and before significant debris removal occurred (Figure 8-27).

Across Highway 36 from the Element hotel was the partially damaged La Quinta Inn in Louisville (Figure 8-28). Two section of the building experience fire damage, adjacent to shrubbery that was closely positioned to the building. Firefighting efforts were able to save the majority of the structure. The facility remained closed at least 3 months following the fire as cleaning of soot and ash were ongoing.

(a)

(b)

Figure 8-26. Element Hotel, 31 December 2021 (39°57’19.1” N, 105°09’48.7” W)

Figure 8-27. RAPID staff teaching students during LiDAR scans of Element Hotel (39°57’19.1” N, 105°09’48.7” W)

Figure 8-28. Damaged La Quinta Inn in Louisville, along Highway 36 (39°57’32.2” N, 105°09’43.6” W)

Also in Louisville is the primary hospital that was within the burn area. Located at the southwest corner of Louisville, Centura-Avista Adventist Hospital was evacuated during the fire by 5 PM (Table 4-2). As shown in Figure 8-29, the hospital is positioned adjacent to Coal Creek Ranch South Neighborhood, which lost the majority of homes. There are reports of hospital staff that fended off approaching fires with garden hoses, to keep the fire from impacting the building or the high-pressure nitrogen tanks located just outside. With the help of firefighter efforts, this structure as saved from direct fire damage. Following significant efforts to clean the interior of the building of smoke damage, the hospital reopened less than 3 weeks after the fire.

Figure 8-29. Coal Creek Ranch South neighborhood with RS1 to the right and Centura-Avista Hospital in the distance (39°57’17.1” N, 105°09’01.6” W)

9.0 FUTURE RESEARCH AGENDA AND RECOMMENDATIONS

9.1 Retaining structures

Based on the damage patterns, response of retaining structures, and their backfill soils in the areas affected by the Marshall Fire, future research is recommended to better understand the interactions between the wall support system (of different materials and geometry) with the backfill soil during and post-fire. Of particular interest is the response of the soil-structure system during compounded hazards (e.g., strong precipitation or flood following fire). In addition to possible burning of the structural support, the properties of shallow or exposed soil layers are expected to alter due to fire (in terms of shear and tensile strength, stiffness, and stress-strain response). These effects are expected to alter the performance and stability of the soil-structure system during fire and its vulnerability to other climate extremes, which are currently not well understood. This understanding is essential in the design and maintenance of climate resilient retaining systems or for avoiding unnecessarily conservative and expensive systems in the future.

9.2 Lifelines

The behavior of lifelines and the role of the utilities throughout the fire and recovery of the 2021 Marshall Fire has proven to be critical. While research on wildfire impacts to water utilities has occurred to better understand the impacts on buried service laterals, there remains to be research that fully understand when pipes within a home need to be replaced if neighboring homes were destroyed by a fire. In addition, the role of utilities during the fire and during the recovery of the fire should be considered as part of the incident command system such that the utilities can communicate directly with the firefighters and emergency responders. Interdependency among lifeline systems also shown to be critical, and the importance of identifying interdependent features and communicating across systems and municipalities are suggested components of table-top hazard scenarios to better prepare for worst-case events.

9.3 Housing

Ongoing and future work is needed to quantify housing damage patterns and develop analytical models of housing survivability that improve design, construction, planning and landscaping. This report documents physical characteristics and damage observations including siding material, date of latest siding renovation, presence of burned entities touching the house (e.g., porches, fences, shrubbery), broken windows, or heated concrete structural elements (e.g., walls, floors, retaining structures or foundations). In ongoing work, this dataset will be expanded by merging data sets (housing, retaining structures, UCAV, etc.). Through the development of statistical models based on these datasets, we will identify which characteristics of the home, neighborhood, community, and firefighting strategy are the strongest indicators of survival. To examine the damage patterns on a larger scale, the damage patterns and behavior of individual homes will be aggregated along with previous research data on the behavior of specific structural components (e.g., windows, foundations, retaining walls) to calculate the temperatures to which homes were exposed. The exposure temperatures of neighboring standing homes can be calculated using the equations for one-dimensional heat transfer and any potential damage the standing home may have (e.g., broken windows, damaged facade or interior). This analysis methodology can develop heat maps of the town during the wildfire and characterize the damage patterns in combination with the physical factors.

