Colorado River Wildfire Collaborative

# Wildfire Ready Action Plan (WRAP)

## December 2024

Middle Colorado Watershed Council

SGM

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# ACKNOWLEDGEMENTS

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De Beque Fire Protection District

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Glenwood Springs Rural Fire Protection District

Grand Valley Fire Protection District

Lower Valley Fire Protection District

Mesa County Emergency Management

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New Castle, Town of

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United States Forest Service, White River National Forest, Rifle Ranger District

Wright Water Engineers

# ACRONYMS

BIP – Basin Implementation Plan

BLM – Bureau of Land Management

CSFS – Colorado State Forest Service

CWCB – Colorado Water Conservation Board

CWPP – Community Wildfire Protection Plan

CRWC – Colorado River Wildfire Collaborative

FHZ – Fluvial Hazard Zone

FPD – Fire Protection District

GIS – Geographic Information System

I-70 – Interstate 70

IWMP – Integrated Water Management Plan

MCIWMP – Middle Colorado Integrated Water Management Plan

MCWC – Middle Colorado Watershed Council

MOU – Memorandum of Understanding

TA Team – Technical Assistance Team

USDA – United States Department of Agriculture

USFS – United States Forest Service

USGS – United States Geological Survey

VARs – Values at Risk

WRAP – Wildfire Ready Action Plan

WRW – Wildfire Ready Watersheds

WUI – Wildland-Urban Interface

# 1. EXECUTIVE SUMMARY

## 1.1. Background

The Colorado Water Conservation Board's (CWCB) Wildfire Ready Watersheds (WRW) Program established a framework to support communities in working together to understand the susceptibility of Colorado's watersheds to post-fire impacts and to plan and prepare for them – ***before* fires occur**.

As of spring 2021, the top three largest wildfires in Colorado history all occurred during the 2020 wildfire season: Cameron Peak fire (208,663 acres), East Troublesome fire (193,812 acres), and the Pine Gulch fire (139,007 acres). In addition, the Grizzly Creek fire burned 32,631 acres in Glenwood Canyon totaling 171,638 acres of fire damaged landscape in the middle reach of the Colorado River Basin.

In the Colorado Basin, increased development at the wildland-urban interface (WUI) has created an increased risk of property damage from wildfires. Debris flows from fire-impacted landscapes can also create damage to property and infrastructure. Other lasting impacts from wildfires include water quality impacts to streams in burned watersheds, especially increased sediment, debris, and turbidity.

With the leadership of the Middle Colorado Watershed Council (MCWC), the stakeholders within the middle reach of the Colorado River Basin convened in late 2022 to understand how to use the WRW framework and become a more fire-adaptive community. One that can provide safety in numbers, work across jurisdictional boundaries, remove barriers, and leverage one another's work to prevent wildfires and mitigate potential impacts before fires occur. The Colorado River Wildfire Collaborative (CRWC) was born from these stakeholders.

There are three active wildfire coalitions on the western slope of Colorado within the Colorado River Basin adjacent to the CRWC. The Roaring Fork Valley Wildfire Collaborative is active in the Roaring Fork valley watershed upstream from the confluence of the Colorado and Roaring Fork Rivers. The Two Rivers Wildfire Coalition is also active in the Mesa County area, downstream along the Colorado River from De Beque to Grand Junction – encompassing all of Mesa County with a small overlap with the CRWC in the eastern portion of the county. The Eagle County Wildfire Group encompasses all of the Colorado River as it runs through the county. The CRWC fills the gap along the Middle Colorado River and encompassing the jurisdictions of the Colorado River Fire Protection District, De Beque Fire Protection District, Grand Valley Fire Protection District, part of the Lower Valley Fire Protection District, part of the Plateau Valley Fire Protection District, Glenwood Springs Rural Fire Protection District, Battlement Mesa Metropolitan District, Town of Collbran, Town of De Beque, City of Glenwood Springs, Town of New Castle, Town of Parachute, Town of Silt, City of Rifle, and lands managed by the Bureau of Land Management Colorado River Valley and Grand Junction Field Offices, Colorado Parks and Wildlife, unincorporated Garfield County and parts of Mesa County, and the United States Forest Service Grand Mesa, Uncompahgre and Gunnison and White River National Forests (**Figure 1-1**).

The CRWC's Wildfire Ready Action Plan (WRAP) describes the efforts of the CRWC to establish strong working relationships across jurisdictional boundaries and leverage resources to protect potential hazards and vulnerabilities that are susceptible to damage after a fire. This report is intended to be reviewed in tandem with the ArcGIS StoryMap available online.

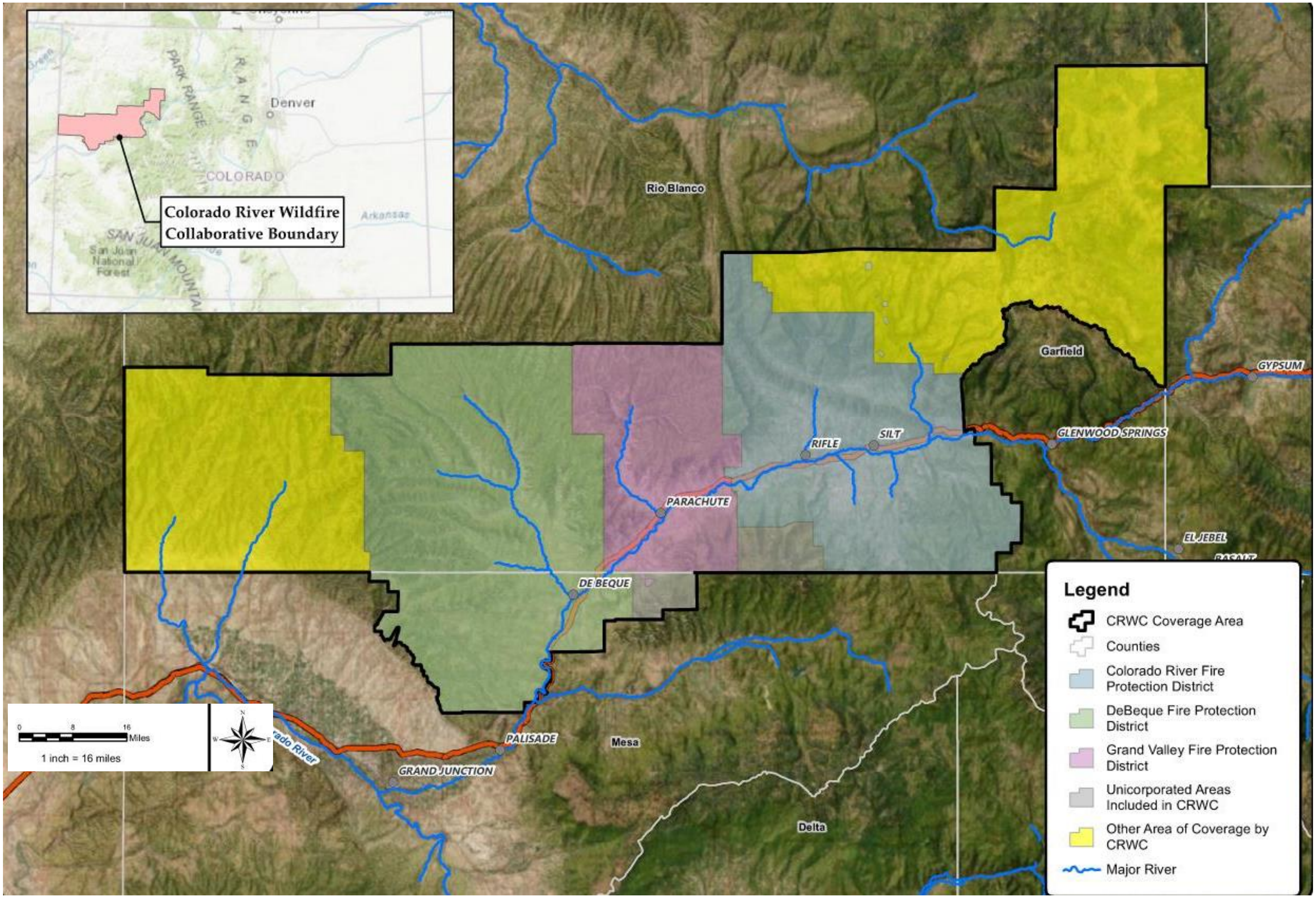


*Figure 1-1. CRWC Area*

## 1.2. Mission, Vision, and Goals of the Colorado River Wildfire Collaborative

### Mission

> *"Uniting stakeholders across jurisdictions to foster a fire-resilient landscape, implementing proactive landscape-based strategies for pre- and post-fire planning and mitigation, and leveraging collective resources to protect people, communities and ecosystems."*

### Vision

> *"Building a cohesive network where communities, ecosystems, and stakeholders collaborate to prevent, prepare for, and recover from wildfires, promoting safety, sustainability, and adaptive resilience across our landscapes."*

These proposed statements encapsulate the CRWC's commitment to collaboration, proactive planning, and resilience-building, to align with its specific goals and objectives. Following is a summary of the goals and the tasks implemented to achieve these goals throughout the project. Goals 1 through 4 have been completed as part of this WRAP development. The tasks associated with Goals 5 through 8 are underway and will be part of the CRWC's work in the future.

### Goal 1: Identify Stakeholders and Partners within the Middle Reach of the Colorado River Basin

The MCWC implemented the following tasks as part of the initial stakeholder identification process on behalf of the CRWC:

- Hosted and facilitated several stakeholder meetings to encourage collaboration and inform stakeholders within the middle reach of the Colorado River Basin about the Wildfire Ready Watersheds framework.
- Identified the geographic area(s) of concern and gaps that will become the group's focus.
- Collaborated with adjacent wildfire collaboratives (Roaring Fork Valley Wildfire Collaborative, Eagle County Watershed Collaborative, and the Two Rivers Wildfire Coalition) to support the communication and benefits of forming a wildfire group within the Middle Colorado River reach.

### Goal 2: Goal Setting Workshop

The MCWC led discussions and targeted outreach efforts with all identified stakeholders and partners on behalf of the CRWC. These discussions:

- Identified and documented stakeholder concerns and priorities (areas of concern and specific assets) and set planning goals and objectives that address the full suite of post-fire hazards and potential assets at risk.
- Identified opportunities to leverage data, funding, or resources; define stakeholder roles and responsibilities, i.e., who is responsible for providing supporting asset data, who will be directly involved in the review of planning deliverables, and at what times and frequency stakeholder groups are brought together for updates and discussions.
- Developed vision and mission statements.
- Identified available resources to support the CRWC and identified projects.
- Established a Steering Committee to support decision-making.
- Submitted a grant application to the CWCB to obtain funding to support the project and developed a WRAP that identified susceptible areas and infrastructure within the project area with the awarded grant monies.

### Goal 3: Develop a Memorandum of Understanding (MOU)

- The CRWC stakeholders developed a Memorandum of Understanding (MOU) that establishes the group as an informal, unincorporated collaborative organization in which members set mutual goals and priorities and aligned decisions needed to most effectively mitigate wildfire risk in the collaborative's geographical region surrounding the middle reach of the Colorado River.
- The MOU identifies a standard set of goals while recognizing the differing missions, goals and objectives of the stakeholders and the organizations they represent.

### Goal 4: Define and identify post-wildfire hazards that threaten life safety, property, and infrastructure

The MCWC, SGM and the CWCB Technical Assistance (TA) Team:

- Developed a dataset of critical public and private infrastructure and natural resource assets susceptible to post-wildfire hazards within the project area.
- Reviewed the dataset with the CRWC to support their evaluation, ranking, and prioritization of these vulnerabilities at a landscape scale.
- Aggregated available post-wildfire hazard data and where needed, performed additional evaluations to develop post-wildfire hazard data at a study scale while leveraging existing partner knowledge, expertise, and information.
- Effectively coordinated with stakeholders to establish an action-based assessment and future relationships for collaboration.

The following goals have not been completed as of December 2024 and will be implemented as part of the CRWC's future work.

### Goal 5: Hire a CRWC coordinator

The MCWC will support the CRWC stakeholder's efforts to hire a collaborative coordinator to facilitate the implementation of Goals 6-8, projects, find funding resources, write grants, and develop a community outreach and education program.

### Goal 6: Develop an effective educational campaign that relays the findings and action items of the WRAP

The CRWC stakeholder organizations will work collaboratively to leverage resources to develop an effective educational campaign. This educational campaign will aim to:

- Convey outcomes of the susceptibility assessment through clear, understandable documentation and online data sharing and mapping applications.
- Create a strategy to engage with local stakeholders, landowners, and residents to implement post-fire hazard mitigation.
- Communicate post-fire risk with stakeholders and encourage actions that further implementation of mitigation.

### Goal 7: Advance a landscape-scale approach to planning projects that will lead to the recovery of the landscape, watershed, wetlands, and stream corridors and reduce susceptibility to hazards following wildfires

The CRWC coordinator will work with the stakeholders to implement the WRAP, specifically:

- Promote natural watershed recovery and stabilization processes as part of post-fire hazard mitigation to minimize the need for operations and maintenance.

- Understand the vulnerabilities associated with land use growth, environmental, recreation, and water supply and suggest regulatory tools and policies and mitigation actions to reduce risk.
- Create and implement a framework through which the long-term successes and failures of mitigation strategies can be monitored and analyzed.
- Plan to implement projects that improve geomorphic and ecological structure and function as part of the mosaic of mitigation actions.
- Plan projects that contribute to improvements at individual site, stream corridor, and watershed scales.

**Goal 8: Develop a long-term communication and collaboration strategy between the CRWC stakeholders that specifically identifies an organizational structure, responsibilities, communication, and implementation actions**

The new CRWC coordinator will work to develop a long-term communication and collaboration strategy that aims to:

- Develop an organizational structure for recovery following a wildfire within the project area.
- Using the results of the susceptibility analysis, develop a priority list of post-fire actions and mitigation projects that can be used by recovery agencies within the project area to identify funding needs.
- Identify a repository of data collected and created during the WRAP for use on post-fire disaster recovery. This will include data for values-at-risk (VARS), hazards, susceptibility, and mitigation actions.
- Link cross-boundary projects.
- Create a post-fire communication plan for agencies, stakeholders, and residents. These may include post-fire hazard maps, outreach regarding evacuation, road closures, and emergency access plans.
- Keep members engaged and retain interest over time.
- Leverage the lessons learned and feedback obtained as part of the educational campaign.

## 1.3. Study Area/Project Area

The CRWC area was delineated to overlap the areas covered by the Roaring Fork Valley Wildfire Collaborative and the Two Rivers Wildfire Coalition to represent stakeholder boundaries of the Colorado River Fire Protection District, De Beque Fire Protection District, Grand Valley Fire Protection District, Lower Valley Fire Protection District, Plateau Valley Fire Protection District, Glenwood Springs Rural Fire Protection District, Battlement Mesa Metropolitan District, Town of Collbran, Town of De Beque, City of Glenwood Springs, Town of New Castle, Town of Parachute, Town of Silt, City of Rifle, and lands managed by the Bureau of Land Management Colorado River Valley and Grand Junction Field Offices, Colorado Parks and Wildlife, unincorporated Garfield County, and the United States Forest Service Grand Mesa, Uncompahgre and Gunnison and White River National Forests (**Figure 1-1**). The full stakeholder list can be found in **Section 3**.

## 1.4. Challenges and Lessons Learned

The WRW program provided a strong set of guidelines and fact sheets, continuous support from the CWCB and the CWCB TA Team, and engagement from the CRWC stakeholders. However, with innovative programs come challenges. A summary of these lessons learned is provided to support future WRAP efforts.

## Stakeholder Education

Most CRWC stakeholders are from organizations that carry out their missions on a landscape scale, not usually defined by watershed boundaries.

There was an initial lack of understanding of how the CWCB plans and supports watershed and fire mitigation projects and why this program was being offered. The MCWC spent a lot of time and effort initially fostering this education and understanding, leading to some misalignment with the grant expectations associated with costs and schedule to complete the WRAP.

Due to this limited understanding of the WRW program and its benefits early on, the stakeholders couldn't provide more matching dollars, which led to a decreased ability to conduct more detailed technical work and modeling in more than three watersheds.

Because of the technical approach for the work, which was informed by hydrology and watershed boundaries, not property lines and jurisdictional boundaries, the collaborative had to identify a more limited scope for the WRAP.

### Lessons Learned

Allow time and budget for this educational process to occur.

## MOU Development

One of the first tasks of the CRWC was to develop a statement of mutual benefit and interest for the project. This effort was successfully completed in the form of a Memorandum of Understanding (MOU) but took time to complete.

### Lessons Learned

Initiate this process early-on in the conversation with a potential stakeholder group. Capitalize on existing similar agreements. Include the Federal Land Management agencies at the first meeting to streamline this process.

## Stakeholder Participation

CRWC has been active since November 2022 with engagement from several stakeholders including government agencies. Processes like project identification and developing MOUs are impacted when staff changes. This collaborative had two town managers retire in the last year, and several agency transfers and retirements.

### Lessons Learned

Identify easily digestible programs and project outlines to quickly initiate incoming participants. Plan for one-on-one engagement with newcomers to share the background and current goals set in motion.

# 2. INTRODUCTION

## 2.1. CWCB Wildfire Ready Watershed Grant

The CWCB awarded the MCWC a grant to support the formation of the CRWC and their WRAP. This grant included use of the CWCB Technical Assistance team to support the hazard and susceptibility analyses for three watersheds – Elk Creek, Rifle Creek, and Battlement Mesa.

## 2.2. What is a Wildfire Ready Action Plan (WRAP)?

There are two types of implementation plans that provide the basis for a community to address critical elements of a WRAP, including:

1. Pre-disaster Preparedness Plan. A plan that considers susceptibility and identifies projects and mitigation that can occur **before a wildfire occurs**.
2. Post-disaster Preparedness Plan. A plan to address threats to life and property **after a wildfire occurs**.

The CRWC's work has resulted in a WRAP that identifies areas of susceptibility in the Elk Creek, Battlement Mesa, and Rifle Creek watersheds, informed by on-the-ground data, modeling, local expertise, and experience.

## 2.3. Wildfires in the Colorado River Basin

### Grizzly Creek Fire

The Grizzly Creek Fire burned a total of 32,631 acres in 2020 when 91% containment was reported. Though the fire did not grow further after October 23, the fire was not reported fully contained until December 18, 2020 when the uncontained areas received significant snowfall (InciWeb 6942).

Grizzly Creek, post-fire
(Photo credit: April Long)

The Grizzly Creek Fire closed I-70 to traffic for two weeks (from August 10, 2020 through August 24, 2020), significantly impacting not only the local economy but also the entire country's supply chain and road and transportation system. The fire also closed the popular Hanging Lake trail. "While Hanging Lake itself was not burned in the Grizzly Creek Fire, the fire burned much of the area above the lake and trail. Some areas of the trail were also burned, as was a large portion of Glenwood Canyon."- White River National Forest Service (Glenwood Springs, 2020).

The burn area included portions of No Name Creek and Grizzly Creek, both of which are essential watersheds to the City of Glenwood Springs' drinking water.

### Pine Gulch Fire 2020

The Pine Gulch fire burned a total of 139,007 acres from July 31, 2020, through September 15, 2020, when 100%

containment was achieved. Of the total acreage, 91,939 acres lie in the Middle Colorado region. The Pine Gulch Fire burn area is within the Colorado River Wildfire Collaborative region located west of Roan Creek and north of the Town of De Beque.

The fire started from a lightning strike approximately 18 miles north of Grand Junction. The burn area includes portions of Garfield and Mesa County and is predominantly (74%) located on the Bureau of Land Management's (BLM) land.

> *The combination of drought-stressed vegetation, unseasonably hot weather and steep terrain led to weeks of active burning. Smoke columns were often visible from Grand Junction and the surrounding area as the wildfire exhibited extreme fire behavior. During the night of August 18, the fire grew quickly due to thunderstorm winds up to 40 mph for a three to four-hour period. As a result, the fire increased by more than 30,000 acres that night.*
>
> *Land Ownership Breakdown: BLM 101,714 / Private: Garfield County 35,791 / Private: Mesa County 1,502. (InciWeb 6906)*

In the Colorado Basin, increased development at the WUI has created a greater risk of property damage from wildfires. Debris flow from fire-impacted landscapes can also create damage to property and water infrastructure. Other lasting impacts from wildfires include water quality impacts to streams in burned watersheds, especially increased sediment and turbidity.

### Debris Flows

Debris flows caused by storm events falling on burned areas are another major challenge associated with wildfires. In burned areas, especially those that experienced high fire intensity, root systems and groundcover are no longer effective at holding soils in place. Furthermore, soils in severely burned areas are covered in ash and can become hydrophobic, reducing the amount of moisture that can infiltrate into the soils and increasing runoff. With less to hold the soil in place and more water running over the ground surface, heavy precipitation events can trigger large and hazardous debris flows. For example, a rain event on July 29, 2021, caused large debris flows in the Grizzly Creek Fire burn area; the debris flows closed I-70 for weeks and left lasting damage to the highway.

In addition to causing damage to infrastructure, these post-fire debris flows can have major water quality impacts to receiving streams. The debris flows that closed I-70 were so large that they altered the channel of the Colorado River and dramatically increased the loads of sediment and organic material coming down the river for months after the rain event. Sediment-laden water can damage the pumps at drinking water intakes and cause water treatment processes to run less efficiently. In addition, these debris flows have a negative impact on aquatic habitat and fish populations, and in some cases cause fish die-off. Even when acute effects are less severe, fine sediments accumulating in the riverbed can have long-term impacts to food sources and spawning habitat for the fish.

Colorado Department of Transportation crews clear debris and assess damage near Mile Marker 123.5 along Interstate 70 in Glenwood Canyon. Eastbound lanes in the section were destroyed by July 29 mudslides. Photo Credit: Pam Boyd and Post Independent (Boyd, 2021).

### Riparian Health

An important aspect of the watershed health that is most often neglected are the riparian areas and floodplains. In some areas, county and municipal building codes allow homeowners and businesses to develop up to a river's bank. The loss of a natural buffer to human activity degrades water quality. Stream and river diversions to fill reservoirs have meant a loss of peak spring flows, resulting in decreased overbank flooding, which is necessary to sustain riparian vegetation. Infringement on the riparian corridor and a loss of flows for riparian health has added additional stress to overall river health.

Grazing practices can also impact riparian health, contributing to loss of riparian plants and resulting in incising of natural stream channels.

Half of the nutrients found in rivers come from riparian areas. To protect watershed health, we must embark on additional assessments to quantitatively identify flow needs to sustain riparian health, and thus help provide clean water and suitable habitat and nutrients for aquatic life.

### Inter-Agency Coordination

Planning for forest health and watershed health protection requires participation from many entities, local, state, and federal. There is a need for more active and continuous conversations among the many stakeholders. Further inter-agency coordination and collaboration needs to be an important part of the overall solution.

## 2.4. Middle Colorado Region

The CRWC's region includes the mainstem Colorado River and some smaller tributaries including Canyon Creek, Elk Creek, Divide Creek, Rifle Creek, Garfield Creek, Mamm Creek, Parachute Creek, and Roan Creek. Several communities are located along the Colorado River and include Glenwood Springs, New Castle, Silt, Rifle, Parachute, Battlement Mesa, and De Beque.


Rafting in Glenwood Canyon. Photo: Bailey Leppek

This region supports the second highest number of irrigated acres (after the Grand Valley), at approximately 52,000 acres, according to the USDA 2017 Census of Agriculture. A significant portion of this acreage is irrigated with water from the smaller tributaries. This region is supported by the Silt Water Conservancy District, Bluestone Water Conservancy District, the Southside Conservation District, the Bookcliff Conservation District, the Mount Sopris Conservation District, and the West Divide Water Conservancy District. This area is also served by the Bureau of Reclamation Silt Project (BOR, 2014) which is located near the towns of Rifle and Silt.

This area is also characterized by the ongoing natural gas drilling and potentially marketable oil shale formations. It contains more natural gas wells than any region in the state outside of Weld County. The Colorado River through this reach is a direct source of drinking water for the Town of Silt, City of Rifle, Parachute, Battlement Mesa and De Beque. It also provides a backup supply for the Town of New Castle (providing redundancy for the Town's primary supply from East Elk Creek). This reach is impacted by all Colorado Basin headwater transmountain diversions which take high quality clean water, leaving less water and lower flows to help dilute the poorer quality water downstream. Concentrations of salinity, selenium, hardness, total dissolved solids, iron and manganese are examples of potential water quality concerns through this reach.

The Endangered Species Act designation of critical habitat for three of the T&E listed fish species extends upstream on the Colorado River mainstem from the 15-Mile Reach in Mesa County to the main Rifle I-70 Bridge. This same reach of river is also home to three native fish species of concern: the roundtail chub, bluehead sucker, and flannelmouth sucker. Management actions are needed to ensure that populations of these species do not decline to the point requiring a T&E listing.

## 2.5. Related Studies and Projects

The CRWCs WRAP was informed by review of a few related studies in the CRWC area. These studies and plans are summarized below.

### Colorado Community Wildfire Protection Plans

Community Wildfire Protection Plans (CWPP) are authorized and defined in Title I of the Healthy Forests Restoration Act, which was passed by Congress in November 2003. Colorado Community Wildfire Protection Plans bring together diverse local interests to discuss their mutual concerns for public safety, community sustainability and natural resources. They offer a positive, solution-oriented environment in which to address challenges such as: wildland-urban interfaces (WUI); local firefighting capability; the need for defensible space around homes and subdivisions; and where and how to prioritize land management on both federal and non-federal land (CSFS, 2021).

Glenwood Springs from Storm King Mountain
(Photo credit: Doug Winter)

In 2022, Garfield County updated the countywide CWPP in response to the increasing severity of catastrophic wildfire fires as well as a continued forecasted increase in population and associated WUI. WUI areas were delineated within each fire protection district (FPD) and analyzed for values at risk and wildfire susceptibility. The Garfield and Mesa County CWPPs largely investigated the behavior of wildfires and the types of fuels that can increase the severity of wildfires and associated hazards, such as types and diversity of vegetation, topography, weather patterns, and lack of defensible spaces within WUI zones. For instance, Garfield County's semi-arid climate and sustained winds, steep terrain, and abundance of cheatgrass and brush vegetation encourage fire ignition and rapid spreading of fires. The CWPP analysis found that the overall risk for WUIs in the county were high to extreme. Various fuel-mitigation techniques such as fuel breaks, defensible space, strategic shrub and forest thinning, and vegetation-fuel treatment options were discussed as good options for reducing the burn severity. The CWPP acts as a living document that provides state and federal grant funding to support identified mitigation actions across the county—bringing together stakeholders to continually reference the document for mitigation projects and encouraging public education about the risks present and the techniques available for reducing loss of life, economy, and ecosystem.

The WRAP discussed herein was informed by and expands upon the CWPP. The identified stakeholders, mitigation techniques, areas of concern, and VARs are still applicable and used within the WRAP. However, beyond the focus on fuel-severity and concurrent wildfire impacts, the WRAP analyzes post-fire hazards/susceptibility from increases in flooding, debris flow, fluvial hazard zones, hydrologic/hydraulic changes, and sediment loads, as well as additional mitigation measures that could be used to reduce the impacts to VARs.

### Colorado Forest Atlas

The Colorado Forest Atlas website serves as a one-stop shop for the Colorado State Forest Service, the public, and numerous partners to access statewide geospatial data and information related to forestry and natural resources. Applications in the Colorado Forest Atlas can be used as decision-support tools for developing new projects, writing forestry plans, assessing wildfire risk to communities, evaluating forest conditions, and more. These applications will be updated on a regular basis using the best available science and data (CSFS, 2021).

The Colorado Forest Atlas has several public applications available on its Colorado Forest Atlas Information Portal.

- The Forest Action Plan 2020 can be used to view and print maps from the 2020 Colorado Forest Action Plan.
- The Risk Reduction Planner is to support community wildfire protection planning efforts. It allows a user to define a project area, generate a detailed risk summary report, and export wildfire risk GIS data.
- The Wildfire Risk Viewer is a web-mapping application that allows users to identify specific wildfire risk levels within a 1/2-mile radius of a home or other point of interest.

### Middle Colorado River Integrated Water Management Plan (IWMP) (2021)

As part of the IWMP, an action plan was developed and used by watershed stakeholders as a quick reference guide for carrying out planned activities that further the mission and goals associated with the Middle Colorado River Integrated Water Management Plan (IWMP). It contains written descriptions for each of the Projects, Initiatives, and Studies identified through the planning process (MCRIWMP, 2021). Many of these projects were added to the BIP Projects Database in 2020 and 2021.

# 3. STAKEHOLDERS + PARTNERS

The following is a list of those who are on the current email distribution list. (Note - not all the members listed have participated on a regular basis but have been present during at least one or a few meetings.)

## 3.1. Federal Land Management Agencies

Bureau of Land Management

United States Forest Service

## 3.2. State Agencies

Colorado State Forest Service

Colorado Parks and Wildlife

Colorado Division of Reclamation, Mining and Safety

Colorado Division of Fire Prevention & Control

Colorado Fire Commission

## 3.3. Fire Districts

Colorado River Fire Protection District

Grand Valley Fire Protection District

Lower Valley Fire District

De Beque Fire Protection District

Glenwood Springs Fire District

Plateau Valley Fire Protection District

## 3.4. Local Land Management Agencies (Municipalities, Towns, and Counties)

Garfield County

Mesa County

Town of New Castle

Town of Silt

City of Rifle

Battlement Mesa Metropolitan District

Town of De Beque

Town of Parachute

City of Glenwood Springs

Town of Colbran

## 3.5. Watershed Groups, Conservancy Districts, and Conservation Districts

Active watershed organizations in the Middle Colorado region include:

Middle Colorado Watershed Council

> The group's mission is "to evaluate, protect and enhance the health of the Middle Colorado River watershed through the cooperative effort of watershed stakeholders." (MCWC, 2021)

- The Middle Colorado region includes the following water conservancy districts:
- West Divide Water Conservancy District
- Bluestone Water Conservancy District
- Silt Water Conservancy District

The Middle Colorado region includes the following resource conservation districts (also sometimes known as soil and water conservation districts):

- Bookcliff Conservation District
- Mount Sopris Conservation District
- Southside Conservation District
- De Beque – Plateau Valley Conservation District
- Natural Resources Conservation District

## 3.6. Energy Companies

Holy Cross Energy

Xcel Energy

## 3.7. Memorandum of Understanding (MOU)

Members of the stakeholder group signed an MOU at the beginning of the project. The purpose of the MOU is to:

> *"…document the cooperation between the parties to establish the Collaborative as an informal, unincorporated collaborative organization, in which the members set mutual goals and priorities, utilize existing forest management tools and legal authorities, and align their decisions on where to make the investments needed to achieve the purpose and goals set forth for the Colorado River Wildfire Collaborative and in accordance with the following provisions."*

A copy of the MOU is provided in **Exhibit A – Memorandum of Understanding**.

# 4. GIS PREPAREDNESS

A spreadsheet overview of the Geographic Information System (GIS) data used to perform the watershed-scale susceptibility assessment is attached as **Exhibit B – GIS Data Overview**.

# 5. HAZARD EVALUATIONS – TYPES + METHODOLOGIES

The WRW program, specifically regarding the WRAPs, identified five major post-fire hazards to VARs in a post-fire environment: Fluvial Hazard Zones (FHZ), Hydrologic Changes and Hydraulics, Flooding after Fire, Sediment Delivery, and Debris and Mud Flow. The CWCB's Technical Assistance (TA) team performed an analysis on the post-fire severity of each hazard throughout the watersheds. A brief introduction to each hazard is provided below; additionally, a more detailed description of the methodology for the hazard evaluations is provided in **Exhibit C – Hazard Evaluations Technical Memorandums**.

## 5.1. Fluvial Hazard Zones

FHZs are areas within a stream's floodplain that are subject to erosion and sedimentation before and after wildfires. This can include streambank erosion, scour, sediment deposition, the development of new channels, and other geomorphic changes. FHZ hazard evaluations are conducted through analyzing the existing geomorphic qualities within the watersheds, such as the soil types, topography, and underlying geology, then implementing GIS systems to identify the hazard zone.

## 5.2. Hydrologic Change and Hydraulics

Hydrologic Changes after a fire are predominantly characterized by increases in runoff volumes and peak flow. Reduced transpiration and infiltration within the watershed because of the fire often leads to increases in runoff and peak flows beyond what a watershed would normally experience.

## 5.3. Flooding after Fire

Reduced transpiration and infiltration within the watershed because of the fire often leads to increased flooding within a watershed. These floods can be devastating to human life, property and infrastructure.

## 5.4. Sediment Delivery

Native vegetation and organic material normally catch and infiltrate rainfall into the soil below, which helps to decrease soil erosion on hillslopes. However, when a fire burns the native vegetation, the soil is no longer protected and is more susceptible to erosion during rainfall events. Soil erosion post-fire can degrade water quality, reduce storage capacity in reservoirs, plug water diversion structures, and increase flood and fluvial hazards in stream channels. The types of vegetation and subsequent burn severity, geological features, and topography can impact the severity of sediment erosion and deposition post-fire.

## 5.5. Debris + Mud Flows

Debris and mud flows are floods of water that also contain materials such as soils, rocks, trees, structures, and other large objects. These debris flows can travel quickly and carry massive amounts of materials. Burn severity, topography, and geology can largely impact the severity of debris flows within a watershed after a fire.

# 6. SUSCEPTIBILITY ANALYSIS

The susceptibility analysis was performed by Olsson and Associates as a part of the CWCB's TA Team. The analysis overlaid the risk probability for each of the identified hazards in **Section 5** with the identified VARs. Upon completion, each VAR is given a susceptibility score for each hazard to indicate how susceptible the VAR would be to these hazards in a post-fire environment. The susceptibility analysis is detailed in the report found in **Exhibit D – Susceptibility Analysis**.

After a fire occurs, it would be beneficial to repeat these analyses for a specific subset of the hazard and susceptibility analyses with the actual burn scar outline and severities to inform the post-fire response. This would help more easily identify exact locations and types of projects that could protect critical infrastructure and life and property concerns.

# 7. PRE-DISASTER PREPAREDNESS PLAN

This section explores mitigation options and plans to reduce the impact of post-fire hazards on the economy, infrastructure, and on human life.

### Burn Severity Mitigation

Many of the hazards studied in this plan can be lessened with pre-fire burn severity mitigation. When a fire severely burns the soil, the soil becomes hydrophobic. In hydrophobic conditions, the soil absorbs a smaller quantity of water during storm events, allowing water to run off instead of being absorbed into the soil. These conditions result in increased probability for hazards, including debris flow, flooding after fire, hydrologic change, and sediment transport.

Burn severity mitigation before the fire, through techniques such as prescribed burning and mechanical or chemical treatment, can help lessen the probability and severity of these hazards. The specific project identification, by reach in **Section 9,** helps identify where appropriate areas may be found. Generally, this plan found the most useful areas to be the headlands of each of the watersheds and areas nearer to the Town of New Castle. Despite the concentration of susceptible VARs, the steep terrain in East Elk Creek and in East Rifle Creek is likely driving the debris flow hazard. While some burn severity mitigation may be beneficial, this mitigation strategy may be best focused in other areas.

A summary of the potential areas most likely to allow some mitigation for post-fire hazard risk can be found in **Exhibit E – Identified Potential Mitigation Areas**. These areas are also available for download through the MCWC GIS information.

### Cross Jurisdictional Planning

As with fire management, the ability to quickly communicate across jurisdictions will decrease response times and mitigation strategies. The CRWC is already working to foster these relationships and tackle projects together when possible, particularly burn severity mitigation projects. Keeping these relationships intact, through the collaborative, will continue to be important.

### Watershed Restoration Projects

One effective mitigation approach for post-fire flooding events post-fire can be the use of the natural environment to temper peak flows. As flow spreads out of the banks of a creek into floodplains, the flooding waters will slow, allowing for sediment and debris to settle out of the water and the peak of the flow to be lessened. Stream restoration and the restoration of wetland areas can allow for the environment to provide this benefit in a post-fire environment. The specific project identification by reach in **Section 9** helps identify where appropriate areas may be found.

Overall, many of the small drainages are characterized by narrow valley bottoms, steep flow paths, and a narrow fluvial hazard zone. These are not candidates for stream restoration. However, many of the lower portions of the Elk Creek and Rifle Creek watersheds have wider valley bottoms and gentler flow paths, making these prime candidates for stream restoration projects. These can be found in West Elk Creek, below the confluence of West and Main Elk Creeks, some small sections of Main and East Elk Creek, West Rifle Creek, the section of East Rifle Creek just above Rifle Gap, Rifle Creek below Rifle Gap Reservoir, and Government Creek above Rifle. A map of these areas can also be found in **Exhibit E – Identified Potential Mitigation Areas**.

### Warning System Preparation

In a post-fire environment, the ability to quickly warn those in the probable path of destruction can save lives. To enable the quick deployment of a warning system, the collaborative should consider reverse 911 infrastructure. Some stakeholders may already have this infrastructure in place for use during an emergency. Garfield and Mesa County's emergency management teams may be good resources for the implementation of automatic notification systems.

To inform the automated notification system, precipitation gauges will be placed in and near the burn scar to monitor rainfall in real-time. Pre-disaster, consideration can be given to the type and number of precipitation gauges, as well as possible funding sources and partnerships to supply these gauges. The quick deployment of these gauges, especially in locations with high concentrations of susceptible VARs downstream, may be crucial to life safety.

Preparing a source for signage in advance can decrease the lead times between a fire and installation of critical warning signs. Signage to warn the general public of the risk of flash flooding and debris flows in highly susceptible areas is beneficial, this is especially true in areas with limited or no cell phone service. Some stakeholders may already have access to previously designed signs and print shops (such as the USFS, the counties, and perhaps municipalities).

## 8. DISASTER PREPAREDNESS PLAN

This section explores the pre- and post-fire mitigation projects for key hazards. Many of the mitigation techniques, such as floodplain improvements, can reduce the impacts across multiple hazards. It is important to note that after a fire, reanalyzing the hazards specific to the fire area could be worthwhile for identifying specific small-scale actions to optimize the benefits per cost for mitigation.

## Sediment Transport Related Projects

There are multiple mitigation techniques that may reduce the severity of sediment erosion impacts after a wildfire. While there are some pre-fire mitigation options, most of these recommendations for sediment erosion control are for immediate post-fire action for recently burned hillslopes.

On a watershed-level scale, post-fire mitigation with targeted mulching, seeding, and reforestation can be beneficial for increasing the infiltration of flood waters and reducing sediment runoff.

- For mulching, wood straw and shred mulch are the best options as they reduce unwanted weed seeds, remain mostly intact during wind events, and have been found to foster the best tree seedling establishment outcomes. Mulching techniques should be prioritized to burned slopes with a steepness of 25-45% for the most effective outcome relative to cost of application.
- Seeding and reforestation techniques have mixed results for effectiveness of long-term native vegetation establishment; however, there have been positive impacts on reduced erosion. Thorough research on the species, viability, timing, and rates should be conducted prior to reseeding to maximize the potential for positive outcomes.

Targeted, small-scale mitigation techniques for sediment erosion include sediment catchment/capture systems (pre- and post-fire), ground cover (post-fire), erosion control barriers and slop length reduction (post-fire), and mechanical raking.

- Sediment catchment/capture systems are natural or artificially made areas wherein water is forced to slow down and spread out, allowing sediment to be deposited. Pre- and post-fire floodplain connectivity actions and/or beaver and wood reintroduction can help restore the natural sink areas for sediment deposition within the floodplain. Engineered sediment ponds can also capture sediment loads but are expensive and can fail during flood events leading to additional sediment issues.
- Ground cover, both natural (e.g. mulch) and artificial (e.g. bonded fiber matrix), can be applied to burned hillslopes to protect soil from rain-induced runoff and increase the rate of vegetation recovery.
- Erosion Control Barriers: runoff and sediment transport can be reduced with physical erosion control barriers such as straw wattles, tree logs, swales, and silt fences. While these structures can be beneficial for reducing soil erosion, improper installation can lead to increased debris flow should the structures fail during a storm event.
- Mechanical Raking of the rills and gullies via farming equipment or manual hand tools can help improve flow during a post-fire storm event and can also help reduce burn severity. Mechanical raking is best applied to concentrated areas with slopes less than a 30% grade.

## Debris Flow Related Projects

There are many mitigation techniques that could be implemented before and after a fire to reduce the severity of debris flow impacts. These options are as follows:

- Watershed rehabilitation (post-fire): Reestablishing vegetation after a fire, such as with mulching or reforestation, is essential for reducing debris flow from sediment erosion and runoff
- Increasing Channel Conveyance Capacity (post-fire): Channel capacity can be increased in high-risk areas to increase conveyance, and channel banks and bottoms can be reinforced to prevent scour
- Increasing Floodplain Connectivity (pre- and post-fire): Restoring vegetation and floodplain connectivity (such as with beaver and wood reintroduction) can help to create natural sediment catchment areas and reduce downstream debris/sediment impacts.

- **Debris Basins** (pre- and post-fire): Like sediment catchments, debris basins can be strategically placed upstream of critical VARs and high-risk areas to catch debris; however, regular dredging and maintenance is required
- **Debris and Rock Nets** (post-fire): Debris and rock nets (metal webbing installed across a channel) can capture larger, more dangerous debris without impeding the flow of water
- **Debris Racks** (pre-fire): In-channel racks installed upstream of primary roads and other structures can protect downstream VARs by trapping larger debris without impeding flow; regular cleaning and maintenance of debris racks is required
- **Planned Overflow Paths and Drainage Infrastructure** (pre-fire): areas where roads and high-risk drainages intersects should be considered for upsizing drainage infrastructure (culverts, bridges) and designed overflow pathways could be considered for reducing roadway failures
- **Roadside Barriers** (post-fire): k-rails and jersey barriers can redirect debris flow away from traffic
- **Structural Floodproofing Deflection Walls** (pre-fire): deflection walls can redirect debris flow away from existing infrastructure and sensitive environments
- **Temporary Diversion Barriers** (post-fire): like deflection walls and roadside barriers, Hesco or sandbags and k-rails can be used to direct flow away from VARs

## Flooding Related Projects

Strategies to assist with mitigating severe flood impacts after a wildfire occurs:

- **Increasing Floodplain Connectivity** (pre- and post-fire): Floodplain reconnectivity projects such as re-introducing beavers and wood, improving native vegetation, and reconnecting incised and degraded channels can help to reduce peak flows and attenuate runoff, as well as catch sediment and debris flows
- **Crossing Upgrades and Retrofits** (pre- and post-fire): Critical roadways and crossings that intersect drainages downstream of potential wildfire areas should be considered for upsizing or retrofitting (e.g. changing culvert to free-span bridges, implementing debris racks) to handle higher peak flows in a post-fire environment
- **Increasing Channel Conveyance Capacity** (pre- and post-fire): Channel improvements in high-risk areas can improve flood conveyance and reduce impacts to VARs. Some examples include limiting vegetation in the channel, expanding flood overbanks, creating overflow channels, reinforcing channel banks and bottoms with placement of setback riprap or hardened flood walls, and implementing grade control structures.
- **Hazard Avoidance via Conservation, Parks, Open Space, and Easements** (pre-fire): Proactive land use planning can reduce flood hazards by focusing on developing infrastructure away from flood zones and improving floodplain reconnectivity with planned open space and rehabilitation
- **Watershed Rehabilitation** (post-fire): Reestablishing vegetation after a fire, such as mulching or reforestation, is essential for reducing excessive runoff
- **Temporary Diversion Barriers** (post-fire): Hesco or sandbags and k-rails can be implemented quickly and help to direct flows away from VARs
- **Infrastructure and Utility Retrofit/ Relocations** (pre- and post-fire): Key VARs located within a flood zone can be relocated or retrofitted prior to a wildfire to reduce post-fire flood impacts

## Fluvial Hazard Related Projects

A few strategies for reducing impacts from FHZ hazards post-fire are as follows:

- **Hazard Avoidance via Conservation, Parks, Open Space, and Easements, and Community Planning:** Proactive land use planning can reduce fluvial hazards by developing infrastructure away from fluvial hazards and improving floodplain reconnectivity with planned open space and rehabilitation. FHZ mapping should be incorporated into community planning and development, regulations, and education programs to limit FHZ hazard impacts.
- **Build Energy Dissipation and Sediment Storage into the System:** Restoration of floodplains can improve natural sinks and sediment catchment areas upstream of key FHZ areas
- **Mitigate Risk in Constrained Areas:** Highly developed reaches with little to no floodplain connection should be considered for upsized crossings (bridges/culverts) and potential retrofit or movement of existing water VARs to reduce post-fire impacts
- **Infrastructure and Utility Retrofit/ Relocations:** VARs within FHZs should be considered for retrofitting, relocation, and redundancy prior to wildfire

## General Warning Systems

Warning systems are essential for all post-fire hazards to reduce the potential loss of human life.

- **Early Communication** (pre-fire): Community education through one-on-one meetings, public meetings, and community websites is essential for allowing property owners to understand the severity of post-fire hazards and to enable owners to acquire the appropriate insurance before rainfall starts
- **Alert Systems and Evacuation** (post-fire): Debris flow and flash flood alert systems can be mobilized in burn areas to collect and communicate real-time information related to the public. If necessary, evacuation orders can be implemented if the data retrieved from the alert systems exceeds set thresholds; however, officials should be wary of potential evacuation fatigue
- **Signage, Storm Patrol, Road Closures** (post-fire): Introducing signage and potential closures in high-risk areas, especially during monsoon season, can help to reduce loss of human life from exposures to post-fire flooding and debris flow events

# 9. PROJECT AREA IDENTIFICATION

## 9.1. Elk Creek Watershed

The Elk Creek Watershed covers the area north of New Castle and the Colorado River. For this narrative review of the susceptible VARs, four main areas were identified. These VARs are found along East Elk Creek, Main Elk Creek, West Elk Creek, and the west side of New Castle.

### East Elk Creek

The topography of East Elk Creek is defined by steep hillsides and narrow valley bottoms. Therefore, many of the VARs in the East Elk Creek watershed tend to be found quite close to the nearby creeks. In this area, the susceptibility analysis has identified groupings of VARs within the first seven miles of the creek, with specific groupings around 1.4, 2.0, 3.0, and 4.3 miles up County Road 241. Among the residences, culverts, roadways, wells, and ditch headgates susceptible are the Town of New Castle's main intake off East Elk Creek and a settling pond located on the west side of the creek, as well as a campground along the banks of the creek. Many of these VARs are susceptible to debris flow hazards as well as flooding and are located within the fluvial hazard zone or buffer. Accessing the mapping for this area will help identify the specific susceptibilities for each individual VAR. Three of the areas are shown in **Figure 9-1** below.

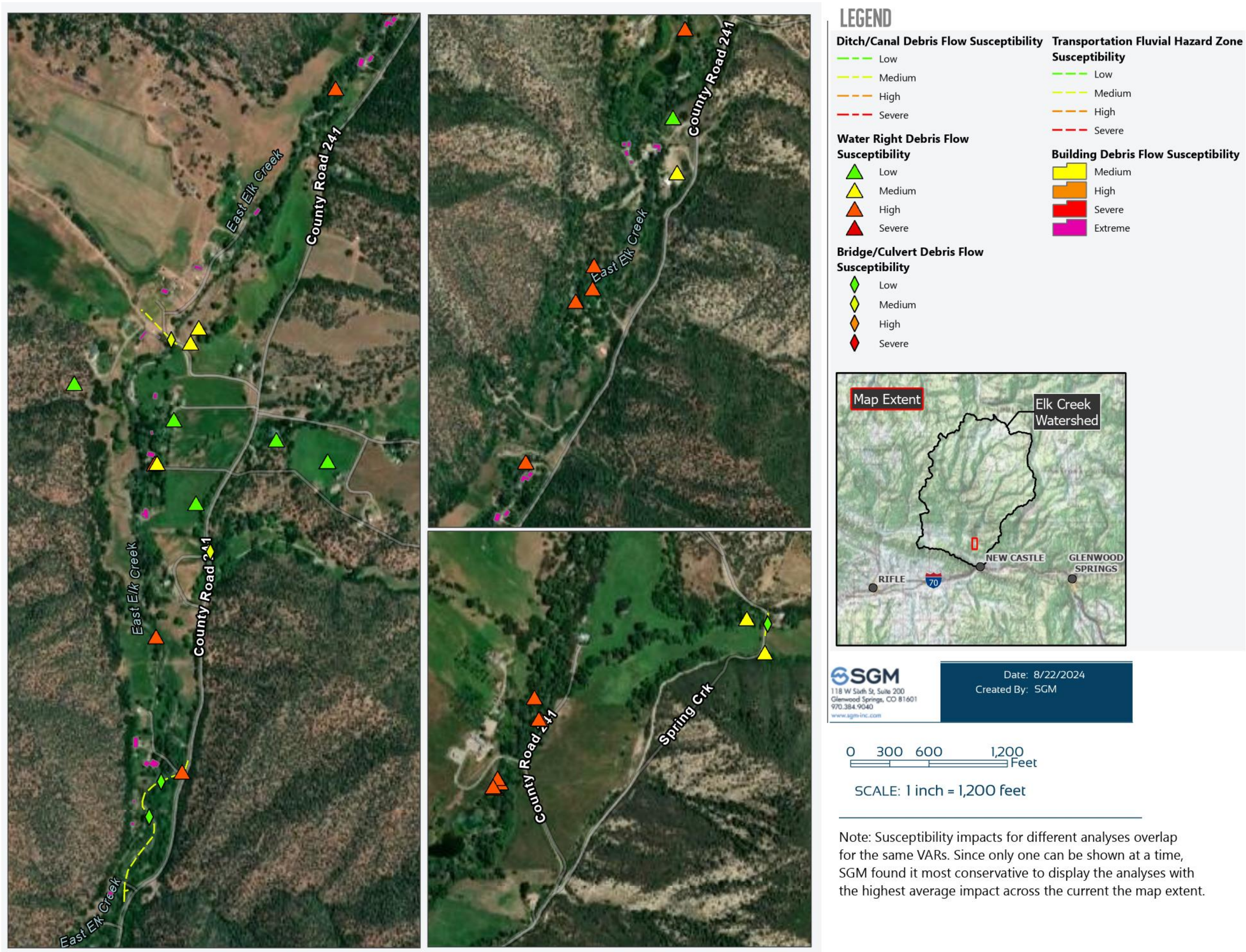


*Figure 9-1. Example of East Elk Creek Susceptible VARs*

Generally, post-fire debris flow hazard can be decreased with pre-fire burn severity mitigation such as prescribed burning or mechanical/chemical vegetation treatment. However, in the East Elk Creek area, specifically the first seven miles, the debris flow hazards are heavily influenced by the steep hillsides on both sides of the creek. Therefore, pre-fire mitigation, while useful for general wildfire mitigation, may not lessen the occurrence probability or severity of a post-fire debris flow. For the VARs in this area susceptible to a debris flow hazard, more effective mitigation will be post-fire mitigation or warning systems to allow people the necessary time to evacuate from the debris-flow-prone area. The precipitation gauges which trigger a warning system should be placed in or near the burn scar and be monitored on a short interval (5 or 15 minutes) to give those in the vicinity of East Elk Creek time to move away from areas susceptible to flooding or debris flows. The warnings from this warning system should extend down the entire creek through to New Castle.

Post-fire mitigation for these VARs would include armoring of water diversion structures, culverts, and bridges and berms around susceptible buildings and residences to redirect flows away from these structures.

There may be some options for stream restoration type mitigation in the uplands of this portion of the watershed, however the lower portion of East Elk Creek is defined by a narrow valley and steep hillsides as previously discussed. Thus, stream restoration projects may be of limited benefit to the susceptible VARs in this area. Again, pre-fire efforts may be better focused on post-fire mitigation projects, installation of warning systems, or identification of locations for future precipitation gauges. The prioritization of investigation of the sizing and condition of culverts in the area may be considered, as well as the consideration for improving the stabilization of roadway sections identified as potentially impacted by erosion or flooding in a post-fire environment. After a fire, berm or sandbag protection as well as armoring of stream segments near susceptible VARs should be an immediate priority, especially with those structures with high susceptibility scoring for a two-year storm event (a storm event with a 50% probability of occurring in any given year).

Post-fire sediment transport in this area is expected to increase and impact susceptible VARs. As the Town of New Castle's primary drinking water intake is in this watershed, the intake can be expected to be impacted by post-fire hazards. The Town of New Castle should consider the sizing of their sedimentation pond and whether it can handle an elevated sediment load. If unable to decrease the sediment load, the plant will need to have the capability to treat water with a higher turbidity. Alternatively, it could fully operate with the redundant source of the Colorado River, including handling the varying water quality found in the Colorado River as compared to Elk Creek (pre-fire).

As the Town of New Castle explores mitigation projects, these projects should be considered:

- Installation of check structures upstream of the water treatment plant intake to slow water flow and allow particle settling
- Preemptive upgrades to the water treatment plant to handle higher turbidity. There are experts who can predict specific post-fire water quality changes based on possible burned vegetation and underlying geology of the area.
- Upgrades needed to run solely on the secondary source.

### Main Elk Creek

The Main Elk Creek runs north to south through two watersheds, a northern watershed that extends from Clinetop Trailhead at its south end to Cliff Lakes Trailhead at its north end, and a southern watershed that runs from Clinetop Trailhead at its north end to the Main Elk Creek and West Elk Creek confluence point at its south end. VARs in this area include a reservoir, transportation infrastructure and crossings, water rights structures (i.e., wells, pipelines, and ditches), several buildings, and two campgrounds. The entirety of the northern watershed sits on White River National Forest land, while most of the southern watershed (excluding much of the floodplain) is BLM land.

At the northern end of the northmost watershed is Meadow Creek Lake, which is the only reservoir in the Main Elk Creek study area (**Figure 9-2**). On its shores, the Meadow Lake Campground on the lake's northern shore and the Meadow Ridge campground in the forest to its east are popular outdoor recreation destinations. As a VAR, Meadow Creek Lake is highly susceptible to post-fire debris flow and increased sediment transport and is also at risk of hydrologic change. While the nearby campgrounds were not included in the VAR analysis, their proximity to Meadow Creek Lake necessitates their consideration as VARs given their importance to the public.

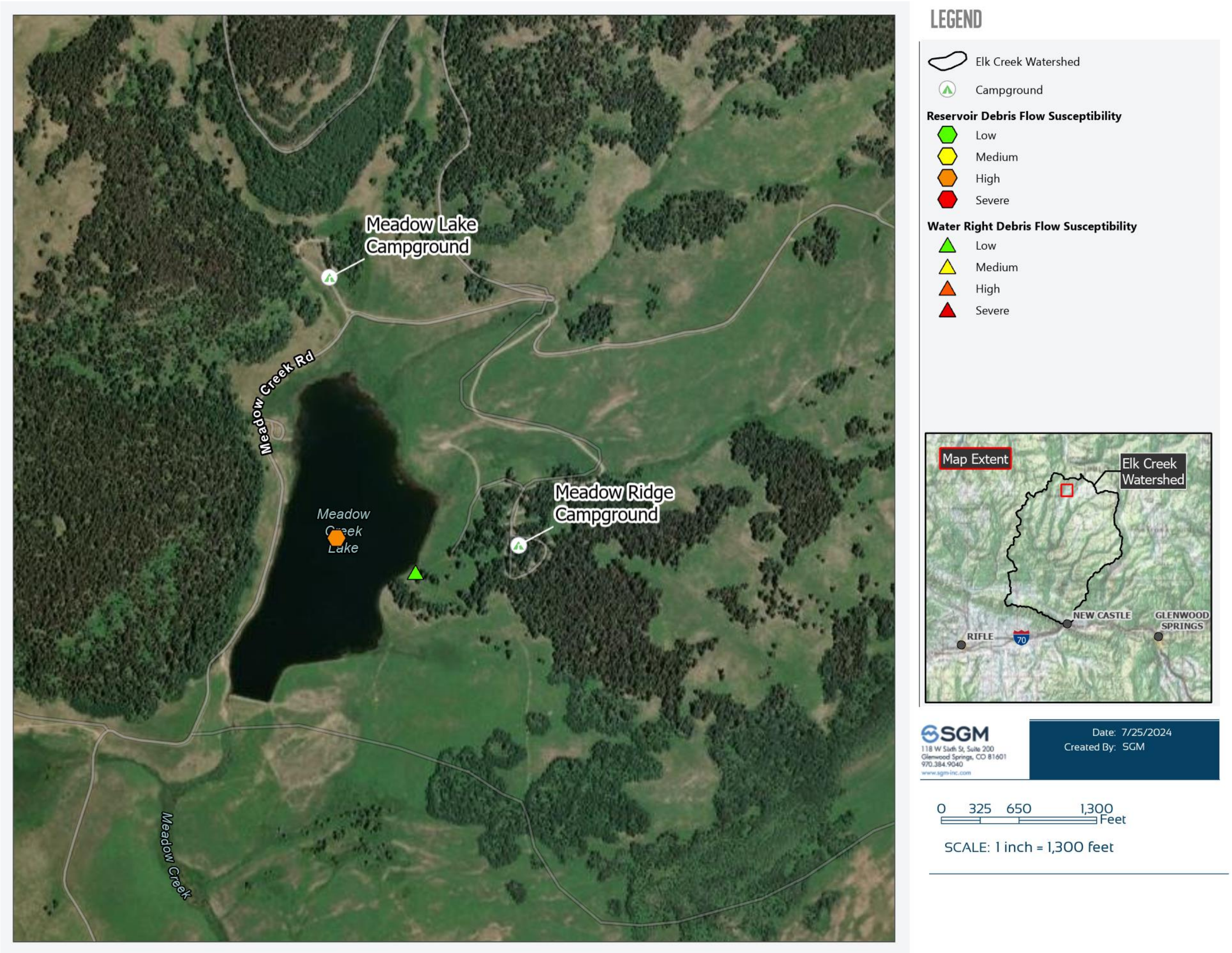


*Figure 9-2. Meadow Creek Lake and associated campgrounds in Main Elk Creek study area.*

The impact of post-fire debris flow and sediment transport on reservoirs, both with respect to ecological health and water quality, is largely mitigated by trapping and storing freed sediments further upstream. To reduce the post-fire debris flow impacts, watershed managers can ensure that the upstream floodplain is well vegetated with native grasses, shrubs, and trees that help to stabilize soil and reduce erosion before fires occur. Manmade structures to control erosion and trap sediment, such as silt fences, wattles, erosion control blankets, check dams, and terraced sediment basins can help to mitigate these risks. Additionally, reservoir channel structures can be updated to account for anticipated sedimentation risk by constructing a diversion dam in the river that allows water to flow around the reservoir during peak flows.

In a post-fire scenario, temporary structures (e.g., Hesco barriers, sandbags, k-rails) can be erected to redirect debris and sediment. Rapid revegetation of burned areas is critical to limit long-term consequences. This can be accomplished via hydromulching, whereby water, fiber mulch, an adhesive tackifier, and native, drought-tolerant seeds are sprayed on burned areas upstream, accelerating revegetation of areas that would otherwise be likely to erode sediment downstream.

Most of the water rights infrastructure are congregated in the southmost watershed, with the inlet ditch for Meadow Creek Reservoir (shown in **Figure 9-2**) and the “Elk-Rifle Proj M Elk” pipeline being the only two water rights structures in the northmost watershed. Unlike Meadow Creek Reservoir, the inlet ditch only exhibits post-fire susceptibility for heightened sediment transport, though the risk is not as severe as it is for the reservoir. The pipeline, found at the southern end of the northmost watershed, is also susceptible to sediment transport. Pre-fire mitigation efforts to decrease burn severity (prescribed burning or chemical/mechanical treatment) above these structures would help decrease the amount of sediment transported post-fire but would not prevent all sediment movement. After a fire, consideration should be given to sedimentation basins and/or check structures above the pipeline and the inlet ditch to help lessen the sediment moving into the structures.

The Main Elk Creek floodplain narrows as water flows from north to south. Consequently, arable and developable land in the southern watershed is largely limited to the floodplain itself, which explains why nearly two-thirds of water rights-related VARs in the southern watershed exhibit heightened susceptibility to debris flow and sediment transport and sit within the fluvial hazard zone as is necessary to maintain the ability to divert water. This includes 13 ditches, seven wells, and three pipelines. A full list of susceptible water rights structures can be found in the accompanying documentation. Any restoration of floodplain connectivity or burn severity mitigation (such as prescribed burning or chemical/mechanical treatment) may help to reduce the peak post-fire flood flow. However, with the narrower floodplain in the southern portion of this area, this susceptibility cannot be entirely mitigated with this pre-fire work. Post-fire mitigation, such as debris racks, head gate armoring, and construction of protective berms, should be considered in the event of a fire.

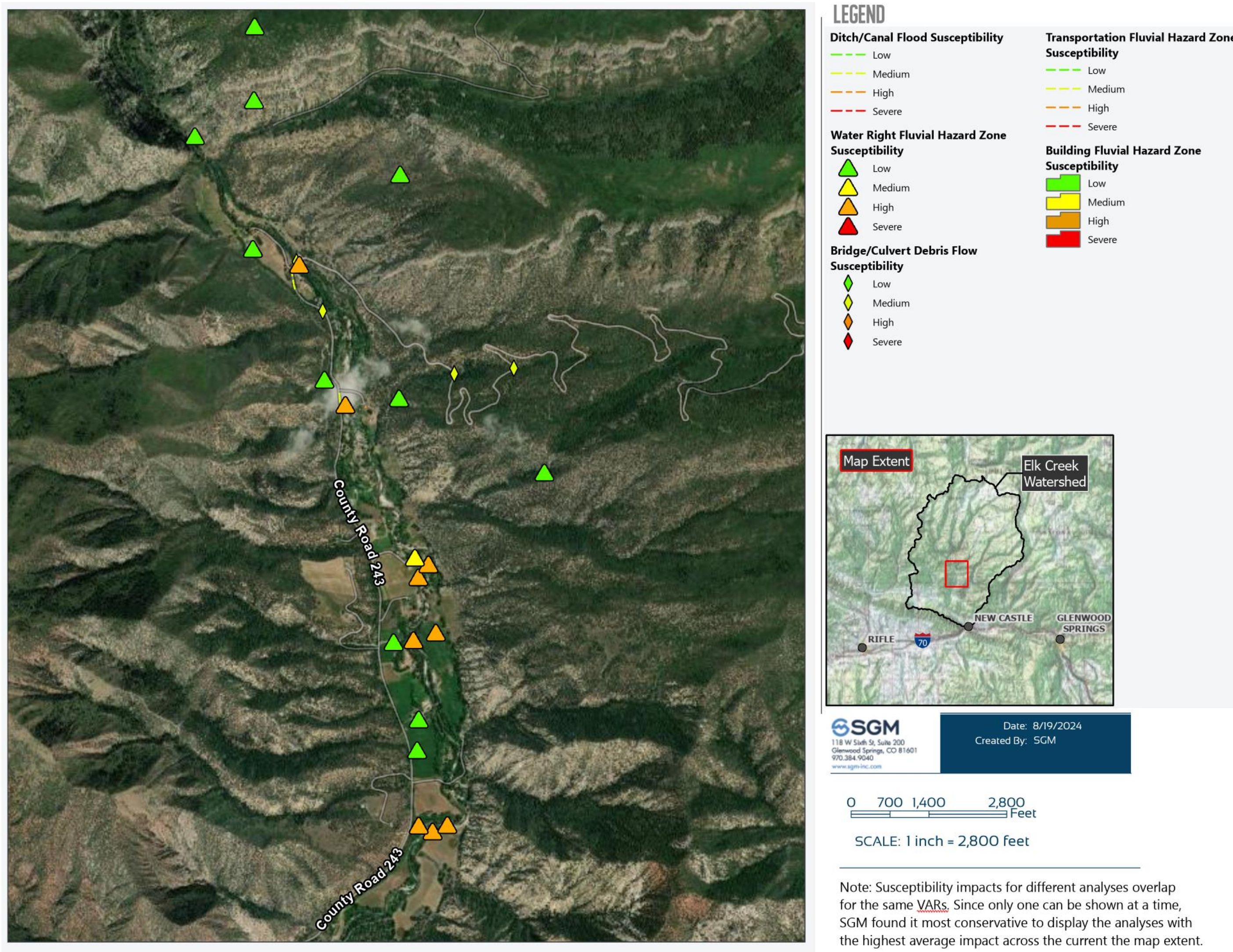


*Figure 9-3. Susceptible VARs in the southern Main Elk watershed*

There are 19 crossings of roadways and waterways in this section of the watershed. The vast majority are slightly or moderately susceptible to hydrologic change (higher peak flow volumes), especially the bridges across West Elk Creek at the start of CR 243, the bridge across Elk Creek on CR 245 just east of the intersection with CR 243, and the bridge across Main Elk on a private road intersecting with CR 245 at approximately 2.40 miles above the intersection. All of these bridges are within the fluvial hazard zone. These bridges should be evaluated and reinforced, if necessary, to ensure structural integrity amid increased flow volume and increased likelihood of debris flow. The remaining crossings are mostly culverts and are slightly to moderately susceptible to increased flow volume. Some of these are also moderately susceptible to debris flow hazard. These culverts should be further analyzed for possible upsizing and the addition of debris racks and sediment prevention to prevent plugging and overtopping of the roadway.

There is a section of CR 243, at approximately 1.6 miles, where approximately a half mile of roadway is within the fluvial hazard zone and is also susceptible to post-fire flooding. This section of the creek should be considered for an armored channel to prevent the creek from moving into the roadway and causing damage—potentially making the roadway impassable.

There are 11 structures susceptible to either flooding or debris flow, or located within the fluvial hazard zone. Of these structures, three are susceptible to flooding, nine are highly susceptible to debris flows, and ten are near or within the fluvial hazard zone. The first line of defense against loss of life will always be flood risk and debris flow communication, deploying a local alert system to provide advance notice of post-fire hazards to property owners and residents. Preemptively addressing stream stability and erosion risks associated with flood and debris flow hazards could also help mitigate risk and prevent loss of life and property. Pre-fire, this could mean employing streambank stabilization strategies, such as bank armoring, at eligible locations where hydraulic impact in high flow is likely to exacerbate erosion of streambanks. In a post-fire mitigation scenario, temporary diversion barriers (e.g., Hesco barriers, sandbags, and k-rails) could serve a similar purpose protecting at-risk properties and neighborhoods from significant flooding and erosion.

### West Elk Creek

West Elk Creek is the least developed of the three forks of Elk Creek. While the upper part of West Elk Creek has steep slopes on the west side of the creek, the rest of the area has lower slope angles and irrigated fields in the valley bottom. County Rd 245 (Buford Road) runs up West Elk Creek, while County Rd 226 runs to the west with County Rd 247 connecting 245 and 226. County Rd 245 continues as Buford Road when the road passes onto USFS lands. A few homes are found near the creek along the length of West Elk Creek.

Pre-fire mitigation is discussed for each section of the creek below. As the post-fire mitigation for all of the following areas is similar, the following mitigation efforts could be beneficial for all of the following susceptible VARs:

- Bridges/Culverts
  - Consider upsizing for increased post-fire peak flow conditions
  - Post-fire armor crossings to prevent scour and damage related to fluvial hazard
  - Post-fire, install debris racks where appropriate to prevent clogging of structures
- Water Rights Headgates
  - Armor headgates to prevent erosion around structures
  - Install debris racks to prevent damage from large debris entering or clogging headgates
  - Consider berms to protect ditch structures during flood events for sections of ditch near the waterway
  - When sediment transport is identified as the susceptibility, consider upstream check structures to create pooling in the creek and encourage settling of suspended sediment before water enters the headgate
- Structures
  - Consider berm construction or sandbag walls to protect structure from flooding
  - An advance warning system is most crucial when structures are at risk to prevent loss of life

## Upper West Elk Creek

West Elk Reservoir sits in the upper reach of West Elk Creek. There are limited susceptible VARs in this area, however the reservoir is highly susceptible to increased sediment transport (see **Figure 9-4**) and moderately susceptible to increased peak flow. The headgates in this area are susceptible to increased sediment loading and have some susceptibility to debris flow. As the headgates are located within the fluvial hazard zone (as is necessary to be able to divert water), these water rights are susceptible to fluvial change. There is a structure which could be at risk for debris flow and flooding. The culverts/bridges in this area are also identified as susceptible to debris flow and sediment as well as a moderate to high susceptibility to increased peak flows. The valley bottom is very narrow in this area, which limits potential stream restoration, however some projects to restore flood plain connectivity could be useful in the areas with wider meadows.

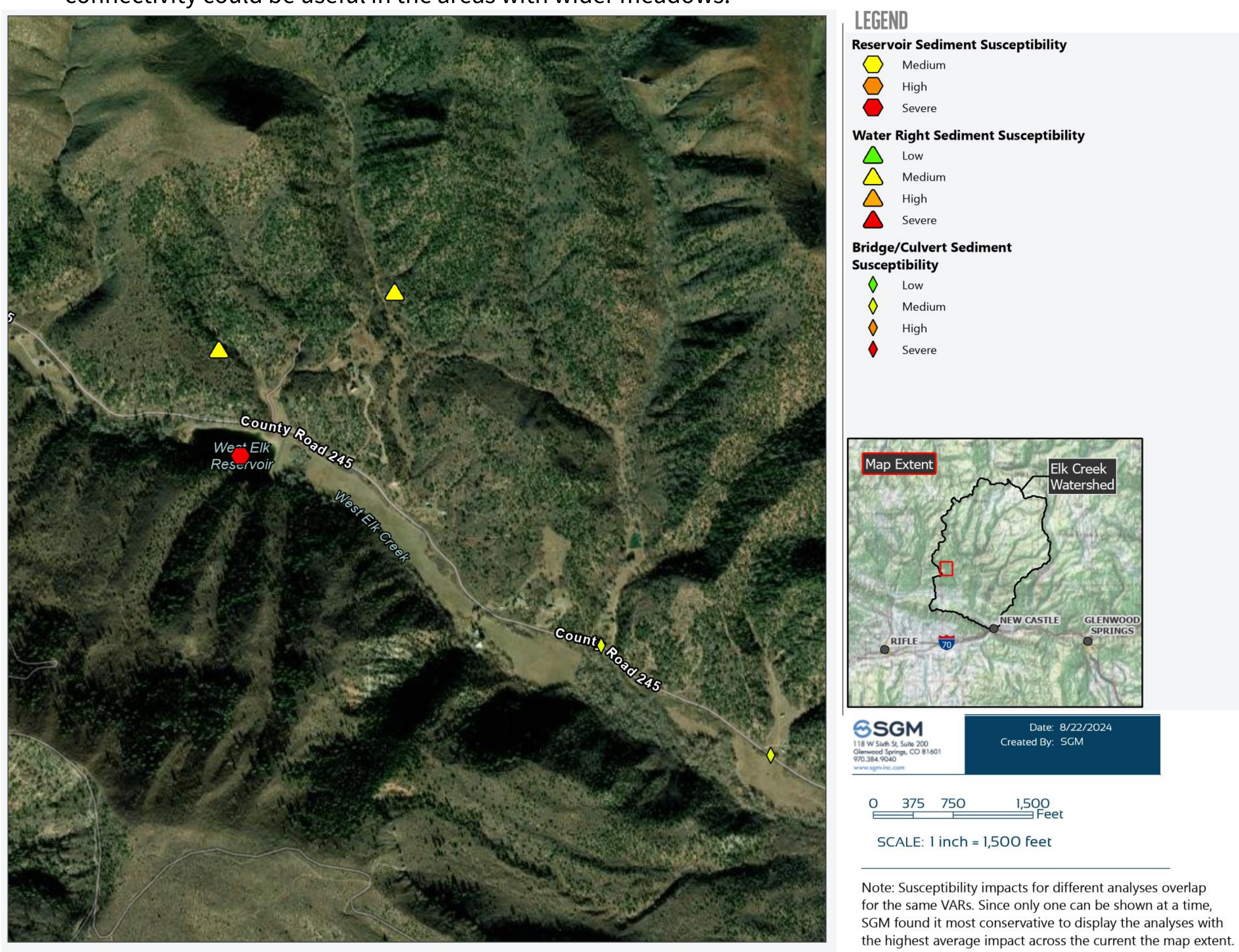


*Figure 9-4. West Elk Reservoir and nearby VARs*

## Middle West Elk Creek

The culverts and bridges in the middle section of West Elk Creek will be highly susceptible to hydrologic changes and moderately susceptible to debris flow. All the bridges and culverts should be considered for upsizing and armoring, especially the culverts located 0.2 and 1.7 miles past the intersection with County Rd 247 on County Rd 245. As indicated in the mapping, these culverts are highly susceptible to increased peak flows from the north and east sides of the road. There is also a bridge or culvert over County Rd 247 which is highly susceptible to hydrologic changes, and a culvert just east of that bridge with moderate susceptibility to the same hazard.

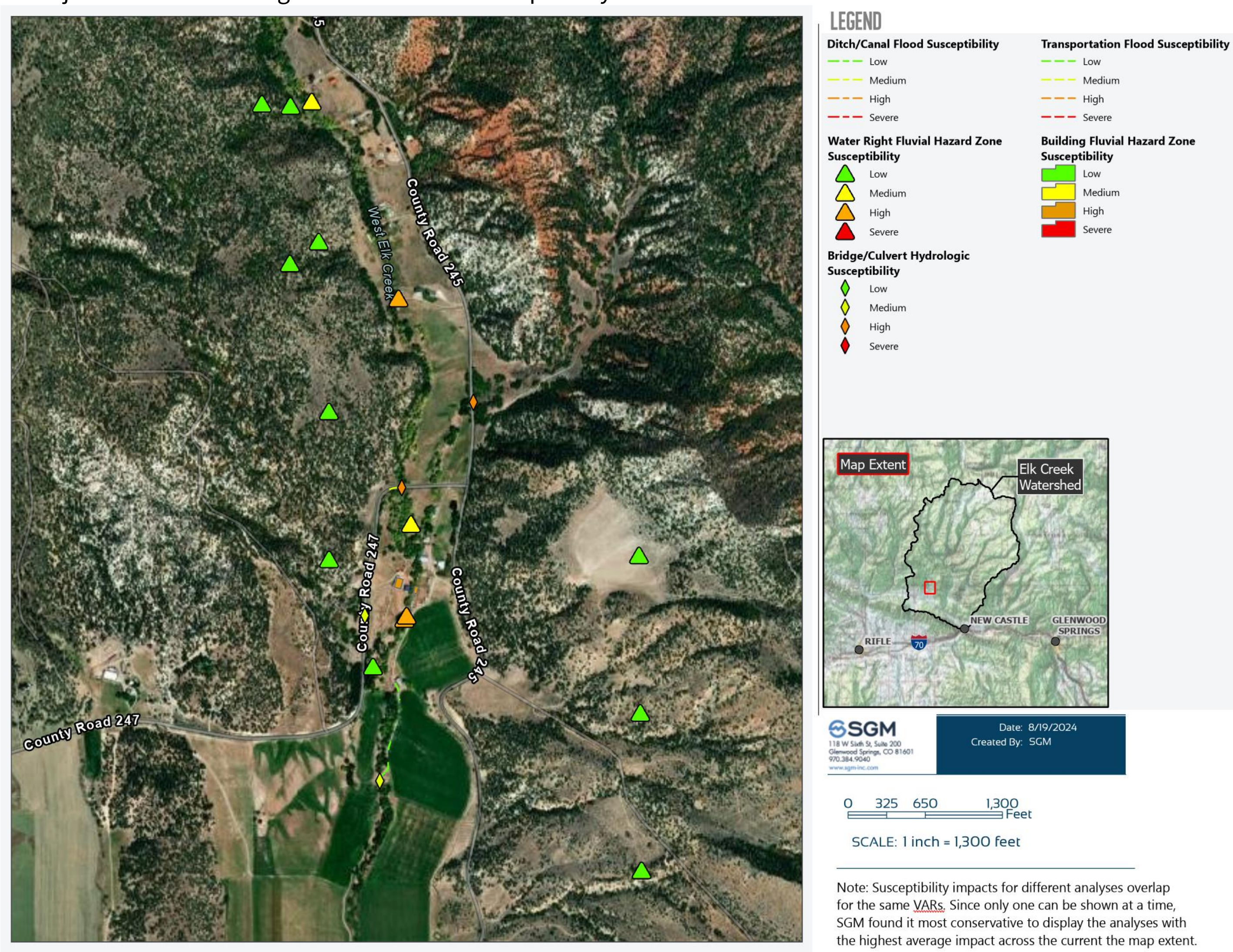


*Figure 9-5. Susceptible VARs near the intersection of County Roads 245 and 247*

There is one structure at risk for flooding identified in this section of West Elk Creek as a susceptible VAR in this area. The structure is near the intersection of County Roads 245 and 247, as shown in **Figure 9-5**. In a pre-fire environment, this structure would also benefit from the stream restoration efforts discussed with the bridges and culverts, as well as pre-fire mitigation in the form of prescribed burns or chemical or mechanical treatment.

### Lower West Elk Creek

At the beginning of County Rd 245, the road crosses West Elk Creek (**Figure 9-6**). Post-fire, this bridge or culvert could be susceptible to an increased peak flow. In the mapping, approximately 270 feet of the roadway are within the fluvial hazard zone, meaning the location of flow in the creek could move within this section of road and impact the roadway. Just below the road, two water rights diversions are also highly susceptible to fluvial hazard and moderately susceptible to increased sediment and debris flows within East Elk Creek. In pre-fire conditions, this channelized section of the creek could benefit from an upstream floodplain reconnection project. This could help slow floodwaters and help sediment settle before water in the creek reaches this location.


*Figure 9-6. County Rd 245 susceptible bridge/crossing over West Elk Creek*

The valley upstream of this bridge/crossing would be a good candidate for stream restoration projects. Burn severity mitigation, as discussed for the upper sections of West Elk Creek, would also serve to improve issues in this area. This could be in the form of prescribed burns or chemical or mechanical treatment.

In a post-fire environment, the bridge/culvert would benefit from armoring near the structure, and upstream, as protection from scouring and channel movement.

## Town of New Castle

The majority of VARs in the Town of New Castle are predominantly found on the east side of West Elk Creek within 0.5 miles of the creek's confluence with the Colorado River. Several buildings in this area are susceptible to post-fire flooding and debris flow hazard, including Elk Creek Elementary School and the nearby footbridge that crosses West Elk Creek to Rollie Gordon Park. Also at risk are 15 residences in the Shady Court Mobile Home Park (MHP), nine residences on Wheeler Ln., seven residences on N 7th St due north of Caywood Ct., and four residences on Shewana Ln (**Figure 9-7**). Of these, four residences in the MHP, four residences on Wheeler Ln., one residence on N 7th St., and two residences on Shewana Ln. exhibit moderate to high susceptibility to flooding.

As mentioned previously, the first line of defense against loss of life will always be flood risk communication and employment of a local alert system to provide advanced notice of post-fire hazards to property owners and residents. Preemptively addressing stream stability and erosion risks associated with flood and debris flow hazards could also help mitigate risk and prevent loss of life and property. This could mean employing pre-fire streambank stabilization strategies, such as bank armoring, at eligible locations where hydraulic impact in high flow is likely to exacerbate erosion of streambanks. In a post-fire mitigation scenario, temporary diversion barriers (e.g., Hesco barriers, sandbags, and k-rails) could serve a similar purpose to protect at-risk properties and neighborhoods from significant flooding and erosion.

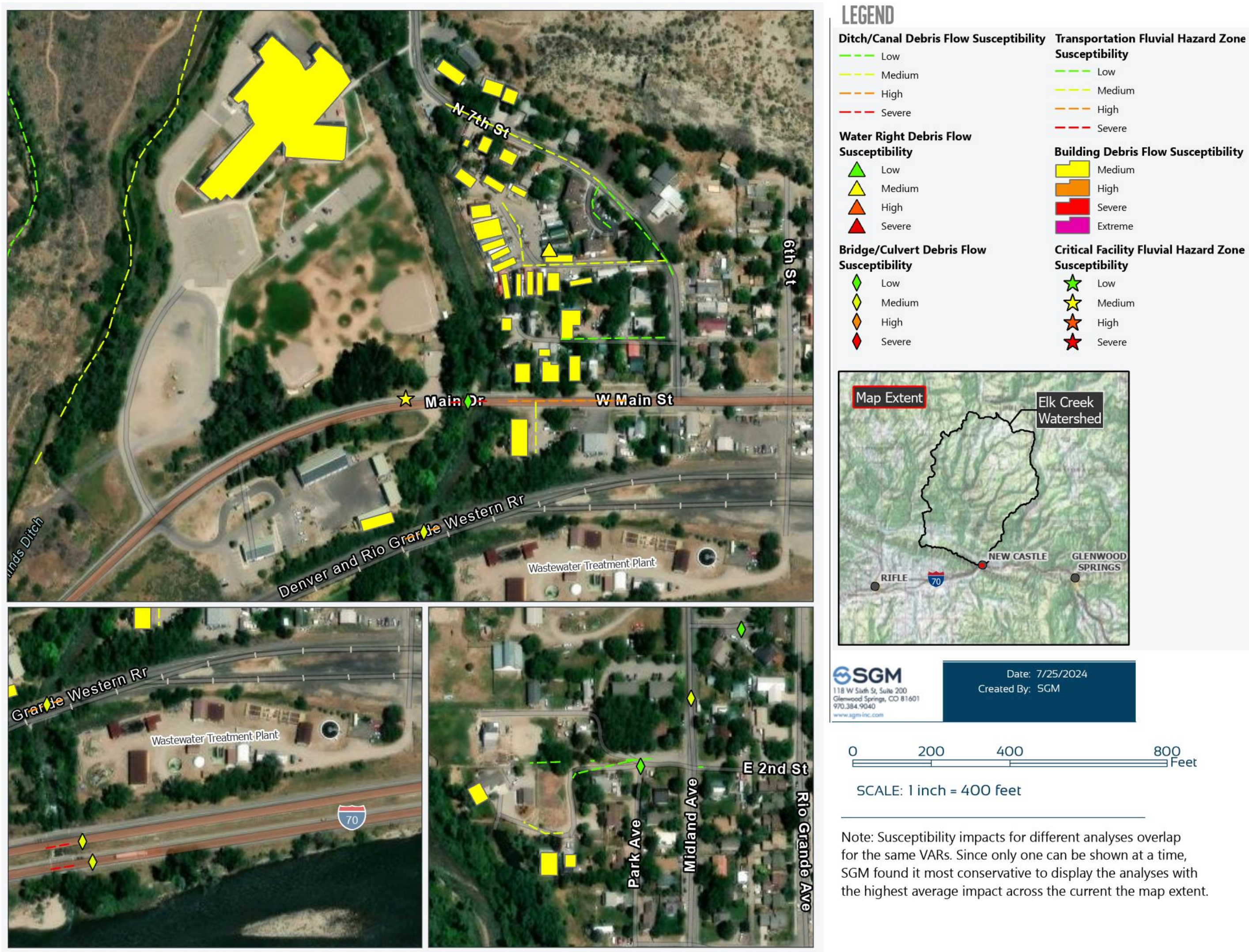


*Figure 9-7. Overview of VARs in Town of New Castle Municipal Boundary. Note that impact score map symbology is intended only as a visual aid to identify some of the VARs highlighted in the study. Refer to source material for an accurate account of VAR impact scoring.*

Post-fire risks to water infrastructure include increases in sediment yield and moderate increases in debris flow susceptibility. Specifically, the southmost 0.8 miles of the Ware and Hinds Ditch and the southmost 1.5 miles of the Tompkins Ditch (see **Figure 9-8**), as well as approximately 0.8 miles of the ditch parallel to Colorow Trail extending west from the retention pond near Silverhorn Dr., are at risk. Importantly, the Ware and Hinds Ditch point of diversion from West Elk Creek is highly susceptible to flooding.

Mitigation strategies would best be focused on reducing damage to ditch, canal, and pipeline infrastructure. Buried pipeline failure due to mass earth movement can be reduced by erecting structures to redirect or slow debris flows, such as built channels, check dams, and debris and rock nets. Ditch bank erosion can be reduced via stabilization with rock revetments and riprap, and channel bottoms can be hardened to reduce scour. Additionally, armoring the headgate and advance notice from a local alert system would allow for pipelines to be physically separated from West Elk Creek before debris flows and periods of high sediment transport.

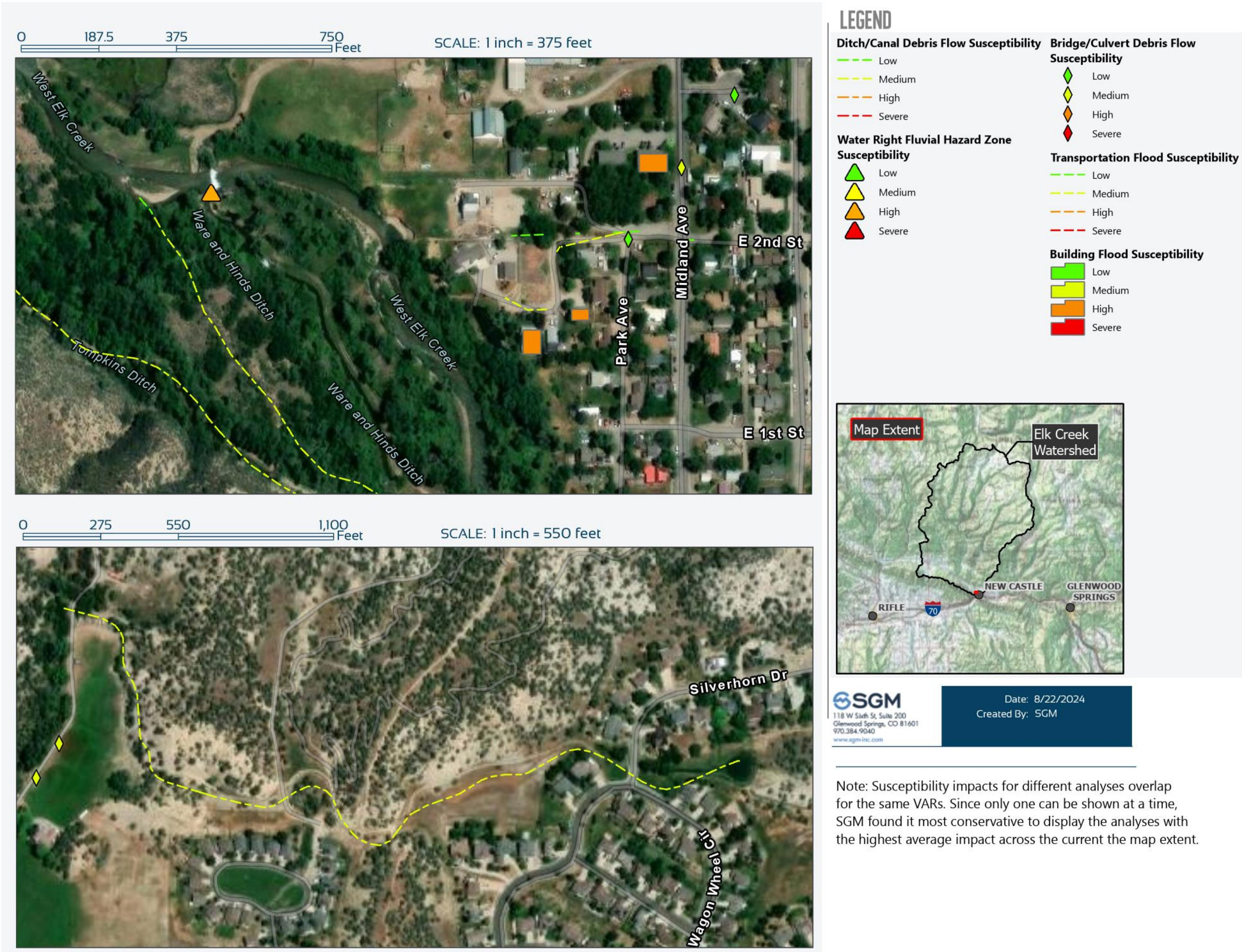


*Figure 9-8. Top Map: Ware and Hinds Ditch with diversion point (orange) and Tompkins Ditch. Lower Map: Ditch parallel to Colorow Trail*

In addition, several wells – namely, Vix Well No. 1 near Alder Park walking path, Vix Well No. 2 on Kathryn Senor Elementary School grounds, and Senor Well in Shady Court MHP – are moderately susceptible to both debris flow and sediment yield. Debris flows can damage well casings and allow for infiltration of floodwater, debris, and sediment into a well, causing possible damage to well infrastructure and contamination of well water. Pre-fire mitigation includes regular maintenance of the well, ensuring that the well cap is securely sealed and in good condition, and improving surface and subsurface drainage around the well to prevent contaminant infiltration. Wells can also be reinforced and protected with semi-permanent or temporary protective structures, such as Hesco barriers, sandbags, or k-rails, and by creating diversion channels to redirect floodwater and debris away from the well cap. In addition to routine, annual well maintenance and testing, well owners should contact a professional contractor to evaluate whether the well was damaged or contaminated immediately following a post-fire flood or debris flow event.

Further south, the I-70 eastbound and westbound bridges, the Denver and Rio Grande Western Railroad bridge, and the W. Main St. bridge—all of which cross Elk Creek—are highly to severely susceptible to post-fire flooding and moderately susceptible to debris flow hazard. Moreover, all four bridges are within the fluvial hazard zone, and the I-70 eastbound and westbound bridges and the W. Main St. bridge are within the active stream corridor. Increases in sediment transport and hydrologic changes are also anticipated in these areas.

The Elk Creek channel is relatively wide as it passes through the Town of New Castle municipal boundary to converge with the Colorado River. As well, large boulders and rock make up much of the existing streambed, suggesting that channel incising and streambed degradation will pose a lesser concern to streambank erosion in high flow, post-fire flood conditions. That said, existing infrastructure should be evaluated and reinforced, if necessary, to ensure structural integrity amid increased flow volume and debris flow impact.

While it was not included in the VAR analysis, as the majority of the facility sits just outside the Elk Creek watershed, the Town of New Castle's Wastewater Treatment Plant is sufficiently close to Elk Creek to warrant the facility's consideration as critical infrastructure that is potentially at risk of flooding, debris flow, hydrologic changes, and sediment transport (**see Figure 9-9**). The flood after fire hazard analysis showed that the treatment plant may be susceptible to increased flooding risks for 5-year and greater storm events.

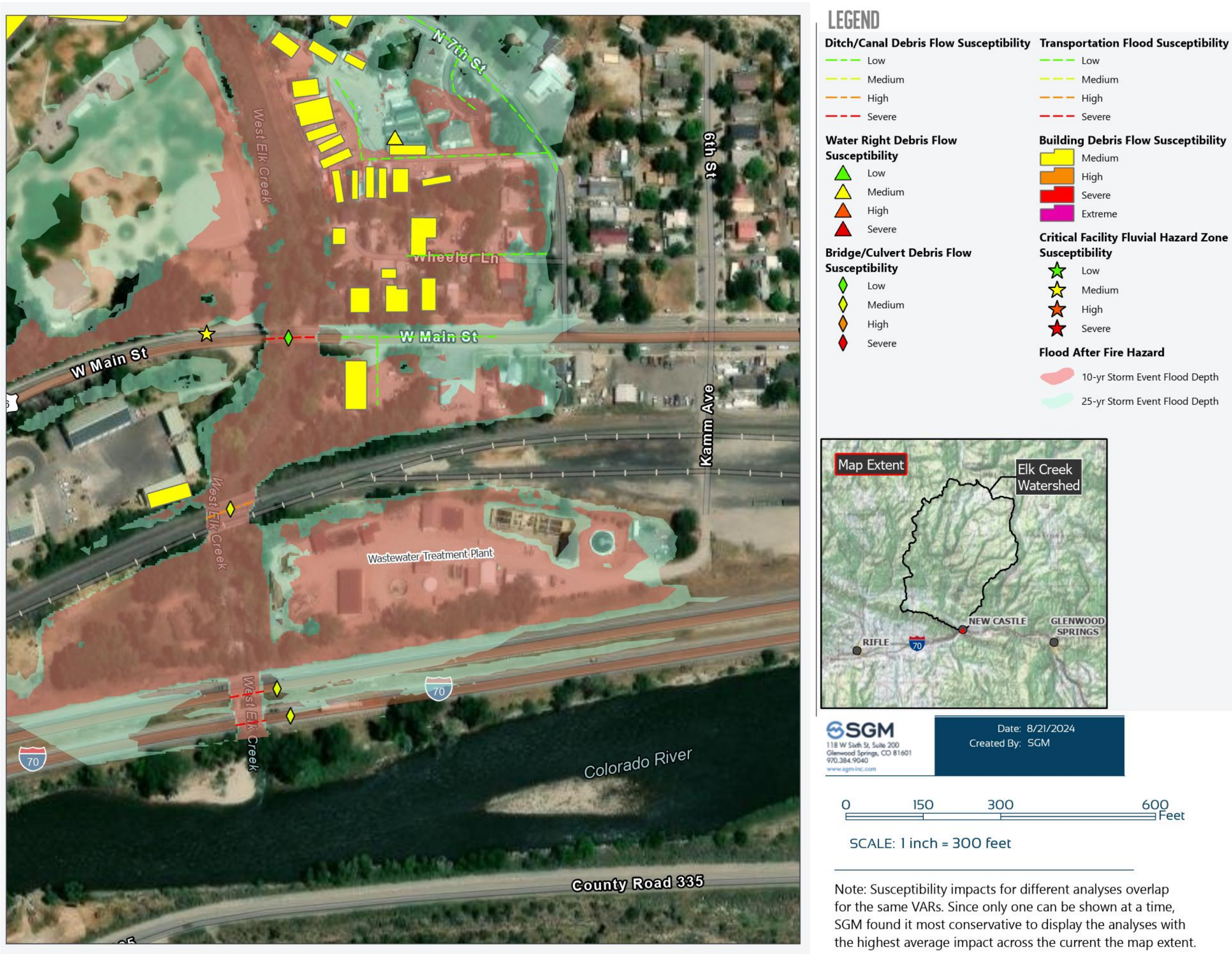


*Figure 9-9. Town of New Castle Wastewater Treatment Plant*

Hazards presented to the Town of New Castle's Wastewater Treatment Plant by post-fire flooding and debris flow would most likely manifest as hillslope erosion on its western property boundary and, in a worst-case scenario, flood water and debris inundation of plant infrastructure. Hillslope erosion could be mitigated via bank armoring and other streambank stabilization methods, as well as through the erection of temporary flood boundaries as mentioned earlier in this section. However, precautions should be taken to account for post-fire changes in runoff yield and timing with respect to everyday treatment operations and function. If unprepared, excess precipitation runoff and flooding associated with post-fire conditions could necessitate an emergency bypass/release of wastewater to the environment. Leaky manholes, open connections, and cracked collection pipes elsewhere in the system can allow runoff to infiltrate and inundate treatment infrastructure (see source from Minnesota Pollution Control Agency). Preemptive action to establish and/or maintain a redundant power source (i.e. emergency generators), regular inspection and lift pumps servicing , a supply of spare parts in the event of pump failure, and routine collection system maintenance can reduce strain on the plant and decrease the likelihood of emergency bypass/release during a post-fire flood or flash runoff event.

