APPENDIX: HAZARDS IN COLORADO

This guide describes the individual hazards that may affect communities in Colorado. Information on identifying hazards that may affect individual communities, conducting a risk assessment, and preparing a hazard mitigation plan is in Chapter 3, *Hazard Identification and Risk Assessment*.

Don't Miss These Resources!

The following data sources are the perfect starting point for identifying hazards and assessing risk. Other hazard-specific data sources are included throughout this appendix. More information on each of these resources is included in this guide under "Summary of Common Hazard Data Sources."

1. *Colorado Climate Center: ccc.atmos.colostate.edu*
2. *Colorado Geological Survey: coloradogeologicalsurvey.org*
3. *Colorado Natural Hazards Mitigation Plan: dhsem.state.co.us/emergency-management/mitigation-recovery/mitigation/state-colorado-natural-hazards-mitigation-plan*
4. *Federal Emergency Management Agency: fema.gov/media-library/assets/documents/7251*
5. *National Centers for Environmental Information: ncei.noaa.gov*
6. *National Oceanic and Atmospheric Administration: noaa.gov*
7. *National Weather Service: weather.gov*
8. *United States Geological Survey: usgs.gov*

Source: CDOT

AVALANCHE

DESCRIPTION

An **avalanche** is a mass of snow, ice, and debris flowing and sliding rapidly down a steep slope (*Colorado Natural Hazards Mitigation Plan,* 2013, p. 3-138). An avalanche is defined in Colorado state statutes as a "geologic hazard."

Snow avalanches occur in the high mountains of Colorado seasonally as the result of heavy snow accumulations on steep slopes. When the snow pack becomes unstable, it suddenly releases and rapidly descends downslope either over a wide area or concentrated in an avalanche track. Only part of an avalanche may release at once. Avalanches may reach speeds of up to 200 miles per hour and exert forces great enough to destroy structures and uproot or snap off large trees. They may be preceded by an "air blast," which is a strong rush of air that can measure over 100 mph and is capable of damaging buildings. They are more common with powder avalanches (where snow grains are largely suspended by fluid turbulence) that occur in parts of Colorado.

Avalanche paths consist of a starting zone, a track, and a runout zone. Generally, the runout zone is the critical area for land use decisions because of its otherwise attractive setting for development. Avalanche-prone lands may pass many winters or even decades without a serious avalanche. Lack of vegetation or a predominance of quick-growing aspen and low shrubs often characterize active portions of an avalanche track and the runout zone, readily identifying the area of seasonal peril.

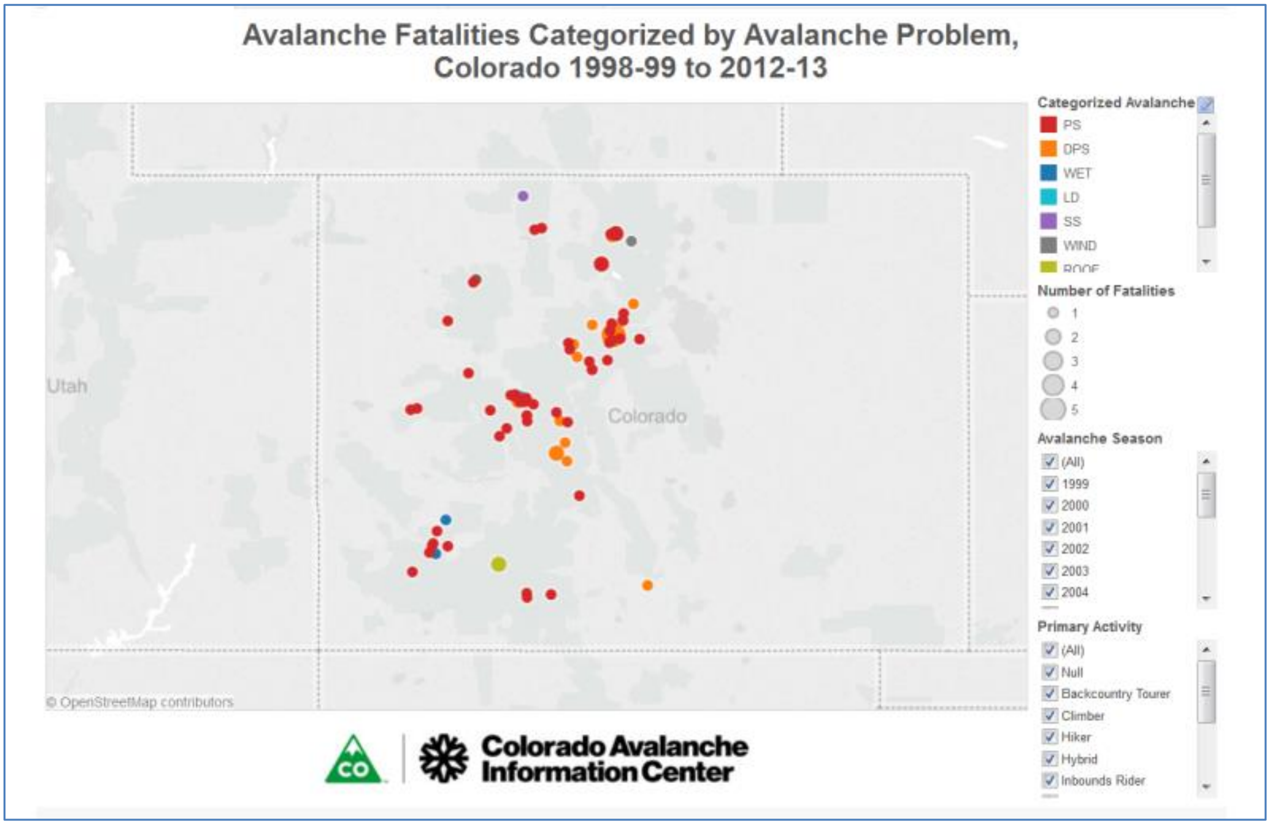
Avalanches can be deadly. Over the past ten years, an average of 28 people per year have died from avalanches in the U.S. (*Statistics and Reporting*, n.d.b) Since records began to be collected in the 1970s, over 990 deaths have been reported as a result of avalanches.

AVALANCHES IN COLORADO

According to the Colorado Avalanche Information Center (CAIC), avalanches have killed more people in Colorado than any other natural hazard since 1950, and Colorado accounts for one-third of all avalanche deaths in the United States. Most deaths are backcountry recreationists and they most commonly occur on the steep mountain slopes in Western Colorado between November and April. Recorded property damage is relatively low, with a total of $313,500 over the last 50 years, suggesting good recognition and avoidance of hazardous construction in known runout zones (*Colorado Natural Hazards Mitigation Plan,* 2013, p. 3-147). However many highways, roads, and railroads intersect with runout zones in Colorado and avalanches remain a constant threat to transportation safety. Road closures are common at various locations across the state due to avalanche threats, damages and cleanup, or mitigation

Large slab avalanche along U.S. Highway 550 at West Riverside, near Red Mountain Pass, Colorado.

Source: Colorado Geological Survey. Snow Avalanche. Photo by Don Bachman. coloradogeologicalsurvey.org/geologic-hazards/avalanches-snow/definition activities. These closures may disrupt commerce and isolate communities with limited road access.



Sample Avalanche Problem Map, available from the Colorado Avalanche Information Center.

Colorado Avalanche Information Center. Statistics and Reporting. avalanche.state.co.us/accidents/statistics-and-reporting

RELATED HAZARDS

Avalanches generally occur independently of other hazards, although they are often caused by increased snow pack from winter precipitation. Earthquakes, thermal changes, and blizzards are also likely to trigger avalanches. Avalanche impacts (damaged structures, loss of lives, etc.) can be similar to those resulting from landslides, mud/debris flows, and rockfalls.

AVAILABLE DATA SOURCES

Colorado Avalanche Information Center (CAIC)

The CAIC is a program within the Colorado Department of Natural Resources. The program is a partnership between the Department of Natural Resources (DNR), Department of Transportation (CDOT), and the Friends of the CAIC (FoCAIC), a 501c3 organization. The mission of the CAIC is to provide avalanche information, education, and promote research for the protection of life, property, and the enhancement of the state's economy. The CAIC website provides useful information such as statistics, maps, photos, and videos about avalanches. avalanche.state.co.us

The Colorado Department of Transportation (CDOT) Avalanche Atlas

CDOT's Avalanche Atlas contains 522 known avalanche paths across the state. CDOT regularly monitors conditions and implements control measures to help mitigate impacts to state highways. codot.gov/travel/winter-driving/AvControl.html

American Avalanche Association

The American Avalanche Association is a national organization whose mission is to promote and support professionalism and excellence in avalanche safety, education, and research in the United States. The Association provides information about snow and avalanches, provides direction for promoting and supporting avalanche education in the U.S., and promotes research and development in avalanche safety. The Association also provides and exchanges technical information and maintains communication among persons engaged in avalanche activities. americanavalancheassociation.org

APPLICABLE PLANNING TOOLS AND STRATEGIES

The table below cites applicable planning tools and strategies that are profiled in this guide.

APPLICABLE PLANNING TOOLS AND STRATEGIES – AVALANCHE	
Addressing Hazards in Plans and Policies	• Comprehensive plan • Climate plan • Hazard mitigation plan • Parks and open space plan • Pre-disaster planning
Strengthening Incentives	• Development agreement • Density bonus • Transfer of development rights
Protecting Sensitive Areas	• 1041 regulations • Cluster subdivision • Conservation easement • Land acquisition • Overlay zoning
Improving Site Development Standards	• Site-specific assessment • Subdivision and site design standards • Use-specific standards
Improving Buildings and Infrastructure	• Building code • Critical infrastructure protection
Enhancing Administration and Enforcement	• Application submittal requirements

DROUGHT

DESCRIPTION

The Colorado Water Conservation Board defines "drought" as a shortage of water associated with a lack of precipitation (*Drought*, n.d.c). Compared with sudden-onset hazards like earthquakes or fires, drought hazards often unfold over years, and it may be difficult to quantify when a drought begins or ends.

According to the National Drought Mitigation Center (NDMC), a drought is operationally defined by its various effects:

- *Meteorological drought* is a period of below-average precipitation.
- *Agricultural drought* occurs when there is an inadequate water supply to meet the needs of the state's crops and other agricultural operations like livestock.
- *Hydrological drought* is a deficiency in surface and subsurface water supplies, generally measured as stream flow, snow pack, groundwater levels, or the level of lakes and/or reservoirs.
- *Socioeconomic drought* impacts health, well-being, and quality of life, or has an adverse economic impact on a region (*Types of Droughts*, 2016b).

DROUGHT IN COLORADO

Drought is one of the most serious hazards affecting Colorado (Colorado Water Conservation Board). Colorado's water supply comes entirely from precipitation, in the form of rain, snow, and hail, because there are no major rivers that flow into the state (*State Drought Planning*, n.d.g). With the semiarid conditions in Colorado, drought is a natural part of the climate and can directly or indirectly affect the entire population of the state. Since 2010, every county in the state has experienced drought impacts (*Colorado Natural Hazards Mitigation Plan,* 2013, p. 3-21). Droughts in Colorado can be short or long-lived, and their impacts come in many forms, particularly in water-intensive sectors such as agriculture, municipal water supplies, recreation, tourism, and wildfire protection.

The 2014 Climate Change in Colorado Report finds that warming temperatures in Colorado have worsened some drought indicators over the past 30 years. The report also predicts that droughts and wildfires will increase in frequency and severity by the mid-21st century because of projected warming (*Climate Change in Colorado*, 2008).

RELATED HAZARDS

Droughts are associated with several other hazards in Colorado. They are an ongoing cause of expansive/shrinking soils, subsidence (the gradual sinking of land), and pest infestation. Droughts can also create conditions conducive to wildfires and flash flood events.

AVAILABLE DATA SOURCES

Colorado Water Conservation Board

- Statewide drought and water supply assessment - cwcb.state.co.us/water-management/drought/Pages/main.aspx
- Drought planning toolbox - cwcb.state.co.us/technical-resources/drought-planning-toolbox/Pages/main.aspx

National Drought Information System

The National Drought Information System operates the U.S. Drought Portal at www.drought.gov, which includes a range of resources made available by the National Drought Policy Commission.