9.4 Decision-making for reconstruction in jurisdictions and homeowner groups

Ongoing and future work is needed to track and analyze decision making for post-fire rebuilding, including code adoption and enforcement of previously adopted codes for damaged and destroyed properties, as well as any changes for permitting and inspections for these properties. Data is being collected through observations of recovery meetings, jurisdictional websites, and emails. Analysis is focused on decisions related to resilience and sustainability for post-fire rebuilding, focusing on fire risk reduction and carbon footprint, and how decisions to build climate resilience are considered with recovery costs and timing. Future work is needed to conduct interviews to uncover decision making processes and tradeoffs associated with decisions. In addition, future work is needed to analyze homeowner decisions in the planning, design, and construction processes, including decisions of whether to rebuild alone or with neighbors, and the processes used to collectively convene and make rebuilding decisions.

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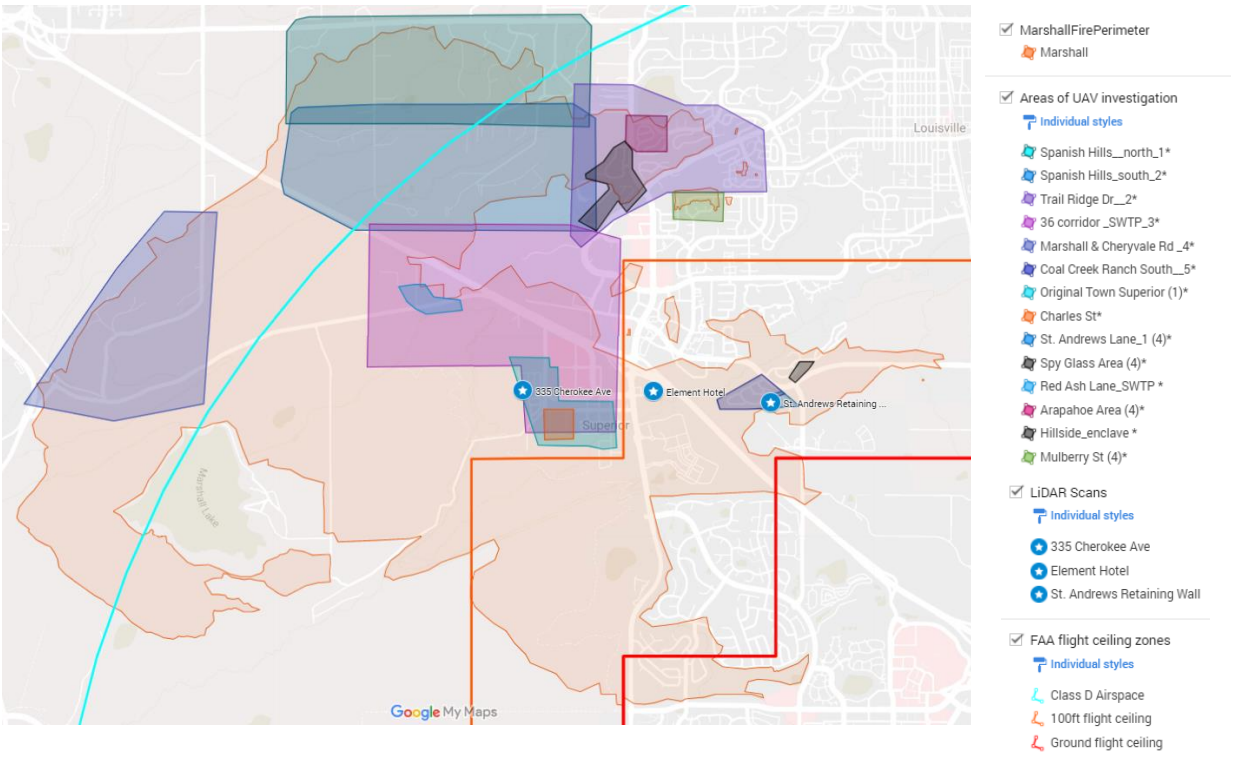
Appendices