Road infrastructure and transportation crossings in several areas in town were found to exhibit vulnerability to risks posed by flooding, hydrologic changes, and moderately susceptible to increased sediment transport (**Figure 9-10).** These include:

- Intersection of Park Avenue and W. 2nd Street
- Aster Court cul-de-sac
- Intersection of Alder Avenue and Castle Valley Boulevard
- Alder Avenue between Castle Valley Boulevard and Ginseng Rd.
- Intersection of Alder Avenue and Ginseng Rd.


*Figure 9-10. Roadways in Town of New Castle susceptible to post-fire hazards*

In addition to being susceptible to hydrologic change and sediment transport, the following transportation crossings were identified as being at heightened (moderate) risk of debris flow (**Figure 9-11):**

- Midland Avenue due north of 2nd Street intersection
- 245th Rd. due north of Hidden Valley Rd.
- CR 245 between Cedar Way and Hidden Valley Rd.

- Private drive on west side of CR 245 across from Hidden Valley Rd.

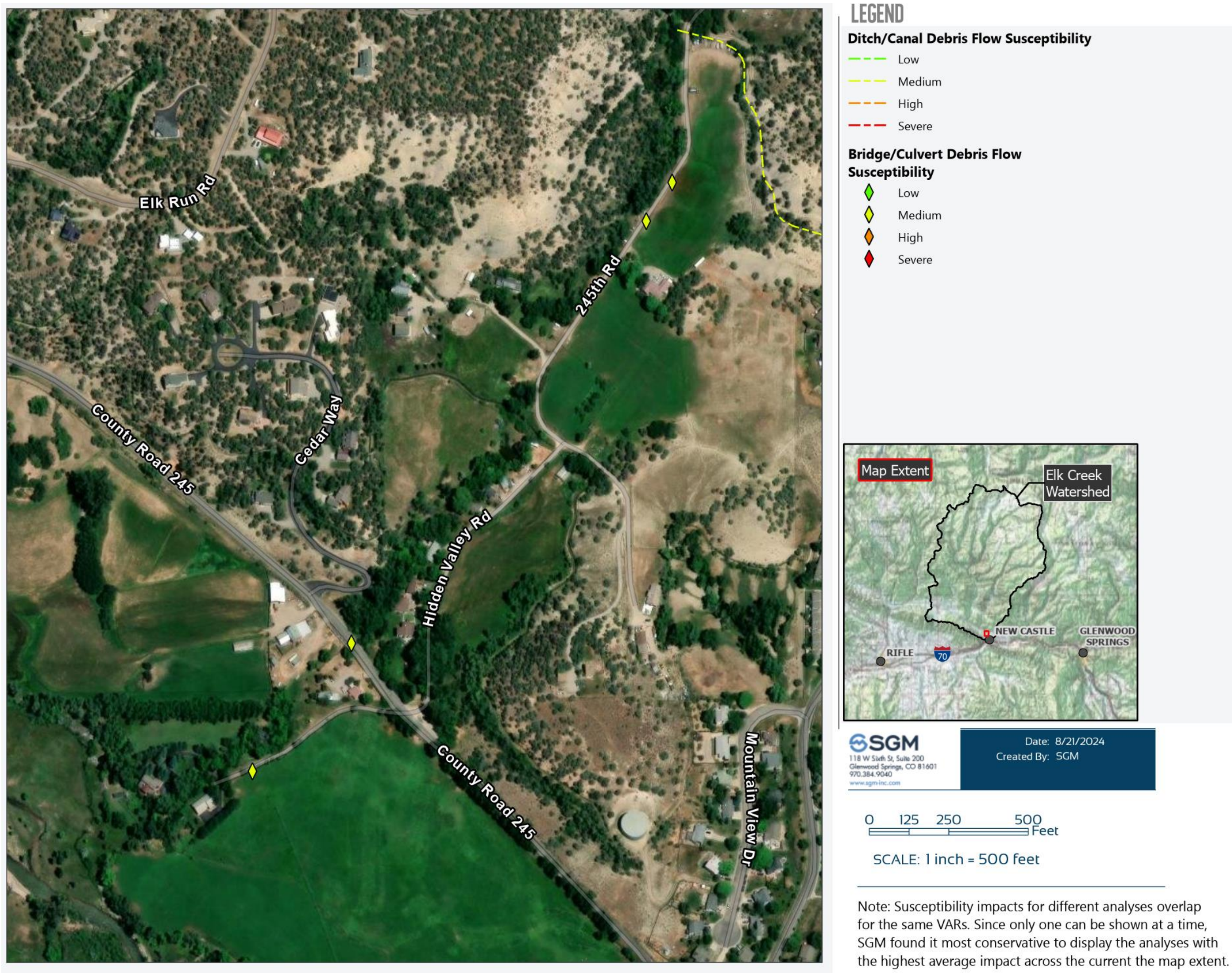


*Figure 9-11. Roadways due north of Town of New Castle susceptible to post-fire hazards*

In comparison to most other VARs in the Town of New Castle, these transportation crossings are relatively distant from West Elk Creek and are not in the creek's floodplain, though these crossings would be in the direct path of post-fire hazards originating from a burn scar in the watershed immediately east of the East Elk Creek watershed. As such, mitigation strategies that would be effective in the immediate floodplain can be employed in these areas and further uphill in the at-risk watershed with similar results. Hydrologic change and erosion caused by heightened post-fire runoff or debris flows can be mitigated through slope stabilization efforts and surface hardening in areas especially vulnerable to avulsion or erosion. Rock revetments, check dams, debris catch basins, and debris redirection channelization of the at-risk watershed uphill of these VARs would be viable pre-fire mitigation efforts. After a wildfire event, hydromulching and rapid revegetation of the affected burn area should be enacted as soon as is feasible. Resultant debris flows could be redirected with diversion barriers—permanent and/or temporary—placed strategically to prioritize damage prevention of highly trafficked roadways and emergency evacuation routes. Community outreach efforts should be taken in tandem with these physical mitigation efforts, with explicit emphasis on pre-fire employment of an emergency alert service, dissemination of post-fire hazard information to the community, and development of an emergency evacuation plan for at-risk residents.

## 9.2. Rifle Creek Watershed

The Rifle Creek watershed covers the area from the City of Rifle to the north of the Colorado River following Rifle and Government Creek drainages. This narrative has broken the areas of focus into the following areas: the City of Rifle, East Rifle Creek, Middle Rifle Creek, West Rifle Creek, Government Creek (along Highway 13).

### City of Rifle

Within the City of Rifle (shown in **Figure 9-12**), the convergence of two creeks and one seasonal gulch occurs before Rifle Creek flows into the Colorado River. The confluence of Government and Rifle Creeks is near 18th Street on the north end of the City, while Hubbard Gulch converges with Rifle Creek just south of Garfield County Fairgrounds. While portions of Rifle north of the Colorado River are situated on mesas, a large swath of Rifle is fairly flat and situated along the banks of Rifle Creek as it flows through the city.

The low-lying areas lead to the higher chance of increased flooding in a post-fire environment. The most susceptible areas are those near Rifle and Government Creeks. These are highlighted in **Figure 9-12** and can also be found in the online StoryMap. There are multiple buildings and areas along Railroad Avenue. Post-fire, performing the flood hazard analysis for this area using a more specific burn area will be beneficial to understand the real susceptibility to flooding in this area.

One key strategy to reduce flooding in a post-fire environment would include increasing the floodplain connectivity upstream of the City of Rifle. “Restoring or enhancing the existing floodplain connection and vegetation can improve flood conveyance, reduce energy within the system, trap sediments, and reduce impacts to downstream residents, infrastructure, and water users.” Prime candidates for this connectivity work are on private land between Rifle Gap Reservoir and the City of Rifle. These lands have Rifle Creek meandering through a relatively flat topography down to Taughenbaugh Field.

In general, crossings near and along Rifle and Government Creek should be considered for upsizing. This study did not specifically consider the size of all crossings and their impact on potential flooding, however key crossings such as Highway 6 across Rifle Creek and the crossings of White River and 16th Street over Rifle Creek should be analyzed to ensure these will convey enough flood water to prevent flooding upstream of the roadways. Post-fire, these crossings should also be considered for installation of debris racks to prevent flooding exacerbated by plugging.

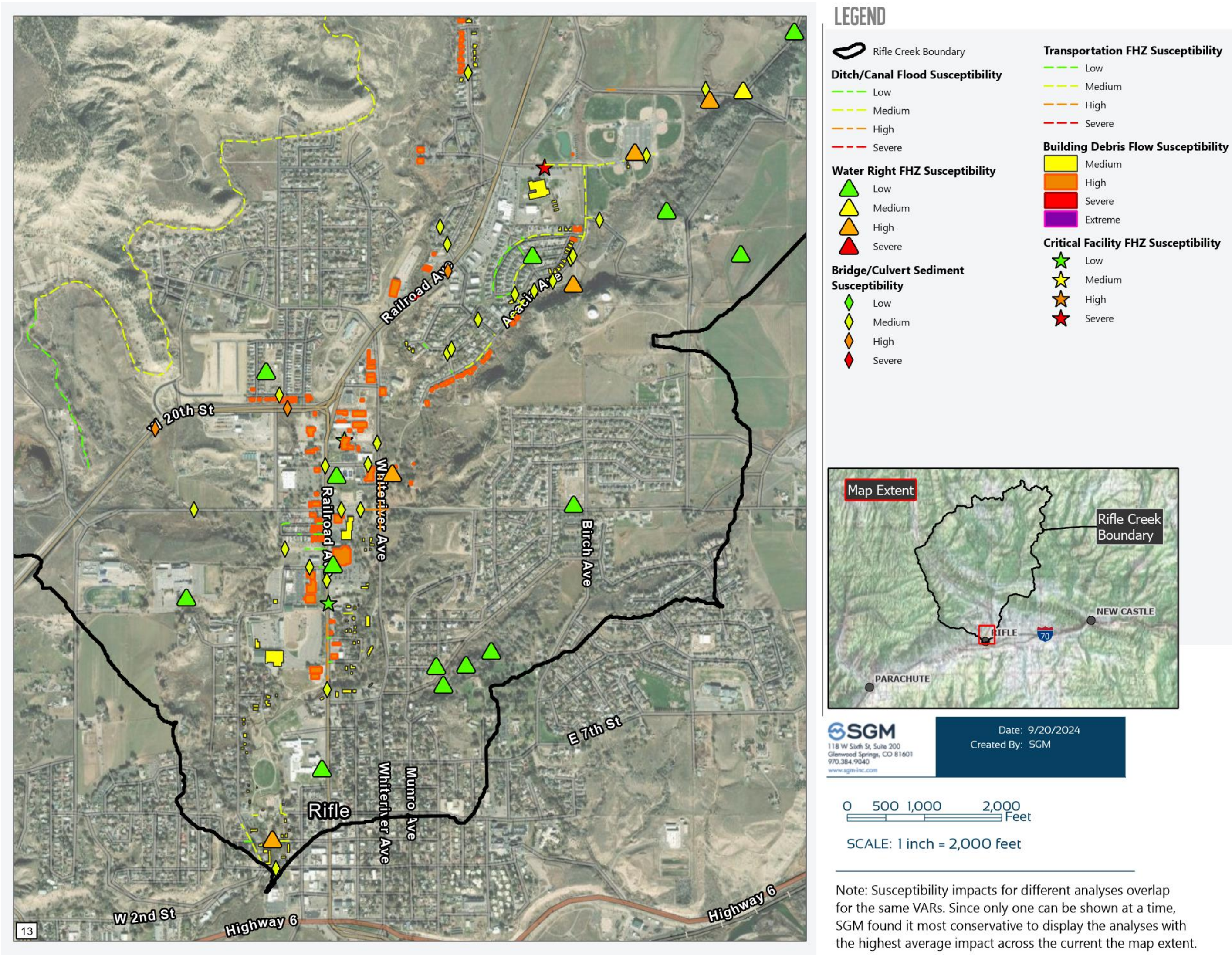


*Figure 9-12. Susceptible VARs in the City of Rifle and nearby areas*

## East Rifle Creek

Rifle Falls State Park, a well-known landmark, is located on East Rifle Creek. The East Rifle Creek watershed is characterized by narrow valley bottoms above the state park and slightly wider valley bottoms below the park.

### Above Rifle Falls State Park

There are multiple crossings and water rights above the state park with susceptibility to post-fire hazards, as shown in **Figure 9-13**. This may be an area which will benefit from pre-fire burn severity mitigation in the areas where this is feasible. This will help lessen the flooding and debris flow hazard downstream on East Rifle Creek.

Many sections of County Rd. 217 are moderately susceptible to floods after fire and fluvial hazard, with low susceptibility to debris flow. With the extremely narrow valley bottom in this area, the most important mitigation in this area will be communication to people in the area to avoid travel on the roadways during storm events. Pre-fire planning should include planned installation of rain gauges and planning of a warning system and signage in the event of a fire. After a fire, creek armoring to prevent movement into the roadway and perhaps increasing the conveyance of the creek may be beneficial in these areas.

In this area of the watershed there are many identified crossings, which may or may not have existing bridges or culverts due to the many small drainages. The crossings have low susceptibility to hydrologic changes (increased peak flows), high susceptibility to debris flows along East Rifle Creek and moderate susceptibility to Huffman Gulch, and moderate susceptibility to sediment transport. Post-fire, debris racks and sediment capture methods will help maintain these culverts and crossings and prevent clogging.

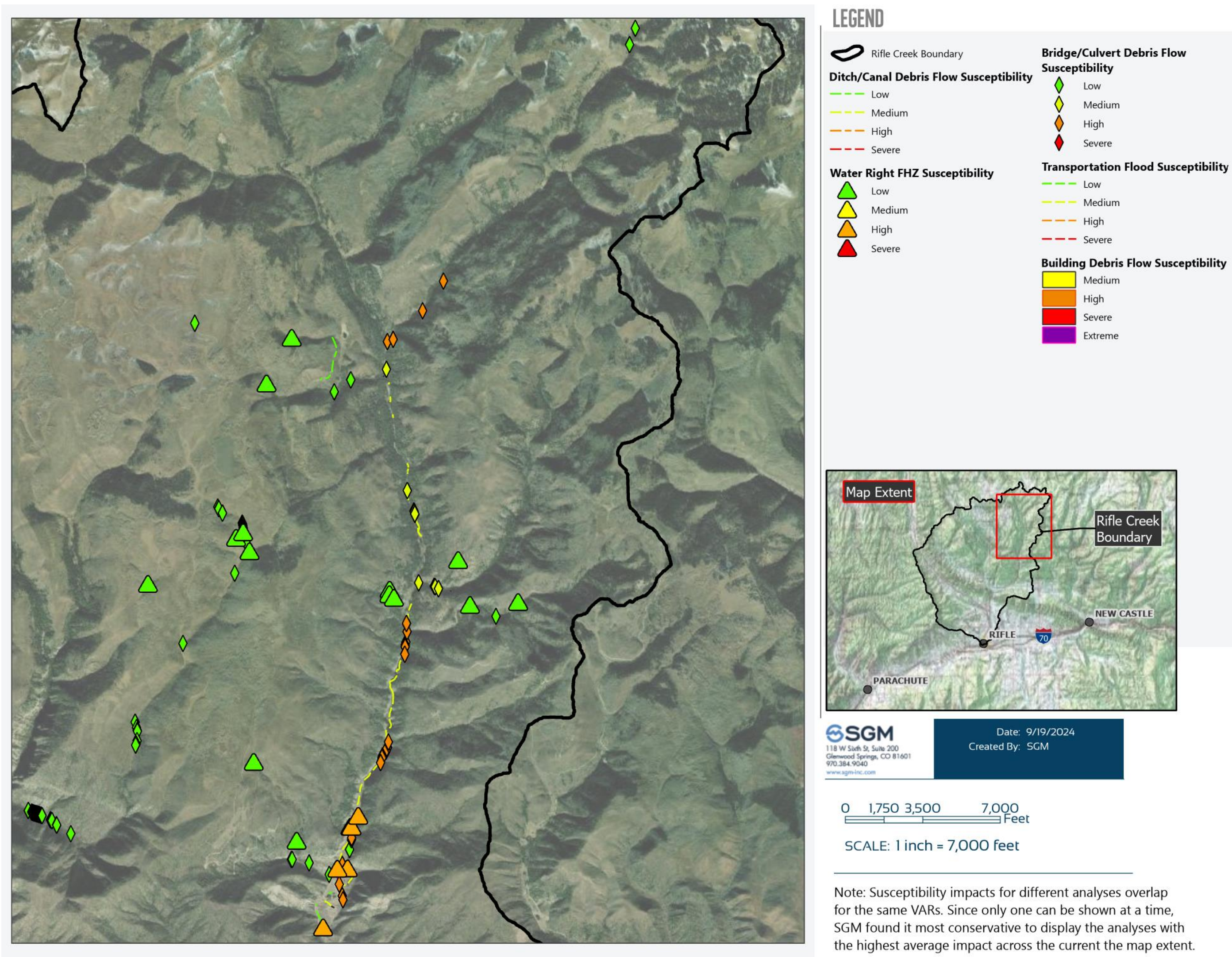


*Figure 9-13. Susceptible VARs along East Rifle Creek Above Rifle Falls State Park*

## Below Rifle Falls State Park

There are multiple buildings at risk in the stream reach below Rifle Falls State Park, as shown in Figure 9-14. This includes the buildings at the fish hatchery, the buildings near Rifle Falls State Park, the campground facilities at the state park, residences below the state park and the residences and associated buildings off County Rd. 226 near the intersection with Highway 325. Many of these residences are highly and moderately susceptible to fluvial hazard, and moderately to extremely susceptible to debris flow hazard. A small number of these buildings are susceptible to flood after fire. As with the area above the state park, protection of human life should be of utmost importance after a fire and in a pre-fire environment.

Protection of these structures will be critical due to the extreme susceptibility and the steep and narrow topography in the area. This topography is a driver in the risk levels and prevents the ability to rely on stream restoration, burn severity mitigation, or mulching to significantly decrease the susceptibility of these structures in a post-fire event. The installation of a post-fire warning system will be critical to life safety, and the preemptive closing of facilities during monsoon events should also be considered.

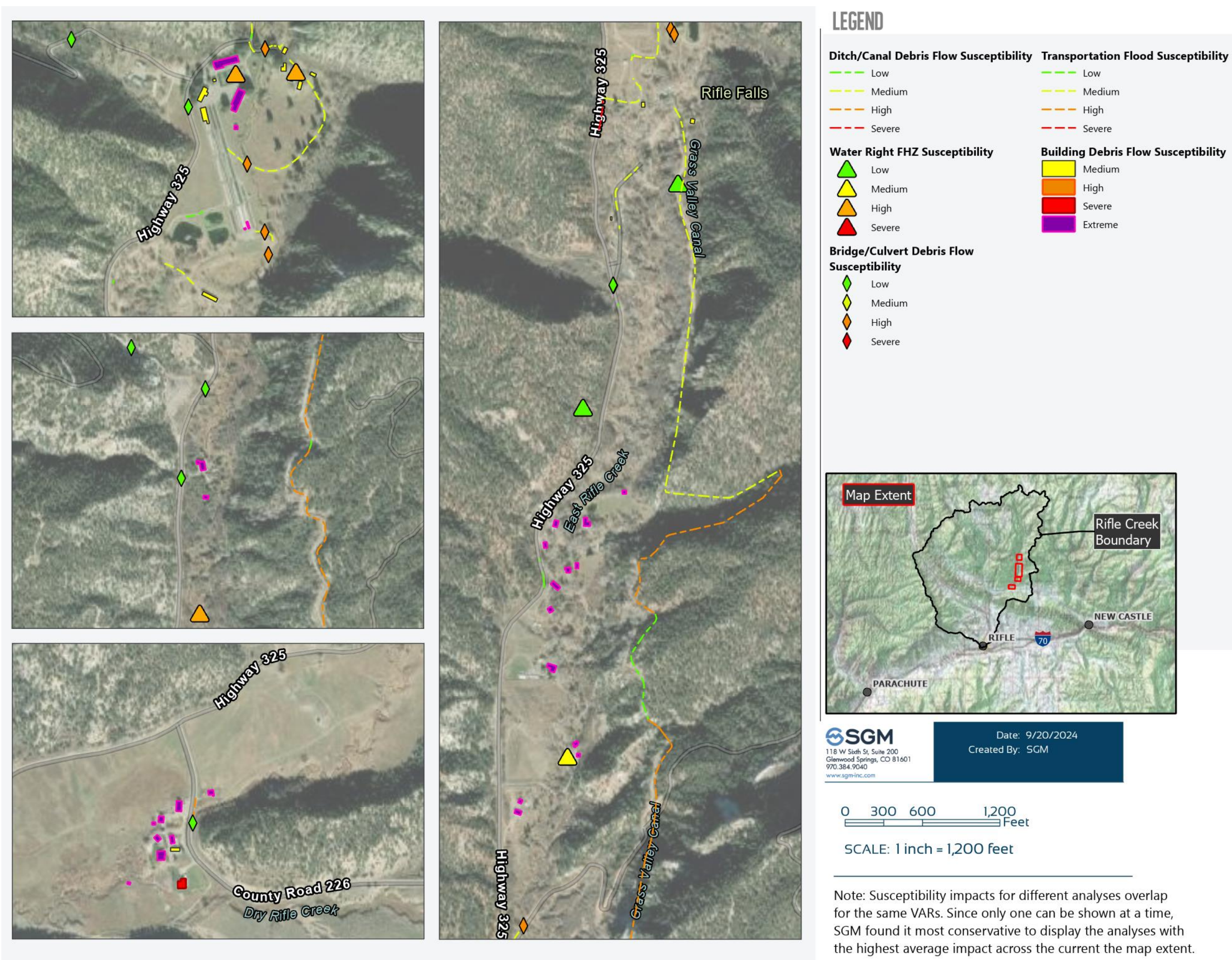


*Figure 9-14. Susceptible VARs along East Rifle Creek Below Rifle Falls State Park*

## West Rifle Creek

West Rifle Creek flows into the west end of Rifle Gap Reservoir. The confluence of West Rifle Creek and Middle Rifle Creek is just upstream. Middle Rifle Creek has a slightly larger watershed and is fed by four smaller creeks (Brush Creek, Middle Rifle Creek, Butler Creek, and Big Parker Creek).

### Upper West Rifle Creek

In the uppermost areas of West Rifle Creek and Harris Gulch, there are several small road crossings (culverts/bridges) with a low susceptibility to debris flow and hydrologic change and moderate susceptibility to sediment transport. Harris Gulch Rd. and County Rd. 252 both have segments that are moderately susceptible to flood after fire, have low susceptibility to debris flow and low/moderate susceptibility to fluvial hazard. These crossings and the roadway are noted in **Figure 9-15**. In pre-fire conditions, this section of the creek could benefit from an upstream floodplain reconnection project. This could help slow floodwater and allow sediment to settle out of the creek before water reaches this area. Burn severity mitigation efforts (prescribed burning and/or chemical and mechanical treatment) would also aid in decreasing the peak flood flows and probability of debris flows. Post-fire, mulching should be considered in a burn area above these VARs, armoring the stream channel along Harris Gulch Rd. and County Rd. 252 in the areas identified, and installing sediment mitigation and debris flow racking for culverts and bridges.

One building, approximately two miles northwest on County Rd 252 after the intersection with Harris Gulch Rd, is highly susceptible to flooding, debris flow and fluvial hazard zone. This building is also noted in **Figure 9-15**. Due to the steep hill slopes west of this building, while pre-fire burn severity mitigation and post-fire mulching could help with the debris flow hazard, the debris flow hazard cannot be fully mitigated. Post-fire, a warning system in the area to warn any occupants of an impending storm event will be crucial to safety. It will also be important to re-run any hazard analysis using actual burn scar data to determine post-fire measures. This building could be protected using berms to redirect debris flows, berms or sandbag walls to prevent flooding, and/or stream channel armoring near and upstream of the building to prevent creek movement from undermining the structural integrity of the building.

Harris Reservoir is noted as susceptible to debris flow. The modeling indicates two drainages to the northeast of the reservoir are capable of debris flow, however it is also possible a debris flow could originate upstream of the reservoir and impact the inflow to the reservoir. Pre-fire, stream restoration upstream of Harris Reservoir may help mitigate this hazard, as well as prescribed burning or mechanical/chemical treatment to the northeast of the reservoir.

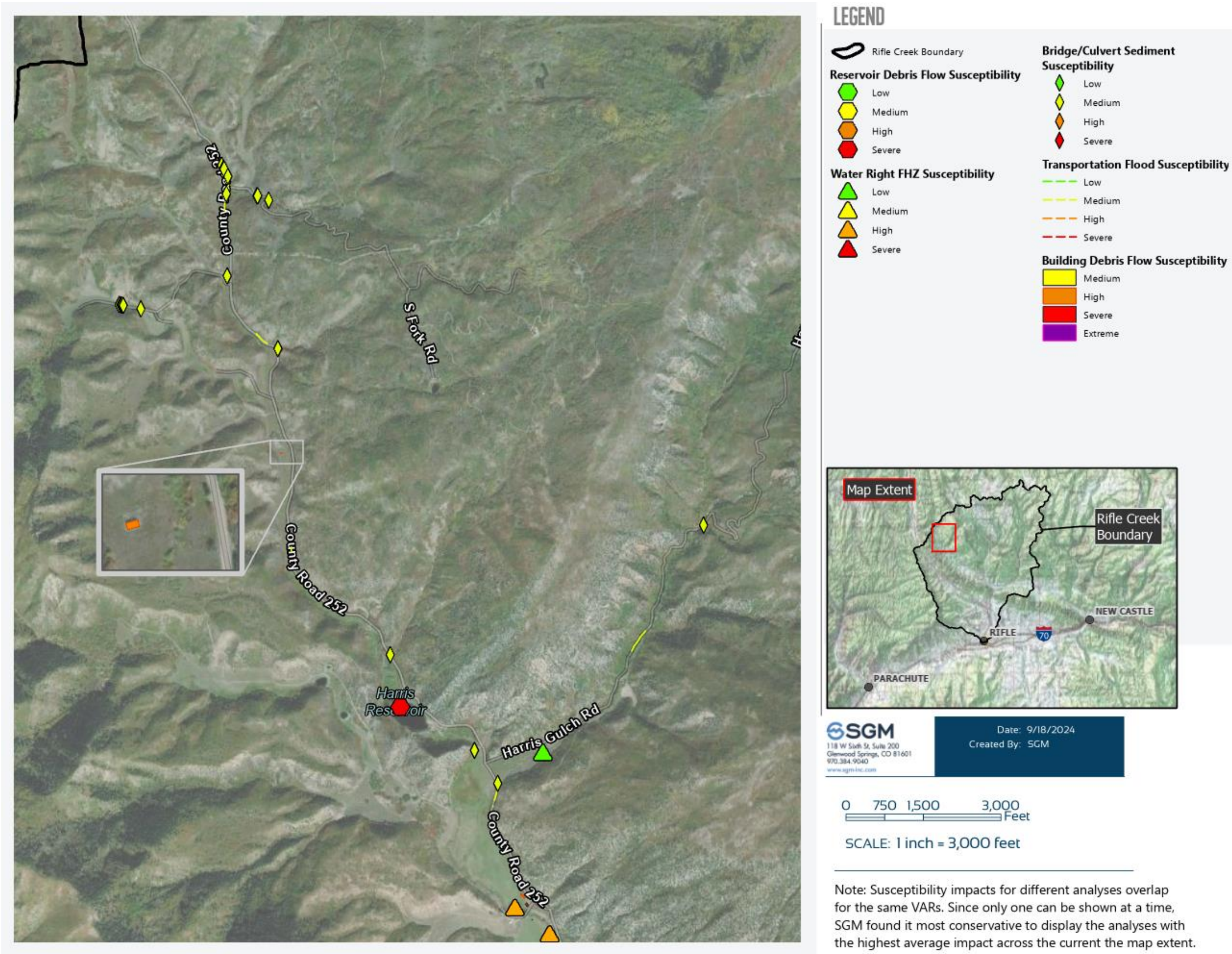


*Figure 9-15. Susceptible VARs along Upper West Rifle Creek*

## Middle West Rifle Creek

Just below the confluence of Harris Gulch and West Rifle Creek is a collection of buildings susceptible to debris flow hazard and one building susceptible to flood after fire, as shown in **Figure 9-16**. There is another building about a mile downstream also susceptible to debris flow. The susceptibility of these buildings could be lessened with pre-fire stream restoration efforts as well as pre-fire mitigation in the form of prescribed burns or chemical or mechanical treatment in the drainages that pose the debris flow hazard. Post-fire, identifying specific debris flow paths will allow for specific protection to be designed for these structures—which will likely be in the form of re-direction berms.

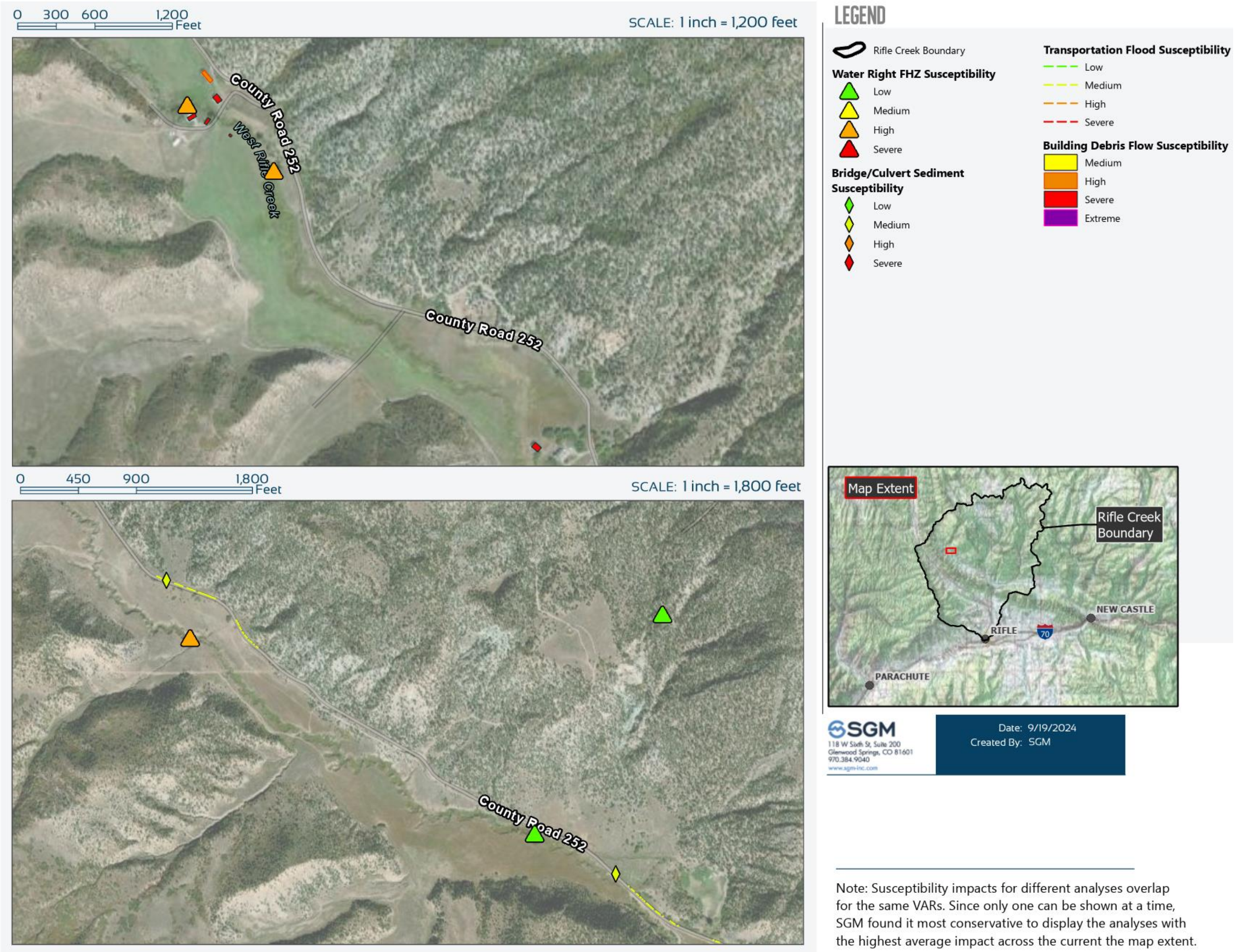


*Figure 9-16. Susceptible VARs along Middle West Rifle Creek*

Multiple water rights in this section of creek are moderately susceptible to debris flow, moderately or highly susceptible to fluvial hazard and also susceptible to sediment transport. All these headgates would benefit from any pre-fire stream restoration and burn severity mitigation to aid in a lower increase in peak flow and lower debris hazard. Post-fire, headgate reinforcement, the addition of debris racks to the headgates, and armoring the stream channel in the vicinity of the structure would help protect these diversion structures from debris flows and fluvial hazard.

Four sections of County Rd. 252 are susceptible to debris flow and moderately susceptible to flood after fire and fluvial hazard. These sections are 480 feet of roadway, 950 feet of roadway, 530 feet of roadway, and 940 feet of roadway located 3.1, 3.3, 4.8 and 5.0 miles, respectively, west of the intersection with County Rd. 219 as noted in **Figure 9-16**.

Four road crossings in this area have been identified as slightly susceptible to increased peak flow and moderately susceptible to sediment transport. Three of these crossings are slightly susceptible to debris with one being moderately susceptible. These crossings are all associated with small drainages on the north side of the road. Burn severity mitigation (prescribed burning and/or chemical and mechanical treatment) could aid in decreasing the peak flood flows from these small drainages and probability of debris flows. Post-fire, mulching should be considered in a burn area above these VARs. Armoring the crossings and installing sediment mitigation and debris flow racking for the crossings will likely be the most effective mitigation strategies for these specific crossings.

### Upper Middle Rifle Creek Watershed

Infrastructure is sparser up Middle Rifle Creek above the confluences of Brush Creek, Butler Creek, and Middle Rifle Creek. However, multiple water rights and road/stream crossings are susceptible in this area. The crossings mostly have low and medium susceptibility to debris flow and sediment and have low susceptibility to increased peak flows. The headgates in the upper areas have low to medium susceptibility to debris flow and a few have low susceptibility to fluvial hazard.

Near the confluences of these creeks and just below, five diversions are moderately susceptible to debris flow hazard, highly susceptible to fluvial hazard, and slightly susceptible to sediment transport. These diversions, shown in **Figure 9-17** would be good candidates for reinforcement and debris racking/screening pre- or post-fire.

The crossings in this area (**Figure 9-17**) range from low and moderate susceptibility to high susceptibility to debris flow for those crossings over Middle Rifle Creek. The susceptibility to hydrologic change is low while the susceptibility to sediment is moderate. In pre-fire conditions, burn severity mitigation efforts (prescribed burning and/or chemical and mechanical treatment) in the head waters would aid in decreasing the peak flood flows and probability of debris flows. Post-fire, mulching should be considered in a burn area above these VARs. Armoring the stream channel along the road and installing sediment mitigation and debris flow racking for culverts and bridges should be considered.

There are three sections of roadway susceptible to post-fire hazards. These include portions of Middle Rifle Creek Rd. and Butler Creek Rd. just above their intersection where each roadway crosses the respective creek, plusa short section approximately 1.8 miles up County Rd. 219. There is moderate susceptibility to flood after fire, low susceptibility to debris flow (with the exception of the County Rd 219 section which is highly susceptible), and moderate susceptibility to fluvial hazard.

Two structures approximately 2.0 miles up County Rd. 219 are extremely susceptible to the debris flow hazard as show in **Figure 9-17**. This topography is, again, a driver in the debris flow and prevents significant risk mitigation with stream restoration, burn severity mitigation, or mulching. There are some areas in the headlands above these structures which could benefit from burn severity mitigation. The installation of a warning system post-fire will be critical to life safety.

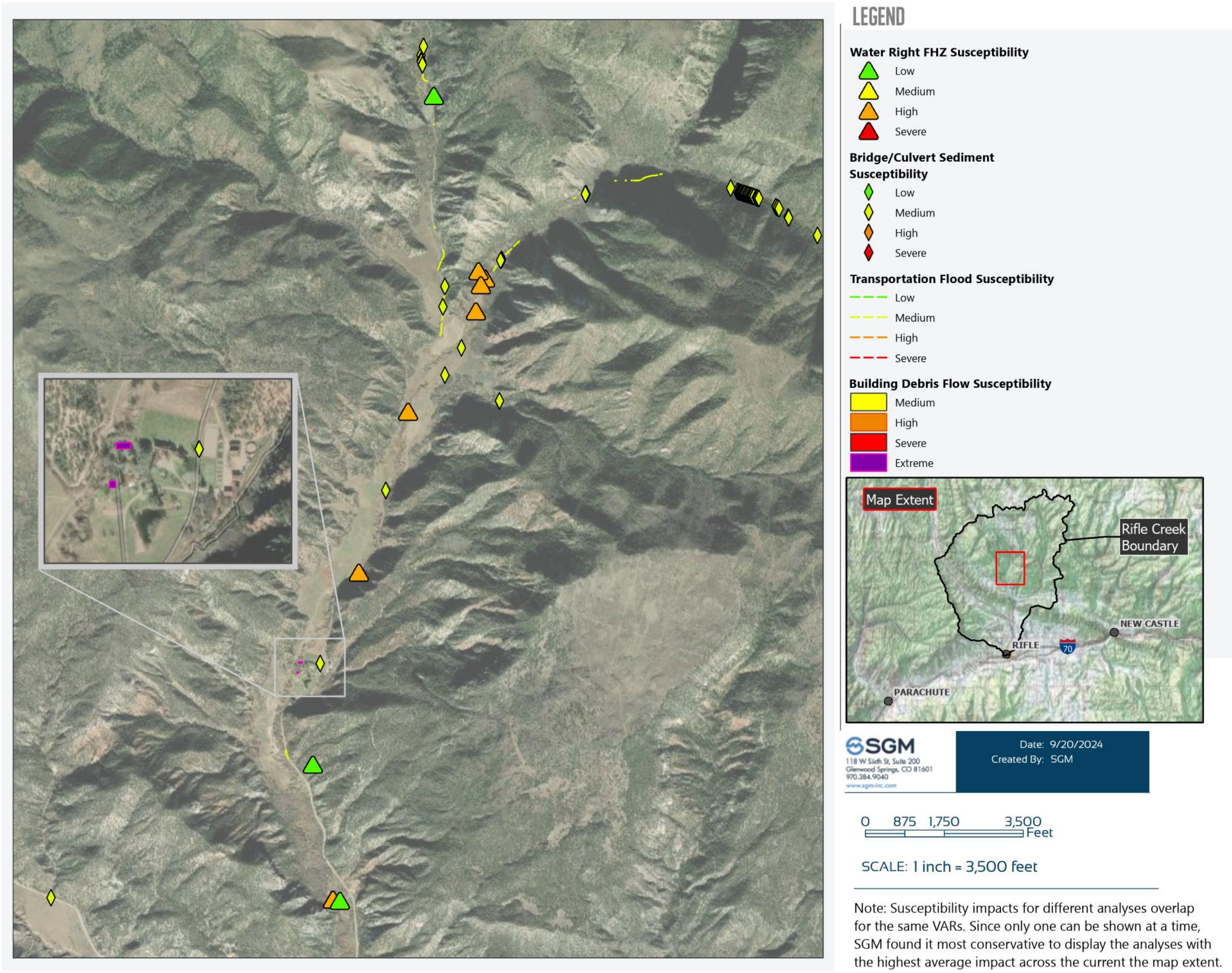


*Figure 9-17. Susceptible VARs in the Upper Middle Rifle Creek Watershed*

## Confluence of West and Middle Rifle Creeks

Near the confluence of West and Middle Rifle Creeks, the two creeks flow on either side of a narrow, small ridge before combining just above Rifle Gap Reservoir. The valley bottoms on both sides of this ridge are wider in this section than upstream on both creeks, which indicates these areas could be potential locations for stream restoration to allow for sediment settling and peak flood attenuation, before Rifle Gap and the areas near the identified buildings.

The water rights structures in this area (**Figure 9-18)** are a combination of wells and ditches. Those closest to the creek have moderate susceptibility to debris flow hazard, most have low susceptibility to fluvial hazard (except for a single correctional facility well, which is highly susceptible), and all have low susceptibility to sediment. All these headgates would benefit from any pre-fire stream restoration and burn severity mitigation to help lower the increase in post-fire peak flow and debris hazard. Post-fire, reinforcement of headgates, the addition of debris racks to the headgates, and armoring of the stream channel in the vicinity of the structure would help protect these diversion structures from debris flows and fluvial hazard. Additionally, protection of any susceptible well infrastructure should also be undertaken.

The crossings and roadways in this area near and over West Rifle and Middle Rifle Creek are susceptible to flooding (Middle – moderate, West – low), debris (both moderate), and fluvial hazard (Middle – moderate, West – high). In pre-fire conditions, this section of the creek could see some benefit from an upstream floodplain reconnection project, though this may be of limited impact. This could help slow floodwaters and give opportunities for sediment to settle out of the creek prior to water reaching this area. Post-fire, armoring the County Rd 219 bridge/culvert over Middle Rifle Creek and the County Rd 252 bridge/culvert over West Rifle Creek should be considered as well as investigating the sizing of these bridges/culverts and installing sediment mitigation and debris flow racking for all crossings identified.

Buildings susceptible to post-fire hazards have been identified along the banks of both creeks. On West Rifle Creek, a house and an outbuilding are highly susceptible to debris flow. On Middle Rifle Creek, one building is moderately susceptible to flooding after fire and three buildings are either moderately or extremely susceptible to debris flow. While some stream restoration and floodplain connectivity work will help to mitigate some susceptibility, the buildings' proximity to the creek will require other mitigation work, such as berm construction to redirect flows and floods and/or stream stabilization to prevent movement of the creek banks.

Just north of the correctional facility, the facility's reservoir has a low susceptibility to hydrologic change and high susceptibility to debris flow.

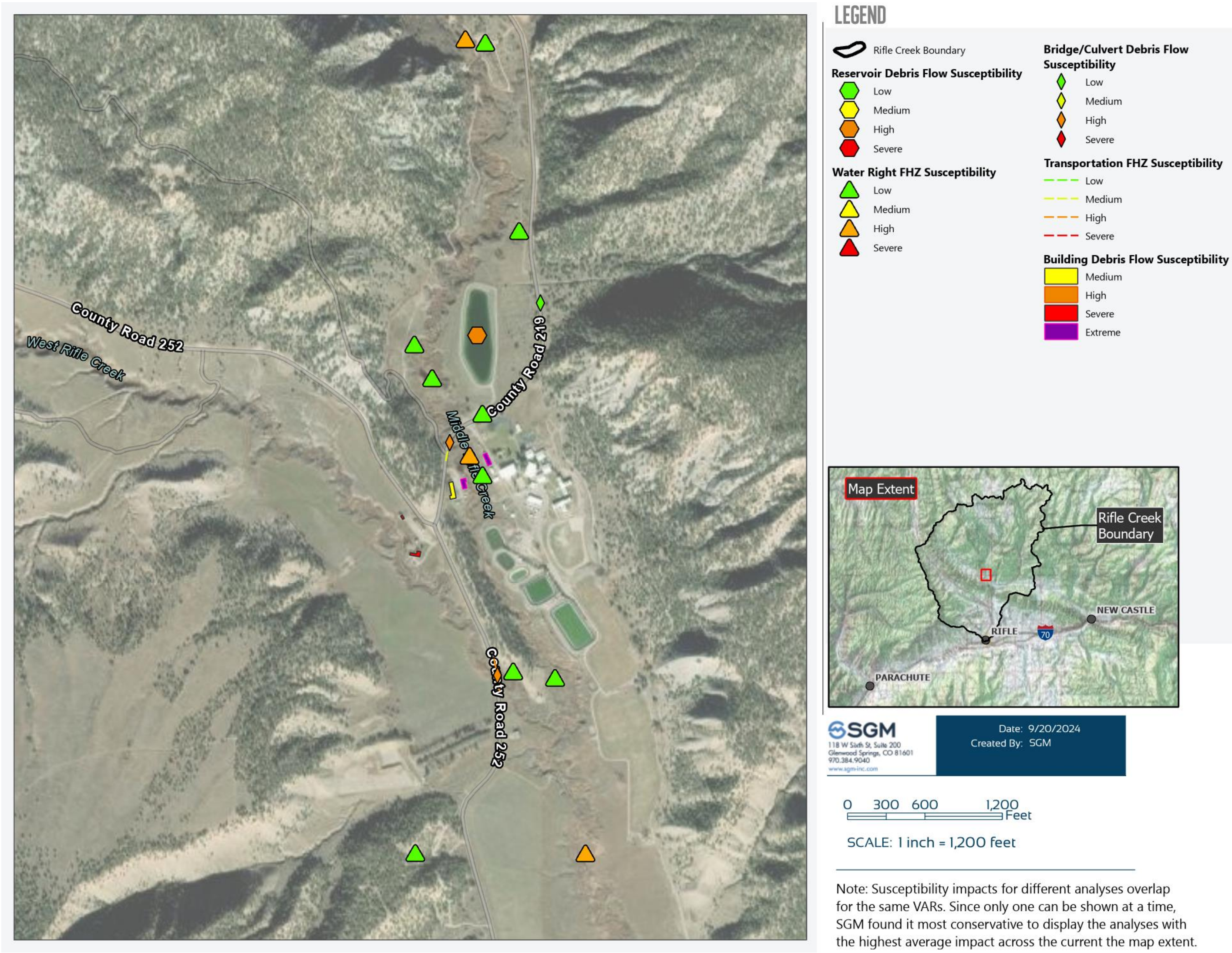


***Figure 9-18. Susceptible VARs near the Confluence of West and Middle Rifle Creeks***

## Rifle Creek from Rifle Gap to City of Rifle

Rifle Gap Reservoir sits at the confluence of East and West Rifle Creeks. Below the dam, the creek flows through wide agricultural meadows before reaching the City of Rifle. These meadows are good candidates for stream restoration in a pre-fire environment. The VARs susceptible to post-fire hazards in this area are shown in **Figure 9-19**.

Post-fire, the reservoir will be highly susceptible to debris flow hazard—likely from inflow from East or West Rifle Creek or Ward Gulch. It will also be susceptible to increased sediment load. East Rifle Creek is a good candidate for stream restoration efforts between the reservoir and Rifle Falls State Park, which would help mitigate susceptibility to these hazards. There are limited areas along West and Middle Rifle Creek where this work would also be beneficial. A restored stream channel could aid in attenuating peak flows and allowing for sediment to settle out of the water, decreasing the sediment load to the reservoir.

Both the Rifle Creek Canyon Ditch and the Grand Tunnel Ditch are highly susceptible to fluvial hazard in the first stretch of the ditches. Either when upgrades are considered pre-fire or in the case of a fire, these ditches should be considered for armoring of the headgates, reinforcement and/or installation of berms on the creek side of the ditches, and possible piping of the ditches to prevent damages.

For the other water rights identified as susceptible, all would benefit from any pre-fire stream restoration and burn severity mitigation to aid in a lower increase in peak flow and lower debris hazard. Post-fire, reinforcement of headgates, the addition of debris racks to the headgates, and armoring of the stream channel in the vicinity of the structure would help protect these diversion structures from debris flows and fluvial hazard. Additionally, protection of any susceptible well infrastructure should also be undertaken.

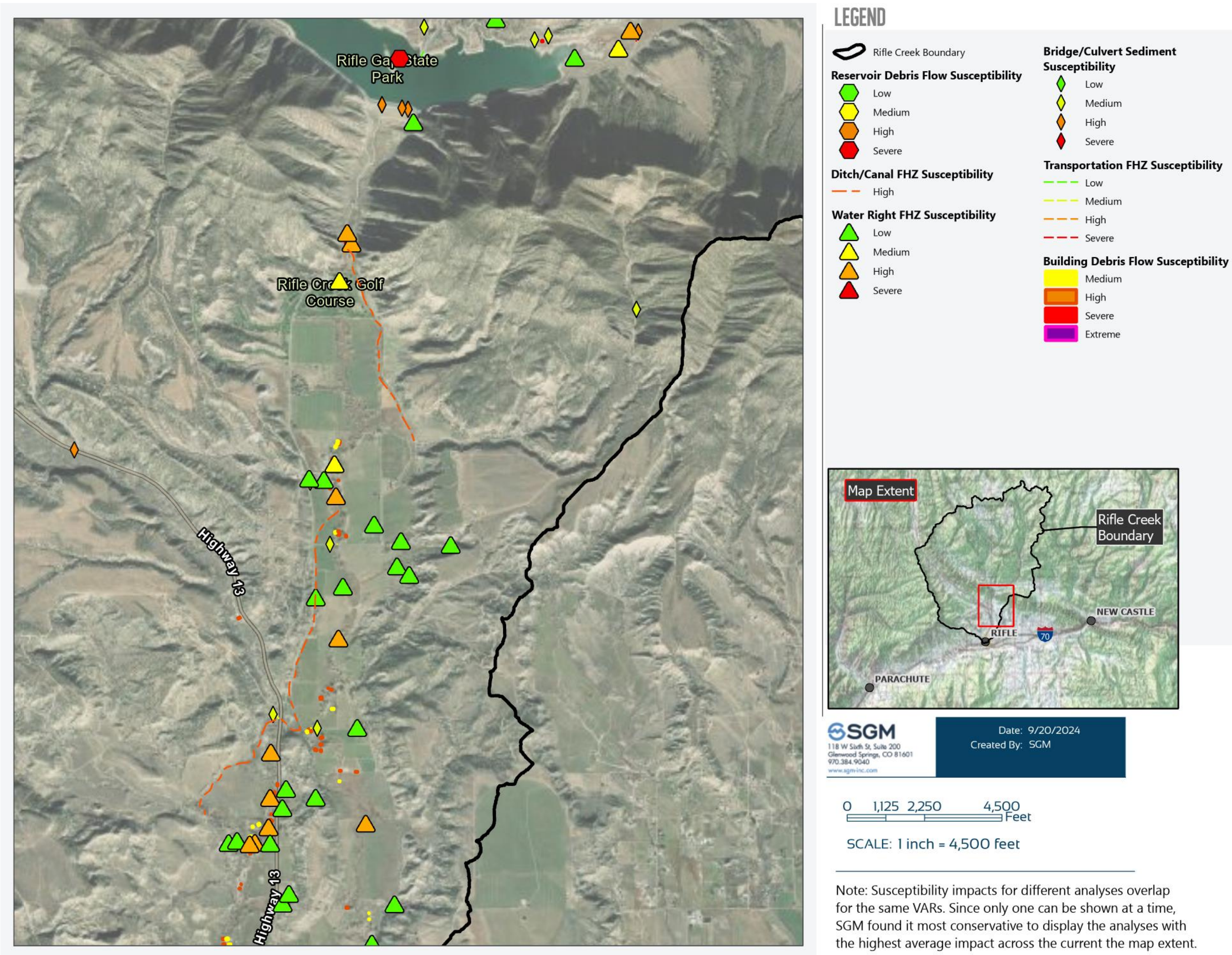


*Figure 9-19. Susceptible VARs along Rifle Creek between Rifle Gap and the City of Rifle*

## Government Creek

Government Creek is a narrower watershed with Colorado State Highway 13 running up the bottom of the watershed from the City of Rifle. Most susceptible VARs in this watershed are road crossings (mostly culverts) on Highway 13 and the local roadways. Government Creek is highly channelized above the City of Rifle and could benefit from stream restoration projects to help reconnect the creek to the floodplain in areas where the valley bottom is wide enough to allow this.

There are nine buildings near Government Creek which would be extremely susceptible to debris flow activity and are within the fluvial hazard zone (see **Figure 9-20** and **Figure 9-21**). There are also three structures on the east side of Highway 13 susceptible to debris flows from drainages on the east side of Government Creek (see online story map). While the susceptibility may be slightly decreased with stream restoration and possible burn severity mitigation, the proximity of these structures to Government Creek and the small drainages on the east side of Highway 13 indicate post-fire mitigation will be most important. Armoring Government Creek near these buildings, installation of berms and/or sandbag walls, possible relocation of the structures, and the installation of a warning system for life safety should all be considered as immediate post-fire mitigation projects should a fire happen in this drainage.

While only one section of Highway 13 north of the City of Rifle is identified as susceptible to post-fire hazards, several small sections of local roads are identified with low susceptibility to debris flow, flooding, and fluvial hazard. Armoring the roadway and installation of berms or sandbags to redirect flow may be helpful to decrease the post-fire susceptibility of these roadways.

There are several ditch headgates along Government Creek. These have low to moderate susceptibility to debris flow, low to high susceptibility to fluvial hazard, and low susceptibility to increased sediment. Even with these lower susceptibilities, post-fire diversion structures should be considered for reinforcement and debris racking to limit their susceptibility to these hazards.

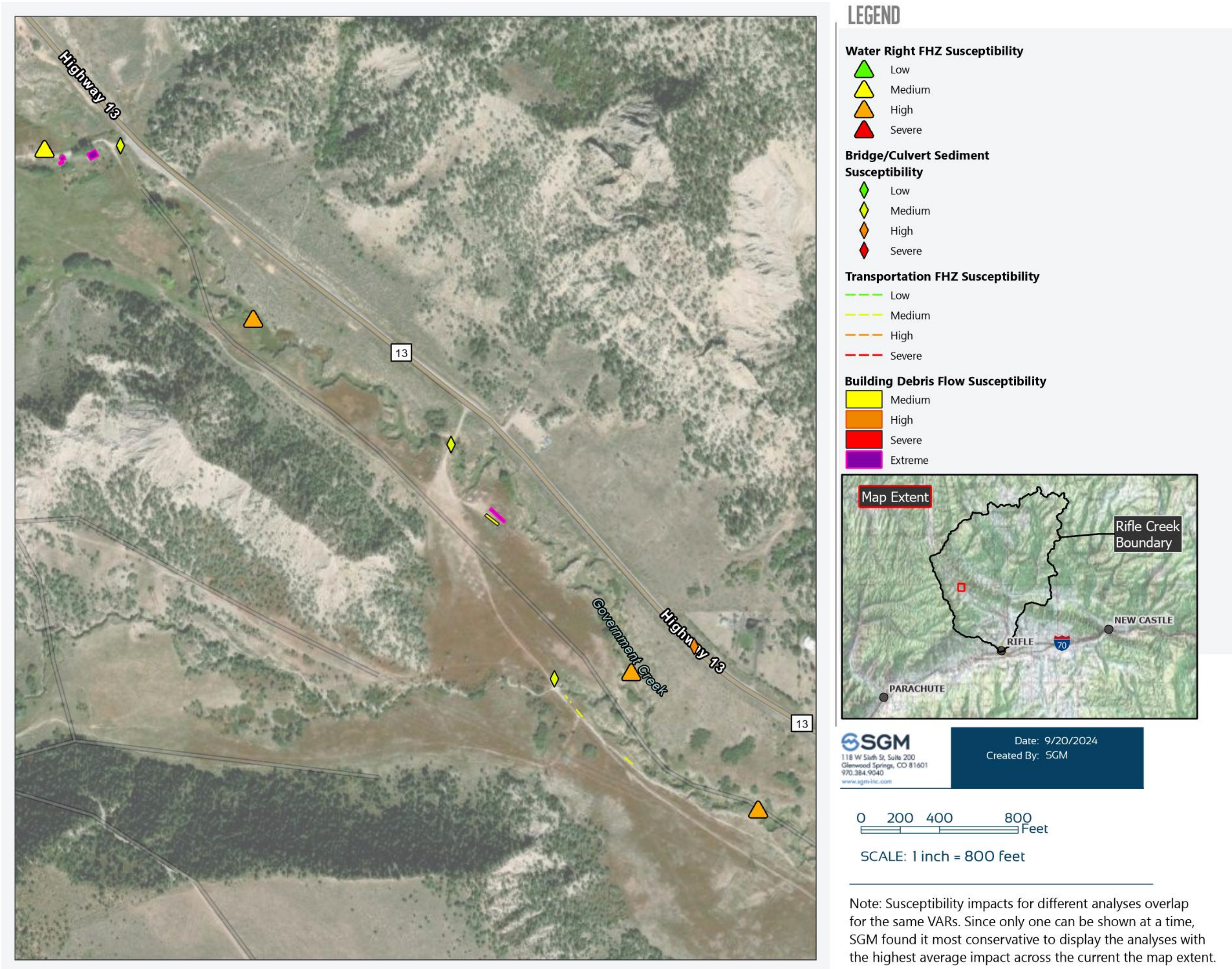


*Figure 9-20. Susceptible VARs along Upper Government Creek*

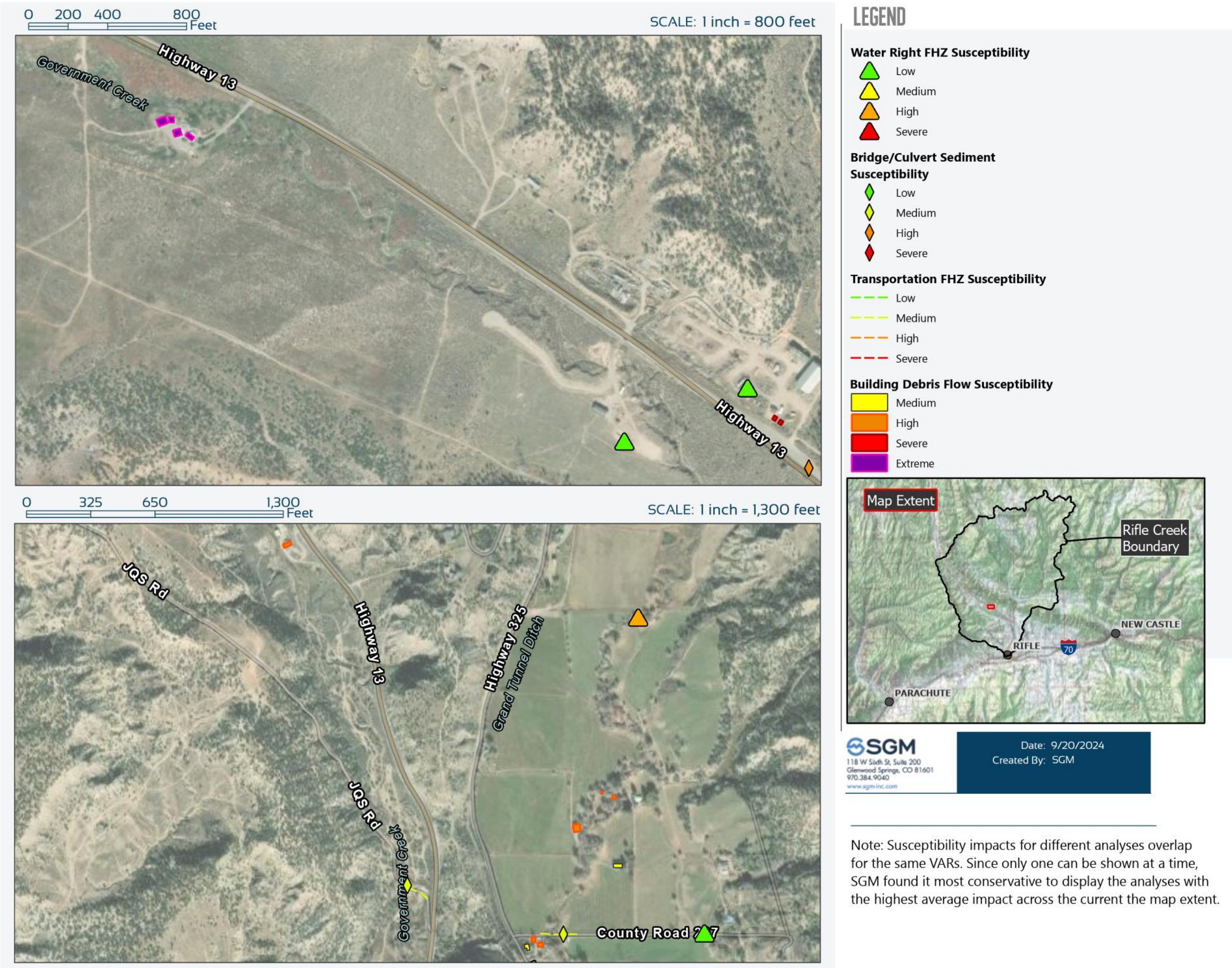


*Figure 9-21. Susceptible VARs along Government Creek*

## 9.3. Battlement Mesa Area Watersheds

The final area of study for the CRWC WRAP are the watersheds south of the Colorado River between Silt and De Beque. These have been subdivided into the following areas for this narrative: Silt Area Watersheds, Beaver Creek, Porcupine Creek, Cache and Cottonwood Creek, Battlement Creek, Battlement Mesa, Wallace and Spring Creek, Alkali Creek, Samson Creek, and watersheds north of the Colorado River.

### Silt Area Watersheds

On the easternmost section of the Battlement Mesa area, near Silt, Colorado, the land is characterized as relatively flat farming land in a basin. Near County Rd. 225, there are a few buildings that are highly and severely susceptible to flooding in a post-fire environment (see **Figure 9-22**). Floodplain connectivity may help to mitigate some susceptibility to this flooding by allowing the natural floodway to attenuate the peak flow. A couple of the buildings near this gulch may require other mitigation work such as berm or sandbag wall construction to redirect flows during a flood event.

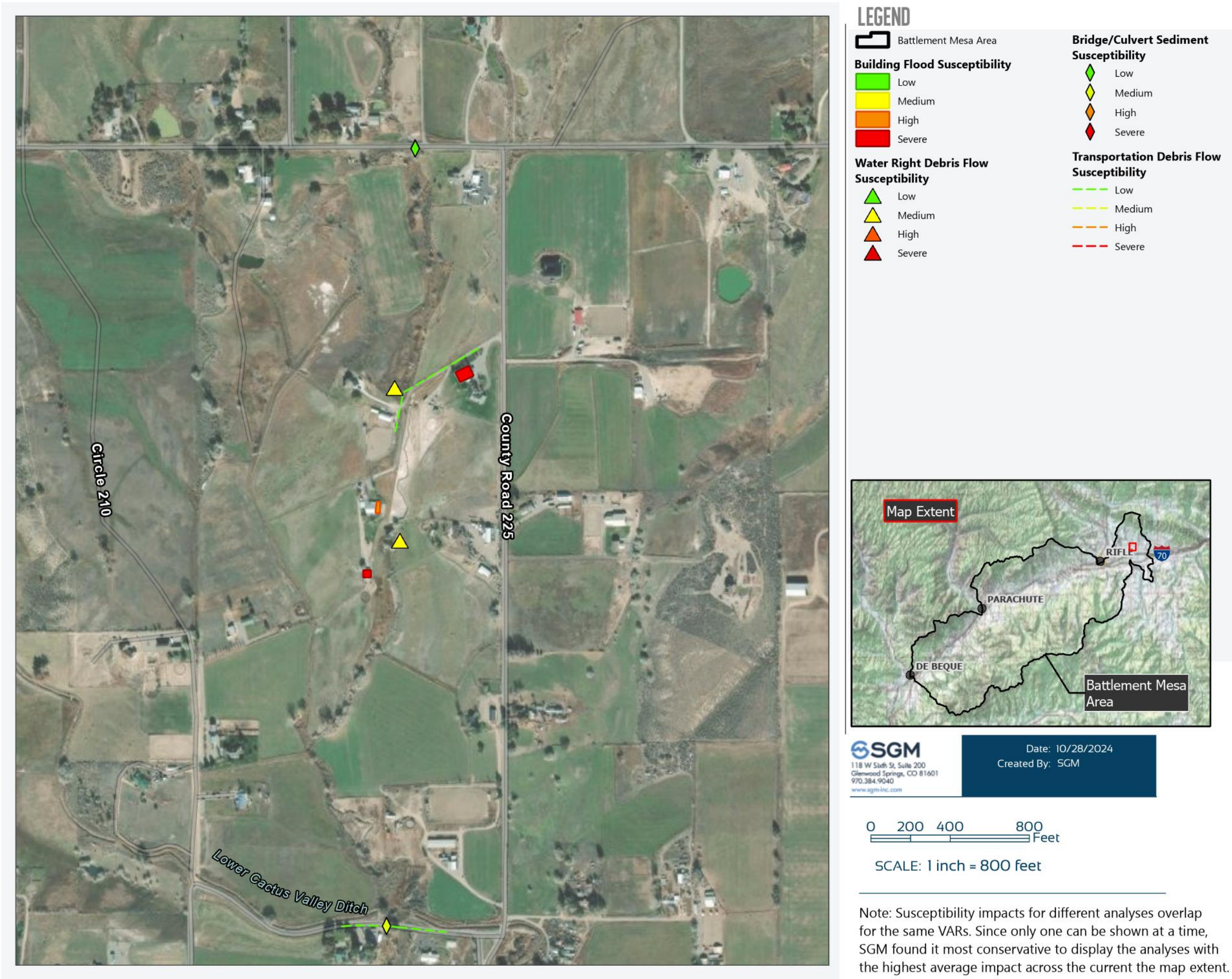


*Figure 9-22. Susceptible VARs along County Rd 225 near Silt*

There are also a few water rights that are moderately susceptible to debris flow in this area. As with the buildings, any work done on the nearby gulches and small creeks to allow for the use of floodplains to attenuate flows will decrease the susceptibility of these water rights to debris flows. For headgates, post-fire armoring and installation of debris racks will be the most beneficial to protect from this hazard. For wells, installing berms/sandbag walls where appropriate will protect the structures in the event of a debris flow.

Sections of the Highway 6 corridor and the culverts that run under it are slightly susceptible to debris flow and sediment as well. One crossing on Highway 6, near the intersection of County Rd. 225 and Highway 6, is highly susceptible to sediment flow post-fire. There are also multiple buildings that are highly or severely susceptible to flooding along County Rd. 225. **Figure 9-23** shows the crossing, buildings, and other VARs susceptible to post-fire impacts west of Silt. In pre-fire conditions, the associated gulches and creeks see some benefit from a floodplain reconnection project, though this may be of limited impact in the dry gulches. This could help slow floodwater and give opportunities for sediment to settle out of the creek before the water reaches the susceptible crossings. Post-fire, armoring the crossings and installing sediment barriers should be considered as well as investigating the size of the crossing on Highway 6. Furthermore, post-fire berming could help to redirect flows away from susceptible buildings.

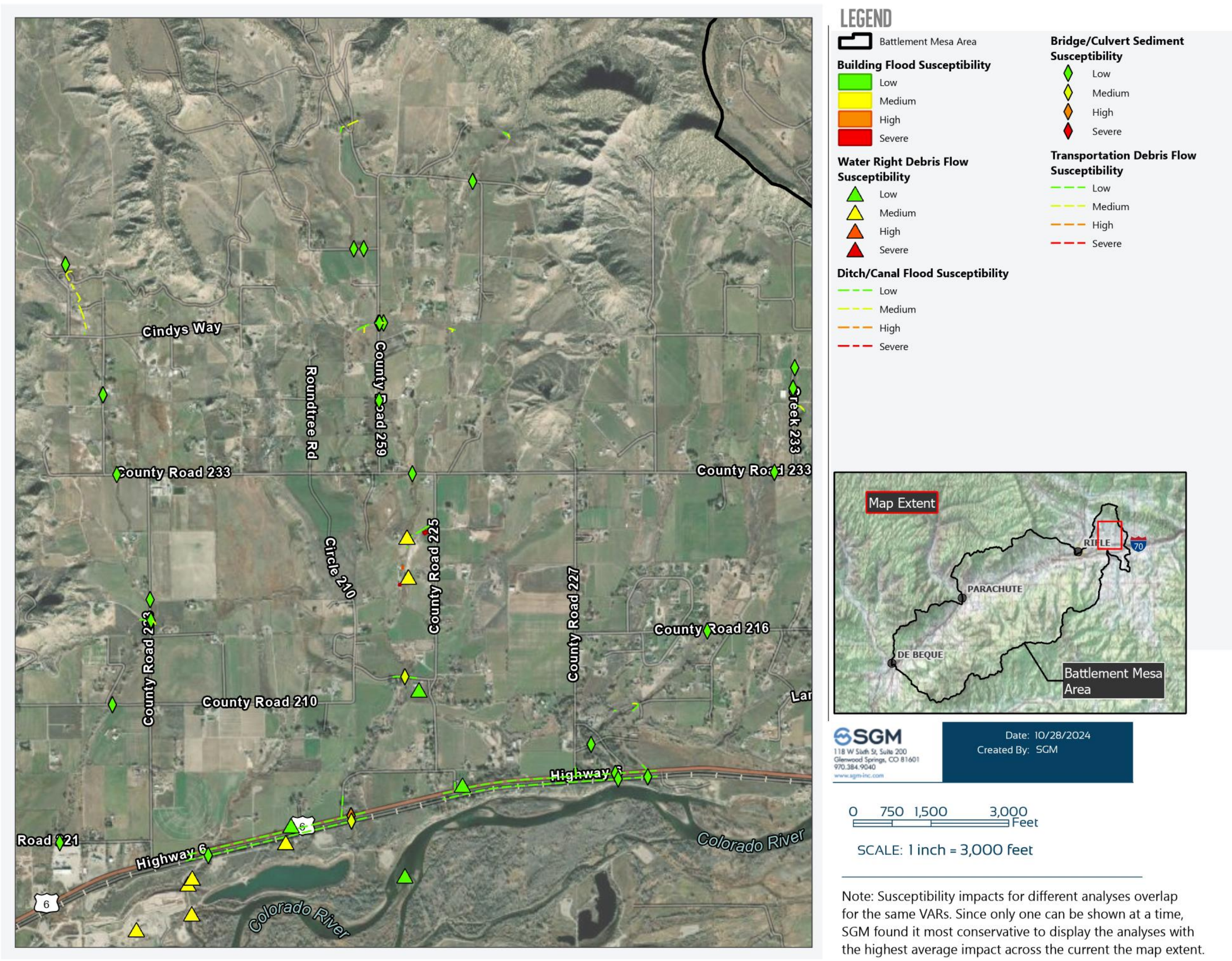


*Figure 9-23. Susceptible VARs north of I-70 near Silt*

Between Silt and Rifle there is a high likelihood of impacts to VARs after a fire, as shown in **Figure 9-24** and **Figure 9-25**. This includes multiple critical facilities potentially susceptible to low levels of debris flow and one that is highly susceptible to low-level flooding. There are also numerous buildings on both sides of I-70 and the Colorado River that are severely susceptible to low-depth flooding. Furthermore, there are parts of the I-70 corridor that may potentially flood after a fire. Pre-fire, the crossings and storm drainages under I-70 should be investigated for sizing to ensure they are able to pass flow quickly enough in the event of a post-fire storm event. As this is a relatively flat area near the Colorado River, any work that improves the stormwater infrastructure in this area will help with the potential low depth flooding post-fire.

Sediment transportation from a post-fire flood could also impact two source water intakes for water treatment facilities in this area along the Colorado River. The City of Rifle already utilizes a settling pond between the river and their intakes, which will continue to help in a post-fire event. The Town of Silt is currently undertaking the construction of a new water treatment facility to aid in treating higher sediment loads following the Grizzly Creek fire. These improvements should allow the plant to operate more efficiently with heavier sediment loads.

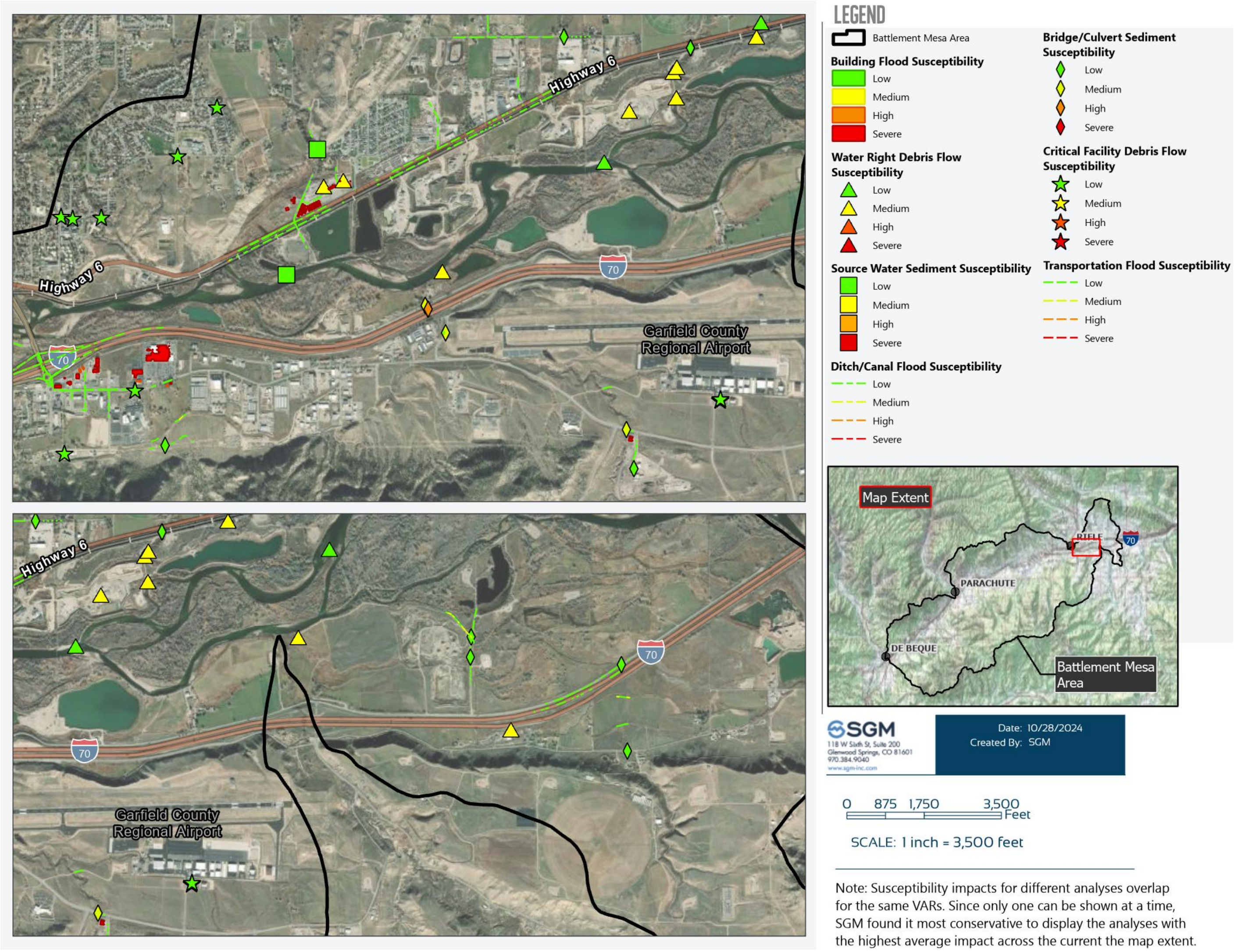


*Figure 9-24. Susceptible VARs along I-70 between Rifle and Silt*

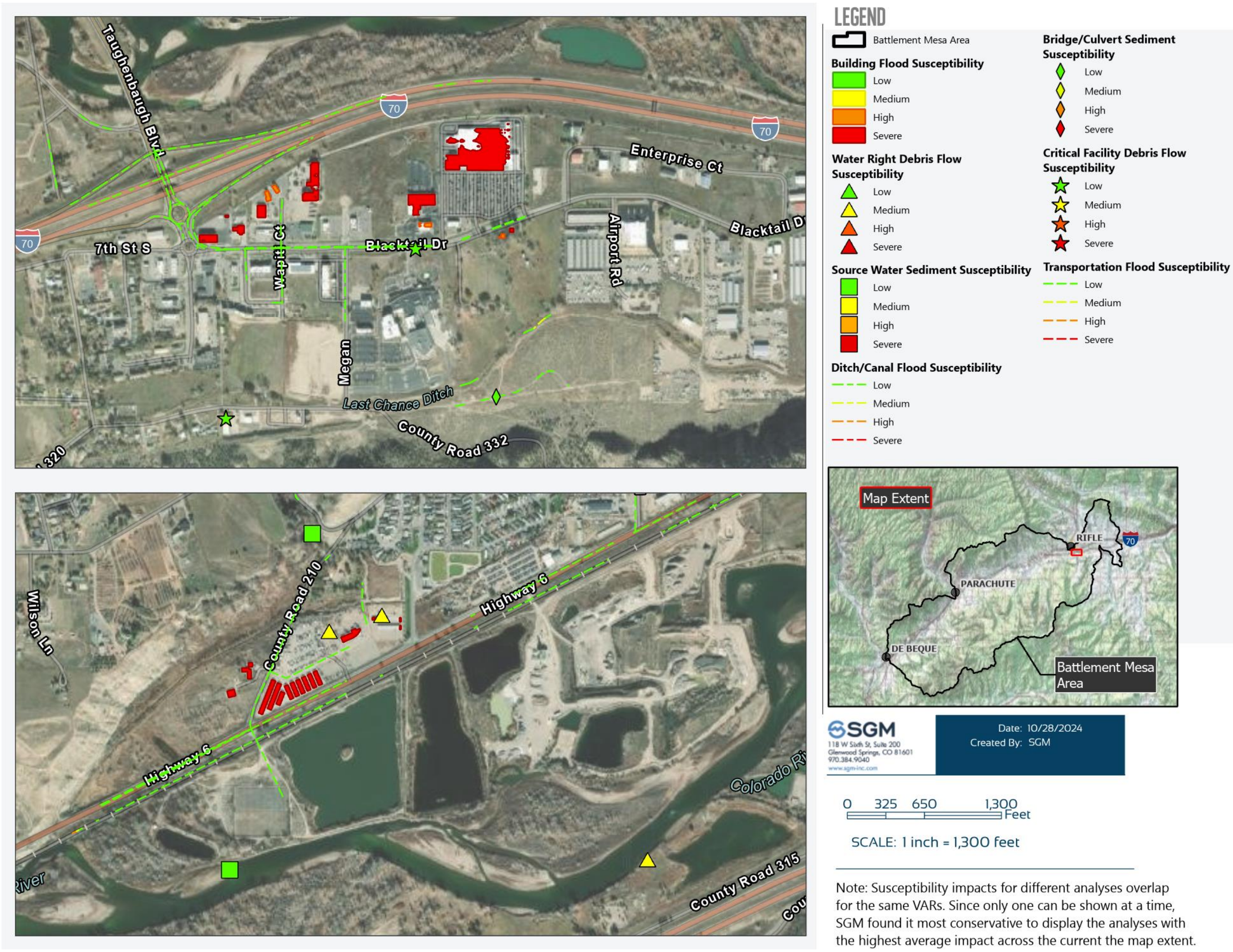


*Figure 9-25. Susceptible VARs southeast of Rifle*

South of the Garfield County Regional Airport near Rifle, sections of County Rd. 319, crossings under the road, and nearby water rights are potentially susceptible to debris flow and sediment flow post-fire, as shown in **Figure 9-26**. Some floodplain connectivity may assist with reducing sediment transfer; however, the bulk of the debris flow and sediment flow would likely come from the surrounding hillsides. Therefore, a focus on early warning systems and revegetation post-fire is the best mitigation. For the post-fire water rights, reinforcement of headgates, the addition of debris racks to the headgates, and armoring the stream channel in the vicinity of the structure would help protect these diversion structures from debris flows. The crossings could benefit from armoring, installation of debris racks and sediment barriers.

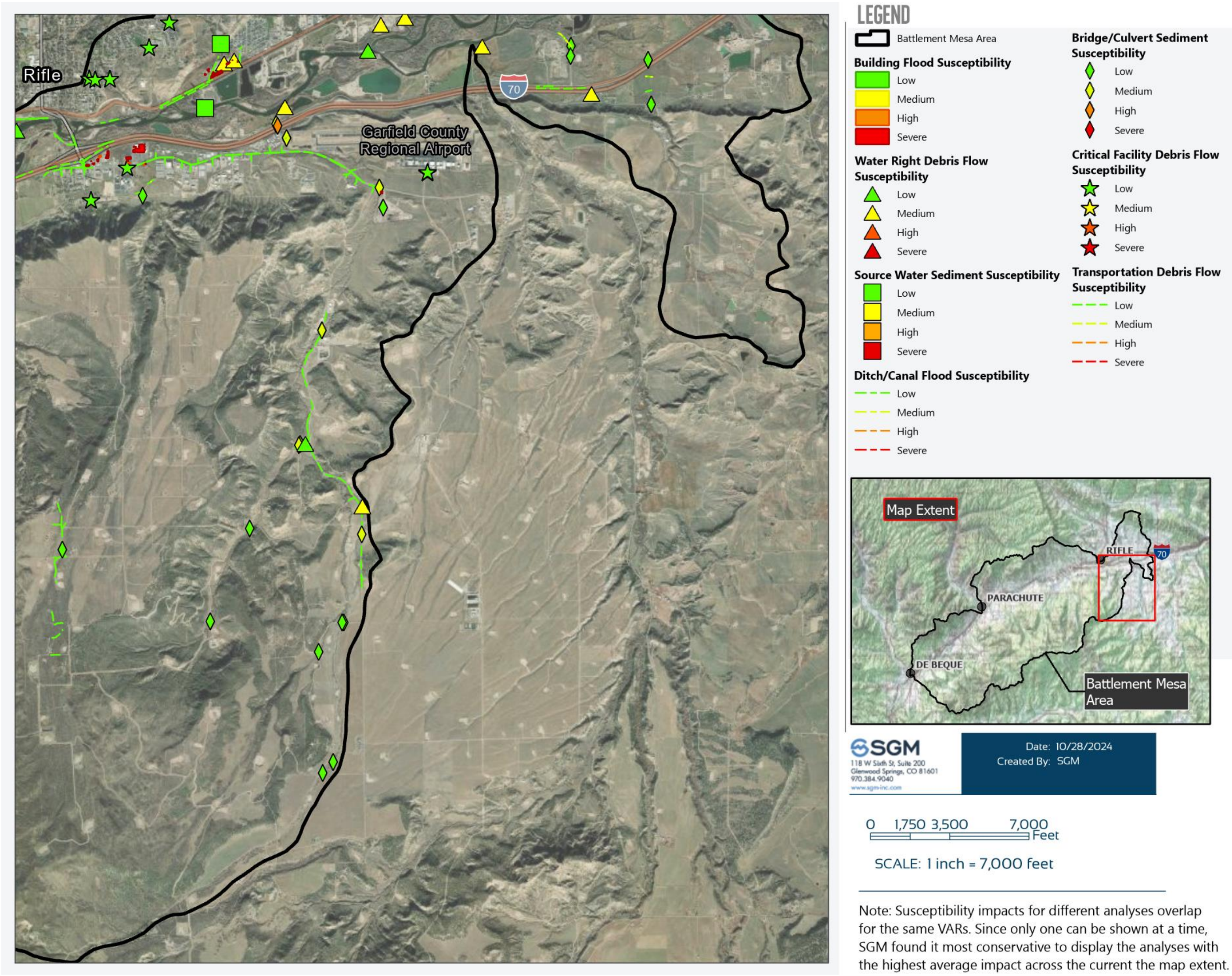


*Figure 9-26. Susceptible VARs in the watersheds south of I-70 between Rifle and Silt*

Near Rifle, Colorado, (**Figure 9-27**) sections of the train track, I-70, and County Rd. 320 could be impacted by debris flow after a fire. Additionally, there are two critical facilities west of Rifle, and multiple crossings along the Rifle Bypass, that are somewhat susceptible to debris flow and sediment transport after a fire. These susceptibilities are likely due to the proximity to either steep hill slopes or the Colorado River. Post-fire, care should be taken to identify ways to stabilize these hillslopes or add armoring to the riverbank.

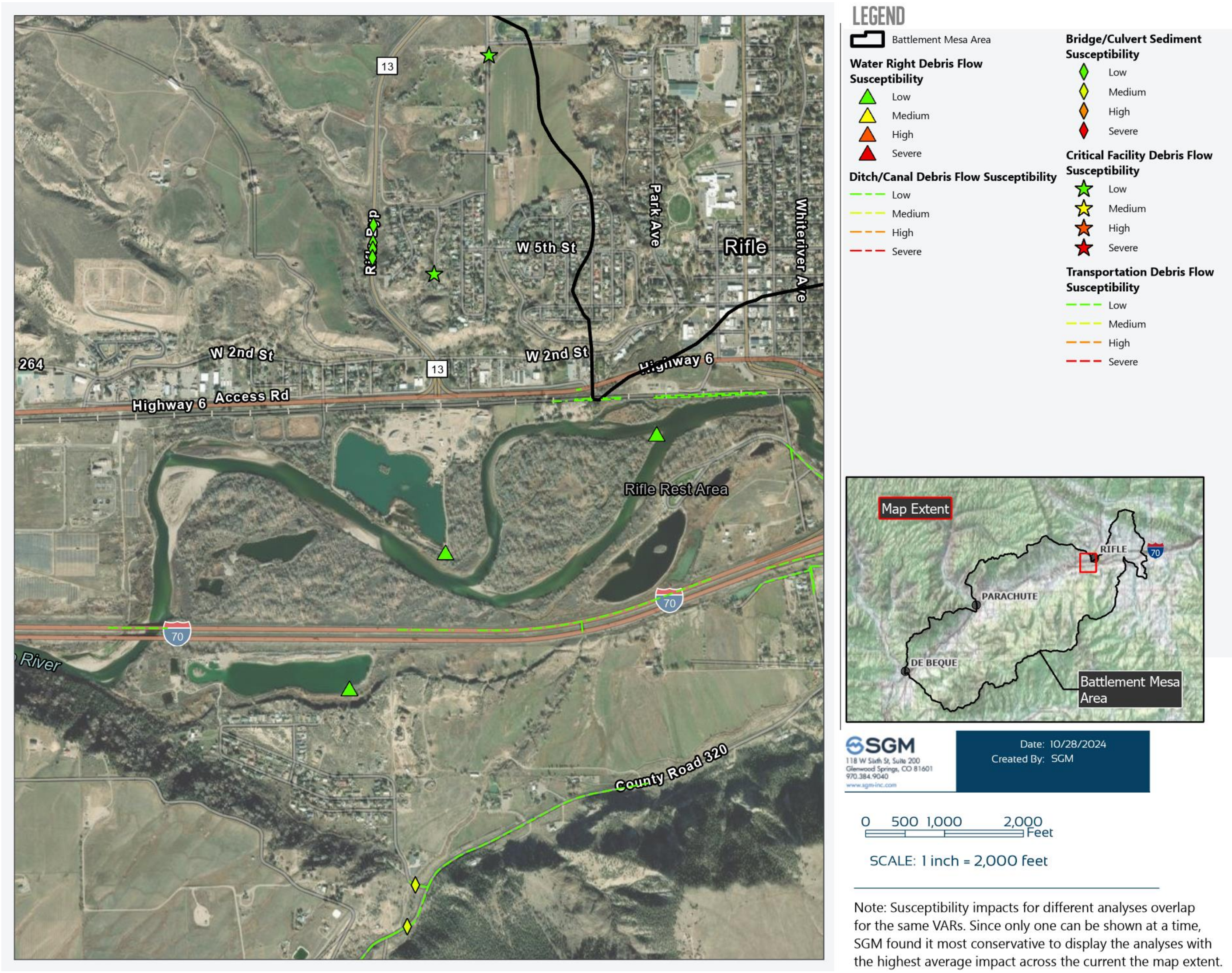


*Figure 9-27. Susceptible VARs along I-70 near Rifle*

There is potential for debris flow to impact parts of Highway 6 and the I-70 corridor, including the crossings along these sections between Rifle and Rulison. Post-fire, armoring the crossings and installing debris racks should be considered as well as investigating the sizing of these bridges/culverts and installing sediment mitigation.

There are also multiple buildings that are severely susceptible to flooding in this area, as shown in **Figure 9-28**. The buildings' proximity to the Colorado River and the gulch will require other mitigation work such as berm construction to redirect floodwater.

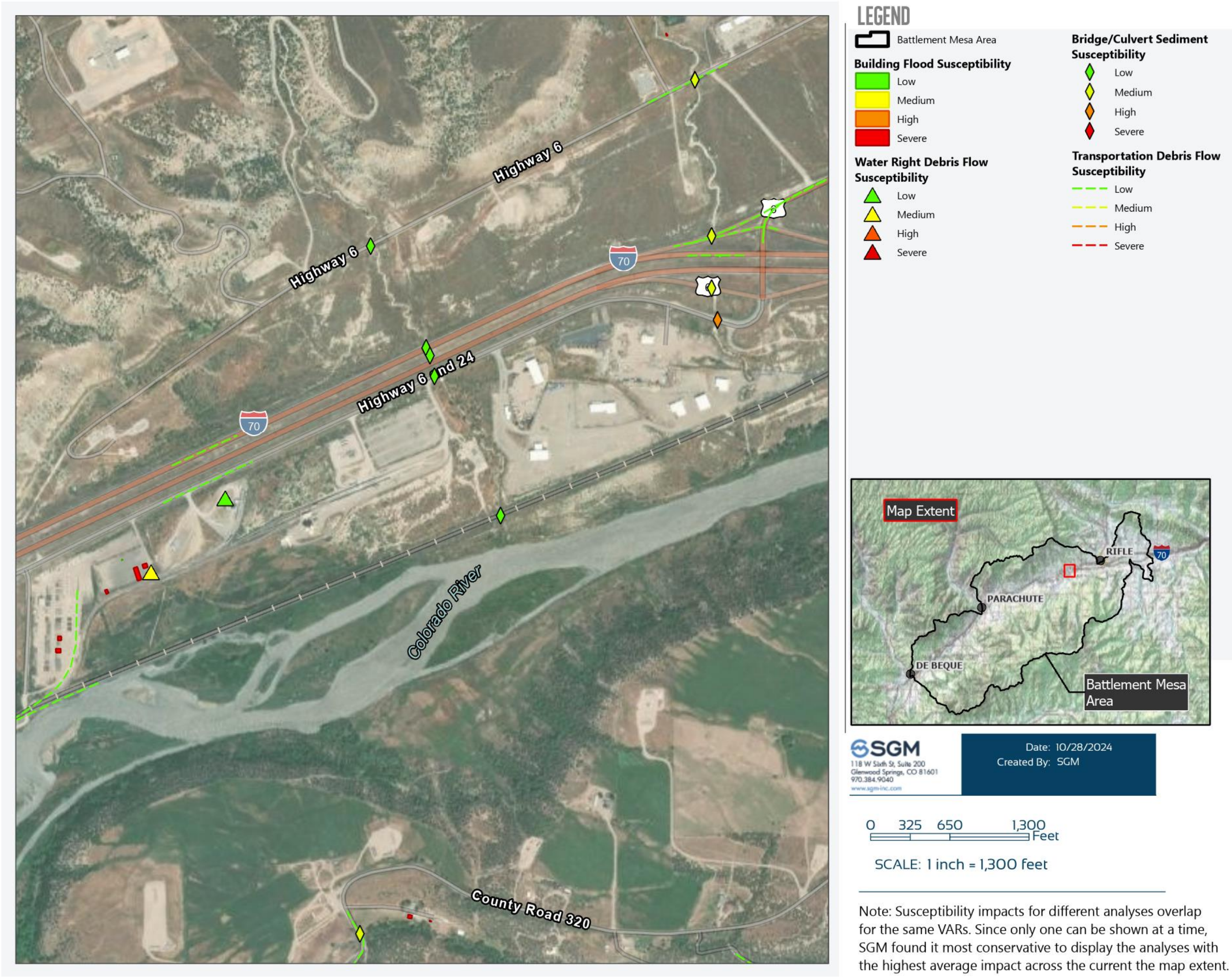


*Figure 9-28. Susceptible VARs along I-70 between Rifle and Rulison*

## Beaver Creek

Along Beaver Creek, located south of **Figure 9-28**, a large section of County Rd. 317 has low susceptibility to debris flow due to proximity to the creek and the steep hillslopes further up the watershed. There are multiple water rights and crossings along this area that are also susceptible to debris flow and sediment transport, as well as a building near County Rd 356 that is severely susceptible to flooding from Beaver Creek post-fire. This area, shown in **Figure 9-29**, is characterized by steep topography. Burn severity pre-fire mitigation techniques may be ineffective for reducing post-fire impacts. Berm construction or sandbag walls could assist in reducing the flood impact for the building, and early warning systems would be essential for ensuring protection of lives.