National Drought Mitigation Center

The National Drought Mitigation Center at the University of Nebraska-Lincoln provides a host of information and tools for drought planning and monitoring. drought.unl.edu/AboutUs.aspx. The U.S. Drought Monitor, jointly produced by the National Drought Mitigation Center, the National Oceanic and Atmospheric Administration, and the U.S. Department of Agriculture, provides current drought condition data for Colorado. droughtmonitor.unl.edu/Home/StateDroughtMonitor.aspx?CO

Colorado Drought Mitigation and Response Plan

The Colorado Drought Mitigation and Response Plan (2013) was developed to "provide an effective and systematic means for the State of Colorado to reduce the impacts of water shortages over the short and long term" (p. vii). The plan contains information about drought hazards, drought risk assessment, drought history in Colorado, and potential mitigation actions at the state and local level. cwcb.state.co.us/water-management/drought/Pages/StateDroughtPlanning.aspx

Colorado Climate Center

The Colorado Climate Center at Colorado State University provides numerous resources on drought including evaporation data, precipitation maps, and a drought index. climate.colostate.edu/drought.php

APPLICABLE PLANNING TOOLS AND STRATEGIES

The table below cites applicable planning tools and strategies that are profiled in this guide.

APPLICABLE PLANNING TOOLS AND STRATEGIES – DROUGHT	
Addressing Hazards in Plans and Policies	• Comprehensive plan • Climate plan • Hazard mitigation plan • Parks and open space plan • Pre-disaster planning
Strengthening Incentives	*N/A*
Protecting Sensitive Areas	• 1041 regulations
Improving Site Development Standards	• Stormwater ordinance • Subdivision and site design standards
Improving Buildings and Infrastructure	• Building code
Enhancing Administration and Enforcement	*N/A*

EARTHQUAKE

DESCRIPTION

Earthquakes are the vibrations or shaking created when large blocks of the earth's crust move against one another. The break between these blocks is a "fault." Most earthquakes in the earth's crust occur from movement on faults. Less frequently, some earthquakes are caused by volcanic or magmatic activity (*Colorado Natural Hazards Mitigation Plan*, 2013, p. 3-153).

Magnitude and intensity are terms used to describe seismic activity. Magnitude (M) is a measure of the total energy released. Each earthquake has one magnitude. Intensity (I) is used to describe the effects of the earthquake at a particular place. Intensity differs throughout the area. The Richter Scale is commonly used to measure magnitude, and the Modified Mercalli Intensity Scale (MMI) measures intensity.

The most intense shaking experienced during earthquakes generally occurs near the rupturing fault and decreases with distance away from the fault. In a single earthquake, however, the shaking at one site can easily be 10 times stronger than at another site, even when their distance from the ruptured fault is the same.

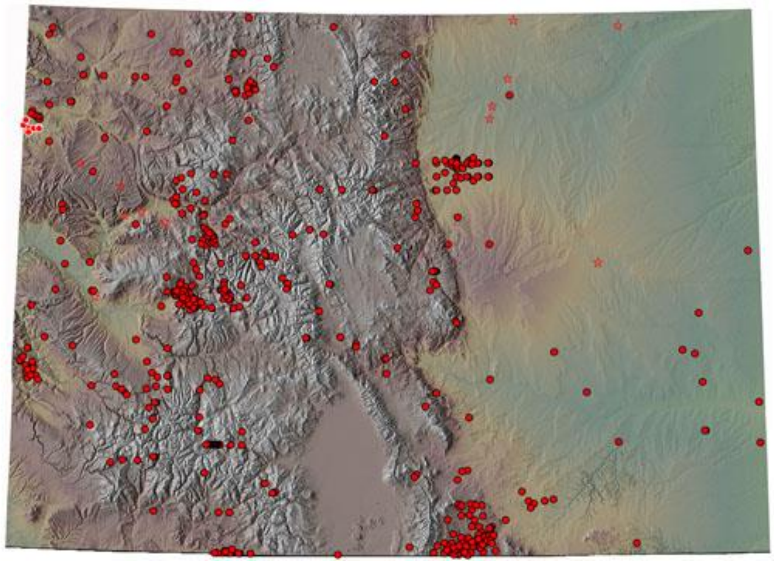
EARTHQUAKES IN COLORADO

Many earthquakes in Colorado occur naturally; however, they can also be caused by human actions. Humans may trigger earthquakes through different types of activities including oil and gas extraction, reservoir impoundment, fluid injection, or mining.

Although many of Colorado's past earthquakes have occurred in mountainous regions, some have been located in the western valleys and plateau region or east of the mountains. Thousands of faults have been mapped in Colorado, but scientists think only about 90 of these have been active in the past 1.6 million years. Portions of the state have clusters of faults, such as near the Denver metro region, central mountains, and the southwestern and northwestern part of the state. Seismic activity is largely absent in Northeast Colorado.

The Sangre de Cristo Fault, which lies at the base of the Sangre de Cristo Mountains along the eastern edge of the San Luis Valley, and the Sawatch Fault, which runs along the eastern margin of the Sawatch Range, are two of the most prominent potentially active faults in Colorado. Not all of Colorado's potentially active faults are in the mountains. For example, the Cheraw Fault, which is in the Great Plains in southeast Colorado, appears to have had movement during the recent geologic past. Some faults, such as the Derby Fault near Commerce City, cannot be seen at the earth's surface.

Even though the seismic hazard risk in Colorado is relatively low to moderate compared to other states like California, it is likely that future damaging earthquakes will occur in Colorado. More than 500 earthquake tremors of magnitude 2.5 or higher have been recorded in the state since 1867. More earthquakes of magnitude 2.5 to 3.0 probably occurred during that time but were not recorded because of the sparse distribution of population and limited instrumental coverage in much of the state (for comparison, more than 20,500 similar-sized events have been recorded in California during the same time period.)



Historic epicenter locations for earthquakes since 1867.

Source: Colorado Geological Survey. Earthquakes. coloradogeologicalsurvey.org/geologic-hazards/earthquakes-2

The largest known earthquake in Colorado occurred on November 7, 1882, and had an estimated magnitude of 6.5. The location of this earthquake, which has been the subject of much debate and controversy over the years, appears to have been in the northern Front Range west of Fort Collins. The most economically damaging earthquake in Colorado's history occurred on August 9, 1967, in the Denver metropolitan area. This 5.3 magnitude earthquake caused more than $1 million in damages in Denver and the northern suburbs (*Colorado Natural Hazards Mitigation Plan*, 2013, p. 3-159). This earthquake is believed to have been induced by the deep injection of liquid waste into a borehole at Rocky Mountain Arsenal.

More recently, a magnitude 5.3 earthquake occurred on August 23, 2011, causing moderate damage near Segundo and Valdez in southern Colorado. In recent years, seismic activity appears to be on an upward trend in Colorado, with 30 seismic events recorded in 2013 and 44 events recorded in 2014.

RELATED HAZARDS

Earthquake events have the potential to trigger avalanches, landslides, soil hazards (liquefaction, uneven ground settling), and flooding caused by the failure of dams, levees or other impoundment structures. Additionally, broken natural gas lines and other pipelines may cause hazardous material releases and often result in structural fires following the event.

AVAILABLE DATA SOURCES

Colorado Geological Survey

The Colorado Geological Survey is the primary agency for maintaining Colorado earthquake hazard information. coloradogeologicalsurvey.org

- The CGS Earthquake page is a one-stop location for finding more information on Colorado earthquakes. coloradogeologicalsurvey.org/geologic-hazards/earthquakes-2
- The Earthquake Reference Collection is a listing of over 500 earthquakes and faulting events that have taken place in Colorado. coloradogeologicalsurvey.org/geologic-hazards/earthquakes-2/earthquake-reference-collection

- The Colorado Earthquake and Late Cenozoic Fault and Fold Map Server is an online map viewer that indicates where fault lines and folds can be found in Colorado. dnrwebcomapg.state.co.us/CGSOnline

Unites States Geological Survey

The United States Geological Survey (USGS) is the primary federal government agency for providing information on earthquakes. earthquake.usgs.gov

- The USGS National Seismic Hazards Map is a national standard for identifying earthquake hazard zones. earthquake.usgs.gov/hazards/products/conterminous
- USGS also maintains a site dedicated to Colorado Earthquake Information. earthquake.usgs.gov/earthquakes/states/?region=Colorado

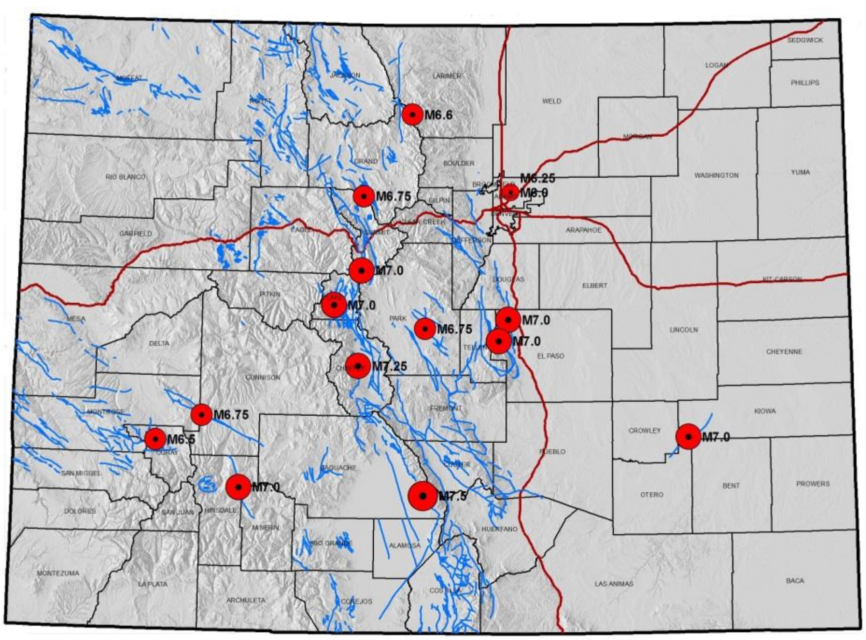
National Earthquake Hazards Reduction Program

The National Earthquake Hazards Reduction Program (NEHRP) is the federal government's coordinated long-term nationwide program to reduce risks to life and property in the U.S. resulting from earthquakes. nehrp.gov/index.htm

Federal Emergency Management Agency (FEMA)

FEMA maintains a resource website that provides useful information regarding earthquakes. fema.gov/earthquake

Additionally, Hazus is available from FEMA for estimating vulnerability due to earthquakes. Hazus is a nationally applicable standardized methodology that contains models for estimating potential losses from earthquakes, floods, and hurricanes. Hazus uses Geographic Information Systems (GIS) technology to estimate physical, economic, and social impacts of disasters. It is a loss estimation tool, but is not predictive. It graphically illustrates the limits of identified high-risk locations due to earthquakes, hurricanes, and floods. Users can then visualize the spatial relationships between populations and other more permanently fixed geographic assets or resources for the specific hazard



The CGS Interactive Hazus Events Map details epicenters of possible future seismic events based on Maximum Credible Earthquakes (MCE) that have been assigned to specific faults by various entities. Each of the event locations have been analyzed using FEMA Hazus software and correspond to statewide reports on potential loss and damage.

being modeled, a crucial function in the pre-disaster planning process. fema.gov/hazus

The Colorado Geological Survey utilized Hazus to determine the potential locations and impacts of various magnitude earthquakes on faults across Colorado. Hazus summary reports on potential losses may be downloaded for both statewide scenarios as well as for individual counties at: coloradogeologicalsurvey.org/geologic-hazards/earthquakes-2/risks-hazards-loss/potential-losses-hazus

Colorado Earthquake Hazard Mitigation Council

The Colorado Earthquake Hazard Mitigation Council (CEHMC) is a multi-disciplinary organization that is interested in developing a better understanding of earthquake hazards in Colorado. The group meets monthly and has been in existence in various forms for more than three decades. coloradogeologicalsurvey.org/geologic-hazards/earthquakes-2/colorado-earthquake-hazard-mitigation-council-cehmc

APPLICABLE PLANNING TOOLS AND STRATEGIES

The table below cites applicable planning tools and strategies that are profiled in this guide.