A.1. UCAV And Lidar Data

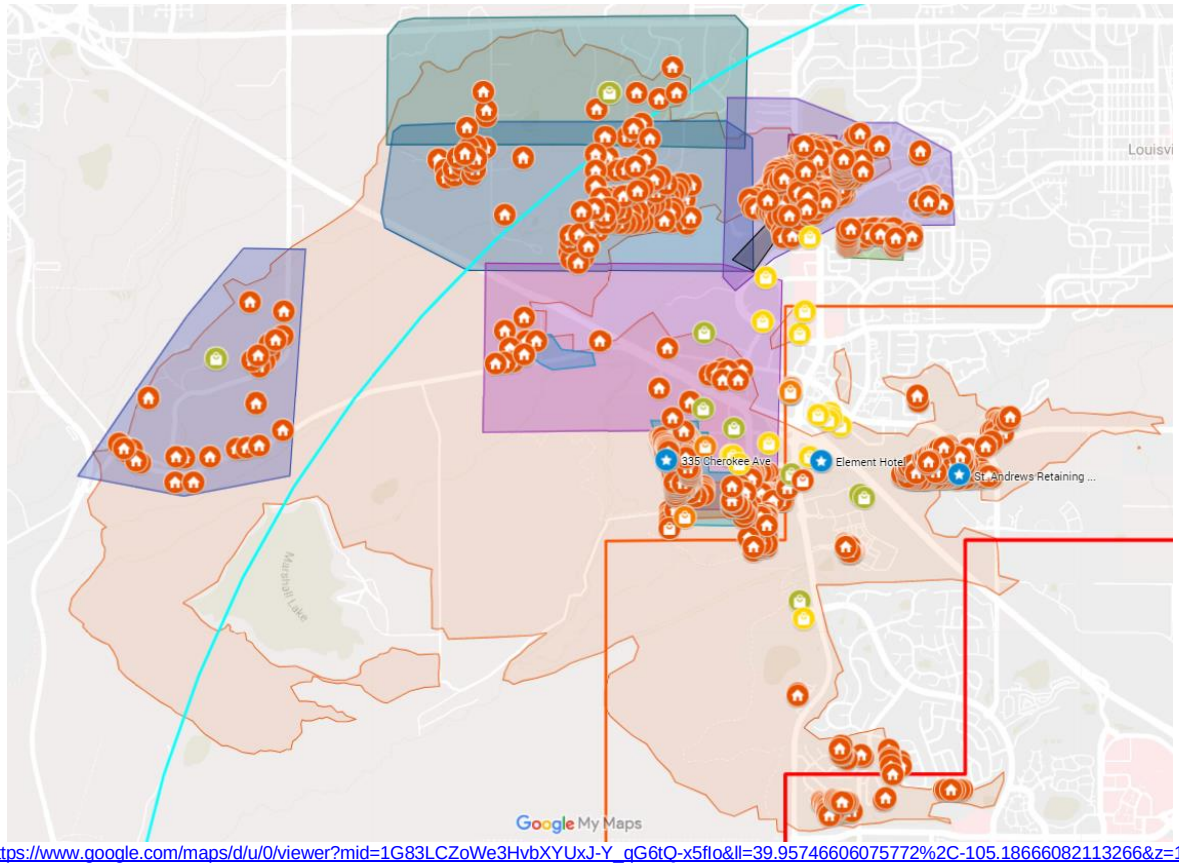
An emphasis of this GEER reconnaissance was the collection of both UCAV and terrestrial lidar scan (TLS) data utilizing NHERI-RAPID equipment and data processing capabilities. These data were then developed into 3D point-cloud models and uploaded to DesignSafe to preserve these post-fire data and make them available to anyone within the hazards community for future research.

An overview of UCAV and LiDAR data collection locations is provided in Section 2.1. Figure A.1 provides a map of UCAV and LiDAR data collection areas overlaid on the approximate fire perimeter while Figure A.2. provides the same figure including destroyed housing and damaged/destroyed businesses.



https://www.google.com/maps/d/u/0/edit?mid=1G83LCZoWe3HvbXYUxJ-Y_qG6tQ-x5fIo&usp=sharing

Figure A.1 Locations of UCAV flight coverage and LiDAR scans collected during this GEER reconnaissance. For map and links to the data click to access



https://www.google.com/maps/d/u/0/viewer?mid=1G83LCZoWe3HvbXYUxJ-Y_qG6tQ-x5fIo&ll=39.95746606075772%2C-105.18666082113266&z=14

Figure A.2. Map showing the locations of UCAV flight coverage and LiDAR scans with fire perimeter and destroyed homes and businesses click to access.