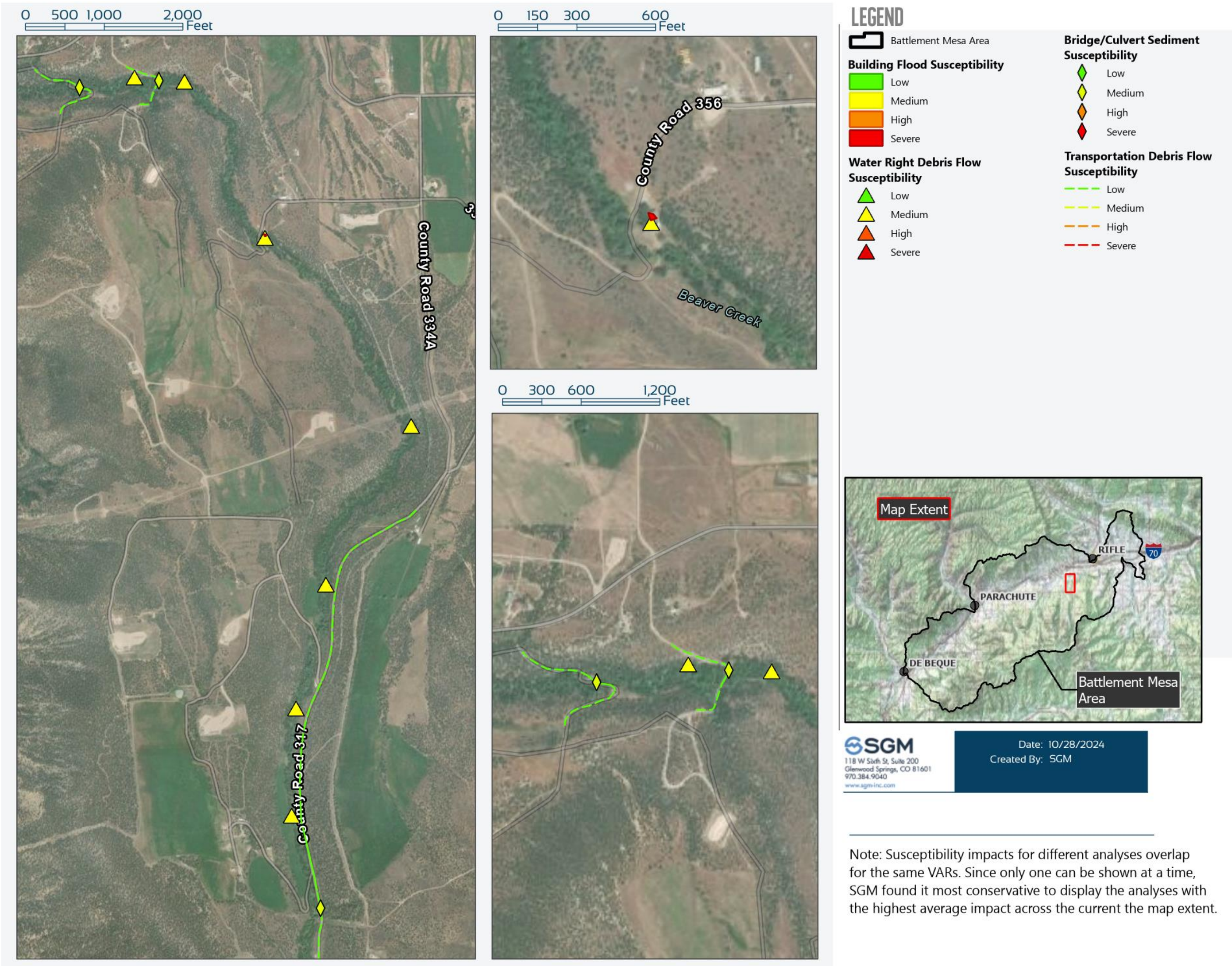


*Figure 9-29. Susceptible VARs along Beaver Creek*

## Porcupine Creek

Porcupine Creek, located slightly west of Beaver Creek, is located between a steep hillside to the east and flatter land to the west. A fire on the steep hillside could result in devastating debris flow in this area. There are multiple buildings and water rights that are severely and extremely susceptible to debris flow post-fire, as shown in **Figure 9-30**. Parts of the roads and culverts could also be impacted by debris flow and sediment transfer. Post-fire, armoring and installing debris racks for the culverts and crossings could reduce debris impacts and possible plugging. Berms along the roads could help to redirect debris flows from crossing and damaging roadways. Debris nets could assist with catching debris upstream of key infrastructure.

With buildings in the area with extreme susceptibility to the debris flow hazard, early warning systems during rain and flood events will be essential to ensure the protection of human lives should a fire occur in this area. Post-fire, mulching may give some improvement to the risk of the debris flow hazard, however due to the steep hillsides and the buildings proximity to Porcupine Creek, warning systems to alert residents to move away in the instance of a storm even will be critical. Berms to redirect flows and floodwaters will also be useful in protecting these buildings.

The water rights infrastructure will best be served with armoring, debris racks, and possible headgate improvements to allow these structures to be able to handle debris flow impacts.

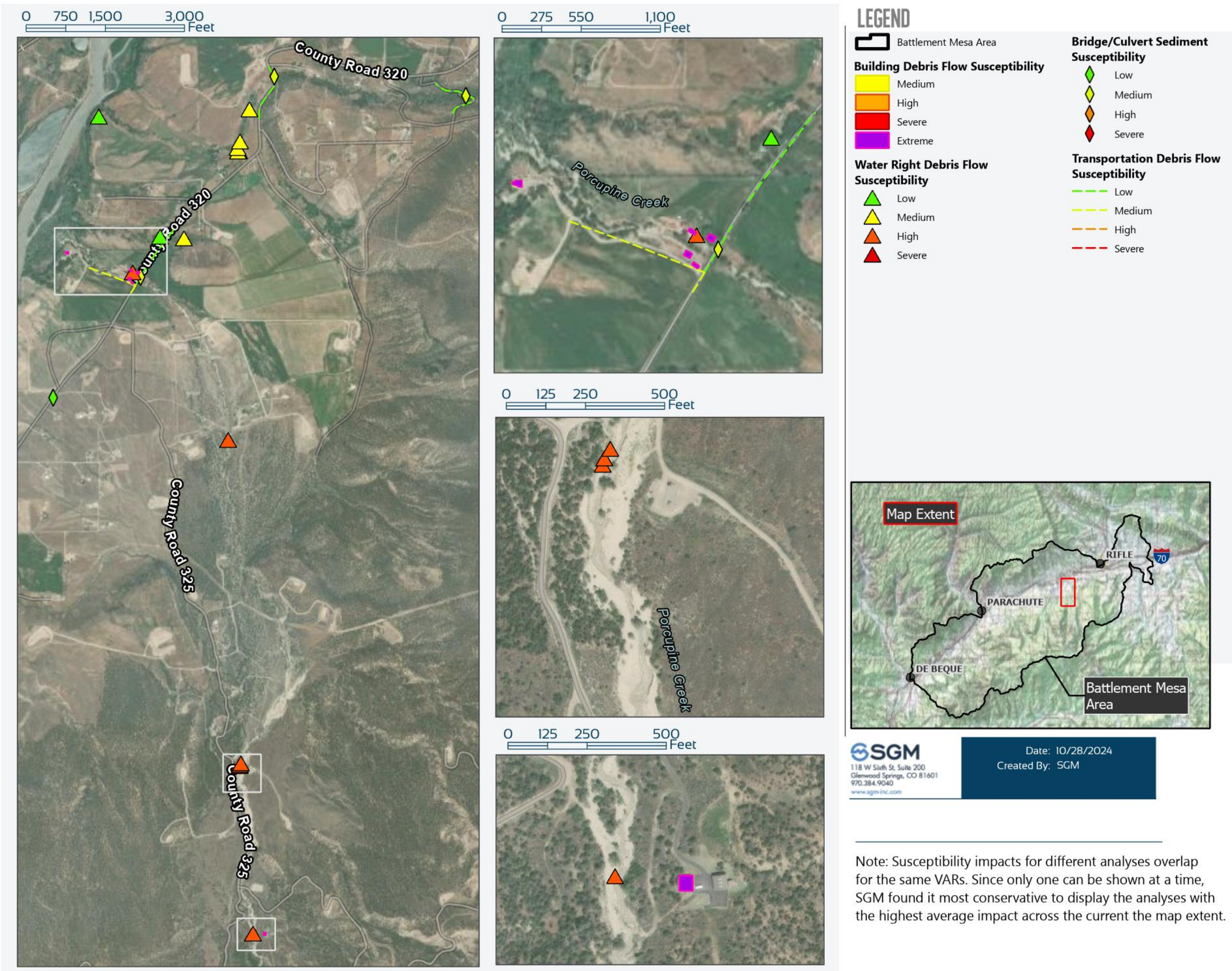


*Figure 9-30. Susceptible VARs along Porcupine Creek*

## Cache and Cottonwood Creeks

Cache Creek carves through a shallow canyon with two mesas on either side, making it a natural candidate for debris flows. The headwaters of Cache Creek are densely vegetated, so pre-fire mitigation of the dense vegetation higher up in Cache Creek could assist with reducing the burn severity and subsequent debris flow post-fire.

Many VARs within the Cache Creek floodplain are moderately susceptible to debris flow and sediment transfer, including multiple buildings that are severely susceptible to debris flow as shown in **Figure 9-31**. After a fire, a warning system for the houses within the Cache Creek floodplain that could be severely impacted will be necessary to prevent the loss of human life. Post-fire, installation of berms to redirect flows and armoring to reinforce creek banks will help protect these buildings.

County Rd. 309 is also susceptible to debris flow and sediment damage where it crosses over Cache Creek. Pre-fire, this specific crossing should be analyzed to understand if it is sized appropriately for larger, post-fire flows – and possibly considered for upsizing. Post-fire armoring and installing debris racks for this and other crossings will help mitigate damage to the roadways.

The water rights infrastructure will best be served with armoring, debris racks, and possible headgate improvements to allow these structures to be able to handle debris flow impacts.

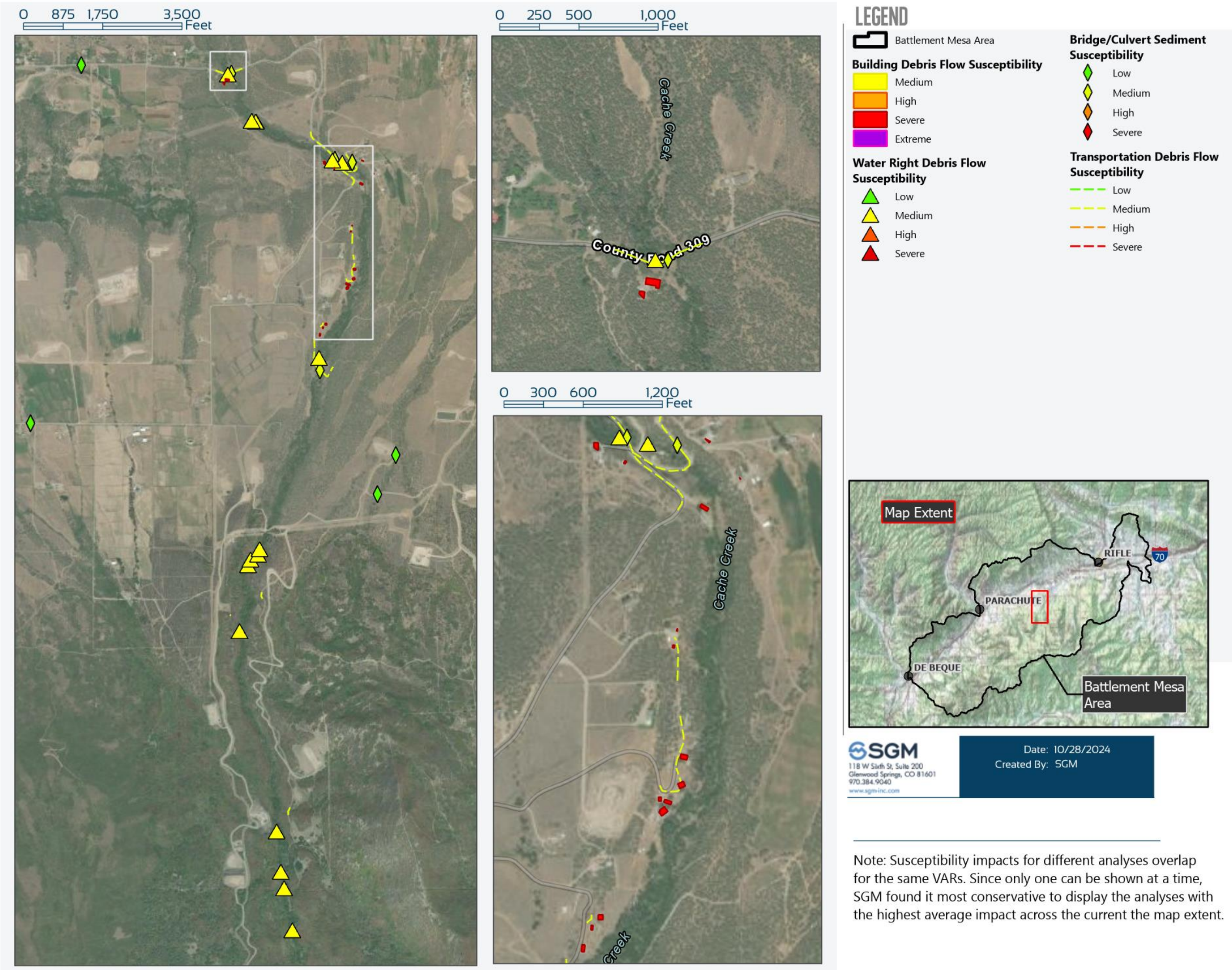


*Figure 9-31. Susceptible VARs along Cache Creek*

At the mouth of Cache Creek, multiple buildings are moderately susceptible to debris flow impacts (**Figure 9-32**). Additionally, near Rulison, sections of Highway 6 and I-70, along with relevant crossings, are susceptible to debris flow and sediment impacts. Debris racks, deflection walls, and berms can be used to protect key crossings and redirect flows from susceptible VARs. Additionally, roadway barriers or planned overflow paths could assist with reducing potential damage and traffic impedance on Highway 6 and I-70 after a fire.

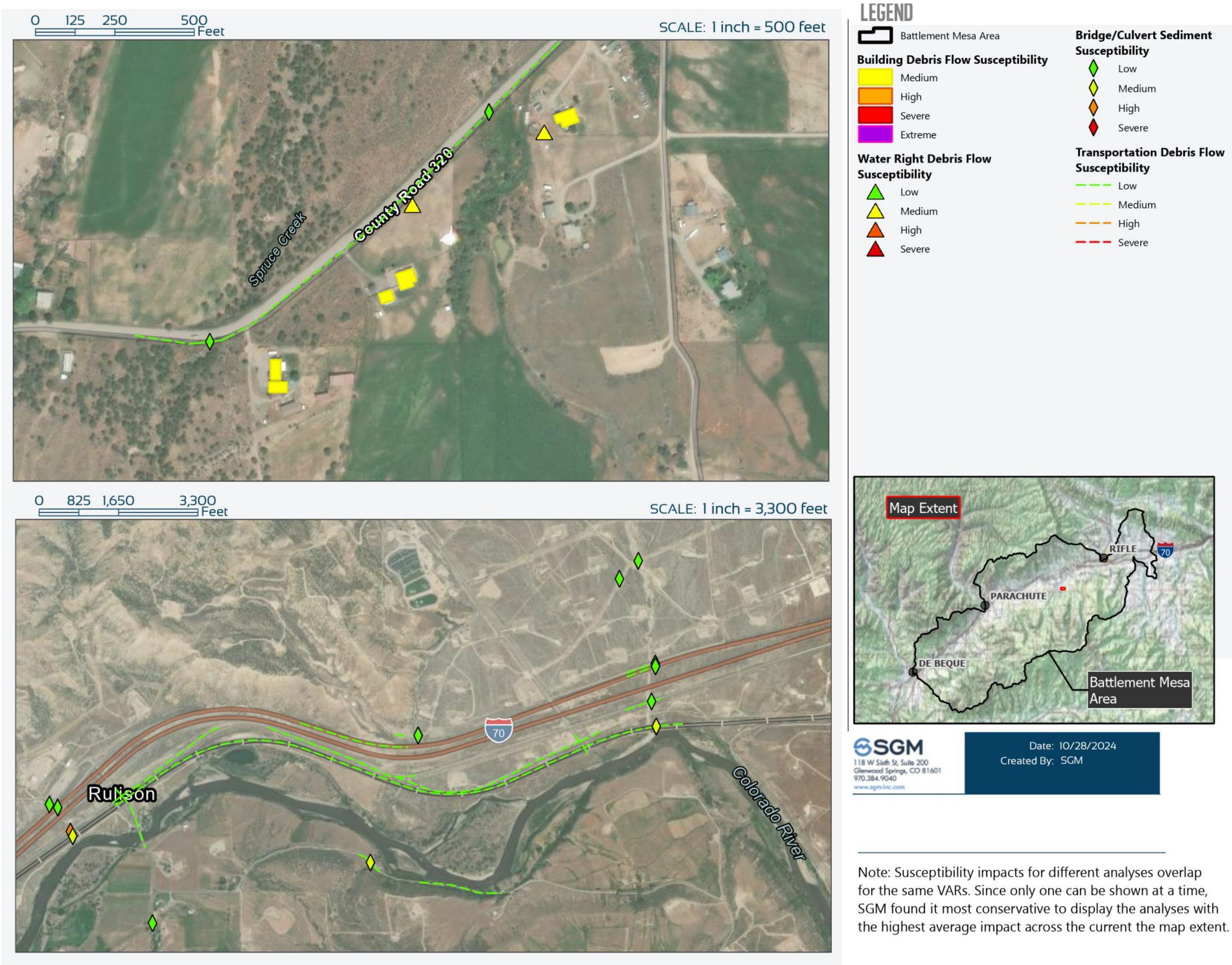


*Figure 9-32. Susceptible VARs at the mouth of Cache Creek*

There are a few buildings moderately susceptible to debris flow along Cottonwood Creek (**Figure 9-33**) after a fire. County Rd. 309, which crosses Cottonwood Creek, could also be susceptible to debris flow and sediment transport. Berms and deflection walls could help to reduce impacts to the susceptible buildings.

North of the Colorado River and the mouth of Cottonwood Creek, the train track, Highway 6 and 24, and I-70 could all be impacted by debris flow. Roadway barriers and planned overflow paths could help to redirect flow and reduce impacts to transportation.

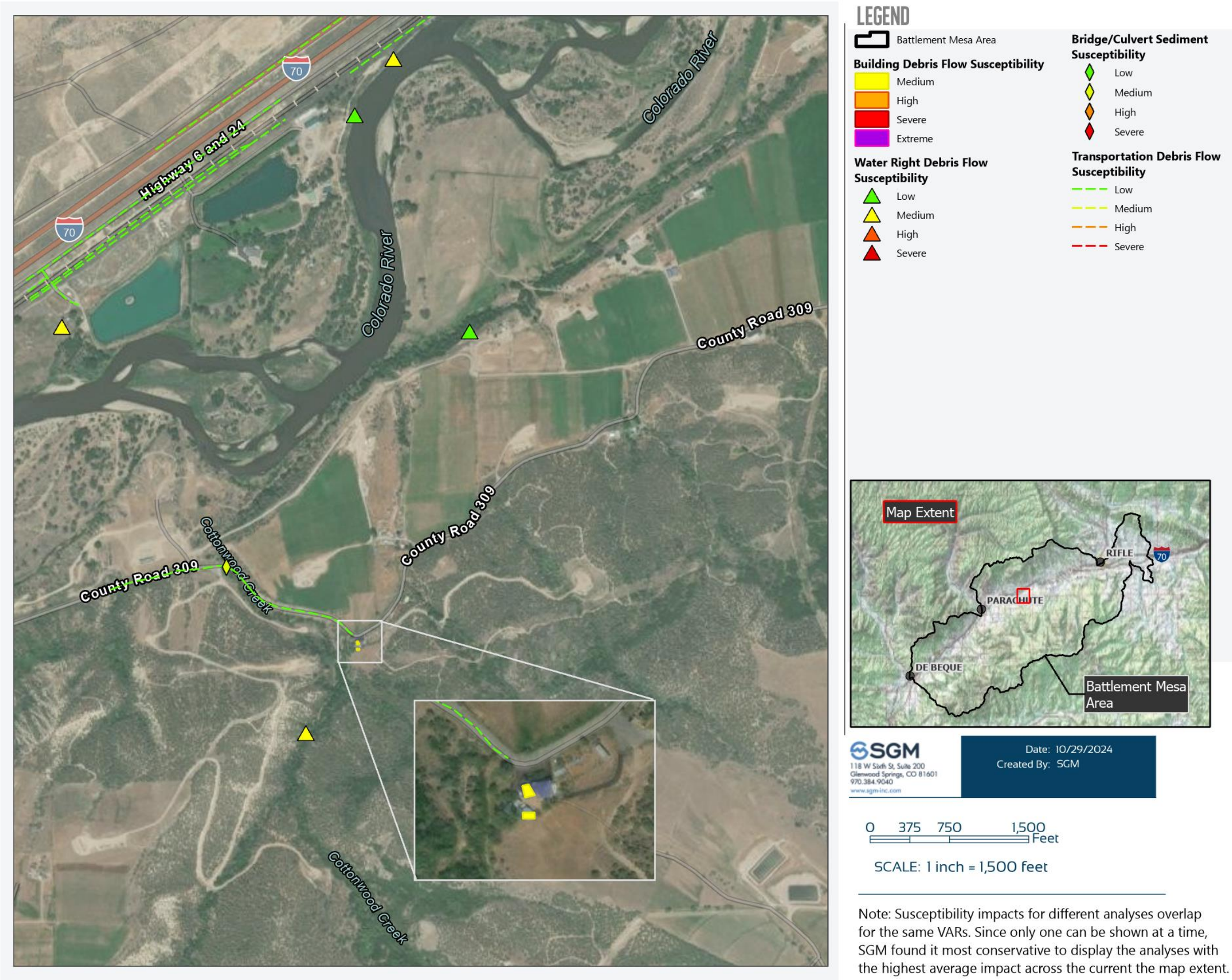


*Figure 9-33. Susceptible VARs along Cottonwood Creek*

## Battlement Mesa and Battlement Creek

Battlement Creek runs between two steep, densely vegetated hillsides. This topography results in increased susceptibility for debris flow for the VARs within its floodplain (see **Figure 9-34**). Particularly, large swaths of County Rd. 302 and sections of Morrisania Mesa Rd are susceptible to debris flow impacts. Pre-fire burn mitigation may help to reduce the burn severity of a wildfire and subsequently reduce post-fire debris flow severity, however the steep hillsides along the creek will decrease the effectiveness of these mitigation strategies. Debris and rock nets installed on the hillside could help to catch larger debris and reduce damage to the roads.

There are also multiple water structures that would be moderately susceptible to debris flow post-fire, and a building that could see severe impacts from debris flow. Due to the limited impact of pre-fire mitigation, post-fire mitigation efforts will be critical. Armoring the creek near the building and water rights structures, installation of berms and/or sandbag walls, and the installation of a warning system for life safety should all be considered as immediate post-fire mitigation projects should a fire happen in this drainage.

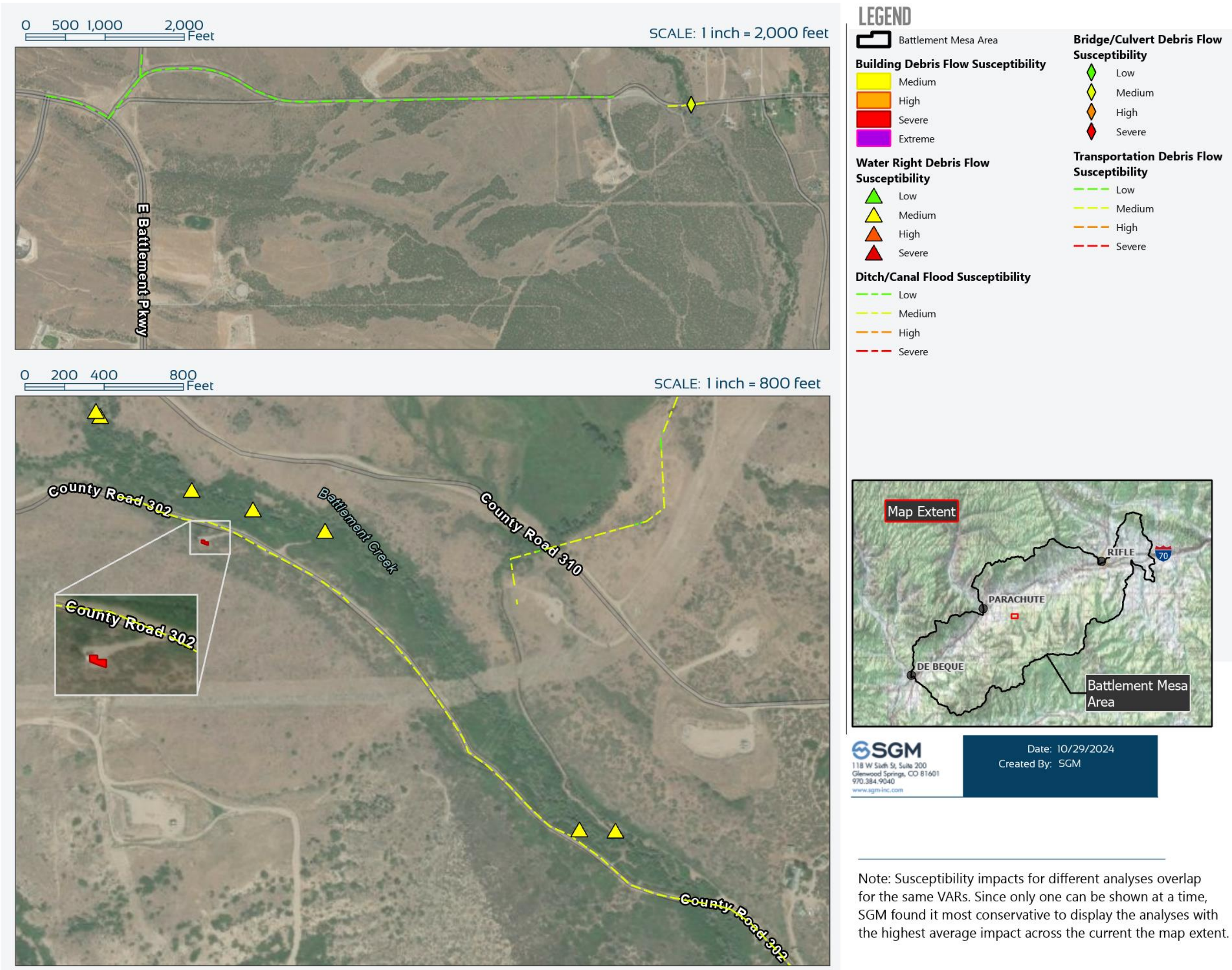


*Figure 9-34. Susceptible VARs along Battlement Creek*

The Battlement Mesa and Parachute area could have impacts from debris flow and sediment transfer after a fire, both from northern and southern watershed impacts (**Figure 9-35**). There are multiple critical facilities, culverts, sections of major roads (Highway 6 and 24, I-70, County Rd 304, and the railroad tracks), and a source water intake that have a low susceptibility to debris flow and sediment (highlighted in **Figure 9-36**). Key culverts, crossings, and the source water intake should be considered for debris racks or sediment catchments. Similarly, crossings should be evaluated for potential upsizing near Highway 6 and the train rail. Post-fire berming or installation of deflection walls near critical facilities could help to reduce potential impacts of debris flows.

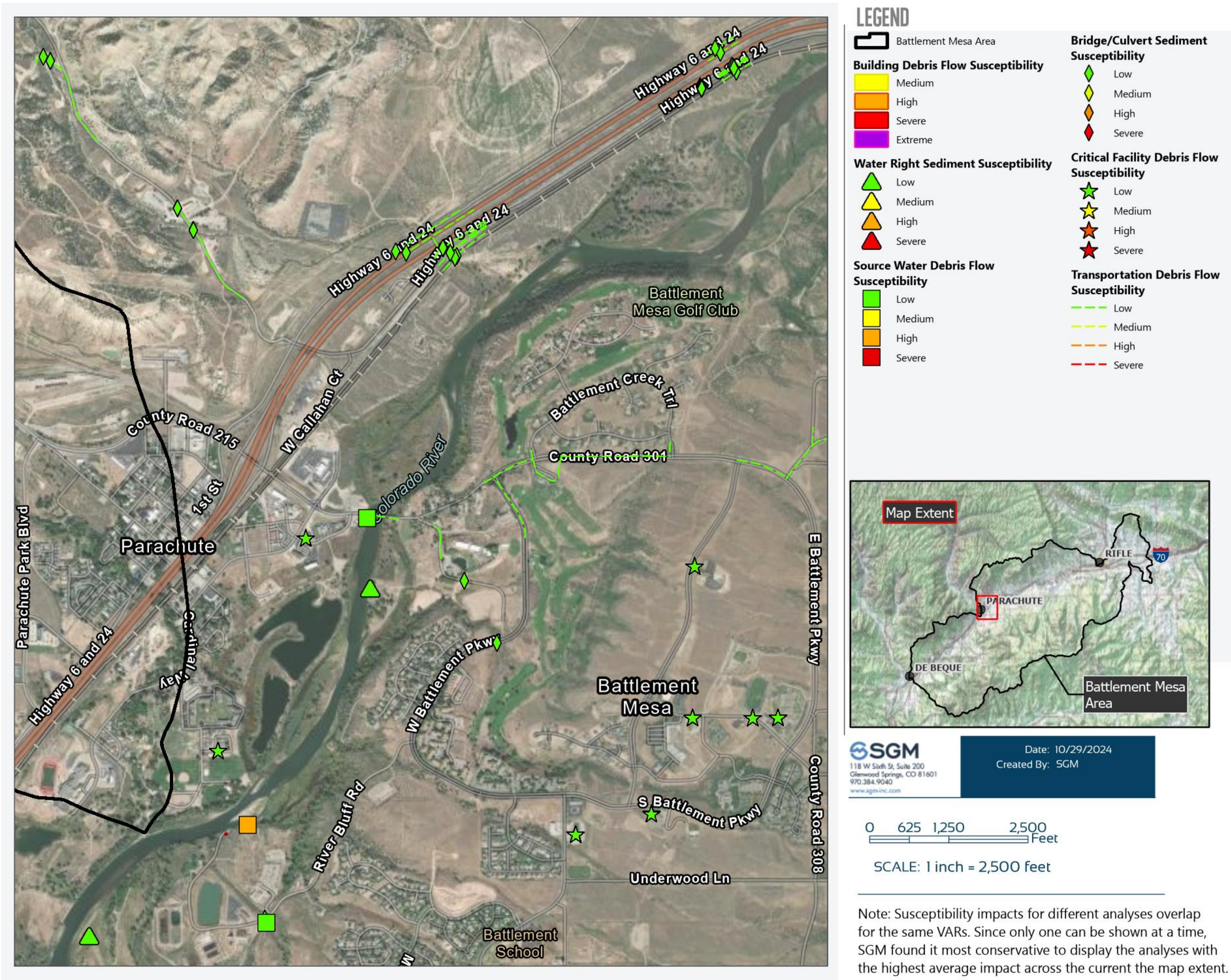


*Figure 9-35. Susceptible VARs in the Battlement Mesa and Parachute area*

There is one section south of Parachute, south of the Colorado River near River Bluff Rd. that could see higher levels of debris flow, resulting in a building that could be severely impacted, as well as a source water intake that is highly susceptible, as highlighted in **Figure 9-36**. The proximity to the Colorado River is the main driver behind this risk, therefore, reinforcing the intake structure and installing berms around the susceptible building may help reduce debris flow impacts.

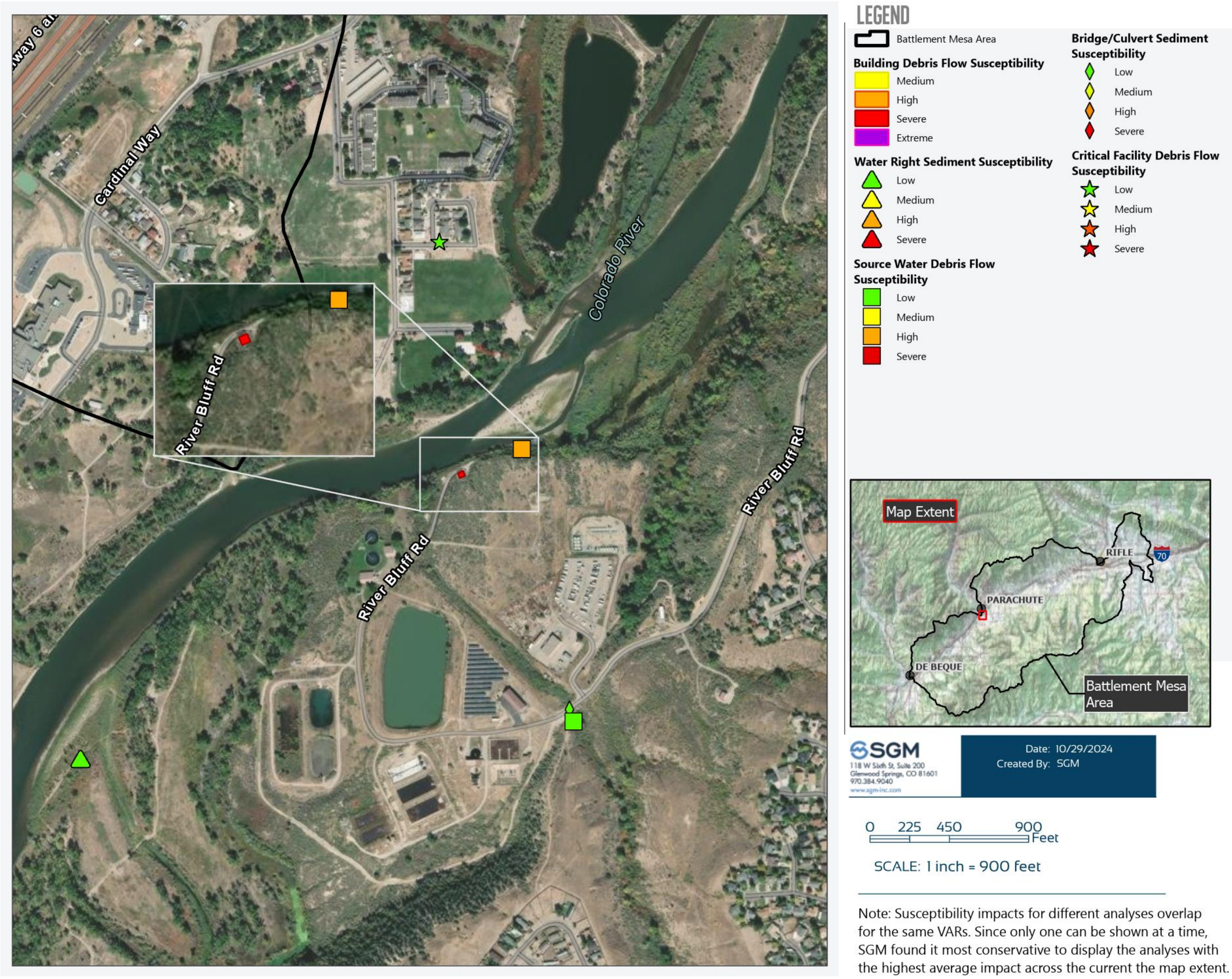


*Figure 9-36. Susceptible VARs south of Parachute along the Colorado River*

In the Monument Gulch area, south of Parachute and Battlement Mesa, the Bea Underwood Elementary School could see low levels of impact from debris flow (**Figure 9-37**). Along the main road south of the school along Stone Quarry Rd., there are multiple buildings that are moderately susceptible to debris flow. Armoring the gulch near these buildings, installation of berms and/or sandbag walls where needed and the installation of a warning system for life safety should all be considered as immediate post-fire mitigation projects should a fire happen in this watershed. Analyzing and possibly improving the stormwater systems in this area could also help to direct flows away from the susceptible buildings.


*Figure 9-37. Susceptible VARs along Stone Quarry Road in the Monument Gulch area*

## Wallace and Spring Creeks

At the mouth of Spring Creek, along Stone Quarry Rd., there are multiple buildings that are moderately and severely susceptible to debris flow (**Figure 9-38**). Post-fire, the installation of an early warning system will be critical to life safety for these buildings. The installation of berms and/or sandbag walls to redirect flows and floodwater should also be considered to protect these structures.

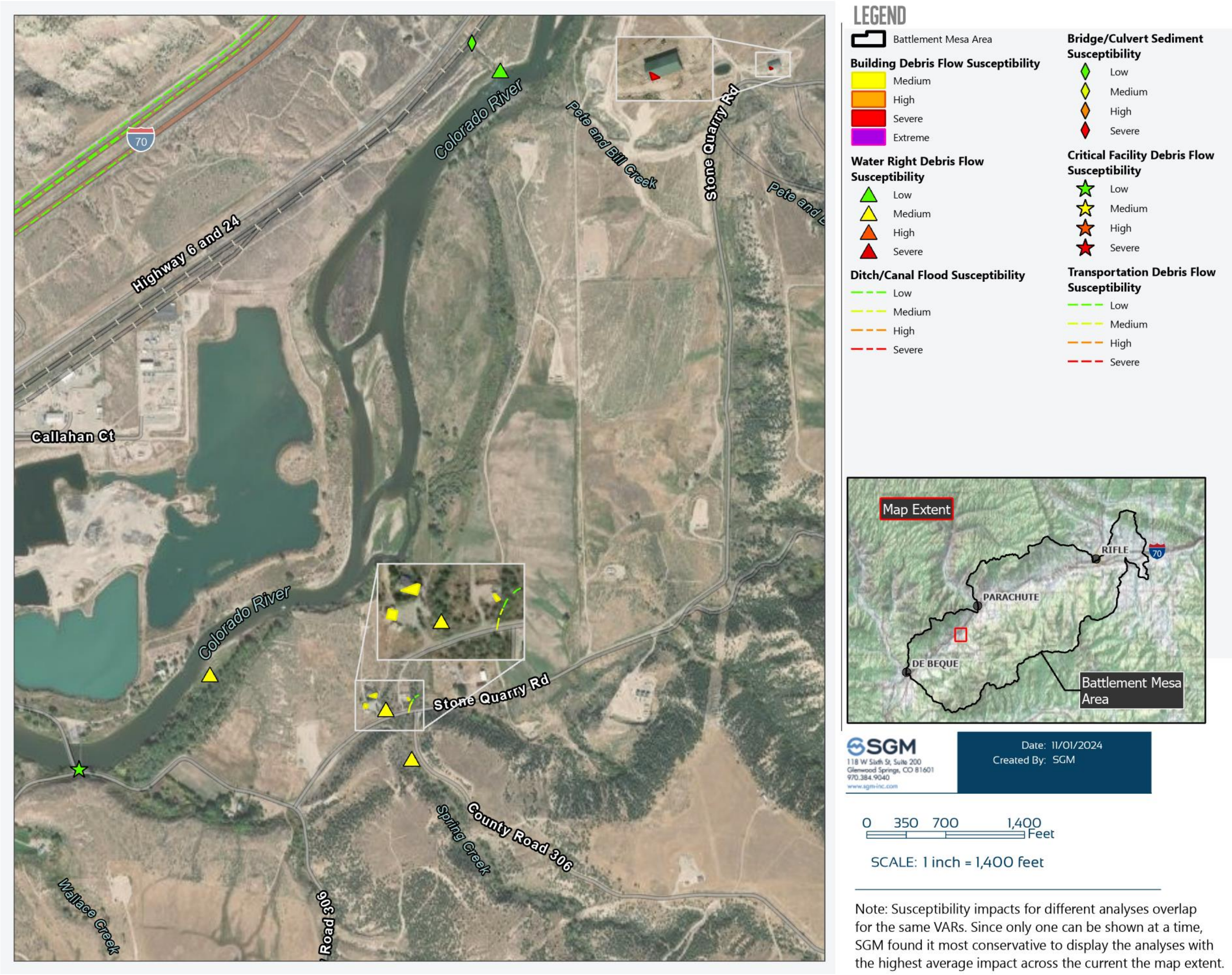


*Figure 9-38. Susceptible VARs near the mouth of Spring Creek*

Along Wallace Creek, large portions of Housetop Mountain Rd. could be impacted by debris flow, and many of the water rights and crossings within the creek's floodplain could be moderately impacted by debris and sediment flows (**Figure 9-39**). There are also multiple buildings that are moderately susceptible to debris flow along Wallace Creek as well. (**Figure 9-40**).

Some pre-fire burn severity mitigation may be effective in the upland areas of this watershed to decrease the severity of post-fire hazards. Post-fire, the installation of a warning system to protect life safety and potential close the road will be critical.

In a post-fire environment, armoring of the creek along the roadside, installation of barriers and debris nets may help to reduce roadway impacts. The installation of debris racks and sediment traps should be considered for the identified crossings – as well as consideration for the sizing of these crossings to adequately pass post-fire peak flows. The susceptible water rights should be reinforced and armored to reduce post-fire impacts.

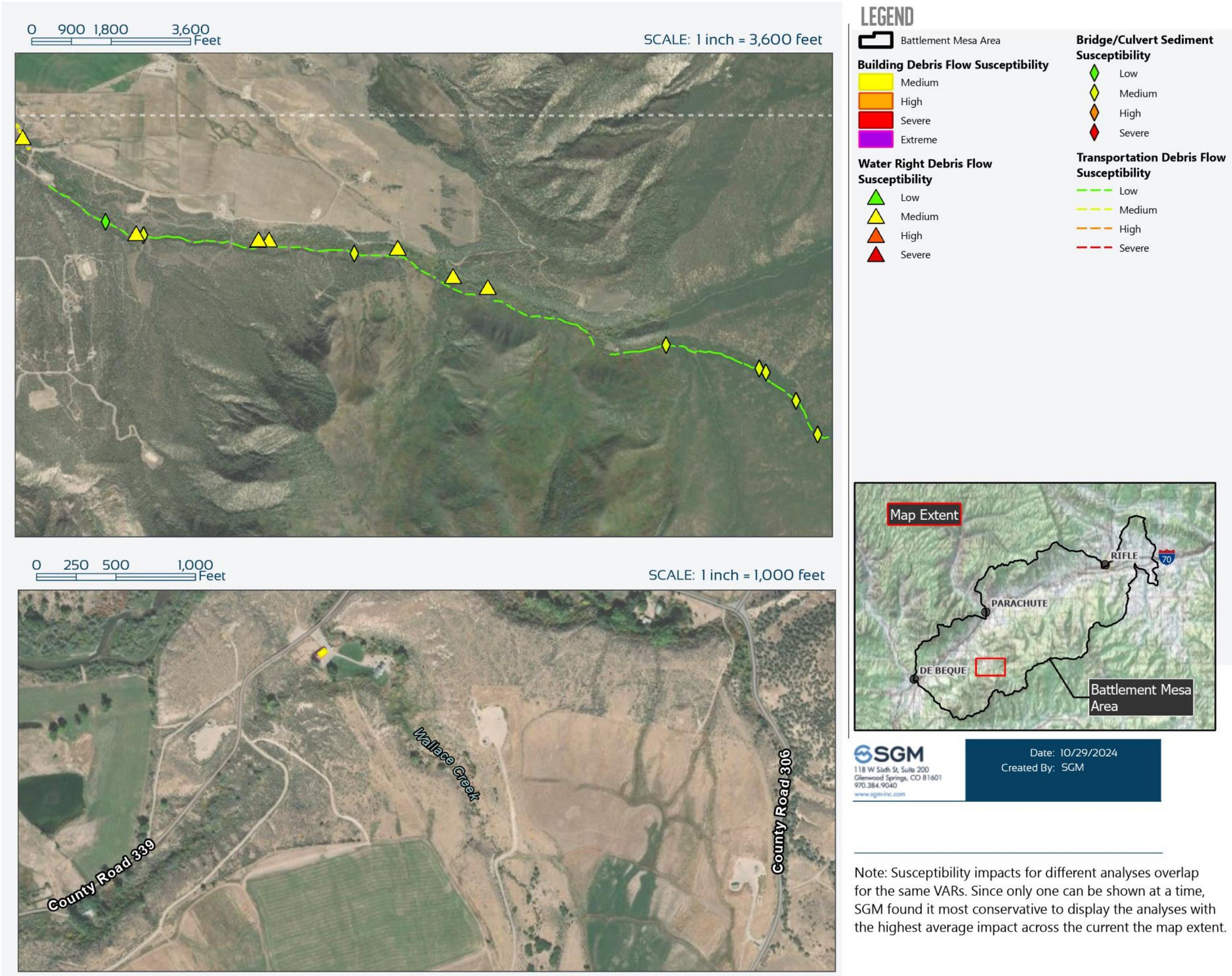


*Figure 9-39. Susceptible VARs along upper Wallace Creek and Housetop Mountain Rd*

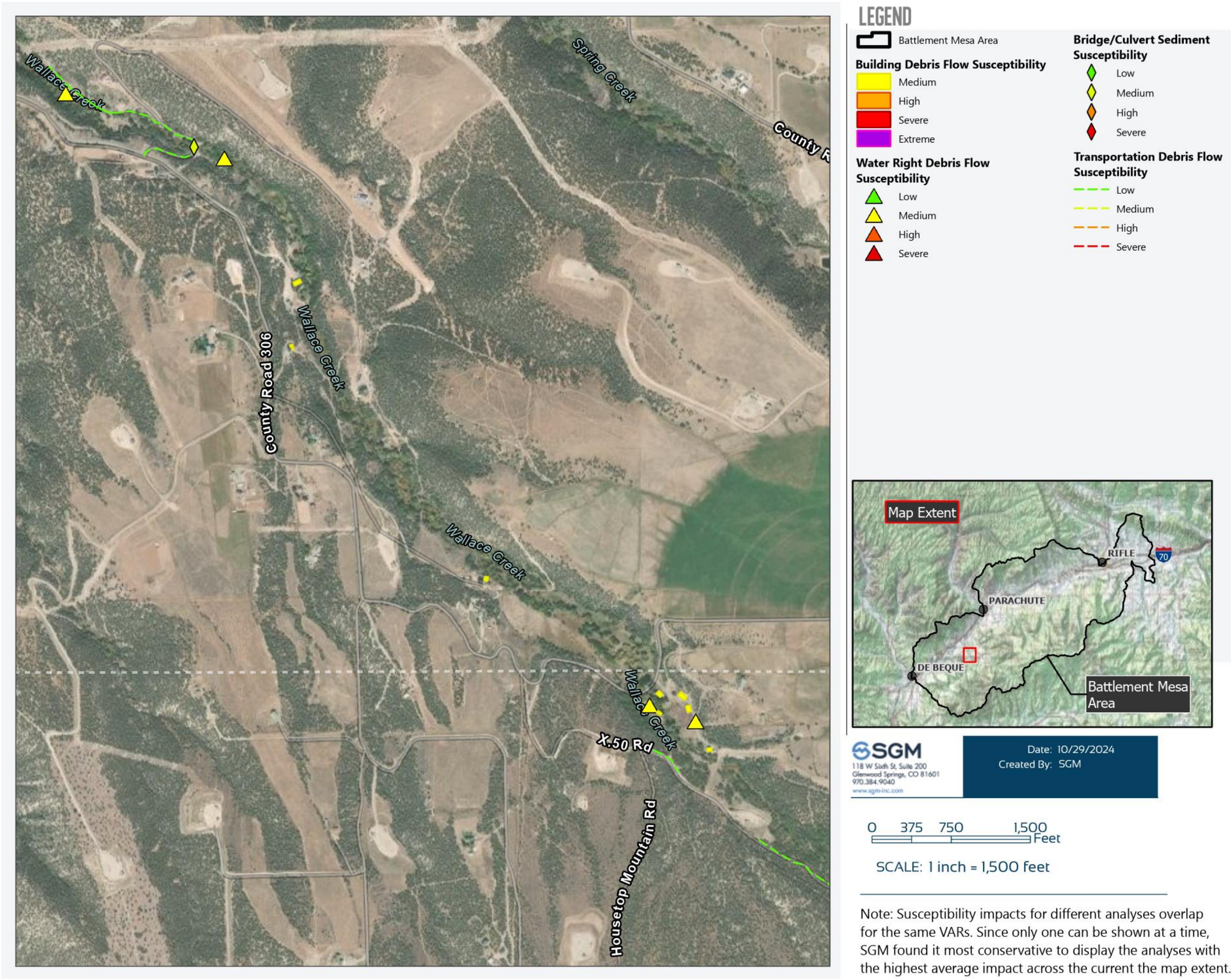


*Figure 9-40. Susceptible VARs along lower Wallace Creek*

## Alkali Creek

Alkali Creek would not see too many impacts to VARs post-fire due to the limited infrastructure next to the creek; however, there are a few water rights structures that are moderately susceptible to debris flow, as shown in **Figure 9-41**. Any possible stream restoration in this area (if feasible and appropriate) could help lessen the impacts to these structures. Post-fire, these headgates should be considered for armoring and the installation of debris racks to prevent damage to the structures.

There is one building that could be moderately impacted by Debris Flow near the mouth of Little Alkali Creek. Additionally, where River Rd. crosses over Alkali Creek is moderately susceptible to sediment and debris flow. Pre-fire, this crossing should be considered for possible upsizing this crossing. Post-fire, installing a debris rack, sediment control, and possible armoring could help reduce potential damage.

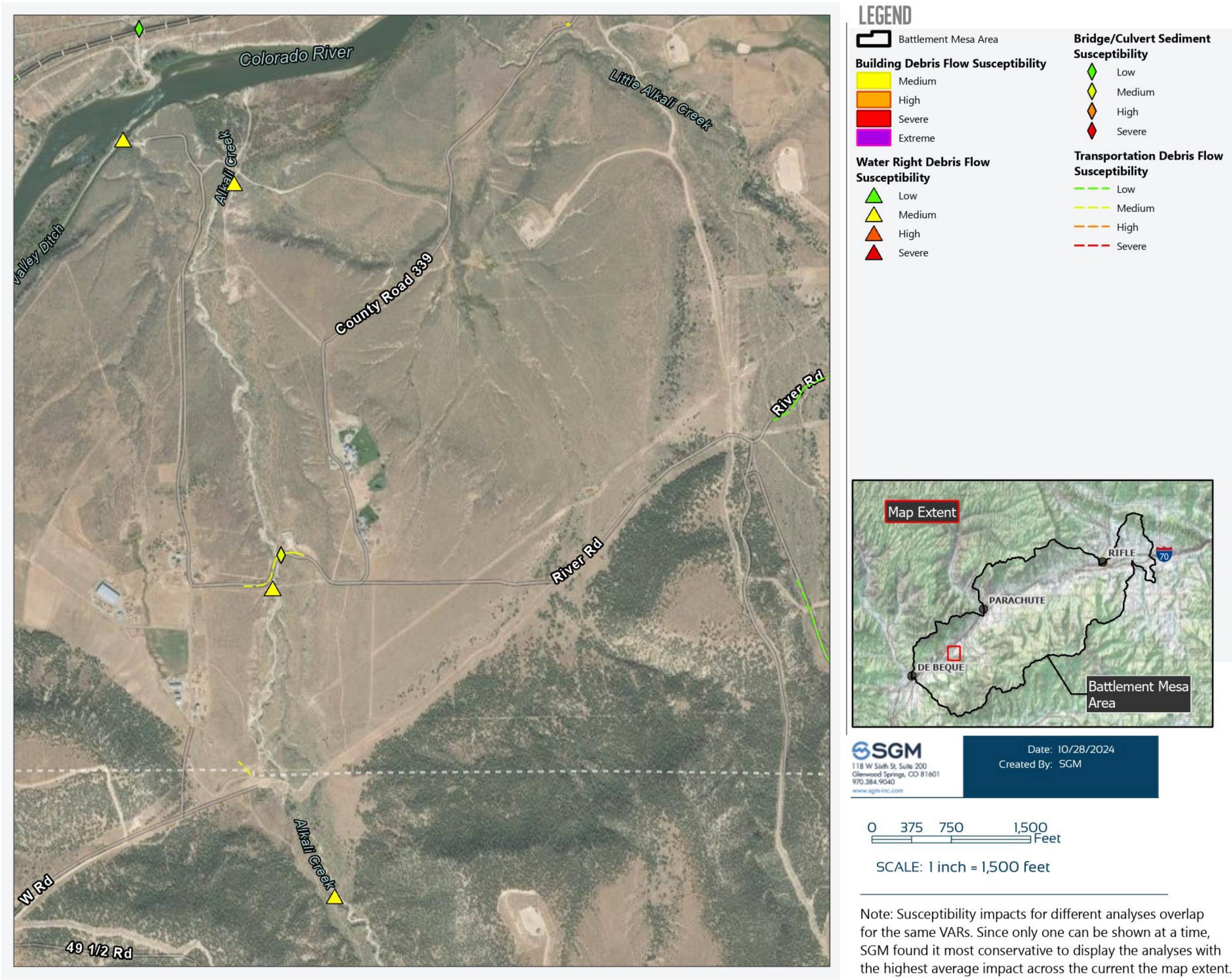


*Figure 9-41. Susceptible VARs along Alkali Creek*

## Samson Creek

At the mouth of Samson Creek, located at the westernmost edge in the Battlement Mesa study area south of De Beque, there is a critical facility—the De Beque Fire Protection District—that is severely susceptible to flooding after a fire, as well as a highly susceptible building. Deflection walls and berms could help to redirect flows away from the critical facility. The I-70 corridor and nearby roads in this area could also be impacted by debris flows (**Figure 9-42**). Roadside barriers and planned overflow paths could help reduce impacts to the highway and interstate. Additionally, rainfall events should be watched closely and potential road closures during severe events may help to reduce impact to civilians.

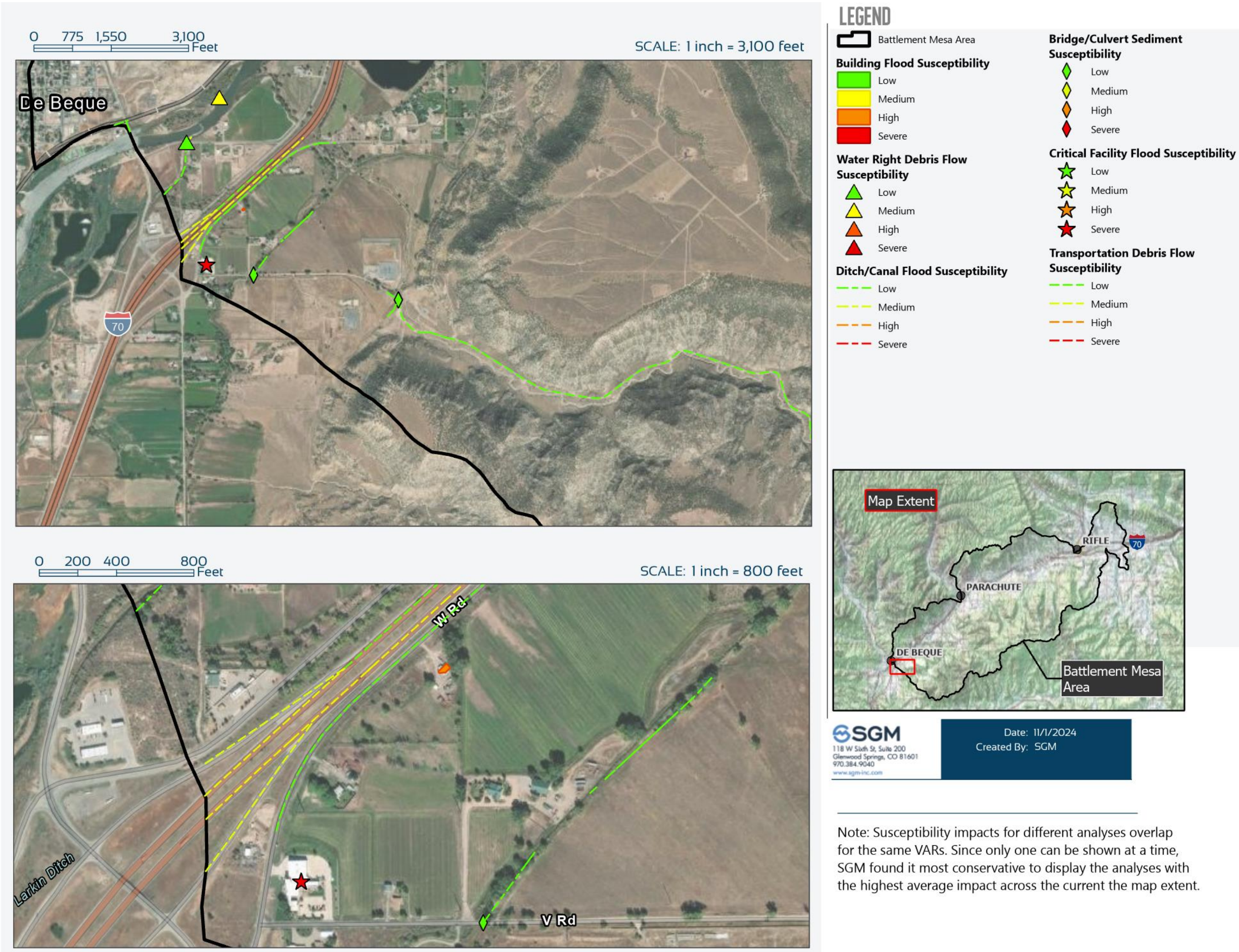


*Figure 9-42. Susceptible VARs along Samson Creek and at the mouth, near De Beque*

Samson Creek is surrounded by steep slopes on either side that could slough off debris and sediment flow during a rain event. Floodplain reconnectivity could be effective between where Samson Creek and V Rd come out of the edge of the mesas up to the Bluestone Valley Ditch, which could help reduce the severity of flood and sediment impacts to the critical facility and highway downstream.

## Watersheds North of Colorado River

Cottonwood Gulch, located north of the Colorado River near Parachute, runs through a very steep canyon with sharp hillslope mesas on either side. The main road in and out of this area is somewhat susceptible to debris flow. There are two buildings that could be severely impacted by flooding in this area, and two that are moderately susceptible to debris flows, as highlighted in **Figure 9-43**. The interstate, major roads, and culverts at the mouth of the canyon could see moderate debris flows and sediment impacts. Key culverts should be considered for armoring and upsizing prior to a fire. Prescribed burning prior to a fire may help to reduce the burn severity and subsequent severity of post-fire debris flow.

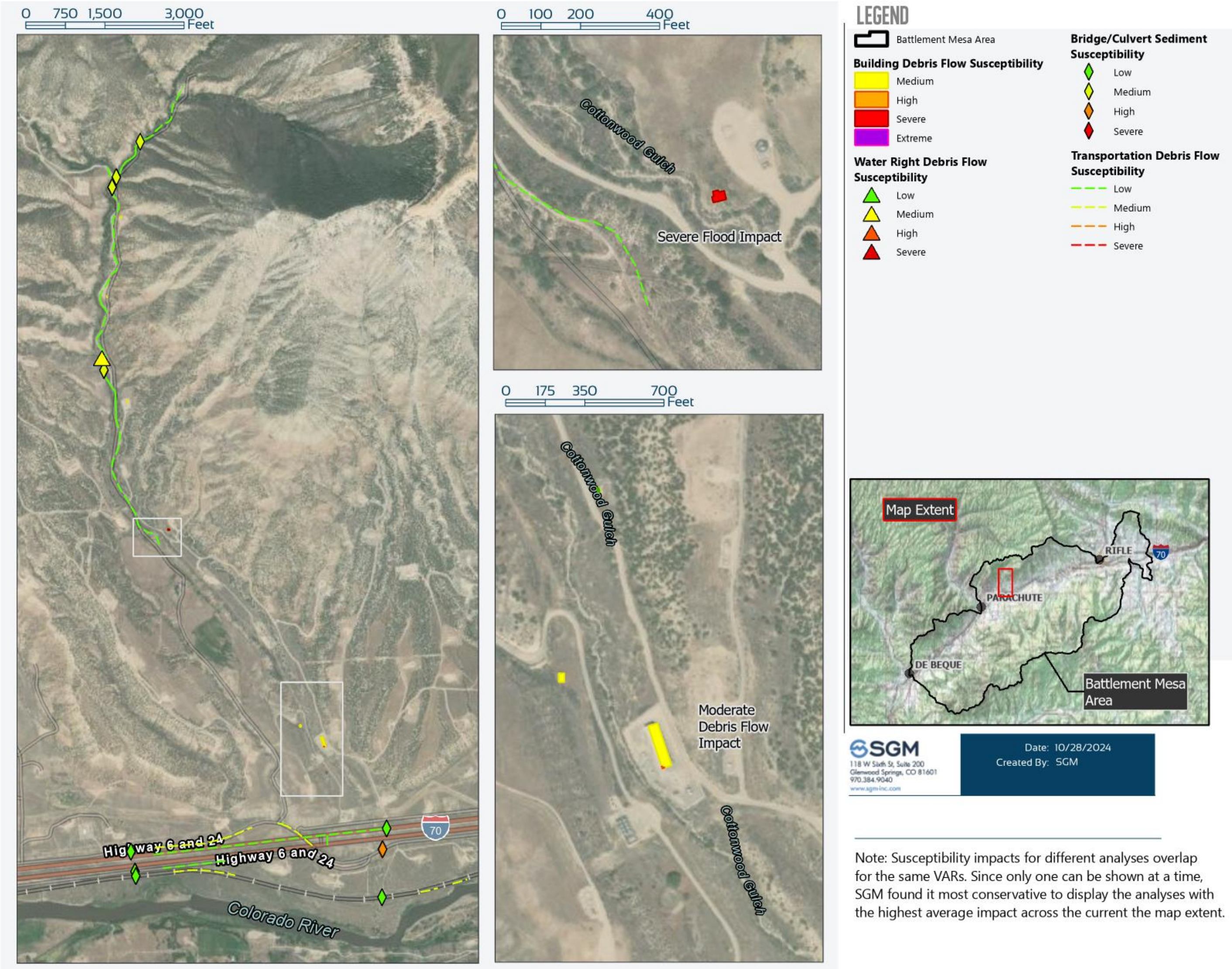


*Figure 9-43. Susceptible VARs along Cottonwood Gulch northeast of Parachute*

Slightly northeast of De Beque (**Figure 9-44)**, there are multiple sections of the interstate, the I-70 Frontage Rd., and the train track that could see impacts from debris flow. Many of the culverts along these sections could also be impacted by sediment flows. Installing debris screens or upsizing the culverts in these areas could assist with reducing potential travel impacts.

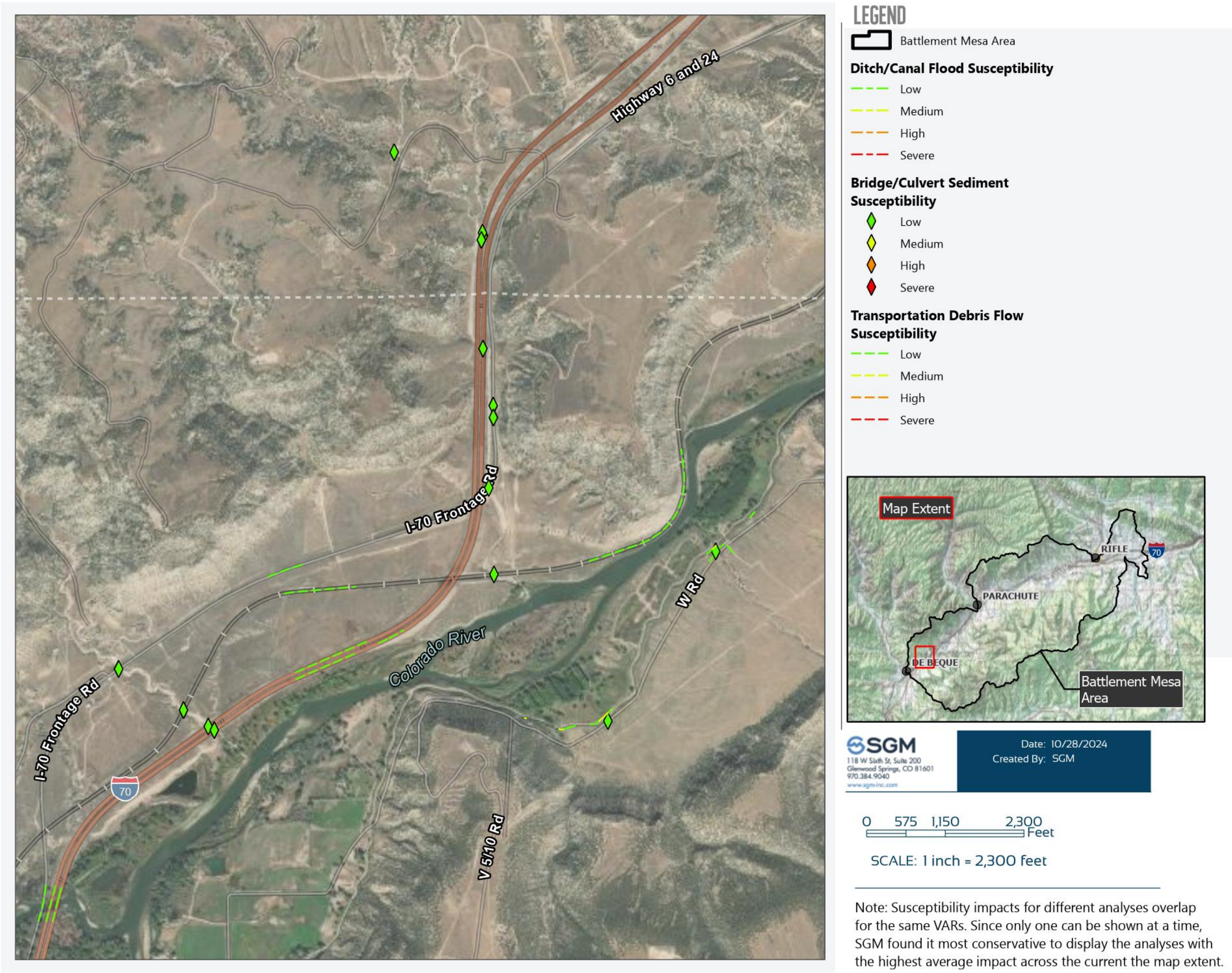


*Figure 9-44. Susceptible VARs along I-70, northeast of De Beque*

# 10. CITATIONS AND REFERENCES

Citations are listed in alphabetical order by the citation used in the text. Hyperlinks are provided where possible.


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# 11. EXHIBITS

## 11.1. Exhibit A – Memorandum of Understanding

## 11.2. Exhibit B – GIS Data Overview

## 11.3. Exhibit C – Hazard Evaluations Technical Memorandums

## 11.4. Exhibit D – Susceptibility Analysis

## 11.5. Exhibit E – Identified Potential Mitigation Areas

## 11.6. Exhibit F – Project Datasheets

# Exhibit A – Memorandum of Understanding

FS Agreement No. 24-MU-11021500

Cooperator Agreement No. _______________

# Colorado River Wildfire Collaborative

**MEMORANDUM OF UNDERSTANDING**

**USDI, BUREAU OF LAND MANAGEMENT, COLORADO RIVER VALLEY FIELD OFFICE, UPPER COLORADO RIVER DISTRICT**

**AND**

**USDI, BUREAU OF LAND MANAGEMENT, GRAND JUNCTION FIELD OFFICE**

**AND**

**USDA, FOREST SERVICE, WHITE RIVER NATIONAL FOREST**

**AND**

**USDA, FOREST SERVICE, GRAND VALLEY RANGER DISTRICT, GRAND MESA, UNCOMPAHGRE, AND GUNNISON NATIONAL FORESTS**

**AND**

**COLORADO STATE FOREST SERVICE**

**AND**

**COLORADO PARKS AND WILDLIFE**

**AND**

**COLORADO RIVER FIRE RESCUE**

**AND**

**DE BEQUE FIRE PROTECTION DISTRICT**

**AND**

**GRAND VALLEY FIRE PROTECTION DISTRICT**

**AND**

**LOWER VALLEY FIRE DISTRICT**

**AND**

**PLATEAU VALLEY FIRE DISTRICT**

**AND**

**GLENWOOD SPRINGS RURAL FIRE PROTECTION DISTRICT**

**AND**

**GARFIELD COUNTY**

**AND**

**MESA COUNTY**

**AND**

**TOWN OF SILT**

**AND**

**CITY OF RIFLE**

**AND**

**TOWN OF NEWCASTLE**

**AND**

**CITY OF GLENWOOD SPRINGS**

**AND**

**TOWN OF PARACHUTE**

**AND**

**TOWN OF DE BEQUE**

**AND**

**TOWN OF COLLBRAN**

**AND**

**BATTLEMENT MESA METROPOLITAN DISTRICT**

This MEMORANDUM OF UNDERSTANDING (MOU) is hereby made and entered into by and between Garfield County, Mesa County, The City of Rifle, The Town of New Castle, The Town of Silt, The Town of Parachute, The City of Glenwood Springs, Town of De Beque, Town of Collbran, Battlement Mesa Metropolitan District, Colorado River Fire Rescue, Grand Valley Fire Protection District, De Beque Fire Protection District, Glenwood Springs Rural Fire Protection District, Colorado State Forest Service, Colorado Parks and Wildlife, and The Bureau of Land Management Colorado River Field Office and the BLM Grand Junction Field Office, hereinafter referred to as Parties, Members, or Cooperators, and the United States Department of Agriculture (USDA), Forest Service, White River National Forest, Rifle Ranger District, and the Grand Mesa, Uncompahgre and Gunnison (GMUG) National Forests.

Background: The Colorado River Wildfire Collaborative works to empower all people to take action to reduce risk in their communities to protect people, property, and places from wildfire loss. The Parties recognize, accept, and respect the differences in missions, goals, and objectives of each other. However, wildfire does not recognize or respect jurisdictional boundaries. The Parties therefore will work collaboratively and in a coordinated fashion to achieve the shared goals of the MOU.

Title: Colorado River Wildfire Collaborative (CRWC)

**I. PURPOSE:** The purpose of this MOU is to document the cooperation between the parties to establish the Collaborative as an informal, unincorporated collaborative organization, in which the members set mutual goals and priorities, utilize existing forest management tools and legal authorities, and align their decisions on where to make the investments needed to achieve the purpose and goals set forth for the Colorado River Wildfire Collaborative and in accordance with the following provisions.

## II. STATEMENT OF MUTUAL BENEFIT AND INTERESTS:

The Colorado River Wildfire Collaborative works to reduce wildfire risk by identifying, prioritizing, and implementing strategic cross-boundary plans and projects aimed at creating fire resilient landscapes and fire-adapted communities while focusing on community engagement, education, and inclusion.

In entering into this MOU, the Cooperators and the U.S. Forest Service recognize that the parties share certain common interests and goals, which include the following:

- Meaningful and ongoing engagement of stakeholders located in the forest and downstream in the development of strategies to achieve outcomes and foster support for the implementation of those strategies.

- A regional network of resilient forests and communities that are better able to absorb and recover from current and future stressors and disturbances.
- A collaboratively developed and supported fire management strategy (wildland and prescribed) so that wildfires are safely and effectively extinguished when and where needed, but also in the right circumstances.
- Resilient landscapes and infrastructure that support water quality and quantity needs, habitat for robust and healthy flora and fauna, livestock grazing, as well as recreation opportunities for residents and visitors to enjoy now and in the future.
- Active management to enhance forest health and reduce wildfire risk based on the best available data and contemporary science to inform the development and application of on-the-ground activities including landscape scale and cross boundary projects where needed. This includes the use of the best available science that will help stakeholders understand how a changing climate will impact our landscapes and ecosystems, while also looking for opportunities to improve understanding through local research.
- Promoting the personal responsibility of residents who live in wildfire risk areas to prepare as follows:

  *homes are built or improved to best resist wildfire;

  *defensible space around homes is created and maintained;

  * insurance policies are regularly updated;

  *emergency alerts are receivable and acted upon;

  *evacuation plans are learned and understood;

  *community mitigation initiatives are engaged in and are sought.
- Develop and implement risk assessment and strategies to evaluate critical infrastructure and increase overall resiliency to wildfire and to lessen the long-term effects that wildfires have on our stream corridors, water infrastructure, and community assets.

To accomplish the above goals, each party commits to:

- Work within their own statutory and regulatory authorities, including planning and decision-making requirements where applicable.
- Collaborate and coordinate to implement this MOU to achieve the purpose and goals expressed herein.

In consideration of the above premises, the parties agree as follows:

## III. THE COOPERATORS SHALL:

A. Provide a liaison to link the parties of this MOU together.

B. Coordinate with the U.S. Forest Service, non-profit organizations, for-profit organizations, institutions of higher education, federal, state, local, and Native American tribe governments, and individuals.

## IV. THE COOPERATORS SHALL:

**(For Non-Profits and Non-Governmental Organizations Only)**

A. Provide a liaison to link the parties of this MOU together.

B. Coordinate with the U.S. Forest Service, non-profit organizations, for-profit organizations, institutions of higher education, federal, state, local, and Native American tribe governments, and individuals.

C. ASSURANCE REGARDING FELONY CONVICTION OR TAX DELINQUENT STATUS FOR CORPORATE ENTITIES. This agreement is

subject to the provisions contained in the Department of Interior, Environment, and Related Agencies Appropriations Act, 2012, P.L. No. 112-74, Division E, Section 433 and 434 regarding corporate felony convictions and corporate federal tax delinquencies. Accordingly, by entering into this agreement Cooperators acknowledges that it: 1) does not have a tax delinquency, meaning that it is not subject to any unpaid Federal tax liability that has been assessed, for which all judicial and administrative remedies have been exhausted or have lapsed, and that is not being paid in a timely manner pursuant to an agreement with the authority responsible for collecting the tax liability, and (2) has not been convicted (or had an officer or agent acting on its behalf convicted) of a felony criminal violation under any Federal law within 24 months preceding the agreement, unless a suspending and debarring official of the USDA has considered suspension or debarment is not necessary to protect the interests of the Government. If Cooperators fail to comply with these provisions, the U.S. Forest Service will annul this agreement and may recover any funds Cooperators has expended in violation of sections 433 and 434.

## V. THE U.S. FOREST SERVICE SHALL:

A. Provide a liaison to link the parties of this MOU together.

B. Ensure that all planning and site-based data collection activities comply with forest plans, National Environmental Policy Act (NEPA) documents, and all applicable laws and regulations.

C. Coordinate with the Parties to this MOU, non-profit organizations, for-profit organizations, institutions of higher education, federal, state, local, and Native American tribe governments, and individuals.

D. Execute necessary instrument(s) to allow Cooperator(s) to complete mutually agreed to activities and projects on National Forest System lands, which includes but is not limited to, providing Cooperator(s) and its agents access to federal lands to perform project implementation, maintenance, and monitoring activities at project sites.

E. Following completion of project implementation and the achievement of all required performance standards for given sites, act as the long-term steward of project sites, conducting any required maintenance.

## VI. IT IS MUTUALLY UNDERSTOOD AND AGREED BY AND BETWEEN THE PARTIES THAT:

A. The Parties recognize, accept, and respect the differences in missions, goals, and objectives of each other. However, wildfire does not recognize or respect jurisdictional boundaries. The Parties therefore agree to work collaboratively and in a coordinated fashion to achieve the purpose and goals sought and described in this MOU.

B. The Parties acknowledge that any Party to this MOU may participate in local activities or implement decisions related to forestry management as part of their site-specific obligations, responsibilities, and authorities. This MOU is not meant to supplant any Party's discretionary authority to make decisions about forest management or wildfire response associated with their individual jurisdictions.

C. This MOU is non-binding and does not obligate any funds of the Parties. As funding and resources are available and authorized (as determined in each Party's sole discretion), the Parties will provide technical, human, and/or financial support to the Partnership under an appropriate authority, as applicable, and by separate instrument(s).

D. PRINCIPAL CONTACTS. Individuals listed below are authorized to act in their respective areas for matters related to this agreement.

| **Garfield County Program Contact** | **Garfield County Administrative Contact** |
|---|---|
| John Martin, Chairman<br>Garfield County Board of County Commissioners<br>108 8th St, Glenwood Springs CO 81601<br>970-945-5004<br>jmartin@garfield-county.com | Chris Bornholdt<br>Commander, Garfield County Emergency Operations<br>107 8th St, Glenwood Springs CO 81601<br>970-945-0453 x 1012<br>cbornholdt@garcosheriff.com |

| Mesa County Program Contact | Mesa County Administrative Contact |
| --- | --- |
| Andy Martsolf<br>Mesa County Emergency Management<br>215 Rice St., Grand Junction CO 81501<br>970-244-1800<br>andrew.martsolf@mesacounty.us | Andy Martsolf<br>Mesa County Emergency Management<br>215 Rice St., Grand Junction CO 81501<br>970-244-1800<br>andrew.martsolf@mesacounty.us |

| City of Rifle Program Contact | City of Rifle Administrative Contact |
| --- | --- |
| Tommy Klein<br>City Manager<br>970-989-3149<br>tklein@rifleco.org | Tommy Klein<br>City Manager<br>970-989-3149<br>tklein@rifleco.org |

| Town of New Castle Program Contact | Town of New Castle Admin. Contact |
| --- | --- |
| David Reynolds<br>Town Administrator<br>Town of New Castle<br>450 W. Main Street<br>New Castle, CO 81647<br>970-984-2311<br>dreynolds@newcastlecolorado.org | Rochelle Firth<br>Assistant to the Town Administrator, PIO<br>Town of New Castle<br>450 W. Main Street<br>New Castle, CO 81647<br>970-984-2311<br>rfirth@newcastlecolorado.org |

| Town of Silt Program Contact | Town of Silt Administrative Contact |
| --- | --- |
| Trey Fonner<br>(970) 876-2353 Ext. 106<br>231 N. 7th Street<br>PO Box 70<br>Silt, CO 81652<br>trey@townofsilt.org | Amie Tucker<br>(970) 876-2353 Ext. 104<br>231 N. 7th Street<br>PO Box 70<br>Silt, CO 81652<br>atucker@townofsilt.org |

| Town of Parachute Program Contact | Town of Parachute Administrative Contact |
| --- | --- |
| Travis Elliott<br>Town Manager<br>Town of Parachute<br>222 Grand Valley Way<br>Parachute, CO 81635<br>970-665-1147<br>telliott@parachutecolorado.com | Teresa Beecraft<br>Finance Director<br>Town of Parachute<br>222 Grand Valley Way<br>Parachute, CO 81635<br>970-665-1145<br>tbeecraft@parachutecolorado.com |

| Town of De Beque Program Contact | Town of De Beque Administrative Contact |
|---|---|
| Care' McInnis, Town Manager<br>cmcinnis@debeque.org<br>970-270-3290<br>PO Box 60, 381 Mintur Ave, De Beque, CO 81630 | Care' McInnis, Town Manager<br>cmcinnis@debeque.org<br>970-270-3290<br>Evelyn Giertz, Administrative Assistant<br>egiertz@debeque.org<br>(970) 283-5475 ext 108<br>PO Box 60, 381 Mintur Ave, DeBeque, CO 81630 |

| Battlement Mesa Metropolitan District Program Contact | Battlement Mesa Metropolitan District Admin. Contact |
|---|---|
| Vinnie Tomasulo<br>vtomasulo@bmmetro.com<br>970-285-9050<br>401 Arroyo Drive, Battlement Mesa, CO 81635 | Vinnie Tomasulo<br>vtomasulo@bmmetro.com<br>970-285-9050<br>401 Arroyo Drive, Battlement Mesa, CO 81635 |

| Town of Collbran Program Contact | Town of Collbran Administrative Contact |
|---|---|
| Melonie Matarozzo<br>Town Administrator<br>Town of Collbran<br>1010 High Street<br>Collbran, Co 81624<br>970-487-3751<br>townmanager@townofcollbran.us | Melonie Matarozzo<br>Town Administrator<br>Town of Collbran<br>1010 High Street<br>Collbran, Co 81624<br>970-487-3751<br>townmanager@townofcollbran.us |

| City of Glenwood Springs Program Contact | City of Glenwood Springs Administrative Contact |
|---|---|
| Steve Boyd<br>970-384-6422<br>101 West 8th Street<br>Glenwood Springs, CO 81601<br>steve.boyd@cogs.us | Steve Boyd<br>970-384-6422<br>101 West 8th Street<br>Glenwood Springs, CO 81601<br>steve.boyd@cogs.us |

| Colorado River Fire Protection District Program Contact | Colorado River Fire Protection District Administrative Contact |
|---|---|
| Zach Pigati<br>Division Chief of Operations and Wildland<br>1850 Railroad Ave<br>Rifle, CO 81650<br>970-319-8787<br>zach.pigati@crfr.us | PJ Tillman<br>Administrative Director<br>1850 Railroad Ave<br>Rifle, CO 81650<br>970-625-1243<br>pj.tillman@crfr.us |

| Grand Valley Fire Protection District Program Contact | Grand Valley Fire Protection District Administrative Contact |
|---|---|
| Chris Jackson, Fire Chief<br>0124 Stone Quarry Road<br>Parachute, CO 81635<br>970-285-9119<br>opschief@gvfpd.org | Kim Reeves, Administrative Specialist<br>0124 Stone Quarry Road<br>Parachute, CO 81635<br>970-285-9119<br>admin@gvfpd.org |

| De Beque Fire Protection District Program Contact | De Beque Fire Protection District Administrative Contact |
|---|---|
| Forest Matis, Fire Chief<br>4580 I-70 Frontage Rd, De Beque, CO 81630<br>970-201-4088<br>forest.matis@debequefire.org | Jason Lee, Captain<br>4580 I-70 Frontage Rd, De Beque, CO 81630<br>970-283-8632<br>jason.lee@debequefire.org |

| Lower Valley Fire Protection District Program Contact | Lower Valley Fire Protection District Administrative Contact |
|---|---|
| Travis Holder, Fire Marshal<br>970-296-4258<br>tholder@lvfdfire.org<br>168 N Mesa St., Fruita CO 81521 | Frank Cavaliere, Fire Chief<br>970-858-3133<br>fcavaliere@lvfdfire.org<br>168 N Mesa St., Fruita CO 81521 |

| Plateau Valley Fire Protection District Program Contact | Plateau Valley Fire Protection District Administrative Contact |
|---|---|
| Karl Belden<br>49084 Ke ½ Rd, Mesa CO 81643<br>970-985-0474<br>k.beldenjr@pvfiredept.org | Eric Bruton<br>Acting Fire Chief<br>49084 Ke ½ Rd., Mesa CO 81643<br>970-261-9773<br>e.bruton@pvfiredept.org |

| Glenwood Springs Rural Fire Protection District Contact | Glenwood Springs Rural Fire Protection District Administrative Contact |
|---|---|
| Gary Tillotson 101<br>W 8th Street<br>Glenwood Springs, CO 81601<br>Telephone: 970-384-6480<br>Email: gary.tillotson@cogs.us | Mina Bolton 101<br>W 8th Street<br>Glenwood Springs, CO 81601<br>Telephone: 970-384-6436<br>Email:mina.bolton@cogs.us |

| Colorado State Forest Service Program Contact | Colorado State Forest Service Administrative Contact |
|---|---|
| Ron Cousineau<br>Northwest Area<br>PO Box 69<br>Granby, CO 80446<br>Telephone: 970-217-7022<br>Email: ron.cousineau@colostate.edu | Scott Woods<br>9769 W 119th Drive, Suite 12<br>Broomfield, CO 80021<br>Telephone: 303-404-9057<br>Email:scott.woods@colostate.edu |

| Colorado Parks and Wildlife Program Contact | Colorado Parks and Wildlife Administrative Contact (alt contact) |
|---|---|
| Molly West<br>711 Independent Ave<br>Grand Junction, CO 81504<br>Telephone: 970-250-3818<br>Email: molly.west@state.co.us | Ivan Archer<br>711 Independent Ave<br>Grand Junction, CO 81504<br>Telephone: 970-200-4026<br>Email:ivan.archer@state.co.us |

| Bureau of Land Management, Colorado River Valley Field Office Program Contact | Bureau of Land Management, Colorado River Valley Field Office Administrative Contact |
|---|---|
| Chad Sewell<br>2300 River Frontage Road Silt,<br>CO 81652<br>Telephone: 970-876-9030<br>Email: csewell@blm.gov | Larry Sandoval<br>2300 River Frontage Road<br>Silt, CO 81652<br>Telephone: 970-876-9002<br>Email: lsandoval@blm.gov |

| Grand Mesa, Uncompahgre and Gunnison National Forests<br>Grand Valley Ranger District<br>Program Contact | Grand Mesa, Uncompahgre and Gunnison National Forests<br>Grand Valley Ranger DistrictAdministrative Contact |
|---|---|
| William Edwards, District Ranger<br>1010 Kimball Ave<br>Grand Junction, CO 81501<br>Telephone: 970-765-6600<br>Email:<br>william.edwards@usda.gov | Amy Sharp<br>1010 Kimball Ave<br>Grand Junction, CO 81501<br>Telephone: 720-689-<br>7045<br>Email:<br>amy.shar@usda.gov |

**Principal U.S. Forest Service Contacts:**

| U.S. Forest Service Program Manager Contact | U.S. Forest Service Administrative Contact |
|---|---|
| Clark Woolley, Partnership Coordinator 900 Grand Avenue Glenwood Springs, CO Telephone: 970-948-9803 Email: clark.woolley@usda.gov | Alex Specht, Grants Management Specialist<br>900 Grand Ave<br>Glenwood Springs, CO 81601<br>Telephone: 605-515-8812 Email: alex.specht@usda.gov |

E. NOTICES. Any communications affecting the operations covered by this agreement given by the U.S. Forest Service or Cooperators is sufficient only if in writing and delivered in person, mailed, or transmitted electronically by e-mail or fax, as follows:

To the U.S. Forest Service Program Manager, at the address specified in the MOU.

To Cooperators, at Cooperator's address shown in the MOU or such other address designated within the MOU.

Notices are effective when delivered in accordance with this provision, or on the effective date of the notice, whichever is later.

F. PARTICIPATION IN SIMILAR ACTIVITIES. This MOU in no way restricts the U.S. Forest Service or Cooperators from participating in similar activities with other public or private agencies, organizations, and individuals.

G. ENDORSEMENT. Any of Cooperator's contributions made under this MOU do not by direct reference or implication convey U.S. Forest Service endorsement of Cooperators' products or activities.

H. NONBINDING AGREEMENT. This MOU creates no right, benefit, or trust responsibility, substantive or procedural, enforceable by law or equity. The parties shall manage their respective resources and activities in a separate, coordinated and mutually beneficial manner to meet the purpose(s) of this MOU. Nothing in this MOU authorizes any of the parties to obligate or transfer anything of value.

Specific, prospective projects or activities that involve the transfer of funds, services, property, and/or anything of value to a party requires the execution of separate agreements and are contingent upon numerous factors, including, as applicable, but not limited to: agency availability of appropriated funds and other resources; cooperator availability of funds and other resources; agency and cooperator administrative and legal requirements (including agency authorization by statute); etc. This MOU neither provides, nor meets these criteria. If the parties elect to enter into an obligation agreement that involves the transfer of funds, services, property, and/or anything of value to a party, then the applicable criteria must be met. Additionally, under a prospective agreement, each party operates under its own laws, regulations, and/or policies, and any Forest Service obligation is subject to the availability of appropriated funds and other resources. The negotiation, execution, and administration of these prospective agreements must comply with all applicable law.

Nothing in this MOU is intended to alter, limit, or expand the agencies' statutory and regulatory authority.

I. USE OF U.S. FOREST SERVICE INSIGNIA. In order for Cooperators to use the U.S. Forest Service insignia on any published media, such as a Web page, printed publication, or audiovisual production, permission must be granted from the U.S. Forest Service's Office of Communications.

A written request must be submitted and approval granted in writing by the Office of Communications (Washington Office) prior to use of the insignia.

J. MEMBERS OF U.S. CONGRESS. Pursuant to 41 U.S.C. 22, no U.S. member of, or U.S. delegate to, Congress shall be admitted to any share or part of this agreement, or benefits that may arise therefrom, either directly or indirectly.

K. FREEDOM OF INFORMATION ACT (FOIA). Public access to MOU or

agreement records must not be limited, except when such records must be kept confidential and would have been exempted from disclosure pursuant to Freedom of Information regulations (5 U.S.C. 552).

L. TEXT MESSAGING WHILE DRIVING. In accordance with Executive Order (EO) 13513, "Federal Leadership on Reducing Text Messaging While Driving,"

any and all text messaging by Federal employees is banned: a) while driving a Government owned vehicle (GOV) or driving a privately owned vehicle (POV) while on official Government business; or b) using any electronic equipment supplied by the Government when driving any vehicle at any time. All cooperators, their employees, volunteers, and contractors are encouraged to adopt and enforce policies that ban text messaging when driving company owned, leased or rented vehicles, POVs or GOVs when driving while on official Government business or when performing any work for or on behalf of the Government.

M. TERMINATION. Any of the parties, in writing, may terminate this MOU in whole, or in part, at any time before the date of expiration.

N. DEBARMENT AND SUSPENSION. Cooperators shall immediately inform the

U.S. Forest Service if they or any of their principals are presently excluded, debarred, or suspended from entering into covered transactions with the federal government according to the terms of 2 CFR Part 180. Additionally, should Cooperators or any of their principals receive a transmittal letter or other official Federal notice of debarment or suspension, then they shall notify the U.S. Forest Service without undue delay. This applies whether the exclusion, debarment, or suspension is voluntary or involuntary.

O. MODIFICATIONS. Modifications within the scope of this MOU must be made by mutual consent of the parties, by the issuance of a written modification signed and dated by all properly authorized, signatory officials, prior to any changes being performed. Requests for modification should be made, in writing, at least 30 days prior to implementation of the requested change.

P. COMMENCEMENT/EXPIRATION DATE. This MOU is executed as of the date of the last signature and is effective through Sept 30, 2028, at which time it will expire.

Q. AUTHORIZED REPRESENTATIVES. By signature below, each party certifies that the individuals listed in this document as representatives of the individual parties are authorized to act in their respective areas for matters related to this MOU.

In witness whereof, the parties hereto have executed this MOU as of the last date written below.

SCOTT G. FITZWILLIAMS, Forest Supervisor
U.S. Forest Service, White River National Forest
Date

The authority and format of this agreement have been reviewed and approved for signature.