APPLICABLE PLANNING TOOLS AND STRATEGIES – EARTHQUAKE	
Addressing Hazards in Plans and Policies	• Comprehensive plan • Hazard mitigation plan • Pre-disaster planning
Strengthening Incentives	*N/A*
Protecting Sensitive Areas	• 1041 Regulations
Improving Site Development Standards	*N/A*
Improving Buildings and Infrastructure	• Building code • Critical infrastructure protection
Enhancing Administration and Enforcement	• Post-disaster building moratorium

FLOOD

DESCRIPTION

Flooding is the most frequent and costly natural hazard in the United States—a hazard that causes more fatalities than any other natural hazard and averages nearly $10 billion in losses per year. Nearly 85 percent of federal disaster declarations result from natural events where flooding was a major factor (*Implementing a Federal*, 2015, p. 2).

Technically, a flood is a general and temporary condition of partial or complete inundation of normally dry land areas from: (1) the overflow of stream banks; (2) the unusual and rapid accumulation of runoff of surface waters from any source; or (3) mudflows or the sudden collapse of shoreline land. Flooding results when the flow of water is greater than the normal carrying capacity of the stream channel or accumulates faster than surface absorbency allows (*Colorado Natural Hazards Mitigation Plan,* 2013, p. 3-47). The severity of a flood event is typically determined by a combination of several factors, including but not limited to precipitation and weather patterns, stream and river basin topography and physiography, stormwater conveyance capacities, recent soil moisture conditions, and the degree of vegetative clearing and/or impervious surface coverage.

Floods in Colorado generally result from the accumulation of water from excessive precipitation and/or rapid snowmelt. They can be classified under two categories: general floods, resulting from heavy precipitation or snowmelt in a given watershed over an extended period of time; and flash floods, the product of heavy localized precipitation in a short time period.

General floods are typically long-term events that may last for multiple days, and over widespread areas. The primary type of general flooding in Colorado is associated with lands adjacent to riverine and lake areas, and is a function of excessive precipitation levels and the inability of natural systems to adequately absorb or convey the resulting volume of runoff. Urban/stormwater flooding occurs where development has obstructed the natural flow of water and decreased the ability of natural groundcover to absorb and retain surface water runoff.

More frequent in Colorado is **flash flooding**, most of which is caused by slow-moving thunderstorms with intense but isolated rainfall. Such events develop rapidly and are intensified by major elevation changes, steep slopes, and base alluvial fans that characterize mountain river canyons. Flash flooding events may also be caused by a sudden failure or release by a dam, levee, retention basin, or other stormwater control facility, or by the obstruction of natural flows by ice jams or other blockages that cause backflow and overtopping. Although flash flooding occurs most often along Colorado's mountain streams, it is also common in urbanized areas where much of the natural landscape is covered by impervious surfaces.

The Big Thompson flood of 1976 was the deadliest flash flood in Colorado's recorded history.

Source: Denver Post. The Archive. July 31, 2012. Photo by Steve Larson. blogs.denverpost.com/library/2012/07/31/big-thompson-flood-disaster-colorado-1976/2795

The periodic flooding of lands adjacent to rivers, streams, lakes, and other water bodies (land commonly known as "floodplain") is a natural and inevitable occurrence that can be expected to take place based upon established recurrence intervals. The recurrence interval of a flood is typically defined as the average projected time (in years) between a particular magnitude flood event or annual percent chance of that flood occurring. For example, the "100-year" flood has a one percent chance of occurring in any given year, and the "500-year" flood has a 0.2 percent chance of occurring in any given year—and these two distinct magnitudes are the basis for the special flood hazard areas identified in FEMA Flood Insurance Rate Maps (FIRMs). The recurrence interval is an *average*; it does not necessarily mean that a flood of such a magnitude will happen exactly every 100 years or 500 years, and in some cases only a few years may pass between major flood events.

It is important to note that flooding is not always confined to special flood hazard areas identified by FEMA. Therefore, evenhomes that are not in the mapped floodplain should exercise caution and diligence during flood events and should prepare themselves before flooding occurs. Some jurisdictions regulate based on their own, more stringent floodplain maps.

FLOODING IN COLORADO

Colorado communities are impacted by flooding on an annual basis, and nearly every community in the state is subject to special flood hazard areas as mapped by FEMA and as made available through the Colorado Water Conservation Board. In addition, there are approximately 677 state-regulated dams that, in the event of a failure, could cause loss of life and/or significant property damage in communities located within downstream flood hazard areas.

The September 2013 flood disaster caused major damage to private property and public infrastructure across the Front Range of Colorado.

Source: Federal Emergency Management Agency. Colorado Town Isolated. May 1, 2014. Photo by Steve Sumwalt. fema.gov/media-library/assets/images/72550

The most flash-flood prone regions of Colorado are found along the base of the lower foothills east of the mountains. Several extreme floods such as the infamous Big Thompson Canyon flood of July 31, 1976, have occurred in this vulnerable area. Flash floods occur on the Western Slope as well, but with typically lower frequency and intensity due to a reduced supply of moisture to fuel such storms (*Colorado Climate Center*, 2015).

Flood hazards pose major risks to property and human life and have caused some of the largest disasters in Colorado history in terms of financial costs and casualties. Between 20 to 30 large-magnitude floods occur somewhere in the state every year, and major flood disasters (warranting a federal disaster declaration) have occurred on average every five years since 1959. The South Platte River floods of 1965 and the 2013 floods in the Front Range and northeast counties caused multiple deaths and nearly $3 billion and $4 billion in total estimated damage in current terms, respectively. The Big Thompson River flood of 1976 caused 144 deaths. Floods can cause billions of dollars of property and infrastructure damage, resulting in significant economic impacts for directly affected communities and for the state as a whole (*Colorado Resiliency Framework,* 2015, p. 3-4).

RELATED HAZARDS

While floods are most frequently caused by heavy precipitation associated with sustained wet weather and/or severe thunderstorms, they may also be caused or exacerbated by other hazards including ice jams or rapid melting and runoff following severe winter storms. In the 2013 Colorado floods, a major cause of flood damage was debris that clogged up bridges and culverts. Another major issue in 2013 was waterways carving entirely new channels, meaning risk had not been conveyed on existing maps. The state is currently developing a new methodology to identify potential risk associated with channel migration, erosion zones, and alluvial fans.

Flooding is one of the three central components (along with drought and wildfire) of a complex system of interrelated natural hazards that are fundamentally tied to Colorado's continental semi-arid climate. Drought conditions may lead to soil compaction, and wildfires may leave slopes denuded and hydrophobic (unable to absorb water). In these cases a single heavy rain event can lead to higher volumes of runoff and a correspondingly higher risk for flash flooding, erosion, and particularly mud/debris flows (described below in this guide).

In addition to the direct impacts a flood event hazard may cause, it can also trigger multiple cascading hazard events. Rising floodwaters may cause the failure of a dam, levee, or other impoundment structure resulting in the rapid inundation of locations outside of mapped special flood hazard areas. Major flood events may also increase the risks of geologic hazard events (landslide, mud/debris flow, and rockfall), soil hazards, and hazardous material releases.

ASSESSING THE RISK OF FLOOD

Community planners should begin assessing flood risk by coordinating with their local floodplain administrator, along with the appropriate staff at the Colorado Water Conservation Board (CWCB), on the identification of the best currently available data and tools for assessing flood risk, as well as the status of any updates or possible enhancements to those resources.

Communities with GIS resources available to support their planning efforts will be able to conduct more rapid and robust risk assessments, including overlay analysis, to quantify the exposure of people, parcels, buildings, critical facilities, and other community assets that are within Special Flood Hazard Areas (SFHAs). They may also use FEMA's *Hazus* software to help estimate monetary losses based on a variety of scenario flood hazard events (this capability exists even for communities without their own digital flood risk data). However, while Hazus is a helpful loss estimation tool, it is not predictive of future events. Communities that do not have GIS capabilities or resources should consult the range of digital online mapping viewers available, including the Colorado Flood Decision Support System (DSS) or the FEMA Flood Map Service Center. These mapping tools allow for some higher-level spatial analysis and the creation of customizable and printable flood maps (FIRMettes) that can be helpful in assessing flood risk for local planning and regulatory measures. In some cases, however, communities may have on-the-ground information that is better than modeling, such as, for example, public works records of roads and bridges that consistently have issues in flood events.

Most communities in Colorado rely on their effective floodplain maps (i.e., Flood Insurance Rate Maps issued by FEMA that become effective on a particular date) as the official source of flood risk information for local planning and regulatory measures, which at a minimum includes adopting and enforcing the State's Model Floodplain Damage Prevention Ordinance (Colorado Department of Natural Resources, 2012). All communities in Colorado with mapped flood hazard areas have access to either hard copy/static Flood Insurance Rate Maps (FIRMs) or Digital Flood Insurance Rate Maps (DFIRMs), along with the associated Flood Insurance Study from the FEMA Flood Map Service Center. Communities with GIS capability but without DFIRM datasets may still have access to digital Q3 flood layers, which provide some limited spatial data for GIS analysis and mapping purposes.

The delineation and updating of floodplain maps is generally performed by private engineering firms under contract with FEMA, which administers the nation's flood hazard mapping program in coordination with CWCB. Based on strict guidelines, floodplain maps are created through the use of statistical information such as data for river flows, rainfall and topographic surveys, and hydrologic and hydraulic (H&H) analyses. Hydrologic modeling calculates the peak discharges of water at key locations in a watershed, while hydraulic modeling computes surface water velocities and elevations along with flood profiles and flood boundaries using input from the hydrologic models. More information on the technical aspects of floodplain mapping can be found at fema.gov/guidelines-and-standards-flood-risk-analysis-and-mapping.

The primary gaps or weaknesses with these tools may include outdated and/or inaccurate map data. Even new DFIRMs may not reflect all flood hazards (e.g., urban drainage/stormwater flooding, fluvial erosion, etc.) or future conditions (e.g., future floodplains and base flood elevations that take into account projected watershed development, hydrologic changes, etc.). Also, aside from a few new Risk MAP projects, most flood risk databases do not include the non-regulatory information that may be useful for enhanced planning purposes (e.g., flood depth/velocity grids, areas of mitigation interest, and other flood risk assessment data). Another challenge for many communities is the lack of GIS capabilities or resources to help facilitate the spatial analysis and mapping of flood risk to support the implementation of additional planning tools or strategies.

The 2013 floods highlighted the need for better mapping (including floodplains, erosion zones, and debris flows), and in response the Colorado legislature provided funding in early 2015 to update natural hazard maps statewide. This update process is currently underway.

Communities that are interested in adjusting or improving the quality of their floodplain maps, or expanding on the accessible flood risk products associated with development, should coordinate closely with the CWCB. While flood risk studies and hazard mapping are often prohibitively expensive, a range of techniques is available to communities through higher regulatory standards encouraged under the National Flood Insurance Program (NFIP) and Community Rating System (CRS) that should be considered.

For example, if a community is interested in regulating new development to flood elevations that are expected to increase due to future growth and development, it may consider the use of future-conditions hydrology in the creation of its own regulatory floodplain maps. Such maps can account for future floodplain conditions and may be adopted by communities to enact more stringent development standards, but would not be linked to insurance rates and purchase requirements under the NFIP. In the absence of pursuing the development of future floodplain conditions maps (which is not part of FEMA's flood hazard mapping program and may be costly), communities may consider adopting the 500-year (or 0.2-percent-annual-chance) flood zone as their regulatory floodplain versus the 100-year (or 1-percent-annual-chance flood zone) as currently required under the NFIP.