A.2. Accessibility

All raw and processed data collected on this reconnaissance are available from DesignSafe. This project, and individual datasets can be accessed via the following links:

- DesignSafe: https://www.designsafe-ci.org/
  - ‘GEER – Marshall Fire, Colorado’. Project ID: PRJ-3379
- UCAV generated Structures from Motion Models, via Hazmapper:
  - https://www.designsafe-ci.org/data/browser/projects/2863292314089755116-242ac117-0001-012/GEER_Marshall%20Fire_Colorado.hazmapper
- UCAV generated orthomosaics, via ArcGIS: https://arcg.is/1aTGnD0
- Google Map with coverage area:
  - https://www.google.com/maps/d/u/0/edit?mid=1G83LCZoWe3HvbXYUxJ-Y_qG6tQ-x5fIo&usp=sharing

A.2.1. DesignSafe: accessing data

If the links in the previous section are no longer supported, or the raw data is of interest, all is available on DesignSafe. One can find and view DesignSafe lidar / UCAV data with Potree. The following outline steps for accessing data.

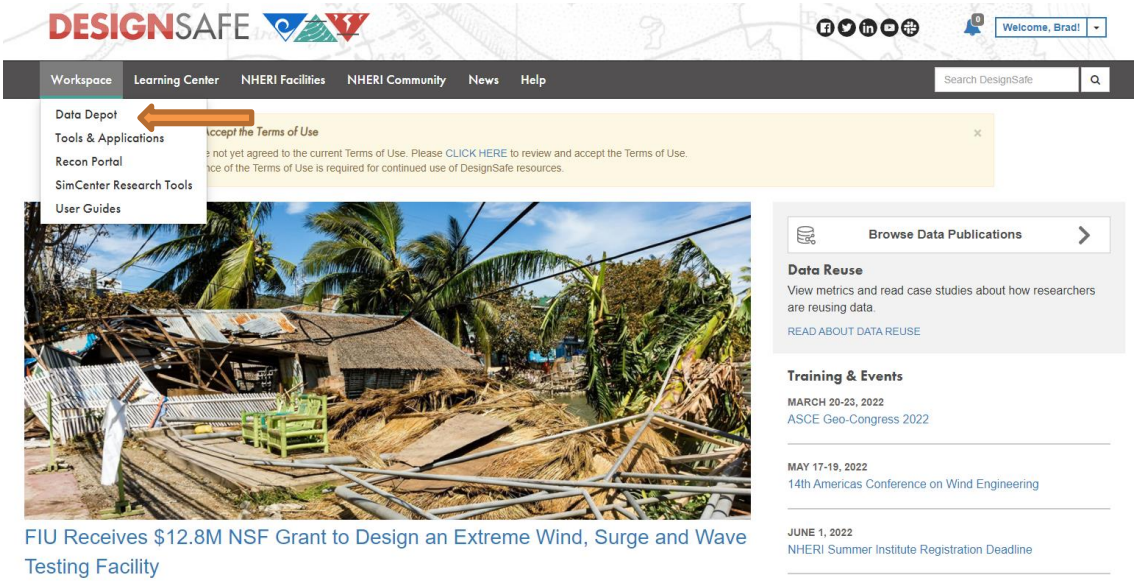


Figure A.3. Once signed into Design Safe, access 'Data Depot' under workspace

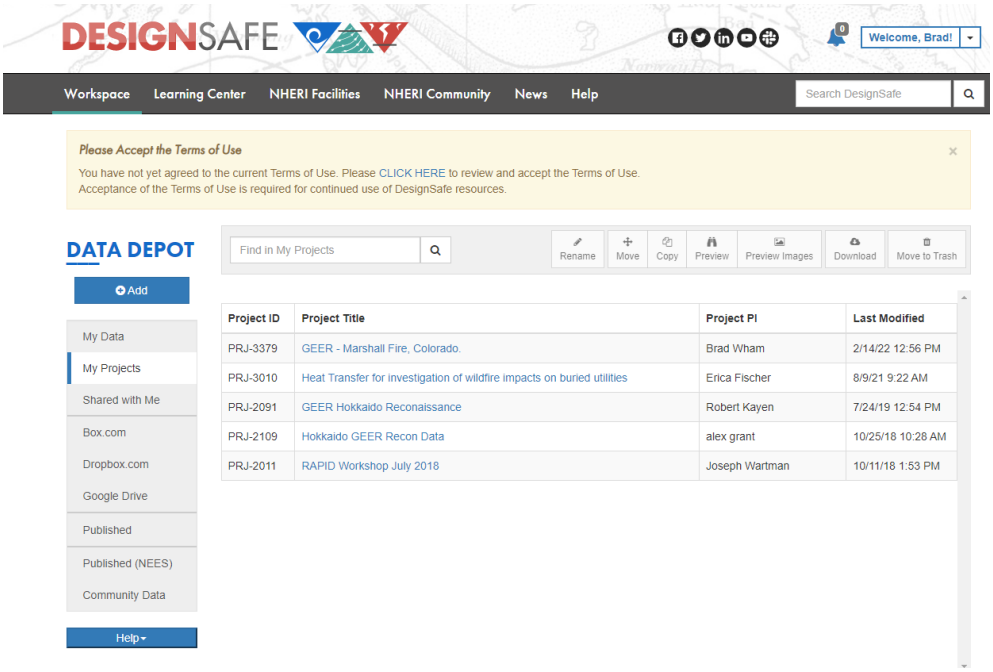


Figure A.4. Project landing page. Here you can connect to personal data, shared public/private projects, published datasets, drobox, or externally hosted data. This project's data is in the folder 'GEER – Marshall Fire, Colorado'. Project ID: PRJ-3379

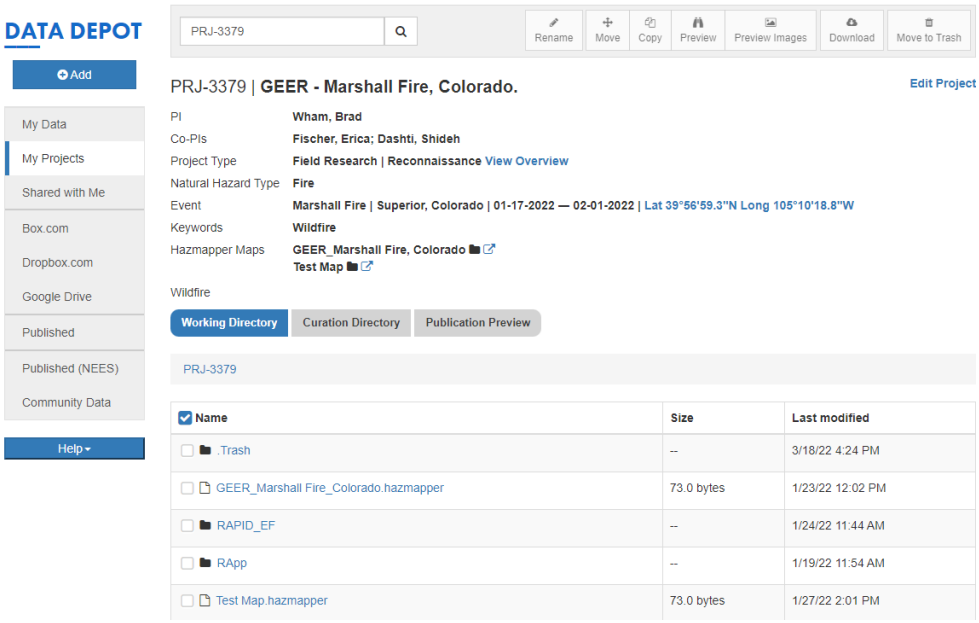
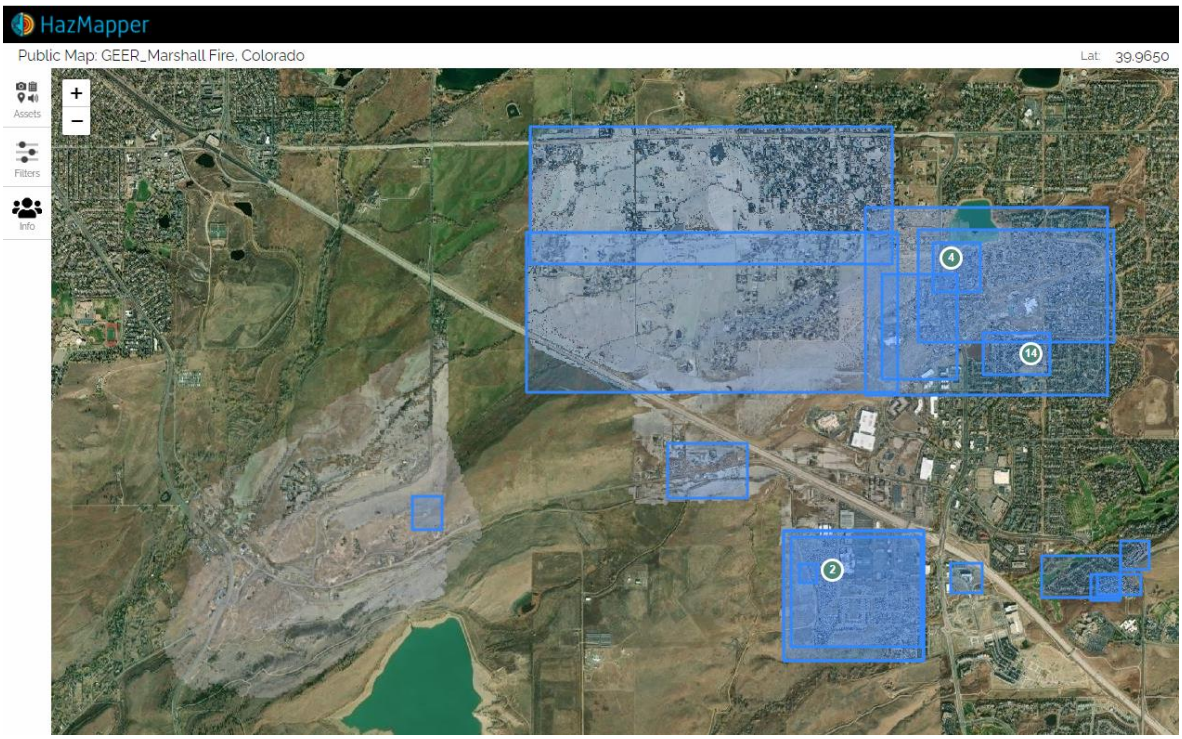