ALEX SPECHT
U.S. Forest Service, Grants Management Specialist
Region 2, Rocky Mountain Region
Date

FS Agreement No. 24-MU-11021500-

# Exhibit B – GIS Data Overview

## MCWC VARs Data

| Task ID | Layer | Description | Publishing Agency | Data Format | Comments |
|---|---|---|---|---|---|
| 1 | Federal, Statewide and Local Datasets | | | | |
| 1.1 | Water Resources Infrastructure | | | | |
| 1.1.1 | Storage Reservoirs | Storage reservoirs within Colorado based on Colorado DWR and NHD Waterbodies. | CWCB (for WRW) | Points | |
| 1.1.2 | Built Flowlines | NHD flowlines (pipelines, canals, and ditches) | NHD | Lines | |
| 1.2 | Transportation Infrastructure | | | | |
| 1.2.1 | Crossings | CDOT Culverts, Bridges and Major Culverts | CDOT | Points | |
| 1.2.2 | Railroad | Railroad lines | USGS | Lines | |
| 1.2.3 | Roads | Highways, Major and Local Roads | USGS | Lines | |
| 1.2.4 | Garfield County Roads | Roads within Garfield County | Garfield County | Lines | |
| 1.2.5 | Mesa County Roads | Roads within Mesa County | Mesa County | Lines | |
| 1.2.6 | Bridges and Culverts | Garfield County Bridges and Culverts | Garfield County | Points | |
| 1.3 | Property | | | | |
| 1.3.1 | Buildings | Building outlines (national data set) | Microsoft | Polygon | |
| 1.3.2 | Garfield County | Address Points, Urban Growth Boundary and Parcel Data | Garfield County | Points/Polygons | |
| 1.3.3 | Rio Blanco County | Parcels and County Boundary | Rio Blanco County | Polygons | |
| 1.3.4 | Mesa County | Parcels and Roads | Mesa County | Lines/Polygons | |
| 1.4 | Natural Resources / Natural Infrastructure | | | | |
| 1.4.1 | Aquatic Resources | Species Conservation Water, Aquatic Gold Medal Waters, Aquatic Cutthroat Trout Designated Conservation Habitat, | CPW | Lines/Polygons | |
| 1.4.2 | CPW Roads | Roads on/in CPW territory. | CPW | Lines | |
| 1.4.3 | CPW Trails | Trails owned and maintained by CPW | CPW | Lines | |
| 1.5 | Power | | | | |
| 1.5.1 | Cellular | Cellular towers | Homeland Infrastructure Foundation Level Data | Points | |
| 1.5.2 | Electric | Electric Substations and Transmission lines | Homeland Infrastructure Foundation Level Data | Lines | |
| 1.5.3 | Transmission Lines | Holy Cross and Xcel | Holy Cross & Xcel | Points/Lines | |
| 1.5.4 | Wells | Well locations within Colorado | Colorado GIS Open Database | Points | |
| 1.6 | Communication Networks | | | | |
| 1.6.1 | Cellular | Cellphone Towers | Homeland Infrastructure Foundation Level Data | Points | |

# MCWC VARs Data

| Task ID | Layer | Description | Publishing Agency | Data Format | Comments |
|---|---|---|---|---|---|
| *1.7* | *Municipal Water Infrastructure* | | | | |
| *1.7.1* | Stormwater Pollution Protection | Stormwater Pollution Sources | CDPHE | Points/Polygons | |
| *1.7.2* | Decreed Water Rights | CDSS Structures | CWCB | Points | |
| *1.8* | *Commodities/Manufacturing* | | | | |
| *1.8.1* | Mines | Coal, Hardrock and Construction Permits; Historic Mines | Reclamation, Mining and Safety;USGS | Points | |
| *1.8.2* | Oil and Gas | Oil and gas infrastructure locations within Colorado | Colorado GIS Open Database | Points | |
| *1.9* | *Critical Facilities* | | | | |
| *1.9.1* | Critical Facilities | 4 layers - CDPHE healtih facilities, emergency medical services, fire stations, public schools, | Infrastructure Foundation Level Data | Points | |

# Exhibit C – Hazard Evaluations Technical Memorandums

Michael Blazewicz
Round River Design
Salida, CO
Michael@RoundRiverDesign.com
802.279.0478

July 2024,

**Dear Middle Colorado Watershed Council Wildfire Ready Action Plan (WRAP) Partner**,

To begin using the preliminary Fluvial Hazard Zone (FHZ) map products for planning purposes we strongly recommend that you start by reading the **FHZ Map Addendum Report**. In chapters one through three of the Addendum, you will find background information about why FHZ mapping is important and how it differs from FEMA floodplain mapping products, the concepts driving this mapping project, the fundamental components of a Fluvial Hazard Zone map, and an overview of the mapping process. Chapters four through six pertain to the specifics of Middle Colorado Watershed FHZ mapping process. These chapters include a general summary of the study area and setting, a high-level geomorphic process assessment of the study streams, and finally specific details about the FHZ mapping methods used for this study are provided.

The Map Addendum is accompanied by an ESRI geodatabase file. Within this geodatabase, the following data have been included:

- Reach breaks (Elk and Rifle only) and stream centerlines for the study streams
- Fluvial Hazard Zone components (Active Stream Corridor and Fluvial Hazard Buffer polygons)
- Relative Elevation Models (REMs) – a raster layer that can be used as a visual approximation of how high land is relative to the creek channel (Elk and Rifle Creek study reaches only).

A metadata document is also included in the deliverables which identifies sources of the data used in this assessment.

**PLEASE NOTE: This is a Preliminary (DRAFT) FHZ that was developed for the purposes of incorporation into a Wildfire Ready Action Plan. The FHZ delineation was conducted at a high-level for purpose of identifying possible intersections between fluvial hazards and community assets that may be at risk from post-wildfire flooding. Methods followed the general guidance of the CWCB protocol but did not include delineations of fans, disconnected ASC's, and/or geotechnical failures. Fluvial hazard buffer boundaries were not adjusted. FHZ delineations for ALL Battlement Mesa drainages was approximated and does not accurately portray fluvial or other hazards on the fans that exist near the bottom of each drainage. Only very high-level third party review of the delineations was conducted.**

Further detailed study is recommended for these communities.

Sincerely,

Michael Blazewicz
Round River Design

# Preliminary Fluvial Hazard Zone Map Addendum

**Prepared for**

# Middle Colorado Watershed Council Wildfire Ready Action Plan (WRAP)

**Produced by Round River Design**

**July 2024**

# Publication and Contact Information

Preliminary Fluvial Hazard Zone maps and supporting documentation were produced with funding provided by Colorado Water Conservation Board for the Middle Colorado Watershed Council's Wildfire Ready Action Plan (WRAP).

The primary author is Michael Blazewicz (Round River Design). The mapping was completed by following guidance provided by the Colorado Water Conservation Board's "Colorado Fluvial Hazard Zone Delineation Protocol Version 1.0".

**FOR MORE INFORMATION ABOUT THIS FHZ MAPPING CONTACT:**

Michael Blazewicz
Round River Design
michael@roundriverdesign.com

**FOR ADDITIONAL GUIDANCE DOCUMENTS AND SUPPORTING MATERIAL REGARDING FHZ MAPS VISIT THE COLORADO FLUVIAL HAZARD MAPPING PROGRAM WEBSITE:**
www.ColoradoFHZ.com

**FOR ADDITIONAL GUIDANCE DOCUMENTS AND SUPPORTING MATERIAL REGARDING WILDFIRE READY ACTION PLANS VISIT THE COLORADO WILDFIRE READY WATERSHEDS WEBSITE:**
www.wildfirereadywatersheds.com

**Cover Photo: Elk Creek, Garfield County.**

# Disclaimer

Fluvial Hazard Zone (FHZ) maps are intended to delineate the area a stream has occupied in recent history, may occupy, or may physically influence as it stores and transports water, sediment, and debris. FHZ maps do not predict the magnitude, frequency, or rate of fluvial geomorphic hazards. The intended use of these Preliminary FHZ maps is to supplement a Wildfire Ready Action Plan (WRAP).

The Fluvial Hazard Zone map authors make no representations or warranties, expressed or implied, as to the accuracy, completeness, timeliness, or rights to the use of these preliminary FHZ maps. The authors shall not be liable for any errors, omissions, or inaccuracies in such information regardless of their cause, and shall not be liable for any decision made, action taken, or action not taken by the user in reliance upon such information. The authors shall not be liable for any general, special, indirect, incidental, or consequential damages including, but not limited to, lost revenues or lost profits resulting from the use or misuse of the information contained on FHZ maps.

It is the responsibility of the FHZ map sponsor agency, not the authors of this study, to evaluate the FHZ and revise the FHZ maps as conditions in the watershed change based on the best data and technical guidance available.

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# Executive Summary

Fluvial geomorphic processes are natural phenomena within stream corridors and include commonly observed occurrences such as erosion, the transport and deposition of sediment, the recruitment and jamming of wood, and the structural influences of plants and animals. Fluvial geomorphic processes become hazardous when they encounter infrastructure, houses, businesses, and other investments within and adjacent to the stream corridor.

To recognize and assess the hazards associated with erosion, sediment deposition, and other dynamic river processes, the Colorado Water Conservation Board (CWCB) has developed a technical protocol to identify and map the areas where fluvial hazards may exist in order to help communities better understand their existing risk.

The State of Colorado's Fluvial Hazard Zone (FHZ) Mapping Program represents a significant and necessary step forward in adaptively managing stream corridors, preparing for, and mitigating flood and post-fire flood and sediment impacts, and making informed land use decisions based on an awareness of fluvial processes. In Colorado, flood hazard identification and mitigation must recognize that streams are naturally dynamic, prone to move within a corridor, and apt to modify their margins as they transport and deposit water, sediment, and debris inputs from their watersheds. Flood insurance claims and property loss data demonstrate that in Colorado, reliance on traditional flood inundation maps alone does not provide a comprehensive characterization of the hazards imposed by fluvial processes. Fluvial Hazard Zone Mapping process considers these dynamic stream processes and represents an important step forward in identifying and communicating these hazards.

> **The Fluvial Hazard Zone (FHZ) is the area a stream has occupied in recent history, may occupy, or may physically influence as it stores and transports water, sediment, and debris.**

Fluvial Hazard Zone Maps are created by fluvial geomorphologists—scientists who study how flowing water shapes and modifies the Earth's surface through erosional and depositional processes. Mapping is completed through the interpretation and synthesis of geomorphic, geologic, hydrologic, and biotic information (i.e., data that describes the physical location, form, flooding intensity, active sediment and debris transport, and ecological conditions of a riverine system).

Fluvial Hazard Zone maps provide communities, individual property owners, and emergency response teams with information on flood- and stream-related hazards beyond those identified by traditional floodplain mapping. Fluvial Hazard Zone maps may be adopted and used for land use regulation at the local level, however, they are not and will not be regulated nor mandated by the State of Colorado. As stream corridors are environmentally and economically important areas, Fluvial Hazard Zone maps can also aid in prioritizing lands for conservation or maintenance of fluvial process compatible land uses.

In addition to providing information related to community safety, Fluvial Hazard Zone maps provide a delineated area where many of the complex physical, chemical, and biological interactions of stream systems could be expected to occur. Recognizing that stream corridors (i.e., streams and their associated riparian, subsurface and in-channel areas, as well as geomorphic floodplains) move and store sediment, debris, and water and employing management practices that avoid conflict with these processes are important; this recognition is important not only for our safety and financial investments, but also because these natural river processes are foundational for preserving the ecosystem services found in riparian corridors.

# 1.0 Fluvial Hazard Mapping Background

## 1.1 Fluvial Processes

Stream corridors are naturally dynamic environments. Fluvial geomorphic processes associated with streams include the erosion, transport, and deposition of sediment, debris, and wood within stream corridors. These physical processes, which may occur gradually over time or abruptly during a flood, become hazards when they interact with human investments within stream corridors.

Streams naturally change their shape and location as a result of the interactions between hydrology, geology, and biology. Stream change may also be influenced by human interventions directly through the placement of armoring or levees and indirectly through actions such as flow regulation and urbanization in the contributing watershed. Stream change is ever-present and even "stable" stream channels will shift from year to year as a result of the influence of annual or sub-annual runoff.

> Rivers and streams are much more than the water we see in their channels. Rivers and streams are corridors that are constantly evolving, responding to and shaping the landscape around them. Stream corridors include the active channels and floodplain, as well as the adjacent hillslopes, all of which are physically and biologically connected a stream. As water, sediment, nutrients, and wood move from steep uplands down to valley bottoms, stream channels slowly, and sometimes rapidly, shift their shape and location. This natural movement leaves behind a tapestry of rich, complex habitats for plants, animals, and insects. A healthy river is a moving river.

Change in a stream corridor becomes a hazard when an adjusting stream threatens infrastructure, houses, businesses, property, and vital transportation corridors or crossings. Fluvial geomorphic hazards are particularly acute when they not only threaten property and infrastructure but also human lives. Because change in stream corridors is episodic, and in some cases infrequent, development and investment in stream corridors may not incorporate information regarding the hazards from this change. Characterizing and mapping these hazards can aid in identifying where property and infrastructure may be at risk and inform future development decisions in and adjacent to stream corridors.

## 1.2 Fluvial Geomorphic Hazards

To better identify these fluvial geomorphic hazards, Fluvial Hazard Zone (FHZ) maps can be developed. The Fluvial Hazard Zone is defined as the area a stream has occupied in recent history, may occupy, or may physically influence as the stream stores and transports water, sediment, and debris. These fluvial geomorphic processes may occur gradually over years or suddenly during a flood event. The primary objective of Fluvial Hazard Zone mapping in Colorado is to identify areas where fluvial geomorphic change is expected, characterize and identify these processes, and ultimately reduce risk to life and property through increased awareness, avoidance, and mitigation.

Traditionally local governments have regulated stream corridors by relying on Federal Emergency Management Agency (FEMA) Guidance and Standards to create Flood Insurance Rate Maps (FIRMs), which are used to establish insurance premiums through the National Flood Insurance Program (NFIP). These maps delineate only flood inundation hazards— as a result, properties located well above base flood elevations or outside FIRM floodplain boundaries are often affected by floods yet they are unaware of and unprepared for the potential damage stemming from stream movement, the erosion of streambanks or hillslopes, or the impacts of sediment and debris deposition.

Floods have resulted in 11 federal disaster declarations for Colorado, with one or more major flood occurring every decade in the state. Average annualized flood-related property damage in Colorado from 1911 to 2013 is estimated to be $99 million dollars (inflation-adjusted for 2021) (Blazewicz et al., 2020). Since 1978, approximately 49% of all NFIP claims in Colorado have come from policies written outside the high-risk area depicted on the FEMA FIRMs, demonstrating their inadequacy for mapping flood risk.

While the process of identifying fluvial geomorphic hazards on a map may be a new endeavor in many places, the act of mapping does not introduce a new hazard to a community or landowner. The hazard has always existed; the map explicitly characterizes and delineates it. Just as with inundation hazards, by identifying, mitigating, and planning for fluvial geomorphic hazards, our communities can reduce their vulnerability to flood damage in the stream corridor and become better equipped to adapt to future conditions.

**WHY NOT "EROSION HAZARD MAPPING" OR "SETBACKS"?**

Erosion is just one of the geomorphic hazards associated with streams. Simply measuring, modeling, or calculating erosion or bank retreat is insufficient in capturing all fluvial geomorphic hazards in a stream corridor. Other fluvial geomorphic hazards include deposition of sediment and large wood which can aggrade channels and cause significant hazard even if the channel itself does not technically erode. Similarly, channel avulsions, fan processes, channel braiding, and cutoffs have the potential to relocate channels abandoning bends where erosion hazards were mapped. Similarly, setbacks defined from an existing static channel location can quickly be made obsolete during a flood as whole channel relocations are common. FHZ maps identify areas susceptible to erosion but also include areas where these other fluvial geomorphic hazards exist.

Fluvial Hazard Zone mapping delineates where stream channels within a river corridor may widen or migrate, where they may find new courses across a floodplain, and where they might result in erosion and mass wasting of the hillslopes adjacent to the floodplain. An FHZ map does not attempt to define the likelihood of damage from fluvial processes nor the rate of change of geomorphic forms within the stream corridor. The mapped boundary defines a zone within which fluvial processes have occurred in the past and may occur in the future, as well as areas that are likely to be indirectly impacted by erosion or failure (i.e., mass wasting) of the valley margin.

These components of a Fluvial Hazard Zone map are described in more detail in Section 2. Methods for delineating them are provided in Colorado Fluvial Hazard Zone Delineation Protocol, Version 1.0 available for download at www.ColoradoFHZ.com.

## 1.3 Colorado's Fluvial Hazard Zone Mapping Program

Colorado hosts a diversity of stream types and associated fluvial geomorphic hazards, and therefore requires a Fluvial Hazard Zone mapping protocol that can be tailored to the dominant processes of stream and floodplain change within a particular geographic and geologic setting while also leaving flexibility for adaptation to specific regional attributes, as well as for more detailed refinement. The Colorado Water Conservation Board, along with their partner agencies, set out to develop a Fluvial Hazard Zone Mapping Program that would employ a scientifically defensible set of mapping standards that could be applied to any stream system in the state. The Protocol was designed to delineate an accurate Fluvial Hazard Zone with a moderate level of effort primarily through the synthesis of geologic and geomorphic information (data that describes the physical forms and processes of a stream system). The FHZ Protocol relies primarily on spatial data such as aerial photography, LiDAR-based digital elevation models (DEMs), and geologic maps, as well as field observations to interpret geomorphic features. Hydraulic and biotic information may also be utilized.

The process for mapping Fluvial Hazard Zones in Colorado builds on a body of work developed in other regions of the United States, including the states of Washington and Vermont. The Protocol was piloted on approximately 450 miles of stream corridors throughout the state, peer-reviewed, and released for public comment in January 2020. The Colorado Fluvial Hazard Zone Delineation Protocol Version 1.0 was finalized and released for general use in the Summer of 2020. The Fluvial Hazard Zone delineations associated with this Addendum was developed using the recommendations and framework provided in the Colorado Fluvial Hazard Zone Delineation Protocol, Version 1.0.

Guidance was also developed to support communities that may want to incorporate FHZ mapping into their community planning and is available at www.ColoradoFHZ.com.

## 1.4 Fluvial Hazard Zone Mapping Applications

Fluvial Hazard Zone maps may provide a wide range of benefits to individuals and communities. First and foremost, they are a tool to help stakeholders visualize and understand the inherent risk that exists on lands that have been—and will someday again—be shaped by water moving through a landscape. They also help to identify areas subject to hazards after wildfires and areas where floodplain rehabilitation and flood management projects are likely to have a considerable impact.

This section outlines some of the ways Fluvial Hazard Zone maps can be used and applied depending on the priorities and goals of the community.

### IDENTIFICATION OF CONSERVATION, OPEN SPACE, AND RECREATIONAL OPPORTUNITIES

Riparian areas provide diverse, dynamic, and complex habitats that are among the most important in Colorado (Rondeau et al., 2011). Fluvial geomorphic processes create shifting mosaics of highly productive habitat for riparian, aquatic and terrestrial species (Cluer and Thorne, 2014); and provide opportunities to protect (and improve) water quality (Piegay et al., 2005; Rupprecht et al., 2009). Fluvial processes occur on a variety of spatial and temporal scales, from local bank erosion to avulsions that create long swaths of new channel. They may even rework floodplains entirely, creating a patchwork mosaic of habitat types and successional stages. This diversity of habitat creates recreational opportunities for wildlife viewing, fishing, foraging, and hunting, as well as trail and path networks for recreation and alternative transportation. Protection of these dynamic areas for ecological conservation, open space, and recreation will reduce the need to place constraints on the streams over time and instead allow them to adjust and stabilize based on their prevailing flow and sediment regimes. Using Fluvial Hazard Zone maps, conservation and recreation planners may identify lands where the environmental benefits of unconstrained rivers are enhanced by the societal benefit of limiting human exposure to fluvial geomorphic hazards.

### IDENTIFICATION OF FLOODPLAIN RESTORATION AND REHABILITATION PROJECTS

Fluvial Hazard Zone maps may guide river and floodplain rehabilitation project identification, scoping, and goals. Generally, the FHZ boundary should be considered when identifying the project extent of any restoration, rehabilitation, or flood mitigation project. The Fluvial Hazard Zone boundaries and supporting documentation can also provide information on geomorphic and hydrologic processes relevant to site-specific restoration. For instance, they may identify areas where restored side channels or floodplain features will be connected, or distinguish active and erosive reaches from depositional reaches. Additionally, identification of disconnected floodplains through FHZ mapping provides an inventory of areas with potential for reconnection. Data products used in the delineation of the FHZ are similar to those used for design and analysis of stream corridor restoration processes (Powers et al., 2018).

### CONSERVATION OF AGRICULTURAL LANDS AND PRACTICES

Many lands adjacent to streams are currently being used for agriculture and grazing. Generally speaking, these land uses are considered compatible for areas within the Fluvial Hazard Zone, much more so than house developments and other static infrastructure. Mapping the FHZ and incorporating the boundaries into community plans can help to prioritize the maintenance of existing agricultural land uses and practices in stream corridors.

### AVOIDING FLOOD DAMAGES THROUGH PLANNING AND INFORMED DEVELOPMENT

Ultimately, the most cost-effective tool to mitigate the impact of fluvial hazards is to reduce exposure to the hazard through forward-looking land use planning and/or regulations and standards for development within mapped Fluvial Hazard Zones. The FHZ delineation process and the resulting maps are intended to provide local land use, floodplain, and emergency response managers insight into the likely long-term behavior of their streams and serve as additional hazard information. It also communicates these hazards to the public so that they are better informed in making emergency preparations as well as personal and business decisions. Fluvial Hazard Zone maps can be integrated into:

#### COMPREHENSIVE PLANNING

Long-term planning that directs land development and infrastructure away from areas subject to fluvial hazards will result in avoided damages during future floods. As identified in the Protocol, limiting development within the Fluvial Hazard Zone might:

- Reduce the costs of repairing or replacing infrastructure and major civil works;
- Provide for temporary flood water storage and allow for a reduction of peak flood flows in adjacent and downstream communities (Habersack et al., 2015; Sholtes and Doyle, 2010);
- Reduce reliance on channelization, levees, and bank armoring, which are often detrimental to stream health, are expensive to maintain, and have proven to be prone to failure. Structural river controls, unless or until they fail, often increase erosion and deposition processes in adjacent and downstream communities (Brierley and Fryirs, 2005; Brookes, 1988; Huggett, 2003; Nagle, 2007);
- Reduce public expenditures for disaster response and recovery;
- Reduce costs of future flood recovery efforts.

Since the late 1990s, there has been a growing movement to allow space for river corridors in community planning in the form of “Room for the River” or “Freedom Space” programs (Biron et al., 2014; Rijke et al., 2012). Fluvial Hazard Zone mapping is a science-based tool that communities can use to define the priority areas in which to incorporate a room for the river management strategy into their long-term planning.

#### REGULATION

Fluvial Hazard Zone maps are not regulated or mandated by the State. However, as allowed under Colorado statute, county and municipal governments may choose to incorporate Fluvial Hazard Zone maps into their

> Fluvial Hazard Zone mapping can be used for a multitude of purposes but any decisions regarding land use or other regulation are made at a <u>local</u>, not State or Federal, level. Fluvial Hazard Zone maps also do not impact flood insurance rates or premiums.

local land use and development permitting process. A Fluvial Hazard Overlay District model ordinance was developed for the CWCB FHZ Program with the intent of assisting communities that wish to utilize zoning to be able to integrate fluvial hazard zone maps into their existing regulatory mechanisms. Additional regulatory tools include establishing disaster recovery ordinances and the possibility of credit for communities who incorporate Fluvial Hazard Zone regulation within the NFIP's Community Rating System.

### WILDFIRE PLANNING AND RESPONSE

FHZ maps are a valuable tool for communicating hazards associated with rainfall after wildfires. After a wildfire, FHZ maps can be quickly and cost-effectively created to delineate areas vulnerable to sediment and debris impacts spurred by rainfall over the burn scar. Mapping these post-fire hazards may allow downstream residents to prepare by preemptively moving vehicles, storage units, and other items to safer locations and to develop evacuation plans. This can also provide communities with an assessment of vulnerable populations for emergency response planning.

Before a wildfire, FHZ maps can be used to identify and prioritize the conservation or restoration of natural depositional areas which can trap debris and sediment that erodes from burned hillslopes upstream of populated areas. The conservation of these areas is important for two reasons: 1) it prevents development and investment in high-risk locations; and 2) these areas can act as a sediment sink and energy sponge, absorbing material and energy from debris flows and mitigating impacts to downstream residents and communities. Furthermore, conserved and natural stream corridors, especially those where beaver (*Castor canadensis*) have been reintroduced and wet meadows and ponds are present, have been documented to provide natural fire breaks, potentially aiding a community's firefighting effort during a wildfire (Fairfax and Whittle, 2020).

### EMERGENCY PLANNING

The mapping of Fluvial Hazard Zones can illuminate which critical emergency response infrastructure (e.g., fire and rescue stations, hospitals, schools, and shelters) may be vulnerable to previously unaccounted-for flood hazards. This can aid a community in planning where to station resources, shelter people, and/or invest in redundant systems so that if one critical component goes offline the whole emergency response system is not paralyzed. Fluvial Hazard Zone maps may also help communities consider which evacuation routes may be unreliable during a flood due to road and bridge washouts from fluvial processes. Disaster response planning without fluvial hazard zone maps is likely to provide an incomplete assessment of a community's true vulnerabilities.

## 1.5 Interpreting FHZ Maps and Understanding Their Limitations

These preliminary Fluvial Hazard Zone maps are presented as a planning tool to be used in identifying conservation and restoration opportunities and for reducing future flood damage; however, the FHZ does not represent an all-inclusive characterization of stream corridor hazard and should be utilized with other tools such as FEMA Special Flood Hazard Area delineations, post-fire flood hazard mapping, debris flow hazard maps, and landslide hazard maps.

The FHZ boundary delineates the extent of the area likely to be influenced by fluvial processes. While fluvial processes are unlikely to occur outside of the FHZ boundary, events such as debris flows, debris jams, landslides, earthquakes, dam failures, and diversion channel captures may trigger geomorphic responses not mapped within the FHZ. In addition to the aforementioned, the following is a list of acknowledged limitations of the FHZ mapping methodology:

- FHZ mapping may not provide a detailed account of fluvial hazards in very small drainages where runoff is transitioning from overland flow to channelized flow.
- Fluvial Hazard Zone mapping may not capture the full extent of geomorphic hazards resulting from catastrophic events such as a dam failure.
- FHZ mapping is dependent on the availability of high-resolution LiDAR. In the absence of this data, the FHZ boundaries are likely to be less accurate and/or require an extended field assessment.
- Fluvial Hazard Zone mapping may not account for all bedrock that may be controlling vertical or lateral channel movements.
- The FHZ map identifies fluvial geomorphic hazards within and adjacent to the stream corridor that has been mapped (i.e., the study reaches). Adjacent hazards related to tributary streams, gullies, and fans may not be mapped or identified unless explicitly stated.

## 1.6 Risk and Probability in Fluvial Hazard Zones

People have become accustomed to thinking about flood hazards through the lens of recurrence intervals (e.g., 10-year flood) and annual exceedance probability (e.g., 10% AEP) as this is how FEMA and the NFIP communicate flood probabilities. Geomorphic hazards, however, do not lend themselves to this same type of statistical analysis given the strongly non-linear and complex relationship between flood magnitude and geomorphic response. Geomorphic changes in stream systems are the result of positive and negative feedbacks between interacting units of variable scale in the climatic, hydrologic, geologic, biotic, and anthropomorphic realms. Accurate quantitative assignments of probability for these multi-faceted, variable, and even unknown relationships (such as underlying geology, soil saturation, water and sediment connectivity, stressors, and explicit estimations of the changes in river conveyance properties over time) are currently not available (Sofia and Nikolopoulous, 2020; Naylor et al., 2016; Phillips and van Dyke, 2016). Furthermore, the effects of on-going climate change and the anomalies of wildfires disrupt statistical assessments of probabilities of disturbance in stream systems (Naylor et al., 2016; Walsh et al., 2014).

In trying to quantify the probability of the occurrence of fluvial hazards within mapped Fluvial Hazard Zones, the following variables would need to be evaluated:

- Precipitation quantity, location, and duration;
- Sediment and debris supply from upstream reaches;
- Debris flow and landslide locations and sizes;
- Erodibility of materials within the Active Stream Corridor and valley margins;
- Location of channel blockages;
- Wildfires impacts on all of the above;
- Timing and corresponding stream response to all the above, in absolute and in relative terms.

> "The magnitude of a storm is only one factor influencing the nature and severity of its geomorphic impacts. The resisting framework, storm timing, event sequencing, and initial conditions (especially proximity to thresholds) may amplify or reduce storm impacts"
>
> -Phillips and van Dyke, 2016

# 2.0 Fundamental Components of Fluvial Hazard Zone Maps

## 2.1 Fundamental Components of the Fluvial Hazard Zone

The Fluvial Hazard Zone consists of two primary components, and these will be present on every Fluvial Hazard Zone map:

**Active Stream Corridor** (ASC) The Active Stream Corridor encompasses the lands shaped by fluvial erosion and deposition under the prevailing flow and sediment regimes (i.e., the modern geomorphic floodplain) (Figures 2-1 and 2-1). Dominant processes within this boundary are lateral channel migration, scour of the floodplain, and deposition of alluvium.

**Fluvial Hazard Buffer** (FHB) The Fluvial Hazard Buffer accounts for erosion-prone land located beyond the Active Stream Corridor, such as hillslopes and terraces, that may be susceptible to slope failure as a result of toe erosion caused by fluvial scour. It is a buffer applied to the outer boundary of the Active Stream Corridor (Figures 2-1 and 2-2).

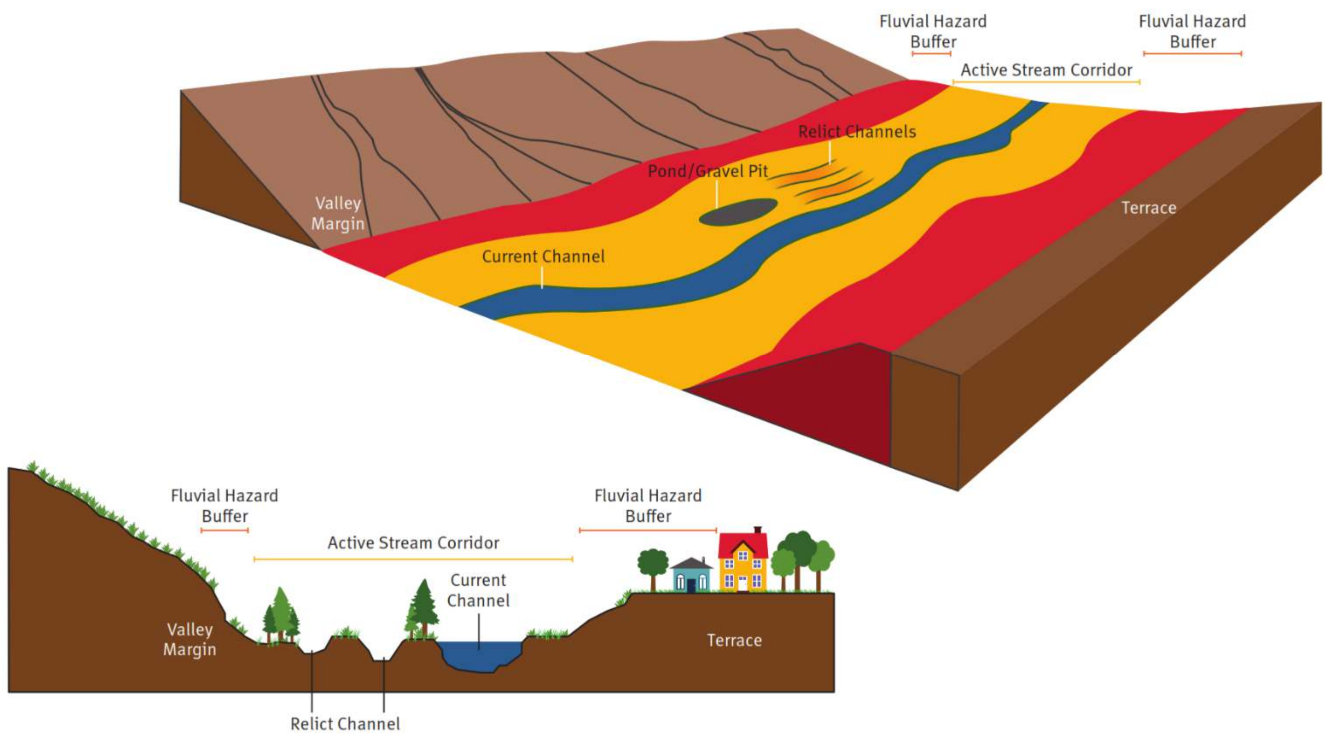


*Figure 2-1: The Active Stream Corridor and Fluvial Hazard Buffer are primary components of a Fluvial Hazard Zone map. Figure from Blazewicz et al. 2020.*

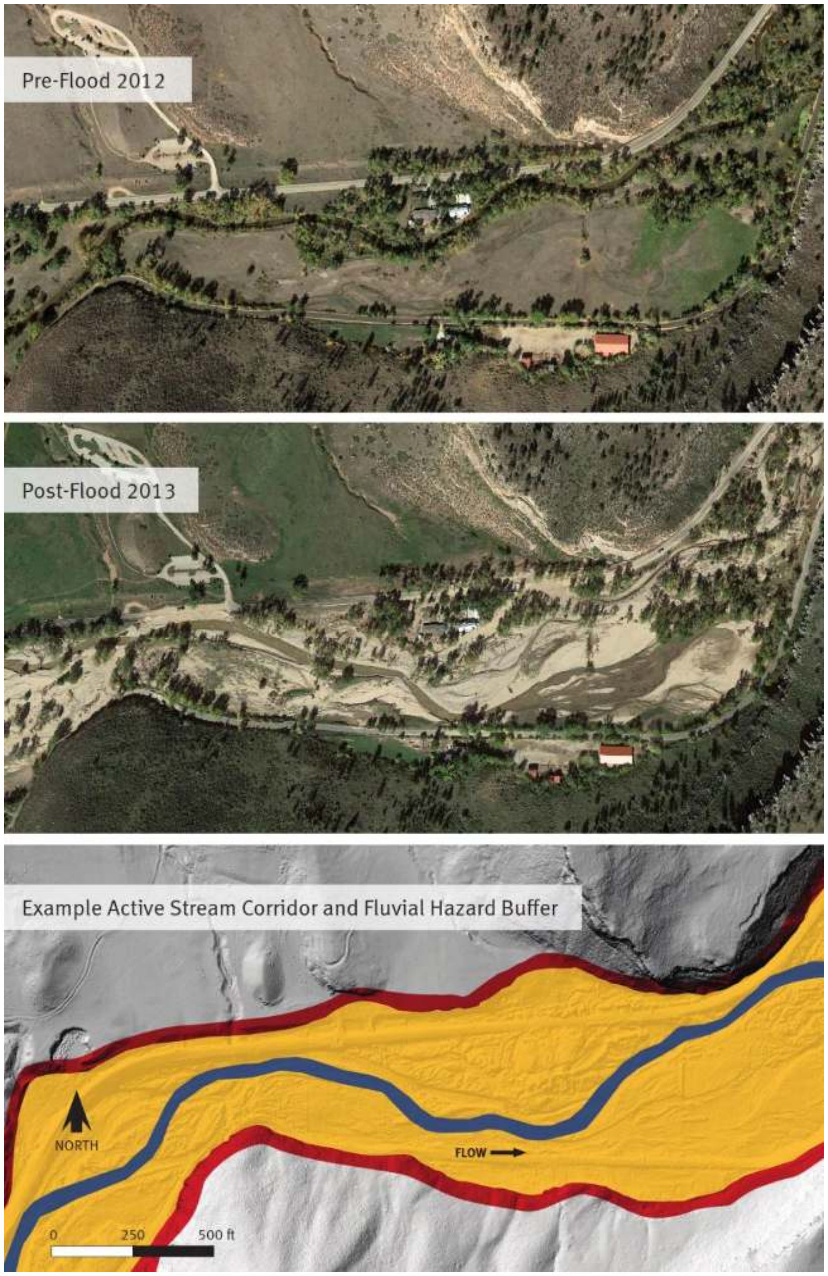


*Figure 2-2: The Active Stream Corridor (yellow) and the Fluvial Hazard Buffer (red) are the main components of an FHZ map. This example is for illustrative purposes and is not an actual FHZ delineation. Figure adapted from Blazewicz et al. 2020.*

## 2.2 Auxiliary Map Components

Auxiliary Fluvial Hazard Zone components demarcate locations where other types of fluvial hazards or fluvial hazards that are not captured by the Active Stream Corridor or Fluvial Hazard Buffer, are likely to occur. The designation of areas where human interventions have reduced the natural extent of the Active Stream Corridor are also considered. Auxiliary Fluvial Hazard Zone components are the: Avulsion Hazard Zone (AHZ), Fans (F), Geo-technical Flags (GF) and Disconnected Active Stream Corridors (D-ASC). Not all streams will have these Auxiliary Fluvial Hazard Zone components, but all mapping efforts must assess if these components are present and map them if they are (Figure 2-3).

**Disconnected Active Stream Corridor (D-ASC)** identifies lands that would normally be mapped as part of the Active Stream Corridor but may not be currently subject to fluvial processes due to human-engineered structures (e.g., certified levees). While these areas may still be subject to inundation during flooding, fluvial geomorphic hazards are not expected.

**Avulsion Hazard Zone (AHZ)** identifies pathways outside of the Active Stream Corridor that a channel might (re)occupy. Only avulsion pathways that exist outside the Active Stream Corridor are identified as Avulsion Hazard Zones.

**Fan (F)** Alluvial and debris fans are typically triangular-shaped landforms created by deposition of material at the intersection of a tributary valley with a larger valley. They may also form in the mainstem of a study stream where a steep confined reach rapidly loses confinement and gradient. In the FHZ Protocol, tributary fans are identified with a point or flag at the topographic apex of the feature. Fans created by the mainstem of the stream should be included within the Active Stream Corridor.

**Geotechnical Flag (GF)** identifies areas where hillslope failures initiated by toe erosion may extend past the Fluvial Hazard Zone delineation due to hillslope steepness, height, and/or material. These should always be examined further through geotechnical analysis before development decisions are made.

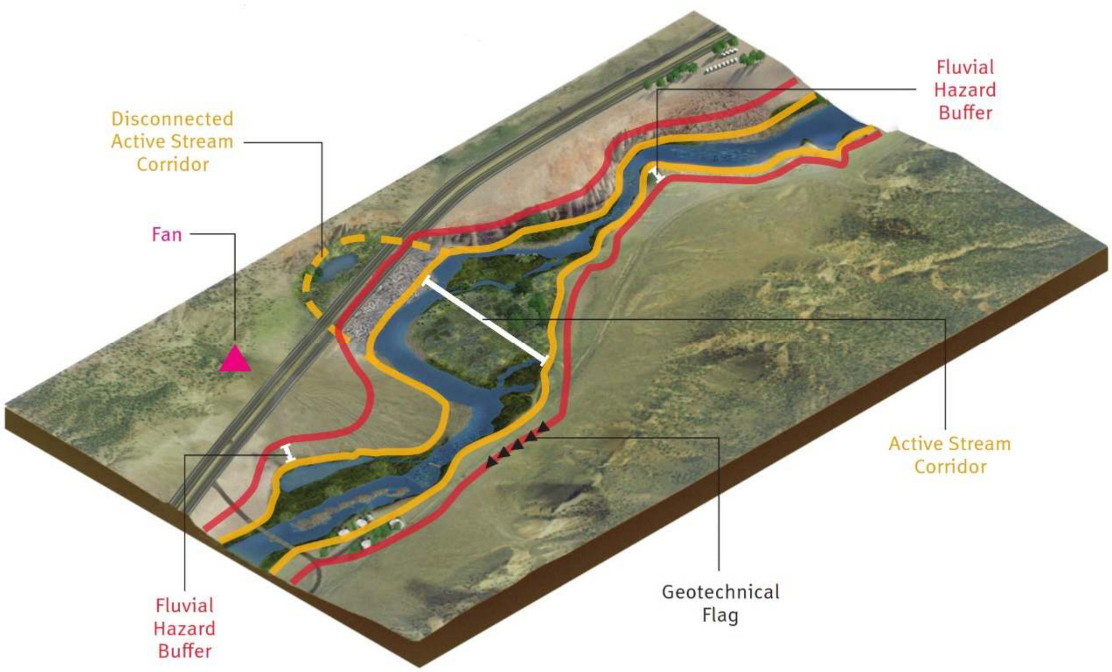


*Figure 2-3: Example Fluvial Hazard Zone map containing primary (ASC, FHB) and auxiliary (D-ASC, Fan, and GF) components. Figure adapted from Blazewicz et al. 2020.*

# 3.0 Preliminary Fluvial Hazard Zone Mapping Process

## 3.1 Preliminary Fluvial Hazard Zone Mapping Process Overview

The FHZ maps and data associated with this Addendum were established with guidance from the Colorado Fluvial Hazard Zone Delineation Protocol, Version 1.0. These maps, and the supporting documentation, are intended *for internal planning purposes only*. Finalization of map products for incorporation into community regulatory programs is strongly advised to go through a third-party QA/QC process led by the community, as well as a public outreach, education, and review process, and are intended for planning purposes. The preliminary FHZ mapping roughly followed the process described below:

→ **DETERMINE AREA OF INTEREST**
The objective of this study was to complete the Fluvial Hazard Zone mapping for select reaches of the Middle Colorado watershed, as identified by the project sponsor and consulting team.

→ **CONDUCT RESEARCH**
Research into the physiographic, geologic, hydrologic, and geomorphic setting and context was compiled during the winter of 2024. This research is summarized in Section 4 of this report.

→ **MAP THE FLUVIAL HAZARD ZONE**
Maps were drafted and refined with field verification in the spring and summer of 2024.

→ **INTERNAL REVIEW**
Internal review consisting of field verification, documentation of the mapping process, data sources, and contextualization and the dominant hydro-geomorphic processes influencing the Fluvial Hazard Zone. *Detailed third-party external review of the map products was not conducted as part of this WRAP mapping process.*

→ **DELIVERY OF PRELIMINARY MAP PRODUCTS AND SUMMARY REPORT**
FHZ delineations were provided as a geodatabase to the project sponsor. Supplemental materials included this Addendum, reach information sheets, and the metadata for the Fluvial Hazard Zone layers. These supplemental materials serve as the documentation of the mapping process and provide transparency for decision-making. These preliminary FHZ products are recommended to be utilized for Wildfire Ready Action Plan as well as to assist in other community planning efforts. Further study and third-party review of the maps is recommended.

## 3.2 FHZ Map Distribution, Maintenance, and Updates

Map distribution, if any, will be determined by the project sponsor. Online, web-based maps are strongly recommended. When displaying maps online, it is recommended to not display map boundaries at a scale finer than 1:1,000 for Fluvial Hazard Zone delineations.

In Colorado, it is recommended that full map revision occur:

- Every 30 years, or
- Following a flood with significant stream corridor change from fluvial processes, or
- When human actions have influenced the stream’s location and/or function, or
- When significant land use or watershed changes (e.g., wildfires) occur.

Map updates, if necessary, are recommended to fall into the categories of “minor updates” or “major updates.” Major updates involve a remapping of the stream using the most recent FHZ methodology. Major updates should be considered when significant alterations to hydrology or sediment supply occur (e.g., dam construction, urbanization, wildfire, and landslides), after major flood events that create significant geomorphic change, or when large-scale infrastructure projects are constructed that include Disconnecting Structures (as defined in the Protocol) or other infrastructure that are anticipated to alter reach scale fluvial geomorphic processes. Minor updates include the correction of mapping errors and adjustments along portions of the mapped area due to new information (e.g., unmapped bedrock outcrop). Documentation of each map update or edit should be retained as part of the public record.

# 4.0 Middle Colorado River Watershed Fluvial Hazard Mapping

## 4.1 Study Area

A Wildfire Ready Action Plan for the Middle Colorado Watershed Council included the Elk Creek, Rifle Creek, and Battlement Mesa watersheds. Each watershed drains to the Colorado River (Figure 4-1). The study watersheds range in elevation from approximately 10,000 feet to 12,600 feet at the highest point down to between 5,000 to 6,500. The watersheds originate in the Flat Tops and Grand Mesa Mountains of Western Colorado. Elk Creek flows into the town of New Castle. Rifle Creek into the City of Rifle. Battlement Mesas many drainages flow into more developed areas in the vicinity of Rifle and Parachute.

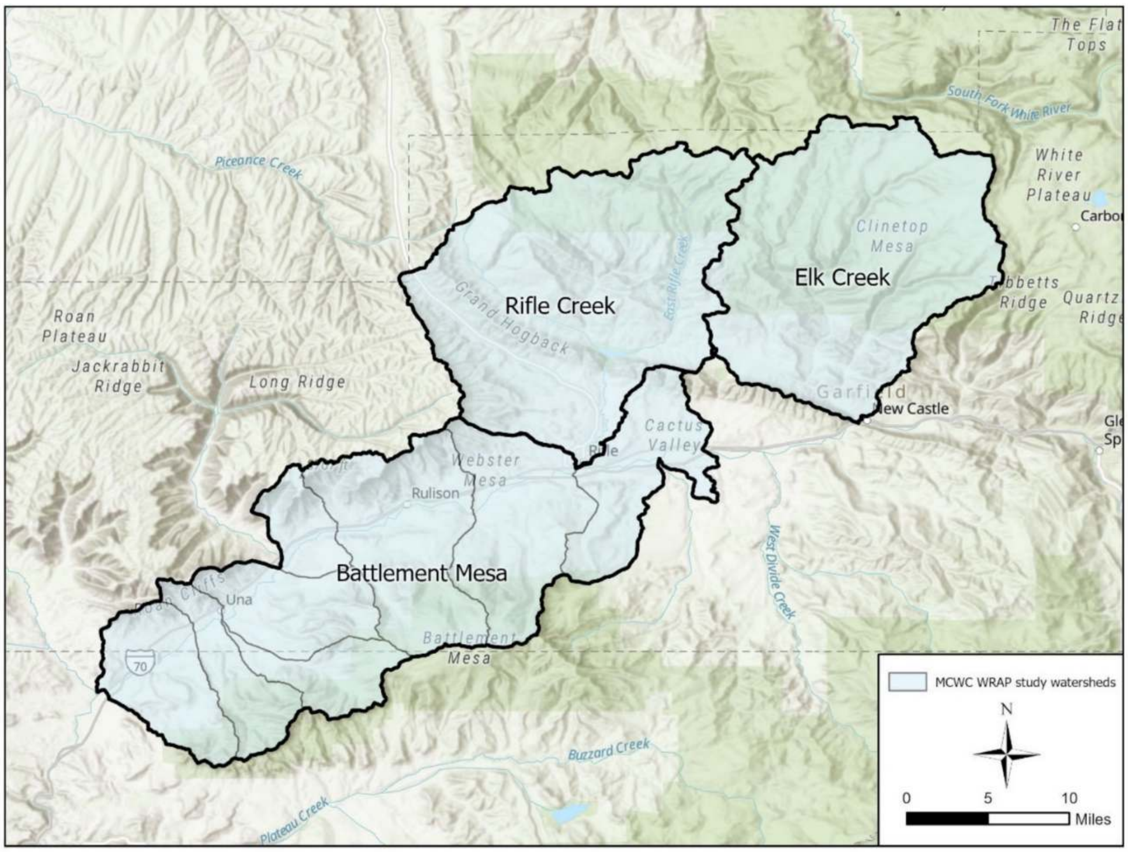


*Figure 4-1. Study watersheds.*

## 4.2 Physio-Geographic and Geologic Setting

The physio-geographic context of a stream is defined by the dominant geologic, topographic, and climatic conditions that influence its form, associated physical processes, and magnitude and frequency of dynamism. These regions broadly delineate areas within which geologic and climatic history are relatively homogenous. The study watersheds are located on the western flank of the Southern Rocky Mountains physio-geographic region near the transition zone to the Colorado Plateau.[1] The Southern Rocky Mountains were uplifted and exposed during the Laramide orogeny, which ended approximately 70 million years ago. As igneous bedrock was lifted along the Rocky Mountains' interior, sedimentary bedrock layers along the eastern edge were uplifted. The study watersheds reflects a mix of both igneous and sedimentary rocks uplifted and tilted and then eroded down by water into v-shaped valleys (Figure 4-2).

Narrow valleys in the headwaters of both Elk and Rifle Creeks have filled over time with a mix of colluvium and alluvium brought down by gravity and moving water. Stream erosion and deposition from both snowmelt-driven and rain-driven flooding have helped form and continue to alter the modern stream corridor topography. In the Battlement Mesa drainages significant downcutting and transport of erosion has led to steep v-shaped valleys. Where these drainages meet the flatter valley bottom of the Colorado River valley massive alluvial fans formed onto which the modern channel interacts.

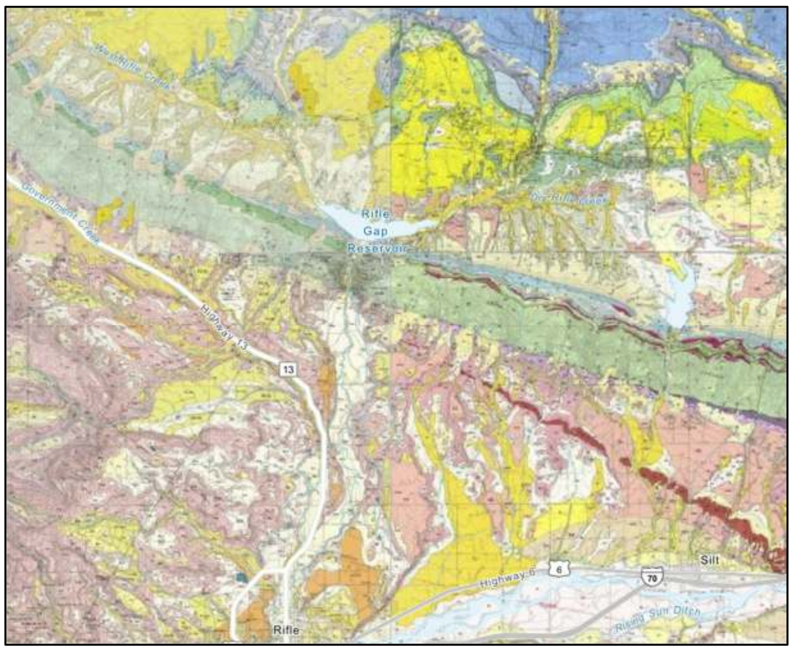


*Figure 4-2. Screenshot of surficial geologic map of the lower portion of the Rifle Creek stream corridor. The geologic map was produced at a scale of 1:24,000 and is therefore relatively coarse. However, generalized identification of geologic deposits are useful for providing the general surficial geology within which the study reaches are passing through and being bounded by.*

## 4.3 Ecologic Setting

The study watersheds drain from EPA Ecoregions 21e (Sedimentary Sub-Alpine Forests) down through 21f (Sedimentary Mid-Elevation Forests), into 20c (Semi-arid Benches and Canyons). Government Creek begins in 20c however it drains down to meet lower Rifle Creek in EPA ecoregion 20b (Shale Deserts and Sedimentary Basins) and ecoregion that also is representative of many of the lower fan areas of the Battlement Mesa drainages near where they meet the valley floor of the Colorado River.[2] Brief descriptions for each EcoRegion are found in Table 4-1 below:

[1] https://coloradogeologicalsurvey.org/wp-content/uploads/ON-010-09-04.pdf

[2] https://www.epa.gov/eco-research/ecoregion-download-files-state-region-8#pane-05

| Table 4-1: EPA EcoRegion descriptions of the Elk and Rifle Creek watersheds | | Natural Vegetation | Land Use and Land Cover |
|---|---|---|---|
| **21e** | The Sedimentary Subalpine Forests ecoregion occupies much of the western half of the Southern Rockies, on sandstone, siltstone, shale, and limestone substrates. The elevation limits of this region are similar to the crystalline (21b) and volcanic (21g) subalpine forests. Stream water quality, water availability, and aquatic biota are affected in places by carbonate substrates that are soluble and nutrient rich. Soils are generally finer-textured than those found on crystalline or metamorphic substrates of Ecoregion 21b, and are also more alkaline where derived from carbonate-rich substrates. Subalpine forests dominated by Englemann spruce and subalpine fir are typical, often interspersed with aspen groves or mountain meadows. Some Douglas-fir forests are at lower elevations. | Subalpine forests dominated by subalpine fir, Engelmann spruce, and lodgepole pine. Areas of Douglas-fir or aspen forests at lower elevations. Understory may include whortleberry, kinnickinnick, snowberry, sedges, mountain brome, and forbs. | Evergreen and some deciduous forest. Timber production, recreation, hunting, wildlife habitat, and seasonal grazing. Some gold mining. Snow cover is a major source of water for lower, more arid ecoregions. |
| **21f** | The Sedimentary Mid-Elevation Forests ecoregion occurs in the western and southern portions of the Southern Rockies, at elevations generally below Ecoregion 21e. The elevation limits and vegetation of this region are similar to the crystalline (21c) and volcanic (21h) mid-elevation forests; however, a larger area of Gambel oak woodlands and forest is found in this region. Carbonate substrates in some areas affect water quality, hydrology, and biota. Soils are generally finer-textured than those found on crystalline and metamorphic substrates such as those in Ecoregion 21c. | Ponderosa pine forest, Gambel oak woodland, and aspen forest (especially on the Western slope). Areas of mountain mahogany and two needle pinyon pine. Shrub vegetation includes antelope bitterbrush, fringed sage, serviceberry, and snowberry. Understory grasses of Arizona fescue, bluegrass, Junegrass, needlegrasses, mountain muhly, pine dropseed, and mountain brome. | Evergreen and some deciduous forest. Timber production, summer livestock grazing, wildlife habitat, and recreation. Some copper, silver, and gold mining. |
| **20c** | Broad, grass-, shrub-, and woodland-covered benches and mesas characterize the Semiarid Benchlands and Canyonlands ecoregion. Areas of high relief alternate with areas of low relief. Low escarpments separate remnant mesa tops and narrow canyons from surrounding benches. Bedrock exposures (e.g., slickrock and fins) are common along rims, escarpments, and on steep dip slopes. Deep eolian soils are composed of fine sand and support warm season grasses, winterfat, Mormon tea, fourwing saltbush, and sagebrush. Two-needle pinyon and Utah juniper occur on shallow, stony soils. Scattered areas of Gambel oak occur at higher elevations. Fire suppression and erosion have allowed this woodland to expand beyond its original range. Overall, the vegetation is not as sparse as in drier areas such as Ecoregions 20b and 20d. Average annual precipitation in the Colorado portion of the region varies from 10 to 18 inches in lower areas; on the highest sites, such as Mesa Verde, 20 to 25 inches can occur. Livestock grazing is a dominant land use, although stock carrying capacity is limited. On floodplains and terraces, some irrigated cropland occurs, primarily hay and grain for livestock. Oil and natural gas wells, oil shale extraction, and coal mining are also present in the region | Pinyon-juniper woodland, Gambel oak woodland, and sagebrush steppe with black sagebrush, winter fat, Mormon tea, four-wing saltbush, shadscale, galleta grass, and blue grama. | Woodland and shrubland. Rangeland, recreation, coal mining, oil and gas production. Oil shale extraction. |
| **20b** | The arid Shale Deserts and Sedimentary Basins ecoregion consists of nearly level basins and valleys, benches, low rounded hills, and badlands. Rock outcrops occur. It is sparsely vegetated with mat saltbush, bud sagebrush, galleta grass, and desert trumpet. Floodplains have alkaline soils that support greasewood, alkali sacaton, seepweed, and shadscale. Scattered, gravel-capped benches occur and protrude from the present denudational surface because they are more resistant to erosion than the surrounding shales. Soils are shallow and types range from clayey to silty. Soils that formed primarily on Mancos shale are found in the areas northwest of Rangley, east of Meeker, in the Grand Valley, in Dry Creek Basin and Disappointment Valley southwest of the Uncompahgre Plateau, and in southwest Colorado near the Mancos River. The Mancos shale basins have the potential for high selenium levels, a particular problem in areas with irrigated agriculture. Soils formed from sandstone, limestone, shale, and gypsum are found in Paradox and Big Gypsum valleys southwest of the Uncompahgre Plateau. Soils formed from claystone, shale, sandstone, and mudstone are found west of Meeker, and in the Colorado River valley near Rifle. Land use includes rangeland, pastureland, and dryland and irrigated cropland, with winter wheat, small grains, forage crops, and pinto beans as major crops. The valleys of the Gunnison and Colorado rivers have areas favorable for growing apples, peaches, pears, and apricots. Shrublands provide important winter habitat for wildlife. | Sparse cover of mat saltbush shrubland and salt desert scrub: shadscale, Nuttall's saltbrush, blackbrush, fourwing saltbush, Wyoming big sagebrush, desert trumpet, galleta grass, and other associated grasses. Floodplain areas support greasewood, alkali sacaton, seepweed, and shadscale. Badland areas have little to no vegetation cover. | Shrubland and rangeland, areas of dryland and irrigated cropland with winter wheat, small grains, forage crops, and pinto beans. Orchards of apples, peaches, pears, and apricots in the Gunnison and Colorado River valleys. Shrublands provide important winter habitat for wildlife. |

## 4.4 Hydrologic Context

Snowmelt results in the most frequent long-duration high-water flows for the study watersheds, however, these runoff events are typically low to moderate in magnitude. Short-duration intensive rainfall occurring in the summer and fall is typically responsible for higher magnitude (flash) floods and debris flows. Long-duration rainfall events, such as those associated with remnant hurricane moisture have been known to affect the area (most recently August 2023 flooding in the Town of Rifle ((Figure 4-3)). As discussed elsewhere in the WRAP, wildfire can result in temporary (3-10+ years) high magnitude and frequency of flooding as a result of changes to the vegetation and soils. Post-wildfire flooding can also deliver significantly elevated amounts of sediment into stream corridors. For more information on local hydrology and historical flooding in the study watersheds please refer to the local Flood Insurance Studies[3] and other resources.

*Figure 4-3. Aftermath of flooding in downtown Rifle, August 2023.*

[3] https://www.newcastlecolorado.org/sites/default/files/fileattachments/planning/page/1690/flood_insurance_study.pdf

## 4.5 Geomorphic Context, Trajectory, and Sensitivity

**Timeline of Geomorphic Change**

Fluvial geomorphic change in the Middle Colorado study watersheds is generally expressed in two ways. One has a long timeline whereby creek boundaries slowly erode and re-deposit sediments changing only very gradually over many years. The other is marked by intense episodic events brought about when the receiving watersheds are energized by heavy runoff, bringing high volumes of water, sediment, and organic debris down into stream corridors. Because these intense episodic geomorphic change events may be followed by relatively long docile interim periods, humans (with our short life spans relative to river and landscape geomorphic change) can easily forget how prone these landscapes are to rapidly reinvent themselves. The etchings of landform change, however, are visible in landscapes unaltered by humans and are what geomorphologists refer to as "fluvial signatures" or "fluvial landforms".

The main forks of the study drainages generally begin in relatively high gradient confining or partially-confining v-shaped valleys. These upper reaches have high connectivity to valley side slopes and side drainages and thus readily recruit and transport sediment and organic debris down the valley. Steeper headwater reaches generally have higher amounts of course sediment (boulder-cobble) in the bed and banks. The primary hazard in these smaller confined reaches is erosion, particularly on outside bends and where streambanks are comprised of softer materials, or where pockets of colluvium can be pulled out from between bedrock outcroppings. Localized deposition induced by debris racking, debris fan constrictions, and infrastructure also induces erosion. These headwater reaches can also be influenced by debris fans which come down from steep side drainages filling the valley floor creating temporary or persistent pinch points affecting channel slope, aggradation and degradation, and channel location. The long-term geomorphic trajectory of these reaches is downward incision. Sensitivity to geomorphologic change in these reaches is low due to confinement and material.

As each creek drops in altitude the valleys tend to become wider and have lower gradient. Stream channel bottom and banks are comprised primarily of small boulders, cobble and gravels that have been washed downstream from high-elevation reaches. These reaches can be erosive and/or depositional. Old channels may fill in during flood events while new ones may form. Avulsion, braiding, flood chutes, split flows, and lateral migration are likely to be found in these transition zone reaches as water and sediment dynamics interact with debris, vegetation (and now human infrastructure). Where land alteration has occurred these fluvial signatures may no longer be visible but underlying alluvium can help point to where stream processes have been at work and where fluvial hazard still exists. Sensitivity to geomorphologic change in these reaches is low to moderate but they can become more dynamic where depositional pockets exist (where the stream corridor expands and/or flattens in slope) and/or where human alterations to the floodplain can disrupt sediment transport or wrack debris such as at an undersized crossing. These transitional reaches are important to consider from a hazard perspective (because they can be dynamic and channels can adjust suddently) as well as a hazard reduction perspective because they can be locations where sediment and debris can be attenuated especially where valley pockets exist (slopes flatten and valley margins widen) (Figure 4-4).

Finally, especially in the drainages of Battlement Mesa, depositional areas where the channel is unconfined and has a low gradient are areas where aggradation of sediment (and resulting erosion as channels shift) becomes the dominant fluvial hazard. Sediment is deposited into alluvial and debris fans as a sudden flattening of the valley slope and reduction in confinement occurs as steep channels coming down off Battlement Mesa enter the wide relatively low-gradient valley of the Colorado River (Figure 4-5). Geomorphic processes on these features are highly unpredictable and thus these fans are especially hazardous.

*Figure 4-4: Large sediment bars formed in a natural depositional area in the Main Elk Creek (u/s from the confluence with West Elk Creek).*

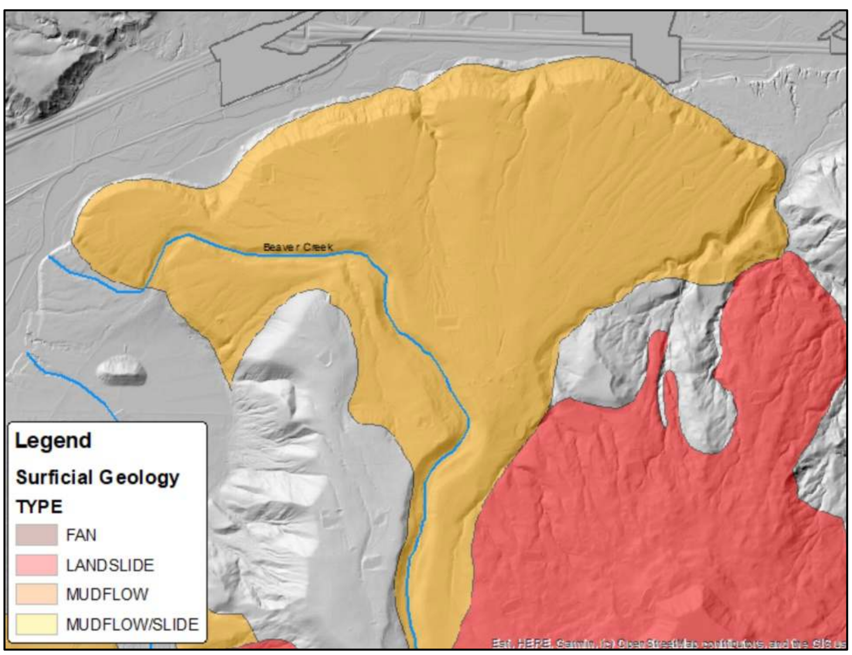


*Figure 4-5: Garfield County geologic hazard layer depicting a mudflow hazard (tan) created by the Beaver Creek drainage.*

## 4.6 Fluvial Process Modifiers

Fluvial Hazard Zone delineation begins with identifying the fundamental processes of river change as driven by gravity and water moving over landforms, surficial geology and sediments, and biotic drivers such as wood and beavers. The interplay of hydrology, geology, and biology influences fluvial erosion and deposition within the active stream corridor.

Human settlement and alterations of landscapes create additional influence on fluvial geomorphic processes. The following subsections offer brief summaries of factors that may affect fluvial hazards in the WRAP stream corridors. This list of subsections is not intended to be comprehensive. Additional information regarding these compounding factors and how they are treated in FHZ delineations are available in the CWCB FHZ Protocol.

### 4.6.2 Bridges and Crossings

Undersized crossings, crossings located on tight channel bends, crossings built askew to the prevailing direction of flood flows, and/or located at sharp changes in valley slopes are notorious for disrupting the natural sediment and debris transport processes in a stream corridor. The resulting disruption (trapping of sediment and debris upstream of a crossing structure) results in upstream deposition of this material and a subsequent geomorphic and hydraulic response (including but not limited to channel erosion, overbank flows, and channel avulsions). On the downstream side of a poorly designed crossing sediment-deprived water becomes more erosive, exacerbating streambank erosion and streambed scour which can undermine the structure and roadway infrastructure and/or impact downstream property. These disruptions to natural fluvial processes should be accounted for in the FHZ delineation, however significant avulsions, especially on alluvial fans and/or in unconfined valleys as a result of crossings can be difficult to predict.

### 4.6.3 Roads

Where road and roadway fills are located within stream corridors (parallel to flow) floodplain areas are diminished and thus erosive energy and sediment transport capacity increases. In other locations, a roadway and its bed may run across a stream corridor (perpendicular to flow) creating a floodplain dam that disrupts down-valley transport of floodwaters, sediment, and debris resulting in aggradation of sediment. In both instances, fluvial response processes should be accounted for in the FHZ delineation.

### 4.6.4 Channelization, Armoring, Fill, and Disconnection of Floodplains

Channelization and fill (straightening, elimination, or relocation of channel meanders; filling of wetlands and side channels to force single-thread channel configurations), sanitization (removal of riparian vegetation, large wood and/or beavers) stream bank armoring (placement of rock riprap or concrete to prevent channel migration or widening) and disconnection of floodplains (through dredging and berming) all result in reduced stream corridor function and increased exposure to fluvial hazard where development is present. Impacts from these activities are often localized and transferred downstream to other reaches.

### 4.6.5 Alluvial and Debris Fan Impacts

**Fluvial hazard mapping *does not* attempt to delineate hazards on fans**. This is especially important in regard to the numerous fans located at the toe of Battlement Mesa. The FHZ on the fans of all Battlement Mesa drainages should be considered a poor approximation for the hazards associated with debris fan/mudflow hazards that exist in these areas.

The fluvial hazard mapping *does* attempt to consider whether fans may exacerbate sedimentation and erosion processes upstream, downstream, and/or at the opposite valley margin when they reach down into stream corridors. FHZ mapping also attempts to consider whether debris flow sediments may be mobilized by the receiving stream and deposited further downstream.

### 4.6.6 Wildfires and Forest Disease

Changes in hydrology and sediment supply due to forest disease and wildfire in the watershed are two additional factors that can affect fluvial geomorphic response and complicate fluvial hazard mapping as extreme amounts of sediment, debris, and floodwaters may be brought down into a stream corridor. Although the mapping team intends that the delineated Fluvial Hazard Zone map should capture the possible area of stream corridor erosion and sedimentation in post-wildfire conditions, the FHZ maps do not identify hillslope hazards (i.e., landslides, debris flows, gullying/rilling, etc.) that may result in the aftermath of a wildfire. For more information on the impacts of wildfires to watersheds and stream corridors visit: www.WildfireReadyWatersheds.com.

# 5.0 Fluvial Hazard Zone Mapping Notes

The study reaches were mapped following the methods outlined in the Colorado Fluvial Hazard Zone Delineation Protocol, Version 1.0. Table 5-1 is a quick reference for outlining additional details of this methodology as applied to this study. Sections 5.1, 5.2, and 5.3 provide further notes on the FHZ mapping done for this WRAP.

***Table 5-1: Quick reference for delineation methods and presence of FHZ auxiliary components in the study reaches.***

| Reach | Active Stream Corridor (ASC) Method | Fluvial Hazard Buffer (FHB) | Fluvial Hazard Buffer Width (Feet) |
|---|---|---|---|
| East Rifle R01 | Fluvial Signature | Type I: Part. confined | 45 |
| Mid Rifle R01 | Fluvial Signature | Type I: Part. confined | 45 |
| West Rifle R01 | Fluvial Signature | Type I: Part. confined | 30 |
| Government R02 | Fluvial Signature | Type I: Confined | 60 |
| Government R01 | Fluvial Signature | Type I: Part. confined | 20 |
| Rifle R04 | Fluvial Signature | Type I: Part. confined | 60 |
| Rifle R03 | Fluvial Signature | Type I: Part. confined | 60 |
| Rifle R02 | Fluvial Signature | Type I: Unconfined far | 20 |
| Rifle R01 | Fluvial Signature | Type I: Unconfined far | 25 |
| West Elk R01 | Fluvial Signature | Type I: Part. confined | 45 |
| East Elk R01 | Fluvial Signature | Type I: Part. confined | 90 |
| Elk R02 | Fluvial Signature | Type I: Part. confined | 120 |
| Elk R01 | Fluvial Signature | Type I: Part. confined | 135 |
| Dry Creek (Garfield Cty) | Headwaters | n/a | 180 |
| Beaver Creek | Headwaters | n/a | 225 |
| Porcupine Creek | Headwaters | n/a | 180 |
| Spruce Creek | Headwaters | n/a | 180 |
| Cache Creek | Headwaters | n/a | 225 |
| Cottonwood Creek | Headwaters | n/a | 225 |
| Battlement Creek | Headwaters | n/a | 225 |
| Monument Gulch | Headwaters | n/a | 225 |
| Unknown | Headwaters | n/a | 180 |
| Dry Creek | Headwaters | n/a | 90 |

| | | | |
|---|---|---|---|
| Pete and Bill Creek | Headwaters | n/a | 180 |
| Spring Creek | Headwaters | n/a | 135 |
| Wallace Creek | Headwaters | n/a | 162 |
| Little Alkali Creek | Headwaters | n/a | 135 |
| Alkali Creek | Headwaters | n/a | 135 |

## 5.1 Active Stream Corridor

The Active Stream Corridor for the Elk and Rifle study reaches were delineated using the Fluvial Signature method as outlined in the CWCB FHZ Protocol. This method typically applies to 2nd to 3rd order and greater streams with a steep to mild slope, a confined to partially confined (may also include steep and unconfined) valley bottom, and a discernable floodplain (though this may be discontinuous). This approach utilizes observations made in the field coupled with remotely sensed data. In these settings, the Active Stream Corridor typically incorporates the entire geomorphic floodplain. Where human alterations (e.g., roadway fill, gravel ponds) have impacted the geomorphic floodplain or where natural conditions (e.g., exposed bedrock) exist, the Active Stream Corridor was delineated as per the guidance in the CWCB FHZ Protocol.

Preliminary mapping for the WRAP the Battlement Mesa drainages were delineated using the Headwaters Protocol. Application of this protocol is based on professional judgment but generally applies to smaller watersheds where geomorphic floodplains are absent, discontinuous, and/or limited. The Headwaters ASC is a buffer applied to either side of a stream corridor centerline. The FHB width in Table 5-1 represents an average stream corridor width for each drainage. This number was derived from a coarse measurement of stream channel widths based on aerial images and then multiplied by 9. The result for each watershed seemed to account for observed erosion in the valley bottom and valley margins of which most of these channels are well entrenched into. FHZ mapping is particularly challenging for these drainages and is presented only as preliminary boundaries for the WRAP but **should be refined for further land use planning and decision-making to protect life and property.**

## 5.2 Fluvial Hazard Buffer

The Fluvial Hazard Buffer for all reaches of this FHZ study was mapped using the guidance for standard Colorado streams. Specific Fluvial Hazard Buffer widths used for each reach are provided in the Reach Information Sheets found in Appendix A. In contrast to the Active Stream Corridor, due to numerous stochastic factors it is highly unlikely that the entirety of the Fluvial Hazard Buffer will be affected by fluvial geomorphic change simultaneously during a flood event. However for this WRAP effort of which FHZ maps are preliminary and not peer reviewed, the Fluvial Hazard Buffer was mapped uniformly by reach. No adjustments to the FHB were made for this WRAP mapping effort.

## 5.3 Auxiliary Hazards

As discussed in Section 2.2, Auxiliary Fluvial Hazard Zone components demarcate locations where other types of fluvial hazards, or fluvial hazards that are not captured by the Active Stream Corridor or Fluvial Hazard Buffer, are likely to occur.

Fans, Geotechnical Flags, and Disconnected Active Stream Corridors were not identified for the WRAP. Refinement and further study are recommended if the community wants to use fluvial hazard maps for other planning efforts.

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|---|---|
| Document Creation: | Generated on July 25, 2024 by Michael Blazewicz. |
| Updates: | n/a |

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GENERAL INFORMATION

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|---|---|
| Title of Dataset: | Fluvial Hazard Zone Map and supporting materials for Middle Colorado Watershed Wildfire Ready Action Plan (WRAP) |
| Study Timeframe: | January 2024 – July 2024. |
| Principal Investigator: | Michael Blazewicz, Round River Design, Inc., michael@roundriverdesign.com |
| Co-investigators: | Joel Sholtes and Katie Jagt |
| Alternate Contact(s): | Chris Sturm, Colorado Water Conservation Board |
| Funding sources: | The *Middle Colorado Watershed WRAP Fluvial Hazard Zone Mapping* was funded by CWCB Wildfire Ready Watersheds funding. |

Intended Use:

FHZ maps are intended to delineate the area a stream has occupied in recent history, may occupy, or may physically influence as it stores and transports water, sediment, and debris. FHZ maps do not predict the magnitude, frequency, or rate of fluvial geomorphic hazards.

**PLEASE NOTE: This is a Preliminary (DRAFT) FHZ that was developed for the purposes of incorporation into a Wildfire Ready Action Plan. The FHZ delineation was conducted at a high-level for purpose of identifying possible intersections between fluvial hazards and community assets that may be at risk from post-wildfire flooding. Methods followed the general guidance of the CWCB protocol but did not include delineations of fans, disconnected ASC's, and/or geotechnical failures. Fluvial hazard buffer boundaries were not adjusted. FHZ delineations for ALL Battlement Mesa drainages was approximated and does not accurately portray fluvial or other hazards on the fans that exist near the bottom of each drainage. Only very high-level third party review of the delineations was conducted.**

The FHZ map authors along with the Colorado Water Conservation Board (CWCB) make no representations or warranties, expressed or implied, as to the accuracy, completeness, timeliness, or rights to the use of FHZ maps. The authors and CWCB shall not be liable for any errors, omissions, or inaccuracies in such information regardless of their cause, and shall not be liable for any decision made, action taken, or action not taken by the user in reliance upon such information. The authors and CWCB shall not be liable for any general, special, indirect, incidental, or consequential damages including, but not limited to, lost revenues or lost profits resulting from the use or misuse of the information contained on FHZ maps.

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SHARING/ACCESS INFORMATION

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Licenses/restrictions placed on the data, or limitations of reuse: Map products are not intended for use as a zoning overlay boundary without further review.

Citation for and links to publications that cite or use the data:

Round River Design. (2024). Middle Colorado Watershed Council Wildfire Ready Action Plan Fluvial Hazard Zone Map and Addendum. Prepared for Middle Colorado Watershed Council.

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STUDY INFORMATION

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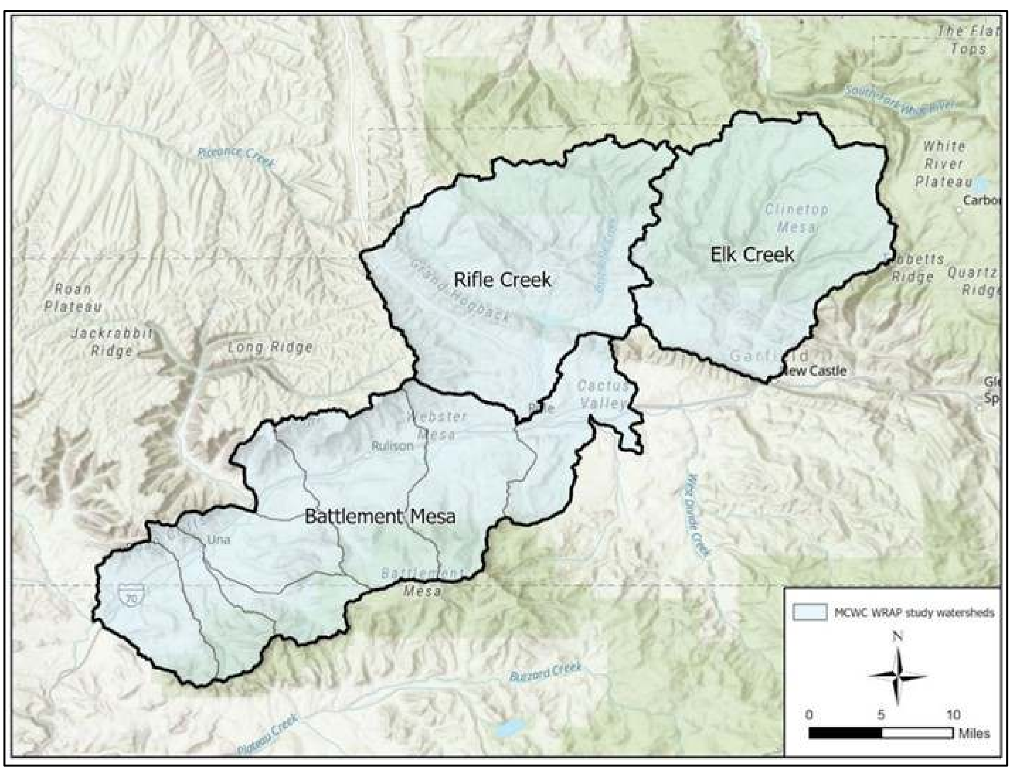
| | |
|---|---|
| Study End Date: | July 2024 |
| Geographic Area: | Elk Creek, Rifle Creek, and Battlement Mesa watersheds (Garfield and Mesa County) |
| Data Types: | A file geodatabase (ArcGIS) containing shapefiles and raster data types. |
| Data gaps: | Data was collected primarily on private lands only. Public/federal lands were not mapped. |

Study Area Map:



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DATA & FILE OVERVIEW

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The geospatial data delineating the Fluvial Hazard Zone and its components along with supplemental data are included in a file geodatabase (.GDB)

The file structure of the FHZ geodatabase is as follows:

FHZ_MiddleColorado_07252024.gdb

> FHZ_Map_Layers (feature dataset)

*Projected in NAD 1983 2011 StatePlane Colorado Central FIPS 0502 Ft US*

> FHZ_Rifle_ASC_07232024.shp (active stream corridor, polyline)

> FHZ_Rifle_FHB_07232024.shp (fluvial hazard buffer, polyline)

> FHZ_Elk_ASC_0723024.shp (active stream corridor, polyline)

> FHZ_Elk_FHB_07232024.shp (fluvial hazard buffer, polyline)

> FHZ_Battlement_08072024.shp (fluvial hazard zone, polyline)

> Stream and Reach Data (feature dataset)

*Projected in NAD 1983 2011 StatePlane Colorado Central FIPS 0502 Ft US*

> FHZ_MidColorado_streams.shp (polyline) (stream centerlines, polyline)

> FHZ_MidColorado_reachbrks_05142024.shp (Reach break nodes used for FHZ, point)

> REM.tif (relative elevation model, raster) [NOTE NO REM's DEVELOPED FOR BATTLEMENT MESA CREEKS]

Created By: Michael Blazewicz

Created Using: CWCB REM Generation Tool v4.0

Projected Coordinate System:
NAD_1983_HARN_StatePlane_Colorado_Central_FIPS_0501_Feet

> Rifle_RelativeDEM_Feet

> EastRifle_RelativeDEM_Feet

> WestRifle_RelativeDEM_Feet

> Government_RelativeDEM_Feet

> Elk_RelativeDEM_Feet

> EastElk_RelativeDEM_Feet

> WestElk_RelativeDEM_Feet

Additional related data used in the study that is not included in the current data package:

Aerial Imagery (historic and contemporary, raster imagery)

Existing Floodplain maps (FEMA FIRMs, polygon shapefiles)

Geologic Hazards (Garfield County)

Surficial Geologic Maps (feature dataset)

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METHODOLOGICAL INFORMATION

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Description of methods used for collection/generation of data:

FHZ Map layers were delineated following guidance in the Colorado Fluvial Hazard Zone Delineation Protocol (Protocol) (Blazewicz et al., 2020). The relative elevation model (REM) was generated following Appendix C of the Protocol with the CWCB REM Tool v4.

Standards and calibration information, if appropriate:

Though FHZ maps are typically delineated using approximately 1 meter x 1 meter horizontal resolution LiDAR data, the appropriate scale for visualization to be used for online viewers is 1:1,000 to 1:4,000.

Quality-assurance procedures:

Preliminary FHZ maps were assessed and validated using field observations. Robust third-party review and detailed mapping were not conducted for this WRAP-level effort.

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SUPPLEMENTAL DATA DOCUMENTATION

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Geological Maps
Discovered at https://ngmdb.usgs.gov/ngmdb/ngmdb_home.html

Geologic Hazards
Discovered at Garfield County GIS https://data-garfieldcolorado.opendata.arcgis.com/

Contemporary Aerial Imagery

Google Earth Images
ESRI aerial imagery

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REFERENCES

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Blazewicz, M., K. Jagt and J. Sholtes. 2020. “Colorado Fluvial Hazard Zone Delineation Protocol”. Colorado Water Conservation Board

# MEMO

- [ ] Overnight
- [ ] Regular Mail
- [ ] Hand Delivery
- [ ] Other: ______________

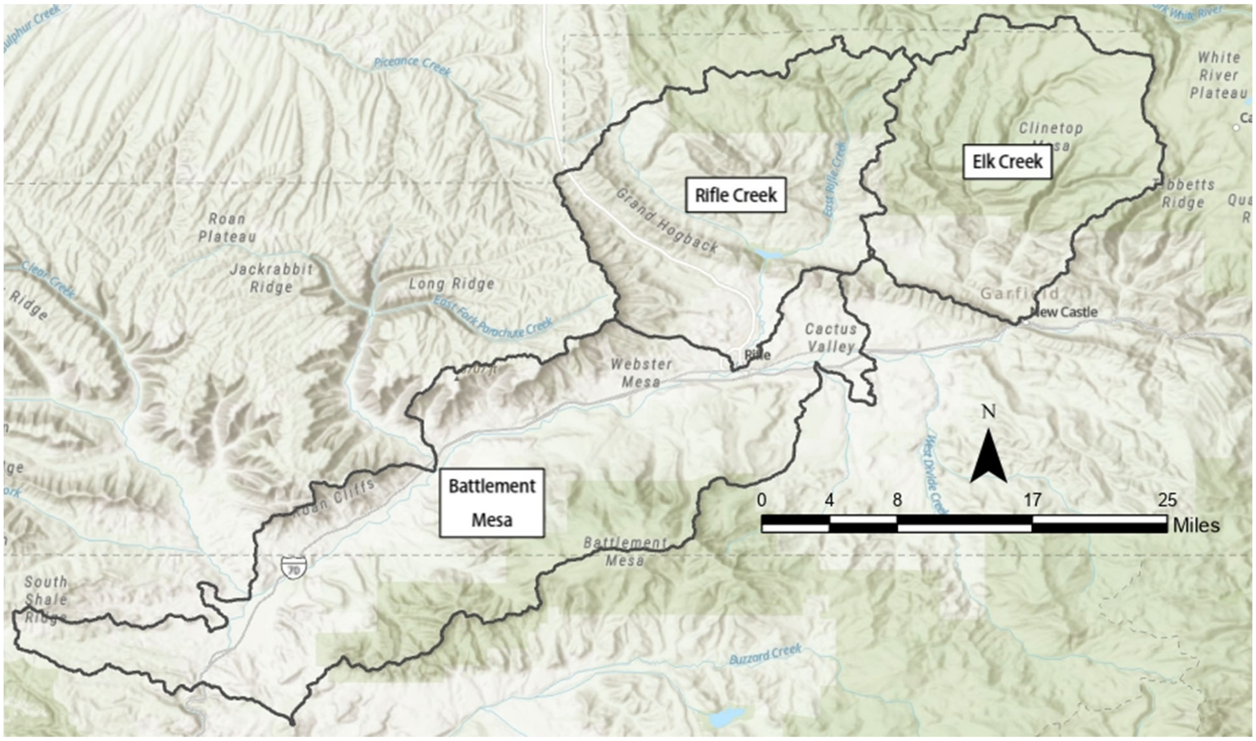
| | |
|---|---|
| **To:** | Middle Colorado Watershed Council<br>SGM |
| **From:** | Olsson |
| **RE:** | Middle Colorado Wildfire Ready Action Plan<br>Hydrology, Hydraulics, and Sediment Yield Technical Analyses |
| **Date:** | July 23, 2024 |
| **Project #:** | 023-02288 |
| **CC:** | Colorado Water Conservation Board (CWCB) |
| **Task:** | |

## Purpose/Background:

Wildfire is an increasing concern as forests become overgrown due to a lack of proactive management, periods of drought increase, and as climatic changes create conditions for wildfires. They are one of the most impactful biome disturbances on hydrologic processes and responses (Ebel, 2023). The state of Colorado has seen an increase in the number and size of wildfires since the start of the 21st Century. In 2020, the state experienced the three largest wildfires in its history (The Nature Conservancy, 2024). Wildfires not only cause damage to infrastructure and property during the fire, but post-fire hazards can be even more impactful to life and property. Wildfires create conditions that result in significant changes to existing hazards including increase runoff, flooding, debris flows, fluvial erosion, and sediment production. The flooding and erosion that occurs post-wildfire can also negatively affect stream habitats, stability, and infrastructure (Cole et al., 2020). The Colorado Water Conservation Board (CWCB) developed the Wildfire Ready Watershed (WRW) program to proactively understand post-fire risk and develop mitigation strategies to reduce impacts from these hazards. A key part of the program is for communities and stakeholders to work together to create a Wildfire Ready Action Plan (WRAP) for their watersheds that will allow for the adoption and implementation of watershed improvement projects.

Olsson, as the lead consulting firm for the CWCB's Technical Assistance team, has partnered with Middle Colorado Watershed, Wright Water Engineers, SGM, and Round River Design to support the development of a WRAP for three study areas including the Elk Creek watershed (180 sq miles), Rifle Creek watershed (200 sq miles), and Battlement Mesa tributaries (375 sq miles) totaling over 755 square miles. Figure 1 below shows all 3 basin areas. Olsson was tasked with providing hazard analyses for the changes to post-fire hydrology, understanding post-fire flooding and inundation, and how a wildfire would impact sediment yield and delivery to downstream systems.

*Figure 1.* MCWC Basins




The purpose of this technical memorandum is to present the hydrologic, hydraulic and erosion analysis that was completed to support the Middle Colorado WRAP.

## Location & Watershed Characteristics

The three major watersheds studied as part of this WRAP are the Battlement Mesa tributaries, Rifle Creek, and Elk Creek. Each drain to the Colorado River. The modeled watersheds range in elevation from approximately 6,500 feet at the basin outlets to the upper watersheds ranging from 10,000 feet to 12,600 feet at the highest point. The watersheds are all in the Flat Tops and Grand Mesa Mountains of western Colorado. The upper portions of the watersheds are heavily forested and include evergreens such as pines, firs, and spruces, as well as deciduous trees, such as aspen and oak. The lower watersheds are dominated by ponderosa pines, which give way to junipers and pinons at lower elevations. The watersheds drain to wide valleys containing a few small developments and some agricultural fields. The lower portion of the watersheds are arid, flat, and contain primarily scattered grasses and shrubs, except along the riparian corridor where cottonwoods and willows receive sufficient moisture to grow. Soils are primarily sandy/silty loams with rock in varying degrees of decomposition. Larger rocks are generally in the higher elevations, with the smaller rocks becoming increasingly more common at the lower elevations. The continuous waterways tend to have an armoring layer that has developed on the bed of the creeks/rivers.

Flooding in the mountain regions is typically the result of either snowmelt or rainfall events of varying duration and intensity (Waltemeyer 2008). For this assessment, only rainfall flooding was considered.

Under the unburned condition, seasonal monsoon events typically do not produce significant debris and flood flows in these watersheds (USACE, 2023).

## Approach

Olsson developed the pre- and post-fire hydrologic model using the Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS Version 4.11). HEC-HMS is a widely used, accepted, and well-reviewed hydrologic model published by the U.S. Army Corp of Engineers (USACE) and is designed to simulate the complete hydrologic process of watershed systems (USACE, 2022). The model is capable of modeling rainfall runoff and predicting debris yield from each subbasin and then routes hydrographs through the connected stream system. Olsson chose to us the widely accepted process known as Technical Release 55 (TR-55) along with the Soil Conservation Service (SCS) Unit Hydrograph. Olsson separated the Middle Colorado Watershed into three Major study regions, Battlement Mesa, Rifle, and Elk Creek. Olsson performed a hydrologic analysis on each area modeling three different types of events in HEC-HM. The objective of the hydrologic analysis was to provide an estimate of the magnitude of the flooding and debris yield potential post-wildfire. The peak flows were then utilized in a hydraulic model (HEC-RAS 6.4.1).

*Table 1. Modeled Conditions.*

| Modeled Condition | Hydrologic Method | Unit Hydrograph Method | Sediment Method | Hydraulic Method |
|---|---|---|---|---|
| **Pre-Fire** | SCS CN | SCS | MUSLE | HEC-HMS[1] |
| **Post-Fire** | SCS CN with Burned Condition | SCS | - | HEC-RAS 2D |
| **Post-Fire w/Sediment** | SCS CN with Burned Conditions | SCS | MUSLE | HEC-HMS |

[1]No pre-fire HEC-RAS hydraulic modeling was performed for this analysis.

The following describes the procedure implemented to determine the pre-fire, post-fire, and sediment yield runoff.

## Data Collection

The following terrain, precipitation, and stream flow data were collected for the development of the HEC-HMS models.

### Terrain

Olsson downloaded terrain data from the US Geological Survey (USGS) for the Elk and Rifle Basins. The digital Elevation model (DEM) was 3-meter resolution from (2023). The spatial reference is Universal Transverse Mercator (UTM) North American Vertical Datum of 1988

(NAVD88). The Battlement Mesa Basin used LiDAR data provided by CWCB. CWCB LiDAR data was downloaded from the Colorado Hazard Mapping & Risk MAP Portal. All CWCB LiDAR data used as a part of this project was collected in 2016 by Merrick & Co on behalf of the CWCB.

### Land Cover

Olsson downloaded land use data from the USGS National Land Cover Data Base for the Battlement Mesa, Elk, and Rifle Basins. The land use data was 30-meter resolution from (2019).

### Soils

Olsson downloaded soil classification data from the Natural Resources Conservation Service's Soil Survey Geographic Database (SSURGO) for the Battlement Mesa, Elk, and Rifle Basins. The soil data was from (2021).

### Precipitation

Precipitation frequency grids are available from the National Oceanic and Atmospheric Administration (NOAA) on the Atlas 14 Precipitation Frequency Data Server. Olsson downloaded these precipitation grids to perform a rainfall-runoff analyses in HEC-HMS for six different annual exceedance probability (AEP) events: 2-, 5-, 10-, 25-, 50-, 100-year. The precipitation grids are specific for the region, the annual maximum series, and a 6-hour duration (NOAA 2017).

### Stream Flow

To better understand the discharge-frequency relationship for these basins and/or similar basins nearby, Olsson gathered a set of discharge records using Stream Stats analysis for each of the three major basins. The stream flow records are summarized in Table 1.

### Bulletin 17C Analysis

Olsson evaluated the collected gage data within the region to perform a Bulletin 17C analysis. Based on the available data, Olsson determined that there were not enough years of record to be valid. Olsson therefore determined to use Stream Stats.

### Burn Severity Data

Two different burn severity data sets were used for this project. Elk and Rifle Creek basins both use fire severity mapping from the Joint Fire Science Program, whereas Battlement Mesa uses the mapping from Colorado Forest Restoration Institute (CFRI). These data sets were compared and found to have no notable differences. The burn severity data was 30-meter resolution from (2009).

## Model Development

Olsson took the following steps to process data and to define the methods and parameters for the watersheds, modeled as separate Major Basin models, in HEC-HMS.

## Basin Delineation and Topographic Parameters

The first step of the analysis was to delineate and define the sub-basins within each Major Basin to be used for the rainfall-runoff model. The terrain data collected from USGS and the CWCB was processed using the Watershed Modeling System (WMS v.11.2) developed by Aquaveo. As there were no appropriate USGS stream gages within any of the Basins, Olsson used an outfall point at the outlet of the basin. Olsson used the delineation tool within WMS to define sub-basins. Sub-basins were reviewed by the team to verify that areas of interest were properly captured and would provide information that would benefit the WRAP process. If necessary, sub-basins were further refined to provide information at strategic locations throughout the watershed. The target size for the sub-basins was 1 to 8 square miles or less, to meet maximum size thresholds required for the SCS CN hydrologic equations within HEC-HMS. The three modeled Basins cover a total area of 755 square miles.

HEC-HMS automatically generates reach elements, which Olsson did not modify, but reviewed to determine if there were any discrepancies based on the terrain data and watershed characteristics. Reaches less than 500 feet in length were removed to reduce model instabilities.

## Losses

Curve Numbers

Olsson used the SCS CN loss method as it is one of the most studied and used methodologies for determining post-fire runoff estimates and is recommended by CWCB as part of WRS, having established methods for adjusting CNs for various burn conditions (Livingston, 2006; Hawkins, 1993). As the SCS CN method is a lumped model, some calibration is needed for each Basin. WMS calculated an area-weighted CN for each Sub-Basin using the 2019 National Land Cover Database (NLCD) and the hydrologic soil group from the 2021 Natural Resources Conservation Service's Soil Survey Geographic Database (SSURGO) data sets. Sub-basins were assigned 4 sets of curve numbers, varying by rainfall events based on the calibration process for the 2-, 5-, 10-, and 25-year. Only one set of CN's was used based on calibration of the 25-year event for the 25-, 50- and 100-year events.