AVAILABLE DATA SOURCES

Colorado Risk MAP

The purpose of the Colorado Risk MAP Program is to deliver quality data, technical assistance, and other non-regulatory tools that increase public awareness of flooding potential and lead to action that reduces risk to life and property. coloradofloodrisk.state.co.us

Colorado Flood Decision Support System (DSS)

The Colorado Flood DSS is an online interactive mapping application that provides useful flood hazard information. flooddss.state.co.us. The application allows users to:

- Review effective floodplain boundaries
- See real-time weather and streamflow conditions
- Access local and county data related to flooding
- Access data related to historical floods, hazards, weather modification, watershed restoration, and FEMA's National Flood Insurance Program

In addition, the DSS provides links to a wide range of additional resources for flood-related information. flooddss.state.co.us/pages/AdditionalResources.aspx

FEMA Flood Map Service Center

The Flood Map Service Center is the official public source for flood hazard information produced in support of the National Flood Insurance Program. From this site, users can obtain official flood maps, access a range of other flood hazard products including Flood Insurance Studies (FIS), and take advantage of tools to better understand flood risk. msc.fema.gov

Colorado Hazus Flood Risk Data

The 2013 *Colorado Natural Hazards Mitigation Plan* includes planning-level flood loss estimates for every county in Colorado, as generated by Hazus, FEMA's loss estimation software. This includes a summary of vulnerability and potential losses by county, as determined though modeling the one percent annual chance (100-year) floodplain and performing associated building and population risk assessments across the state. See pages 3-55 through 3-59 of the plan at dhsem.state.co.us/emergency-management/mitigation-recovery/mitigation/state-colorado-natural-hazards-mitigation-plan

Colorado National Flood Insurance Program (NFIP) information

State NFIP, repetitive loss, and Risk MAP data is available through the Colorado Water Conservation Board or the Division of Homeland Security and Emergency Management. cwcb.state.co.us, dhsem.state.co.us

NFIP Policy and Claim Statistics by Jurisdiction

These policy and claim statistics provide routinely updated data on the number of policies in-force, amount of coverage, and premiums paid for each participating NFIP community, along with data on the number of insured losses and total payments of past claims. fema.gov/policy-claim-statistics-flood-insurance/policy-claim-statistics-flood-insurance/policy-claim-13

Colorado Dam Safety Information

Upon request, the Colorado Division of Water Resources can provide helpful data and information to local officials on existing dam structures, such as hazard classifications, emergency action plans, and dam failure inundation maps. Access to all such information is subject to DWR's Public Access to Dam Files and Records policy. water.state.co.us/DWRIPub/Documents/policy01-05.pdf

Division of Water Resources, Dam Safety Branch: water.state.co.us/damsafety/dams.asp

Dam inundation maps: bill.mccormick@state.co.us.

APPLICABLE PLANNING TOOLS AND STRATEGIES

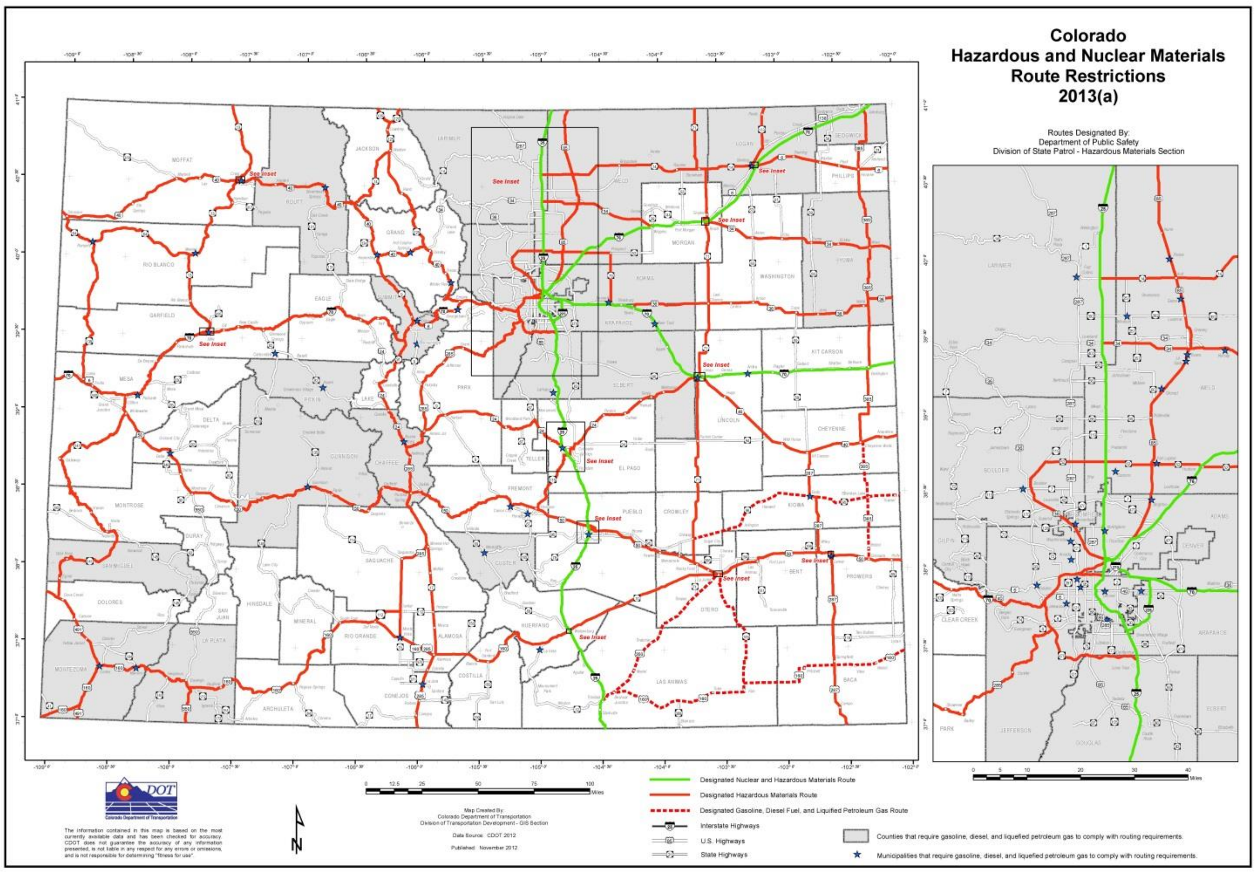
The table below cites applicable planning tools and strategies that are profiled in this guide.

APPLICABLE PLANNING TOOLS AND STRATEGIES – FLOOD	
Addressing Hazards in Plans and Policies	• Comprehensive plan • Climate plan • Hazard mitigation plan • Parks and open space plan • Pre-disaster planning
Strengthening Incentives	• Community Rating System • Development agreement • Density bonus • Transfer of development rights
Protecting Sensitive Areas	• 1041 regulations**Error! Bookmark not defined.** • Cluster subdivision • Conservation easement • Land acquisition • Overlay zoning • Stream buffers and setbacks
Improving Site Development Standards	• Stormwater ordinance • Site-specific assessment • Subdivision and site design standards • Use-specific standards
Improving Buildings and Infrastructure	• Building code • Critical infrastructure protection
Enhancing Administration and Enforcement	• Application submittal requirements • Post-disaster building moratorium

HAZARDOUS MATERIAL RELEASE

DESCRIPTION

A hazardous material (HAZMAT) is any element or compound that, because of handling, storing, processing, or packaging, may have detrimental effects upon the public (especially emergency personnel) and/or the environment (*State Emergency Operations Plan*, 2015, p. Tab A-6 to Tab A-7). Hazardous materials are found in forms and quantities that can potentially cause death, serious injury, long-lasting health effects, and property damage in varying degrees. They may be flammable, corrosive, detonable, toxic, radioactive, oxidizers, disease-causing agents, or highly reactive. They are routinely used and stored in homes and businesses and are also shipped daily on Colorado's highways, railroads, waterways, and pipelines. Hazardous material releases include spilling, disposal, or other form of discharge into the environment.



Colorado's HAZMAT routing map provides information on the major roadways designated for the transport of mobile hazardous materials. The red lines are designated hazardous materials routes, and the green lines are designated nuclear and hazardous materials routes.

Source: Colorado State Patrol. Hazardous Materials Routing Map. 2013. colorado.gov/pacific/sites/default/files/Hazardous Materials Routing Map.pdf

Incidents involving hazardous material releases can apply to fixed facilities as well as mobile, transportation-related accidents. Between 2005 and 2014, approximately 166,000 HAZMAT incidents were reported nationwide. Nearly 86 percent of these were highway incidents, nine percent involved the air industry, and four percent were railroad incidents (*Incident Reports Database Search*, n.d.*)*. These HAZMAT events generally consist of solid, liquid, and/or gaseous contaminants that are released from fixed or mobile containers, and most by accident versus an intentional act. A HAZMAT incident can last hours to days, while some chemicals can be corrosive or otherwise damaging over longer periods of time. In addition to the primary release, explosions and/or fires can result from a HAZMAT release, and contaminants can be extended beyond the initial area by persons, vehicles, water, wind, and possibly wildlife.

HAZARDOUS MATERIAL RELEASES IN COLORADO

Hazardous materials used in agriculture, industry, and in the home pose a daily hazard to people and the environment. Coloradans are vulnerable to the adverse effects of accidental leakage of hazardous materials or a deliberate act using these materials. According to the State Emergency Operations Plan, statewide there are approximately 5,800 fixed facilities where reportable concentrations of hazardous materials are used and/or stored, and the oil and gas production industry accounts for approximately 4,200 of those facilities. Between 2010 and 2012, the Colorado Department of Public Health and Environment (CDPHE) recorded 2,718 reported spills or releases. More than one-third of those were at fixed facilities, with the remainder associated with mobile HAZMATs. The steady growth in the use of chemicals has resulted in an increased need to transport these materials, and according to DHSEM, hazardous materials are transported over nearly every roadway throughout the state (*State Emergency Operations Plan*, 2015, p. 12). All roads that permit hazardous material transport are considered potentially at risk of an incident.

Hazardous material releases can also occur at fixed sites, such as abandoned mines, where materials are being stored and/or treated on site. The Colorado Division of Reclamation Mining & Safety estimates that there are over 22,000 abandoned mines in the state (Ogburn, 2015).

In August 2015, the EPA accidently released 1 million gallons of toxic water from an abandoned mine near Silverton, Colorado into the Animas River. The spill triggered warnings from health officials to steer clear from the river until officials deemed the river safe (Paul & Finley, 2015).

RELATED HAZARDS

Hazardous material releases may be caused by a range of incidents including an industrial or transportation accident, or deliberate criminal act. They can also occur as a result of or in tandem with natural hazard events such as earthquakes and other geologic hazards, floods, windstorms, and winter storms. In addition to causing additional life safety threats, these compound hazard events can also greatly complicate and hinder response efforts and result in major environmental impacts. The large-scale release of hazardous materials in combination with events such as flooding or windstorms can increase the spread of contamination threat zones to large geographic areas and amplify the potential long-term impacts to human and ecological health.

ASSESSING THE RISK OF HAZARDOUS MATERIAL RELEASE

Hazardous material releases can be localized events (such as small releases at a fixed site) or regional events (such as nuclear/radiological events). Several variables come into play when determining a community's risk to hazardous material releases. Factors that help determine a community's vulnerability to this hazard include:

- The size of the community (both geographically and physically)
- The location and number of fixed sites containing potential hazardous material(s)
- The community's proximity to mobile HAZMAT (road and rail) risk areas where releases could occur

One of the difficulties of addressing the hazardous material release hazard is that it takes time and effort to identify all of the potential fixed hazardous material sites in a community. There are several federal, state, and local sources to investigate, and each community will have a different level of vulnerability.

When assessing community risk to hazardous materials release, the first step a community will want to take is to conduct a hazard identification process that will include development of a hazard profile that identifies the potential sources of the hazard, how the hazard has impacted the community in the past, how it could impact the community in the future, and the extent to which the hazard could impact the community.

Once a detailed hazard profile has been assembled, a vulnerability assessment can be conducted to determine the exposure of people and other community assets that could potentially be impacted by a hazardous material release. Community planners will have to evaluate which type of vulnerability analyses will work best for their community's needs based on what types of threats are present. For example: Are air plume analyses needed for airborne releases? Is it necessary to determine vulnerabilities to water systems for potential water-borne releases? Or is it necessary to consider other, more serious types of analyses due to potential radioactive or nuclear risks?

AVAILABLE DATA SOURCES

Environmental Protection Agency (EPA) Toxic Release Inventory Program
Tier II Reports are required by the EPA whenever a hazardous material is released, and are available at the county level from County Emergency Managers and/or the Environmental Protection Agency. epa.gov/toxics-release-inventory-tri-program
U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration
The Pipeline and Hazardous Materials Safety Administration (PHMSA) was established to protect people and the environment from the risks of hazardous materials transportation. The PHMSA website is a good source of hazardous materials incident data and other information relevant for hazardous materials and pipeline safety. phmsa.dot.gov
Colorado Department of Transportation (CDOT)
CDOT's Hazmat Routing Overview page provides current Hazmat routes and information related to designating roadways as Hazmat routes. codot.gov/business/hazmat-routing

EPA's Areal Locations of Hazardous Atmospheres (ALOHA) Program

EPA's ALOHA is a modeling program for the CAMEO (Computer-Aided Management of Emergency Operations) software suite, which is widely used to plan for and respond to chemical spills. ALOHA allows users to enter details about a real or potential chemical release, and will generate threat zone estimates for various types of hazards. The threat zone estimates are shown on a grid in ALOHA, and they can also be plotted on maps in MARPLOT (Mapping Application for Response, Planning, and Local Operational Tasks), Esri's ArcMap, Google Earth, Hazus, and Google Maps.