Figure A.5. File structure containing directory of .las, .e57, and potree converted lidar and UCAV data collected during the reconnaissance. When published and with a DOI users will be able to directly access this directory



https://www.designsafe-ci.org/data/browser/projects/2863292314089755116-242ac117-0001-012/GEER_Marshall%20Fire_Colorado.hazmapper

Figure A.6. Map of flight locations with SfM processed for viewing Hazmapper

A2.2. DesignSafe: Viewing Data

Return to the Research Workbench tab and select 'Tools and Applications'

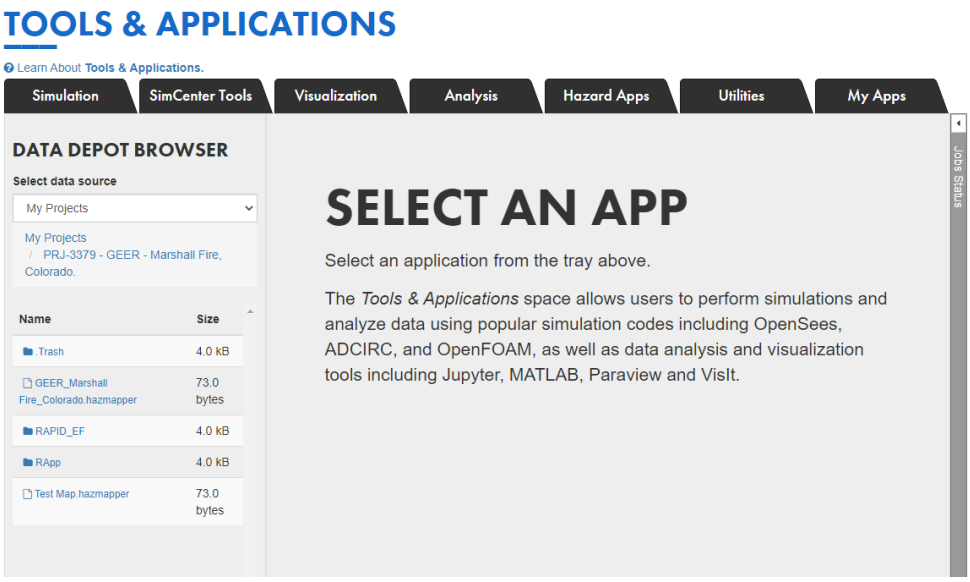


Figure A.7. In the Tools and Applications, change your data source to 'my projects' (or wherever your data are), select the parent folder of the data you're interested in, and select the Visualization tab.