Post Fire CN Methodology

Two different methods for adjusting curve numbers for post fire conditions were analyzed for use in this project, and are discussed below:

- Livingston (2006)
  - Livingston analyzes the burn severity (using the base data described above) within each basin and determines a Wildfire Hydrologic Impact (WHI) zone of Low, Moderate or Severe as a function of the percentage of basin area in "high" and "moderate" burn severity zones. Depending on which WHI zone the basin of interest lies in, a specific ratio is applied to the pre-fire curve number value to determine the post-fire curve number.

- Hawkins (1993)
  - Hawkins discretizes low, moderate and severe burn areas into constant values to adjust pre-fire curve numbers; with low being an addition of 5, moderate an addition of 10, and severe 15. The percentage of each burn category within a basin's boundary is found, and then used to create a weighted average by which to increase the basin's curve number to represent the post-fire condition.

While both methods were analyzed for each study area, Olsson chose to use the Livingston method as it produced more conservative results.

Initial Abstractions

Olsson calculated initial abstraction using a ratio of 0.2 times the potential retention (S), which is determined from the CN. Since the CN is considered a lumped parameter and land use was accounted for in the CN values, Olsson set the percent impervious to 0.0%.

### Transform

Olsson selected the SCS Unit Hydrograph method to transform the excess rainfall hyetograph to a direct runoff hydrograph. The SCS Unit Hydrograph input parameters include the graph type for peak factor (PRF) and lag time. Olsson used the Standard PRF of 484 for all sub-basins. Lag time is computed as a function of flow length, watershed slope, and maximum potential retention which is a function of the CN. Since CN values varied during calibration, Olsson adjusted the lag time based on the calibrated CN values.

### Canopy/Surface

A canopy and surface model were not utilized as it is assumed that it is accounted for in the CN.

### Baseflow

Olsson did not use a baseflow method as part of this analysis. Most of these Basins have flow year-round, however the magnitude of the baseflow compared to the magnitude of the flood events is small and is not expected to impact the magnitude of the modeled flood events.

### Routing

The Muskingum-Cunge routing method was selected by Olsson as it utilizes physically based input parameters which is more robust to other empirically based methods given the limited post-fire calibration data. Olsson assumed a steady-state condition, ie- inflow equals outflow, for the initial type. WMS computed the length and slope of each reach. Olsson estimated the roughness values (Manning's n) for each reach based on reference tables related to land cover (USACE 2022b) and aerial imagery. HEC-HMS has an auto DX and DT program method that selects the appropriate space and time intervals to maintain numeric stability. Olsson used this method and selected a Celerity index of 5 ft/s for all reaches.

### Meteorologic Model

A hypothetical storm was used by Olsson for the HEC-HMS models. Olsson chose to use the annual maximum precipitation frequency grids from NOAA Atlas 14 as the precipitation source. Olsson modeled the 2-, 5-, 10-, 25-, 50-, and 100-year AEP events for the Basins. As the SCS Curve number method only considers total rainfall volume, not intensity, or duration (Ebel et. al. 2023, Chin 2013) Olsson chose to use a 6-hour storm duration to represent the short-duration convective storms expected to occur during the monsoon season. This required that CNs be adjusted for less than 24-hours (Meadows, 2015). Olsson also reviewed the different storm patterns from NOAA Atlas 14 and previous wildfire models completed in the southwest (AuBuchon et. al. 2022) and chose to use the first quartile 70% of duration storm pattern for all the events and Basins modeled. It's noted here that the SCS method was practically developed for the 24-hour duration event, but for this analysis a 6 hour was chosen based on various statewide criteria from CWCB and others and to better reflect a shorter duration event that still was longer than the calculated time of concentration for the entire basin.

As previously discussed, Olsson used the NOAA Atlas 14 precipitation frequency grids to prepare independent hyetographs for each sub-basin. To be conservative, Olsson did not apply any area reduction factors to the Basins.

## Calibration

It should be noted that the intended purpose of the SCS CN model is to evaluate the effects of land-use changes on direct runoff, which it does very well. But it was not developed to reproduce individual historical events and only limited success has been achieved in using it for that purpose (Chin, 2013). Also, Dunne and Leopold (1978) have indicated that the unit hydrograph method gives estimates of flood peaks that are usually within 25% of their true value. Dingman (2002) also indicated that errors larger than this can be expected if synthetic unit hydrographs are used without verification for the region.

Due to a lack of stream flow data, Olsson used a simplified method of calibrating peak flows to Stream Stats flow-frequency curves for the pre-fire condition. No information was available at the time of the modeling analysis for a post-wildfire hydrology or sediment yield calibration. Olsson calibrated the peak flow from each frequency event by adjusting the basin loss (CN values), transform parameters (lag time), and initial abstraction ratio.

The initial CN values were adjusted based on the change in rainfall duration (24-hour to 6-hour) by Olsson following the recommendations of Meadows (2015). Olsson then adjusted these values by a constant factor to provide realistic CNs for a pre-fire condition to match the Stream Stats estimates. Further calibration efforts by Olsson included optimization trials (a tool within HEC-HMS) and hydrographs based on the timing of uncalibrated flows using the peak flows from Stream Stats to calibrate the model. This resulted in refinement to the CNs, initial abstraction ratio, and lag time for the pre-fire input parameters. The final verification was to evaluate the peak flows against the expected peaks from Stream Stats.

The figures and table below present the calibration with the Stream Stats data. As noted previously, each event up to the 25-year event was calibrated separately and CN's adjusted for each.  For the 25-year and beyond, only one set of CN's were used based on calibration of the 25-year event.

*Figure 2.* Elk Creek Calibration

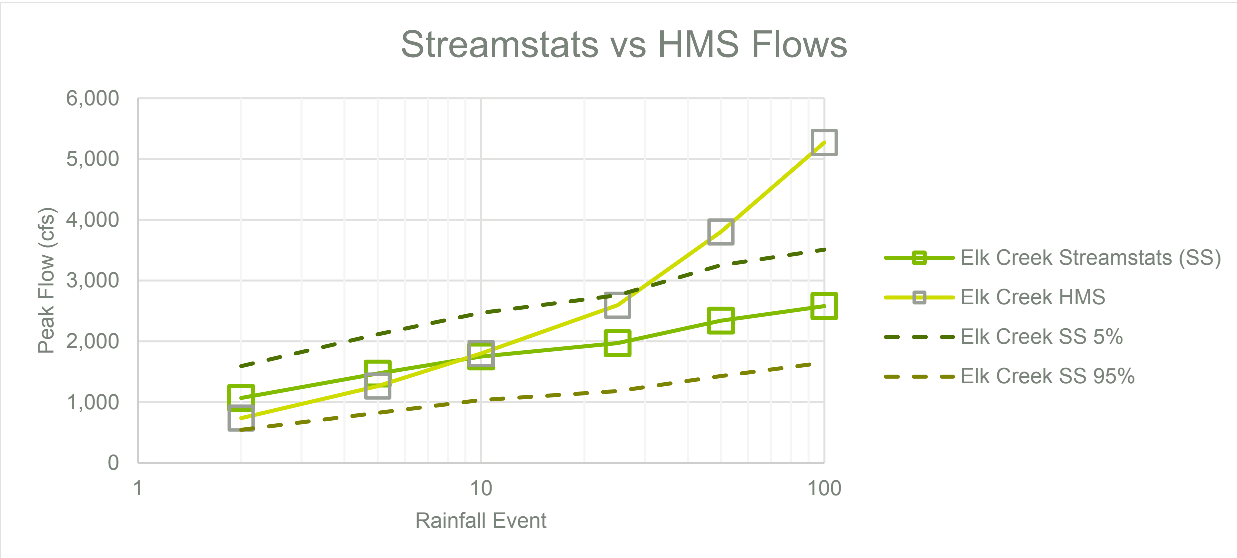



*Figure 3.* Rifle Creek Calibration

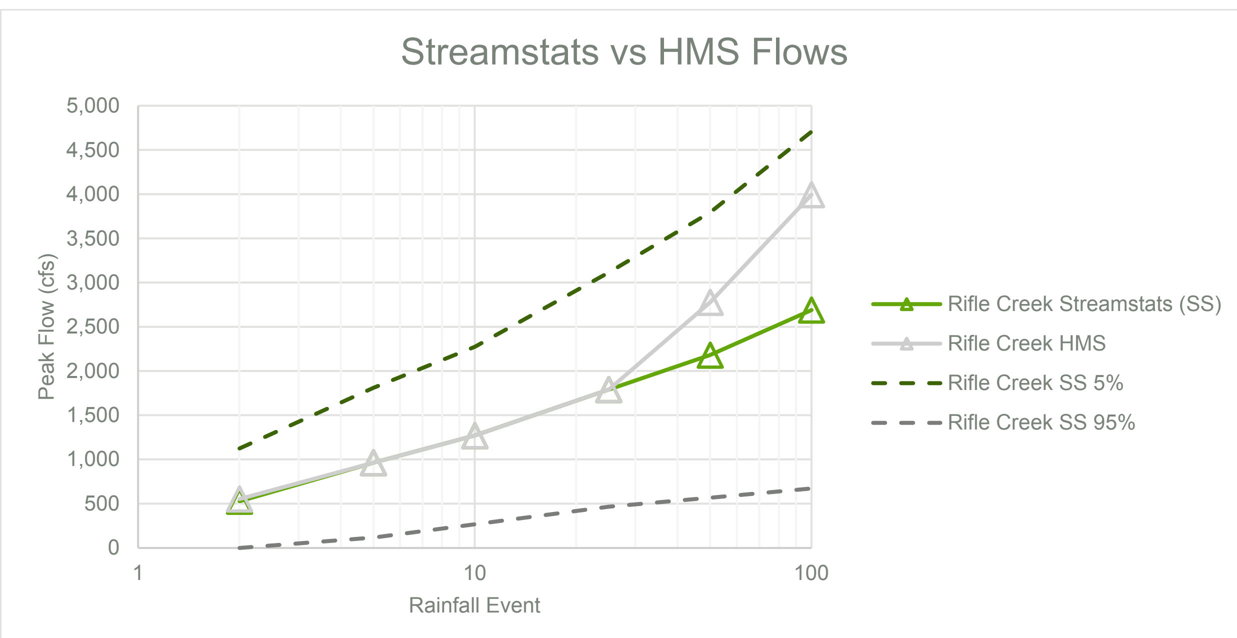


*Figure 4.* Battlement Mesa Calibration

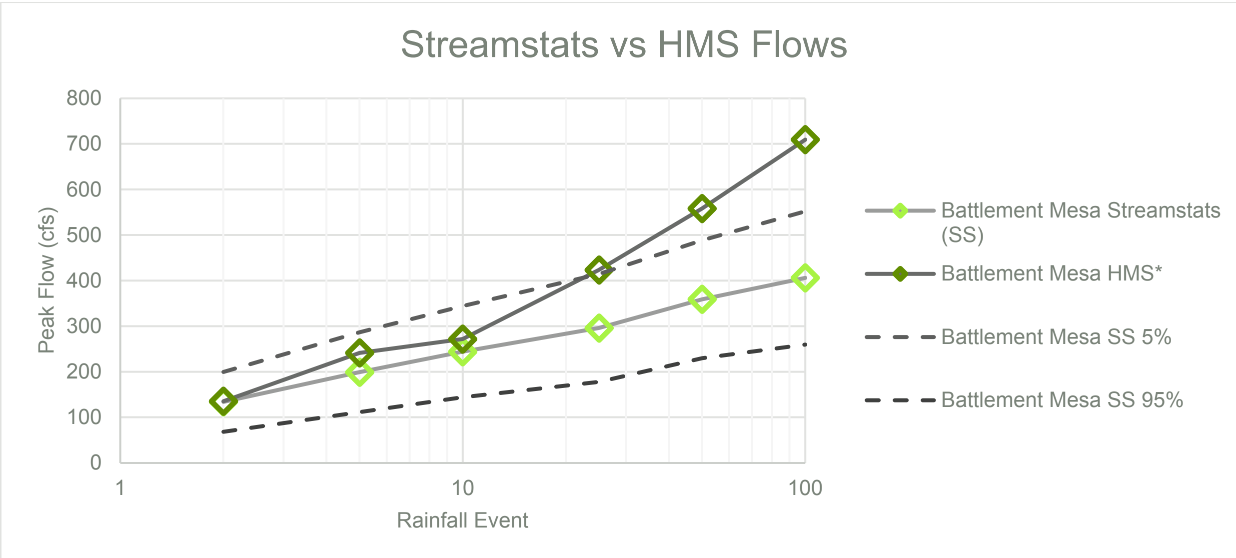



*Table 2.* Calibration of HMS vs Stream Stats

| Study Basin | 2 | 5 | 10 | 25 | 50 | 100 |
|---|---|---|---|---|---|---|
| Elk Creek Stream Stats (SS) | 1,070 | 1,470 | 1,750 | 1,970 | 2,340 | 2,580 |
| Elk Creek SS 5% | 1,594 | 2,117 | 2,468 | 2,758 | 3,253 | 3,509 |
| Elk Creek SS 95% | 546 | 823 | 1,033 | 1,182 | 1,427 | 1,651 |
| Elk Creek HMS | 737 | 1,263 | 1,800 | 2,595 | 3,800 | 5,272 |
| Rifle Creek Stream Stats (SS) | 528 | 963 | 1,270 | 1,790 | 2,180 | 2,690 |
| Rifle Creek SS 5% | 1,125 | 1,810 | 2,273 | 3,115 | 3,793 | 4,708 |
| Rifle Creek SS 95% | 0 | 116 | 267 | 465 | 567 | 673 |
| Rifle Creek HMS | 553 | 963 | 1,270 | 1,790 | 2,776 | 3,994 |
| Battlement Mesa Stream Stats (SS) | 134 | 199 | 244 | 296 | 359 | 406 |
| Battlement Mesa SS 5% | 200 | 287 | 344 | 414 | 488 | 552 |
| Battlement Mesa SS 95% | 68 | 111 | 144 | 178 | 230 | 260 |
| Battlement Mesa HMS* | 135 | 241 | 272 | 423 | 558 | 709 |

*HMS results are local flows from Junction-19, subtracting the flows from SB192.

## Post Fire Hydrology

Olsson adjusted the pre-fire input parameters to determine post-fire conditions. The general process Olsson followed to model post-fire hydrology was to adjust CNs to represent changes to the land use and soils and to estimate post-fire peak flows. Next, the post-fire models were used by Olsson to determine post-fire sediment yields that were used to calculate total sediment change for each sub-basin and reach. Finally, Olsson compiled the post-fire peak flows and used them in a separate hydraulic modeling software (HEC-RAS) to produce inundation maps. The table below provides links to interactive ArcGIS

Online maps which contain visualizations of all results discussed herein. Results have had symbology applied to them where applicable to help increase the understanding of their meaning. Each feature within these maps can be selected, where upon a table including key results will be presented to the user.

## Hydrology

Olsson performed separate basin models and frequency analysis for the post-fire conditions in HEC-HMS. The adjusted post-fire CN values were applied by Olsson to the appropriate basin models and the lag time was calculated based on the post-fire CN values. Pre and post fire CNs are shown in Appendix A Table 1.

As discussed above, Olsson analyzed CN changes post-fire using two different methods, Livingston and Hawkins. When reviewing the results, Olsson found that the Livingston Method was consistently higher than the Hawkins method in the Elk Creek and Rifle Creek study areas (See Table 3). Battlement Mesa contains lesser burn severity areas, and as the Livingston method was chosen for both other study areas, only a Livingston analysis was done for Battlement Mesa.

### Bulking Factor

In addition to increased runoff, increased sediment erosion will change the viscosity and volume of water that is released downstream. This volume of sediment is typically accounted for using a bulking factor. Bulking factors for post-fire flows can range from 1.5 (for the annual AEP event) to 1.25 (for the 1% AEP event). The use of bulking factors was considered but was not incorporated into the flow estimates. The Olsson team took into account the conservative nature of the Livingston CN methodology vs. the Hawkins methodology that had been used on several of the 2020 Colorado post-fire H&H analyses. Since the Livingston method produces higher flows ranging from 1.11 to 1.90 versus Hawkins, Olsson determined that this more conservative approach can act as a proxy for a 'bulking factor'. Although Olsson did not apply a bulking factor to the flow rates, the use of the more conservative CN using the Livington method creates more conservative flow estimates that begin to approximate bulked flow rates that typically would be in the range of 1.3 to 1.4 times the clear water estimate. For future analyses, a design team may consider the use of bulking factors to be even more conservative.

*Table 3. Livingston vs. Hawkins results percent difference.*

| Modeled Condition | Elk (Average Diff) | Rifle (Average Diff) |
|---|---|---|
| **Livingston vs. Hawkins** | 111% | 190% |
| **Increased Factor** | 1.11 | 1.90 |

Hydrology results are included in the maps referenced in **Table 6,** below. The results are symbolized by the ratio of change for the 10-year event, with green basins, reaches and junctions having the least change, and red elements having the greatest.

## Hillslope Erosion Analysis

In addition to increased runoff, post-fire watersheds will have increased hillslope erosion generating increased sediment yields which will change the viscosity and volume of water that is received downstream and result in deposition within drainageways and reservoirs. To provide an estimate of the increase sediment load, Olsson evaluated the erosion impacts within each sub-basin identified as hillslope and gully/rill erosion. Olsson chose to use the MUSLE model within HEC-HMS to estimate the volume of sediment post-fire.

The Universal Soil Loss Equation (USLE) is one of the most used soil erosion models. There are three variations of the USLE that measure soil loss per unit area at an annual timescale. They are the Revised Universal Soil Loss Equation (RUSLE), the Revised Universal Soil Loss Equation version 2 (RUSLE2), and the Modified Universal Soil Loss Equation (MUSLE). USLE and its suite of models is an empirical model used to estimate the annual average rate of soil erosion (tons per unit area) for a given combination of crop system, management practice, soil type, rainfall pattern, and topography. It was originally developed at the plot scale for agricultural plots in the United States of America (Wischmeier and Smith, 1978). RUSLE was updated to include new rainfall erosivity maps for the U.S. and improvements to the method of calculating the different USLE factors (Renard et al., 1997). RUSLE added changes in soil erodibility due to freeze-thaw and soil moisture, a method for calculating cover and management factors, changes to how the influence of topography is incorporated into the model, and updated values to represent soil conservation practices (Renard and Freimund, 1994). RUSLE2 is a computer interface framework programmed to handle more complex field simulations, including an updated database of factors (Foster et al., 2003). MUSLE is an extension to work at finer temporal resolution, using runoff and peak flow rate to estimate event-based soil loss (Sadeghi et al., 2014).

The MUSLE and Volume Ratio analysis was completed in GIS and HMS using available data sets for the three major basins. Olsson followed the HEC-HMS manual and the USLE manual to determine and input the following parameters:

- Erosion Factor (K): This factor describes the difficulty of eroding the soil. It is a function of the soil texture, structure, organic matter content, and permeability.
- Topographic Factor (LS): This factor describes the surface's susceptibility to erosion due to length and slope. It is based on the observation that long and steep slopes have more erosion than short and flat slopes.
- Practice Factor (P): This factor describes the effect of specific soil conservation practices, sometimes referred to as best management practices. These could include terracing, contouring, or seeding. The practice factor was assumed to be 1.0 for this analysis.
- Cover & Management Factor (C): This factor describes the influence of plant cover on surface erosion. It is based on the fact that bare ground is most susceptible to erosion while a thick vegetation cover significantly reduces erosion.
- Threshold (CFS): This factor describes the precipitation threshold events that will result in surface erosion. It is a function of the runoff peak flow. The threshold was assumed to be 1.0 for this analysis.
- Gradation Curve: This factor defines the distribution of the total sediment load into grain size classes and subclasses at each sub-basin outlet. It is a function of the diameter and percentage

of each grain size. A gradation curve was creates using SSURGO data for each of the three watersheds, following procedures documented by the Army Corp of Engineers.

- Bed Depth: The depth of the riverbed in which degradation and aggregation can occur. The bed depth was assumed to be 4 feet for this analysis.
- Active Bed Factor: The factor used to calculate the depth of the upper layer of the bed model. Assumed to be 1 for this analysis.

### Results

Two sets of results were produced via HMS:

- Watershed Runoff: HEC-HMS calculates the hydrologic results as both an excess rainfall depth in inches over each sub-basin, and as a hydrograph (flow rate over time) in cubic feet per second at the outlet of each sub-basin, within routed watershed reaches, and at reach junctions, as described in the model methodology section.
- Sediment Yield: HEC-HMS estimated the sediment and erosion losses and total yield in tons of sediment for each storm event using the MUSLE and Volume Ratio model.

Hydrologic and sediment results were both evaluated utilizing a ratio of post-fire to pre-fire conditions to understand the magnitude of change from the two conditions. Creating these ratios allowed Olsson to check the validity of the modeling results and highlight the areas within each basin where the post-fire CN adjustments have the largest impact. All hydrologic and sediment results and ratios can be found in Appendix A Tables 2 and 3, respectively. It should be noted that any ratio results which deviate greatly from the average indicate areas where no pre-fire flow or sediment was present. These ratios are showing the results of the post-fire analysis.

A visualization of these results, with color coded symbology highlighting areas of least and greatest increase for each study basin, can be found in **Table 6**, located at the end of the “Post Fire Hydrology” section. Green basins and junctions have the least change, whereas red basins and junctions have the greatest. Reaches are symbolized by erosion condition, with red being degradation and green being aggradation.

## Hydraulic Analysis

A 2-D unsteady hydraulic model was developed for the major basins using the U.S. Army Corp of Engineer’s (USACE) HEC-RAS version 6.4.1. Results from HEC-HMS were coupled with HEC-RAS and routed via 2D computational elements. The model uses Continuity and the Diffusive Wave of the Saint Venant Equations to compute inundation areas for both post-fire hydraulic flood routing through the primary reaches of the watershed. This model highlights changes in the flood extents and potential flow paths that the water may take if culverts become clogged, or the channel fills with debris. The hydraulic modeling results are in a preliminary development stage and are provided as a starting point of understanding risk, and potential locations of stream mitigation.

### Input Data

Olsson used CWCB LiDAR as the basis for topography in all hydraulic models. Manning’s n values were assigned with spatial variability along the mesh cell faces based on the NLCD raster, reference Table 4, and aerial observation. Internal and external boundary conditions were applied to the model. Normal Depth was selected for external boundary conditions. Internal boundary conditions were set as inflow hydrographs and linked directly to HEC-HMS through DSS files. Time-step was determined using the courant method. Only the post fire condition was run for the 2D hydraulic analysis, and therefore 4 Plans are present for each of the 3 Major Basin models: Post2yr, Post5yr, Post10yr and Post25yr.

*Table 4.* HEC-RAS 2D Manning's n Values

| NLCD Code | NLCD Description | Manning's n |
|---|---|---|
| 0 | NoData | 0.06 |
| 11 | Open Water | 0.04 |
| 21 | Developed, Open Space | 0.04 |
| 22 | Developed, Low Intensity | 0.06 |
| 23 | Developed, Medium Intensity | 0.08 |
| 24 | Developed, High Intensity | 0.12 |
| 31 | Barren Land Rock-Sand-Clay | 0.04 |
| 41 | Deciduous Forest | 0.15 |
| 42 | Evergreen Forest | 0.12 |
| 43 | Mixed Forest | 0.1 |
| 52 | Shrub-Scrub | 0.1 |
| 71 | Grassland-Herbaceous | 0.04 |
| 81 | Pasture-Hay | 0.04 |
| 82 | Cultivated Crops | 0.04 |
| 90 | Woody Wetlands | 0.08 |
| 95 | Emergent Herbaceous Wetlands | 0.06 |

Model mesh boundaries do not include the entire basin for any of the 3 study areas, to streamline model efficiency. Higher order streams within each of the basins were prioritized, especially in areas where multiple Values at Risk (VARs) are present. Mesh boundaries are confined to the river corridors; small enough to reduce computation time and large enough to contain the floodplain of all modeled events.

## Results

To ensure model accuracy across all plans, the outflow hydrographs of each 2D mesh were compared to the results from the hydrologic analysis. Model results were validated by comparing the outlet peak flows to the HMS analysis peak flows, which can be seen below in Table 5. While the results between both analyses are not the exact same, they were deemed acceptable due to the extreme differences in how RAS 2D and HMS route water. After the model results were validated, inundation boundaries and depth rasters were exported into GIS to both check the results and prepare them for use in the susceptibility analysis. These outputs are included in the maps referenced in **Table 6**, located in the end of the “Discussion of Analysis” section. Pre and post fire floodplains were not analyzed against each other. The post fire floodplain was used directly in the susceptibility study.

*Table 5.* Model Validation Results

| Basin | Results (cfs) | | Description of Validation Point |
|---|---|---|---|
| | HMS | RAS2D | |
| Elk Creek | 6638.4 | 5354.1 | Basin Outlet Point (Element 243C) |
| Rifle Creek | 4668.3 | 4081.3 | Basin Outlet Point (Element 380C) |
| Battlement Mesa | 891.3 | 1053.2 | Wallace Creek (Element R90) |

## Discussion of Analysis

The results identify the impacts to the different study area's hydrology, hillslope erosion, and hydraulic analysis due to a wildfire. Values and results can be viewed online at:

*Table 6.* Results Map Links

| Study Area | Map Link |
|---|---|
| Elk Creek | https://olsson.maps.arcgis.com/apps/mapviewer/index.html?webmap=fa072c756c3b47b4910a68c94e8a7699 |
| Rifle Creek | https://olsson.maps.arcgis.com/apps/mapviewer/index.html?webmap=374d8012c9034792bed6cff063d0ac7e |
| Battlement Mesa | https://olsson.maps.arcgis.com/apps/mapviewer/index.html?webmap=09394ab7bc694ae48f8967427f76acd0 |

This data is being provided as a starting point for identifying values at risk as part of the susceptibility analysis. A lower risk does NOT mean there is a low risk, it simply means that the risk is lower when compared to other structures in the data set. It is strongly recommended to review this data with other data sets and information to make the best-informed decision for each agency. When projects are moved into design, it is strongly recommended to take a closer look at each portion and perform a more refined assessment.

The data provided as part of this analysis are:

- HEC HMS Flow Junctions and Basins: All pre- and post-fire basins and parameters including CNs, pre- and post-fire estimates for flow rates at different design points and reaches.
- HEC-RAS 2D inundation boundaries and depths.
- Sediment Yield Analysis for hillslope erosion.

### How to use this Data

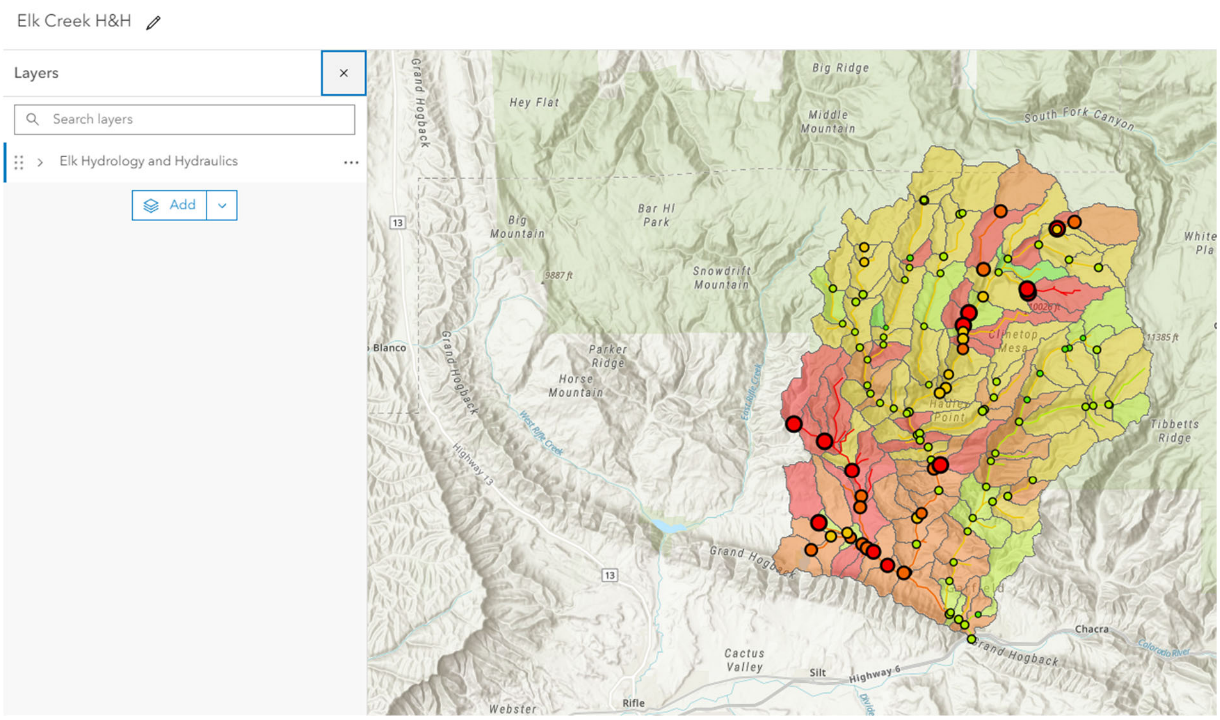
To assist the user, the data and results of this project are presented in online maps. This allows the user to visualize and interact with the data versus static paper exhibits and large tables.

To view an area of interest, the user opens the online map, zooms to the area, and then selects elements of interest within that area. Once an element is selected, a table will appear with all of the available data for that element. All data sets discussed within this report are included in the maps, and the user can toggle on and off the desired results. Below is an example of the process.

### Hydrologic Results Example

Upon opening one of the maps from Table 6, you will find a screen similar to this:

*Figure 5.* Online Map Overview

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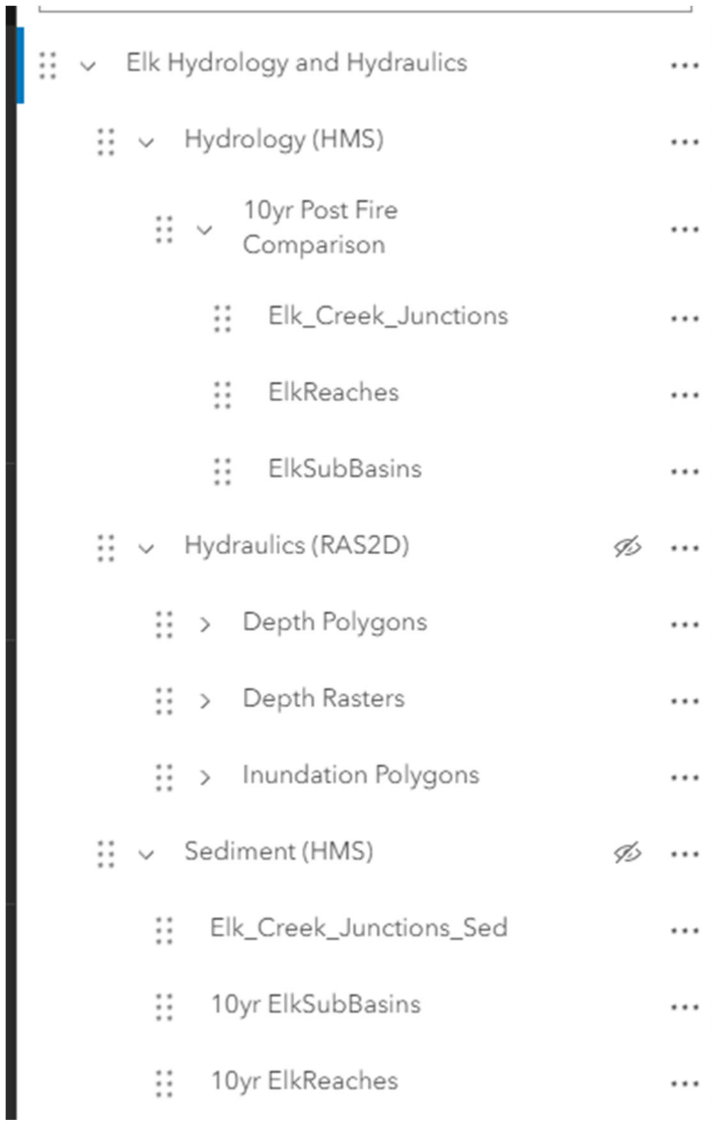
**Phone** 303.237.2072 / **Fax** 303.237.2659 / **olsson.com**

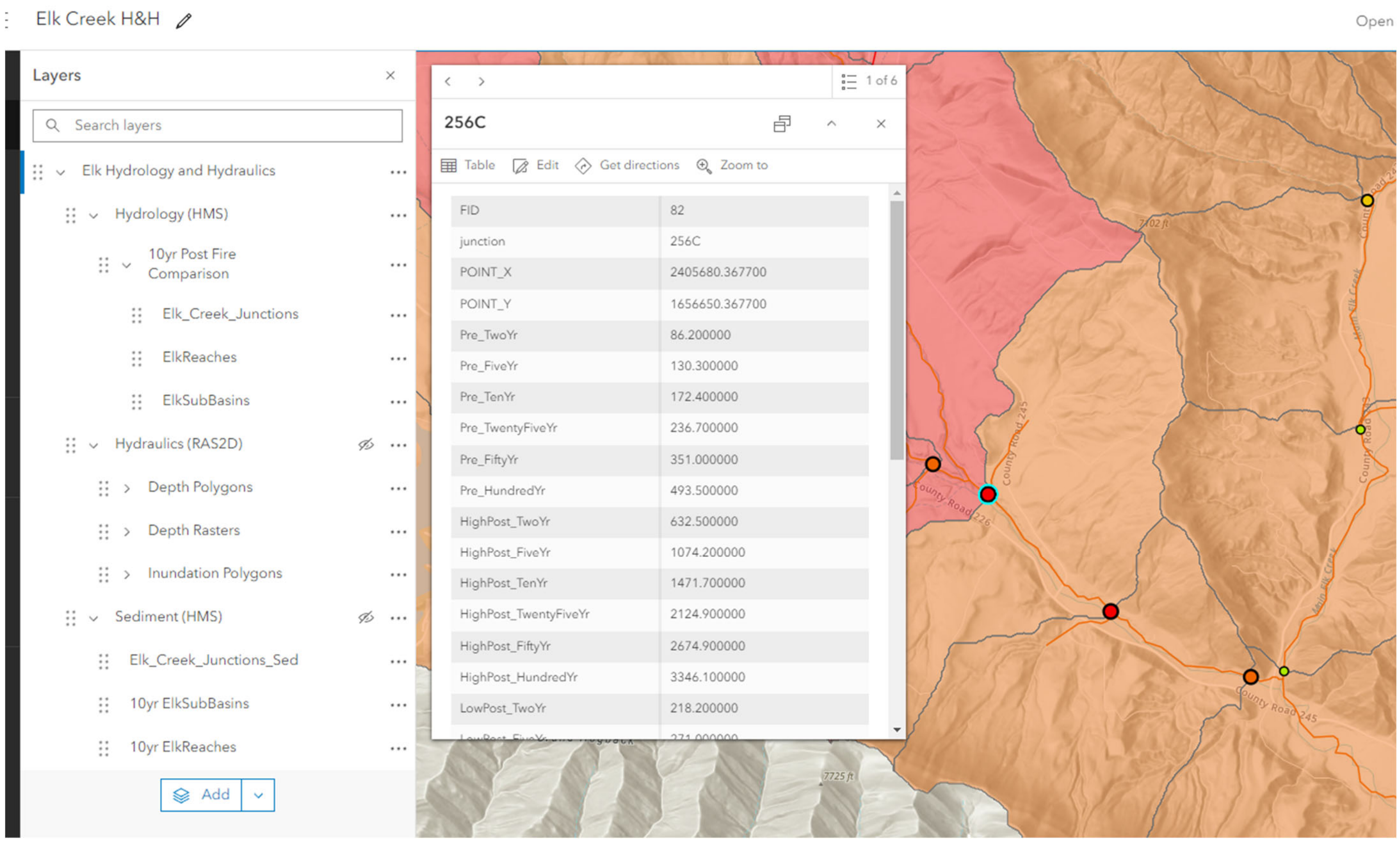
From here, the catalog on the left side can be expanded to show all available data.

*Figure 6.* Online Map Catalog




Only the Hydrology (HMS Results) are currently displayed. By clicking on the eye next to each element, results can be toggled on or off. To display individual results, the user can navigate to the area of interest and select the appropriate element. A table is displayed which shows all the data for the element of interest (inputs and results). Also, when selecting an element, the user can also toggle through nearby elements by clicking on the arrows present above the element name in the pop-up table.

*Figure 7.* Online Map Results



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WRIGHT WATER ENGINEERS, INC.

# MIDDLE COLORADO WATERSHED COUNCIL WRAP: POST-FIRE DEBRIS FLOW OCCURRENCE LIKELIHOOD MODELING

Summary of Methods

## TABLE OF CONTENTS

**MEMORANDUM**

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**To:** Jeff Sickles, P.E., CFM
Olsson Associates
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Claire Vavrus, E.I.
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**Date:** June 17, 2024

**Re:** **Middle Colorado Watershed Council Wildfire Ready Action Plan: Post-fire Debris Flow Occurrence Likelihood Modeling Summary of Methods**

## 1.0 INTRODUCTION

Wright Water Engineers, Inc. (WWE) evaluated post-fire debris flow (PFDF) occurrence likelihood for the Middle Colorado Watershed Council's (MCWC) Colorado Water Conservation Board's (CWCB) Colorado Wildfire Ready Action Plan (WRAP). Our PFDF evaluation was one of several post-fire hazard analyses conducted for the MCWC WRAP under the December 2022 WRAP Template Scope of Work Task 4 (post-fire hazard analysis).

## 2.0 PROJECT BACKGROUND

### 2.1 Study Area

The MCWC represents watershed stakeholders along the Colorado River and its major tributaries from Glenwood Springs to De Beque, Colorado. At the direction of the MCWC, CWCB, and project prime, Olsson, WWE's PFDF occurrence likelihood analysis was performed on a subset of the HUC12 watersheds between Glenwood Springs to De Beque including the Rifle Creek, Elk Creek, and Battlement Mesa drainage areas along the Colorado River (Figure 1).

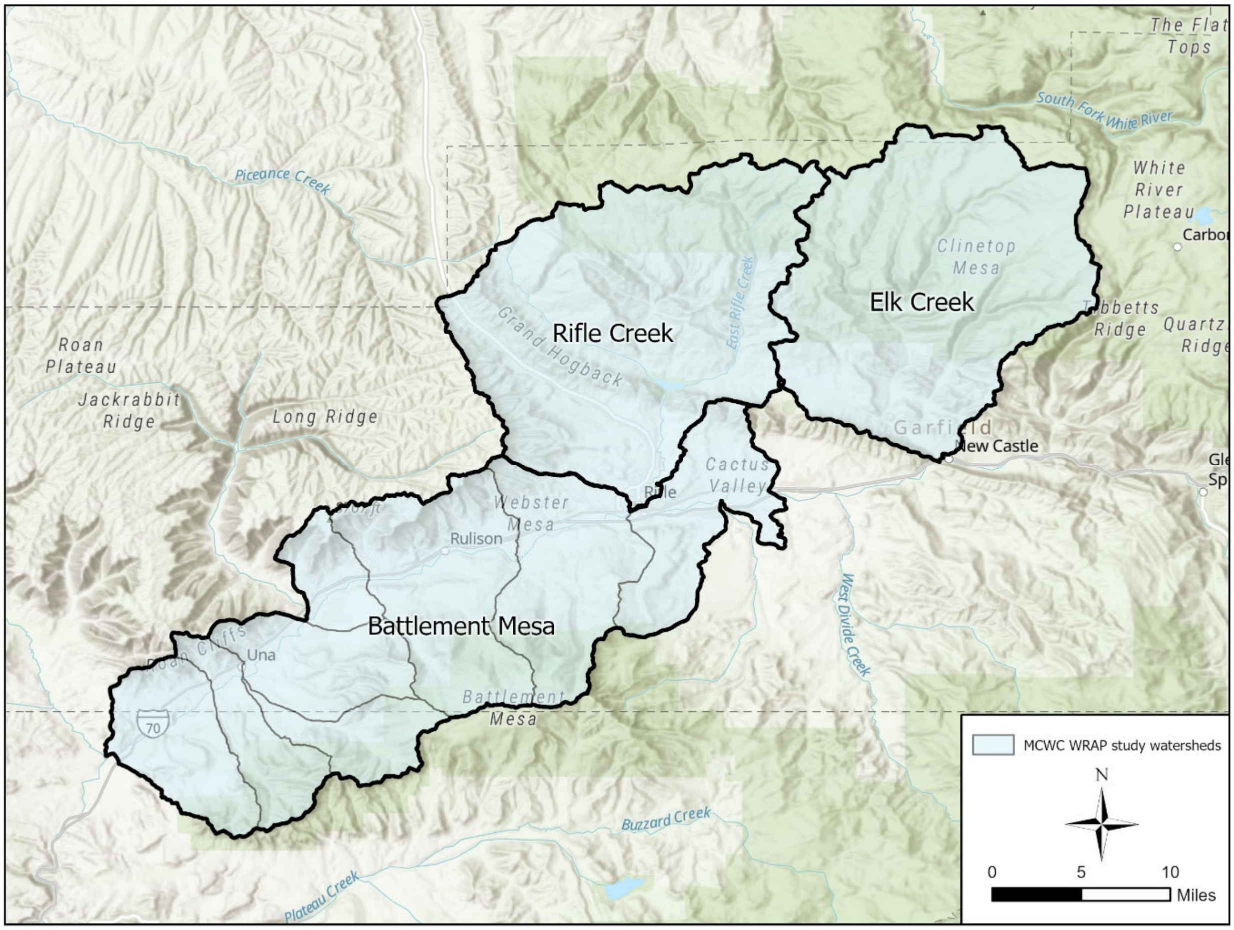


**Figure 1.** *HUC12 watersheds included in WWE's debris flow probability analysis.*

## 2.2 PFDF Occurrence Likelihood Model

To estimate PFDF occurrence likelihood for each subbasin included in the study area *prior to fire disturbance*, WWE followed the approach described by Tillery et al. (2014) for predicting burn severity pre-emptively. Predicted burn severity and differenced normalized burn ratios (dNBR) were then input to the current United States Geological Survey's (USGS) M1 logistic regression model (Staley et al., 2016) which calculates the statistical likelihood of debris flow occurrence as:

$$P = \frac{e^x}{1 + e^x}$$

where, $P$ is the statistical likelihood of debris-flow occurrence and $x$ is the link function, defined for the M1 model as:

$$x = -3.63 + 0.41X_1R + 0.67X_2R + 0.70X_3R$$

where, $X_1$ is the fraction of upstream area with slopes ≥ 23˚ burned at moderate or high severity, $X_2$ is the dNBR divided by 1000, $X_3$ is the soil erodibility factor ($K_f$ factor), and $R$ is the peak 15-minute rainfall accumulation in millimeters per hour (mm/hour). For this application, we assessed PFDF occurrence likelihoods for three 15-minute rainfall recurrence intervals (Table 1).

The original USGS PFDF model was developed in the early 2000s with 388 data points from 15 burn scars in the western United States (Cannon et al., 2010; Gartner et al., 2005). Each data point represented a burned drainage that experienced a precipitation event with a known depth, duration, and frequency. Debris flow occurrence was recorded as a binary "1" if debris flow activity was observed and "0" if not. Additional data describing physical attributes of each basin (e.g., topographic, soil property, burn severity, and precipitation metrics) were also recorded so their potential explanatory powers could be evaluated. Logistic regression models were fit to combinations of the debris flow occurrence observations and the potential explanatory variables in a rigorous variable selection procedure to determine which explanatory variable(s) best predicted PFDF occurrence. Several years later, the current M1 model was retrained on 939 data points from 19 burn scars in southern California and tested on 611 additional data points from 15 burn scars in Montana, Utah, Colorado, Arizona, and New Mexico (Staley et al., 2017, 2016).

This model and approach was first applied by WWE on the drainages identified by the United States Environmental Protection Agency (USEPA) Catchments layer (https://www.usgs.gov/national-hydrography/national-hydrography-dataset) for a statewide debris flow susceptibility analysis in 2022. This statewide analysis was used to identify watersheds with moderate to high risk of PFDF activity, ultimately triggering the more detailed, site-specific analyses performed in WRAPs. In other words, WWE used the M1 model for the CWCB's statewide susceptibility study completed in 2022, and we also used the M1 model, but with refined model inputs, for this MCWC WRAP.

## 3.0 MODEL INPUTS

### 3.1 Spatial Unit of Analysis

#### 3.1.1 Digital Elevation Model

WWE used a Light Detection and Ranging (LiDAR)-derived 4-foot digital elevation model (DEM) provided by CWCB via Olsson. An Olsson engineer mosaiced the DEM tiles and then provided the mosaic to WWE.

#### 3.1.2 Subbasin Delineation

WWE developed a subbasin delineation model in ArcGIS Pro that produces drainage areas similar to those used by the USGS's Landslide Hazard Program (LHP) during their post-fire emergency hazard assessments (https://landslides.usgs.gov/hazards/postfire_debrisflow/). First, a flow accumulation raster was generated from the best-available topographic surface (4-foot LiDAR-derived DEM in this case). A stream network was delineated from the flow accumulation raster, where a contributing drainage area of at least approximately 100 acres was required for a stream segment to begin. The Strahler stream order of the resultant flowlines was determined and then basin outlets (i.e., pour points) were automatically delineated anywhere a 3$^{rd}$ order stream or lower intersected a 4$^{th}$ order stream or higher, *or* where the 4$^{th}$ + order stream network intersected a NHD water body. The 3$^{rd}$ order (and lower) stream network was first buffered by 10 feet to ensure basin outlets were snapped to the 3$^{rd}$ order (and lower) tributary network and not to the mainstem streams (4$^{th}$ + order). Watersheds were delineated upstream of each basin outlet. Then, an analyst inspected the delineated subwatershed network and made adjustments if additional pour points were needed to assess PFDF risk at a particular value-at-risk (VAR). If additional pour points were added by the analyst, the basin delineation model was rerun to incorporate the manually added pour points.

### 3.2 Soil Erodibility

The M1 model uses the soil $K_f$ factor as a metric for soil erodibility. The $K_f$ factor represents the soil's susceptibility to erosion via rainfall and rate of runoff. Specifically, it quantifies the susceptibility of soil grains to be detached from soil clods by erosive raindrop or rain splash forces. It also accounts for the influence of soil texture and other physical soil properties on soil shear strength (Renard et al., 1997). The M1 model was trained on soil $K_f$ factor data compiled in the USGS State Soil Geographic (STATSGO) database (https://water.usgs.gov/GIS/metadata/usgswrd/XML/ussoils.xml). For each of our 61,871 USEPA catchments (analysis units), the area-weighted averaged $K_f$ factor was calculated from the same STATSGO spatial data.

## 3.3 Rainfall Accumulation

Rainfall accumulation is included in all three model input variables (Table 1). For the current study, gridded point precipitation frequency (PPF) estimates for Colorado were obtained from the National Oceanic and Atmospheric Administration's (NOAA) Atlas 14 data product (https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_gis.html) for 15-minute duration events with 1, 2, and 5-year recurrence intervals. We used 15-minute duration data to be consistent with the storm durations used to train the M1 logistic regression model (Staley et al., 2016). In the original variable selection study, numerous rainfall accumulation durations were tested including the peak 10, 15, 30, and 60-minute rainfall intensities (Cannon et al., 2010). In the updated logistic equation, PFDF likelihood predictions models were fit to peak 15, 30, and 60-minute rainfall intensity data, with the 15-minute duration M1 outperforming all other models tested according to the threat score (TS) skill statistic.

$$\text{Threat Score} = \frac{\text{True Positive}}{\text{True Positive} + \text{False Negative} + \text{False Positive}}$$

### 3.3.1 Comparison Against USGS M1 Rainfall Thresholds at 2020 Grizzly Creek Burn Scar

USGS recently observed actual debris flow-triggering rainfall thresholds at the 2020 Grizzly Creek burn scar (Rengers et al., 2023). This burn scar is approximately 18 miles as the crow flies from the upstream end of our study area (New Castle, CO). Rengers et al. (2023) also studied the ability of their M1 model to accurately predict this threshold.

During the first post-fire year at the Grizzly Creek burn scar, USGS observed that actual debris flows were triggered during storm events with peak 15-minute rainfall intensities ($I_{max}15$) ranging from below the 1-year/15-minute recurrence interval to well above the 5-year/15-minute recurrence interval; WWE obtained the Grizzley Creek's PPF estimates from NOAA Atlas 14 (https://hdsc.nws.noaa.gov/pfds/). The M1 model predicted the "fire-wide" $I_{max}15$ for the 50% debris flow probability to be approximately 25.9 mm/hour, or just above the 1-year/15-minute event. A network of 11 onsite tipping bucket rain gages recorded 15 storm events with $I_{max}15$s that exceeded 25.9 mm/hour during the first post-fire year, and debris flows were observed following 8 of those 15 storms, or just over 50% of the time. One additional debris flow was generated from the burn scar during post-fire year 1 that was triggered during a storm with an $I_{max}15$ below the 50% debris flow probability rainfall threshold. However, had the USGS 50% threshold been low enough to capture that 9th debris flow, it would have falsely predicted debris flow occurrence in over one dozen storms (Figure 2).

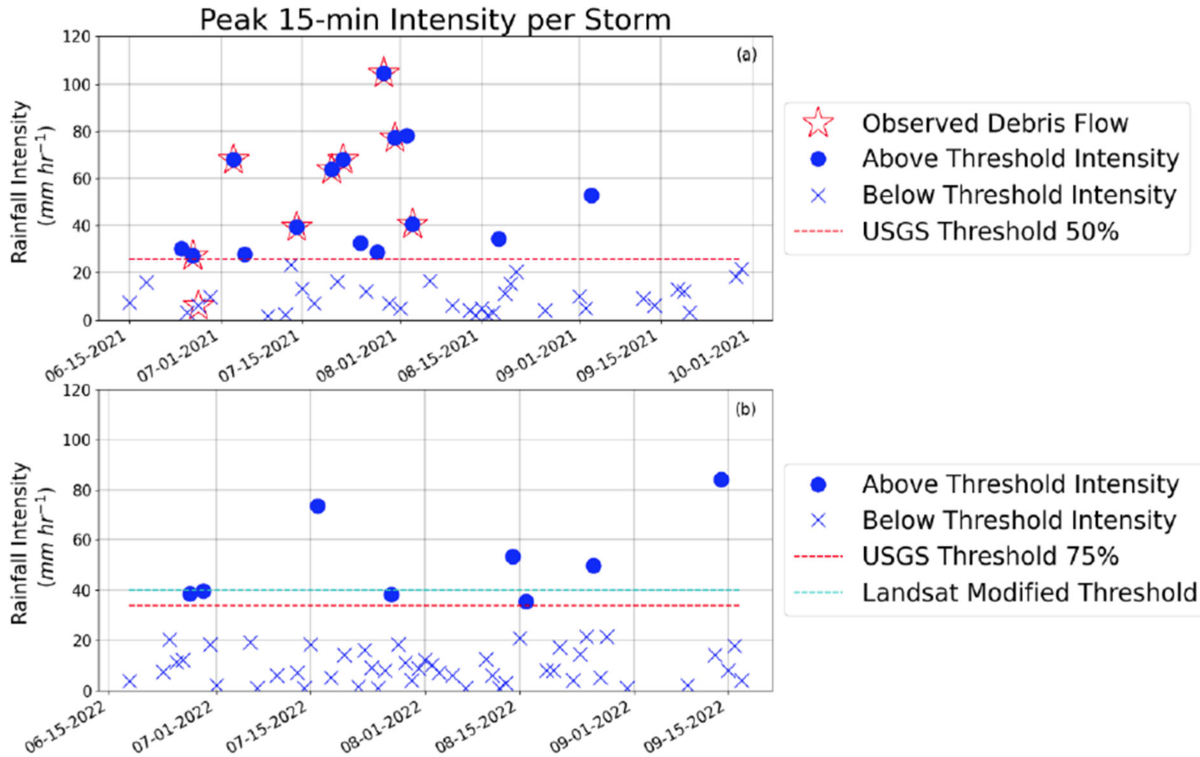


**Figure 2.** *Figure 8 from Rengers et al. (2023).*

USGS typically adjusts their PFDF rainfall threshold to solve for the 75% probability event for post-fire year 2. The purpose of this is to reflect the pace of recovery of land surface hydrologic processes back to pre-fire conditions. The bottom graph in Figure 2 shows that even though several storm events exceeded the predicted 75% debris flow occurrence probability rainfall threshold during post-fire year 2 at Grizzly Creek (33.7 mm/hour), no debris flows from the burn scar were recorded. This may indicate that "*the operational model for debris flow initiation rainfall thresholds works well in this region during the first year but may be too conservative in year 2 due to vegetation recovery and sediment exhaustion*," (Rengers et al., 2023).

Based on these findings, WWE considers our application of the M1 model to 1, 2, and 5-year/15-minute NOAA Atlas 14 rainfall accumulations to be reasonable. These rainfall accumulations sample the range of events that are most likely to occur during the first few post-fire years when fire-exacerbated debris flow activity is most likely. Running the M1 model with rainfall intensities exceeding the 5-year will provide less and less information as the sub-watersheds with the highest debris flow occurrence risk (i.e., the most vulnerable) will no longer stand out from the remaining study areas.

## 3.4 Burn Severity Classification and dNBR

The M1 model was trained on data from real fire events. This means the burn severity and dNBR values used to fit the regression coefficients (first and second variables in Table 1) were derived from data obtained during actual post-fire data collection efforts. In contrast, the current study required predictive burn severity class and dNBR data for the entire study domain. No predictive dNBR or burn severity class datasets currently exist for the study area. Because development of such a data layer from scratch was outside

WRW's scope, the authors assessed other readily available data that could be used to infer dNBR and burn severity class.

A fire behavior model predicting crown fire activity (CFA) was used as burn severity class has been inferred from CFA categories previously (Tillery et al., 2014; Tillery and Haas, 2016).The CFA dataset used for this study was developed with the FlamMap fire analysis application (https://www.firelab.org/project/flammap). This application provides every CFA class occurrence likelihood for a given fire weather scenario in a single layer. This made the FlamMap dataset readily transformable to burn severity classes and dNBR values. The FlamMap CFA results layer was generated by the Colorado Forest Restoration Institute using the most extreme fire weather scenario ($\geq 97^{th}$ percentile fire weather variables (fuel moisture and wind speed)). The layer was generated using 2016 Landfire imagery data, meaning the input fuel data (i.e., "fuelscape") do not account for fires or fuel treatments that occurred after 2016. WWE received spatial data indicating the extent and type of fuel treatments conducted after 2016. In combination with spatial data indicating the location and extent of post-2016 burn scars from MTBS, we determined that the fraction of post-2016 land disturbances that could meaningfully impact future fire activity comprised less than 1% of the total drainage area included in the study. As such, the MCWC WRAP technical team determined that updating the predictive burn severity data layer to capture more recent fuel conditions was not necessary.

To infer burn severity from FlamMap's CFA classes, we repeated a procedure used previously (Haas et al., 2016; Tillery et al., 2014) where surface fire pixels were transformed to low burn severity pixels, passive crown fire to moderate severity, and active crown fire to high severity. However, because the CFA data layer is comprised of categorical data, transforming the CFA classes to dNBR's continuous scale required additional processing. It also presented an opportunity to adjust the dNBR-burn severity thresholds to Colorado-specific data. First, we generated summary statistics of the dNBR burn severity thresholds at each of Colorado's 393 MTBS-mapped historical fires (Eidenshink et al., 2007). We found that the standard deviation of dNBR thresholds for each burn severity class was reduced when the 393 MTBS fires were separated into arid and non-arid climate classifications (according to their intersection with the Koppen-Geiger arid vs. non-arid climate polygons (Kottek et al., 2006), comporting with the previous finding that debris flow triggering rainfall thresholds vary in arid and non-arid climates (Cannon et al., 2011; Staley et al., 2017). The burn severity raster layer was clipped into arid and non-arid rasters and then transformed to dNBR values (scale -500 to 2,000). To do so, the mean dNBR value associated with each burn severity class threshold was calculated for all MTBS-mapped fires in each climate class. Then, the burn severity class threshold was used as the dNBR value for the respective burn severity class. For example, if there were 200 mapped wildfires in Colorado's non-arid areas, we calculated the mean dNBR value of each burn severity class threshold for all 200 fires. If the transition from low to moderate severity occurred at 400 (on average) and the transition from moderate and high occurred at 600 (on average), a pixel assigned to the moderate burn severity class would have a dNBR value of 400 and the high burn severity class would have a dNBR value of 600.

**Table 1.** *USGS M1 model inputs.*

| **Variable** | **Input Variables Assessed in Cannon et al. (2010)** | **Final M1 Input Variables** (Staley et al., 2016) | **Data Source used by USGS for M1 Model Application** (Staley et al., 2016) | **Data for Input Variable Used in Current Study** |
|---|---|---|---|---|
| Primary spatial unit of analysis | Basins intersecting burn scar were delineated in a geographic information | Basins intersecting burn scar were delineated in GIS from a 10-m DEM | 10-m DEM | Basins intersecting major streams, water bodies, and roads delineated in |

| Variable | Input Variables Assessed in Cannon et al. (2010) | Final M1 Input Variables (Staley et al., 2016) | Data Source used by USGS for M1 Model Application (Staley et al., 2016) | Data for Input Variable Used in Current Study |
|---|---|---|---|---|
| | system (GIS) from a 10 or 30-m Digital Elevation Model (DEM) | | | GIS from a 4-ft DEM. |
| Terrain | - Average basin gradient<br>- Percent of basin area with slopes ≥ 30%<br>- Percent of basin area with slopes ≥ 50 %<br>- Basin ruggedness<br>-Relief ratio<br>-Aspect | $X_1$<br>Percent of upslope area with moderate to high burn severity and gradients ≥ 23˚ (× *Rainfall accumulation*) | -10-m DEM<br>-BAER-generated burn severity map | -Landfire 30-m Slope gridded dataset<br>-FlamMap transformed burned severity |
| Burn Severity | - Percent of basin area burned at low severity<br>- Percent of basin area burned at moderate severity<br>- Percent of basin area burned at high severity<br>- Percent of basin area burned at high and moderate severities<br>- Percent of basin area burned | $X_2$<br>(dNBR / 1,000) (× *Rainfall accumulation*) | -BAER-generated burn severity map from Landsat imagery and field observations | FlamMap transformed dNBR and burn severity classification map |
| Soil Properties | - Soil-size properties from grain-size distribution<br>-Clay content<br>-Available water capacity<br>-Permeability<br>-Erodibility<br>-Organic Matter (%)<br>-Soil thickness<br>-Liquid limit (%)<br>-Hydrologic group<br>-Hydric capacity | $X_3$<br>Soil Kf factor (× *Rainfall accumulation*) | STATSGO | STATSGO |
| Precipitation | -Total storm depth<br>-Storm duration<br>-Average storm intensity<br>-Max. 10 min rainfall intensity (RI)<br>- Max. 15 min (RI) | Rainfall accumulation (included in the final three M1 input variables $X_1$, $X_2$, $X_3$) | 15-minute rainfall accumulation for 20, 24, 28, 32, 36, 40 mm/hour events | NOAA Atlas 14 15-minute rainfall accumulation for 1, 2, & 5-year RI |

| Variable | Input Variables Assessed in Cannon et al. (2010) | Final M1 Input Variables (Staley et al., 2016) | Data Source used by USGS for M1 Model Application (Staley et al., 2016) | Data for Input Variable Used in Current Study |
|---|---|---|---|---|
| | - Max. 30 min (RI)<br>- Max. 60 min (RI) | | | |

## 4.0 RESULTS

The following figures present our PFDF occurrence likelihood results for the 1, 2, and 5-year 15-minute rainfall accumulations at all modeled subbasins in the MCWC WRAP study area. WWE generated additional results for Olsson's susceptibility analysis (Task 5 in the WRAP Template Scope of Work) which are not provided herein, such as spatial data indicating the ratio of pre to post-fire debris flow occurrence likelihood for each subbasin. For each rainfall recurrence interval, pre-fire debris flow occurrence likelihoods were calculated by rerunning the M1 model on each subbasin with the dNBR value and the percentage of drainage area burned at moderate and high burn severity at or above 23˚ both set to zero (first and second variables in Table 1). We acknowledge that the M1 model was not trained on data from unburned drainage areas. As such, the pre to post-fire ratios should be considered in relational terms only (i.e., not as absolute values).

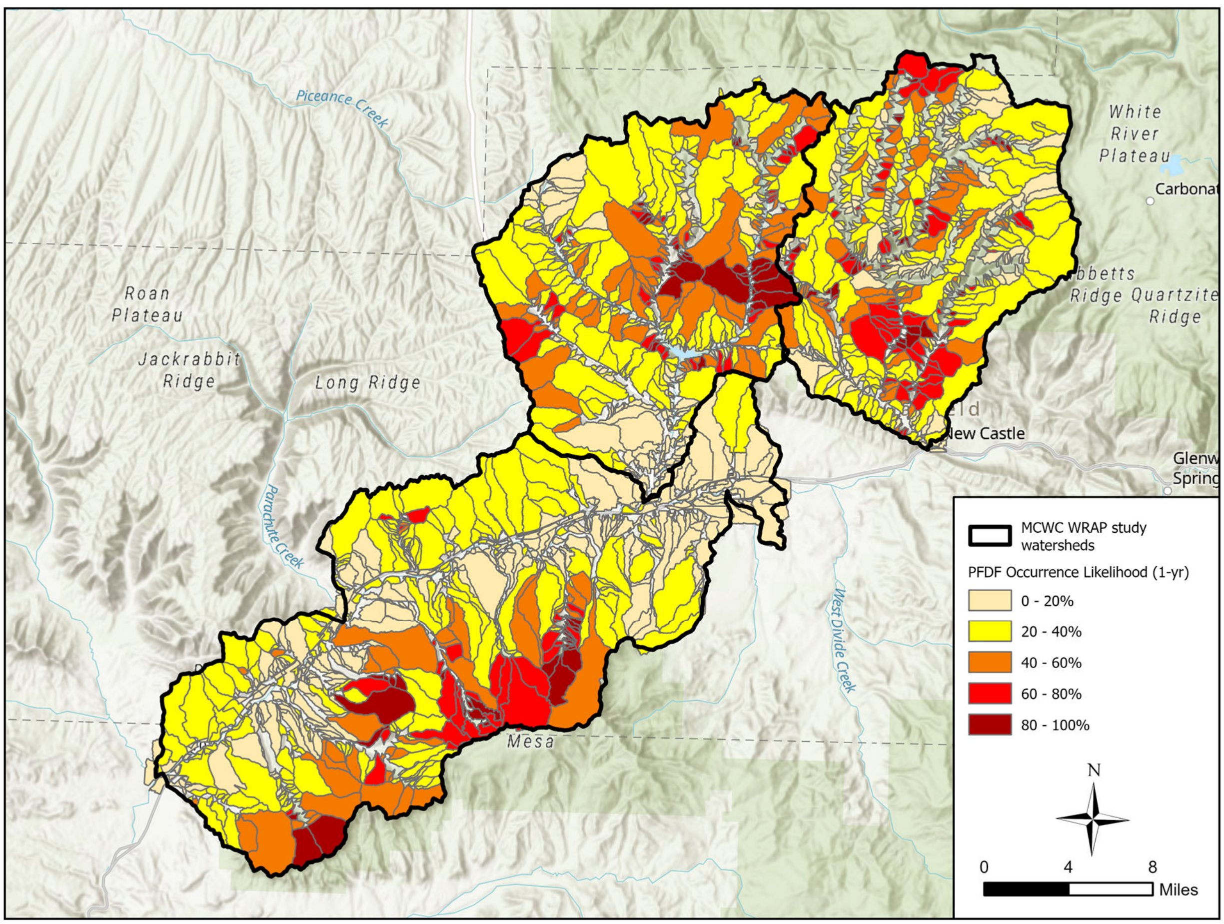


**Figure 3.** *Estimated PFDF occurrence probability by sub-watershed for the 1-year/15-minute rainfall.*

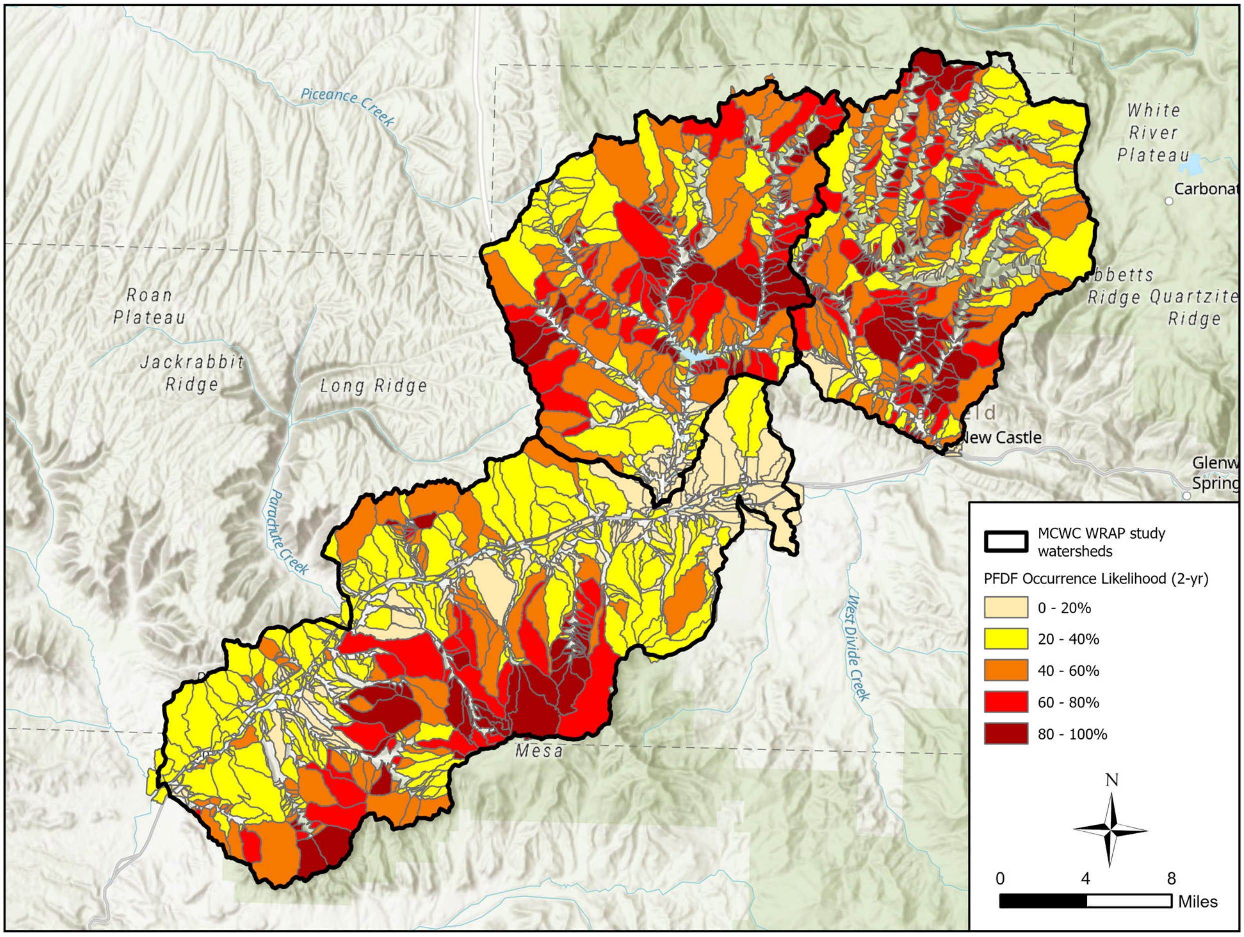


**Figure 4.** *Estimated PFDF occurrence probability by sub-watershed for the 2-year/15-minute rainfall.*

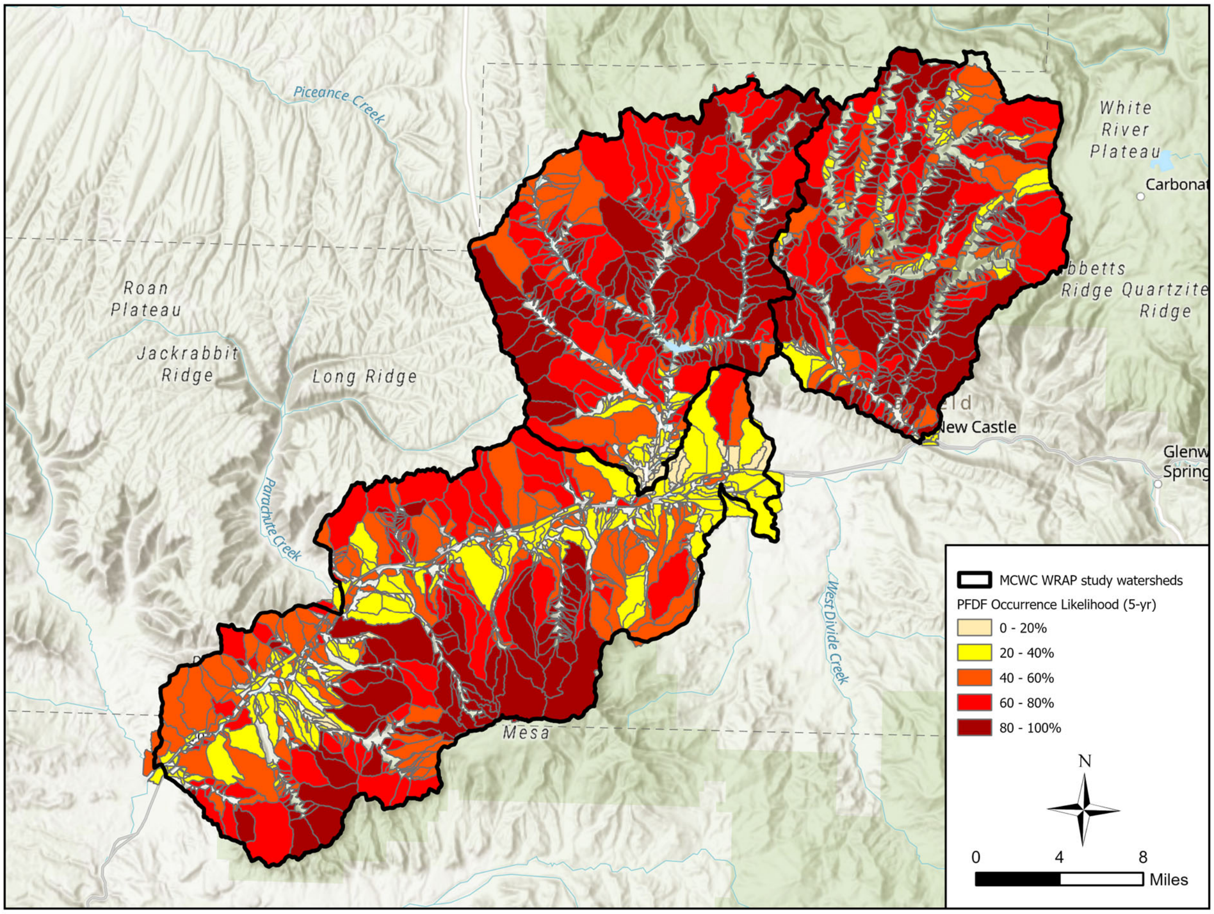


**Figure 5.** *Estimated PFDF occurrence probability by sub-watershed for the 5-year/15-minute rainfall.*

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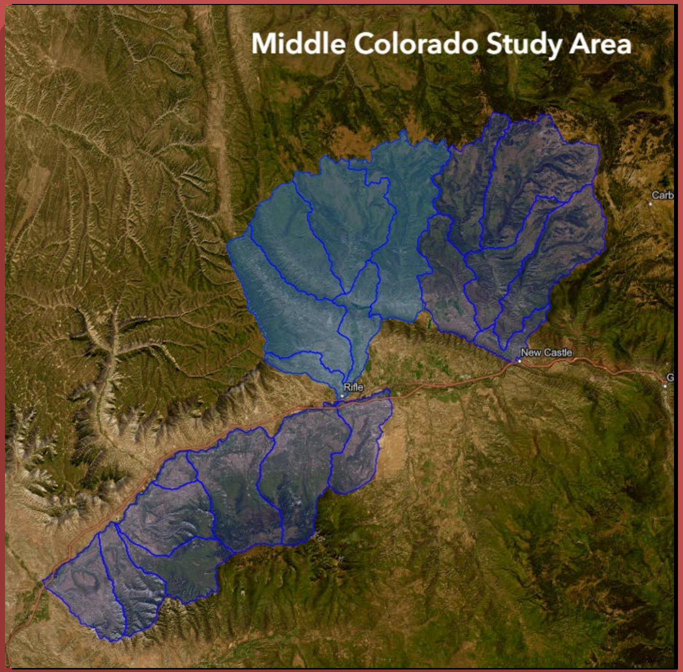
# Exhibit D – Susceptibility Analysis




# Middle Colorado

## Wildfire Ready Action Plan

## Susceptibility Analysis

# Wildfire Ready Watersheds

## Susceptibility Analysis for a Wildfire Ready Action Plan

## Middle Colorado WRAP 2024

### Credits

This susceptibility analysis and the described processes herein were developed by Olsson as part of ongoing work for the Colorado Water Conservation Board.

The processes described are meant to support the Wildfire Ready Watersheds program, specifically the development of Wildfire Ready Action Plans.

Specific analyses for the Middle Colorado WRAP are further described within.

Questions can be directed to Jeffrey Sickles, PE, CFM at jsickles@olsson.com or via phone at 303.570.4609.

# Post-Fire Hazard Susceptibility Analysis

WRW

# Susceptibility Analysis

## Susceptibility Analysis Scope of Work

The mission of Wildfire Ready Watersheds is to assess the susceptibility of Colorado's water resources, communities, and critical infrastructure to post-wildfire impacts and advance a framework for communities to plan and implement mitigation strategies to minimize these impacts – before wildfires occur. A Wildfire Ready Action Plan supports the vision of hazard identification, susceptibility assessment, and pre- and post-fire mitigation planning.

For the susceptibility analysis performed for the Middle Colorado WRAP, the following tasks have been completed.

**Intersection of Values at Risk with Hazards (point-of-impact)**. Using available or developed hazard data, a geospatial overlay of the identified values with the post-fire hazards was completed to assess risk. This evaluation was be based on the WRW Framework Risk Matrix. The intersection of assets and hazards generated a preliminary binary and expanded impact store as a tool to determine whether assets are at risk from post-fire hazards and to what severity and impact to the community.

Additional analyses include:

**Watershed susceptibility Risk Evaluation (watershed risk).** This analysis evaluates risk on a watershed by watershed basis and identifies susceptibility as low, moderate, or high based on the intersection analysis.

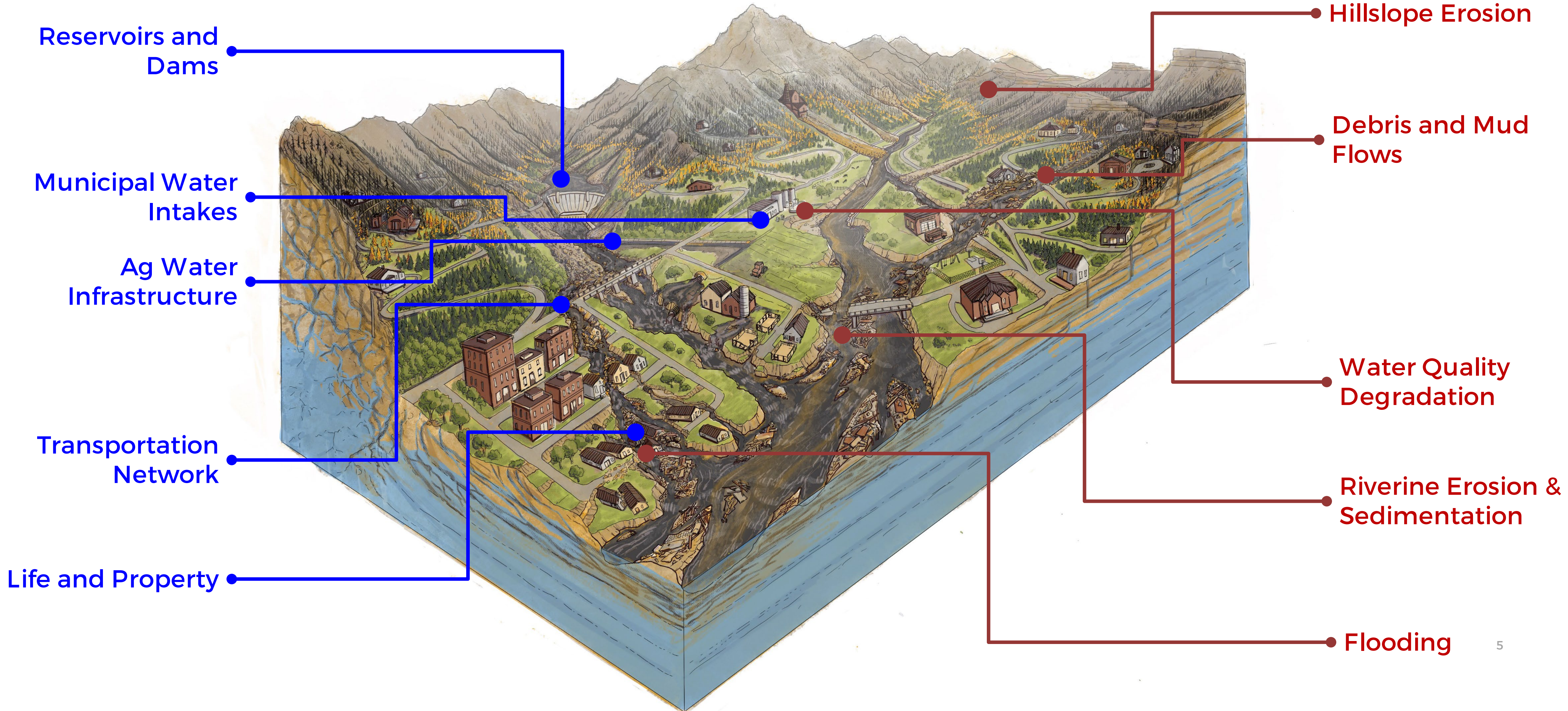
**Susceptibility analysis.** The susceptibility analysis looked at at various asset classes and individual assets and generated a gridded heat map based on impact scores. From there, susceptibility was documented in further detail summarizing consequences, system redundancy, repairability, emergency access and evacuation, and other considerations. These are documented on value-by-value basis.

**Reporting and Mapping.** A web based map showing basin-wide susceptibility, watershed susceptibility, and VAR risk severity and impact was generated for each studied watershed.

# Wildfire Ready Watersheds

## VALUES AT RISK

## HAZARDS



# Post-Fire Hazards

# Wildfire Ready Watersheds

Post-fire hazard evaluations were completed for hydrologic change, flood after fire, debris flow, fluvial hazards, and sediment delivery (sediment yield and transport). These hazard analyses generated data to be used in the susceptibility analysis. Hazard data was packaged together in the Hazards Geodatabase.

## Hydrologic Change

Increased runoff was estimated using the USACE HEC-HMS tool. Runoff was estimated using the SCS Curve Number methodology comparing pre- and post- fire runoff estimates for several AEP events.

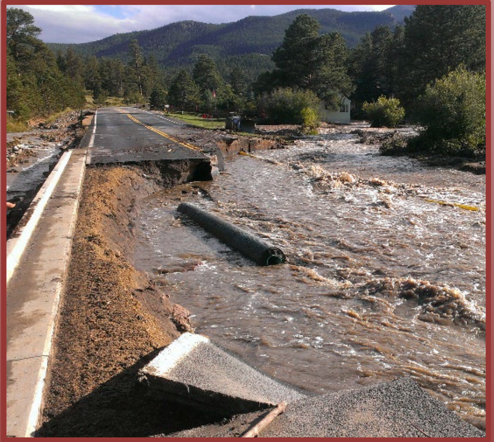
Sediment yield analyses were completed using the USACE HEC-HMS tool and estimating sediment yield with the Modified Uniform Soil Loss Equation. Transport was performed with HMS to determine transport vs depositional reaches.

## HILLSLOPE EROSION


## DEBRIS FLOW

Debris probability estimates were developed based on the USGS regression equations.

Flood inundation estimates were generated using the USACE HEC-RAS 2D model. Post-fire hydrographs from HMS were input into the RAS model and inundation estimates were generated for numerous AEP events.



## FLOOD AFTER FIRE

## FLUVIAL HAZARDS

Fluvial hazard zones were delineated based on the State of Colorado's FHZ protocol. Boundaries for the active stream corridor and fluvial hazard buffer were generated for corridors of interest within the watershed, but not on all streams.

WRW

# Risk

## Susceptibility = Hazard Severity × Impact to Community

### Risk & Susceptibility

For this MCWC susceptibility analysis, susceptibility was evaluated based on:

- Severity of hazard risk related to the proximity to the hazard to the value, probability of the hazard impacting the value, or other hazard attributes.
- Impact to the community considering how losing the asset or having a significant impairment would disrupt daily life to residents.

# WRAP Susceptibility

# Wildfire Ready Watersheds

## Susceptibility considers both the risk severity to a given VAR and the potential impact to the community.

- **Risk Severity** is scored from 1 to 10 for each VAR based on the type of asset/value and the associated hazard. Risk severity is based on a direct impact analysis and used the scoring shown in the table below.
- **Impacts** are scored from 1 to 10 for each VAR based on the potential impact to the community. For example, impacts to a reservoir are considered "exigent" or worst case. These impact scores can be weighted based on community input to generate varying outcomes and susceptibility scenarios. Impacts. Scoring of impacts is shown on the table below.
- Risk Severity and Hazard scores are intersected to generate overall risk score from 0-100 with great values indicating great post-fire susceptibility.

| Risk Severity | Impacts |
|---|---|
| 10 - Severe | 10 – Exigent |
| 7 - High | 7 – High |
| 4 - Moderate | 4 – Moderate |
| 1 - Low | 1 - Low |

Greater Post-Fire Susceptibility

| Impact to Community (VAR Type) | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 10 | 10 | 20 | 30 | 40 | 50 | 60 | 70 | 80 | 90 | 100 |
| 9 | 9 | 18 | 27 | 36 | 45 | 54 | 63 | 72 | 81 | 90 |
| 8 | 8 | 16 | 24 | 32 | 40 | 48 | 56 | 64 | 72 | 80 |
| 7 | 7 | 14 | 21 | 28 | 35 | 42 | 49 | 56 | 63 | 70 |
| 6 | 6 | 12 | 18 | 24 | 30 | 36 | 42 | 48 | 54 | 60 |
| 5 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 |
| 4 | 4 | 8 | 12 | 16 | 20 | 24 | 28 | 32 | 36 | 40 |
| 3 | 3 | 6 | 9 | 12 | 15 | 18 | 21 | 24 | 27 | 30 |
| 2 | 2 | 4 | 6 | 8 | 10 | 12 | 14 | 16 | 18 | 20 |
| 1 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
| 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |

Risk Severity to VAR (Post-Fire Hazard)

Greater Post-Fire Susceptibility

# Project Risk Matrix

# Wildfire Ready Watersheds

The risk matrix shown below was generally followed (further details are associated with each value-at-risk later in this SlideDoc. Intersections performed as part of this study are indicated in the matrix. This matrix served as the starting point for performing the intersection analysis for to evaluate susceptibility.

## Middle Colorado WRAP - Framework Risk Matrix

| | | | | Values-at-Risk | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Water Infrastructure | | | | | Life and Property | | | Comments |
| | Idenfied Value at Risk | | | Reservoirs | Built Flowlines | Decreed Water | Source Water | Aquatic Resources | Buildings | Crossings | Roads | |
| | Data Scale | | | State | State | State | State | State | National | Local | State | National, State, Local |
| | Type of Intersection Analysis | | | Direct | Direct | Direct | Direct | Direct | Direct | Direct | Direct | Watershed x Watershed or Direct |
| | Impact Scores | Min | | 0 | 0 | 0 | 0 | 0 | N/A | 0 | N/A | Impact scores vary based on community impact. See susceptibility analysis for details. |
| | | Max | | 10 | 10 | 10 | 10 | 10 | N/A | 10 | N/A | |
| | Risk Severity Scores | | | | | | | | | | | |
| | | Min | Max | | | | | | | | | Comments |
| Post-Fire Hazards | Hazard Data Class | Magnitude of Change | | X | N/A | N/A | N/A | N/A | N/A | X | N/A | Hydrologic Change |
| | HQ-WRW | Complete (Yes/No)--->>> | | Yes | No | No | No | No | No | Yes | No | |
| | Hydrologic Change | 0 | 10 | Increased runoff volumes and peak flows through reservoir. Regular flooding may put stress on reservoir operations. | Not Analyzed | Not Analyzed | Not Analyzed | Not Analyzed | Not Analyzed | Increased flow rates can overwhelm existing drainage infrastructure resulting in flooding and failures. | Not Analyzed | |
| | Hazard Data Class | Actual Inundation | | N/A | X | N/A | N/A | N/A | X | N/A | X | Flooding (Hydraulics) |
| | HQ-WRW | Complete (Yes/No)--->>> | | No | Yes | No | No | No | Yes | N/A | Yes | |
| | Flooding (Hydraulics) | 0 | 10 | Not Analyzed | Floods that inundate built flowlines may cause damage via erosion, debris impacts, or destabilize foundations or embankments. | Not Analyzed | Not Analyzed | Not Analyzed | Post-fire flooding can cause damage or complete structural failure/loss. | Not Analyzed | Increased flows in streams can result in increased flood frequency on linear transportation features. | |
| | Hazard Data Class | Percent Probability | | X | X | X | X | X | X | X | X | Debris Flow |
| | HQ-WRW | Complete (Yes/No)--->>> | | Yes | Yes | Yes | Yes | Yes | Yes | Yes | Yes | |
| | Debris Flow | 0 | 10 | Debris flow entering the reservoir delivering significant sediment and debris that can damage reservoir infrastructure. | Debris flow entering ditches via drainage crossings or debris flows causing failure of buried pipelines via mass earth movement. | Debris flow damaging diversion infrastructure and/or entering ditch/pipe facilities via diversion. | Debris flow damaging intakes and/or burying facilities. . | Debris flows can dramatically impact natural areas creating system instability for short or long periods of time | Debris flows can create dangerous landslides, mud flows, and bulked flood flows that can damage/destroy buildings. | Debris flows can plug openings, resulting in overtopping and/or upstream flooding, resulting in failures. | Debris flow can damage roadway or linear transportation infrastructure. | |
| | Hazard Data Class | Actual Boundary Mapping | | N/A | X | X | X | X | X | N/A | X | Fluvial Geomorphic Hazards |
| | HQ-WRW | Complete (Yes/No)--->>> | | No | Yes | Yes | Yes | Yes | Yes | No | Yes | |
| | Fluvial Geomorphic Hazards | 0 | 10 | Not Analyzed | Erosion from avulsions or bank erosion impacting linear water infrastructure facilities. | Erosion from avulsions or bank erosion impacting linear water infrastructure facilities. | Erosion from avulsions or bank erosion impacting municipal infrastructure. | FHZs are natural processes, but can be exacerbated due to post-fire system changes. | VARs within this zone are subject to erosion, avulsions, flooding, and deposition that can damage and destroy structures. | Not Analyzed | Erosion zones can result in roadway failures due to geomorphic processes. | |
| | Hazard Data Class | Magnitude of Change | | X | X | X | X | X | N/A | X | N/A | Sediment Yield Change |
| | HQ-WRW | Complete (Yes/No)--->>> | | Yes | Yes | Yes | Yes | Yes | No | Yes | No | |
| | Sediment Yield Change | 0 | 10 | Deposition of sediment within the reservoir can limit storage volumes, impact outlet works, and can be costly or impossible to | Sediment delivered to built flowlines can impact facility function and create significant maintenance costs. | Delivery of sediment to ditch diversions can impact facility function and require significant maintenance. | Delivery of sediment to intakes can impact facility function. | Sediment deposition can impact stream system function and ecology. | Not Analyzed | Sediment deposition or degradation can cause culverts to fail. | Not Analyzed | |

# Data Sets

# Wildfire Ready Watersheds

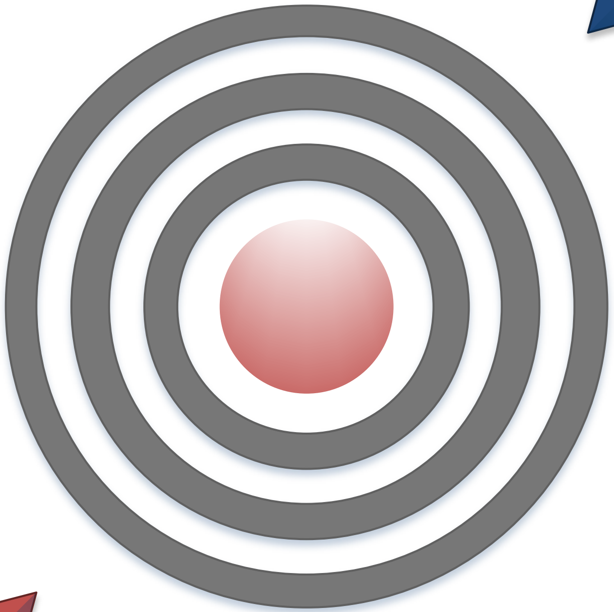
For the susceptibility analysis, the **VARS Geodatabase** and **Hazards Geodatabase** were intersected to create the **Susceptiblity Geodatabase**.  These three data sets can be used together for planning and for post-fire recovery efforts.

## Values-at-Risk Geodatabase

The Values-at-Risk Geodatabase contains all values evaluated in the susceptibility analysis as part of the WRAP.  This includes water resources infrastructure and life and property assets.

## Susceptibility Geodatabase

The Susceptibility Geodatabase contains all of the results of the intersection analysis between VARs and Hazards. Within this geodatabase, VARs are given risk severity scores and impact scores as described previously.



## Hazards Geodatabase

The Hazards Geodatabase contains all hazard data create or compiled as part of the WRAP.  This includes hydrology, hydraulics, debris flow, fluvial hazards, and sediment yield and transport.

IMPORTANT.  While the Susceptibiltly Database represents a direct intersection analysis, it does not fully represent all susceptibility.  It is simply a starting point for further evaluating vulnerability to post-fire hazards and requires a planning team to further analyze site context and details, for example egress routes along transportation corridors.

# Water Resources Infrastructure: Reservoirs and Dams

1

# Values-at-Risk Data Source

## Data Sources

The Reservoirs and Dams layers (CO_Reservoirs) are modified data sets developed by the CWCB Technical Assistance team as part of the Wildfire Ready Watersheds statewide susceptibility analysis. It is a combination of two data sets that have been reviewed and edited to improve their usability and application to post-fire risk assessment. The DWR Jurisdictional Dams layer is a points feature class while the USGS NHD Waterbodies layer is a polygon feature class. These two layers have been reviewed against aerial imagery and other base maps and brought together creating two feature classes (one points and one polygon). Attributes have been combined to align reservoir names (names vary across data sets) and to show normal storage volumes. The accompanying table provides descriptions of data and their sources if available.

## How Data Sets Can be Used for Susceptibility and Planning

The CO_Reservoirs layer (polygon feature class) can be used for direct intersection analyses for hazards against values-at-risk. The polygons generally represent reservoir extents based on the NHD waterbodies data set. Reservoir size can be understood by reviewing the normal storage (Normal_Sto) attribute within the data table. If additional details are desired, the user can refer back to the original data sets and correlate the dam ID (DAMID) against the DWR Jurisdictional Dams layer.