- ALOHA - epa.gov/cameo/aloha-software
- CAMEO - epa.gov/cameo/what-cameo-software-suite
- MARPLOT - epa.gov/cameo/marplot-software

APPLICABLE PLANNING TOOLS AND STRATEGIES

The table below cites applicable planning tools and strategies that are profiled in this guide.

APPLICABLE PLANNING TOOLS AND STRATEGIES – HAZARDOUS MATERIAL RELEASE	
Addressing Hazards in Plans and Policies	• Comprehensive plan • Hazard mitigation plan • Pre-disaster planning
Strengthening Incentives	• Development agreement
Protecting Sensitive Areas	• 1041 regulations
Improving Site Development Standards	• Subdivision and site design standards • Use-specific standards
Improving Buildings and Infrastructure	• Critical infrastructure protection
Enhancing Administration and Enforcement	• Application submittal requirements • Post-disaster building moratorium

EXTREME HEAT

DESCRIPTION

Extreme heat is defined as weather that is "substantially hotter and/or more humid than average for a location at that time of year" (*Hazard Identification and Risk*, 2011, p. 31) The Heat Index, which measures the "apparent temperature" when considering both air temperature and humidity, is used by organizations like the National Weather Service to identify extreme heat days. Extreme heat is particularly dangerous when occurring for a prolonged period (known as a "heat wave").

Periods of extreme heat can cause serious injury or death to exposed populations, especially the elderly, infants, transient populations, persons with physical and mental impairments, and those without access to air conditioning or social services. Extreme heat is also associated with increased demands for electricity and water, and can potentially stress local and regional infrastructure and services. Prolonged periods of extreme heat can have negative impacts on farming and livestock, and may lead to algae blooms that increase the risk of fish kills. Extreme heat can also have a negative impact on health and productivity, with a direct impact on economic activity and travel. Warming temperatures and extreme heat have also been shown to have negative impacts on forests, aquatic ecosystems, and wildlife and fish populations (*Rocky Mountain Forests,* 2014).

EXTREME HEAT IN COLORADO

Summertime temperatures are lower in the mountains and at higher elevations; therefore, extreme heat hazards in Colorado tend to occur in the Front Range, Grand Valley, Eastern Plains, and extreme southwest (*Colorado Natural Hazards Mitigation Plan*, 2013, p. 3-38). The number of extreme heat days in Colorado has been rising in recent years. In Denver, for instance, seven of the ten hottest years since 1874 occurred from 2000-2012 (*NWS Boulder Denver*, n.d.b). In Fort Collins, the number of days per year over 90 degrees from 2000-2013 was almost double the historic average (*Extreme Heat,* 2014). While the overall mortality rate due to extreme heat events has been declining in Colorado over the past several decades, largely due to the increased availability of air conditioning and preparedness for extreme heat hazards, certain groups remain vulnerable. Past extreme heat events have caused damage to state and local infrastructure, especially roadways and utility networks.

RELATED HAZARDS

Extreme heat can help create the conditions for drought and can exacerbate the impacts of drought by putting additional stress on available water supplies. Extreme heat can also lead to increased storm activity, which is linked to both high wind and flash flood hazards. It can also contribute to the spread of wildfires.

AVAILABLE DATA SOURCES

Colorado Natural Hazards Mitigation Plan

The *Colorado Natural Hazards Mitigation Plan* is a key resource for an overview of extreme heat hazards and summaries of national and state-level data on extreme heat. dhsem.state.co.us/emergency-management/mitigation-recovery/mitigation/state-colorado-natural-hazards-mitigation-plan

National Weather Service

The National Weather Service is a key resource for the forecasting of extreme heat events and for the issuance of advisories and warnings. weather.gov

National Oceanic and Atmospheric Administration (NOAA)

The National Oceanic and Atmospheric Administration's National Climatic Data Center (NCDC) provides data on temperatures and extreme heat for the United States and for Colorado. ncdc.noaa.gov/cdo-web/datasets

FEMA and Ready.Gov

FEMA and Ready.Gov have published useful guides for extreme heat preparation and response. ready.gov/heat

APPLICABLE PLANNING TOOLS AND STRATEGIES

The table below cites applicable planning tools and strategies that are profiled in this guide. In addition to the tools and strategies cited below, other site development standards such as **site selection, building orientation, and landscaping** can also be important tools for reducing potential risks from extreme heat.

APPLICABLE PLANNING TOOLS AND STRATEGIES – EXTREME HEAT	
Addressing Hazards in Plans and Policies	• Comprehensive plan • Climate plan • Hazard mitigation plan • Pre-disaster planning
Strengthening Incentives	*N/A*
Protecting Sensitive Areas	*N/A*
Improving Site Development Standards	*N/A*
Improving Buildings and Infrastructure	• Critical infrastructure protection
Enhancing Administration and Enforcement	*N/A*

LANDSLIDE, MUD/DEBRIS FLOW, AND ROCKFALL

DESCRIPTION

Landslides, mud flows, debris flows, and rockfalls are among many geologic and soil hazards that impact Colorado.

Landslides are the downward and outward movement of slopes composed of natural rock, soils, artificial fills, or combinations thereof. Common names for landslide types include slump, rockslide, debris slide, lateral spreading, debris avalanche, earth flow, and soil creep (*Colorado Natural Hazards Mitigation Plan*, 2013*)*. Landslides move by falling, sliding, and flowing along surfaces marked by differences in soil or rock characteristics. A landslide is the result of a decrease in resisting forces that hold the earth mass in place and/or an increase in the driving forces that facilitate its movement. The rates of movement for landslides can be very quick (tens of feet per second) or very slow (fractions of inches per year). Landslides can occur as reactivated old slides or as new slides in areas that have not previously experienced them. Areas of past or active landslides can be recognized by their topographic and physical appearance. Areas susceptible to landslides but not previously active can frequently be identified by the similarity of geologic materials and conditions to areas of known landslide activity (p. 3-267 to 3-270).

A **mud flow** is a mass of water and fine-grained earth materials that flows down a stream, ravine, canyon, arroyo, or gulch. If more than half of the solids in the mass are larger than sand grains—-rocks, stones, boulders—the event is called a **debris flow**. Debris and mud flows are combinations of fast-moving water and great volumes of sediment and debris that surge down a slope with tremendous force. They are similar to flash floods and can occur suddenly without time for adequate warning. When the drainage channel eventually becomes less steep, the liquid mass spreads out and slows down to form a part of a debris fan or a mud flow deposit. In the steep channel itself, erosion is the dominant process as the flow picks up more solid material. Any given drainage area may have several mud flows a year, or none for several years or decades. They are common events in the steep terrain of Colorado and vary widely in size and destructiveness. Extreme amounts of precipitation in a very short period of time (e.g., cloudbursts) and flash floods are the usual sources for creating a mud flow in Colorado (p. 3-268 to 3-270).

Rockfalls are a newly detached mass of rock falling from a cliff or down a very steep slope. Rockfalls are the fastest type of landslide and occur most frequently in mountains or other steep areas during early spring when there is abundant moisture and repeated freezing and thawing. Ice wedging, root growth, or ground shaking, as well as a loss of support through erosion or chemical weathering may start the fall (p. 3-269 to 3-270).

2011 landslide along West Mosquito Creek in Park County, Colorado.

Source: Colorado Geological Survey, photo by Division of Reclamation and Mining. coloradogeologicalsurvey.org/geologic-hazards/landslides-2/colorado-landslide-inventor/

LANDSLIDE, MUD/DEBRIS FLOW AND ROCKFALL IN COLORADO

Land movement related to landslides, mud and debris flows, and rockfalls occurs naturally across Colorado on a continuous basis, and can also be triggered through human activity (primarily related to mining, land development, and other disturbances). These events can occur at any time of the year from almost any location along a slope; however, because they are correlated with elevation change, these hazards largely occur in the mountainous region from the Front Range to the West Slope.

According to *READY Colorado*, it is estimated that there are thousands of landslides in Colorado each year, with varying degrees of frequency and severity. Most of these events do not result in casualties or property damage, though the annual damage in Colorado is estimated to exceed $3 million to buildings alone (*Colorado Natural Hazards Mitigation Plan,* 2013, p. 3-185). A massive landslide in a relatively unpopulated area of Mesa County near Grand Junction killed three people in 2014, leaving a swath of debris three miles long and ¾ of a mile wide. A deadly rockfall in September 2013 claimed five lives of a vacationing family following heavy rains near a popular hiking location near Buena Vista, Colorado (Shoichet, et al., 2013). Rockfalls are less frequent but remain a constant threat, particularly to Colorado's mountain roadways. All of these geologic hazards may endanger Colorado's built environment and can damage or destroy buildings, roads, and other infrastructure when proper land use or mitigation practices are not considered.

RELATED HAZARDS

Flash flooding or ongoing heavy rain can be precursors to landslides, mud/debris flows, and even rockfalls. Additionally, drought conditions may lead to soil compaction, and severe wildfire events may leave slopes denuded and hydrophobic. In these cases, a single heavy rain event can lead to higher volumes of runoff and correspondingly a higher risk for flash flooding, erosion, and especially mud/debris flows. Rockfalls are often caused by erosion of earth around larger rocks that then become loose and fall. Earthquakes can also lead to landslides and rockfalls.

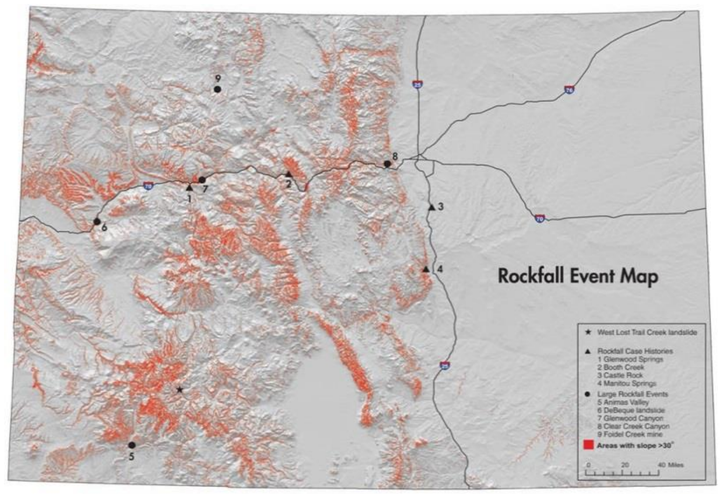
ASSESSING THE RISK OF GEOLOGIC AND SOIL HAZARDS

Nearly all geologic and soil hazards are highly localized events. The nature and extent of risk associated with each hazard is specific to local terrain conditions such as slope stability, vegetative cover, and geologic and soil composition beneath the earth's surface. In fact, much of what helps determine the level of hazard risk at a precise location are the features and process that lie underground. Other factors include seasonal, climate, and weather-related phenomena (including other hazards) that can alter the local conditions that affect an area's current risk. These variables make the identification, assessment, and mapping of geologic and soil hazards more difficult, especially for the purpose of designing and implementing planning tools or strategies. However, given the extreme danger these hazards pose, the knowledge and understanding of a site's geology is essential in order to adequately plan, design, and construct a safe development.

In recognition of this fact, the Colorado Geological Survey (CGS) provides a range of services and resources to assist and advise local planners on geologic hazards, including the review of preliminary plans or reports for new development as well as conducting studies, collecting geologic information, and publishing maps, reports, and bulletins with regard to land use activities.

Still, while a variety of relevant national and statewide data exists to determine hazard risk in a very general sense (including geologic, topographic, and soil maps), most Colorado communities do not have readily accessible information or detailed maps necessary for implementing local regulations. Doing so often requires field surveys and even geotechnical tests by trained earth scientists to identify specific problems associated with land development and public safety.

Consultation with geologists and other experts familiar with local conditions is an important first step for local planners seeking to assess the risk of their community and specific areas that are susceptible to geologic and soil hazards. The CGS and other official sources can provide map information on levels of risk, past hazard events, and the probability of future events. More site-specific data and mapping, however, will need to be obtained through technical studies for specific areas of concern. Communities may opt to hire a consulting geologist or geotechnical engineer to perform this work, or require such expert studies as part of the local development permitting process.