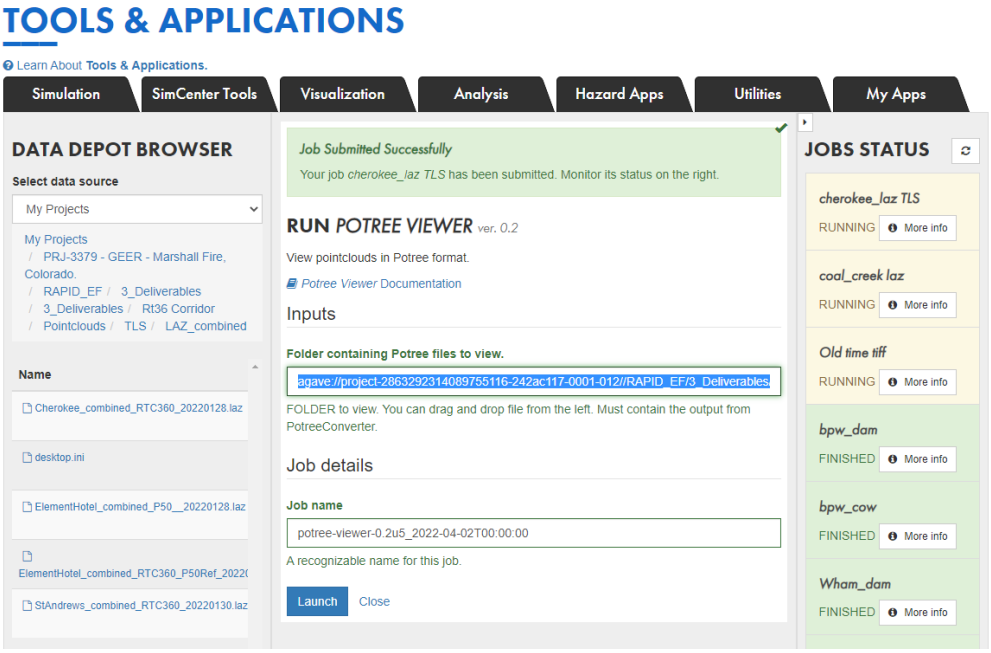
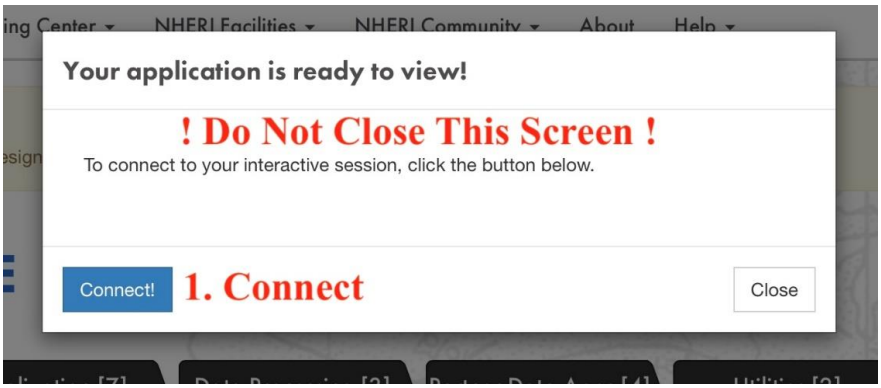


Figure A.8. Select 'Potree Viewer' and then drag and drop the '*_*converted*' folder of interest into the top input. Fill in the remaining job details (runs capped at 24hr) and select run.

Wait. (Usually 1 – 5min)

This window will appear:



You can connect here, or close and connect via the “more information” link under “Job Status” to the right of the screen (Figure A.8).

You can now explore the data*, start by copying the url and saving it somewhere. You can reconnect via this public URL, but DesignSafe will not reconnect you any other way. Second, move the top-left slider (point budget) all the way to the right for max resolution.

*in Chrome or Firefox, this part does not work in Safari.