# Values-at-Risk: Supporting Data Sources

| Layer | Description | Source | Publishing Agency |
|---|---|---|---|
| **DWR Jurisdictional Dams (Feature Class: Points)** | This layer maps statewide jurisdictional dams. A Jurisdictional Dam is a dam creating a reservoir with a capacity of more than 100 acre-feet, or creates a reservoir with a surface area in excess of 20 acres at the high-water line, or exceeds 10 feet in height measured vertically from the elevation of the lowest point of the natural surface of the ground where that point occurs along the longitudinal centerline of the dam up to the crest of the emergency spillway of the dam. | Data Link | Colorado Division of Water Resources |
| **NHD Waterbodies (Feature Class: Polygons)** | The National Hydrography Dataset (NHD) is a feature-based database that interconnects and uniquely identifies the stream segments or reaches that make up the nation's surface water drainage system. | Data Link | United States Geological Survey |
| **CO_Reservoirs (Feature Class: Points and Polygons)** | A data set combining DWR Jurisdictional Dams and NHD Waterbodies including reservoir/dam names for cross referencing and normal water storage volumes. | CWCB | Not Published |

# Susceptibility to Hazards

This susceptibility matrix provides an overview of impacts from the five post-fire hazards considered under Wildfire Ready Watersheds (WRW). The severity of impact is noted under each hazard. Further detail regarding impacts from each hazard against the value-at-risk is provided under each heading.

| Hydrologic Change | Flood After Fire | Debris Flow | Fluvial Hazard Zones | Sediment Delivery |
|---|---|---|---|---|
|  |  |  |  |  |
| **Moderate** | **Moderate** | **Exigent** | **Moderate** | **Exigent** |
| Increased runoff volumes and peak flows through reservoir. These flows are likely well below Probable Maximum Flood, but planners should confirm. Regular flooding may put stress on reservoir operations. | Increased frequency of flooding at facilities. May result in erosion or deposition. Could put stress on reservoir operations. | Debris flow entering the reservoir delivering significant sediment and debris that can damage reservoir infrastructure. | Erosion upstream and through the reservoir facility may deposit sediment and put appurtenances at risk. | Deposition of sediment within the reservoir can limit storage volumes, impact outlet works, and can be costly or impossible to remove. |
| **Intersection** | **No Intersection** | **Intersection** | **No Intersection** | **Intersection** |

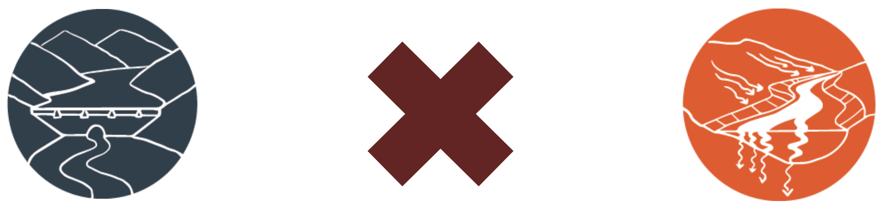
# Susceptibility Scoring Methodology

Using hydrologic junctions and/or stream segments with 10- and 100-year peak flows and associated post- / pre- fire peak flow ratios.

1. Review inflow hydrographs and post/peak ratios above reservoir for 10-year and 100-year events.
2. Run GIS intersection per susceptibility analysis an/or populate GIS attributes.
3. Score severity of susceptibility based on the following:

| Severity | Metric(s) |
|---|---|
| 10 - Severe | Post/Pre Peak Flow > 10x |
| 7 - High | 10x > Post/Pre Peak Flow > 5x |
| 4 - Moderate | 5x > Post/Pre Peak Flow > 2x |
| 1 - Low | Post/Pre Peak Flow < 2X |

Photo: Tarryall Reservoir.



# Susceptibility Analysis

This flow chart provides the high-level process followed by the planning team in evaluating the hazard data against each value-at-risk. The accompanying table provides attributes to be included in the susceptibly layer for each VAR.

## Modeling Results

- Complete pre- and post-fire hydrologic modeling and compile results
- Assign pre- to post-fire ratios to hydrologic junctions data set for all AEPs
- Assign pre- to post-fire ratios to stream segments between junctions for all AEPs

## Assess Susceptibility

- Create a new asset susceptibility layer for reservoirs (Risk_Reservoirs)
- Intersect or review post/pre fire peak flow ratios against reservoir layer and populate RO_Rat_10, RO_Rat_100, and RO_Rat_Max in Risk_Reservoirs layer
- Score severity of risk based on scoring methodology. Populate RO_Sev

## Assess Impact

- Score impact by multiplying RO_Sev against Impact type (4 – Moderate for reservoirs and dams) to generate score of 1-100. Populate RO_Impact.

# Data Attributes

The following attributes will be populated in the Risk_Reservoirs susceptibility layer.

| Attribute | Description | Type |
|---|---|---|
| RO_Rat_10 | Ratio of post- to pre-fire conditions peak flows for 10-year AEP | Double |
| RO_Rat_100 | Ratio of post- to pre-fire conditions peak flows for 100-year AEP | Double |
| RO_Rat_Max | Maximum post/pre fire peak flow ratio. | Double |
| RO_Sev | Severity score of 1 to 10 based on post- to pre- fire ratios. | Integer |
| RO_Impact | Impact score from 1-100. | Integer |

# Susceptibility Scoring Methodology

Using debris flow watersheds with Post-Fire Debris Flow (PFDF) estimates and extrapolated stream corridor lines (and buffers) indicating PFDF:

1. Review pour points directly entering reservoir
2. Identify stream corridors that are significantly impacted and feed directly into reservoir.
3. Run GIS intersection per susceptibility analysis an/or populate GIS attributes.
4. Score severity of susceptibility based on the accompanying table:

| Severity | Metric(s) |
|---|---|
| 10 - Severe | Probability > 80% of debris flow along streamline running through reservoir or pour points discharging directly to reservoir with PFDF probability > 80% |
| 7 - High | Probabiltiy 80% > PFDF > 60% of debris flow along streamline running through reservoir or pour points discharging directly to reservoir with PFDF probability 80% > PFDF > 60% |
| 4 - Moderate | Probability 60% > PFDF > 40% of debris flow along streamline running through reservoir or pour points discharging directly to reservoir with PFDF probability 60% > PFDF > 40% |
| 1 - Low | Probability 40% > PFDF > 20% of debris flow along streamline running through reservoir or pour points discharging directly to reservoir with PFDF probability 40% > PFDF > 20% |

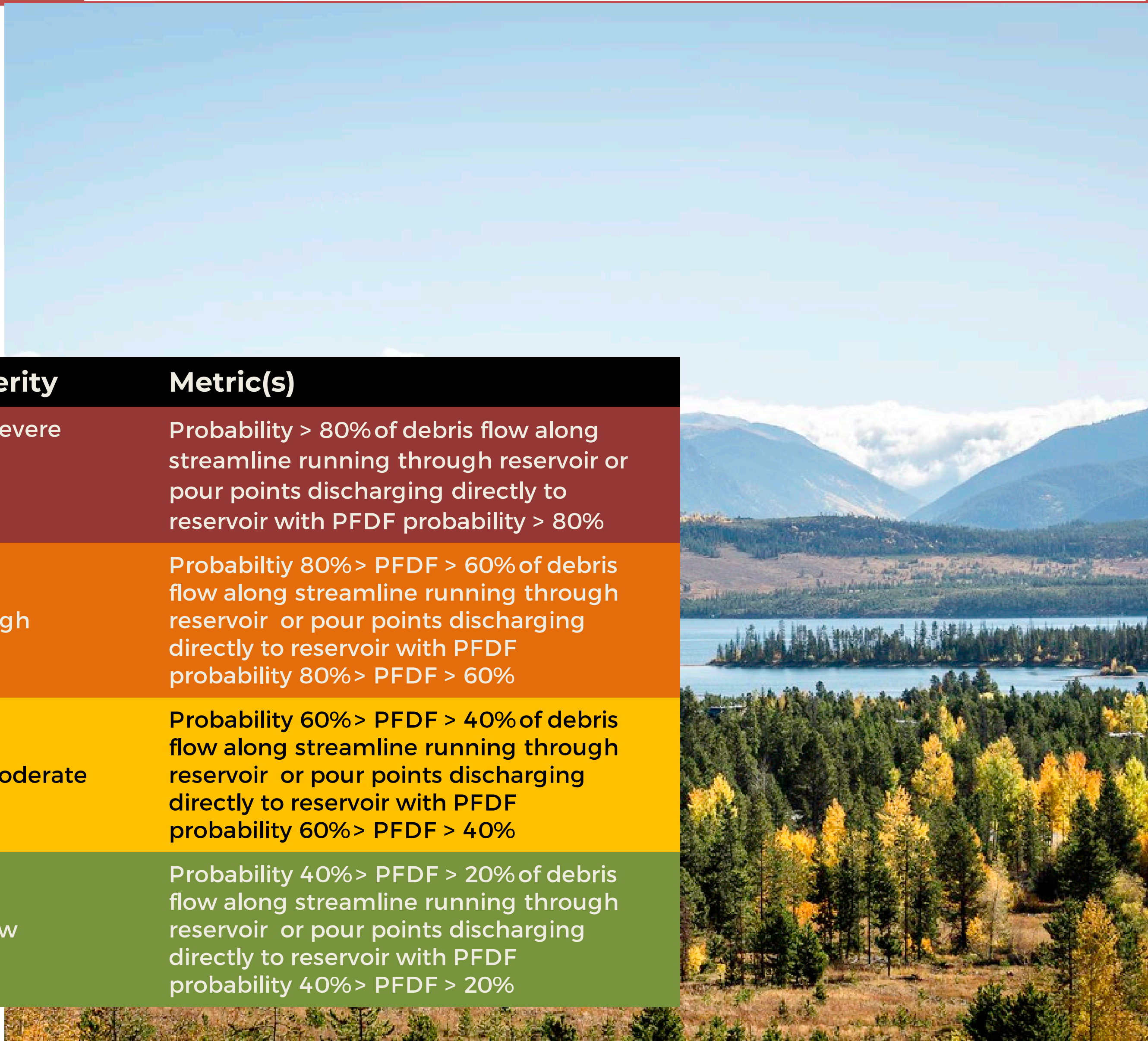
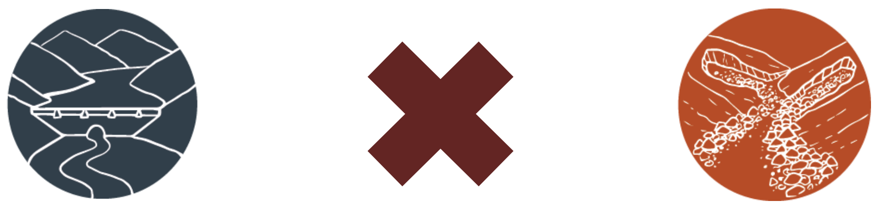


Photo: Dillon Reservoir



# Susceptibility Analysis

This flow chart provides the high-level process followed by the planning team in evaluating the hazard data against each value-at-risk. The accompanying table provides attributes to be included in the susceptibly layer for each VAR.

## Modeling Results

- Complete debris flow probability modeling
- Generate probability by basin (polygon)
- Generate stream network with aggregated debris probability (lines)

## Assess Susceptibility

- Create a new asset susceptibility layer for reservoirs (Risk_Reservoirs)[1]
- Intersect or review PDDF probability against reservoirs. Populate DF_Prob in Risk_Reservoirs layer
- Score severity of risk based on scoring methodology. Populate DF_Sev

## Assess Impact

- Score impact by multiplying DF_Sev against Impact type (10 – Exigent for reservoirs and dams) to generate score of 1-100. Populate DF_Impact.

[1]Ideally there will be one susceptibility data set per major asset scoring all hazards as appropriate.

# Data Attributes

The following attributes will be populated in the Risk_Reservoirs susceptibility layer.

| Attribute | Description | Type |
|---|---|---|
| DF_Prob | Highest debris flow probability entering reservoir via major stream or pour points. | Double |
| DF_Sev | Severity score of 1 to 10 based on maximum PDDF entering reservoir. | Double |
| DF_Impact | Impact score from 1-100. | Integer |

# Susceptibility Scoring Methodology

Using the sediment yield (SY) values generated in HEC-HMS for the 10-year AEP, create a line layer incorporating the ratio of post vs pre fire sediment yield.

1. Run GIS intersection per susceptibility analysis an/or populate GIS attributes.

2. Score severity of susceptibility based on the following:

| Severity | Metric(s) |
|---|---|
| 10 - Severe | Sediment yield post/pre > 10x for 10-year post-fire event |
| 7 - High | Sediment yield post/pre 10x > SY > 5x for 10-year post-fire event |
| 4 - Moderate | Sediment yield post/pre 5X < SY < 2x for 10-year post-fire event |
| 1 - Low | Sediment yield post/pre < 2x for 10-year post-fire event |

Photo: Post-fire sediment fan.

# Susceptibility Analysis

This flow chart provides the high-level process followed by the planning team in evaluating the hazard data against each value-at-risk. The accompanying table provides attributes to be included in the susceptibly layer for each VAR.

## Modeling Results

Complete pre- and post-fire sediment yield (SY) modeling

Calculate ratios of post/pre sediment yield

Create a reach-by-reach line layer showing ratio of SY increase

## Assess Susceptibility

Create a new asset susceptibility layer for reservoirs (Risk_Reservoirs)[1]

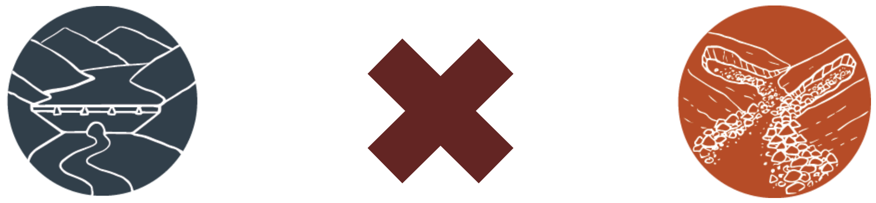
Intersect or review post/pre fire SY ratios against reservoir layer and populate Sed_Max_Rat in Risk_Reservoirs layer

Score severity of risk based on scoring methodology. Populate Sed_Sev

## Assess Impact

Score impact by multiplying Sed_Sev against Impact type (10 – Exigent for reservoirs and dams) to generate score of 1-100. Populate Sed_Impact.

[1]Ideally there will be one susceptibility data set per major asset scoring all hazards as appropriate.



# Data Attributes

The following attributes will be populated in the Risk_Reservoirs susceptibility layer.

| Attribute | Description | Type |
|---|---|---|
| **RO_Max_Rat** | Ratio of post- to pre-fire conditions peak flows for 10-year AEP | Double |
| **Sed_Sev** | Severity score of 1 to 10 based on post- to pre- fire ratios. | Integer |
| **Sed_Impact** | Impact score from 1-100. | Integer |

# 2

# Water Resources Infrastructure: Built Flowlines

# Values-at-Risk Data Source

## Data Sources

Built Flowlines is derived from the USGS NHD Flowlines layer and is a line feature class. The layer is composed of numerous features, but for the Wildfire Ready Watersheds analysis, the data is pared down via query to only include pipes, canals, and ditches.

## How Data Sets Can be Used for Susceptibility and Planning

The Built Flowlines (line feature class) can be used for direct intersection analyses for hazards against values-at-risk. The lines represent geospatial locations of built flowlines and can be used in intersection analyses to understand impacts to water conveyance systems. This data can be leveraged against the Colorado Decision Support Systems Structures data (Decreed Features) to better understand stakeholders and diversion flows (although this data is not always available).

# Values-at-Risk: Supporting Data Sources

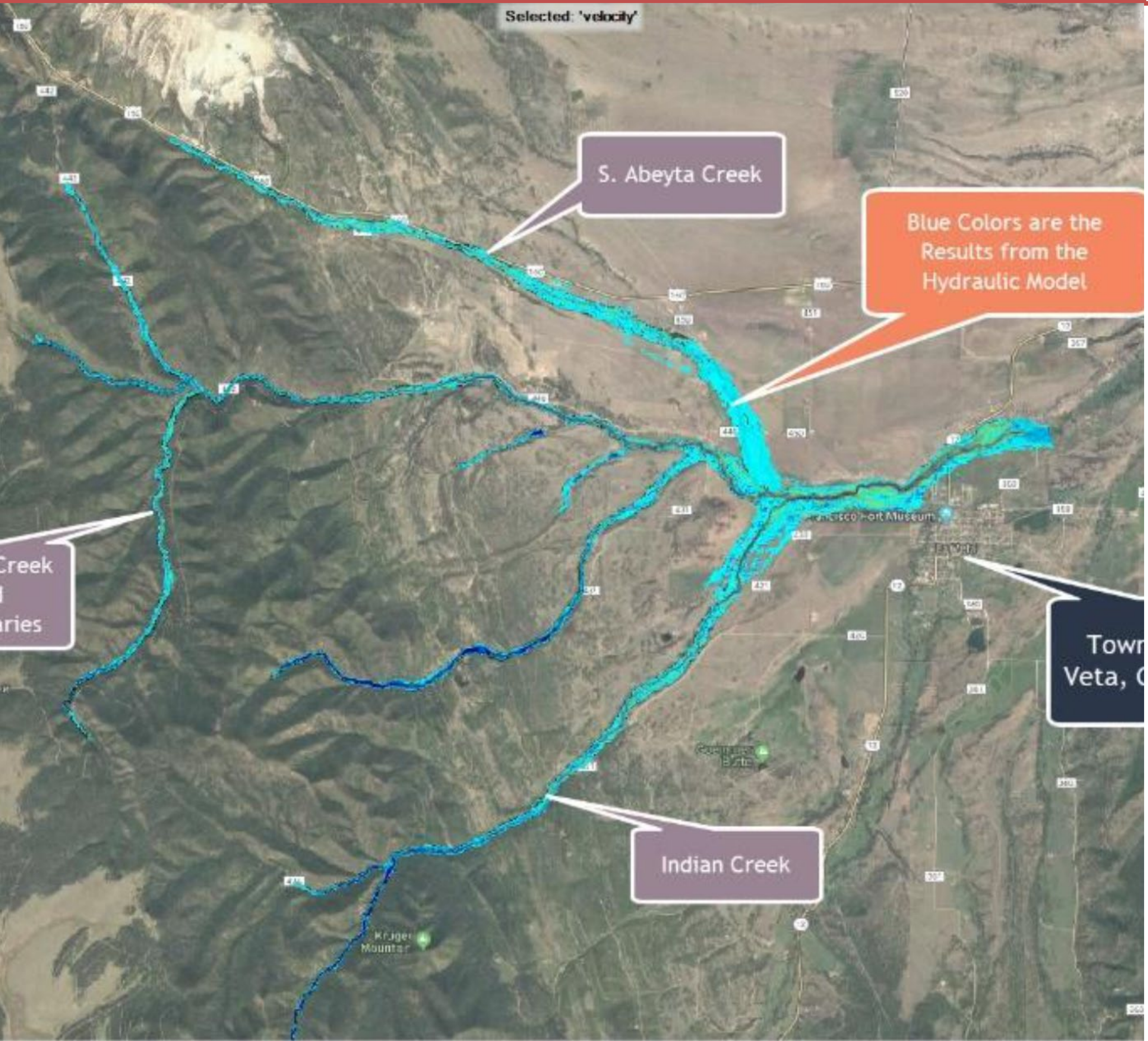
| Layer | Description | Source | Publishing Agency |
|---|---|---|---|
| NHDFlowlines<br>(Feature Class: Lines) | The National Hydrography Dataset (NHD) is a feature-based database that interconnects and uniquely identifies the stream segments or reaches that make up the nation's surface water drainage system | Data Link | United States Geological Survey |

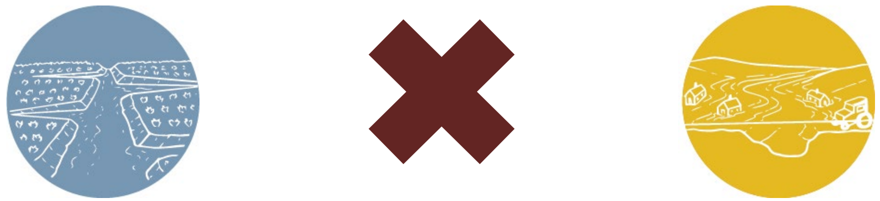
# Susceptibility to Hazards

This susceptibility matrix provides an overview of impacts from the five post-fire hazards considered under Wildfire Ready Watersheds (WRW). The severity of impact is noted under each hazard. Further detail regarding impacts from each hazard against the value-at-risk is provided under each heading.

| Hydrologic Change | Flood After Fire | Debris Flow | Fluvial Hazard Zones | Sediment Delivery |
|---|---|---|---|---|
|  |  |  |  |  |
| **Moderate** | **Moderate** | **High** | **High** | **High** |
| Increased peaks and volumes may impact function of existing water resources infrastructure. | Floods that inundate built flowlines may cause damage via erosion, debris impacts, or destabilize foundations or embankments. | Debris flow entering ditches via drainage crossings or debris flows causing failure of buried pipelines via mass earth movement. | Erosion from avulsions or bank erosion impacting linear water infrastructure facilities. | Sediment delivered to built flowlines can impact facility function and create significant maintenance costs. |
| **No Intersection** | **Intersection** | **Intersection** | **Intersection** | **Intersection** |

## Built Flowlines x Flood After Fire



# Susceptibility Scoring Methodology

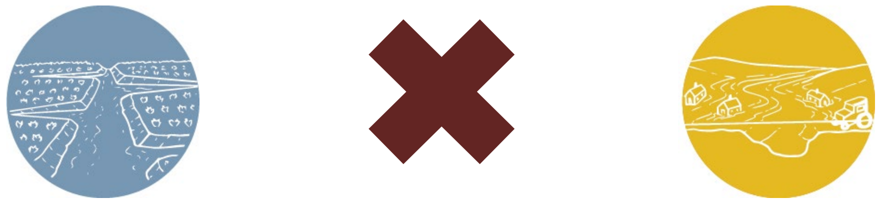
Using the post-fire hydraulic analysis, generate floodplain boundaries for the 2-, 5-, 10-, and 25-year AEP.

1. Create an intersection layer of built flowlines within the 2-, 5-, 10-, and 25-year post-fire AEP flood boundary.

2. Score severity of susceptibility based on the following:

| Severity | Metric(s) |
|---|---|
| 10 – Severe | Feature/VARs within the 2-year PF floodplain |
| 7 – High | Features/VARS within the 5-year PF floodplain |
| 4 – Moderate | Features/VARs within the 10-year PF floodpain |
| 1 – Low | Features/VARs within the 25-year floodplain |

Photo: Post-fire flood analysis in Spring Creek burn area in Huerfano County.



# Susceptibility Analysis

This flow chart provides the high-level process followed by the planning team in evaluating the hazard data against each value-at-risk. The accompanying table provides attributes to be included in the susceptibly layer for each VAR.

## Modeling Results

Complete pre- and post-fire hydraulic modeling

Generate flood boundaries for 2-, 5-, 10-, and 25-year AEP post-fire events

## Assess Susceptibility

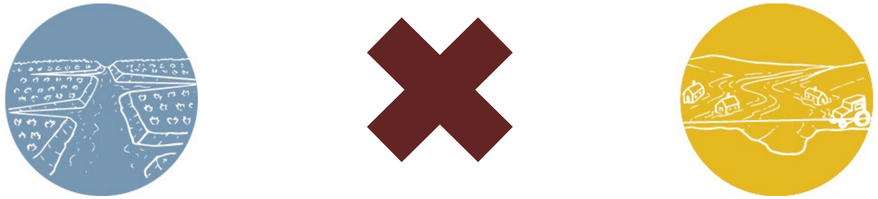
Create a new asset susceptibility layer for reservoirs (Risk_Built_Flow). This will be a data set trimmed to the 25-year FP boundary.

Intersect flood boundaries with flowlines and populate FP_2, FP_5, FP_10, FP_25 in Risk_Built_Flow layer

Score severity of risk based on scoring methodology. Populate Flood_Sev

## Assess Impact

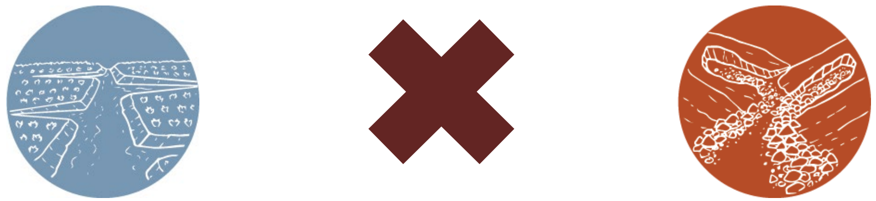
Score impact by multiplying Flood_Sev against Impact type (4 – Moderate for built flowlines) to generate score of 1-100. Populate Flood_Impact.



# Data Attributes

The following attributes will be populated in the Risk_Built_Flow susceptibility layer.

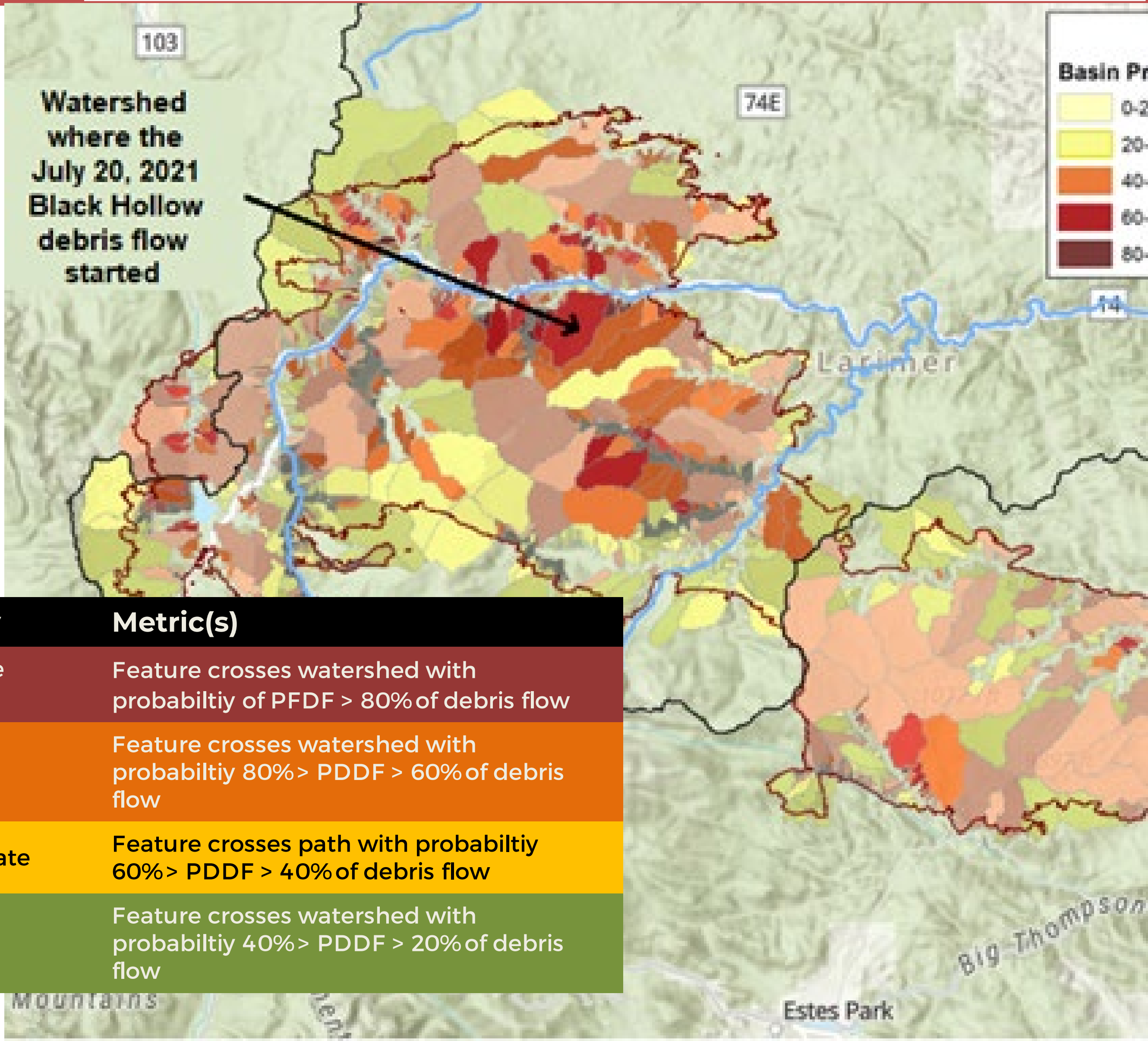
| Attribute | Description | Type |
|---|---|---|
| FP_2 | Intersection confirmation of asset that is within 2-year flood inundation boundary. Binary, in (1) and out (0). | Double |
| FP_5 | Intersection confirmation of asset that is within 5-year flood inundation boundary. Binary, in (1) and out (0). | Integer |
| FP_10 | Intersection confirmation of asset that is within 10-year flood inundation boundary. Binary, in (1) and out (0). | Integer |
| FP_25 | Intersection confirmation of asset that is within 25-year flood inundation boundary. Binary, in (1) and out (0). | |
| Flood_Sev | Severity score of 1 to 10 based location of asset within identified floodplains. | Integer |
| Flood_Impact | Impact score from 1-100. | Integer |



# Susceptibility Scoring Methodology

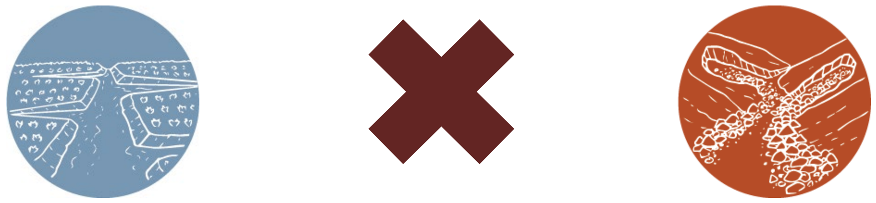
Using debris flow watersheds with Post-Fire Debris Flow (PFDF) estimates and/or extrapolated stream corridor lines (and buffers) indicating PFDF:

1. Intersect PDDF watersheds with linear line features of built flowlines and create a new data set of segments with PDDF probability assigned to the feature. Build in severity scores for each feature as described in the susceptibility matrix.
2. Alternatively, intersect linear features with flow path debris flow probablilty to create points with PDDF probability.
3. Score severity of susceptibility based on the accompanying table:




| Severity | Metric(s) |
|---|---|
| 10 - Severe | Feature crosses watershed with probabiltiy of PFDF > 80% of debris flow |
| 7 - High | Feature crosses watershed with probabiltiy 80% > PDDF > 60% of debris flow |
| 4 - Moderate | Feature crosses path with probabiltiy 60% > PDDF > 40% of debris flow |
| 1 - Low | Feature crosses watershed with probabiltiy 40% > PDDF > 20% of debris flow |

Photo: Cameron Peak debris flow probability analysis in Larimer County, CO.



# Susceptibility Analysis

This flow chart provides the high-level process followed by the planning team in evaluating the hazard data against each value-at-risk. The accompanying table provides attributes to be included in the susceptibly layer for each VAR.

**Modeling Results**

- Complete debris flow probability modeling
- Generate probability by basin (polygon)
- Generate stream network with aggregated debris probability (lines)

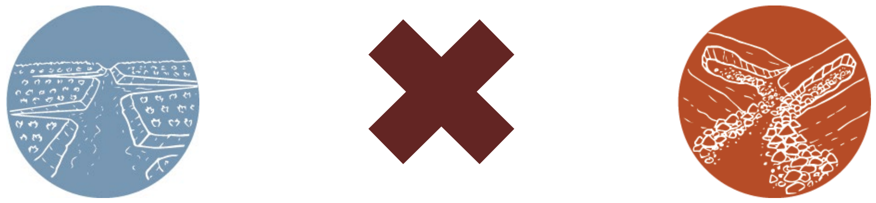
**Assess Susceptibility**

- Create a new asset susceptibility layer for reservoirs (Risk_Built_Flow)[1]
- Intersect or review PDDF probabilitybasins against built flowlines. Populate DF_Prob in Risk_Built_Flow layer
- Score severity of risk based on scoring methodology. Populate DF_Sev

**Assess Impact**

- Score impact by multiplying DF_Sev against Impact type (7 – High for built flowlines) to generate score of 1-100. Populate DF_Impact.

[1]Ideally there will be one susceptibility data set per major asset scoring all hazards as appropriate.



# Data Attributes

The following attributes will be populated in the Risk_Built_Flow susceptibility layer.

| Attribute | Description | Type |
|---|---|---|
| DF_Prob | Highest debris flow probability entering reservoir via major stream or pour points. | Double |
| DF_Sev | Severity score of 1 to 10 based on maximum PDDF entering reservoir. | Double |
| DF_Impact | Impact score from 1-100. | Integer |

# Susceptibility Scoring Methodology

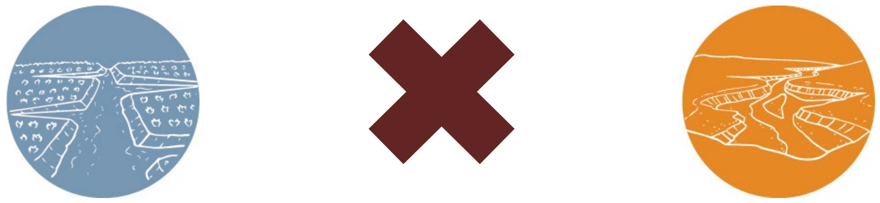
Using FHZ/ASC boundary and FHB (buffer) boundary.

1. Create an intersection layer of built flowlines within the FHZ boundary/ASC (Active Stream Corridor) and FHB (fluvial hazard bufer).

2. Score severity of susceptibility based on the following:

| Severity | Metric(s) |
|---|---|
| 10 - Severe | Feature within the ASC |
| 7 - High | Feature within the FHB |
| 4 - Moderate | N/A |
| 1 - Low | N/A |

Photo: Erosion due to flooding along Fish Creek in Estes Park, CO.



# Susceptibility Analysis

This flow chart provides the high-level process followed by the planning team in evaluating the hazard data against each value-at-risk. The accompanying table provides attributes to be included in the susceptibly layer for each VAR.

**Modeling Results**

- Complete fluvial hazard analysis
- Generate ASC and FHB for stream corridors

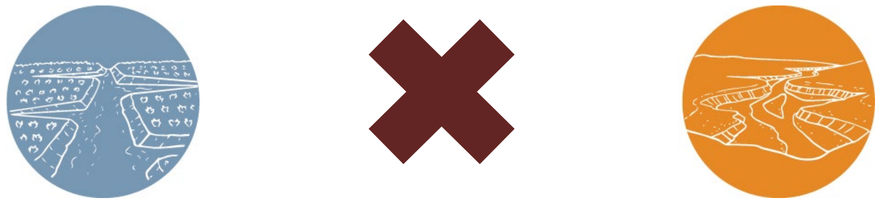
**Assess Susceptibility**

- Create a new asset susceptibility layer for reservoirs (Risk_Built_Flow)[1]. This will be a data set trimmed to the FHB.
- Intersect FHZ boundaries with flowlines and populate FHZ, and FHB in Risk_Built_Flow layer
- Score severity of risk based on scoring methodology. Populate Flood_Sev

**Assess Impact**

- Score impact by multiplying FHZ_Sev against Impact type (7 – High for built flowlines) to generate score of 1-100. Populate FHZ_Impact.

[1]Ideally there will be one susceptibility data set per major asset scoring all hazards as appropriate.



# Data Attributes

The following attributes will be populated in the Risk_Built_Flow susceptibility layer.

| Attribute | Description | Type |
|---|---|---|
| **FHZ** | Intersection confirmation of asset that is within any a given FHZ boundary, i.e. the ASC. Binary 1 (in) and 0 (out). | Double |
| **FHB** | Intersection confirmation of asset that is within any a given FHZ boundary, i.e. the FHB. Binary 1 (in) and 0 (out). | Double |
| **FHZ_Sev** | Severity score of 1 to 10 based location of asset within identified FHZs. | Integer |
| **FHZ_Impact** | Impact score from 1-100. | Integer |

# Susceptibility Scoring Methodology

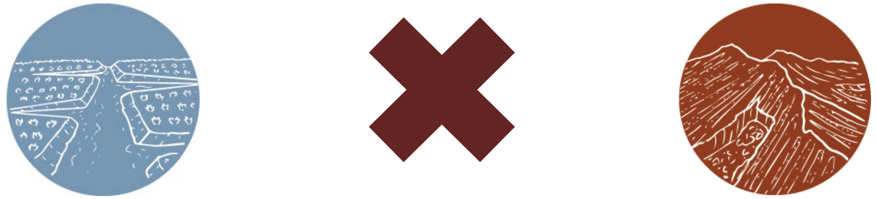
Using the sediment yield (SY) values generated in HEC-HMS 10-year AEP:

1. Intersect watersheds from hydrologic analysis with built features and populate GIS attributes.

2. Score severity of susceptibility based on the accompanying table:

| Severity | Metric(s) |
|---|---|
| 10 - Severe | Sediment yield post/pre > 10x for 10-year post-fire event |
| 7 - High | Sediment yield post/pre 10x > SY > 5x for 10-year post-fire event |
| 4 - Moderate | Sediment yield post/pre < 5x for 10-year post-fire even |
| 1 - Low | Burned watersheds upstream of VAR |

Photo: Cameron Peak hillslope erosion upstream of Black Hollow.



# Susceptibility Analysis

This flow chart provides the high-level process followed by the planning team in evaluating the hazard data against each value-at-risk. The accompanying table provides attributes to be included in the susceptibly layer for each VAR.

## Modeling Results

- Complete pre- and post-fire sediment yield (SY) modeling
- Calculate ratios of post/pre sediment yield

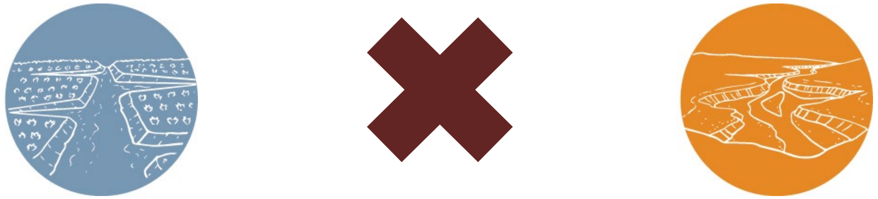
## Assess Susceptibility

- Create a new asset susceptibility layer for reservoirs (Risk_Built_Flow)[1] by intersecting watershed basins with features.
- Intersect SY data with flowlines and populate Sed_Rat in Risk_Built_Flow layer
- Score severity of risk based on scoring methodology. Populate Sed_Sev

## Assess Impact

- Score impact by multiplying Sed_Sev against Impact type (7 – High for built flowlines) to generate score of 1-100. Populate Sed_Impact.

[1]Ideally there will be one susceptibility data set per major asset scoring all hazards as appropriate.



# Data Attributes

The following attributes will be populated in the **Risk_Built_Flow** susceptibility layer.

| Attribute | Description | Type |
|---|---|---|
| **Sed_Rat** | Ratio of post- vs pre-fire sediment yield for the 10-year AEP. | Double |
| **Sed_Sev** | Severity score of 1 to 10 based on sediment ratio from pre to post-fire conditions. | Double |
| **Sed_Impact** | Impact score from 1-100. | Integer |

# Water Resources Infrastructure: Decreed Water Rights/Diversions

3

## Decreed Water Rights: Diversions

# Values-at-Risk Data Source

### Data Sources

CDSS Structures is a subset of CDSS Structures consisting of ditches, ditch systems, pipeline, and pumps. *For purposes of WRW, this data set has been queried with a Use Code of A (Active Structure with contemporary diversion records) or U (Active structure but diversion records are not maintained). The attribute DCRRatAbbs (Decreed Rate Absolute) was used for aggregation by summation for all features in each HUC. (Note – the above filter is still being reviewed to confirm process and filtering)*

### How Data Sets Can be Used for Susceptibility and Planning

The CDSS Structures (point feature class) can be used for direct intersection analyses for hazards against values-at-risk.

Decreed Water Rights: Diversions

# Values-at-Risk: Supporting Data Sources

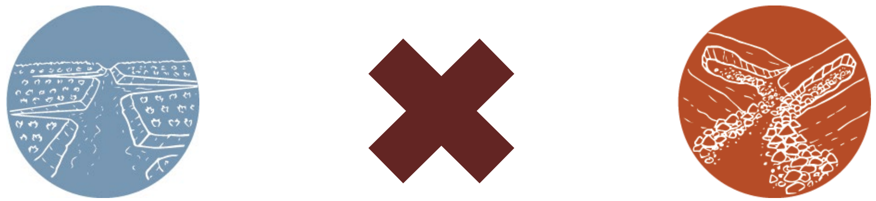
| Layer | Description | Source | Publishing Agency |
|---|---|---|---|
| NHDFlowlines (Feature Class: Lines) | Colorado's Decision Support Systems (CDSS) is a water management system. The goal of this system is to assist in making informed decisions regarding historic and future use of water. CDSS Structures consist of features associated with diversions and diversion records. | Data Link | Colorado Department of Natural Resources, Colorado Water Conservation Board |

## Decreed Water Rights: Diversions

# Susceptibility to Hazards

This susceptibility matrix provides an overview of impacts from the five post-fire hazards considered under Wildfire Ready Watersheds (WRW). The severity of impact is noted under each hazard. Further detail regarding impacts from each hazard against the value-at-risk is provided under each heading.

| Hydrologic Change | Flood After Fire | Debris Flow | Fluvial Hazard Zones | Sediment Delivery |
|---|---|---|---|---|
|  |  |  |  |  |
| **Moderate** | **High** | **High** | **High** | **Moderate** |
| Increased peaks and volumes may impact function of existing water resources infrastructure. | Floods that inundate diversion structures may cause damage via erosion, debris impacts, or destabilize foundations or embankments. | Debris flow damaging diversion infrastructure and/or entering ditch/pipe facilities via diversion. | Erosion from avulsions or bank erosion impacting linear water infrastructure facilities. | Delivery of sediment to ditch diversions can impact facility function and require significant maintenance and/or can affect ability to use diversion, i.e. sediment impacts diversion flow delivery. |
| **No Intersection** | **No Intersection** | **Intersection** | **Intersection** | **Intersection** |



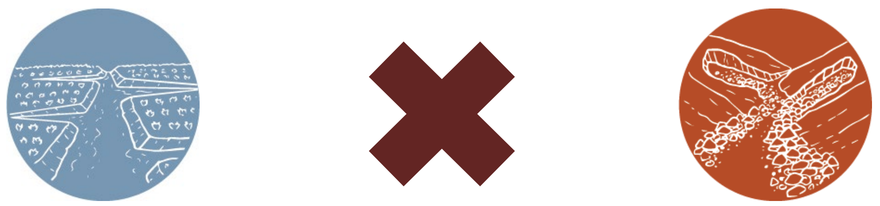
# Susceptibility Scoring Methodology

Using debris flow watersheds with PostFire Debris Flow (PFDF) estimates and extrapolated stream corridor lines (and buffers) indicating PFDF:

1. Run GIS intersection per susceptibility analysis procedure and/or populate GIS attributes.
2. Score severity of susceptibility based on the following:

| Severity | Metric(s) |
|---|---|
| 10 - Severe | Probability > 80% of debris flow with VARs within a 250 foot corridor from the drainage flowline |
| 7 - High | High: Probability PFDF > 60% of debris flow with VARs within a 500 foot corridor from the drainage flowline |
| 4 - Moderate | Probability 60% > PFDF > 40% of debris flow with VARs within a 500 foot corridor from the drainage flowline |
| 1 - Low | Probability 40% > PFDF > 20% of debris flow with VARs within a 500 foot corridor from the drainage flowline |

Photo: Post-fire debris flow and fan adjacent to river system (Sholtes).



# Susceptibility Analysis

This flow chart provides the high-level process followed by the planning team in evaluating the hazard data against each value-at-risk. The accompanying table provides attributes to be included in the susceptibly layer for each VAR.

## Modeling Results

Complete debris flow probability modeling

Generate streamline with PFDF probability and associated buffers.

## Assess Susceptibility

Create a new asset susceptibility layer for decreed features (Risk_Water_Rights)[1]

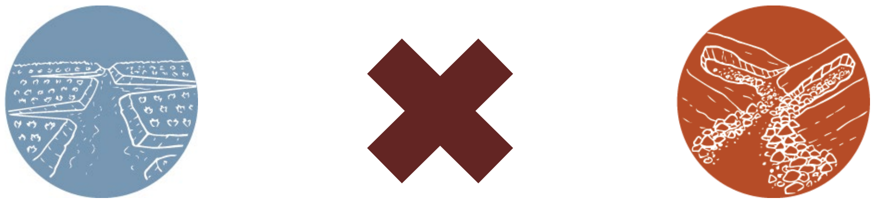
Intersect buffers with VARS. Populate DF_Prob_250 and DF_Prob_500 in Risk_Water_Rights layer

Score severity of risk based on scoring methodology. Populate DF_Sev

## Assess Impact

Score impact by multiplying DF_Sev against Impact type (7 – High for decreed features) to generate score of 1-100. Populate DF_Impact.

[1]Ideally there will be one susceptibility data set per major asset scoring all hazards as appropriate.



# Data Attributes

The following attributes will be populated in the Risk_Water_Rights susceptibility layer.

| Attribute | Description | Type |
|---|---|---|
| **DF_Prob_250** | PFDF probability for VAR within 250 feet of stream flowline. | Double |
| **DF_Prob_500** | PFDF probability for VAR within 500 feet of stream flowline. | Double |
| **DF_Sev** | Severity score of 1 to 10 based on PFDF. | Double |
| **DF_Impact** | Impact score from 1-100. | Integer |

# Susceptibility Scoring Methodology

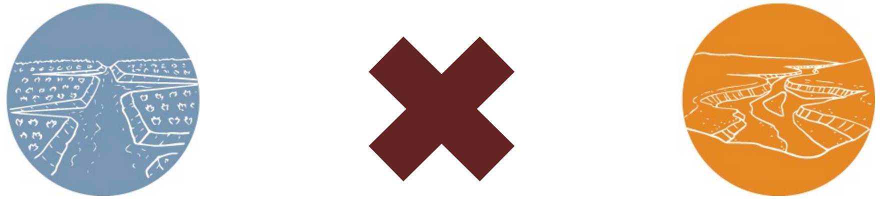
Using FHZ/ASC boundary and FHB (buffer) boundary:

1. Create an intersection layer of diversions/structures/water right access within the FHZ boundary/ASC (Active Stream Corridor) and the FHB (Fluvial Hazard Buffer).

2. Score severity of susceptibility based on the following:

| Severity | Metric(s) |
|---|---|
| 10 - Severe | Feature within the ASC |
| 7 - High | Feature within the FHB |
| 4 - Moderate | N/A |
| 1 - Low | N/A |

Photo: Diversion for City of Walsenburg water supply, downstream of 2018 Spring Creek Fire near La Veta, Co.



# Susceptibility Analysis

This flow chart provides the high-level process followed by the planning team in evaluating the hazard data against each value-at-risk. The accompanying table provides attributes to be included in the susceptibly layer for each VAR.

**Modeling Results**

- Complete fluvial hazard analysis
- Generate ASC and FHB for stream corridors

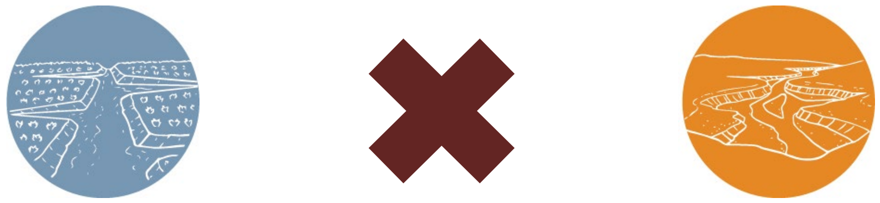
**Assess Susceptibility**

- Create a new asset susceptibility layer for decreed features (Risk_Water_Rights)[1]. This will be a data set trimmed to the FHB.
- Intersect FHZ boundaries with flowlines and populate FHZ, and FHB in Risk_Water_Rights layer
- Score severity of risk based on scoring methodology. Populate FHZ_Sev

**Assess Impact**

- Score impact by multiplying FHZ_Sev against Impact type (7 – High for decreed features) to generate score of 1-100. Populate FHZ_Impact.

[1]Ideally there will be one susceptibility data set per major asset scoring all hazards as appropriate.



# Data Attributes

The following attributes will be populated in the Risk_Water_Rights susceptibility layer.

| Attribute | Description | Type |
|---|---|---|
| FHZ | Intersection confirmation of asset that is within any a given FHZ boundary, i.e. the ASC. Binary 1 (in) and 0 (out). | Double |
| FHB | Intersection confirmation of asset that is within any a given FHZ boundary, i.e. the FHB. Binary 1 (in) and 0 (out). | Double |
| FHZ_Sev | Severity score of 1 to 10 based location of asset within identified FHZs. | Integer |
| FHZ_Impact | Impact score from 1-100. | Integer |

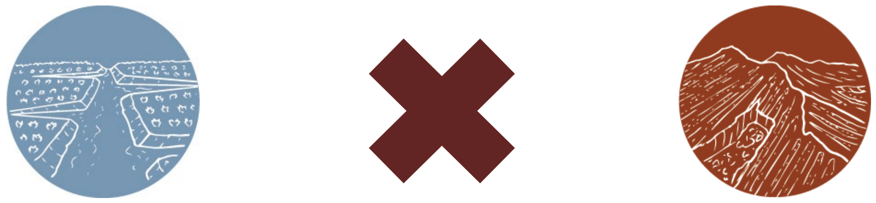
Decreed Water Rights x Sediment Yield

# Susceptibility Scoring Methodology

Using the sediment yield (SY) values generated in HEC-HMS for the 10-year AEP, create a line layer incorporating the ratio of post vs pre fire sediment yield.

1. Create a buffer of 250 - 500 feet to capture all diversion structures within major stream corridors.
2. Run GIS intersection per susceptibility analysis an/or populate GIS attributes.
3. Score severity of susceptibility based on the following:

| Severity | Metric(s) |
|---|---|
| 10 - Severe | Sediment yield post/pre > 10x for 10-year post-fire event |
| 7 - High | Sediment yield post/pre 10x > SY > 5x for 10-year post-fire event |
| 4 - Moderate | Sediment yield post/pre 5X < SY < 2x for 10-year post-fire event |
| 1 - Low | Sediment yield post/pre < 2x for 10-year post-fire event |



# Susceptibility Analysis

This flow chart provides the high-level process followed by the planning team in evaluating the hazard data against each value-at-risk. The accompanying table provides attributes to be included in the susceptibly layer for each VAR.

## Modeling Results

**Complete pre- and post-fire sediment yield (SY) modeling**

**Calculate ratios of post/pre sediment yield**

**Create a reach-by-reach line layer showing ratio of SY increase and offset to create a buffer to capture all diversion features**

## Assess Susceptibility

**Create a new asset susceptibility layer for decreed features (Risk_Water_Rights)[1]**

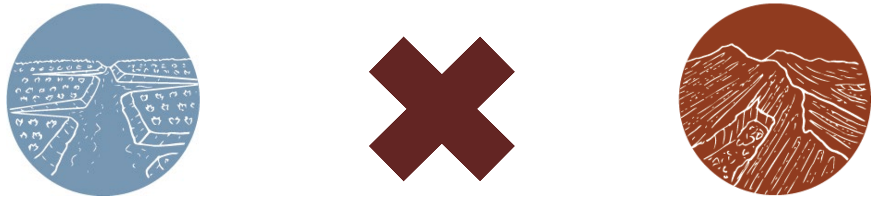
**Intersect or review post/pre fire SY ratios against reservoir layer and populate Sed_Rat in Risk_Water_Rights layer**

**Score severity of risk based on scoring methodology. Populate Sed_Sev**

## Assess Impact

**Score impact by multiplying Sed_Sev against Impact type (4 – Moderate for decreed features) to generate score of 1-100. Populate Sed_Impact.**

[1]Ideally there will be one susceptibility data set per major asset scoring all hazards as appropriate.



# Data Attributes

The following attributes will be populated in the Risk_Water_Rights susceptibility layer.

| Attribute | Description | Type |
|---|---|---|
| **Sed_Rat** | Ratio of post- to pre-fire conditions peak flows for 10-year AEP | Double |
| **Sed_Sev** | Severity score of 1 to 10 based on post- to pre- fire ratios. | Integer |
| **Sed_Impact** | Impact score from 1-100. | Integer |

# 4

# Transportation Infrastructure: Crossings

# Values-at-Risk Data Source

## Data Sources

For this WRAP, several crossing data sets were collected. However, these data sets can be insufficient to understand every roadway crossing. Those data sets are better suited for supporting planning decisions. For susceptibility, a data set (Transportation Xings) was developed that represents all locations where NHD flowlines intersect roads and highways. Roadway crossings were classified according to their roadway classification with a weight assigned to crossings as either highways (5), major roads (3), and local roads (1).

## How Data Sets Can be Used for Susceptibility and Planning

The Transporation Xings (point feature class) can be used for direct intersection analyses for hazards against values-at-risk. Specifically, the risk associated with various hazards including increased post-fire flows, flood after fire, debris flow, fluvial hazard zones, and increases in sediment delivery can be assessed at each of these crossings to understand risk to roadway failures or emergency access.

The specific structure data collected during the data collection effort can be used by the planning team to understand current conditions and if a crossing might be able to withstand increased hazard risk and/or if replacement of a crossing might be prudent as a recommended action.

Transportation Crossings

# Values-at-Risk: Supporting Data Sources

| Layer | Description | Source | Publishing Agency |
|---|---|---|---|
| **Transportation Xings**<br>**(Feature Class: Points)** | Intersection of NHD flow lines against roadways to identify hydraulic crossings within the study area. | None | N/A<br>Project Specific |
| **CDOT Highways**<br>**CDOT Major Roads**<br>**CDOT Local Roads**<br>**(Feature Class: Lines)** | Polyline (linear) geographic dataset representing public roads under state and local jurisdiction that are functionally classified as highways, arterials, collectors, or local roads. | Data Link | CDOT |
| **Garfield County Roads** | Roads within Garfield County, Colorado. Includes county roads, Forest Service, local roads, state, and interstate. | Data Link | Garfield County |
| **Mesa County Roads**<br>**(Feature Class: Lines)** | Road Centerlines within Mesa County, CO. Some roads extend into Garfield County, CO and Grand County, UT. | Data Link | Mesa County |
| **CDOT Bridges and Culverts**<br>**(Feature Class: Points)** | CDOT bridges and large culverts along State Highways | Data Link | CDOT |
| **Garfield County Bridges and Culverts**<br>**(Feature Class: Points)** | Garfield County bridges and large culverts along State Highways | Data Link | Garfield County |

# Susceptibility to Hazards

This susceptibility matrix provides an overview of impacts from the five post-fire hazards considered under Wildfire Ready Watersheds (WRW). The severity of impact is noted under each hazard. Further detail regarding impacts from each hazard against the value-at-risk is provided under each heading.

| Hydrologic Change | Flood After Fire | Debris Flow | Fluvial Hazard Zones | Sediment Delivery |
|---|---|---|---|---|
|  |  |  |  |  |
| **High** | **High** | **High** | **High** | **Moderate** |
| Increased flow rates can overwhelm existing drainage infrastructure resulting in flooding, limited access during emergencies, and result in roadway crossing failures. | Increased flood peaks create overflows and overtopping of roadways that can result in failures. | Debris flows can plug openings, resulting in overtopping and/or upstream flooding, resulting in failures of existing drainage crossing infrastructure and flooding of nearby values-at-risk. | Erosion zones can cause roadway failures and impact roadway embankments. | Sediment deposition or degradation can cause culverts to fail due to pipes or openings becoming clogged, resulting in overtopping of roadways or upstream flooding or failures can occur due to local erosion nad stream downcutting. |
| **Intersection** | **No Intersection** | **Intersection** | **No Intersection** | **Intersection** |

Transportation Crossings x Hydrologic Change

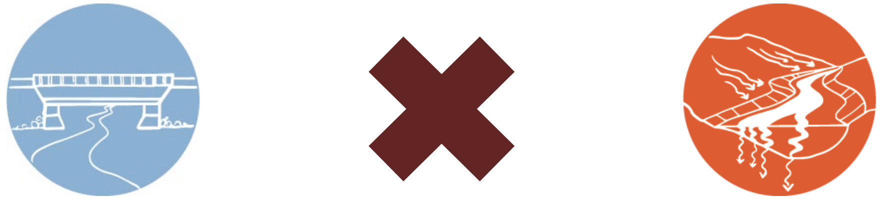
Photo: Embankment damage due to culvert overtopping in Huerfano County, Co.

# Susceptibility Scoring Methodology

Crossings should consider all hydraulic crossings, i.e. where drainageways intersect roadways. Using the crossings layer (see VAR data source), and hydrologic output data:

1. Generate a stream line layer with the ratios of post/pre-fire peak flows for the 2-, 5-, 10, 25-, and 100 year AEPs.
2. Intersect stream lines with crossings (use the same streams used to create the hydraulic crossings VARs) and intersect flow lines with roadways and populate GIS attributes.
3. Score severity of susceptibility based on the following:

| Severity | Metric(s) |
|---|---|
| 10 - Severe | Post/Pre Peak Flow > 10x |
| 7 - High | 10x > Post/Pre Peak Flow > 5x |
| 4 - Moderate | 5x > Post/Pre Peak Flow > 2x |
| 1 - Low | Post/Pre Peak Flow < 2X |



# Susceptibility Analysis

This flow chart provides the high-level process followed by the planning team in evaluating the hazard data against each value-at-risk. The accompanying table provides attributes to be included in the susceptibly layer for each VAR.

## Modeling Results

Complete pre- and post-fire hydrologic modeling and compile results

Assign pre- to post-fire ratios to hydrologic junctions data set for all AEPs

Assign pre- to post-fire ratios to stream segments between junctions for all AEPs

## Assess Susceptibility

Create a new asset susceptibility layer for reservoirs (Risk_Xings)

Intersect or review post/pre fire peak flow ratios against linear transportation features and populate RO_Rat_10 in Risk_Xings layer

Score severity of risk based on scoring methodology. Populate RO_Sev

## Assess Impact

Score impact by multiplying RO_Sev against transportation feature type as follows:

highway (10)

major roads (7)

Railway (7)

local roads (4)

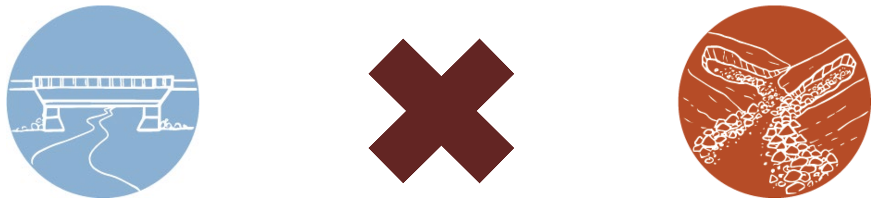
other (1)

Generate score of 1-100. Populate RO_Impact.

# Data Attributes

The following attributes will be populated in the Risk_Xings susceptibility layer.

| Attribute | Description | Type |
|---|---|---|
| RO_Rat_2 | Ratio of post- to pre-fire conditions peak flows for 2-year AEP | Double |
| RO_Rat_5 | Ratio of post- to pre-fire conditions peak flows for 5-year AEP | Double |
| RO_Rat_10 | Ratio of post- to pre-fire conditions peak flows for 10-year AEP | Double |
| RO_Rat_25 | Ratio of post- to pre-fire conditions peak flows for 25-year AEP | Double |
| RO_Rat_100 | Ratio of post- to pre-fire conditions peak flows for 100-year AEP | Double |
| RO_Sev | Severity score of 1 to 10 based on post- to pre- fire ratios. | Integer |
| RO_Impact | Impact score from 1-100. | Integer |



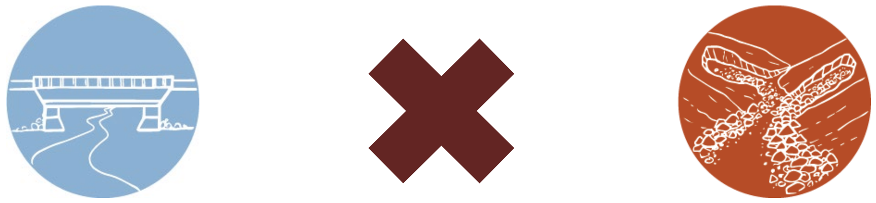
# Susceptibility Scoring Methodology

Using debris flow watersheds with PostFire Debris Flow (PFDF) estimates and extrapolated stream corridor lines (and buffers) indicating PFDF:

1. Run GIS intersection per susceptibility analysis procedure and/or populate GIS attributes.
2. Score severity of susceptibility based on the following:

| Severity | Metric(s) |
|---|---|
| 10 - Severe | Probability > 80% of debris flow |
| 7 - High | Probability 80%> PFDF > 60% of debris flow |
| 4 - Moderate | Probability 60%> PFDF > 40% of debris flow |
| 1 - Low | Probability 40%> PFDF > 20% of debris flow |

Photo: Post-fire debris flow and fan extending through railway crossing in Glenwood Canyon after the Grizzly Creek fire near Glenwood Springs, CO (Sickles).



# Susceptibility Analysis

This flow chart provides the high-level process followed by the planning team in evaluating the hazard data against each value-at-risk. The accompanying table provides attributes to be included in the susceptibly layer for each VAR.

## Modeling Results

**Complete debris flow probability modeling**

**Generate streamline with PFDF probability and associated buffers.**

## Assess Susceptibility

**Create a new asset susceptibility layer for reservoirs (Risk_Xings)[1]**

**Intersect streamlines with VARS. Populate DF_Prob in Risk_Xings layer**

**Score severity of risk based on scoring methodology. Populate DF_Sev**

## Assess Impact

**Score impact by multiplying DF_Sev against transportation feature type as follows:**

**highway (10)**

**major roads (7)**

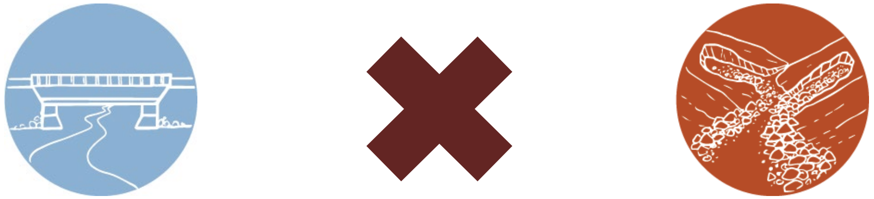
**Railway (7)**

**local roads (4)**

**other (1)**

**Generate score of 1-100. Populate DF_Impact.**

[1]Ideally there will be one susceptibility data set per major asset scoring all hazards as appropriate.

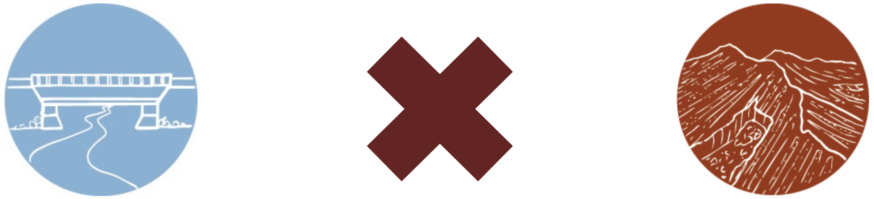


# Data Attributes

The following attributes will be populated in the Risk_Xings susceptibility layer.

| Attribute | Description | Type |
|---|---|---|
| DF_Prob | PFDF probability at crossing. | Double |
| DF_Sev | Severity score of 1 to 10 based on PFDF. | Double |
| DF_Impact | Impact score from 1-100. | Integer |

## Transportation Crossings x Sediment Yield



| Severity | Metric(s) |
|---|---|
| **Aggradational (Deposition)** | |
| 7 - High | Channel indicates strong potential for aggradation based on HMS transport, HEC-RAS2D sediment transport, or low velocities based on stream hydraulics analyses that indicates depositional reach with VARs located adjacent to crossing on upstream or downstream sides. |
| 1 - Low | Channel indicates strong potential for aggradation based on HMS transport, HEC-RAS2D sediment transport, or low velocities based on stream hydraulics analyses that indicates depositional reach and with no significant VARs located adjacent to crossing on upstream or downstream sides. |
| **Degradational (Erosion)** | |
| 7 - High | Channel indicates strong potential for degradation based on HMS transport, HEC-RAS2D sediment transport, or low velocities based on stream hydraulics analyses that indicates depositional reach with VARs located adjacent to crossing on upstream or downstream sides |
| 1 - Low | Channel indicates strong potential for degradation based on HMS transport, HEC-RAS2D sediment transport, or low velocities based on stream hydraulics analyses that indicates depositional reach and with no signifcant VARs adjacent to crossing on upstream and downstream side |

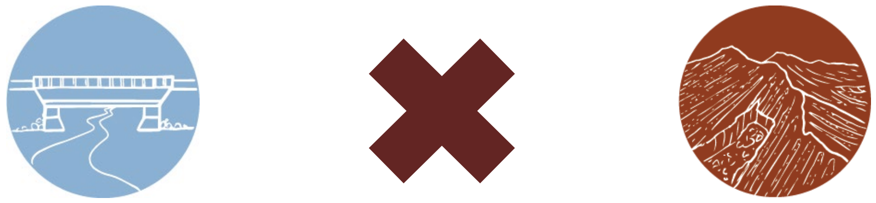
# Susceptibility Scoring Methodology

Using the sediment yield (SY) values generated in HEC-HMS for the 10-year AEP, create an aggradation/degradation data set for all reaches within the watershed.

1. Perform GIS intersection of the aggradation/degradation streamlines against roadway crossings.
2. Create a circular buffer from center of crossing equal to equal to 100-year post-fire floodplain width.
3. Score severity of susceptibility based on the accompanying table depending on if reach is aggradational (depositional) or degradational (erosional):



Photo: Failed culvert and associated channel degeradation in Huerfano County, CO.



# Susceptibility Analysis

This flow chart provides the high-level process followed by the planning team in evaluating the hazard data against each value-at-risk. The accompanying table provides attributes to be included in the susceptibly layer for each VAR.

## Modeling Results

Complete pre- and post-fire sediment yield (SY) modeling

Calculate ratios of post/pre sediment yield

Create a reach-by-reach line layer showing whether reach is aggradational or depositional.

## Assess Susceptibility

Create a new asset susceptibility layer for reservoirs (Risk_Xings)[1]

Intersect lines with crossings and populate Sed_Agg_Deg in Risk_Xings layer

Create a circular buffer from xing center point = 100-year post-fire floodplain width (or at least 2x the width of the roadway crossing where embankment starts/ends) and determine number of VARs adjacent to xing and populate Sed_VAR_Ct

Score severity of risk based on scoring methodology. Populate Sed_Sev

## Assess Impact

Score impact by multiplying Sed_Sev against transportation feature type as follows:

highway (10)

major roads (7)

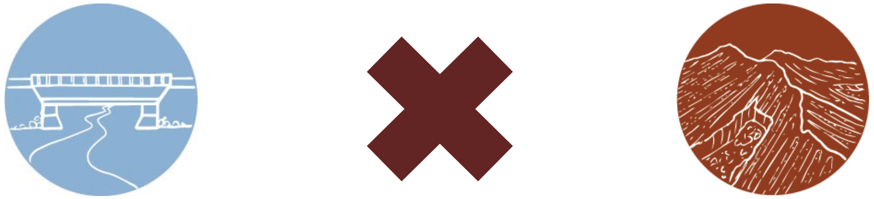
Railway (7)

local roads (4)

other (1)

Generate score of 1-100. Populate Sed_Impact.

[1]Ideally there will be one susceptibility data set per major asset scoring all hazards as appropriate.



# Data Attributes

The following attributes will be populated in the Risk_Xings susceptibility layer.

| Attribute | Description | Type |
|---|---|---|
| **Sed_Agg_Deg** | Indicates if crossing is in aggrading reach or degrading reach. | Double |
| **Sed_VAR_Ct** | The count of VARs within a circular buffer equal to the 100-year post-fire width (or at least 2x the width of the roadway crossing where embankment starts/ends) the center of the xing. | Integer |
| **Sed_Sev** | Severity score of 1 to 10 based on post- to pre- fire ratios. | Integer |
| **Sed_Impact** | Impact score from 1-100. | Integer |

# Transportation Infrastructure: Linear Features

5

# Values-at-Risk Data Source

## Data Sources

Data was compiled from multiple data sources for linear transportation features including highways, local roads, and railroads. See the accompanying table for details regarding referenced data sets.

## How Data Sets Can be Used for Susceptibility and Planning

The roadway data sets (line feature class) can be used for direct intersection analyses for hazards against values-at-risk. Specifically, the risk associated with various hazards including increased post-fire flows, flood after fire, debris flow, fluvial hazard zones, and increases in sediment delivery can be assessed to understand risk to roadway failures or emergency access.

The roadway classifications and/or transportation types can be used to assess impacts from post-fire hazards, i.e. highways may be considered to have more significant impact than local roads.

# Values-at-Risk: Supporting Data Sources

| Layer | Description | Source | Publishing Agency |
|---|---|---|---|
| CDOT Highways<br>CDOT Major Roads<br>CDOT Local Roads<br>(Feature Class: Lines) | Polyline (linear) geographic dataset representing public roads under state and local jurisdiction that are functionally classified as highways, arterials, collectors, or local roads. | Data Link | CDOT |
| Garfield County Roads | Roads within Garfield County, Colorado. Includes county roads, Forest Service, local roads, state, and interstate. | Data Link | Garfield County |
| Mesa County Roads<br>(Feature Class: Lines) | Road Centerlines within Mesa County, CO. Some roads extend into Garfield County, CO and Grand County, UT. | Data Link | Mesa County |
| CPW Roads | Roads within CPW boundaries. | Data Link | CPW |
| Railroads | The North American Rail Network (NARN) Rail Lines dataset | Data Link | FRA |
| FS Roads | Forest service roads. | Data Link | USFS |

## Transportation Linear Features

# Susceptibility to Hazards

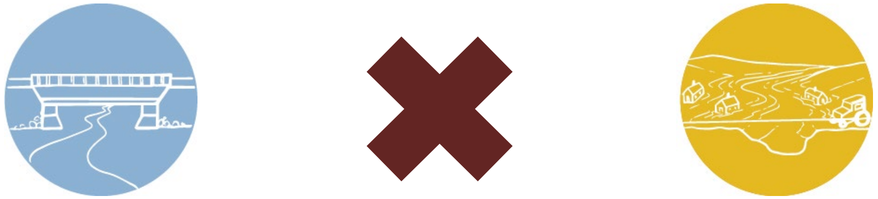
This susceptibility matrix provides an overview of impacts from the five post-fire hazards considered under Wildfire Ready Watersheds (WRW). The severity of impact is noted under each hazard. Further detail regarding impacts from each hazard against the value-at-risk is provided under each heading.





| Hydrologic Change | Flood After Fire | Debris Flow | Fluvial Hazard Zones | Sediment Delivery |
|---|---|---|---|---|
| **High** | **High** | **High** | **High** | **Moderate** |
| Increased flows in streams can result in increased flood frequency on linear transportation features and increased flows may also increase velocities or erosion potential. | Increased flows in streams can result in increased flood frequency on linear transportation features and increased flows may also increase velocities or erosion potential. | Debris flow can damage roadway or linear transportation infrastructure and can directly impact conveyance capacity of streams and hydraulic crossings. | Erosion zones can result in roadway failures due to geomorphic processes. | Aggradation or erosion can impact parallel transportation features resulting in failure of infrastructure |
| **No Intersection** | **Intersection** | **Intersection** | **Intersection** | **No Intersection** |

Linear Transportation x Flood After Fire



# Susceptibility Scoring Methodology

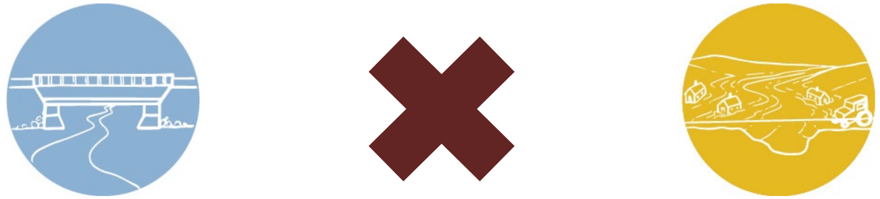
Using the flood inundation layers created through the post-fire hydraulic analysis:

1. Intersect the 2-, 5-, 10, and 25-year flood boundary and associated depths with linear transportation features.

2. Score severity of susceptibility based on the following

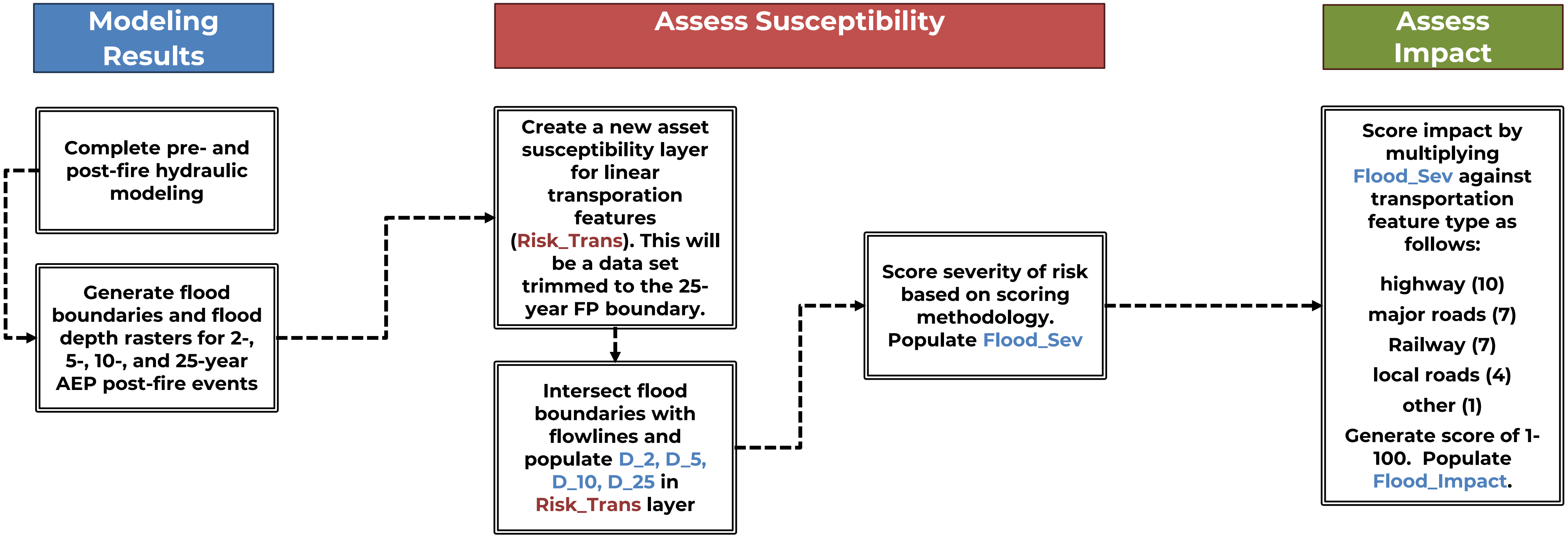
| Severity | Metric(s) |
|---|---|
| 10 - Severe | Overtopping of parallel roadways at depths greater than 1-foot during the 2-year post-fire flood |
| 7 - High | Overtopping of parallel roadways at depths greater than 1-foot for the 5-year post-fire flood |
| 4 - Moderate | Overtopping of parrallel roadways at depths greater than 1-foot for the 10-year post-fire flood |
| 1 - Low | Overtopping of parallel roadways at depths greater than 1-foot for the 25-year post-fire flood |

Photo: Damage to highway after the 2013 floods in Colorado.



# Susceptibility Analysis

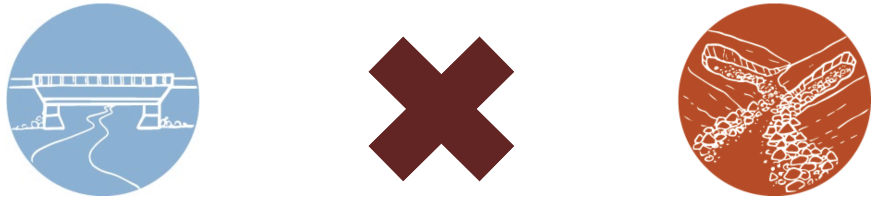
This flow chart provides the high-level process followed by the planning team in evaluating the hazard data against each value-at-risk. The accompanying table provides attributes to be included in the susceptibly layer for each VAR.



# Data Attributes

The following attributes will be populated in the Risk_Trans susceptibility layer.

| Attribute | Description | Type |
|---|---|---|
| D_2 | Maximum depth on roadway during select AEP events. | Double |
| D_5 | Maximum depth on roadway during select AEP events. | Double |
| D_10 | Maximum depth on roadway during select AEP events. | Double |
| D_25 | Maximum depth on roadway during select AEP events. | Double |
| Flood_Sev | Severity score of 1 to 10 based location of asset within identified floodplains. | Integer |
| Flood_Impact | Impact score from 1-100. | Integer |



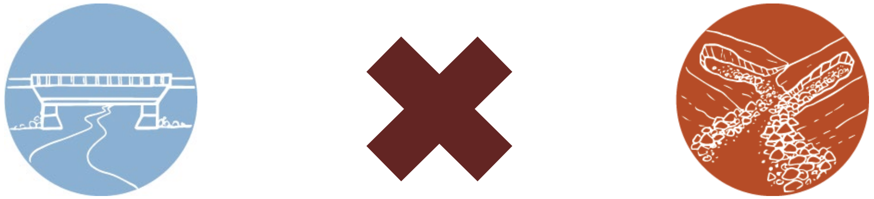
# Susceptibility Scoring Methodology

Using debris flow watersheds with PostFire Debris Flow (PFDF) estimates and extrapolated stream corridor lines (and buffers) indicating PFDF:

1. Create an intersection severity score for roadways/linear features using pre-defined buffers.
2. Score severity of susceptibility based on the following:

| Severity | Metric(s) |
|---|---|
| 10 - Severe | Probability > 80% of debris flow with VARs within a 250 foot corridor from the drainage flowline |
| 7 - High | High: Probability PFDF > 60% of debris flow with VARs within a 500 foot corridor from the drainage flowline |
| 4 - Moderate | Probability 60% > PFDF > 40% of debris flow with VARs within a 500 foot corridor from the drainage flowline |
| 1 - Low | Probability 40% > PFDF > 20% of debris flow with VARs within a 500 foot corridor from the drainage flowline |

Photo: Post-fire debris flow in the Glenwood Canyon into the Colorado River near Glenwood Springs, CO (CDOT).



# Susceptibility Analysis

This flow chart provides the high-level process followed by the planning team in evaluating the hazard data against each value-at-risk. The accompanying table provides attributes to be included in the susceptibly layer for each VAR.

## Modeling Results

Complete debris flow probability modeling

Generate streamline with PFDF probability and associated buffers.

## Assess Susceptibility

Create a new asset susceptibility layer for linear transporation features (Risk_Trans)[1] based on intersections with PFDF buffers

Intersect buffers with VARS. Populate DF_Prob_250 and DF_Prob_500 in Risk_Trans layer

Score severity of risk based on scoring methodology. Populate DF_Sev

## Assess Impact

Score impact by multiplying DF_Sev against transportation feature type as follows:

highway (10)

major roads (7)

Railway (7)

local roads (4)

other (1)

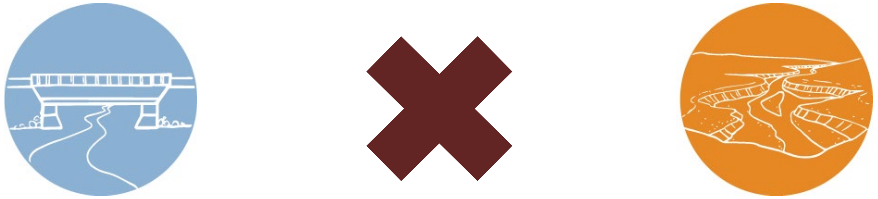
Generate score of 1-100. Populate DF_Impact.

[1]Ideally there will be one susceptibility data set per major asset scoring all hazards as appropriate.

# Data Attributes

The following attributes will be populated in the Risk_Xings susceptibility layer.

| Attribute | Description | Type |
|---|---|---|
| DF_Prob_250 | PFDF probability for VAR within 250 feet of stream flowline. | Double |
| DF_Prob_500 | PFDF probability for VAR within 500 feet of stream flowline. | Double |
| DF_Sev | Severity score of 1 to 10 based on PFDF. | Double |
| DF_Impact | Impact score from 1-100. | Integer |



# Susceptibility Scoring Methodology

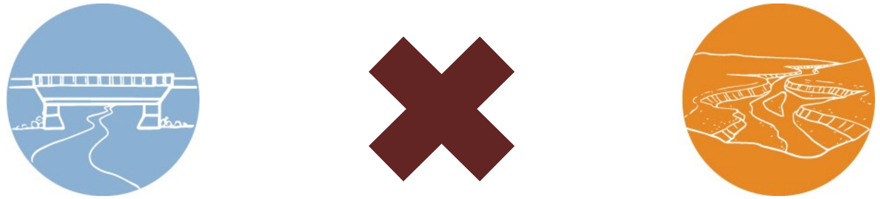
Using FHZ/ASC boundary and FHB (buffer) boundary:

1. Create an intersection layer of linear transportation features within the FHZ boundary/ASC (Active Stream Corridor) and a predefined buffer.

2. Score severity of susceptibility based on the following:

| Severity | Metric(s) |
|---|---|
| 10 - Severe | Feature within the ASC |
| 7 - High | Feature within the FHB |
| 4 - Moderate | Feature within the FHB |
| 1 - Low | N/A |

Photo: Post flood erosion along Highway 34 in the Big Thompson Canyon near Drake, CO.



# Susceptibility Analysis

This flow chart provides the high-level process followed by the planning team in evaluating the hazard data against each value-at-risk. The accompanying table provides attributes to be included in the susceptibly layer for each VAR.

## Modeling Results

Complete fluvial hazard analysis

Generate ASC and FHB for stream corridors

## Assess Susceptibility

Create a new asset susceptibility layer for reservoirs (Risk_Trans)[1]. This will be a data set trimmed to the FHB.

Intersect FHZ boundaries with flowlines and populate FHZ, and FHB in Risk_Trans layer

Score severity of risk based on scoring methodology. Populate FHZ_Sev

## Assess Impact

Score impact by multiplying FHZ_Sev against transportation feature type as follows:

highway (10)

major roads (7)

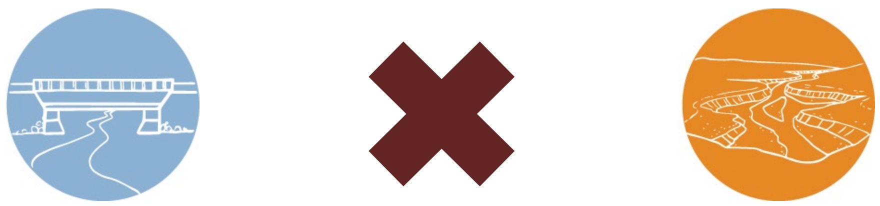
Railway (7)

local roads (4)

other (1)

Generate score of 1-100. Populate FHZ_Impact.

[1]Ideally there will be one susceptibility data set per major asset scoring all hazards as appropriate.



# Data Attributes

The following attributes will be populated in the Risk_Water_Rights susceptibility layer.

| Attribute | Description | Type |
|---|---|---|
| FHZ | Intersection confirmation of asset that is within any a given FHZ boundary, i.e. the ASC. Binary 1 (in) and 0 (out). | Double |
| FHB | Intersection confirmation of asset that is within any a given FHZ boundary, i.e. the FHB. Binary 1 (in) and 0 (out). | Double |
| FHZ_Sev | Severity score of 1 to 10 based location of asset within identified FHZs. | Integer |
| FHZ_Impact | Impact score from 1-100. | Integer |

# 6

# Life & Property: Structures & Critical Facilities (Buildings)

# Values-at-Risk Data Source

## Data Sources

Building footprint data comes from the national Microsoft **US Building Footprints** layer. This dataset contains 1computer generated building footprints derived using Microsoft's computer vision algorithms on satellite imagery. This data is freely available for download and use.

**Critical Facilities** data was collected from CDPHE. This data represents an aggregation of several data sets related to emergency and critical community facilities.  These data are provided a point file and are associated with addresses, so additional data processing was necessary to identify critical facilities in the building footprints data set.

## How Data Sets Can be Used for Susceptibility and Planning

The building outlines can be used for direct intersection analyses for hazards against values-at-risk. Footprints can be intersected with various hazards and hazard buffers.

# Values-at-Risk: Supporting Data Sources

| Layer | Description | Source | Publishing Agency |
|---|---|---|---|
| **Building Footprints (Feature Class: Polygons)** | This dataset contains 1computer generated building footprints derived using Microsoft's computer vision algorithms on satellite imagery. This data is freely available for download and use. | Data Link | Microsoft |
| **Critical Facilities (Feature Class: Points)** | This is an aggregation of several data sets including health facilities, emergency medical services, fire stations, and public schools. | Data Link | CDPHE |

Structures (Buildings)

# Susceptibility to Hazards

This susceptibility matrix provides an overview of impacts from the five post-fire hazards considered under Wildfire Ready Watersheds (WRW). The severity of impact is noted under each hazard. Further detail regarding impacts from each hazard against the value-at-risk is provided under each heading.

| Hydrologic Change | Flood After Fire | Debris Flow | Fluvial Hazard Zones | Sediment Delivery |
|---|---|---|---|---|
|  |  |  |  |  |
| **High** | **High** | **Exigent** | **High** | **Moderate** |
| Higher peak flows result in increased inundation areas and flooding. | Increased runoff potential increases flooding frequency, peak flows, and inundation depths/areas. Post-fire flooding can cause damage or complete structural failure/loss. | Debris flows can create dangerous landslides, mud flows, and bulked flood flows that can increase flood depths and create powerful forces that can damage/destroy buildings. | Fluvial hazard zones predict both the area a river has occupied or may occupy in the future. VARs within this zone are subject to erosion, avulsions, flooding, and deposition that can damage and destroy structures. | Aggradation or erosion can impact homes, limiting conveyance capacity due to aggradation and increasing flood risk and/or due to erosion, shifting flood risk horizontally through a stream reach. |
| **No Intersection** | **Intersection** | **Intersection** | **Intersection** | **No Intersection** |

# Susceptibility to Hazards

This susceptibility matrix provides an overview of impacts from the five post-fire hazards considered under Wildfire Ready Watersheds (WRW). The severity of impact is noted under each hazard. Further detail regarding impacts from each hazard against the value-at-risk is provided under each heading.

| Hydrologic Change | Flood After Fire | Debris Flow | Fluvial Hazard Zones | Sediment Delivery |
|---|---|---|---|---|
|  |  |  |  |  |
| **High** | **Exigent** | **Exigent** | **Exigent** | **Moderate** |
| Higher peak flows result in increased inundation areas and flooding. | Increased runoff potential increases flooding frequency, peak flows, and inundation depths/areas. Where flooding intersects can cause damage or complete structural failure/loss. For CF's, this may disrupt emergency services and support. | Debris flows can create dangerous landslides, mud flows, and bulked flood flows that can increase flood depths and create powerful forces that can damage/destroy buildings. For CF's, this may disrupt emergency services and support. | Fluvial hazard zones predict both the area a river has occupied or may occupy in the future. VARs within this zone are subject to erosion, avulsions, flooding, and deposition that can damage and destroy structures. This can disrupt emergency services and support. | Aggradation or erosion can impact homes, limiting conveyance capacity due to aggradation and increasing flood risk and/or due to erosion, shifting flood risk horizontally through a stream reach. |
| **No Intersection** | **Intersection** | **Intersection** | **Intersection** | **No Intersection** |

# Susceptibility Scoring Methodology

Using the flood inundation layers created through the post-fire hydraulic analysis:

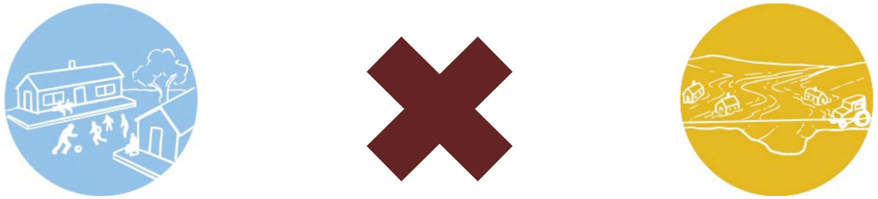
1. Intersect structures/buildings with the post-fire inundation areas generated based on post-fire hydrologic conditions.

2. Score severity of susceptibility based on the following

| Severity | Metric(s) |
|---|---|
| 10 - Severe | Structure within the 2-year post-fire floodplain |
| 7 - High | Structure within the 5-year post-fire floodplain |
| 4 - Moderate | Structure within the 10-year post-fire floodplain |
| 1 - Low | Structure within the 25-year post-fire floodplain |



Photo: Structure damaged by 2013 flooding along the Saint Vrain River near Lyons, CO.



# Susceptibility Analysis

This flow chart provides the high-level process followed by the planning team in evaluating the hazard data against each value-at-risk. The accompanying table provides attributes to be included in the susceptibly layer for each VAR.

## Modeling Results

- Complete pre- and post-fire hydraulic modeling
- Generate flood boundaries for 2-, 5-, 10-, and 25-year AEP post-fire events

## Assess Susceptibility

- Create a new asset susceptibility layer for building features (Risk_Structures and Risk_CF). This will be a data set based on intersections with the 25-year event.
- Intersect flood boundaries with flowlines and populate D_2, D_5, D_10, D_25 in Risk_Stuctures and Risk_CF layers
- Score severity of risk based on scoring methodology. Populate Flood_Sev

## Assess Impact

- Score impact by multiplying Flood_Sev with against Impact type (7 – High for buildings and 10 – Exigent for critical facilities) to generate score of 1-100. Populate Flood_Impact.

# Data Attributes

The following attributes will be populated in the Risk_Structures and Risk_CF susceptibility layers.

| Attribute | Description | Type |
|---|---|---|
| D_2 | Maximum depth against building during 2-year flood event. | Double |
| D_5 | Maximum depth against building during 5-year flood event. | Double |
| D_10 | Maximum depth against building during 10-year flood event. | Double |
| D_25 | Maximum depth against building during 25-year flood event. | Double |
| Flood_Sev | Severity score of 1 to 10 based location of asset within identified floodplains. | Integer |
| FHZ_Impact | Impact score from 1-100 based on | Integer |

# Susceptibility Scoring Methodology

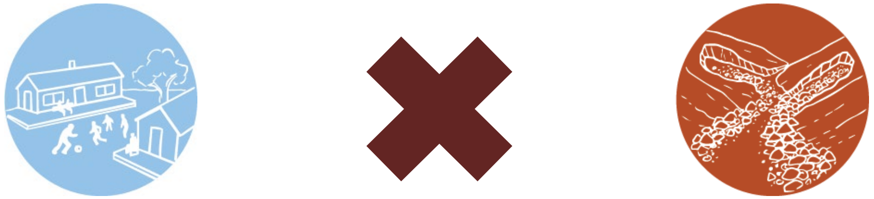
Using debris flow watersheds with PostFire Debris Flow (PFDF) estimates and extrapolated stream corridor lines (and buffers) indicating PFDF:

1. Run GIS intersection per susceptibility analysis procedure and/or populate GIS attributes.

2. Score severity of susceptibility based on the following:

| Severity | Metric(s) |
|---|---|
| 10 - Severe | Probability PFDF > 80% with VARs within a 250 foot corridor from the drainage flowline |
| 7 - High | Probability PFDF > 60% with VARs within a 500 foot corridor from the drainage flowlin |
| 4 - Moderate | Probability 60%> PFDF > 40% of debris flow with VARs within a 500 foot corridor from the drainage flowline |
| 1 - Low | Probability 40%> PFDF > 20% of debris flow with VARs within a 500 foot corridor from the drainage flowline |


Photo: Post-fire debris flow at Black Hollow following the Cameron Peak Fire (Jagt).



# Susceptibility Analysis

This flow chart provides the high-level process followed by the planning team in evaluating the hazard data against each value-at-risk. The accompanying table provides attributes to be included in the susceptibly layer for each VAR.

**Modeling Results**

- Complete debris flow probability modeling
- Generate streamline with PFDF probability and associated buffers.

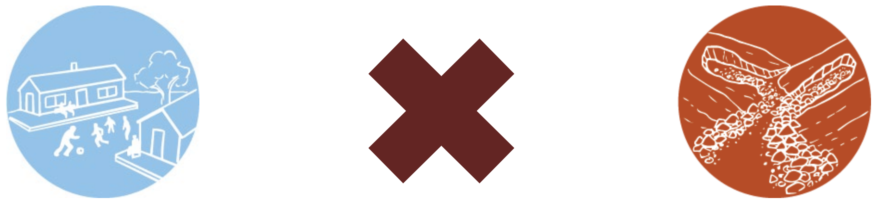
**Assess Susceptibility**

- Create a new asset susceptibility layer for buildings (Risk_Structures and Risk_CF)[1]
- Intersect buffers with VARS. Populate DF_Prob_250 and DF_Prob_500 in Risk_Structures and Risk_CF layers
- Score severity of risk based on scoring methodology. Populate DF_Sev

**Assess Impact**

- Score impact by multiplying DF_Sev against Impact type (10 – exigent for buildings and 10-exigent for critical facilities) to generate score of 1-100. Populate DF_Impact.

[1]Ideally there will be one susceptibility data set per major asset scoring all hazards as appropriate.