The Colorado Geological Survey's "Rockfall Event Map" identifies locations of historic rockfall events along with steeply sloped areas that are more susceptible to future occurrences.

As summarized in Chapter 2, there are several state statutes and regulations that specify requirements for the submission of geologic suitability reports in conjunction with land use applications to be reviewed by CGS.[1] Other statutes address the manner in which geologic and soil hazards are to be addressed by developers and local governments, including but not limited to hazard analyses and site recommendations.

At a minimum, planners should have a general understanding of where geologic and soil hazards exist and what their implications are for safe development so that the viability of available planning tools and strategies to reduce their risk can be further evaluated. Ideally, using this information, most communities should be able to prepare a map of the entire community that distinguishes particular areas of concern. This type of map can help planners and decision makers identify areas that are generally less desirable for future development and may require further technical study, along with smaller-scale maps for implementing regulations or requiring closer examination during the review of development proposals.

[1] Senate Bill 35 (1972)-3 requires subdividers to submit reports concerning geologic characteristics and any soil or topographic conditions that present hazards or require special precautions. House Bill 1041 requires that all developments in areas designated by counties as geological hazard areas be engineered and administered in a manner that will minimize significant hazards to public health and safety or to property. House Bill 1045 (1984)-4 requires school districts to submit reports regarding geologic suitability for raw land purchases, new school plans, and improvements to existing schools to the CGS for review.

AVAILABLE DATA SOURCES

Geologic hazards such as landslides, mud and debris flows, and rockfalls are sporadic and somewhat unpredictable; however, geologic studies can determine historic runs and existing movement in the earth suggesting movement is occurring or imminent.

Colorado Geological Survey

The Colorado Geological Survey is the primary State agency for providing information and maps on geologic hazards such as landslides, mud/debris flows, and rockfall. Additionally, the Colorado Landslide Hazard Mitigation Plan and the Colorado Landslide Viewer are useful tools addressing these hazards locally. coloradogeologicalsurvey.org

- Landslides - coloradogeologicalsurvey.org/geologic-hazards/landslides-2
- Mud/debris flow - coloradogeologicalsurvey.org/geologic-hazards/debris-flows-fans-mudslides
- Rockfall - coloradogeologicalsurvey.org/geologic-hazards/rockfall
- Landslide Hazard Mitigation Plan - store.coloradogeologicalsurvey.org/product/colorado-landslide-hazard-mitigation-plan
- Colorado Landslide Viewer - coloradogeologicalsurvey.org/geologic-hazards/landslides-2/colorado-landslide-inventory
- Through the CGS's ongoing STATEMAP program, new geologic map information is becoming more readily available and more frequently incorporated into local and countywide decision-making. CGS also manages a GIS library of digital geologic data that can be combined with local datasets to better understand the relationship between community assets and areas of potential hazard concern. coloradogeologicalsurvey.org/geologic-mapping/statemap-program

United States Geological Survey (USGS)

USGS is the primary federal reference for national data regarding these hazards. The USGS Landslides Hazards Program provides several useful resources related to these hazards including the USGS Landslide Overview Map of the Conterminous United States.

- Landslide program - landslides.usgs.gov
- Landslide overview map - landslides.usgs.gov/hazards/nationalmap

Colorado Department of Transportation

The Colorado Department of Transportation, Materials and Geotechnical Branch, manages the state's soils and rockfall program. This agency is responsible for the Rockfall Mitigation Project Plan (RMPP), which includes a list of the 756 rockfall sites identified in Colorado as having chronic rockfall problems. codot.gov/business/designsupport/materials-and-geotechnical

APPLICABLE PLANNING TOOLS AND STRATEGIES

In addition to the tools and strategies cited below that are profiled in this guide, **hillside development standards** are also important tools for reducing potential risks from landslides and similar hazards. Hillside standards often include limitations on grading and earth removal and standards for site improvements such as retaining walls.

APPLICABLE PLANNING TOOLS AND STRATEGIES – LANDSLIDE, MUD/DEBRIS FLOW, AND ROCKFALL	
Addressing Hazards in Plans and Policies	• Comprehensive plan • Climate plan • Hazard mitigation plan • Parks and open space plan • Pre-disaster planning
Strengthening Incentives	• Development agreement • Density bonus • Transfer of development rights
Protecting Sensitive Areas	• 1041 regulations • Cluster subdivision • Conservation easement • Land acquisition • Overlay zoning • Stream buffers and setbacks
Improving Site Development Standards	• Stormwater ordinance • Site-specific assessment • Subdivision and site design standards • Use-specific standards
Improving Buildings and Infrastructure	• Building code • Critical infrastructure protection
Enhancing Administration and Enforcement	• Application submittal requirements • Post-disaster building moratorium

SOIL HAZARDS: EROSION AND DEPOSITION, EXPANSIVE SOILS, AND SUBSIDENCE

DESCRIPTION

Erosion is the removal and simultaneous transportation of earth materials from one location to another by water, wind, waves, or moving ice. **Deposition** is the placing of the eroded material in a new location. All material that is eroded is later deposited in another location (*Colorado Natural Hazards Mitigation Plan*, 2013, p. 3-166). In Colorado, erosion and deposition are typically initiated by water or wind.

- **Riverine erosion** is the long-term process whereby river banks and riverbeds are worn away. This process is best described as a river's tendency for constant course alteration, shape and depth change, and the balancing act between the water's sediment transport capacity and its sediment supply. Swiftly moving floodwaters cause rapid local erosion as the water carries away earth materials. Deposition occurs where flood waters slow down, pool or lose energy in other ways, and materials settle out.
- **Wind erosion** occurs when wind is responsible for land removal, movement, and deposition and most commonly occurs in exposed areas such as fields, tailings, and deserts. Another factor that controls the amount of erosion is the ease with which material can be dislodged and transported. Hard granites erode very slowly while soft silts and sands erode very quickly.

Expansive (or swelling) soils are soils or soft bedrock that increase in volume as they get wet and shrink as they dry out. Expansive soils contain a high percentage of certain kinds of clay particles that are capable of absorbing large quantities of water. Soil volume may expand 10 percent or more as the clay becomes wet, and the powerful force of expansion is capable of exerting damaging pressures on foundations, slabs, or other confining structures. Subsurface Colorado swelling soils tend to remain at constant moisture content in their natural state and are usually relatively dry at the outset of disturbance for construction on them. Exposure to natural or human-caused water sources during or after development results in swelling, and in many instances the soils do not regain their original dryness after construction, but remain moist and expanded due to the changed environment.

Ground **subsidence** is the sinking of land over man-made or natural underground voids, which can result in serious structural damage to buildings, roads, irrigation ditches, underground utilities, and pipelines. In Colorado, the type of subsidence of greatest concern is the settling of the ground over abandoned mine workings. Collapsing and settling soils are relatively low-density materials that shrink in volume when they become wet and/or are subjected to great weight such as from a building or road. Human activities that lead to subsidence include underground mining, pumping groundwater or petroleum, hydrocompaction, and draining organic soils. Natural causes of subsidence include the development of sinkholes, rock sliding downward along faults, natural sediment compaction, and melting of permafrost. Subsidence may occur virtually instantly or gradually over many years. It may occur uniformly over a wide area or as local depressions or pits separated by areas that have not visibly subsided. In Colorado, it is most common in the sedimentary rocks over abandoned coal and clay mines. Although less common, subsidence can also occur where underground water has dissolved subsurface materials or has been withdrawn by wells.

Subsidence is a particular concern for many communities across Colorado. This image from 2005 shows road damage likely initiated by subsidence in Golden near the Colorado School of Mines.

Source: Colorado Geological Survey. Case Histories. coloradogeologicalsurvey.org/geologic-hazards/subsidence-mine/case-histories

SOIL HAZARDS IN COLORADO

Erosion and deposition are occurring continually at varying rates all over Colorado. Point sources of erosion are common to construction sites or other areas where human interaction with the earth results in exposed soil or removal of vegetation, and natural waterways perpetually remove and carry soil from the earth to locations downstream.

About 50 percent of Colorado's soil has a high or very high potential for shrinking and swelling. This, coupled with the fact that most of the homes, schools, public and commercial buildings, and roads in the state are located in areas of potentially swelling clay, means that expansive soils are one of the most significant, widespread, costly, and least publicized geologic hazards in Colorado.

Expansive soils are one of the most significant, widespread, costly, and least publicized geologic hazards in Colorado.

Subsidence and collapsible soils tend to be problematic along the Front Range, Western Slope, and in the central mountains near Eagle County. Occurrences of subsiding and collapsing soils date back to Colorado's early history throughout these locations.

RELATED HAZARDS

Many other hazards and naturally occurring events are related to erosion and deposition. The natural flow of rivers and streams causes minor erosion and deposition, but flood events create accelerated and more dramatic erosion and deposition rates. For example, the deposition of material can block culverts or impede other engineered and natural conveyances which further aggravate flood conditions. Channel migration resulting from flooding can introduce hazard risk into new areas. Similarly, windstorm events rapidly increase the erosion and deposition of soft silts and sands in exposed areas. Landslides, mud/debris flows, and rockfalls may exacerbate the problems associated with erosion and deposition by making more material available and potentially increasing the rates of each process. Erosion and deposition issues are also exacerbated in wildfire burn areas.

Expansive soils and subsidence are generally influenced by how wet or dry those types of soils become, so the climate of an area, and more specifically the seasonal precipitation/drought cycle associated with arid or semi-arid regions such as Colorado, heavily influences the occurrence and severity of these hazards.

AVAILABLE DATA SOURCES

Colorado Geological Survey

The Colorado Geological Survey is the primary source of soil hazard data specific to Colorado communities. coloradogeologicalsurvey.org. Hazard-specific pages exist for the following hazards:

- Erosion (includes deposition) - coloradogeologicalsurvey.org/geologic-hazards/erosion
- Collapsible Soils (includes online viewer) - coloradogeologicalsurvey.org/geologic-hazards/collapsible-soils-2
- Subsidence (Mines) - coloradogeologicalsurvey.org/geologic-hazards/subsidence-mine
- Subsidence (Natural) - coloradogeologicalsurvey.org/geologic-hazards/subsidence-natural
- Swelling Soils - coloradogeologicalsurvey.org/geologic-hazards/swelling-soils

Natural Resources Conservation Service Colorado

The Natural Resources Conservation Service (NRCS) Colorado maintains soil surveys for Colorado. The NRCS also employs a State Conservationist that is a good contact for information about soils hazards. nrcs.usda.gov/wps/portal/nrcs/site/co/home

- Soil Surveys - nrcs.usda.gov/wps/portal/nrcs/surveylist/soils/survey/state/?stateId=CO
- State Conservationist - nrcs.usda.gov/wps/portal/nrcs/main/co/contact/state

APPLICABLE PLANNING TOOLS AND STRATEGIES

The table below cites applicable planning tools and strategies that are profiled in this guide.

APPLICABLE PLANNING TOOLS AND STRATEGIES – SOIL HAZARDS	
Addressing Hazards in Plans and Policies	• Comprehensive plan • Hazard mitigation plan • Parks and open space plan • Pre-disaster planning
Strengthening Incentives	• Development agreement • Density bonus • Transfer of development rights
Protecting Sensitive Areas	• 1041 regulations • Cluster subdivision • Conservation easement • Land acquisition • Overlay zoning
Improving Site Development Standards	• Stormwater ordinance • Site-specific assessment • Subdivision and site design standards • Use-specific standards
Improving Buildings and Infrastructure	• Building code • Critical infrastructure protection
Enhancing Administration and Enforcement	• Application submittal requirements • Post-disaster building moratorium

WILDFIRE

DESCRIPTION

A **wildfire** is an unplanned, unwanted wildland fire. Wildfires include unauthorized human-caused fires, escaped wildland fire use events (where appropriate management response to naturally-ignited wildland fires escape), escaped prescribed fire projects, and all other wildland fires where the objective is to put the fire out (Botts, et al., 2015). While this section's emphasis is on wildfires as an unwanted hazard, it also discusses wildfire in the context of how and why wildland fires occur.

A **wildland fire** is any non-structure fire that occurs in areas of vegetation or natural fuels, and can be either prescribed fire or wildfire. Wildland fire occurs when vegetation, or "fuel," such as grass, leaf litter, trees, or shrubs, is exposed to an ignition source and the conditions for combustion are met, resulting in fire growth and spread through adjacent combustible material. Wildland fires are either ignited by lightning or by some consequence of human activity. In Colorado, lightning accounts for only 17 percent of wildfires, with human ignitions accounting for the remainder (*Colorado Natural Hazards Mitigation Plan,* 2013). Human causes vary and can include escaped debris pile burning, campfires, fireworks, construction sparks, downed transmission lines, and arson.

Wildland fires can occur during any time of year. Although there are frequent references to a "fire season," ignitions are a result of the ability of fuels to support combustion. In addition to an ignition source, the fuel type, amount of fuel, distribution pattern, and moisture content—coupled with weather and topography—will determine the conditions for combustion and resulting fire behavior. Fire behavior characteristics, often referred to as "outputs," include intensity, residence time (i.e., the time required for the active flame zone to pass a stationary point at the surface of the fuel), rate of spread, ember production, ember transport distance, and fire size. These fire behavior outputs determine the influence the wildfire has on adjacent and surrounding fuels through radiant, convective, and conductive heat.

Wildland fire is a natural ecological disturbance process, and in many cases it is necessary ecosystem health. Historically, "natural" fire varied in size, intensity, and severity, creating a mosaic of native vegetation communities across different landscapes. Multiple fire events will occur over time and the frequency and length of the fire return interval is

Wildfires and Human Behavior

Wildfires are distinct from other natural hazards in two ways: 1) wildfire activity is not limited to natural environmental causes (such as earthquakes, tornados, or hurricanes) because ignition can also result from human activity; 2) humans have the ability to significantly reduce wildfire threat by altering, redirecting, or (in some cases) extinguishing a wildfire.

Sources: Kari Greer/ NIFC (creative commons license); Castle Rock Fire, Ketchum, ID 2007; National Interagency Fire Center Photo Gallery dependent upon the vegetation type and climatic conditions. This natural variation of fire has declined in North America over the past two centuries due to a number of human influences. These influences have significantly altered the natural fire regime and created extensive areas of homogeneous forests (forests of the same composition including trees of the same age, size, species etc.), causing a significant and widespread change in fire effects and fire's influence on ecosystems and people.

Wildfires become wildland-urban interface fires when they transition from natural areas of vegetation to a combination of vegetation and the built environment, such as the Waldo Canyon Fire in 2012.

Fire Adapted Communities, Waldo Canyon Fire 2012, National Interagency Fire Center Photo Gallery. Kari Greer/US Forest Service

The introduction and increasing growth of development adjacent to and intermixed within the natural vegetation across the landscape poses additional risk to people and property. In the context of wildfire, the combustible components of buildings, infrastructure, and associated accessories make them susceptible to ignition and are also considered fuel for the fire. A fire burning in this situation has transitioned from a wildfire to a **wildland-urban interface (WUI) fire**, where a combination of vegetation and man-made structures provide fuel for the fire. This situation increases the complexity, cost, and risk of wildfire in Colorado. In most WUI fire situations, fire suppression resources are quickly overwhelmed and multiple structures are lost.

The terms wildfire hazard and wildfire risk are distinctly different. **Wildfire hazard** refers to the fuels in a given location and represents the intensity with which an area is likely to burn if a fire does occur there. **Wildfire risk** is the probability and consequence of a wildfire burning in an area (based on the wildfire hazard, potential losses, and weather conditions). Identifying wildfire hazard is an important first step in assessing the risk of wildfires. Wildfire risk assessments can be analyzed on different spatial scales, depending on the intended use of the assessment.

WILDFIRES IN COLORADO

Between 2010 and 2014, an average of 1,192 wildland fires, excluding prescribed fires, occurred annually in Colorado. The number of acres can vary greatly; for example, in 2014, a reported 24,949 acres burned throughout the state, while in 2012 a total of 246,445 acres burned due to wildland fires. Annual structural losses across the state also fluctuate. Between 2012 and 2013, more than 1,200 structures were damaged or destroyed by wildfires that swept across the state, resulting in nearly $1 billion in property damage (Badger, 2015). Other years, however, have reported significantly fewer structural losses and damage.

Wildfire size (reported as acres burned) is not always indicative of its impact. The Royal Gorge Fire that began on June 11, 2013 outside of Cañon City, burned a total area of 3,218 acres and destroyed 90 percent of the Royal Gorge Bridge and Park. The Royal Gorge Bridge itself was relatively unaffected, but 48 of 52 buildings—including the visitor center, Aerial Tram, Incline Railway, and other attractions—were destroyed (*Royal Gorge Bridge,* 2014). Examples like this illustrate the long-lasting impacts that wildfires can have on the local economy and the variety of community values at risk.

CoreLogic, a national provider of financial and property information, estimates that Colorado ranks as one of the leading states across the western United States in terms of residential properties potentially at risk of future wildfire damage. A 2015 report shows that Colorado has nearly 100,000 homes that are either at high or very high risk of wildfire – translating into $28 billion of residential assets exposed to potential future wildfire damage (Botts, et al., 2015).These trends also reflect a larger pattern associated with increased development in wildfire-prone areas in the West. Community wildfire risk will continue unless more action is taken to reduce and/or mitigate the threat.

A 2015 report shows that Colorado has nearly 100,000 homes that are either at high or very high risk of wildfire – translating into $28 billion of residential assets exposed to potential future wildfire damage.

RELATED HAZARDS

Other hazards can contribute to the potential for wildfires or can influence wildfire behavior:

- High winds can down power lines (providing an ignition source), and/or result in areas of downed and dead trees (increasing fuel loads); high winds can also produce rapid rates of spread on active fires and increase the distance of ember transport beyond the active fire perimeter.
- Floods, landslides, and avalanches can result in areas of heavy fuel loading.
- Earthquakes can crack gas lines, creating a higher potential for ignition.
- Lightning can ignite fuels, resulting in wildland fires.
- Drought conditions increase wildfire potential by decreasing fuel moisture. Warm winters, hot and dry summers, severe drought, insect and disease infestations, years of fire suppression, and growth in the wildland-urban interface continue to increase wildfire risk and the potential for catastrophic wildfire in Colorado (*Colorado Natural Hazards Mitigation Plan*, 2013, p. 3-214).

Wildfires can also contribute to and influence the magnitude of other hazards. Severe wildfire events may leave slopes denuded and hydrophobic. In these cases a single heavy rain event can lead to higher volumes of runoff and correspondingly a higher risk for flash flooding, erosion and deposition, and mud/debris flows.

Wildfire events may also create open slopes through the consumption of mature timber. In some locations where this occurs, this can create new avalanche slide paths, or enlarge existing avalanche slide paths. Finally, major wildfire events may also cause increased risks for geologic hazard events (landslide, mud/debris flow, and rockfall), soil hazards, and hazardous material releases.

ASSESSING THE RISK OF WILDFIRE

Generally, wildfire risk is assessed through combining the following:

- Ignition probability
- Fire behavior potential

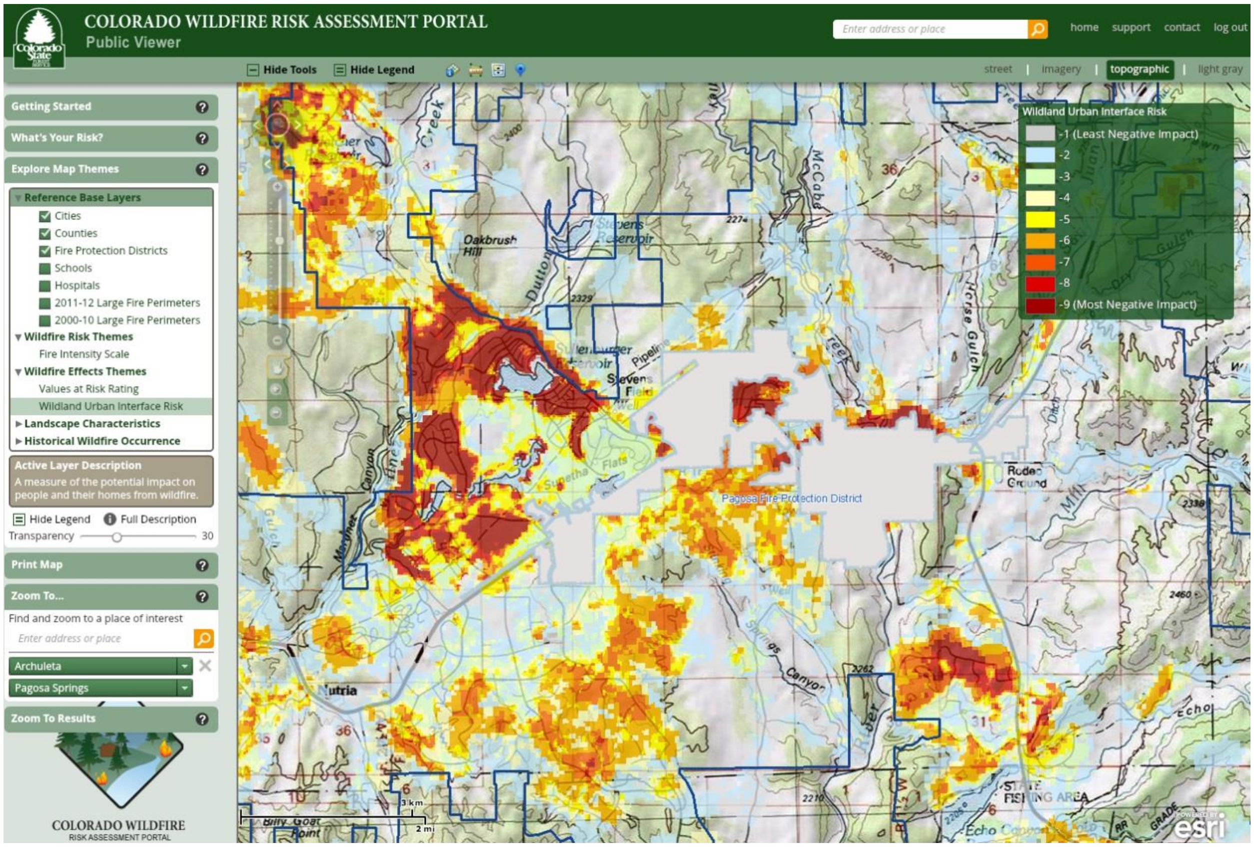
- Vulnerability of the values at risk to direct fire impingement (convective and radiant heat from the fire front) and indirect ignition (airborne embers transported ahead of the fire perimeter)

Assessment inputs include the appropriate fuel, weather, topography, and values at risk for a given area, as discussed in more detail below.

Assessing wildfire hazard and wildfire risk, including the risk of WUI fires, requires specialized expert knowledge in fire behavior, forest ecology and dynamics, and structure and infrastructure ignition vulnerability. However, land use planners and other non-specialists should work closely with experts to provide input and understand the implications of the risk assessment on local land uses.

Some communities have a dedicated wildfire mitigation specialist on staff that can provide this level of expertise. Other communities may have access to specialized expertise through the local fire authority, district forest service, academic partners, or other local organizations (e.g., nonprofit or research organizations). It is also common for communities to hire external consultants that specialize in this area.

There are a number of wildfire hazard and risk assessment tools available to communities. For those communities with limited capacity or resources, the most accessible tool developed specifically for Colorado is the Colorado Wildfire Risk Assessment Portal (COWRAP).



The Colorado Wildfire Risk Assessment Portal (CO-WRAP) supports communities in assessing their wildfire risk by providing a helpful starting point in viewing and analyzing areas at risk.

Source: Colorado Wildfire. 2016. coloradowidlfirerisk.com

In addition, there are many widely available guides to help communities develop Community Wildfire Protection Plans, such as *Preparing a Community Wildfire Protection Plan: A Handbook for Wildland–Urban Interface Communities* (2004) (frequently referred to as the CWPP Handbook). These (and similar publications) provide communities with concise, step-by-step approaches for developing a Community Wildfire Protection Plan (CWPP), including a hazard and risk assessment. Summit County is an example of a community that followed the CWPP Handbook guidance for the hazard and risk assessment process in the development of their CWPP. For more information on CWPPs, refer to the tool profile in the main body of the guide.

Finally, some communities elect to work with a consultant that provides a risk assessment based on their own unique proprietary tool. Eagle County, for example, used a proprietary tool that classifies the jurisdiction into "firesheds;" and Glenwood Springs approached their hazard assessment through the use of a proprietary tool that identifies wildfire hazard by evaluating a number of structure loss factors, from immediate hazards near an individual property to proximity area hazards, and then combines these with historical fire occurrence.