# Data Attributes

The following attributes will be populated in the Risk_Xings and Risk_CF susceptibility layers.

| Attribute | Description | Type |
|---|---|---|
| DF_Prob_250 | PFDF probability for VAR within 250 feet of stream flowline. | Double |
| DF_Prob_500 | PFDF probability for VAR within 500 feet of stream flowline. | Double |
| DF_Sev | Severity score of 1 to 10 based on PFDF. | Double |
| DF_Impact | Impact score from 1-100. | Integer |

# Susceptibility Scoring Methodology

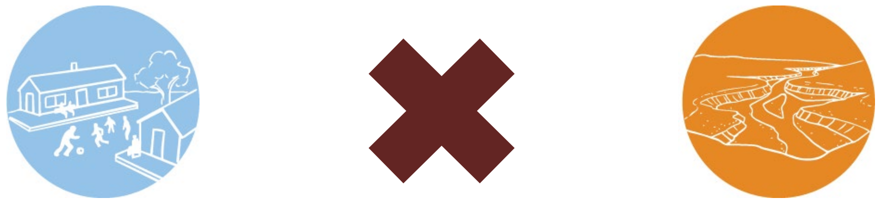
Using FHZ/ASC boundary and FHB (buffer) boundary:

1. Create an intersection layer of buildings/structures within the FHZ boundary/ASC (Active Stream Corridor) and a fluvial hazard buffer (FHB).

2. Score severity of susceptibility based on the following:

| Severity | Metric(s) |
|---|---|
| 10 - Severe | Feature within the ASC |
| 7 - High | Feature within the FHB |
| 4 - Moderate | N/A |
| 1 - Low | N/A |

Photo: Post flood erosion caused by 2013 flood in Estes Park, CO.



# Susceptibility Analysis

This flow chart provides the high-level process followed by the planning team in evaluating the hazard data against each value-at-risk. The accompanying table provides attributes to be included in the susceptibly layer for each VAR.

## Modeling Results

**Complete fluvial hazard analysis**

**Generate ASC and FHB for stream corridors**

## Assess Susceptibility

**Create a new asset susceptibility layer for reservoirs (Risk_Structures and Risk_CF)[1].**

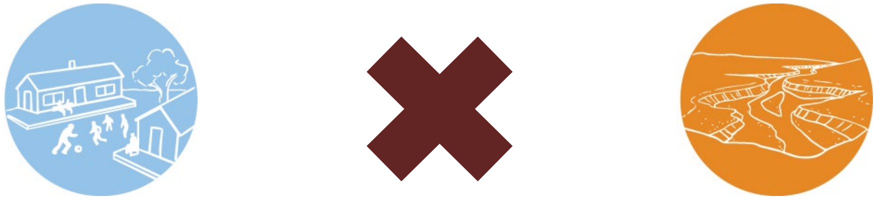
**Intersect FHZ boundaries with structures and populate FHZ, and FHB in Risk_Structures and Risk_CF layers**

**Score severity of risk based on scoring methodology. Populate FHZ_Sev**

## Assess Impact

**Score impact by multiplying FHZ_Sev Impact type (7 – High for buildings or 10- Exigent for critical facilities) to generate score of 1-100. Populate FHZ_Impact.**

[1]Ideally there will be one susceptibility data set per major asset scoring all hazards as appropriate.



# Data Attributes

The following attributes will be populated in the Risk_Structures and Risk_CF susceptibility layers.

| Attribute | Description | Type |
| --- | --- | --- |
| FHZ | Intersection confirmation of asset that is within any a given FHZ boundary, i.e. the ASC. Binary 1 (in) and 0 (out). | Integer |
| FHB | Intersection confirmation of asset that is within any a given FHZ boundary, i.e. the FHB. Binary 1 (in) and 0 (out). | Integer |
| FHZ_Sev | Severity score of 1 to 10 based location of asset within identified FHZs. | Integer |
| FHZ_Impact | Impact score from 1-100 based on | Integer |

# 7

# Sourcewater:
# Municipal Intakes

# Values-at-Risk Data Source

## Data Sources

**Public Water System** (intakes) are represented by data provided by CDPHE under their Sourcewater Protection Program.

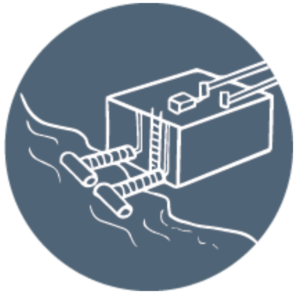
## How Data Sets Can be Used for Susceptibility and Planning

The points can be used for direct intersection analyses to understand impacts from post-fire hazards and how they might affect operations or facility function.

# Values-at-Risk: Supporting Data Sources

| Layer | Description | Source | Publishing Agency |
|---|---|---|---|
| **Municipal Water Intakes (Feature Class: Points)** | Sourcewater Protection (SWAP) data from the CDPHE | Data Link | CDPHE |

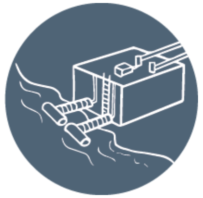
## Municipal Water



# Susceptibility to Hazards

This susceptibility matrix provides an overview of impacts from the five post-fire hazards considered under Wildfire Ready Watersheds (WRW). The severity of impact is noted under each hazard. Further detail regarding impacts from each hazard against the value-at-risk is provided under each heading.

| Hydrologic Change | Flood After Fire | Debris Flow | Fluvial Hazard Zones | Sediment Delivery |
|---|---|---|---|---|
|  |  |  |  |  |
| **Moderate** | **High** | **Exigent** | **Exigent** | **Moderate** |
| Increased peaks and volumes may impact function of existing water resources infrastructure. | Floods that inundate intake structures may cause damage via erosion, debris impacts, or destabilize foundations or embankments. | Debris flow damaging intakes and/or burying facilities. Because intakes are such a significant resource for local agencies, the number of intakes is not taken into consideration for severity, just whether an intake exists within a hazard zone. | Erosion from avulsions or bank erosion impacting municipal infrastructure. Because intakes are such a significant resource for local agencies, the number of intakes is not taken into consideration for severity, just whether an intake exists within a hazard zone. | Delivery of sediment to intakes can impact facility function and require significant maintenance and/or can affect ability to use diversion, i.e. sediment impacts water delivery. |
| **No Intersection** | **No Intersection** | **Intersection** | **Intersection** | **Intersection** |



## Municipal Water x Debris Flow

# Susceptibility Scoring Methodology

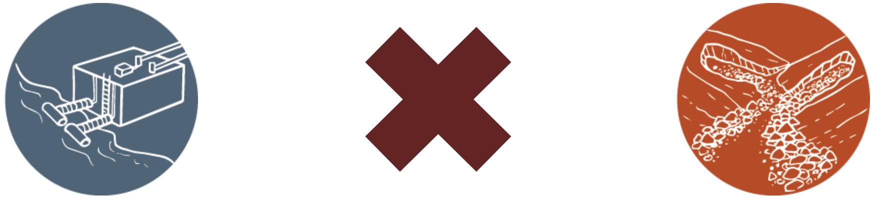
Using debris flow watersheds with PostFire Debris Flow (PFDF) estimates and extrapolated stream corridor lines (and buffers) indicating PFDF:

1. Run GIS intersection per susceptibility analysis procedure and/or populate GIS attributes.

2. Score severity of susceptibility based on the following:

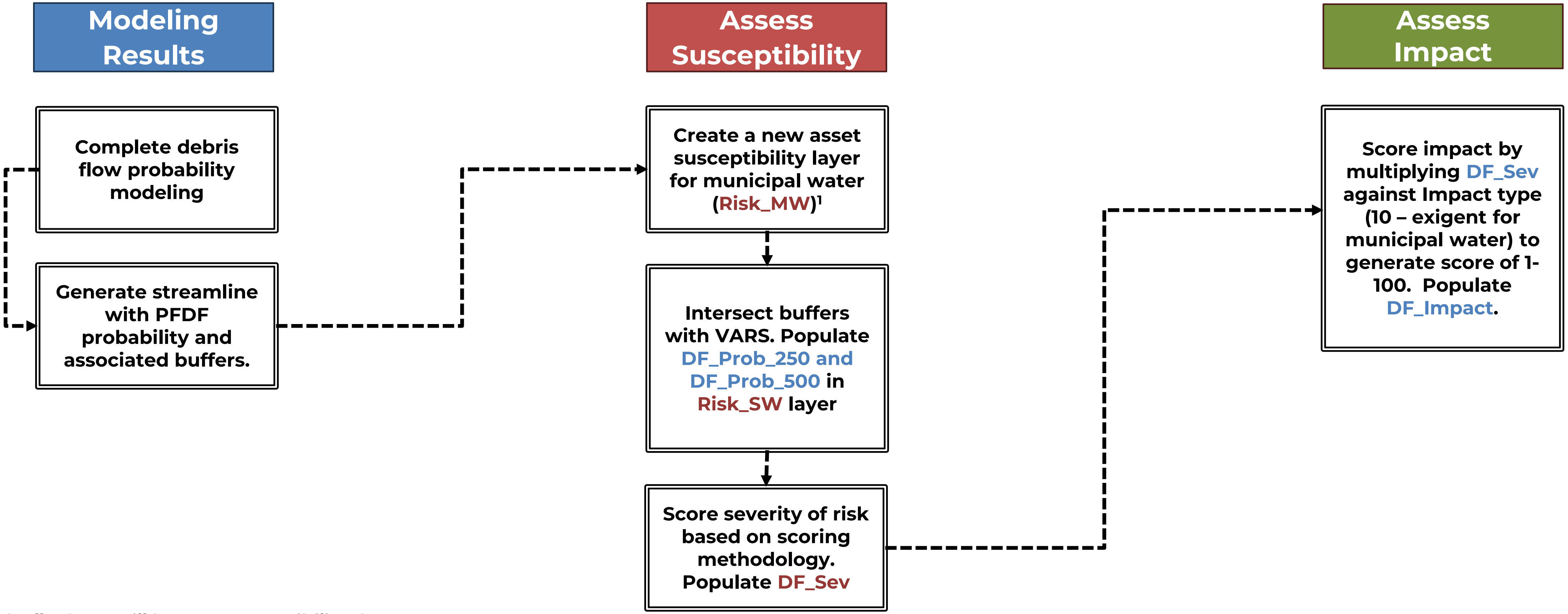
| Severity | Metric(s) |
|---|---|
| 10 - Severe | Probability > 80% of debris flow with VARs within a 250 foot corridor from the drainage flowline |
| 7 - High | High: Probability PFDF > 60% of debris flow with VARs within a 500 foot corridor from the drainage flowline |
| 4 - Moderate | Probability 60% > PFDF > 40% of debris flow with VARs within a 500 foot corridor from the drainage flowline |
| 1 - Low | Probability 40% > PFDF > 20% of debris flow with VARs within a 500 foot corridor from the drainage flowline |

Photo:

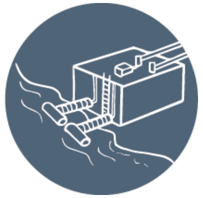


# Susceptibility Analysis

This flow chart provides the high-level process followed by the planning team in evaluating the hazard data against each value-at-risk.




[1]Ideally there will be one susceptibility data set per major asset scoring all hazards as appropriate.



# Data Attributes

The following attributes will be populated in the Risk_SW susceptibility layer.

| Attribute | Description | Type |
|---|---|---|
| **DF_Prob_250** | PFDF probability for VAR within 250 feet of stream flowline. | Double |
| **DF_Prob_500** | PFDF probability for VAR within 500 feet of stream flowline. | Double |
| **DF_Sev** | Severity score of 1 to 10 based on PFDF. | Double |
| **DF_Impact** | Impact score from 1-100. | Integer |

# Susceptibility Scoring Methodology

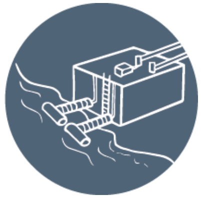
Using FHZ/ASC boundary and FHB (buffer) boundary:

1. Create an intersection layer of intake structures within the FHZ boundary/ASC (Active Stream Corridor) and a predefined buffer.

2. Score severity of susceptibility based on the following:

| Severity | Metric(s) |
|---|---|
| 10 - Severe | Feature within the ASC |
| 7 - High | Feature within the FHB |
| 4 - Moderate | N/A |
| 1 - Low | N/A |

Photo: Erosion along the Big Thompson River in Larimer County, CO.



# Susceptibility Analysis

This flow chart provides the high-level process followed by the planning team in evaluating the hazard data against each value-at-risk. The accompanying table provides attributes to be included in the susceptibly layer for each VAR.

## Modeling Results

**Complete fluvial hazard analysis**

**Generate ASC and FHB for stream corridors**

## Assess Susceptibility

**Create a new asset susceptibility layer for municipal water (Risk_SW)[1]. This will be a data set trimmed to the FHB.**

**Intersect FHZ boundaries with flowlines and populate FHZ, and FHB in Risk_SW layer**

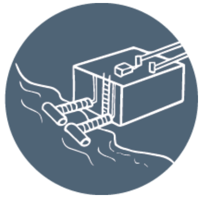
**Score severity of risk based on scoring methodology. Populate FHZ_Sev**

## Assess Impact

**Score impact by multiplying FHZ_Sev against Impact type (10 – exigent for municipal water) to generate score of 1-100. Populate FHZ_Impact.**

[1]Ideally there will be one susceptibility data set per major asset scoring all hazards as appropriate.

Municiap Water x Fluvial Hazard Zone



# Data Attributes

The following attributes will be populated in the Risk_Structures and Risk_CF susceptibility layers.

| Attribute | Description | Type |
|---|---|---|
| FHZ | Intersection confirmation of asset that is within any a given FHZ boundary, i.e. the ASC. Binary 1 (in) and 0 (out). | Integer |
| FHB | Intersection confirmation of asset that is within any a given FHZ boundary, i.e. the FHB. Binary 1 (in) and 0 (out). | Integer |
| FHZ_Sev | Severity score of 1 to 10 based location of asset within identified FHZs. | Integer |
| FHZ_Impact | Impact score from 1-100 based on | Integer |

Municipal Water x Sediment Yield

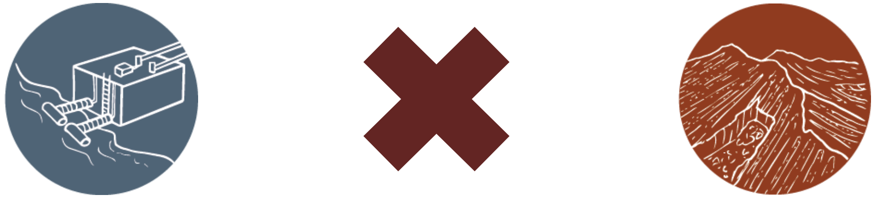
Photo: Post-fire hillslope condition following Calwood fire in Boulder County, CO (Jagt).

# Susceptibility Scoring Methodology

Using the sediment yield (SY) values generated in HEC-HMS for the 10-year AEP, create a line layer incorporating the ratio of post vs pre fire sediment yield.

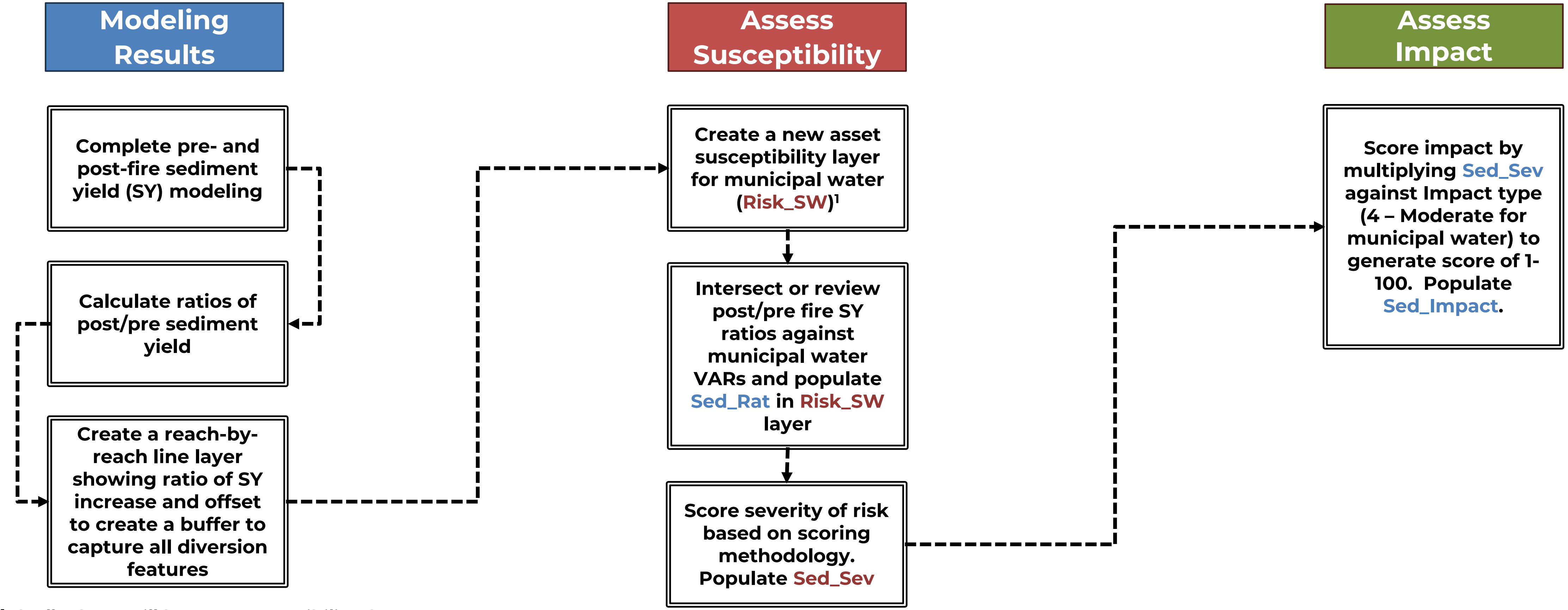
1. Create a buffer of 250 - 500 feet to capture all intake structures within major stream corridors.
2. Run GIS intersection per susceptibility analysis an/or populate GIS attributes.
3. Score severity of susceptibility based on the following:

| Severity | Metric(s) |
|---|---|
| 10 - Severe | Sediment yield post/pre > 10x for 10-year post-fire event |
| 7 - High | Sediment yield post/pre 10x > SY > 5x for 10-year post-fire event |
| 4 - Moderate | Sediment yield post/pre 5X < SY < 2x for 10-year post-fire event |
| 1 - Low | Sediment yield post/pre < 2x for 10-year post-fire event |

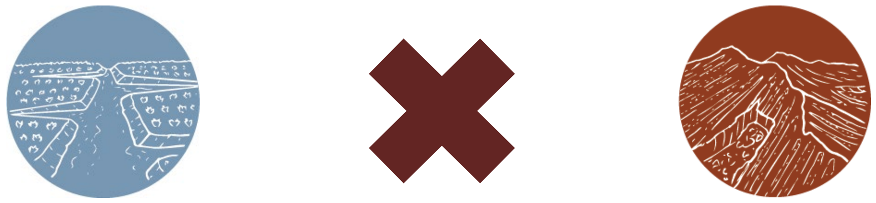


# Susceptibility Analysis

This flow chart provides the high-level process followed by the planning team in evaluating the hazard data against each value-at-risk. The accompanying table provides attributes to be included in the susceptibly layer for each VAR.




[1]Ideally there will be one susceptibility data set per major asset scoring all hazards as appropriate.



# Data Attributes

The following attributes will be populated in the Risk_SW susceptibility layer.

| Attribute | Description | Type |
|---|---|---|
| **Sed_Rat** | Ratio of post- to pre-fire conditions peak flows for 10-year AEP | Double |
| **Sed_Sev** | Severity score of 1 to 10 based on post- to pre- fire ratios. | Integer |
| **Sed_Impact** | Impact score from 1-100. | Integer |

# 8

# Ecology:
# Aquatic Resources

## Aquatic Resources

# Values-at-Risk Data Source

### Data Sources

The **Aquatic Resources** layer was developed by the Colorado Department of Wildlife. The data covers five different categories of aquatic resources as follows:

1. Sportfish Management Waters

2. Native Species Conservation Waters

3. Gold Medal Waters

4. Cutthroat Trout Designated Conservation Habitat

These data are provided as polygons that are buffers on stream corridors of interest.

### How Data Sets Can be Used for Susceptibility and Planning

The polygons can be used to identify potential direct impacts from post-fire hazards.

# Values-at-Risk: Supporting Data Sources

| Layer | Description | Source | Publishing Agency |
|---|---|---|---|
| Sportfish Management Waters<br><br>(Feature Class: Polygons) | CPW Sportfish Management Waters are polygons based on a 500m buffer from applicable water features | Data Link | CPW |
| Native Species Conservation Waters<br><br>(Feature Class: Polygons) | CPW Native Species Conservation Waters are polygons based on a 500m buffer from applicable water features | Data Link | CPW |
| Gold Medal Waters<br><br>(Feature Class: Polygons) | CPW Gold Medal Waters are polygons based on a 500m buffer from applicable water features | Data Link | CPW |
| Cutthroat Trout Designated Conservation Habitat<br><br>(Feature Class: Polygons) | CPW Cutthroat Trout Designated Conservation Habitat are polygons based on a 500m buffer from applicable water features | Data Link | CPW |

# Susceptibility to Hazards

This susceptibility matrix provides an overview of impacts from the five post-fire hazards considered under Wildfire Ready Watersheds (WRW). The severity of impact is noted under each hazard. Further detail regarding impacts from each hazard against the value-at-risk is provided under each heading.





| Hydrologic Change | Flood After Fire | Debris Flow | Fluvial Hazard Zones | Sediment Delivery |
|---|---|---|---|---|
| **Moderate** | **High** | **High** | **Moderate** | **Moderate** |
| Changes in hydrology resulting from fire may affect flow regimes and temporarily impact wildlife habitat and ecology | Increased flooding may result in damage from erosion or stream change. | Debris flows can dramatically impact natural areas creating system instability for short or long periods of time. | FHZs are natural processes, but can be exacerbated due to post-fire system changes including sediment delivery and increases in stream flows. For aquatic systems, this may mean that systems become highly geomorphically dynamic, creating temporay impacts to ecology. | Sediment deposition can impact stream system function and ecology. Although tempororary, post-fire sedimentation can take years to return to pre-fire conditions. |
| **No Intersection** | **No Intersection** | **Intersection** | **Intersection** | **Intersection** |

# Susceptibility Scoring Methodology

Using debris flow watersheds with PostFire Debris Flow (PFDF) estimates and extrapolated stream corridor lines (and buffers) indicating PFDF:

1. Run GIS intersection per susceptibility analysis procedure and/or populate GIS attributes.
2. Score severity of susceptibility based on the following:

| Severity | Metric(s) |
|---|---|
| 10 - Severe | Probability > 80% of debris flow |
| 7 - High | Probability 80%> PFDF > 60% of debris flow |
| 4 - Moderate | Probability 60%> PFDF > 40% of debris flow |
| 1 - Low | Probability 40%> PFDF > 20% of debris flow |

Photo: Riparian corridor within the Cameron Peak burn area in Larimer County, CO (Sturm).

# Susceptibility Analysis

This flow chart provides the high-level process followed by the planning team in evaluating the hazard data against each value-at-risk. The accompanying table provides attributes to be included in the susceptibly layer for each VAR.

## Modeling Results

Complete debris flow probability modeling

Generate streamline with PFDF probability and associated buffer to capture in-stream polygons (use 500 feet as starting point.

## Assess Susceptibility

Create a new asset susceptibility layer for aquatic resources (Risk_Aqua)[1]

Intersect buffers with VARS. Populate DF_Prob in Risk_Aqua layer

Score severity of risk based on scoring methodology. Populate DF_Sev

## Assess Impact

Score impact by multiplying DF_Sev against Impact type (7 – High for aquatic resources) to generate score of 1-100. Populate DF_Impact.

[1]Ideally there will be one susceptibility data set per major asset scoring all hazards as appropriate.

# Data Attributes

The following attributes will be populated in the Risk_Aqua susceptibility layer.

| Attribute | Description | Type |
| --- | --- | --- |
| **DF_Prob_250** | PFDF probability for area with VAR. | Double |
| **DF_Sev** | Severity score of 1 to 10 based on PFDF. | Double |
| **DF_Impact** | Impact score from 1-100. | Integer |

# Susceptibility Scoring Methodology

Using FHZ/ASC boundary and FHB (buffer) boundary:

1. Create an intersection layer of aquatic resources within the FHZ boundary/ASC (Active Stream Corridor).

2. Score severity of susceptibility based on the following:

| Severity | Metric(s) |
|---|---|
| 10 - Severe | N/A |
| 7 - High | Feature within the ASC |
| 4 - Moderate | N/A |
| 1 - Low | N/A |

Photo: Debris flow path at Black Hollow following the Cameron Peak fire in Larimer County, CO.

# Susceptibility Analysis

This flow chart provides the high-level process followed by the planning team in evaluating the hazard data against each value-at-risk. The accompanying table provides attributes to be included in the susceptibly layer for each VAR.

## Modeling Results

**Complete fluvial hazard analysis**

**Generate ASC and FHB for stream corridors**

## Assess Susceptibility

**Create a new asset susceptibility layer for municipal water (Risk_Aqua)[1]. This will be a data set trimmed to the FHZ.**

**Intersect FHZ boundaries with aquatic resources and populate FHZ, in Risk_Aqua layer**

**Score severity of risk based on scoring methodology. Populate FHZ_Sev**

## Assess Impact

**Score impact by multiplying FHZ_Sev against Impact type (4 – Moderate for municipal water) to generate score of 1-100. Populate FHZ_Impact.**

[1]Ideally there will be one susceptibility data set per major asset scoring all hazards as appropriate.

# Data Attributes

The following attributes will be populated in the Risk_Aqua susceptibility layer.

| Attribute | Description | Type |
|---|---|---|
| FHZ | Intersection confirmation of asset that is within any a given FHZ boundary, i.e. the ASC. Binary 1 (in) and 0 (out). | Integer |
| FHZ_Sev | Severity score of 1 to 10 based location of asset within identified FHZs. | Integer |
| FHZ_Impact | Impact score from 1-100 based on | Integer |

Aquatic Resources x Sediment Yield

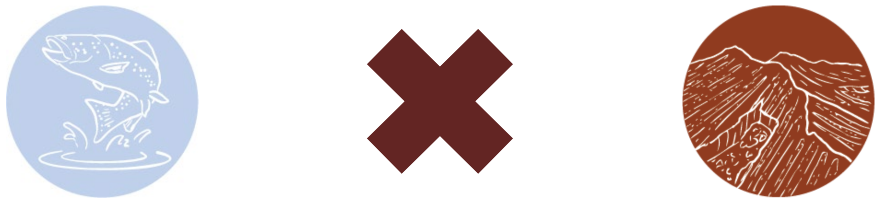
Photo: Gully erosion following a wildfire (WWE).

# Susceptibility Scoring Methodology

Using the sediment yield (SY) values generated in HEC-HMS for the 10-year AEP, create a line layer incorporating the ratio of post vs pre fire sediment yield.

1. Create a buffer of 250 - 500 feet to capture all aquatic resources within major stream corridors.
2. Run GIS intersection per susceptibility analysis an/or populate GIS attributes.
3. Score severity of susceptibility based on the following:

| Severity | Metric(s) |
|---|---|
| 10 - Severe | Sediment yield post/pre > 10x for 10-year post-fire event |
| 7 - High | Sediment yield post/pre 10x > SY > 5x for 10-year post-fire event |
| 4 - Moderate | Sediment yield post/pre 5X <  SY < 2x for 10-year post-fire event |
| 1 - Low | Sediment yield post/pre < 2x for 10-year post-fire event |



# Susceptibility Analysis

This flow chart provides the high-level process followed by the planning team in evaluating the hazard data against each value-at-risk. The accompanying table provides attributes to be included in the susceptibly layer for each VAR.

## Modeling Results

- Complete pre- and post-fire sediment yield (SY) modeling
- Calculate ratios of post/pre sediment yield
- Create a reach-by-reach line layer showing ratio of SY increase and offset to create a buffer to capture all aquatic resource features

## Assess Susceptibility

- Create a new asset susceptibility layer for municipal water (Risk_Aqua)[1]
- Intersect or review post/pre fire SY ratios against aqutic resources VARs and populate Sed_Rat in Risk_Aqua layer
- Score severity of risk based on scoring methodology. Populate Sed_Sev

## Assess Impact

- Score impact by multiplying Sed_Sev against Impact type (4 – Moderate for aquatic resources) to generate score of 1-100. Populate Sed_Impact.

[1]Ideally there will be one susceptibility data set per major asset scoring all hazards as appropriate.

# Data Attributes

The following attributes will be populated in the Risk_SW susceptibility layer.

| Attribute | Description | Type |
| --- | --- | --- |
| **Sed_Rat** | Ratio of post- to pre-fire conditions peak flows for 10-year AEP | Double |
| **Sed_Sev** | Severity score of 1 to 10 based on post- to pre- fire ratios. | Integer |
| **Sed_Impact** | Impact score from 1-100. | Integer |

9

# Power and Communications: Power Supply

# Values-at-Risk Data Source

## Data Sources

**Power Data** data was collected from Holy Cross Energy (HCE). This data represents power poles as a point layer.

**Communications** data was collected from Homeland Infrastructure. This data represents communication towers as a point layer.

## How Data Sets Can be Used for Susceptibility and Planning

The point layers can be used for direct intersection analyses for hazards against values-at-risk.

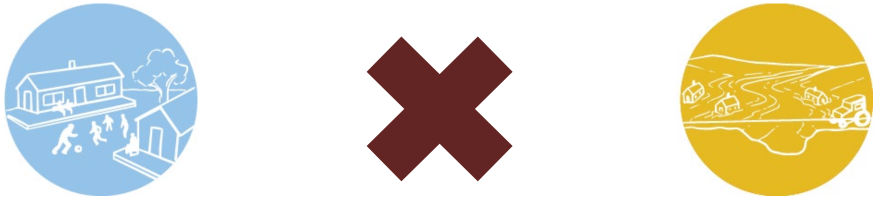
# Values-at-Risk: Supporting Data Sources

| Layer | Description | Source | Publishing Agency |
|---|---|---|---|
| **Power Points** (Feature Class: Points) | This dataset contains power poles owned by HCE represented as points. This data was provided by HCE for this project, and is not freely available. | N/A | HCE |
| **Power Comms** (Feature Class: Points) | This dataset contains points representing cell towers. This data is freely available for download and use. | Data Link | Homeland Infrastructure |

# Susceptibility to Hazards

This susceptibility matrix provides an overview of impacts from the five post-fire hazards considered under Wildfire Ready Watersheds (WRW). The severity of impact is noted under each hazard. Further detail regarding impacts from each hazard against the value-at-risk is provided under each heading.

| Hydrologic Change | Flood After Fire | Debris Flow | Fluvial Hazard Zones | Sediment Delivery |
|---|---|---|---|---|
|  |  |  |  |  |
| **High** | **Exigent** | **Exigent** | **Exigent** | **Moderate** |
| Higher peak flows result in increased inundation areas and flooding. | Increased runoff potential increases flooding frequency, peak flows, and inundation depths/areas. Where flooding intersects can cause damage or complete structural failure/loss. For CF's, this may disrupt emergency services and support. | Debris flows can create dangerous landslides, mud flows, and bulked flood flows that can increase flood depths and create powerful forces that can damage/destroy buildings. For CF's, this may disrupt emergency services and support. | Fluvial hazard zones predict both the area a river has occupied or may occupy in the future. VARs within this zone are subject to erosion, avulsions, flooding, and deposition that can damage and destroy structures. This can disrupt emergency services and support. | Aggradation or erosion can impact homes, limiting conveyance capacity due to aggradation and increasing flood risk and/or due to erosion, shifting flood risk horizontally through a stream reach. |
| **No Intersection** | **Intersection** | **Intersection** | **Intersection** | **No Intersection** |



# Susceptibility Scoring Methodology

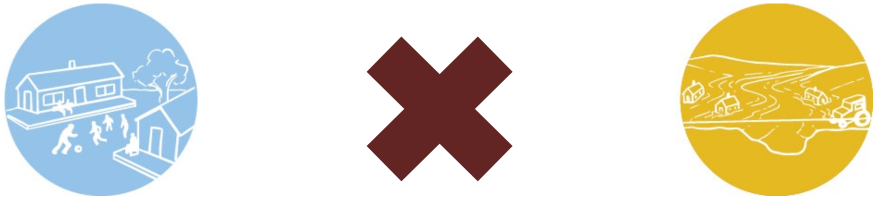
Using the flood inundation layers created through the post-fire hydraulic analysis:

1. Intersect structures/buildings with the post-fire inundation areas generated based on post-fire hydrologic conditions.
2. Score severity of susceptibility based on the following

| Severity | Metric(s) |
|---|---|
| 10 - Severe | Structure within the 2-year post-fire floodplain |
| 7 - High | Structure within the 5-year post-fire floodplain |
| 4 - Moderate | Structure within the 10-year post-fire floodplain |
| 1 - Low | Structure within the 25-year post-fire floodplain |

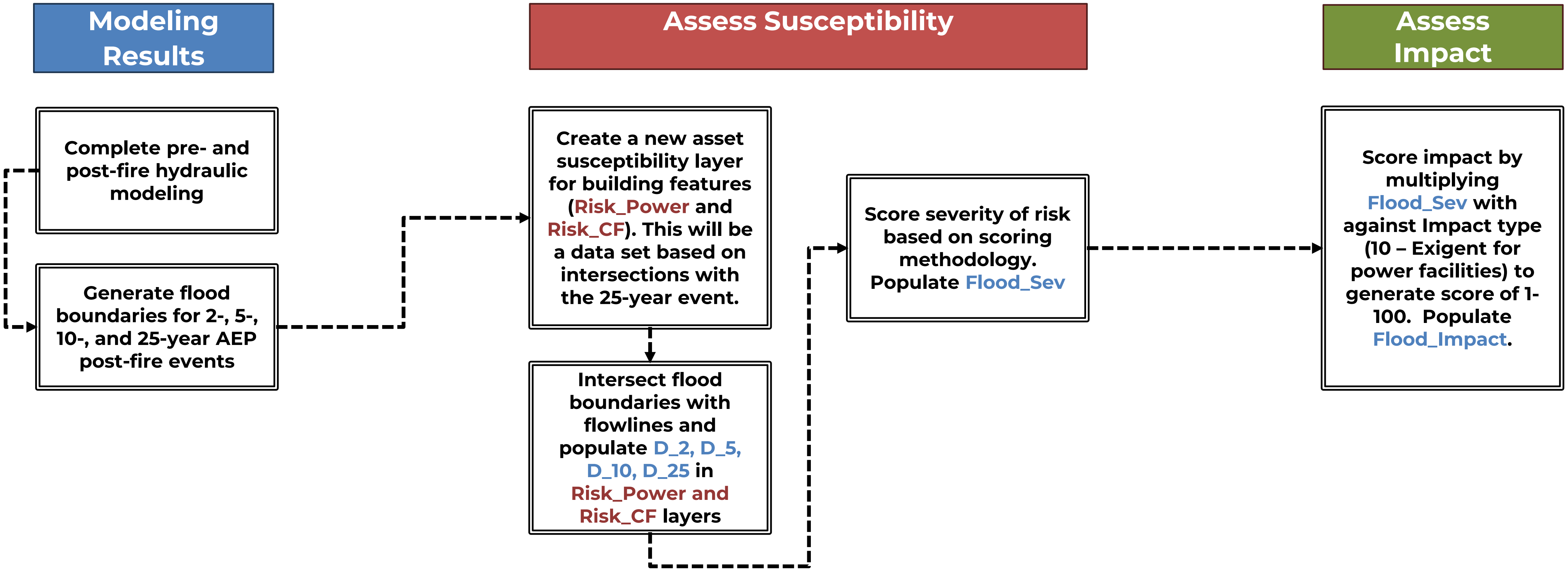


Photo: Power lines being repaired and relocated after 2013 flooding along Left Hand Creek.



# Susceptibility Analysis

This flow chart provides the high-level process followed by the planning team in evaluating the hazard data against each value-at-risk. The accompanying table provides attributes to be included in the susceptibly layer for each VAR.



# Data Attributes

The following attributes will be populated in the Risk_Structures and Risk_CF susceptibility layers.

| Attribute | Description | Type |
|---|---|---|
| D_2 | Maximum depth against building during 2-year flood event. | Double |
| D_5 | Maximum depth against building during 5-year flood event. | Double |
| D_10 | Maximum depth against building during 10-year flood event. | Double |
| D_25 | Maximum depth against building during 25-year flood event. | Double |
| Flood_Sev | Severity score of 1 to 10 based location of asset within identified floodplains. | Integer |
| FHZ_Impact | Impact score from 1-100 based on | Integer |

# Susceptibility Scoring Methodology

Using debris flow watersheds with PostFire Debris Flow (PFDF) estimates and extrapolated stream corridor lines (and buffers) indicating PFDF:

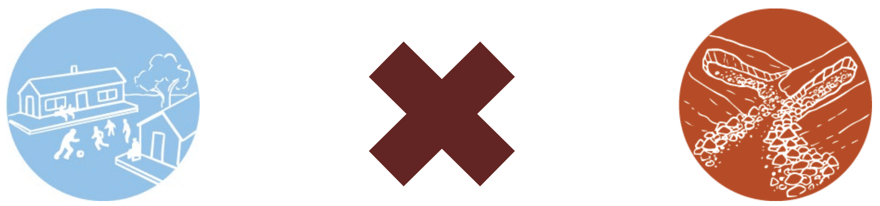
1. Run GIS intersection per susceptibility analysis procedure and/or populate GIS attributes.

2. Score severity of susceptibility based on the following:

| Severity | Metric(s) |
|---|---|
| 10 - Severe | Probability PFDF > 80% with VARs within a 250 foot corridor from the drainage flowline |
| 7 - High | Probability PFDF > 60% with VARs within a 500 foot corridor from the drainage flowlin |
| 4 - Moderate | Probability 60% > PFDF > 40% of debris flow with VARs within a 500 foot corridor from the drainage flowline |
| 1 - Low | Probability 40% > PFDF > 20% of debris flow with VARs within a 500 foot corridor from the drainage flowline |



Photo: Post-fire debris flow at Black Hollow following the Cameron Peak Fire (Jagt).



# Susceptibility Analysis

This flow chart provides the high-level process followed by the planning team in evaluating the hazard data against each value-at-risk. The accompanying table provides attributes to be included in the susceptibly layer for each VAR.

**Modeling Results**

- Complete debris flow probability modeling
- Generate streamline with PFDF probability and associated buffers.

**Assess Susceptibility**

- Create a new asset susceptibility layer for buildings (Risk_Power and Risk_CF)[1]
- Intersect buffers with VARS. Populate DF_Prob_250 and DF_Prob_500 in Risk_Power and Risk_CF layers
- Score severity of risk based on scoring methodology. Populate DF_Sev

**Assess Impact**

- Score impact by multiplying DF_Sev against Impact type (10 – exigent for power facilities) to generate score of 1-100. Populate DF_Impact.

[1]Ideally there will be one susceptibility data set per major asset scoring all hazards as appropriate.

# Data Attributes

The following attributes will be populated in the Risk_Xings and Risk_CF susceptibility layers.

| Attribute | Description | Type |
|---|---|---|
| DF_Prob_250 | PFDF probability for VAR within 250 feet of stream flowline. | Double |
| DF_Prob_500 | PFDF probability for VAR within 500 feet of stream flowline. | Double |
| DF_Sev | Severity score of 1 to 10 based on PFDF. | Double |
| DF_Impact | Impact score from 1-100. | Integer |

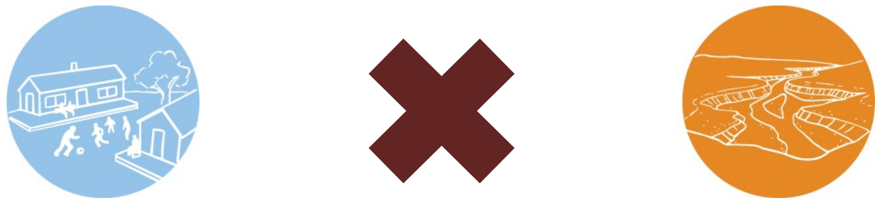
# Susceptibility Scoring Methodology

Using FHZ/ASC boundary and FHB (buffer) boundary:

1. Create an intersection layer of buildings/structures within the FHZ boundary/ASC (Active Stream Corridor) and a fluvial hazard buffer (FHB).

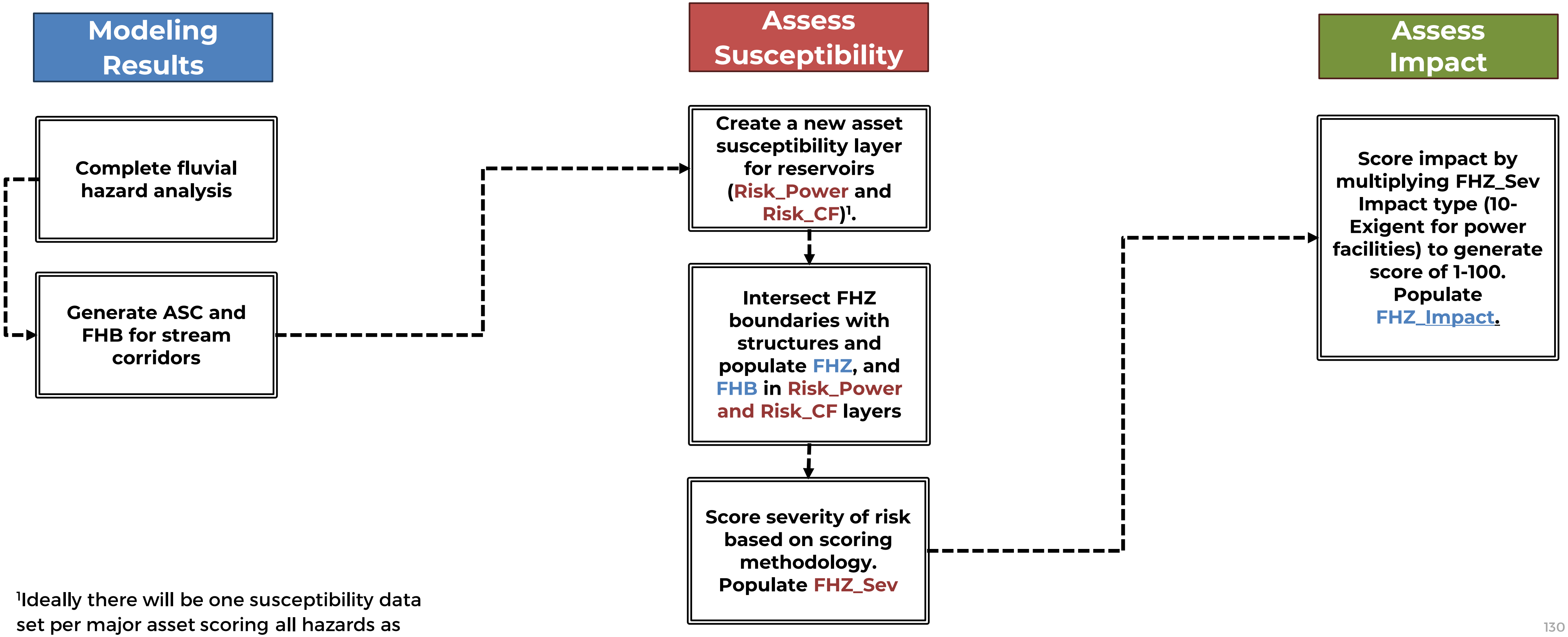
2. Score severity of susceptibility based on the following:

| Severity | Metric(s) |
|---|---|
| 10 - Severe | Feature within the ASC |
| 7 - High | Feature within the FHB |
| 4 - Moderate | N/A |
| 1 - Low | N/A |



# Susceptibility Analysis

This flow chart provides the high-level process followed by the planning team in evaluating the hazard data against each value-at-risk. The accompanying table provides attributes to be included in the susceptibly layer for each VAR.




[1]Ideally there will be one susceptibility data set per major asset scoring all hazards as appropriate.

# Data Attributes

The following attributes will be populated in the Risk_Structures and Risk_CF susceptibility layers.

| Attribute | Description | Type |
|---|---|---|
| **FHZ** | Intersection confirmation of asset that is within any a given FHZ boundary, i.e. the ASC. Binary 1 (in) and 0 (out). | Integer |
| **FHB** | Intersection confirmation of asset that is within any a given FHZ boundary, i.e. the FHB. Binary 1 (in) and 0 (out). | Integer |
| **FHZ_Sev** | Severity score of 1 to 10 based location of asset within identified FHZs. | Integer |
| **FHZ_Impact** | Impact score from 1-100 based on | Integer |

# 10

# Susceptibility: Results

# Susceptibility Analysis
# Gridded Risk Identification

## Susceptibility Analysis Scope of Work

Results from the susceptibility analysis are included within the Susceptiblity Geodatabase. Each VAR has a severity score (1-10) and an impact score (1-100). Linear features have been trimmed so as to represent the segment of the feature that is at risk from a particular hazard or group of hazards. Only VARs that have post-fire hazard risk are contained within the Susceptibility Geodatabase.

**Gridded Results**

**(Gridded Risk Identification Procedure - GRIP)**

For purposes of creating a "heat map" throughout each study watershed, the team developed a hexagonal grid for the purposes of binning (or grouping) impacted values. Hexagons were chosen instead of a square grid for several reasons as can be reviewed on this web article from ESRI (Why hexagons? ). The hexagons have lengths of 1000 feet on each edge with a total area of approximately 0.11 square miles.

VARs were binned and aggregated based on the hexagon footprint they occupied. For features that crossed polygon edges, those impact scores were applied to each polygon in which the feature resided. Impact scores were totaled for all VARS within each polygon. For example, if five VARs resided in a polygon with impact scores of 80, 75, 50, 65, and 90, the total impact score was calculated as 360.

Impact scores were developed for all hexagonal polygons within the watershed and then were categorized using a Geometric distribution into seven categories from

**Gridded Impact Data**

The hexagonal grid has separate impact scores for each major VAR, allowing users to look at the impact to each VARs class separately. There is also a total aggregated impact score for all VARs to understand areas of greatest susceptibility.

**Results**

Fully aggregated results are shown for each watershed on the slides that follow. Discussion regarding generalized and/or specific findings based on the analysis are provided when appropriate.

# Using Results for Planning

## Interpreting Results

The gridded impact results represents the starting point for understating watershed susceptibly to post-fire hazards. The grid itself is not the endpoint and only begins the process of understanding where hazards are having impact and to what values. Going deeper, the planning team needs to:

1. Evaluate underlying values-at-risk to understand the community impacts and how
2. Determine the most critical infrastructure or life and property risk to create some level of prioritization
3. Look at holistic watershed scale projects that can be used as part of a mosaic of mitigation strategies (pre-fire actions), and
4. Develop post-fire recovery actions to protect life and property at the pont-of-impact (post-fire actions)

Interpreting the results is a multi level process.

1. Start with the overall aggregated susceptibly and review the overall watershed risk with an eye towards upstream factors creating the hazard.
2. Review the gridded impact scores for each major VAR, noting specific areas of concern.
3. Review the underlying VARS and consider the following
   - The consequences that may occur due to adverse impacts from hazards with detail for each high value asset
   - Redundancy of systems or lack of redundancy (water supply, sewerage, transportation, emergency response systems)
   - Whether the value is easily repaired or replaced if damaged
   - If the post-fire hazard can be reasonably mitigated and a brief description of how,
   - Whether hazards may require closing of lands, and/or access via roads or bridges,
   - If emergency access or evacuation is will likely be prevented or will require extraordinary measures such as air support, and
   - Any other community specific details regarding the adverse impacts or consequences of post-fire hazards.

# Susceptibility Analysis Results

**Gridded Results (Total Aggregated Impact Scores)**

The Elk Creek Watershed is composed of six HUC-12 sub-watersheds. The most highly susceptible areas fall within the lower portions of the watershed near New Castle. These watersheds are more developed and have a great number of VARs. These are also areas where in-stream flows show the largest increase following a wildfire.

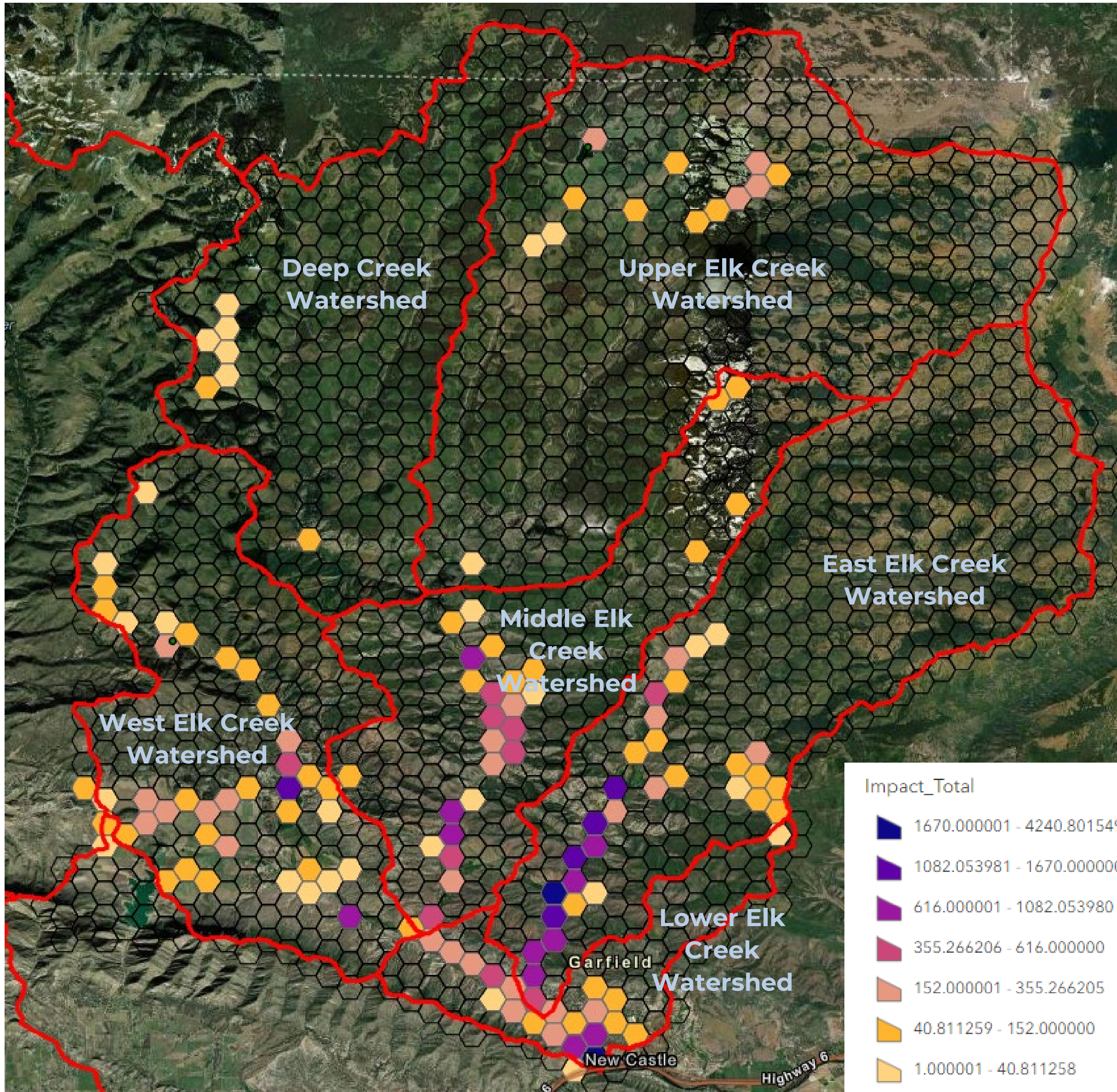
Total impact scores have been grouped following a geometrical break classification for purposes of determining areas of higher vs. lower risk. Any polygon with an impact score has identified values that are susceptible to post-fire hazards.

Highest risk watersheds include:

- Middle Elk Creek
- East Elk Creek
- Lower Elk Creek
- West Elk Creek

Although this is where the most impacts have been identified, impacts throughout the watershed should be reviewed and addressed based on stakeholder input and severity of risk to life and property.

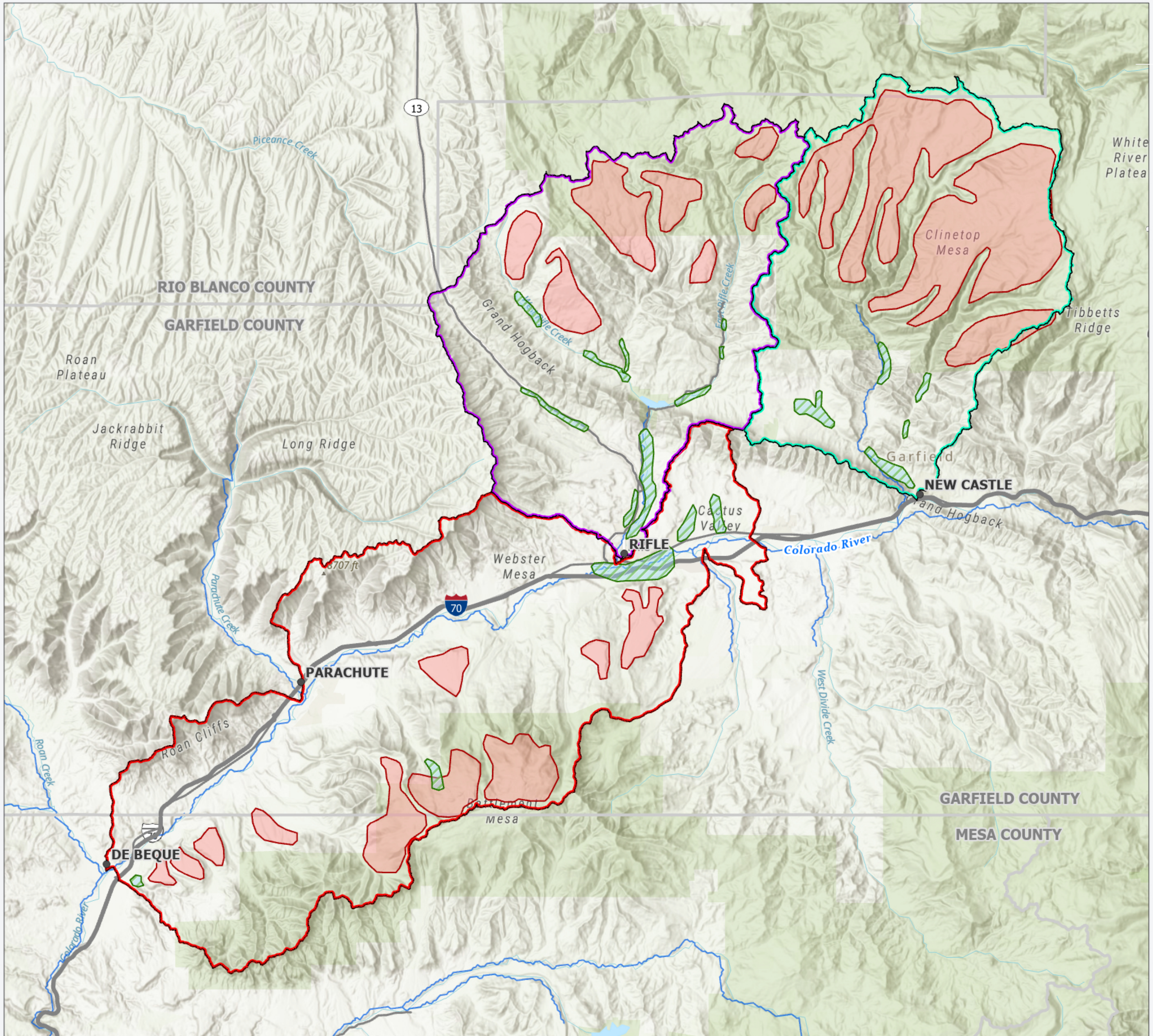
## Elk Creek Watershed



# Exhibit E – Identified Potential Mitigation Areas

# EXHIBIT E

## Identified Potential Mitigation Areas




## LEGEND

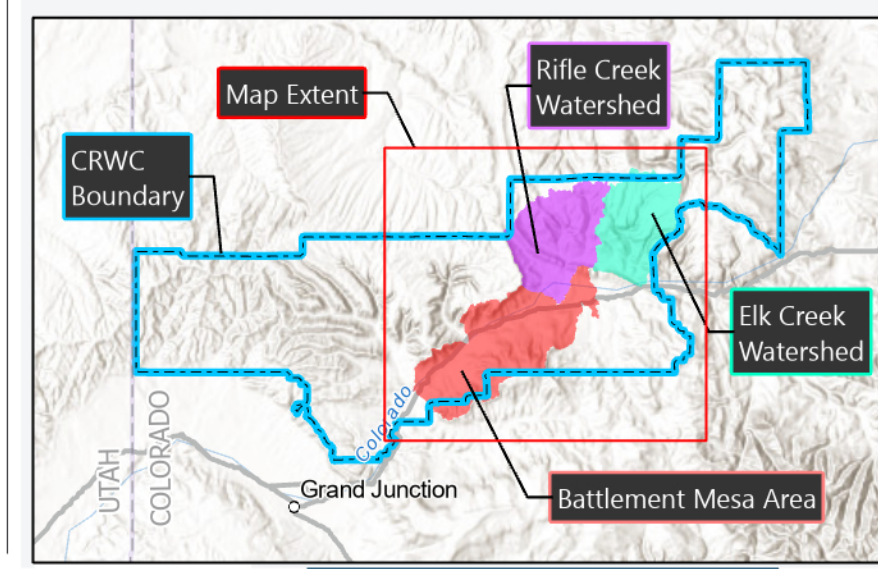
- County
- City
- I-70
- Highway
- River

**Study Area Watershed**

- Elk Creek Watershed
- Rifle Creek Watershed
- Battlement Mesa Area

**Potential Mitigation Project Areas**

- Potential Floodplain Mitigation Area
- Potential Burn Mitigation Area





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SCALE: 1 inch = 6 miles

The information displayed above is intended for general planning purposes. Refer to legal documentation/data sources for descriptions/locations.

# Exhibit F – Project Datasheets

# DEBRIS FLOWS AFTER A WILDFIRE

**WILDFIRE READY WATERSHEDS**
FACT SHEET

**Version 22.01 |** December, 2022

## OVERVIEW

This Wildfire Ready Watersheds (WRW) fact sheet provides guidance on post-fire mud and debris flow hazards. Communities and residents on or below hillsides -- especially in areas impacted by recent wildfires -- should be aware that rain events onto recently burned areas increases the possibility of potentially dangerous debris flows, a geologic hazard that is often identified as a "mudflow" or "mudslide" in the media. Debris flows can occur in watersheds ranging in size from several acres to multiple square miles. Large debris flows can transport boulders the size of cars and create deposits that bury houses. Even smaller debris flows can be dangerous on a local scale due to the high density of the soil, rock, and water mixture.

For more info on debris flows, check out the Colorado Geologic Survey's video here.

## HAZARD AND RISK CHARACTERIZATION

A "debris flow" is a flood of water that also contains soil, rock, organic (e.g., trees), and inorganic (e.g., building materials) materials that travel down a hillslope or channel under the influence of gravity. It is defined according to the quantity and character of sediment it contains, which constantly changes as sediment is picked up or dropped out as the debris flow travels down a drainage. Because of their high sediment concentrations and density, debris flows create large buoyant forces allowing them to pick up and carry large objects (e.g., trees and boulders) over long distances in ways that water alone typically cannot. This, and their ability to flow at speeds up to and exceeding 35 miles per hour (mph), can make debris flows an extremely destructive hazard. After a wildfire, debris flows become more likely as described below.


Debris Flows in Glenwood Canyon in 2021 after the Grizzly Creek fire. Credit: Colorado Department of Transportation.

### Hazard Overview and Causes

The tendency for a watershed to generate a debris flow is determined by numerous factors related to its physical characteristics and localized weather and rainfall. In general, steeper watersheds are more likely to generate debris flows than ones that are more mildly sloped. Smaller watersheds also pose a higher risk than larger watersheds because more of their drainage area is likely to be impacted by a high-intensity rainfall event.

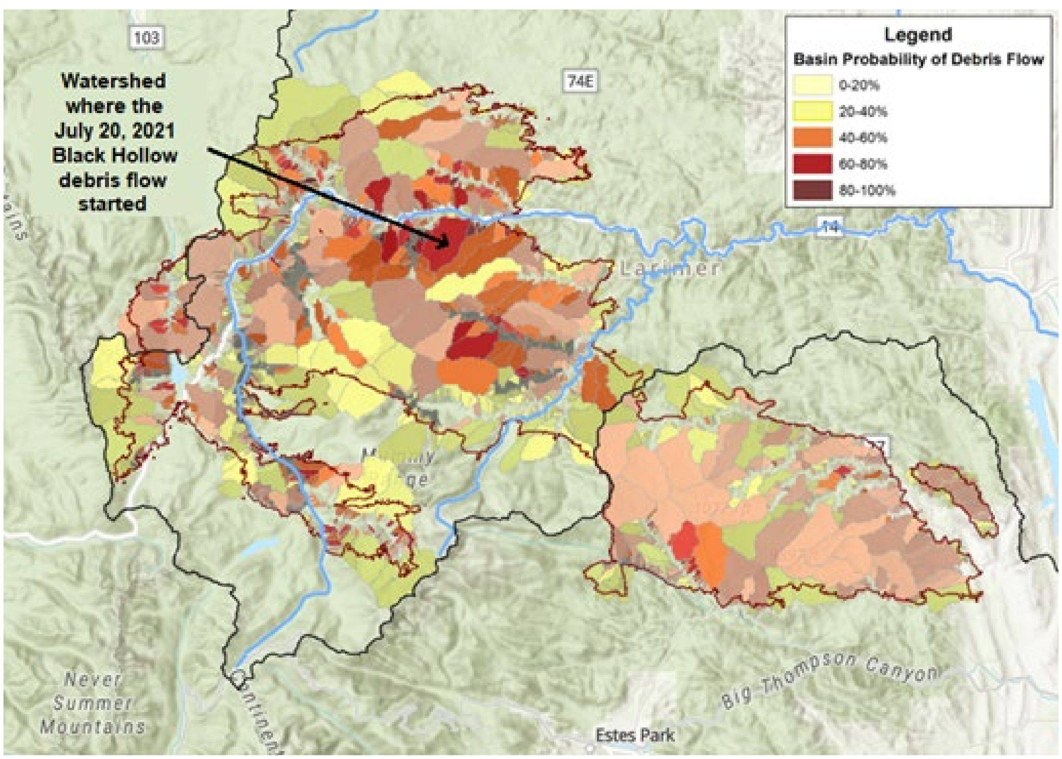
Wildfires increase debris flow risk by altering many factors related to rainfall runoff and erosion. For example, fire can remove trees, shrubs, and grasses; accumulated litter and duff on the ground surface; and organic material in the top layers of the soil. Because vegetation and litter tend to slow and store water during storm events and cause it to seep down into the ground, their loss can increase the rate and volume of water that runs off a hillslope. Fire can also change the physical and chemical composition of near-surface soils, which can reduce the amount of water that infiltrates into the ground during storm events or when snow melts. This, in turn, can increase the quantity and velocity of water that runs over the surface of the earth during storm events which leads to increased erosion. In addition, soil strength can diminish if soils are exposed to high enough temperatures for a long enough period during the fire event which can increase erosion potential.

## FACTORS THAT INCREASE THE LIKELIHOOD FOR DEBRIS FLOWS INCLUDE:

Factors that increase the likelihood for debris flows include:

- Recent wildfire occurrence
- High-intensity rainfall
- Reduced infiltration and increased surface runoff
- Weakened soil strength
- Steep hillslopes and small catchments
- Availability of materials to be entrained in the flow

The amount of rainfall needed to trigger a debris flow, also known as a “rainfall threshold,” is reduced following a wildfire. Before fire, higher




2020 Cameron Peak Fire showing USGS debris flow probability mapping and location of July 20, 2021, Black Hollow debris flow. Source: https://storymaps.arcgis.com/stories/66393e20dd674741b43d024a2f2d9188

DEBRIS FLOWS AFTER A WILDFIRE

volumes of water associated with more infrequent larger intensity or longer duration rainfall events are required to trigger a debris flow. After a fire, relatively smaller and more frequent rainfall events may be sufficient to cause the same amount of runoff and erosion.

Fire typically increases mud and debris flow risk for at least two to three years depending on the site-specific conditions that control vegetation recovery rates. As recovery progresses and vegetation approaches its pre-disturbance condition, the probability of a debris flow occurring reduces.

## Hazard Identification

There are two main approaches to modeling and mapping debris flow that can identify and predict these hazards:

1. Debris flow initiation and runout mapping (footprint of debris flow)
2. Debris flow probability (watershed-based)

Many types of models and methods can be used to accomplish these two approaches, and they can be accomplished under three scenarios: (1) in a predictive manner without assuming a wildfire has occurred, (2) in a predictive manner assuming a wildfire has occurred with maps of predicted burn severity, and (3) in a reactive manner after a wildfire has occurred with maps of actual burn severity.

The State of Colorado has created a post-fire debris flow hazard map for the WRW program that identifies the relative risk of debris flows occurring at the watershed scale (HUC-12), based on predicted burn severity, across all of Colorado. If property owners or natural resource managers have structural or non-structural critical assets, infrastructure, homes, utilities, or transportation networks within or below a drainage identified as having moderate to high potential debris flow risk, a more detailed assessment should be conducted if a fire occurs in the future.

Before or after a wildfire, statistical models developed by the United States Geological Survey (USGS) can be used to estimate debris flow probability and sediment volume based on the following variables: rainfall depth, watershed slope, observations or predictions of soil burn severity, and soil erodibility.

Because debris flows can have very high momentum, they pose risk to areas far downstream from where they initiate. It is important to recognize that WRW and USGS post-fire debris flow risk maps indicate the relative

## DEBRIS FLOW MAPS IN COLORADO

The Colorado Geological Survey (CGS) has mapped the footprints of areas susceptible to debris flows for some counties within the state. Contact CGS if your county is not yet mapped and there is a desire to do so. These debris flow hazard maps provide useful information regarding locations and the potential of debris flows but do not account for post-fire conditions.

Completed maps can be found here.


Example of Colorado Geological Survey's debris flow susceptibility maps.

probability of a drainage to generate a debris flow, not how far the debris flow is likely to travel (termed a "runout" or "deposition" zone). One way to determine if you are in a potential runout or deposition zone is to figure out where sediment was deposited historically, such as on a fan (see the Fans section). Pre-existing landforms can provide valuable insight into how natural processes have played out in the past. The Fluvial Hazard Zone mapping process is also a valuable tool to determine the areas that are likely to see sediment deposition downstream of debris flows.

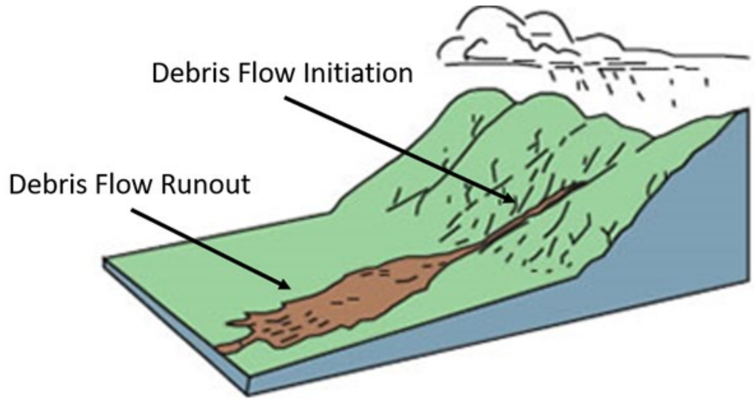



Figure adapted from the USGS.

## Fans

Fans are triangular- or cone-shaped deposits of sediment that typically form where drainages exit a steep and confined valley and enter a flatter and wider floodplain or valley bottom. Fans can be formed by a variety of processes including debris flows or mud flows-- described in this fact sheet-- rockfalls, or floods. Sometimes fans form instantaneously and sometimes they are built incrementally over time. Fans are landforms that are readily identifiable in the landscape and are hazardous places to build homes and infrastructure.

Fans are inherently hazardous because they are locations where sediment gathered from hillslope erosion, debris flows, or channel erosion falls out of the flowing water and deposits. This deposition itself is hazardous and it can cause the location of channels on fans to change their paths in unpredictable ways. In large debris flows, the entirety of a fan's surface can experience flooding and sediment and debris deposition.

While fans themselves are hazardous, they can also affect and influence other hazards. The input of sediment from fans into a river or stream can cause sediment accumulation and channel movement in the reaches downstream. With enough material, fans can push a channel into the opposing valley margin (lower photo) leading to erosion, hillslope failures,

Upper: Fan that is being replenished due to debris flows resulting from rain on the 2020 Cameron Peak Fire. Lower: Fan in Glenwood Canyon that formed as a result of rainfall on 2020 Grizzly Creek Fire burn scar. The new fan is pushing the Colorado River into the embankment of I-70 and backing up water which caused flooding and highway closures. Source: USFS or threats to infrastructure. Large fans can also cause constrictions in rivers which may lead to backed up water, flooding, and bed aggradation upstream (lower photo).

The existence of fans can be ephemeral, with fans either appearing in locations where they previously did not exist or disappearing when the receiving stream erodes the sediments and transports them downstream. This means that understanding not just the location of the existing fans, but also the locations where fans can be built, is important for hazard identification.

## Potential Impacts

Debris flows can severely impact structures, infrastructure, and the form and function of natural habitats in or downstream of a burned area. For example, impacts can include:

- **Loss of life:** Loss of life can occur where humans live or recreate in or downstream of locations that are susceptible to debris flows such as fans, which sometimes serve as sites for homes in confined valleys..
- **Property Damage:** Man-made structures located in or adjacent to debris flow generation or deposition zones are at risk of being damaged, buried, or transported by flowing water and debris.
- **Infrastructure Damage:** Debris flows can damage critical above- and below-ground civil infrastructure such as roads and culverts, bridges, power lines, and buried utility lines.
- **Water Supply Disruption:** Debris flows can damage water supply infrastructure such as ditches, pipes, and dams. For example, shallow wet utility lines can be damaged if they are not adequately protected from scour. This can interrupt service providers' abilities to deliver safe drinking water. Post-fire debris flows can also contribute to reservoir sedimentation which can diminish water supply reservoir capacity and create in-reservoir water quality impacts.
- **Water Quality Degradation**: Elevated turbidity and sediment load in raw water supplies can pose water treatment challenges requiring altered treatment processes. Anthropogenic pollutants that were present before the fire, or that were generated during the combustion process, can pose additional management challenges when they adsorb to and are subsequently transported downstream by the sediments suspended in a post-fire debris flow.
- **Aquatic Ecosystem Impacts:** Debris flows can impede natural vegetation growth and the survival of small aquatic organisms by increasing turbidity and suspended solids in streams and lakes. Elevated nitrate and organic carbon concentrations and warmer water temperatures have also been observed following wildfire, causing toxic algae blooms in downstream waterways that have been attributed to post-fire fish kills). In addition, elevated water velocities and sediment transport capacities can change the physical shape (geometry) and function of aquatic and riparian ecosystems.

## PRE-FIRE PREPAREDNESS

Debris flow risk can be minimized or prevented altogether with pre-fire planning and post-fire hazard mitigation and communication. The prior section discussed how debris flows risk may increase following a wildfire along with some guidance on how communities can identify where these hazards are likely to occur; the following section discusses land management strategies for reducing the chances of high severity disturbance and how to properly communicate potential post-fire geologic and hydrologic-based risks to agencies and stakeholders.

### Resource Management

Natural resource managers may consider the variety of land uses and any sensitive environmental habitats in their purview and make management decisions that protect those uses and ecosystems. A watershed's natural fire history regime can be used as a guide for management actions. For example, potential fuel sources can be managed to reduce the chance of high severity disturbance, such as with controlled burns and mechanical forest thinning. This can subsequently reduce post-fire debris flow risk because higher disturbance severity tends to cause more post-fire runoff and erosion than lower-severity disturbance.

### Pre-Fire Planning, Coordination, and Communication

Communicating post-fire debris flow risk is imperative for protecting life and property and can begin before wildfire activity occurs. First, general awareness of debris flow hazards can be communicated to stakeholders. The characteristics that make a catchment more susceptible to post-fire runoff generation and erosion, potential debris flow pathways and runout zones, and indicators of historical debris flows are all features that can be mapped or visualized and communicated. Various venues or platforms can be used to accomplish this such as televised information reports, trailhead and road signage, websites and other social media outlets, and published reports. Agencies or local community groups can consider compiling results of pre-fire hazard evaluations into a comprehensive pre-fire hydrologic and geologic hazard mitigation plan. The Multi-hazard Mitigation Plan for Ventura County, California provides a representative example (http://www.vcfloodinfo.com/resources/ventura-county-hazards-mitigation-plan).

### DEBRIS FLOWS: FATALITIES AND REPRESENTATIVE ASSOCIATED COSTS INCLUDE:

Factors that increase the likelihood for debris flows include:

- Black Hollow Debris Flow in Cache la Poudre Canyon, Colorado (July 20, 2021) occurred within the 2020 Cameron Peak Fire. It killed four and caused $1.7 million in public infrastructure damage.
- Glenwood Canyon Debris Flows in Garfield County, Colorado (June-July 2021) occurred within the 2020 Grizzly Creek Fire. It resulted in $116 million to repair I-70 road corridor damages and mitigate future debris flow risk) and caused additional economic impacts from road closure and rerouting traffic.
- Montecito Debris Flow in Santa Barbara County, California (January 8, 2018) occurred within the 2017 Thomas Fire, California. It resulted in 23 deaths and at least $420 million in private insurance claims from damaged residences.


2021 Black Hollow debris flow Credit: CWCB Technical Assistance Team.

Prior to fire activity, assets at risk may be identified and cataloged in a geospatial information system. Resources such as WRW's post-fire debris flow hazard map and the Colorado Geological Survey's geological hazard map can be used to identify locations where values at risk (VARs) inventories should be focused. Once VARs have been identified, local governments can communicate potential risk to stakeholders and community members to promote pre-event preparatory activities, such as those outlined in the following section.

Local governments can also coordinate with local contractors, engineers, stakeholders, and community members to develop emergency post-fire stabilization and recovery plans that can be executed in the event of a wildfire. These plans can be developed before a fire and may include obtaining emergency use authorization at strategic locations, such as ingress/egress right-of-way permits, contractual agreements with specialist personnel such as watershed rehabilitation experts and erosion control professionals, and materials procurement.

## MITIGATION

This Post-fire Hazard Mitigation section reviews pre- and post-fire best management practices (BMPs) or treatment and strategies for reducing fire-exacerbated debris flow risk. BMPs can be applied to stop sediment from eroding in the first place (source control) or to trap and retain runoff and/or sediment after they have already been generated.

### Watershed Treatments

**Watershed rehabilitation:** (Post-Fire) Reestablishing vegetation after a fire is critical for reducing runoff and erosion rates in areas susceptible to debris flows. Application of native seed mixes or cover crops can be used to accelerate revegetation rates in high-risk areas or where natural vegetation succession is slow or absent.

## Stream Corridor Treatments

**Increasing Floodplain Connectivity:** (Pre- and Post-Fire) In certain landscapes, restoring or enhancing existing floodplain connection and vegetation can trap sediments and reduce impacts to downstream residents, infrastructure, and water users.

**Debris and Rock Nets:** (Post-Fire) Debris and rock nets are flexible metal webbing installed across a channel perpendicular to the direction of flow (such as the ring net pictured below). As a debris flow moves down the channel, the net captures larger-grained material while letting the water and finer grained material pass through.

**Increasing Channel Conveyance Capacity:** (Post-Fire) In high-risk drainages, engineering evaluations can be conducted to determine if channels are properly sized to convey post-fire flood flows. Increased sediment and debris transport capacity should be considered during the evaluation to understand the potential for erosion and deposition. Where appropriate, channel conveyance capacity can be increased and channel banks and bottoms can be hardened to prevent excessive scour.

## Debris Basins

**Debris basins:** (Pre- and Post-Fire) These basins can be used to trap sediment. They are typically placed upstream of critical VARs that would otherwise be located in the direct path of potential debris flow activity. They may be installed where channel slopes decrease and/or valley margins widen, causing material to deposit. Extensive debris basin networks are located throughout southern California's San Bernardino Mountains, infamous for frequent and often catastrophic fire-debris flow cycles. Debris basins require rigorous monitoring and dredging activity to maintain adequate storage capacity.

A ring net installed in a drainage channel after the 2012 Waldo Canyon Fire, northwest of Colorado Springs, Colorado. Source: Wright Water Engineers, Inc.

## Road and Trail Treatments

**Planned Overflow Paths and Drainage Infrastructure:** (Pre-Fire) Locations where future potential debris flows will intersect roads and appurtenant drainage infrastructure should be identified. Properly sizing drainage features (e.g., culverts, roadside swales) and anticipating and planning for likely overflow pathways can reduce the likelihood of roadway embankment failures, overtopping, and traffic disruptions should a debris flow occur.

**Debris racks:** (Pre-Fire) These in-channel structures that trap larger debris from a flow while allowing the finer material and water to pass through. Debris racks are often installed upstream of roads and other structures to protect them from inundation and other damage. Like debris basins, racks must be maintained and cleared between flood and debris flow events to remove accumulated material and maintain storage capacity.

**Signage, Storm Patrol, Road Closures:** (Post-Fire) Marking high-risk areas with signage and enforcing road/area closures can reduce exposures to potential post-fire hydrologic and hydrologic hazards. In the Calwood burn area of Boulder County, for example, public-parks were closed in the afternoon each day during the monsoon season to limit the likelihood of visitors being caught by afternoon debris flow-causing rain events. Decision making was also connected to remote sensing technologies to help emergency management teams notify the public as weather and conditions changed on the ground.

Debris rack installed after the 2002 Missionary Ridge Fire near Durango, Colorado, and the debris it captured in a subsequent debris flow. Source: Wright Water Engineers, Inc.

**Roadside Barriers:** (Post-Fire) Roadside barriers, including k-rails and jersey barriers, can protect roads by directing debris and water away from the traffic corridor.

### Structural Floodproofing

**Deflection Walls:** (Pre-Fire) These can be used to route debris and water away from vulnerable natural landforms (e.g., a sensitive wetland) or existing infrastructure.

**Temporary Diversion Barriers:** (Post-Fire) For protection against nuisance erosion and minor flood events, temporary diversion barriers (e.g., Hesco or sand bags, k-rails) can be implemented to direct flows away from structures, undersized drainage inlets, and other at-risk features.

Sandbags were used to divert debris and water from homes after the 2010 Fourmile Canyon Fire in Boulder County, Colorado. Source: Wright Water Engineers, Inc.

## MONITORING AND ALERTS

Debris flow and flash flood alert systems can be mobilized in burn areas to collect and disseminate realtime information related to the public. Examples of this include rain and stream flow gages installed in the Cameron

Peak burn scar in Larimer County as well as the Grizzly Creek burn scar in Garfield County. These systems are typically run as partnerships between local entities, the US Geological Survey, and the Colorado Geological Survey.

There are many data sources that can be used to characterize post-fire debris flow risk including:

USGS Debris Flow probability and Volume Predictions (https://landslides.usgs.gov/hazards/postfire_debrisflow/). When it is available after a wildfire, USGS debris flow hazard mapping may be widely disseminated to fire-affected communities to increase awareness and guide emergency hazard mitigation efforts.

**Weather forecasts** can provide valuable information as debris flows are often triggered by short bursts of high-intensity rainfall. The National Oceanic and Atmospheric Administration (NOAA)'s weather prediction center generates quantitative precipitation forecasts of rainfall depths at 6-hour intervals (https://www.wpc.ncep.noaa.gov/qpf/qpf2.shtml). If a location's specific debris flow-triggering rainfall thresholds are known, these forecasts can be monitored for rainfall amounts that exceed these thresholds (Staley et al., 2017).

**Monitoring equipment** that measures in-situ soil moisture levels and subsurface pore pressures (indicating potential landslide hazards), seismic activity (indicating potential debris flow activity), and rainfall can be deployed in particularly high-risk areas. Communities can develop their own weather-based local alert system based on this information. See the monitoring activity conducted by the USGS in the I-70 Glenwood Canyon roadway corridor following the 2020 Grizzly Creek fire as an example: https://storymaps.arcgis.com/collections/494cf41689414e24a6066ea75188a653. As another example, Boulder County has been integrating soil moisture and pore pressure with current and forecasted precipitation over debris flow susceptible areas using rain gauges and gauge adjusted rainfall radar into their emergency warning system. This system also integrates with downstream floodplain modeling and fluvial hazard zone maps to account for potential runout and sediment deposition.

All available information should be considered holistically when local officials delineate evacuation zones and issue evacuation orders. The origin of each data source, sources of uncertainty and error, and the nature of the hazard being relayed by mapping data products should all be evaluated and discussed before use in emergency response decision making and communication. For example, USGS debris flow probability maps do indicate the likelihood that a watershed will produce a debris flow for a rainstorm of a given intensity. They do not indicate likely debris flow runout paths or footprints. Finally, when issuing evacuation orders for potential post-fire hazards, officials should be wary of potential evacuation fatigue if the community was also evacuated during the active wildfire.

# FLOODING AFTER A WILDFIRE

**WILDFIRE READY WATERSHEDS**
FACT SHEET

**Version 22.01 | December, 2022**

## OVERVIEW

Watersheds experience significant change as a result of wildfires. Some of those changes include the loss of vegetative cover and soil stability, the loss of tree canopy, and the ability of soils within the watershed to infiltrate water. These changes often result in increased runoff from rainfall. Not only is the amount of runoff increased, runoff leading to concentrated flows occur more rapidly, leading to more frequent and larger flood events. These alterations in the watershed can lead to many different impacts including:

- More frequent and more severe flooding
- Reduced snowpack and altered streamflow
- Increased erosion and sedimentation
- Degraded water quality

This Wildfire Ready Watersheds Fact Sheet provides information on the behavior of water within a burned watershed (post-fire hydrology) as well as what happens to that water when it reaches a stream corridor as a flood (post-fire hydraulics). It also provides guidance on how potential flood hazards can be characterized and used to evaluate a community's susceptibility to post-fire flooding.

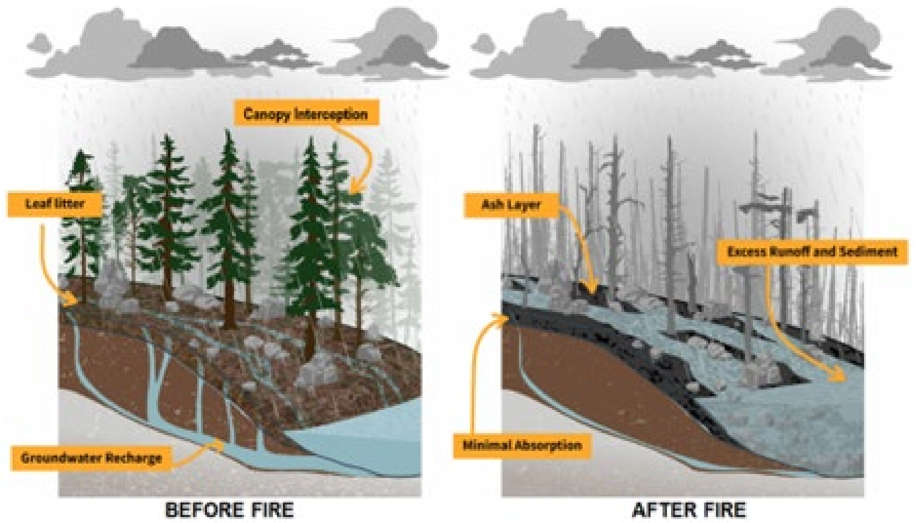
## HAZARD AND RISK CHARACTERIZATION

### Changes to Water's Pathways in Fire-Impacted Watersheds

When it comes to understanding and mitigating the impacts of wildfire on hydrology within a watershed, communities are likely to be most concerned about their potential for flooding. Flooding after fires can be more frequent and more severe. This is due to a reduction in the amount of water that the ground can absorb or infiltrate during a rainstorm. Heat from a fire "bakes" the soil column and creates a water-repellent layer of ash and organic matter. A water repellent layer left after a fire is termed hydrophobicity. Hydrophobicity decreases infiltration and initial rainfall losses to ground and increases direct runoff from a watershed. Because of this, what may have been a relatively frequent and not catastrophic rainfall event before a wildfire can become a devastating flood after a wildfire.

Rainfall runoff in a burn scar. Credit: NW Interagency Incident Management, WA.

# FLOODING AFTER A WILDFIRE




Conceptual diagram of selected watershed rainfall-runoff processes before and after fire disturbance. (USGS).

The magnitude of hydrologic change that occurs in a watershed following a wildfire is influenced by a host of factors. The severity of the fire, location within the watershed, topography (slope, shape, aspect), type of vegetation within and downstream of the burn scar, geology, soil type, and climate all influence the quantity of excess water and the speed at which water runs off a watershed during and after a rainstorm. As such, the rainfall-runoff response both before and after a fire is complex and unique to each watershed.

Typical hydrologic changes to a watershed following a wildfire include:

- **Reduced Initial Runoff Losses:** Pre-fire, forested and well-vegetated watersheds catch, slow down, and store a portion of rainfall within the tree canopy and ground vegetation, and organic material (mulch or litter) on the forest floor. When this canopy, vegetation, and litter are burned, the watershed is no longer able to store and slow down rainfall, resulting in more water running off more quickly.
- **Reduced Infiltration:** After a fire, burned soil cannot soak in (infiltrate) and store water from rainfall as well as it could in the pre-fire condition. This is due to the water repellency that can be established in burned soils and the lack of vegetation and litter. Reduced water infiltration and storage in the soil increases the amount of surface runoff and flooding.
- **Faster and Larger Flood Peaks:** With less interception from trees, vegetation, and litter, and less storage in the soil, more rainfall will run off the landscape and concentrate more rapidly causing a larger flood peak to occur sooner than in an unburned watershed. Additionally, the forest floor will have less roughness on the ground. This increases the velocity of flow running off the landscape. Faster runoff from hillslopes leads to larger flood peaks downstream.
- **Increased Soil Erosion:** Without trees and vegetation holding the soil on hillslopes in place, soil erosion increases. Soil is dislodged by more

direct rainfall impact detaching exposed soil. Further, erosion increases from the increase in velocity of water flowing over the burned ground. The larger and faster-moving overland flow has more energy to carry soil, and the fire has exposed more soil to erode.

## WHAT'S YOUR POST-FIRE FLOOD FREQUENCY?

We know that floods after fires can be more severe, but did you know that they can also be more likely to occur?

Though it may seem so, burned watersheds do not invite more rainfall. However, they can amplify the volume and peak of floods following rain events. For a given depth of rain falling over a watershed, a larger flood will result if the watershed has burned. From a probability standpoint, a 1% annual chance flood (100-year return period) has about a 5% chance of occurring over five years. Say that a storm with a rainfall depth having a 10% annual chance of occurring (10-year return period) falling over a burn scar produces a peak flow rate from that watershed that is equivalent to the 1% annual chance pre-fire flood flow rate. The runoff from the burn scar is amplified relative to pre-fire conditions. Under this scenario, the pre-fire 1% chance flood now has a 40% chance of occurring within a typical five-year post-fire recovery window (note that this recovery window can be longer).

## Flooding After Fire

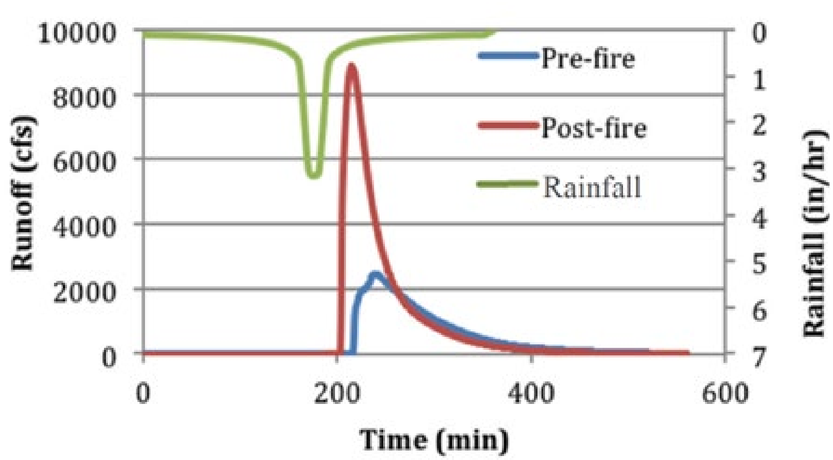
As a result of the changes in hydrologic response as described above, more water travels rapidly to streams and rivers in burned watersheds. The post-fire runoff will often contain ash, debris, and eroded soil. Greater runoff volumes, increased runoff velocity, and the additional bulk or volume from eroded soil and debris carried by flood waters leads to larger and more destructive floods with larger peaks. Also, because the flood peak and volume will be larger for a given rainfall event after a wildfire, destructive floods become more probable and more frequent (see information box above).

Floods after fire are hazardous to residents living in or near burned areas as well as infrastructure such as roads, bridges, culverts, and utilities.

## Changes to Water Yield and Baseflow Volume and Timing

Fire can alter the timing and volume of water produced by a watershed because it can change the processes that influence how much precipitation (rain and snow) returns into the atmosphere through sublimation and evapotranspiration, infiltrates into the groundwater table, or runs off into streams and rivers. Impacts of fire on water over an annual time scale include:

- **Reduced Snowpack:** Ash and litter (e.g., pine needles) from burned vegetation can deposit on top of or become mixed into the snowpack. This, along with the removal of




Simulated pre- and post-fire hydrographs from hydrologic modeling. (Goodrich et al. 2012, Trans. ASABE).

FLOODING AFTER A WILDFIRE

the tree canopy from fire increases the amount of solar radiation reaching and absorbed by the snowpack leading to quicker and earlier melt off and less overall water yield.

- **Altered Baseflow:** Baseflow may increase or decrease depending on the severity and location of burns within a watershed. The decrease in infiltration and increase in surface runoff described above can lead to less precipitation recharging groundwater resulting in lower baseflow. Alternatively, with less living vegetation, less water may be lost to evapotranspiration leaving more water in the soil and water table for increase baseflows.

## Water Quality Implications

Post-fire flooding and water quality issues are typically interrelated. Post-fire increases in runoff can also amplify a watershed's ability to erode and transport soil and rocks from hillslopes and water channels, which causes erosion rates to increase. Sediment itself can be considered a pollutant if concentrations exceed background levels. Higher suspended sediment loads along with ash and debris can change the odor, color, and taste of drinking water. Increased turbidity of water from sediment in a stream can alter water temperature and the amount of light available to aquatic plants for photosynthesis. More sediment can also pose problems for water infrastructure if it is deposited in a reservoir (reservoir sedimentation) or clogs diversion or stream crossing infrastructure. Nutrients, heavy metals (especially mercury), organics, or pathogens can also be delivered in post-fire runoff. Firefighting retardants and foams have been shown to introduce water contaminants into surface and subsurface water supplies as well (ammonium sulfates and PFAS).

## Hazard Identification

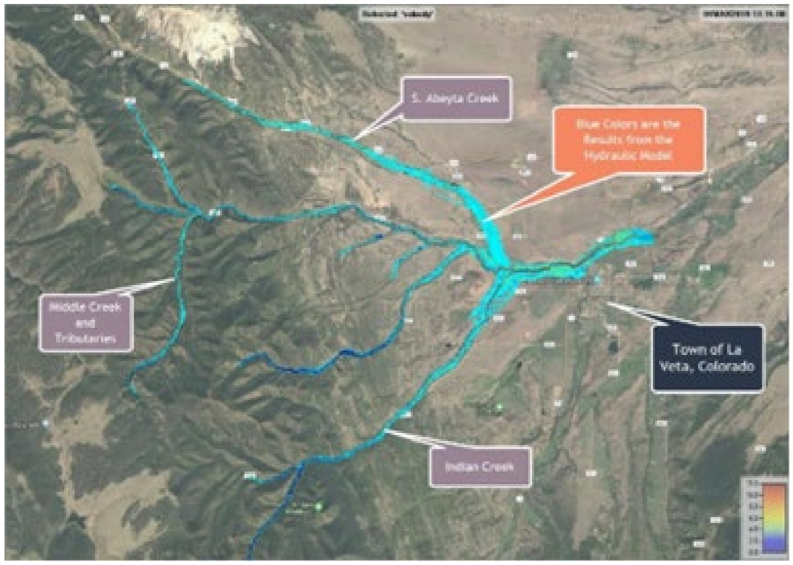
Post-fire flood hazards are typically evaluated in two steps:

1. The volume, timing, and peak of the flood event are evaluated (hydrologic modeling)
2. The extent or area of flooding within a stream corridor and associated flow depth, velocity, and erosivity (hydraulic modeling)

Post-fire hydrologic modeling tools vary in sophistication, data requirements, and level of detail. At a high level, one can evaluate the expected relative change in flood volume or peak discharge resulting from a fire in a particular watershed. Such "flood amplification" studies can be completed for many watersheds at once and help communities identify watersheds that are more susceptible to post-fire flooding. One can also predict the actual changes to volume, timing, and peak for post-fire flood events.

### HYDRAULIC MODELING, FLOODPLAIN IDENTIFICATION, AND MAPPING

Hydraulic models are used to simulate flood flows within a stream corridor. They can be used to model where flood waters will be, flood depths, and velocity. Flood mapping can be performed under pre- and post-fire flood conditions. Hydraulic models use inputs from hydrologic models, which estimate the flow rate of floods over time, and then model where that water will travel through a stream corridor.




Example of predicted post-fire inundation extent and flow velocity (in feet per second) for a watershed from a hydraulic model. Credit: Enginuity Engineering Soilutions, LLC.

Outputs from a hydrologic model such as peak discharge are brought into a hydraulic model, which uses topography, typically from LiDAR or on the ground surveys, and estimates of channel and floodplain roughness to predict flood inundation area, depth, and velocity. Hydraulic modeling of pre- and post-fire floods can be compared to identify where significant changes in flooded areas are expected and where damage to structures and infrastructure may occur. A list of outputs from this modeling that can be of use to planners and recovery managers is included as an attachment to this fact sheet.

A variety of available models can be used to understand post-fire hydrology and flood inundation, but to be most useful and accessible it is recommended that publicly available, industry standard models such as the United States Army Corps of Engineers HEC-HMS (hydrology) and HEC-RAS (hydraulics) be used to model post fire conditions. Additionally, HEC-RAS now offers the ability to perform Rain-on-Grid analyses that incorporate both the rainfall response and hydraulic floodplain modeling in one model. To read more about specific models and modeling approaches for wildfires, see the **Post-Fire Modeling** technical fact sheet.

## PRE-FIRE PREPAREDNESS

Increased risk related to increased runoff and flooding can be reduced with proper pre-fire planning and adequate post-fire hazard mitigation and communication. The prior sections discussed how hydrologic flows and risk may increase following a wildfire along with some guidance on how communities can identify where these hazards are likely to occur. This and subsequent sections discuss strategies for reducing the chances of high severity disturbance and how to communicate potential post-fire flood risks to agencies and stakeholders.

### Identify the Hazard and Understand Where Risk Exists

- Model post-fire flood runoff and flooding extents (hydrologic and hydraulic modeling). Understand the data needs of these models and ensure that baseline data is available for the community.
- Identify values at risk from flooding and prioritization. For flood after fire, impacted values at risk include structures, critical facilities, roads and road crossings, and infrastructure within the stream corridor.
- Pair these assessments with fluvial hazard zone evaluations to understand not only the limits of flood inundation, but the limits of the active stream

corridor where erosion or deposition can rapidly change the channel location.

### Identify Local/State/Federal Resources and Coordination

- Review multi-hazard mitigation plans with a team of multi-disciplined professionals including experts in soils, water resources, engineering, geomorphology, vegetation, ecology, and biology.
- Develop stakeholder communications to identify contacts and strategize mitigation planning based on understanding of assets at risk.
- Develop communication and emergency response plans to be deployed with other community outreach efforts.

### Evaluate Pre-Fire Mitigation Options

- Incorporate modeled post-fire runoff and flooding hazards into Watershed Hazard Mitigation Plans.
- Develop priorities, concept designs, and implementation recommendations for a post-fire scenario that are appropriate for your watershed.
- Identify restoration, infrastructure retrofits, and other pre-wildfire mitigation projects that might reduce flood peaks to downstream communities, i.e., reconnect incised and degraded channels with overbanks and floodplains to store additional runoff and slow down flood waves.
- Consider upstream river corridors that could be candidates for the restoration of beaver habitat, re-introducing wood back into stream corridors, and reconnecting degraded floodplains, which can serve to attenuate flood flows upstream of a community.

## MITIGATION

Many of the same mitigation actions recommended to address other post-fire hazards are also beneficial to protect against post-fire flooding. Mitigation can be categorized as either pre-fire mitigation, watershed or corridor scale actions that can be implemented before a fire occurs, and post-fire, point-of-impact actions that can be implemented after a fire occurs. In some cases actions can be used both pre-fire and post-fire. The following provides a summary of major mitigation activities a community might consider, however this is not an exhaustive list and there are numerous small-scale mitigation techniques that planners and designers might consider to mitigate post-fire flooding.

### Strategy 1: Increasing Floodplain Connectivity

**Pre- and Post-Fire**

In certain landscapes, restoring or enhancing existing floodplain connection and vegetation can improve flood conveyance, reduce energy within the system, trap sediments and reduce impacts to downstream residents, infrastructure, and water users. Reconnecting floodplains allows for water to flow into backwater areas, across wide shallow floodplains, and pond in broad valleys, reducing peak flows delivered to downstream corridors. These actions can protect against increased flows from post-fire conditions and provide stream function and ecological benefits to stream corridors.

## Strategy 2: Crossing Upgrades and Retrofits

**Pre- and Post-Fire**

Post-fire watershed conditions result in increased peak flows from rainfall events as well as sediment laden flows that increase the volume of flows. Roadway crossings designed for pre-fire flows are sized for watershed conditions that minimize excess runoff, i.e. natural forest conditions with high infiltration. As a result, when a fire occurs, these crossings are significantly undersized and prone to overtopping and failure. Additionally, debris and sediment in post-fire flows often jam or plug roadway crossings. Communities should identify roadway corridors that are critical for emergency access, evacuation, or economic use and consider upsizing those crossings ahead of a fire or after a fire to protect against roadway failures. This may include upsizing crossings or transitioning culverts to free-span bridges. At the same time, trash and debris racks may be considered in parallel to protect against plugging of the crossings.

## Strategy 3: Increasing Channel Conveyance Capacity

**Pre- and Post-Fire**

Once a community has identified its post-fire flood risk, even before a fire such as with a Wildfire Ready Action Plan (WRAP), there may be locations where increased channel conveyance may help reduce flood risk. Hydraulic and floodplain evaluations can identify these locations and engineering and river design teams can consider where channel improvements might be considered to improve flood conveyance and alleviate flooding of buildings or infrastructure. In some cases, simple improvements such as limiting vegetation in the channel can have a significant impact on flood depths and conveyance in critical corridors. Channel cross section improvements such as expanding flood overbanks or creating overflow channels can reduce flood risk through highly developed areas. Increased sediment and debris transport capacity should be considered during the evaluation to understand the potential for erosion and deposition. Where appropriate, channel conveyance capacity can be increased and channel banks and bottoms can be hardened to prevent excessive scouring.

## Strategy 4: Address Stream Stability and Erosion

**Pre-and Post-Fire**

Lateral and longitudinal instability should be considered in stream systems, especially in locations with buildings and critical infrastructure. Bank erosion during high flow events, especially post-fire flooding, can dramatically change the shape and location of a stream channel (see the Fluvial Hazards After Wildfire fact sheet). When evaluating post-fire conditions, planners should consider the risk of bank erosion as well as channel bottom incision and degradation. In critical locations, bank protection should be considered to limit or slow down erosion processes during high flows. Bank protection could include simply regarding and vegetating the channel banks, installation of large wood revetment, placement of setback riprap, or even hardened flood walls or sheet pile to protect critical infrastructure. Stream bottoms are also susceptible to erosion and incision and sometimes stream bottoms can drop several feet after one flood event. This is especially important where infrastructure crosses streams, such as water lines, sewer lines, and roadways. In these locations, grade control structures might be considered to maintain the channel bottom elevation and protect infrastructure. Grade control structures include constructed riffles, hardened drop structures, or sheet pile driven below estimated scour depths. These actions can be considered both before and after a wildfire occurs.

## Strategy 5: Hazard Avoidance via Conservation, Parks, Open Space, and Easements

**Pre-Fire**

The most cost-effective tool for a community to mitigate the impact of flood hazards is to reduce their exposure through forward-looking land-use planning. Long-term planning that directs land development and infrastructure away from areas subject to flood hazards will result in preventing damages during future floods. These practices are similar for Fluvial Hazard Zones (see Fluvial Hazards After Wildfire fact sheet). Strategies for mitigating flood hazards via non-structural measures may include conservation easements for all or portions of parcels within the floodplain or buyouts of existing properties.

## Strategy 6: Watershed Rehabilitation

**Post-Fire**

Reestablishing vegetation after a fire is critical for reducing runoff and erosion rates in areas susceptible to debris flows. Application of wood mulch, native seed mixes, or cover crops can be used to accelerate revegetation rates in high-risk areas or where natural vegetation succession is slow or absent. Mulching and revegetation accelerate watershed recovery ultimately mitigating post-fire changes in the watershed over time.

## Strategy 7: Structural Floodproofing

**Post-Fire**

In many cases, mitigation actions require fast implementation and full-scale stream corridor, or watershed projects are not viable for protection of life and property. In these cases, temporary (or even permanent) flood protection may be warranted. Examples include:

- Temporary diversion barriers: (Post-Fire) For protection against post-fire flooding, nuisance erosion, and minor flood events, temporary diversion barriers (e.g., Hesco or sand bags, k-rails) can be implemented to direct flows away from structures, undersized drainage inlets, and other at-risk features.

FLOODING AFTER A WILDFIRE

- Deflection or Flood walls: (Pre-Fire) These can be used to route debris and water away from vulnerable natural landforms (e.g., a sensitive wetland) or existing buildings or infrastructure.

## Strategy 8: Infrastructure and Utility Retrofit/ Relocations

**Pre- and Post-Fire**

Infrastructure such as roads, road crossings, water sanitation, electric/ telecommunication lines, etc., are often located in flood and erosion zones. Evaluating these in the context of large-scale disaster planning may highlight vulnerabilities and therefore opportunities for retrofitting or relocating this infrastructure before a wildfire occurs. This also allows a community to consider what portions of its infrastructure or utility network have redundancies, and which do not.

## Strategy 9: Flood Risk Communication

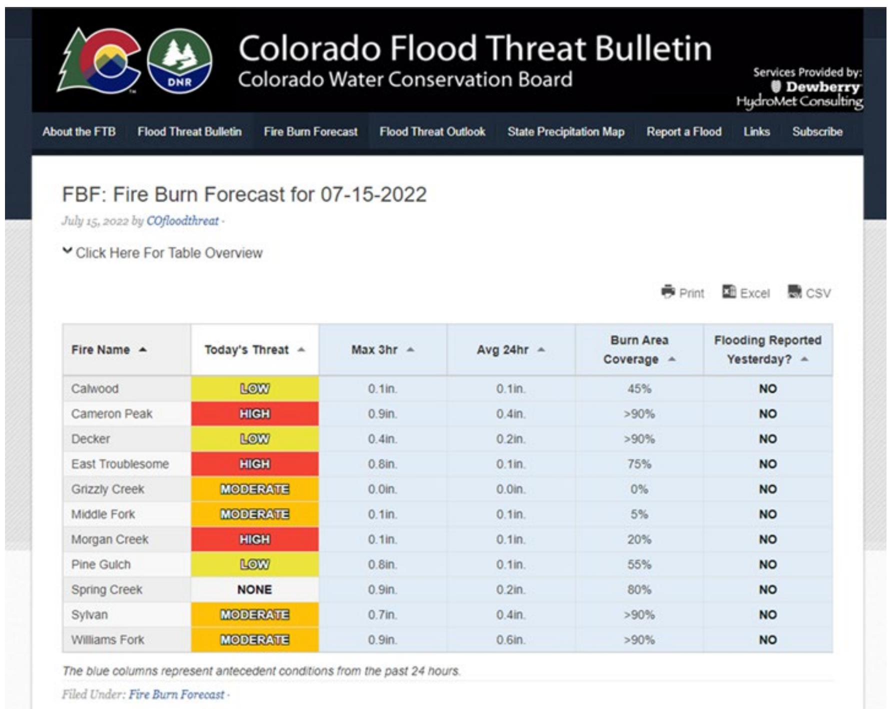
**Pre- and Post-Fire**


Example of handouts, which include marked evacuation routes, available at trailheads and parking lots in the Calwood burn scar in Boulder County, Colorado.

Often, very little can be done to reduce increases in post-fire flooding. Point of impact improvements such as flood barriers and erosion protection are temporary measures and only protect for a certain level of event, often up to a 10-year rainfall. Because of this, flood risk communication is one of the most important activities that a community can implement both before and after a wildfire occurs. Once a post-fire hydrologic and hydraulic model with associated flood inundation limits has been developed, structures and property at risk can be identified and property owners and residents can be warned and informed regarding post-fire flood risk. Individual one-on-one meetings, public meetings, and well-designed community websites can all be effective tools in communicating flood risk. Early communication is critical as some property owners may need to obtain flood insurance before rainfall starts occurring over the burned area. Citizens should be connected with local floodplain managers who can direct them to additional information about obtaining flood insurance and coverage details. Additionally, evacuation plans and actions that should be taken by residents, visitors, and landowners in the area should be communicated clearly. It is also important that residents understand that small rainfall events after a fire can generate tremendous flood risk as well as understanding rainfall events upstream can occur and cause downstream flooding with limited warning.

The location of many burn areas presents significant challenges to flood warning and flood risk communication. Some locations may see many visitors traveling through high risk canyons to get to recreation areas or recreating on the rivers themselves. Additionally, flood warning systems such as reverse 911, Twitter, or other social media platforms can be of little benefit within canyon areas where cell phone coverage may be poor or non-existent or at times when power is out. To address these types of locations and the associated challenges in delivery of flood warnings, e.g., that technology such as Twitter or Reverse 9-1-1 has limitations within canyon areas, it is recommended that signs be placed at the bottom of the burn area for all roadways (ingress routes) informing travelers of the increased risk of flash flooding and indicating that they should avoid camping in low lying areas and/or seek high ground during rainfall events.


Example of a possible roadside sign that could be used to relay NWS threat information in more remote areas.



Colorado Flood Threat Bulletin
Colorado Water Conservation Board
Services Provided by: Dewberry HydroMet Consulting

About the FTB | Flood Threat Bulletin | Fire Burn Forecast | Flood Threat Outlook | State Precipitation Map | Report a Flood | Links | Subscribe

FBF: Fire Burn Forecast for 07-15-2022

*July 15, 2022 by COfloodthreat ·*

Click Here For Table Overview

Print Excel CSV

| Fire Name | Today's Threat | Max 3hr | Avg 24hr | Burn Area Coverage | Flooding Reported Yesterday? |
|---|---|---|---|---|---|
| Calwood | LOW | 0.1in. | 0.1in. | 45% | NO |
| Cameron Peak | HIGH | 0.9in. | 0.4in. | >90% | NO |
| Decker | LOW | 0.4in. | 0.2in. | >90% | NO |
| East Troublesome | HIGH | 0.8in. | 0.1in. | 75% | NO |
| Grizzly Creek | MODERATE | 0.0in. | 0.0in. | 0% | NO |
| Middle Fork | MODERATE | 0.1in. | 0.1in. | 5% | NO |
| Morgan Creek | HIGH | 0.1in. | 0.1in. | 20% | NO |
| Pine Gulch | LOW | 0.8in. | 0.1in. | 55% | NO |
| Spring Creek | NONE | 0.9in. | 0.2in. | 80% | NO |
| Sylvan | MODERATE | 0.7in. | 0.4in. | >90% | NO |
| Williams Fork | MODERATE | 0.9in. | 0.6in. | >90% | NO |

*The blue columns represent antecedent conditions from the past 24 hours.*

*Filed Under: Fire Burn Forecast ·*

Flood Threat Bulletin Flood Forecast for July 15, 2022.

Example of a possible roadside sign that could be used to relay NWS threat information in more remote areas.

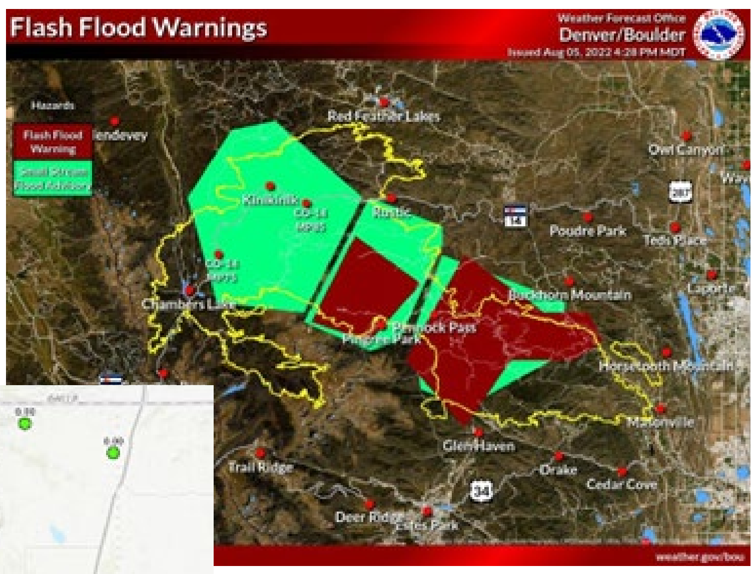
The Colorado Flood Threat Bulletin (https://www.coloradofloodthreat.com/), hosted and supported by the CWCB since the 2013 floods, provides daily forecasts of flood risk around the state, including over burn scars. Local agencies should refer to this website and recommend residents or visitors review the site daily. Additionally, forecasts can be highlighted on recovery and flood warning Twitter accounts, fire recovery websites, and referenced in flood after fire informational pamphlets. The Colorado Flood Threat Bulletin can also be found on Twitter @COFloodUpdates.

The NWS also does a good job of putting out the daily burn area flash flood threat (https://www.weather.gov/bou/weatherstory) —but the distribution of this may be limited to those with cell service or internet connections and/or those who actively seek it out.

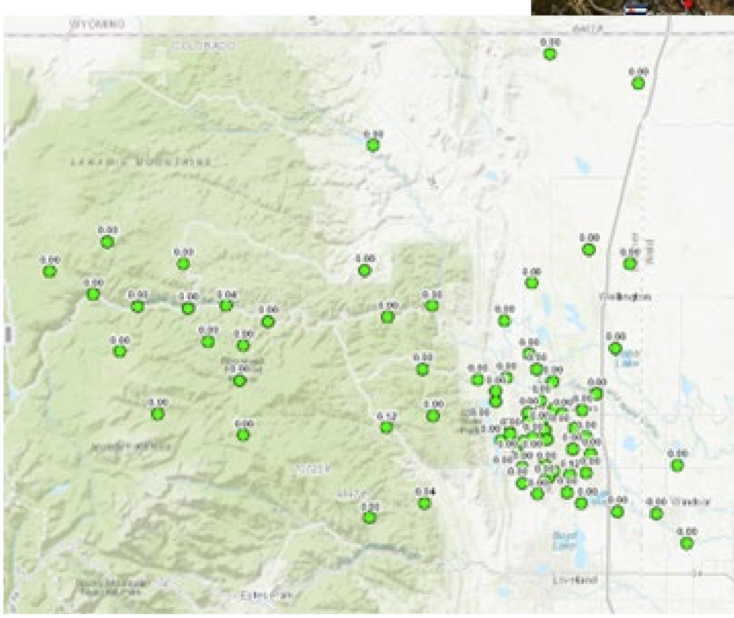
Similarly, a variable message sign (VMS) might be considered in lieu of a printed sign at these access points.  A VMS might draw more attention than a static posted sign.  These could be placed during the rainy season and taken down during the winter months. Finally, it may be prudent to develop a flood risk pamphlet and make those available in a waterproof box adjacent to the warning signs to provide better information for both residents and those staying in the area to educate them regarding the post-fire flood risk and ways to protect themselves in the event of a flood.  Finally, similar to messaging in the desert southwest, is also important to relay that even if rain doesn't fall on you, that you could still be at significant risk if precipitation falls in the watershed upstream of you.

## MONITORING AND ALERTS

Early warning systems for floods in burn areas can play important roles in communicating impending floods, evacuation recommendations, and ultimately save lives. Collaborations with the National Weather Service and the U.S. Geologic Survey (among other potential partners) can support emergency communications of flood warnings in burned areas based on weather forecasts, radar, or rain gages with satellite telemetry deployed in burn scars. More detailed maps of post-fire flood or fluvial hazard zones, disseminated before floods occur, can aid emergency response personnel and residents in understanding more precisely where flood hazard zones may exist.




Flash flood warning over Cameron Peak fire burn area. (NWS Boulder)



City of Fort Collins flash flood early warning rain gage network linked to modeled flood extents. (City of Fort Collins)

| OUTPUT AND INFORMATION TO BE USED FROM HYDROLOGIC AND HYDRAULIC MODELING | | |
|---|---|---|
| **PHYSICAL PARAMETER** | **DESCRIPTION** | **HOW THE INFORMATION CAN BE USED** |
| Water Surface Elevation | How high the water is before and after a wildfire for a certain runoff event | Informs communities of increased flood risk to structures and facilities |
| Velocity | How fast the water travels both before and after a wildfire event | Provides valuable information on flood wave travel times and supports flood warning and evacuation times |
| Inundation Boundary | The extents of water before and after a wildfire | Can show the increase in flood extents. Can help support identification of where incised channels need to be connected to banks for connectivity |
| Depth | How deep water is before, and after a wildfire. | Can define incised channel locations that need to be connected. Can identify reduction in depth on structures. Can find reduction in overtopping of roadways. |
| Froude Number | Defines erosive and non-erosive flows and turbulent flows | Identify highly erosive reaches that contribute to channel incisions and reduction in floodplain connectivity. Lower Froude numbers indicate less erosion risk and reduce risks on structures. |
| Shear Stress | Defines locations of erosive bed material and locations where channel incision is more likely or already high. | Identifies locations where floodplain reconnection and roughening can reduce the amount of sediment and pollutants flowing into downstream waters. Reduction in shear creates a more stable stream system. |
| Depth x Velocity | Similar to shear, depth x (times) velocity can identify stream locations that are highly erosive. Depth times velocity also supports identification of increased risk onto structures and flooding forces. | Reduction in depth times velocity helps with cost benefit analysis to quantify the benefits of slowing down water with wetland restoration. Identifies reduction in damages, reduction in risk to culverts and structures. |
| Energy (Depth and Elevation) | Total energy includes the potential and kinetic energy of flow. | Total energy informs us how transforming kinetic energy into potential energy increases or reduces stream erosion and risk to structures, culverts, and infrastructure. Increasing floodplain connectivity reduces kinetic energy and slows down waters. |
| Arrival Time | How fast a flood wave arrives at a location. | Increasing wetland connectivity reduces arrival time of a flood wave and reduces risk onto structures, culverts, and roadway crossings. |
| Recession | How long it takes a flood wave to recede. | Recession onto structures and total inundation time onto crossings from a flood impact emergency services. Better floodplain connectivity that stores water in wetlands and not on roadways or culvert locations helps emergency services better respond to assist stranded citizens. |
| Duration | How long a flood wave happens. | Provides an understanding of the length of flooding. This information can begin to inform managers where storing water in upstream floodplains could decreases the peak flow and duration of flooding on downstream structures (houses, roads, and infrastructure). |
| Stream Power | How much power is in the moving water. | Identifies stream stability, mobilization of sediment, and stream movement. Reduction of stream power from connected and roughened floodplains decreases sedimentation and debris flows during floods. |
| Rainfall Excess | How much rain turns into runoff. | Fires dramatically change runoff response in watersheds. Hydrologic modeling can inform managers as to the amount of excess runoff to expect as a comparison to pre-fire conditions and which watersheds may pose more significant post-fire risk. |

# PRESERVING WATER QUALITY AFTER WILDFIRES

**WILDFIRE READY WATERSHEDS**
FACT SHEET

**Version 22.01 | December, 2022**

## OVERVIEW

This Wildfire Ready Watersheds Fact Sheet provides guidance on hazard identification and characterization, Best Management Practices (BMPs) and mitigation strategies for reducing the impact of wildfire on water quality, alert/warning systems, and practical tips for protecting water quality after wildfires in urban and suburban areas. This fact sheet also provides guidance for preparing for these impacts before a wildfire starts. The information is both behavioral and structural, as both combine to best preserve water quality in the aftermath of a wildfire.

Melted metal can be seen on the driveway around this car. Particles of these and other remaining metals can easily be suspended in stormwater runoff and be carried downstream. Proper cleanup after urban wildfires is an essential tool for protecting water quality.

Wildfires in urban and suburban areas pose different challenges than ones that occur in less densely developed areas because of the higher presence of synthetic materials that are found in homes, garages, and sheds. Once exposed by a wildfire, these materials become pollutants when they are carried into streams and reservoirs by rain, snowmelt, and wind. To effectively manage this threat to water quality, the hazards must be characterized, and stormwater management techniques specific to each phase of the post-wildfire cleanup and rebuilding process must be implemented to limit water contamination. Every wildfire is unique, and the guidance here is meant to be a starting point that will need to be adapted to each community's individual conditions.

## POLLUTANTS MAY INCLUDE:

- Asbestos from building materials,
- Metals like cadmium, lead, and aluminum from batteries, appliances, and other household products,
- Polyaromatic hydrocarbons or polycyclic aromatic hydrocarbons (PAHs) from burned tires and plastic products,
- Sediment and ash from exposed areas (CalEPA, 2011),
- Benzenes and formaldehyde resulting from thermal degradation of certain plastics used for water piping (Chong et al., 2019),
- Polychlorinated biphenyls from appliances and automotive parts (CalEPA, 2011),
- Per and polyfluoroalkyl substances (PFAS) from common household products like certain nonstick cookware, carpet, stain-resistant textiles, and cleaning products (ATSDR, 2021) or from wildfire suppression activities (EGLE, 2022),
- Fire retardants (Angeler & Moreno, 2006; Pittinger & Pecquet, 2018; Tobin et al., 2015),
- Solvents, paints, fuels, and pool chemicals (CalEPA, 2011),
- Common chemicals from personal care products (Wang et al., 2022),
- Surfactants such as laundry and dish soaps (Wang et al., 2022),
- Pesticides (Wang et al., 2022),
- Debris including burned vehicles, structure contents, and landscaping materials which contain a broad spectrum of potential pollutants and can also become mobilized in stormwater and clog drainage facilities,
- Bioavailable nutrients from burned vegetation, and
- Fertilizers.

Many of the materials found in residential and commercial buildings and infrastructure can generate or leave behind substances known to be harmful to human health and the environment when exposed to extreme heat. These pollutants all have the potential to degrade water resources when they are transported in runoff from burn sites into the receiving waterways or leach directly into groundwater. To reduce the impacts of this chemical contamination, agencies, local utilities, and community groups should consider how they can assist owners and residents as they work through clean up and recovery.

## HAZARD AND RISK CHARACTERIZATION

After a fire in an urban or suburban setting, thoroughly characterizing the burned area is a critical step for identifying potential hazards to downstream water resources and selecting appropriate BMPs for protection of water quality. Site assessment and characterization may involve sampling of representative areas to identify hazardous materials that may pose health risks to debris clean up contractors.

From a water quality standpoint, the fundamental purpose of the site characterization is to identify pollutant sources and how runoff from these sources makes its way to receiving waters so that BMPs can be selected to keep pollutants at source locations through erosion controls and to remove pollutants that are entrained in runoff using sediment controls. Site characterization can be used to prioritize areas for BMP implementation based on proximity to water bodies, presence of pollutant sources, and other factors. Provide documentation of site characteristics and hazard assessments to cleanup and recovery personnel to help guide prioritization of areas, decisions on appropriate disposal methods for materials removed from the site, and for personal protective equipment (PPE) decisions.

## ACTION ITEMS FOR COMPLETING A WATER QUALITY HAZARD ASSESSMENT

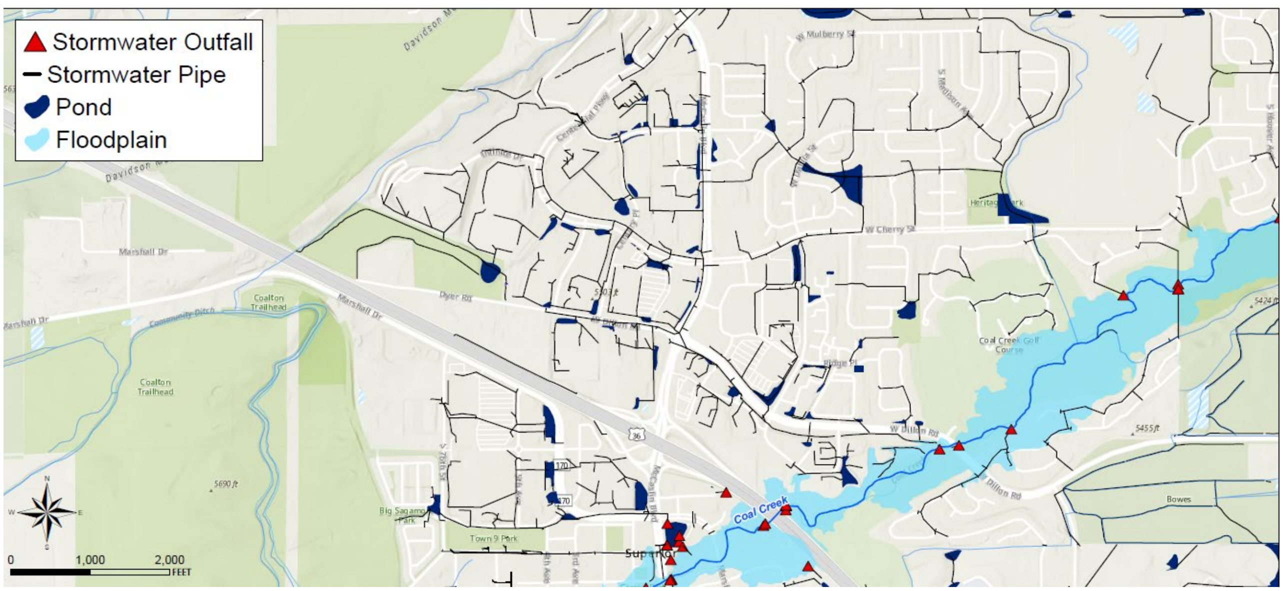
- Evaluating site characteristics such as topography, distance from drainageways, land uses/potential contaminants, seasonal potential for runoff, proximity of hazards to resources, and potential hazards to cleanup and recovery personnel and site visitors (e.g., wildfire-damaged trees that may fall, intact propane tanks, underground utilities).
- Reviewing local land use information to determine if pollutant “hot spots” are present in the burn area such as businesses that store or process significant quantities of chemicals or areas with unsecured mine tailings.
- Identifying water intakes, ditches, and other water utilities in the area that may be affected by post-wildfire runoff.
- Documenting materials associated with structures and infrastructure that may contain pollutants to the extent feasible given the burned condition.
- Identifying drainage paths from burned areas to outfalls to receiving waters and determining how much of the burned area drains to different outfalls.
- Documenting the location and condition of existing water quality and detention facilities that may be used as post-wildfire stormwater controls.
- Assessing water repellency of soils using a water drop penetration test (qualitative) or a mini-disc infiltrometer (quantitative).
- Collecting representative samples from water distribution lines in burned areas to screen for potential contaminants.
- Mapping and field-verify soil types and associated erosion and water management characteristics (erodibility, hydrologic soil group, and related parameters).
- Obtaining and overlaying flood and/or fluvial hazard mapping to determine if burned areas are present within the stream corridor where they may be exposed to flooding or erosion.

## PRE-FIRE PREPAREDNESS

Time is of the essence following a wildfire, so planning the framework of the post-wildfire response proactively can save significant time and money when a wildfire occurs and will better protect human health and water quality. Much of the groundwork for coordination and communication can be laid before a wildfire even occurs by developing emergency response plans that identify the key parties that would be involved following a wildfire in a community and their roles in post-wildfire response.

The first step in developing a wildfire response plan (Plan) to protect water quality is to determine the scale at which the Plan will apply. Plans can be developed at a high-level by states and counties or can be developed at a more granular level by cities or neighborhoods. Making this decision will inform the degree of specificity that is appropriate for the Plan as well as the selection of stakeholders to provide input on the Plan.

The Plan will be bolstered by performing preemptive general triage of potential areas that could be affected by a wildfire. For example, if an industrial part of the community is known to store significant quantities of chemicals in a manner that could result in a release during a wildfire, identify that part of the community as a higher priority for characterization and mitigation than an area with few pollutants such as a park. Hazard and risk characterization is discussed in greater detail in a subsequent section.




Gathering information about the assets and liabilities within a community can help to inform prioritization decisions that will be needed after a wildfire occurs. This mapping shows the locations of stormwater infrastructure and surface waters and can be used to identify areas where water quality is likely to be more vulnerable after a wildfire.

Next, account for the necessary steps of a post-wildfire recovery in an urban or suburban setting and delegate responsibility for overseeing and executing each step. The Plan should start with hazard and risk characterization before moving to mitigation, debris removal, reconstruction, and permanent stabilization. Community officials should issue appropriate warnings and alerts regarding public health and safety should be issued throughout the response, as designated in the wildfire response plan. If some or all of these

Preparing a plan to protect water quality ahead of a wildfire will promote a prompt cleanup and re-stabilization effort in high-priority areas. Here, a stormwater drainageway has been cleaned and restabilized with seed and hydromulch after the Marshall Fire. Areas in the background that have yet to be cleaned are contained with sediment control logs.

steps will be overseen or executed by contractors, consider preemptively drafting contracts and determining funding sources for the necessary work so that mobilization can occur as quickly as possible after a wildfire.

Finally, determine how the elements of the Plan will be communicated to the relevant stakeholders. Property owners affected by a wildfire are particularly likely to ask for prompt and comprehensive information on when and how they can expect the post-fire response to proceed and whether they have a role to play in that response. Developing materials such as webpages and flyers that communicate the relevant points in the Plan in advance of a wildfire will make it easier to coordinate the activities of stakeholders following a wildfire disaster.

While county hazard mitigation plans are often a good place to start when developing a post-fire response plan that addresses water quality, they usually lack the specificity needed to address water quality at a watershed or stream level, which is the scale at which water quality impacts occur. Therefore, communities should consider developing plans on a watershed basis, using available information on hydrology, hydraulics, and water quality that is likely to be included in any existing watershed plans.

## COORDINATION AND COMMUNICATION

Coordination and communication provide the foundation for successful and efficient post-wildfire clean-up and reconstruction. There are often many parties involved including local governments, state and federal agencies, special districts, local environmental organizations, engineers, scientists, contractors, property owners and occupants, and others. Frequent and effective communication is important because conditions are dynamic in the aftermath of a wildfire.

Coordination with contractors conducting debris removal and reconstruction activities is important for ensuring that post-wildfire BMPs are implemented effectively. BMPs must be installed in accordance with design details and specifications to be effective. Tips for coordination with contractors include:

- The way that payment is structured for hydraulic mulch applications is important. Payment for hydraulic mulch application should be on a per gallon basis, not on the basis of acreage. Because the surface area of debris that must be covered is greater than the plan view area due to the irregular surfaces of debris, application rates must be fine-tuned in the field to assure adequate coverage. If the hydraulic mulch pay item is on an area basis, the contractor has an incentive to cover as much area as they can with as little product as possible, which can result in application rates that are lower than needed to be effective. By paying contractors on a volumetric basis for hydraulic mulch application, the contractor is more likely to apply hydraulic mulch at correct rates, and the rate of application can be adjusted more easily in the field.

A contractor is seen applying temporary stabilization measures to a foundation. Application of hydraulic temporary stabilization measures must occur at the correct rate. To help ensure that application occurs correctly, rely on contractors with demonstrated experience in the field and set up a payment structure that incentivizes quality work.

- Ensure the contractor is experienced with erosion and sediment control installation and maintenance. If a contractor is hired to perform inspections mandated by construction stormwater permits, the inspector(s) must also be qualified. Look for professional accreditations such as Certified Professional in Erosion and Sediment Control (CPESC), Transportation Erosion Control Supervisor (TECS), or Certified Inspector of Sediment and Erosion Control (CISEC).
- At the start of each new phase, hold a meeting with all parties involved in the phase to ensure that roles, responsibilities, and phase objectives are reasonable and well-understood.

## MITIGATION

When time or resources are limited, efforts should focus on implementing stabilization to minimize the release of pollutants from within the burn perimeter until debris removal and reconstruction are complete.

The purpose of initial site stabilization is to establish cover for exposed burned areas that will reduce erosion potential and to provide perimeter containment. In many cases, the initial site stabilization will occur concurrently with site characterization since these controls will be needed regardless of the results of the site characterization. Evaluate whether stormwater permit coverage from the State of Colorado and/or from the

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Personal protective equipment (PPE) should be worn by all site visitors until any potential hazards and contamination sources are thoroughly understood and PPE is deemed unwarranted. PPE needs vary depending on the specific health hazards that are known or suspected to be found on-site. PPE includes hard hats, vests, eye protection, and steel toed boots and may include respirators, air testing equipment, hearing protection, gloves, and other protective devices depending on the hazards that are present. Landowners, contractors, subcontractors, and other site visitors should consult with the local jurisdiction once the site assessment has been completed to determine which forms of PPE must be used while on-site.

local jurisdiction are required to commence cleanup and construction. If stormwater permit coverage is required, prepare stormwater permit-mandated documents (stormwater management plan [SWMP] and others as dictated by the local jurisdiction) and obtain permit coverage.

Existing guidance on erosion and sediment control is generally not specific to post-fire conditions in urban areas. The guidance provided below for erosion and sediment control through different phases of post-wildfire recovery in urbanized areas is adapted from principles of erosion and sediment control that are well-established for use during construction. Please refer to resources such as (EnviroCert Int'l., 2017; Fifield, 2011; MHFD, 2010) for additional discussion of these practices.

## PRIORITIZE AREAS

Prioritize implementation of BMPs in areas that are closest to water features and have the greatest potential to deliver pollutants to receiving waters.

## PERIMETER CONTROL

Place a perimeter control around the downgradient side(s) of any burned structures to contain ash, debris, and associated pollutants. Sediment can be a primary transport mechanism for any organic and inorganic pollutants adsorbed to the soil particles (Jain and Ram, 1997). Many options are available for perimeter controls including compost logs, compost berms, sandbags, sediment control logs, and silt fence. Compost perimeter controls have the advantage of providing a high level of filtration, as well as the potential for adsorption/absorption of pollutants. Providing perimeter controls across driveways that drain directly to curb and gutter is important since this provides a direct flow path to the storm drainage system for pollutants associated with materials typically stored in garages. Use a perimeter control across driveways that is both designed for use without trenching/anchoring and can be moved without undue difficulty such as a weighted wattle or a similar proprietary product. Regardless of the type of perimeter control selected, it is critical to properly install the BMP. Consult with the local jurisdiction on acceptable approaches.

## BMP DETAILS

There are many sources for BMP details and selecting the correct detail to apply can be complicated. It is best to start with local government BMP details if available because these details are consistent with local practices, availability of materials, etc. The Mile High Flood District's (MHFD's) Urban Storm Drainage Criteria Manual, Volume 3 provides details for many of these types of perimeter controls, and many local governments have their own perimeter control details.

## RE-ROUTE CLEAN WATER

Where feasible, re-route flow around burned structures to prevent mixing of clean and contaminated stormwater. Clean runoff can be routed away from a burned structure using earthen berms, sandbags, temporary pipes, or other structures. Minimizing run-on to areas that are known to contain pollutants (e.g., burned structures) is an important source control BMP.

## EXISTING WATER QUALITY FACILITIES

Assess existing water quality and detention facilities  in and downgradient of the burned area to determine if they can serve a temporary role as sediment and debris basins while the burned area recovers. The burned area will generate greater rates and volumes of runoff relative to the unburned condition, so evaluate water quality and detention facilities to determine if there is adequate freeboard or if sandbagging may be needed to protect adjacent areas from flooding. Given the nature of burned watersheds, existing water quality and detention facilities will require more frequent maintenance to remove accumulated sediment and debris.

This permanent stormwater management feature is temporarily serving to capture debris from burn areas upstream, as evidenced by the roof shingles found near the outlet structure. Stormwater quality and detention facilities that can serve as post-fire BMPs require more frequent removal of accumulated sediment and debris to maintain the capacity of the facility and to minimize re-suspension of pollutants during future runoff events. However, the frequency of maintenance can be minimized by implementing effective erosion and source controls upgradient

## TEMPORARY COVER

Provide temporary cover for burned structures and adjacent areas for erosion control.  Temporary cover helps to address erosion from water and wind and has water and air quality benefits. Application of a hydraulic mulch is the most common method of providing temporary cover. Hydraulic mulch consists of water, fiber, and a

PRESERVING WATER QUALITY AFTER WILDFIRES

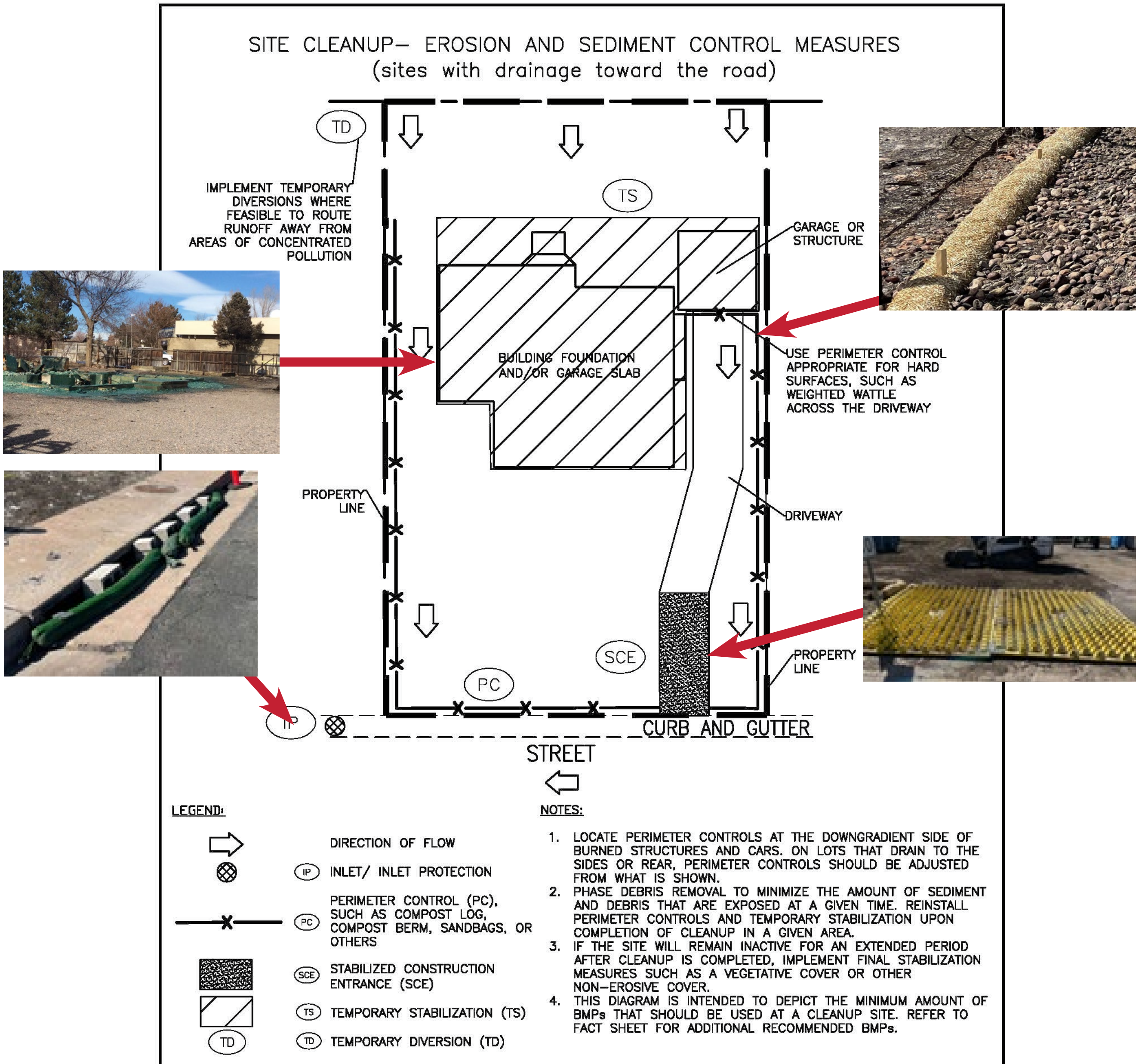
stabilizing emulsion or tackifier. Seed may also be used in hydraulic mulch, but seed is not typically included for temporary stabilization purposes. Hydraulic mulch limits the erosive power of raindrops and overland flow (i.e., reduces particle detachment from occurring in the first place).

Hydraulic mulch recipes, application rates, and application methods vary substantially, depending on factors such as the materials available for use in the mix, the degree of tack desired in the mix, degree of cover desired, and whether special conditions must be met such as use of only natural ingredients. Hydraulic mulch recipes should therefore be selected on a case-by-case basis according to site conditions and long-term objectives and with input from the local jurisdiction.

## INLET PROTECTION & SEDIMENT CONTROL

Consider implementing inlet protection and other sediment control BMPs for storm drainage systems that will receive runoff from burned areas. As noted above, erosion controls generally are more effective and require less maintenance than sediment controls; however, sediment controls may be needed for areas that cannot be contained with perimeter controls (e.g., streets) until debris has been removed from these areas and perimeter controls have been installed around burned structures. Sediment controls may require frequent maintenance in burned areas, so use these practices selectively where needed, and focus on erosion controls that manage pollutants at the source. If a sediment control BMP will not be maintained regularly, do not install it.

A hydraulic mulch containing water, fiber, and guar gel – a plant-derived substance – has been applied to the foundation of the burned structure and remaining debris at this property. The hydraulic mulch will help to limit the sediment and pollutants that wash into the stormwater system during runoff events at the property until the debris can be removed.




CONCEPTUAL SITE CLEANUP DETAIL

PRESERVING WATER QUALITY AFTER WILDFIRES

## DEBRIS REMOVAL

The BMPs in place during debris removal are the same as those installed during initial site stabilization. However, additional BMPs are also needed to address the impacts of construction as debris is removed from burned sites.

### PHASE THE WORK

Phase debris removal to minimize the amount of debris and sediment that is exposed at a given time. Sections of perimeter control BMPs must be removed for access to remove debris and temporary cover will also be disturbed, leaving the work areas exposed to mobilization of pollutants from the site. Replace perimeter controls and re-apply temporary cover after debris removal if sites will be inactive for more than 14 days before reconstruction activities begin. If a site will be inactive for an extended period, implement final stabilization measures including vegetation or another non-erosive cover.

### STREET SWEEPING

Complete street sweeping as needed to remove sediment from streets. Frequent street sweeping, in combination with maintaining erosion controls will reduce the frequency of maintenance or potentially the need for sediment control BMPs.

### CONSTRUCTION ENTRANCES

Add stabilized construction entrances (SCE) where vehicles will transition between pavement and soft surfaces. SCEs work by limiting contact between vehicle tires and disturbed soils to reduce the amount of sediment and other pollutants that are transported offsite on the tire. Once in the street, tracked sediment and pollutants can easily be suspended in stormwater runoff and carried to a receiving water. SCEs can be constructed using materials such as road base, asphalt millings, sheets of plywood, fractured rock, or others, depending on the local jurisdiction's regulations. If a driveway remains in place, a BMP such as a Mud Mat or similar product may be used.

### MAINTAIN SITE STABILIZATION BMPs

Maintain perimeter controls, diversions, and sediment controls at regular intervals. Only install BMPs that will be properly maintained.

Debris removal is underway on this site. Dumpsters have been brought to the site to contain fire debris that will be hauled away. In the foreground, a sediment control log and a proprietary stabilized construction entrance can be seen.

PRESERVING WATER QUALITY AFTER WILDFIRES

# RECONSTRUCTION

After debris removal has been completed and sites have been restabilized, reconstruction can begin. During this phase, the BMPs used are the same as those used for traditional construction. Keep in mind that hazard levels may be elevated at sites undergoing reconstruction as compared with a typical construction site, due to post-fire conditions such as lingering contaminants at the site or hydrophobic soils.

## STORMWATER MANAGEMENT PLAN (SWMP)

A stormwater management plan (SWMP) is a collection of plans, specifications, and narrative text that describes how the pollution of stormwater will be minimized at a construction site and documents adherence to the plan throughout the construction process. In Colorado, SWMPs must be drafted for and implemented on all construction sites that disturb one or more acres of land. SWMPs must also be drafted and implemented on sites that disturb less than an acre but are part of a larger common plan of development or sale disturbing one acre or more of land. These sites must also obtain a certification to discharge under permit COR400000 or an alternate permit issued by the Colorado Department of Public Health and Environment (CDPHE). The required elements of the SWMP and inspections of SWMP-related control measures can be found in permit COR400000 on CDPHE's website.

Some jurisdictions may have more stringent requirements for when construction stormwater discharge permits and SWMPs are required. In all cases, the most restrictive regulations must be followed.

Common construction BMPs such as silt fence and street sweeping should be used during the reconstruction phase. SWMPs contain information on where and how to install the construction BMPs.

PRESERVING WATER QUALITY AFTER WILDFIRES

## PERMANENT STABILIZATION

Permanent stabilization must be implemented once construction activities are complete so that sediment transport by runoff will be minimized in the future. At this stage, much of a site may already be stabilized by the placement of buildings, sidewalks, driveways, parking lots, and landscaped areas. Where no formal installations are planned, stabilization should consist of native vegetation.

### VEGETATION

Crimp mulch works best when it forms a covering that is thick enough to protect the soil surface without being too thick to allow for seed germination.

Once lot has reached "final" configuration (after debris removal or construction, depending on landowner's intent), install seed and mulch or seed and blanket wherever the land is not otherwise covered. Where feasible, use drill seeding to ensure good contact with the soils or use a hydraulic mulch with a locally-approved seed mix. The Final Stabilization fact sheet in Volume 3 and the Revegetation Chapter of Volume 2 of the MHFD Manual provide regional guidance and criteria for establishing a healthy vegetative cover. It is very important to follow local criteria for seed mixes because many local governments have specific seed mixes. Specific seed mixes are developed for different soil types and land uses, and for different stabilization goals. Some seed mixes may prioritize getting a stand of vegetation to grow in quickly by emphasizing the use of annuals, while others may prioritize restoring native vegetation by relying primarily on perennial grasses and/or forbs.

### COMPOST

Consider supplementing soils to be restabilized with native vegetation with compost. In addition to supporting the regrowth of vegetation, research suggests that PAH contamination in soils can be bioremediated to some degree by certain microorganisms found in compost (Ghosal et al., 2016).

### WATERING & IRRIGATION

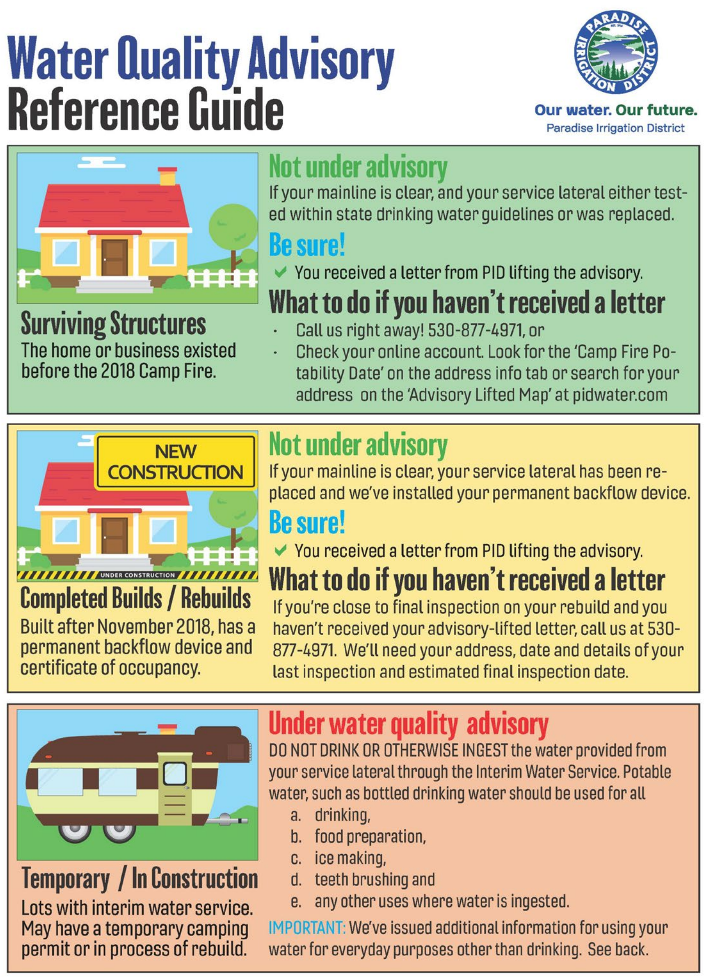
It can be challenging to germinate and maintain vegetative soil covers following a wildfire in arid and semi-arid regions. Temporary or permanent irrigation may be appropriate depending on the use of the site. Care should be taken to ensure that irrigation is applied only as needed to avoid over-saturating soils or causing irrigation runoff which can also mobilize and transport pollutants offsite.

## MONITORING AND ALERTS

After a fire, many property owners in the community will want to return to their property quickly to either resume use of their property or begin cleanup. It is of vital importance to provide warnings and alerts for known or potential health impacts resulting from post-wildfire conditions as soon as possible after the wildfire, and ideally before permitting reentry onto affected property.

Some warnings and alerts can be created in advance and deployed immediately after the fire. For example, potable water supplies that flow through plastic piping may contain carcinogenic compounds that were generated during the fire event (Chong et al., 2019). Property owners and occupants should be advised to avoid use of tap water until the supply can be tested and verified for safety.

Planning for how warnings and alerts will be issued should account for the audience, considering both the media that will best convey the information and the degree of specificity and overall tone of the communication. Whereas a memorandum containing technical information on water quality test parameters may be most valuable to scientists and engineers, a pamphlet containing a high-level overview of key behavioral changes is likely better suited to property owners and occupants. Consider planning for the use of multiple media, both so that a broader audience can be reached and as a resilience strategy in case the primary method is rendered infeasible as a result of the wildfire.



Water Quality Advisory
Reference Guide

Our water. Our future.
Paradise Irrigation District

Surviving Structures
The home or business existed before the 2018 Camp Fire.

Not under advisory
If your mainline is clear, and your service lateral either tested within state drinking water guidelines or was replaced.

Be sure!
✔ You received a letter from PID lifting the advisory.

What to do if you haven't received a letter
- Call us right away! 530-877-4971, or
- Check your online account. Look for the 'Camp Fire Potability Date' on the address info tab or search for your address on the 'Advisory Lifted Map' at pidwater.com

NEW CONSTRUCTION

Completed Builds / Rebuilds
Built after November 2018, has a permanent backflow device and certificate of occupancy.

Not under advisory
If your mainline is clear, your service lateral has been replaced and we've installed your permanent backflow device.

Be sure!
✔ You received a letter from PID lifting the advisory.

What to do if you haven't received a letter
If you're close to final inspection on your rebuild and you haven't received your advisory-lifted letter, call us at 530-877-4971. We'll need your address, date and details of your last inspection and estimated final inspection date.

Temporary / In Construction
Lots with interim water service. May have a temporary camping permit or in process of rebuild.

Under water quality advisory
DO NOT DRINK OR OTHERWISE INGEST the water provided from your service lateral through the Interim Water Service. Potable water, such as bottled drinking water should be used for all
a. drinking,
b. food preparation,
c. ice making,
d. teeth brushing and
e. any other uses where water is ingested.

IMPORTANT: We've issued additional information for using your water for everyday purposes other than drinking. See back.

Above is an example of a reference guide produced by the Paradise Irrigation District after the Camp Fire in 2018. The reference guide is intended for property owners and occupants and provides a high-level and easily-digestible overview of the key points of the advisory to promote widespread awareness and understanding of the advisory.

# EROSION AND SEDIMENT AFTER A WILDFIRE

WILDFIRE READY WATERSHEDS
FACT SHEET

Version 22.01 | December, 2022

## OVERVIEW

Soil erosion from a hillslope after a fire. Credit: John Moody, USGS

After a wildfire, erosion of soil from the hillsides can increase dramatically compared to pre-fire conditions. The transport and deposition of this eroded soil further down a valley can:

- Degrade water quality for people and wildlife,
- Reduce the storage capacity of reservoirs,
- Plug water diversion and delivery infrastructure as well as culverts and bridges, and
- Increase flood and fluvial hazards through sedimentation in stream channels.[1]

Before a fire, trees and shrubs along with the leaves, sticks, and duff (organic material) that normally cover a forest floor all work together to catch and soak rainfall into the soil below. When rainfall soaks into the soil, less runs off the surface resulting in lower rates of soil erosion from hillslopes.  This protective ground cover is often burned in a fire and, along with an increase in water repellency of the burned soil itself (hydrophobicity), less rainfall is absorbed into the soil and instead more rainfall runs off along the ground leading to more erosion of soil.

This Wildfire Ready Watersheds Fact Sheet provides high-level guidance on methods and tools for helping communities predict where and how much soil erosion will happen following a wildfire and what the effects will be on downstream assets. It also identifies actions that may be taken to reduce the impact of these landscape processes on infrastructure and natural resources – both before, and after, a wildfire occurs. This Fact Sheet supports pre-and post-wildfire planning and response efforts in your community.

## HAZARD AND RISK CHARACTERIZATION

### Hazard Overview and Causes

There are three primary sources of problematic erosion after a wildfire:

1 https://labs.waterdata.usgs.gov/visualizations/fire-hydro/

- Surface erosion (rill, inter-rill, and gullying) from hillslopes where soil particles are entrained by surface runoff and move downslope in sheet flow and/ or small rivulets. The focus of this Fact Sheet
- Debris flows (a concentrated mass of sediment, debris and water moving down a steep gully). See **Debris Flow Fact Sheet**.
- Erosion and deposition of sediment within a stream corridor caused by flooding. See **Fluvial Hazards After Fire** and **Flood After Fire** Fact Sheets.

Alluvial Fan delivering sediment to a stream. Credit: R.H. Meade, USGS

Surface erosion of soils from hillslopes increases following a wildfire as a result of increased exposure to raindrops which dislodge and move soil particles with greater ease once protective groundcover and vegetation are removed from the landscape. The more intense a fire, the deeper it will burn into the soil column making vegetation re-establishment slower and prolonging the time over which soil erosion is a post-fire hazard. Additionally, intense heat from a wildfire can physically alter soil causing it to repel water, a condition called hydrophobicity. When soil becomes hydrophobic, water infiltration decreases and surface runoff increases, often condensing in small rivulettes which then erode into rills and gullies, further increasing the erosion of soil particles, or sediment, from hillslopes. Combined, these changes to vegetation cover and soil structure increase the soil erosion potential of burned hillslopes, often dramatically increasing soil erosion and its impacts downstream following a wildfire.

## Potential Impacts

Soil erosion from hillslopes can impact the built and natural environment in three primary ways:

- Delaying and negatively impacting re-vegetation of burned areas, which can alter the species, quantity, and vigor of surviving plants and the native seed bank.
- Direct erosion impacts to infrastructure, like roads, trails, and even building foundations, through gully formation that can affect access and safety.
- Downstream deposition of eroded soil (sediment deposition and stream channel aggradation).

Soil erosion after a fire removes organic material important for vegetation re-establishment. Erosion plus the altered characteristics of the soil after a fire means that the quantity and vigor of plants is reduced. Even the composition of species that can colonize and establish in a burned area can be different from what existed before the fire. Where erosion is concentrated, gully formation can create challenges for humans by eroding away access (e.g., roads, trails) or even infrastructure (e.g., foundations, septic, etc.).

Finally, soil erosion can lead to sedimentation problems as the eroded soil moves downslope or downstream. Hillslope soils eroded from burn scars typically deposit where slopes transition from steep to less steep valley bottoms. If these transition points are located in or near a stream, then eroded soils can be carried down into stream systems where their impacts are numerous. Excessive eroded soil in a channel (sediment) can increase flood depths of surrounding properties, plug stream crossings (culverts and bridges), degrade habitat, impact diversion infrastructure, and more. If these streams carry water toward a lake or reservoir, then this sediment can degrade the water quality of that body of water and reduce the volume of water that is able to be stored there.

A rule of thumb is that for the first two to three years following a wildfire the hillslope erosion rates will be high and similar to erosion rates just after the fire. This is a particularly hazardous time. Then, erosion rates and sediment loads decline up until approximately year six or seven (or sooner) following a fire, at which point the recovery slows down. Over the long term, recovery to pre-fire soil-erosion rates may never occur as the forest structure and plant composition and density may permanently change because of the fire and because of climate change. Once in a stream or river, eroded sediments may take decades to centuries to transport through a stream.

*"A rule of thumb is that for the first two to three years following a wildfire the hillslope erosion rates will be high and similar to erosion rates just after the fire."*

Gully erosion following a fire. Credit: John Moody, USGS

## Hazard Identification

Land managers often need to predict watershed-scale erosion rates and erosion hot spots after a wildfire. Soil erosion can be modeled geospatially (GIS) to identify hillslopes and other areas that are expected to be more prone to post-fire erosion. Other alternatives include using the Soil erosion modeling such as the Revised Universal Soil Loss Equation (RUSLE ). Modeling estimates often are limited in their accuracy in predicting the actual quantity or yield of soil eroded from a particular area; however, these models can be put to use in a pre/post wildfire comparison to identify erosion hotspots or areas that are relatively more erosion prone. Identifying valleys and stream corridors that are more likely to recruit and export soil eroded within the uplands is an important analysis to conduct as well. These analyses can be converted into maps that show where a community can expect more soil loss and sediment supply to downstream systems.

## PRE-FIRE PREPAREDNESS

This section provides information on how communities can prepare for and mitigate soil erosion impacts before a wildfire occurs.

### Identify the Hazard and Understand Where Risk Exists

- Conduct a baseline conditions assessment – a GIS-based analysis to identify the most vulnerable hillslopes that are connected to stream corridors or other at-risk assets.
- Identify where additional data and evaluations are needed to support decision-making.
- Model soil erosion and sediment transport: understand the data needs of these models and ensure that baseline data is available for the community.
- Identify values at risk from soil erosion and sedimentation and prioritization. This includes assets like drinking water infrastructure, reservoirs, irrigation infrastructure, as well as important aquatic resources .

### Identify Local/State/Federal Resources and Coordination

- Review multi-hazard mitigation plans with a team of multi-disciplined professionals including experts in soils, water resources, engineering, geomorphology, vegetation, ecology, and biology.
- Develop stakeholder communications to identify contacts and strategize mitigation planning based on understanding of assets at risk.
- Develop communication around the topic to be deployed with other community outreach efforts.

### Evaluate Pre-Fire Mitigation Options

- Incorporate soil erosion and deposition hazards into Watershed Hazard Mitigation Plans.
- Develop priorities, concept designs, and implementation recommendations for a post-fire scenario that are appropriate for your watershed.
- Identify restoration, infrastructure retrofits, and other pre-wildfire mitigation projects.
- Reverse a century's trend and begin the process of restoring beaver and wood back into stream corridors, and reconnecting degraded floodplains. These elements of stream corridor restoration provide a multitude of benefits in non-fire impacted landscapes and become even more

important when fires do occur as they can capture and store eroded sediment.

## MITIGATION

This section provides a high-level overview of potential mitigation efforts that could be made to reduce the impacts of soil erosion following a wildfire. Most of these recommendations are for immediate post-fire action while some could be considered for pre-fire mitigation. Runoff and erosion reduction treatments can be applied to recently burned hillslopes to promote infiltration and abate the development of erosional features (e.g., rills and gullies) that ultimately contribute to debris flow occurrence. See the WRW Sediment Fact Sheet for more information on these treatments.

### Watershed-Scale Mitigation

**Targeted Mulching** – Mulching can be an effective tool to reduce sediment yield from hillslopes as well as aid in the establishment of vegetation. Identification and prioritization of critical areas for mulching should be a primary strategy of recovery efforts, as it would be impractical to mulch an entire burn scar. For example, slopes with anticipated high sediment yields, as determined through sediment yield modeling and that are highly connected streams that flow into infrastructure like diversions and to reservoirs would likely rank high for priority. Wood straw and shred mulch are preferred over straw mulch due to the latter's propensity for introducing unwanted weed seeds and for being displaced by wind events. Furthermore, wood mulch has been found to be superior for tree seedling establishment.[2,3,4] Depending on the type (hydro, straw, wood shred, etc.), mulch can be applied on slopes of up to 65%, as mulching on steeper slopes may have declining effectiveness with increased cost. Slopes in the range of 25-45% are

### IS YOUR STREAM CORRIDOR A SOURCE OR A SINK?

The existing form of a stream channel and its floodplain is often influenced by both natural and human-made stressors and drivers. Physical stressors refer to natural and anthropomorphic alterations to the landscape that affect the form and physical processes of the stream corridor. Identification and consideration of historical and contemporary stressors at the watershed- and reach scale may help to explain the modern form of the stream and illuminate the ability of a stream corridor to capture sediment during a post-fire flood event. For example, significant alterations to natural biotic conditions such as density and composition of riparian vegetation, presence of beaver, and abundance of large wood within a stream corridor will likely change a stream's ability to resist erosion and attenuate sediment and water (Nardi and Rinaldi, 2015). Furthermore, the incision of small tributary streams has sent sediment downstream causing channel widening and sedimentation in many mainstem rivers affecting water infrastructure. Stabilizing channels and reconnecting floodplains on your land today can help us all out tomorrow.

2 Napper, C. (2006). Burned Area Emergency Response Treatments Catalog. Technical Report. 0625 1801-SDTDC, Washington, D.C.: U.S. Department of Agriculture, Forest Service, National Technology & Development Program, Watershed, Soil, Air Management. 266 p. http://www.fs.fed.us/eng/pubs/pdf/BAERCAT/lo_res/06251801L

3 Rocky Mountain Research Station. (2017). Science You Can Use Bulletin: Learn from the Burn: The High Park Fire 5 Years Later. May/June. Issue 25. https://www.fs.usda.gov/treesearch/pubs/54288

4 Robichaud, P. et al. (2013). Production and aerial application of wood shreds as a post-fire hillslope erosion mitigation treatment. Gen. Tech. Rep. RMRS-GTR-307. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 31p. https://www.fs.usda.gov/treesearch/pubs/43920

most likely to achieve overall effectiveness relative to cost for aerial mulching and are also good slopes for targeted seeding if that is also an identified strategy.

**Targeted Seeding/Reforestation** – Re-seeding efforts have had mixed results with some Colorado studies fining no significant increase in vegetation growth or post-fire sediment delivery rates and other studies finding more diverse and dense re-vegetation in burned plots that were re-seeded. If seeding and reforestation efforts are conducted, numerous factors should go into planning efforts to investigate such things as species selection and seed viability, natural regeneration capacity (e.g., litter and crown cover), soil and moisture conditions, timing, and rates. Both positive impacts (reduced erosion and reduced invasive species) and negative impacts of seeding (limited long-term native vegetation establishment) must be weighed.

## Point-of-Impact Mitigation

**Targeted Sediment Catchment/Capture Systems** – Sediment can be captured and stored in floodplains and other natural "sink" areas where water is forced to slow down and spread out. An analysis of valley geomorphology and/or other data may help a recovery team identify where these sediment sink areas exist in the watershed and stream corridors and if enhancing their sediment storage potential through restoration actions would be appropriate. Such restoration actions may include floodplain reconnection and rehabilitation, and/or beaver and wood re-introduction. Similarly, engineered sediment ponds may be constructed to capture sediment, although these may be expensive to construct and only marginally effective due to limited lifespans and propensity to fail during large floods. Such failures can lead to more sedimentation problems downstream.

Mulching and tree logs placed to intercept sediment and disrupt runoff to reduce erosion. Credit: XXXX

**Ground Cover** – Various ground covers can be applied to bare hillslopes immediately after a fire to promote infiltration and reduce soil erosion. When properly applied, natural or artificial ground cover can protect soils from raindrop impact and increase the rate of vegetation recovery. Potential cover types include natural mulches, such as wheat straw and wood shreds, and hydraulic mulches, such as a bonded fiber matrix, among others.

**Erosion Control Barriers and Slope Length Reduction** - Physical barriers such as straw wattles, downed tree logs, interceptor swales, and silt fences can be used to reduce downgradient runoff and sediment transport by intercepting sediment and water. However, care must be taken to properly install and maintain these physical hillslope barriers as undermining, piping, excessive sediment accumulation, inadequate density and spacing, etc. can lead to failure. It is not uncommon for failed structural hillslope and channel BMPs (discussed below) to become entrained and subsequently incorporated into a debris flow (which only makes the problem worse). Felling logs on contours on hillslopes to reduce soil erosion has been found to be relatively ineffective due to undercutting of logs by erosion, off-contour placement, or overtopping by eroded sediment.

**Mechanical Raking** - Mechanical raking can be used to break up rills and gullies before they increase in size. Raking is typically achieved with large farming equipment or manually with hand tools and is often applied in tandem with one or more of the aforementioned erosion control BMPs. Mechanical raking is not typically feasible for large areas or areas with a slope greater than 30 percent.

## MONITORING AND ALERTS

The CWCB is available to assist in providing guidance for predicting changes in post-wildfire sediment delivery and to help prepare communities for sediment impact scenarios downstream of fire impacted areas. At this time no known monitoring or alert systems are known for soil erosion hazards.

Black Hollow watershed in the burned area within the Cameron Peak Fire Boundary. Credit: Chris Sturm, Colorado Water Conservation Board.

# POST-FIRE HAZARDS AND WATER INFRASTRUCTURE

| WILDFIRE READY WATERSHEDS<br>FACT SHEET | **Version 22.01** \| December, 2022 |
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## OVERVIEW

This Wildfire Ready Watersheds (WRW) Fact Sheet introduces readers to Colorado's water supply infrastructure, which includes how we move, store, treat, and use water. It discusses why those systems are vulnerable to wildfire disturbance and how risks can be reduced in before and after a wildfire.

## HAZARD AND RISK CHARACTERIZATION

As a headwaters state, Colorado's watersheds supply high quality water to millions of people within the state and to downstream states as well. That water is quantified, monitored, impounded, transported, treated, and distributed with an intricate network of natural and built infrastructure. The following sections describe how specific components of that infrastructure system are vulnerable to post-wildfire impacts.

### Source Water

Areas or watersheds that provide surface and groundwater drinking supplies are considered "source water areas." Much of Colorado's source water areas in the Rocky Mountains and foothills are forested making these areas vulnerable to wildfire. Where source water areas overlap with designated Wilderness Areas and steep terrain, mitigating the impacts from potential wildfires can be challenging. Management activities that aim to make source water areas more resilient to various disturbances have become more popular over the last decade, including actions that limit the chances of moderate to high burn severity fire. Source water protection is discussed in more detail in the "Pre-fire Preparedness" section of this fact sheet.

### Storage Infrastructure

Colorado's public water utilities collect and store water supplies with a complex network of infrastructure. In 2019, Colorado had 1,953 surface reservoirs under the jurisdiction of the State with a total storage capacity of approximately 7.5 million acre-feet. Water is also collected from underground aquifers. Fire can impact storage infrastructure by reducing storage capacity via enhanced sedimentation, impeding access for utility maintenance crews (both during and after the fire event), altering water quantity, and degrading water quality. For example, fire has been shown to

Dredging operation in Strontia Springs Reservoir. Photo Credit: Denver Water

increase reservoir sedimentation rate
as far as 100 miles downstream from
2002 Hayman Fire, the City of Denver
spent approximately $30 million dred
sediment, ash, and debris from Chees
the following decade.

## Diversion Structures


Typical layout of a water diversion structure. Graphic from Image from Planning and layout of small-stream diversions Axness & Clarkin, 2013

Structures to divert the flow of water
conveyance features and pipelines ar
municipal water supply, and hydropo
common for ranchers and farmers to
called headgates to divert a specified
volume of water from a main channel
and then a network of canals, ditches, and pipelines to move that water to individual farms and fields. Mobilization and accumulation of sediment and debris from fire-impacted watersheds can clog water intake structures and create backwater effects and ditch overtopping/failure, fill in conveyance features, and degrade the stability and function of the natural channel. Downstream, that same ash and sediment can clog sprinkler filtration and drip systems.

Ash- and sediment-laden runoff passing by a water diversion structure. Credit: Katie Jagt, Watershed Science and Design.

## Water Treatment Facilities and Processes

Wildfires can cause direct impacts to and operational challenges for drinking water treatment plants. Direct impacts can include damage or destruction of the plant, its intake and conveyance structures, or its storage structures; loss of power; and loss of access to the plant. Because water treatment plants function most efficiently when incoming raw water quality is consistent, a

POST-FIRE HAZARDS AND WATER INFRASTRUCTURE primary post-fire challenge is the variable quality of source water delivered from burned watersheds. Water taste, odor, and color may all be affected. Burned watersheds typically produce higher concentrations of suspended sediment, which elevates turbidity. Depending on the treatment technologies and processes used, this may require enhanced solids removal including sedimentation, coagulation, and flocculation. Particle loading and altered chemical constituents in the raw water can change its pH and alkalinity affecting dosing for these processes. For systems that rely on mechanical filtering, sediment loads can clog membrane filters and require shorter filter run times and higher backwashing frequency. Elevated concentrations of dissolved organic carbon can react with some of the disinfection agents commonly used to remove pathogens resulting in higher concentrations of disinfection by-products. All of these potential impacts to drinking water quality from wildfires may require short or long term changes to treatment processes and technologies, real time monitoring of raw water quality, as well as alternative water supplies.

### Drinking Water Distribution Systems

The majority of drinking water distribution systems are buried pipelines, which often have sections composed of plastic materials. Though typically buried several feet under ground, these pipes can be exposed to high temperatures during a wildfire leading to thermal degradation and melting. Subsequently, plastic pipes can leach volatile organic compounds (VOCs) into local drinking water supplies, including benzene, which is a known carcinogen. Another concern for drinking water distribution systems is back siphoning of contaminated water from heat-damaged buildings and their plumbing (some of which may be plastic). Entrainment of contaminated ash or air in the distribution system if it depressurizes has also been hypothesized as potential causes of wildfire-induced drinking water contamination.

Relevant federal and state guidance documents for drinking water wildfire protection include:

- EPA Incident Action Checklist
- CDPHE Critical Community Watershed Wildfire Protection plan implementation guidance
- Source Water Assessment and Protection (SWAP) planning

## PRE-FIRE PREPAREDNESS

The following section describes actions that communities and water providers can take to reduce their wildfire-related water supply risk before a wildfire occurs.

### Land Management

Source water protection

Source water assessment and protection (SWAP) has become an increasingly popular management technique for protecting high quality drinking water supplies. The Colorado SWAP program works with water providers to identify susceptibility of current and future water supplies to potential contaminant sources and develop plans and policies to protect them. This includes contamination from wildfires. SWAP addresses root causes by working to prevent source water contamination from happening. Thus, SWAP can be more cost-effective than an end-of-pipe treatment solution because it is much easier to transform high quality raw water into safe drinking water than it is to address contamination on the back end. High quality source water also tends to yield fewer potentially harmful disinfection byproducts.

Source water contamination may occur outside of a wildfire; however, wildfires can exacerbate contamination by causing spills and releasing organic chemicals and heavy metals into the environment and water supply from burned buildings and human-made items. Water providers can use SWAP to safeguard all aspects of drinking water supply, including the quantity, timing of availability, and quality of their water. SWAP activities might include compiling a detailed inventory of water resources within the source area, identifying and prioritizing vulnerable areas (e.g., sensitive wetland habitats), areas where forest health improvement activities would be beneficial (see next section), surveying all potential contaminant sources, and implementing a rigorous set of policy tools and actions to prevent or minimize contamination from those sources.

## Forest health

Before a fire occurs, watershed managers can take steps to increase the health and resilience of their forested areas to disturbances, including severe wildfire activity. Forest health initiatives may include actions that reduce the likelihood for ignition sources to contact potential fuel, or for low severity fires to grow into larger events that are harder to control. Fuel management is one common tactic for this. Foresters may remove vegetation where potential ignition sources exist (e.g., along electrical utility lines; a buffer around vehicular traffic roads as cars dragging chains, or improper cigarette disposal can generate sparks), removing the lower branches from evergreen trees to reduce the chance of a ground surface fire to climb upwards into the tree canopy (ladder fuel), or conducting prescribed burns to thin understory vegetation. Other forest health initiatives may include treatments to reduce insect-driven tree mortality, funding the expansion of monitoring equipment, such as stream gages or snow pillows, or creating cost-sharing frameworks for local agencies to access federal funding mechanisms.

Pre-fire mechanical thinning of a forested hillside

## Water providers

### Structural Asset Management

Water utilities can utilize structural asset management to reduce potential wildfire-related service disruptions. Before fires occur, water providers should compile a detailed inventory of assets to understand where pre-fire protection measures should be focused. Hard measures to capture sediment and larger debris can be installed above critical surface water storage features, such as debris basins, settling ponds, and rock nets. Because they are particularly susceptible to damage, critical surface diversions should be protected under the guidance of an engineer. An operations, monitoring, and maintenance plan (OM&M) should be prepared for surface diversions to identify what actions are required to ensure the diversion is operating effectively and efficiently to limit impacts to riparian area, the stream channel, water quality, and aquatic species. OM&M actions may include routine inspection and repair of the various diversion structure's components (e.g., headgate, water conveyance system (canal, ditch, pipe), in-stream features to build head, screen or pass fish, improve sediment transport, water measurement devices); removal of excess vegetation and sediments before and after wet weather events; and observation during peak flow events.

### Non-structural Asset Management and Redundancy

Water providers can also consider non-structural management measures to boost resilience of their assets. Non-structural actions may include the diversification of water supply portfolios to reduce dependence on any one water source, planning for periods of shutdown by ensuring storage is adequate to provide carryover, and engineering system components such that rapid system-wide shutdowns and restarts are possible. Where feasible, including redundant raw water diversions, intakes, or conveyance paths from a reservoir can also boost wildfire resilience by allowing water managers to choose which part of the storage pool to draw from. Communities with redundant water supply sources are far less likely to experience service disruptions than those with a single water source. This is because larger or more spatially distributed source water areas are less likely to have all of their area impacted by wildfire and/or high intensity storm events at the same time.

Other considerations for pre-fire and incident water system management and planning are outlined below in the text boxes entitled Long-term Improvements and Incident Preparation and Incident Plans

## MITIGATION

In addition to pre-fire preparedness, communities and water providers can reduce wildfire-related water supply risks in the weeks, months, and years following the wildfire event. The following section describes post-fire hazard mitigation techniques.

## LONG-TERM IMPROVEMENTS AND INCIDENT PREPARATION

Develop a working group with local fire authorities; watershed and/or forest managers; local municipalities or relevant utility companies; and drinking water utility managers, operators, and engineers

- Identify, prioritize, and implement improvements to the watershed to reduce the risk of wildfires and ensure evacuation/access roads
- Identify, prioritize, and implement site- and infrastructure-specific defensible space and ignitability improvements, and remove and protect combustible fuels

Drinking water treatment engineers and operators conduct a drinking water utility wildfire-specific vulnerability assessment and develop an associated tool for prioritizing vulnerabilities

- Develop design, modification, or relocation plans and identify funds associated with the following areas of system vulnerabilities/susceptibilities: Infrastructure vulnerable or susceptible to fire, flash-flooding, and post-fire debris inundation and sediment
- Improve redundancy with adjacent systems and explore diversifying water sources (i.e., different source waters in adjacent watersheds and groundwater sources)
- Develop plans to adjust drinking water treatment processes based on potential short- and long-term effects of wildfire on drinking water quantity, quality, and treatability
    - Consider impacts to secondary processes and treatment trains such as residuals handling and onsite chemical storage
    - Consider additional monitoring requirements for operational control and infrastructure protection
    - Conduct emergency power supply load testing of foreseeable wildfire response conditions
    - Conduct training exercises and drills for during- and post-wildfire operations

## INCIDENT PLANS

- Life and safety plans to protect personnel
- Emergency operations plans, including appropriate laboratory testing and chemical stocks
- Emergency drinking water supply plan with specific plans for priority water customers (i.e., medical facilities and nursing homes)
    - Options include interconnected systems, bottled water, bulk water hauling, mobile treatment units, or temporary supply lines
- Power and fuel supply plan including booster stations and remote or satellite infrastructure power needs
- Personnel plans for incident response and increased laboratory and operational workload
- Communication plans with drinking water treatment facility operators, distribution personnel, emergency responders, and customers

## Emergency Monitoring and Alerts

### Early Warning Systems

Severe forest disturbance should be a reminder to look out for incoming severe weather. Instrumentation to support early warning systems can be installed in and around burn scars of interest to assess real-time conditions. Rain gages or radar data can help meteorologists and hydrologists predict and continuously monitor the likelihood of a debris flow generating rainfall threshold being exceeded; soil moisture probes can inform scientists when soil moisture content and pore pressure are high enough on burned hillslopes to potentially cause or contribute to shallow slope failures; and turbidity probes upstream of water intakes can aid operators in determining when incoming pulses of sediment should trigger closures of intakes or diversion headgates before damage to processes occurs. Following the 2012 High Park fire, for example, in-stream turbidity sensors enabled upstream monitoring and provided an early warning system for the City of Fort Collins. High turbidity triggered intake pipeline shut down which protected treatment infrastructure from abnormally high incoming sediment loads. A pre-sedimentation basin also helped mitigate damages to the treatment plant by capturing solids upstream of the treatment.

Water providers can also utilize data analytics solutions to streamline and automate monitoring and effectively keep track of assets. Automated tools such as supervisory control and data acquisition (SCADA) can be used to improve operations and ensure goals are met during periods with high raw water quality variability. Advanced asset management programs are becoming more widespread for predicting performance instead of reacting to component failures, reducing the frequency and duration of service disruptions.


Online data dashboard for real time turbidity measurements in the raw water supply upstream of the Town of Silt's drinking water intake structure. Silt can reduce or temporarily halt its water intake during high turbidity events. Source: Middle Colorado River Watershed Council

## Watershed recovery and rehabilitation

Hillslope erosion, channel, and road trail treatments such as mulching or the installation of check dams can be used to decrease erosion and storage sedimentation. In addition, foresters can implement a variety of measures to increase revegetation success following a wildfire. The accompanying WRW Fact Sheets (along with other resources available on the WRW website) can be visited for additional information on common post-fire best management practices (BMPs) for watershed recovery and rehabilitation.

Straw bale check dams capturing sediment in a small drainage upstream of a water supply reservoir. Photo Credit: Katie Jagt, Watershed Science and Design.

## Public communication

Public communication is an important component of post-fire hazard mitigation. The more the public knows about the potential risks of severe wildfire to water supply infrastructure, the more diligent each member of society can be about reducing the risk of wildfire damage to critical infrastructure. Examples of actions that water providers can take include; public outreach campaigns to educate their user base about ways to minimize water quality contamination (e.g., proper perimeter control of burned residential structures – see associated Urban Water Quality Considerations WRW fact sheet); issuance of boil-water advisories or do-not-use orders in the event of water contamination; advising customers to keep emergency supplies on-hand in the event of service disruption; and keeping communication lines strong between and within partnerships.

# FLUVIAL HAZARDS AFTER A WILDFIRE

**WILDFIRE READY WATERSHEDS**
FACT SHEET

**Version 22.01** | **December, 2022**

## OVERVIEW

This Wildfire Ready Watersheds Fact Sheet provides information about fluvial hazards, and how communities can better prepare for and mitigate these hazards in their communities.

Fluvial processes within Colorado's stream corridors include streambank erosion, deposition of sediment and woody debris, scour and cutting of new channels, and channel movement into terraces and hillslopes that result in landslides or hillslope failures. These natural fluvial processes are part of living near a stream corridor. These processes become especially hazardous to infrastructure, property, and life in the aftermath of wildfires.

### FLUVIAL HAZARD ZONE

The Fluvial Hazard Zone (FHZ) is defined in the State of Colorado as the area a stream has occupied in recent history, may occupy, or may physically influence as the stream stores and transports water, sediment, and debris.

## HAZARD AND RISK CHARACTERIZATION

### Hazard Overview and Causes

Fluvial processes such as streambank erosion, deposition of sediment and woody debris, scour, and cutting of new channels are the result of physical interactions between water, sediment, vegetation, and debris in a stream corridor. Wildfires significantly alter watersheds resulting in sometimes dramatic increases in the amount of runoff from hillslopes, flood waters, and the quantity of sediment and debris that is delivered to a creek or river channel. The increased amount of water, sediment, and debris that a burned watershed contributes to a stream corridor can lead to rapid, frequent, or large expressions of these natural fluvial processes.

Bank erosion along a roadway corridor in the 2013 flood events in Colorado. Credit: Colorado Department of Transportation.

Fluvial processes become hazardous when infrastructure, houses, businesses, and other community or commercial values are constructed in locations where fluvial processes naturally occur. These natural processes can even be amplified by human alterations to stream corridors such as the placement of undersized bridges, culverts, and diversion structures that impede natural sediment transport, or projects that reconfigure and disconnect channels from their floodplains such as channelization, fill, development, armoring, and levees.

Fluvial processes are not limited to the areas immediately adjacent to stream channels. These processes occur throughout the floodplain and sometimes also impact hillsides or terraces many feet away from and above the surface of the water in a stream channel. Accounting for the full area of potential impacts is critical to accurately plan for the protection of life and property.

## Hazard Identification

Fluvial Hazard Zone (FHZ) mapping is a means to help identify areas subject to erosion and sedimentation hazards both before and after wildfires. It can also be used to identify areas where floodplain rehabilitation, flood improvement projects, and land conservation can mitigate these hazards.

As a part of many different types of planning efforts, some Colorado communities are choosing to map Fluvial Hazard Zones – the areas that a stream has occupied in recent history, may occupy, or may physically influence as it stores and transports water, sediment, and debris. FHZs are mapped primarily by fluvial geomorphologists through the interpretation of topographic, geologic, and geomorphic information (i.e., data that describes the physical location, form, and active sediment and debris transport processes of a riverine system). Mapping is completed through the interpretation and synthesis of geomorphic, geologic, hydrologic, and biotic information.

FHZ maps are a valuable tool for communicating hazards associated with rainfall, flooding, and debris flows after wildfires. After a wildfire, FHZ maps can be quickly and cost-effectively created to delineate areas vulnerable to sediment and flood impacts spurred by rainfall over the burn scar. Mapping these post-fire hazards may allow downstream residents to prepare by preemptively moving vehicles, storage units, and other items to safer locations and to develop evacuation plans. This can also provide communities with an assessment of vulnerable populations for emergency response planning.

The Colorado Water Conservation Board has developed a scientifically-backed and expert-vetted mapping protocol for professionals to follow; however, various methods for delineating the FHZ exist in the field of practice.

Fluvial hazard maps:

- Identify where a stream or river may move or may cause damage during a flood or a flood after a wildfire i.e., erode a high bank and undermine a structure or deposit sediment and debris.
- Show susceptibility rather than probability; FHZs provide the estimated maximum extents of the active stream corridor rather than the limits of a specific flood occurrence.
- Are separate and different from Flood Insurance Rate Maps (FIRMs) but may use information from Flood Insurance Rate Maps

### FLUVIAL HAZARD ZONE

The FHZ mapping protocol and other information related to the program can be found at:

www.coloradofhz.com

(FIRMs), local floodplain studies, or post-fire H&H analyses to inform their extent.

- Use a variety of data and methodologies for verification of the active stream corridor including high-resolution topographic data (i.e., LiDAR), geologic and soils maps, and field verification.
- Assume that stream dimensions change during a flood event and that flows transport sediment and debris.
- Are not related to and do not affect flood insurance rates.
- Are a non-Federally regulated product (regulation, if any, is determined by local communities).

## PRE-FIRE PREPAREDNESS

FHZ mapping can assist with the identification of properties, homes, infrastructure, and critical emergency facilities (e.g., fire and rescue stations, hospitals, schools, shelters, and similar facilities) may be vulnerable to fluvial hazards associated with erosion and deposition of sediment within a stream corridor. This can aid a community in planning where to station resources, shelter people, and/or invest in redundant systems so that if one critical component goes offline the emergency response system is not paralyzed or hindered. FHZ maps may also help communities consider which evacuation routes may be unreliable during a flood due to road and bridge washouts from fluvial processes. Disaster response and disaster response planning without Fluvial Hazard Zone maps is likely to provide an incomplete assessment of a community's true vulnerabilities.

Before a wildfire, FHZ maps can be used to plan for safer locations for development or redevelopment as well as to inform less hazardous locations for critical infrastructure and utilities. Additionally, they can be used to identify and prioritize the conservation or rehabilitation of natural depositional areas which can trap debris and sediment that erodes from burned hillslopes before it enters reservoirs and developed areas. Furthermore, conserved and natural stream corridors provide natural fire breaks, potentially aiding a community's firefighting effort during a wildfire.

### Communication and Coordination

It is important to communicate that these stream processes are natural and that communities have the ability to plan for and mitigate these impacts. Mapping the areas prone to hazards from erosion and sedimentation does not introduce a new hazard into the community—the hazard has always existed, the map is a tool that allows us to make more informed decisions around it.

Fluvial hazards can activate and evolve rapidly or very slowly depending on the specific characteristics of a watershed and the stream system. In some areas, there will be adequate time for weather warnings and evacuations and in others, there will not.

Fluvial Hazard Zone maps are a part of a larger hazard assessment and lend insight into hazards after a wildfire. These maps are complemented by, but are distinctly different from, traditional flood flow modeling which models flood inundation and flood depths for a variety of rainfall and runoff events. Additionally, Fluvial Hazard Zone maps account for sediment impacts of debris flows for but do not identify specific debris flow hazard locations or runouts. Together, the available analysis tools (runoff modeling, flood modeling, sediment transport simulation, FHZ, and debris flow hazard and runout modeling), along with information about hillslope erosion, water quality, and asset locations, will give the greatest insight into how to best account for and plan for post-wildfire impacts on a community.

## MITIGATION

The following are examples of mitigation strategies being employed by communities in Colorado that are working to reduce their exposure to fluvial hazards.

### Strategy 1: Hazard Avoidance via Conservation, Parks, Open Space, and Easements

The most cost-effective tool for a community to mitigate the impact of fluvial hazards is to reduce their exposure through forward-looking land-use planning. Long-term planning that directs land development and infrastructure away from areas subject to fluvial hazards will result in prevented damages during future floods. Discouraging development within areas identified in a Fluvial Hazard Zone may also:

- Provide for temporary floodwater, sediment and debris storage and allow for a reduction of peak flood flows in adjacent and downstream communities (Habersack et al., 2015; Sholtes and Doyle, 2010).
- Reduce reliance on channelization, levees, and bank armoring, which are often detrimental to stream health, are expensive to maintain, and often increase erosion and deposition processes in adjacent and downstream communities (Brierley and Fryirs, 2005; Brookes, 1988; Huggett, 2003; Nagle, 2007).
- Increase channel stability by improving floodplain connection and sediment transport.
- Reduce costs of future flood recovery efforts.
- Reduce public expenditures for disaster response and recovery.

Strategies for avoiding fluvial hazards may include conservation easements for all or portions of parcels within the FHZ. It may also involve fee simple purchase of parcels and the addition of them to existing open space.

### Strategy 2: Build Energy Dissipation and Sediment Storage into the System

Fluvial Hazard Zone maps can be used to identify and prioritize the restoration and rehabilitation of natural depositional areas which can trap debris and sediment that erodes from upstream reaches in locations where the consequence of aggradation is low. These areas can act as a sediment sink and energy sponge, absorbing material and energy from debris flows and post-wildfire floods and mitigating impacts to downstream residents and communities.

### Strategy 3: Mitigate Risk in Constrained Areas

Fluvial Hazard Zone maps can also be used to identify reaches that are highly altered, developed, inhabited, and have little to no floodplain connection, and where the transfer of sediment and debris through the reach and into natural or restored depositional areas downstream should be prioritized. This may include upsizing crossings or transitioning culverts to free-span bridges. This may also include moving or retrofitting diversion or water intake structures.

### Strategy 4: Infrastructure and Utility Retrofit/ Relocations

Infrastructure such as roads, road crossings, water sanitation, electric/ telecommunication lines, etc., are often located in fluvial hazard zones. Evaluating these in the context of large-scale disaster planning may highlight vulnerabilities and therefore opportunities for retrofitting or relocating this infrastructure before a wildfire occurs.  This also allows for a community to consider what portions of its infrastructure or utility network have redundancy, and which do not.

### Strategy 5: Development and Community Planning

Numerous additional suggestions for mitigating fluvial hazards through such things as incorporating Fluvial Hazard Zone Maps into community planning, incentivizing development away from an FHZ, development review, adopting local regulation, developing information and educational programs, and providing other directed actions can be found on the CWCB Quickstart Guide.

## MONITORING AND ALERTS

Adhering to local, state, or National Weather Service (NWS) warnings and guidance on debris flow and flash flood hazards can help to inform a community when fluvial hazards are likely. When flash flood warnings are issued within stream corridors for which the FHZ has been mapped, the alert should include the FHZ boundary so that residents are aware of the potential aerial extent of the hazard.