Many of these tools are based on models or processes that have difference assumptions, limitations, uses, and scales of use. For example, COWRAP will provide a description of the fire intensity potential based on the conditions within the general vicinity of the location defined by the user. Basic recommendations are also provided for preparedness.

All of the wildfire assessment tools face limitations regarding the accuracy of the inputs. For example, many of the tools rely on a combination of vegetation cover inventory, weather, structure, subdivision, and infrastructure/critical spatial data input. Wildland vegetation, weather and community growth, and layout can be extremely dynamic and in a constant state of change. In many cases, there can be significant challenges in keeping the data inputs that feed these tools updated in order to keep the resulting wildfire hazard and risk assessments accurate. In some cases, this lag can be measured in years. Typically, the more complex the assessment, the more difficult it is to keep up to date; however, if kept updated, the complex assessments become a very powerful tool. Finally, all of the current models are based on past and present conditions, and typically do not predict the future. For the same reasons that make keeping the assessments current a difficult task, using these tools to predict future conditions with any degree of accuracy is extremely challenging. It is important that the user of these tools have the knowledge and expertise to thoroughly understand the inputs, outputs, limitations, and assumptions of all of these tools to ensure they are used accurately and in the most effective manner.

When seeking the professional assistance and advice of a wildfire hazard and risk assessment expert, the planner should look for an individual or team that has advanced knowledge and experience in:

- Wildland fire behavior
- The application of structure ignition concepts

Non-Specialists and the Hazard Identification and Risk Assessment

Wildfire hazard identification and wildfire risk assessments require specialized expert knowledge. Non-specialists, however, play an important role in the process. For example, community planners provide necessary information to help identify community values at risk, planned areas of future growth, key demographic trends, emergency response access and evacuation routes, and other features.

As another example, a public works director can provide information on critical infrastructure and planned capital improvements. By participating in the risk assessment process, non-specialists from other departments and/or agencies contribute knowledge and can better understand how wildfire may potentially affect future community risk.

- Wildland fuel model identification and classification
- The assessment of forest and rangeland dynamics and health influence on fire behavior
- Field and model-based wildfire hazard and risk assessment
- The assumptions and limitations of available wildfire assessment tools
- The use and application of spatial applications for wildfire hazard and risk assessment

AVAILABLE DATA SOURCES

Colorado communities have access to several sources of wildfire hazard data that are useful for identifying wildfire hazard areas and determining community vulnerability to the hazard.

Colorado State Forest Service (CSFS)

The CSFS is the lead state agency for providing information on wildfire risk and mitigation. The Colorado Wildfire Risk Assessment Portal (COWRAP) is the primary mechanism for CSFS to deploy risk information and create awareness about wildfire issues across the state. A public and professional viewer is available online for free (note: anyone can sign up for the professional viewer, which provides additional detail to aid community wildfire planning). coloradowildfirerisk.com. CSFS also promotes multiple programs to help reduce wildfire threat, and provides technical assistance to counties, communities, and residents. csfs.colostate.edu/wildfire-mitigation.

Rocky Mountain Insurance Information Association (RMIIA)

RMIIA is a non-profit insurance communications organization representing property and casualty insurers in Colorado, New Mexico, Utah, and Wyoming. RMIIA compiles overall estimates of insured losses and number of claims filed for catastrophes (insured natural disasters that cause more than $25 million in damages). rmiia.org/catastrophes_and_statistics/Wildfire.asp

LANDFIRE data

LANDFIRE, Landscape Fire and Resource Management Planning Tools, is a shared program between the wildland fire management programs of the USDA Forest Service and the US Department of the Interior. The website provides free landscape-scale maps and data describing fire recurrence intervals, vegetation, wildland fuel, and fire regimes across the United States. For the advanced wildfire practitioner, LANDFIRE offers fuel model, disturbance, vegetation cover, topography and fire regime data that can be used in conjunction with other inputs (weather, local data) and processed using tools such as ArcFuels, BehavePlus and FlamMap to determine the wildland fire behavior potential and ultimately the wildfire hazard. landfire.gov

Fire-Adapted Communities

A "fire-adapted community" incorporates people, buildings, businesses, infrastructure, cultural resources, and natural areas to prepare for the effects of wildfire. Fire-adapted communities also incorporate other programs and tools, such as Community Wildfire Protection Plans (which are covered in this guide), Firewise Communities/USA®, the Fire-Adapted Community Learning Network, and Ready, Set, Go! fireadapted.org

National Interagency Fire Center (NIFC)

The NIFC is the nation's support center for wildland firefighting. Eight different agencies and organizations are part of NIFC. Established in 1965 in Boise, Idaho, the center was created as a joint effort by the US Forest Service, Bureau of Land Management (BLM), and National Weather Service, among others, to work together to reduce the duplication of services, cut costs, and coordinate national fire planning and operations. nifc.gov

Colorado Division of Fire Prevention and Control

The agency's mission is to provide leadership and support to Colorado communities in reducing threats to lives, property, and the environment from fire through fire prevention and code enforcement; wildfire preparedness, response, and management; and the training and certification of firefighters. dfpc.state.co.us

National Fire Incident Reporting System (NFIRS)

The system provides information on the type and frequency of wildfires that have occurred, including number of wildfires, structure fires, and even other hazard events such as floods, hazardous material spills, etc. Local communities can use the information to help determine risk. nfirs.fema.gov

APPLICABLE PLANNING TOOLS AND STRATEGIES

In addition to the tools and strategies cited below that are included in this guide, **landscaping requirements** are also important tools for reducing potential risks from wildfire. Landscaping standards often address issues such as plant material selection (e.g., requiring low-water, native vegetation) and the location of new plant materials installed as part of new development.

APPLICABLE PLANNING TOOLS AND STRATEGIES – WILDFIRE	
Addressing Hazards in Plans and Policies	• Comprehensive plan • Climate plan • Community Wildfire Protection Plan (CWPP) • Hazard mitigation plan • Parks and open space plan • Pre-disaster planning
Strengthening Incentives	• Development agreement • Density bonus • Transfer of development rights
Protecting Sensitive Areas	• 1041 regulations • Cluster subdivision • Conservation easement • Land acquisition • Overlay zoning
Improving Site Development Standards	• Site-specific assessment • Subdivision and site design standards • Use-specific standards
Improving Buildings and Infrastructure	• Building code • Critical infrastructure protection • Wildland-urban interface (WUI) code
Enhancing Administration and Enforcement	• Application submittal requirements • Post-disaster building moratorium

WIND HAZARDS

DESCRIPTION

Wind hazards in Colorado take three forms: high wind, tornadoes, and severe thunderstorms. It is not unusual to see tornadoes spin out of major thunderstorms or see severe wind accompany thunderstorms.

High winds are wind events with sustained wind speeds of 40 mph or greater and lasting for one hour or longer, or winds of 58 mph or greater for any duration (*National Weather Service,* 2009). Common in Colorado, Chinook winds are warm dry winds that descend from the eastern slopes of the Rocky Mountains, causing a rapid rise in temperature. Sometimes these winds move with considerable force. Cold, dry Bora winds are also experienced in Colorado. These winds are experienced after cold fronts pass through the state from the northwest. Bora winds can reach speeds of over 100 mph (*Colorado Natural Hazards Mitigation Plan,* 2013, p. 3-88).

A **tornado** is a localized, violently destructive windstorm occurring over land. Tornadoes are generated by severe thunderstorms. Tornadoes in Colorado are most frequent in the spring and early summer when warm, moist air from the Gulf of Mexico collides with cold air from the polar regions to generate severe thunderstorms. These thunderstorms often produce the violently rotating columns of wind know as funnel clouds (*National Weather Service,* 2009).

A **thunderstorm** is characterized by the presence of lightning and its resulting thunder. Thunderstorms are usually accompanied by strong winds, heavy rain, and hail, or sometimes no precipitation at all. Thunderstorms may line up in a series of rain bands known as a squall line. A **severe thunderstorm** is a storm that produces a tornado, winds of at least 58 mph (50 knots), and/or hail at least one inch in diameter. Structural wind damage may imply the occurrence of a severe thunderstorm. Strong or severe thunderstorms that rotate are known as super cells (*National Weather Service,* 2009).

WIND HAZARDS IN COLORADO

High wind events in Colorado are most common along the Front Range (due to Chinook and Bora winds coming down from the mountains) and in the northeastern counties. Additionally, the Grand Valley in the western part of the state has also experienced a high number of wind events.

In Colorado, the primary threat of tornado is east of the Continental Divide along the Front Range and foothills. Three counties (Adams, Weld, and Washington) each had over 100 reported tornadoes between 1950 and 2010. Most of these tornadoes are small and short lived. However, occasional strong tornadoes have been reported. The number of tornado fatalities remains very low for Colorado, but much of this is due to the low population density of some of the most tornado-prone areas of eastern Colorado (*Colorado Natural Hazards Mitigation Plan,* 2013, p. 3-108).

The average number of thunderstorms exceeding 50 knots from 2010 to 2015 was just over 100 storms per year *(Storm Events Database, n.d.)*. Thunderstorms are quite prevalent in the Eastern Plains and along the eastern slopes of the mountains during the spring and summer.

RELATED HAZARDS

Severe thunderstorms can spawn super cells that can have tornadoes or hail embedded in them. The frequency of hail damage to crops in northeastern Colorado is quite high. With an average frequency of six or more hail days per year, some counties in eastern Colorado are among the most hail-prone areas in the country *(Storm Events Database, n.d.)*. Another related hazard is flash flooding. The greatest threat of flooding in Colorado is not snowmelt; rather, it is flash flooding from localized intense thunderstorms.

ASSESSING THE RISK OF WIND HAZARDS

Unlike some of the other hazards that have loss estimation tools such as Hazus, there are no widely used tools available for predicting or assessing risks or potential losses to wind hazards. To assess wind hazards, communities may need to rely on historical wind hazards as documented in local or regional hazard mitigation plans, or as made available through data resources mentioned below in the available data sources section.

Some key questions for planners to consider in assessing their community's risk to wind hazards may include:

- Is there a history of damaging or destructive wind events in the community? If so, what has been done to minimize future damages to particular assets or sectors?
- Does the hazard event occur more frequently now than previously?
- Do local building codes or regulations adequately address wind hazards?
- Are current warning systems, shelter plans, and emergency procedures in place to protect people from tornadoes?
- Should there be any additional regulatory or incentive-based measures to increase the safety and protection of the community to wind hazards?

Whether to hire a consultant or conduct a community self-assessment is best determined by considering answers to these questions, in addition to consulting with the resources and other local experts as described below in the available data sources section. Planners should also collaborate with the local emergency manager, building inspector, and/or engineer for information regarding wind hazards and associated risks, as well as risk mitigation measures already in place or recommended for future consideration and implementation.

AVAILABLE DATA SOURCES

Colorado Natural Hazards Mitigation Plan

The *Colorado Natural Hazards Mitigation Plan* is the State's FEMA-approved plan that serves as a foundation for the State's program to reduce risks to people, property, and infrastructure from natural hazards. The Plan is administered and updated by the Colorado Division of Homeland Security and Emergency Management. dhsem.state.co.us/emergency-management/mitigation-recovery/mitigation/state-colorado-natural-hazards-mitigation-plan

Colorado Climate Center

The Colorado Climate Center is housed in the Department of Atmospheric Science at Colorado State University. It is a source of useful information on natural hazards in Colorado and provides an excellent resource to learn about climate in Colorado. ccc.atmos.colostate.edu

National Centers for Environmental Information

The National Centers for Environmental Information (NCEI) was formed in 2015 as a merger of NOAA's three existing National Data Centers. This site is a rich data source for climate and historical weather information and contains historical event data on a host of natural hazards. ncdc.noaa.gov/stormevents

SHELDUS™

Developed by the Hazards & Vulnerability and Research Institute at the University of South Carolina, SHELDUS™ provides a county-level hazard loss data and map set for 18 different natural hazard events types, including wind hazards, and has been used by some Colorado communities in completing the risk assessments for their local or regional hazard mitigation plans. hvri.geog.sc.edu/SHELDUS

American Society of Civil Engineers

A widely-recognized resource worth consulting for wind hazards is the American Society of Civil Engineers (ASCE), and particularly the data and information made available through *Minimum Design Loads for Buildings and Other Structures (*ASCE/SEI 7-10). This technical publication represents a national standard for requirements on general structural design and it contains ultimate event wind maps for determining wind loads which are suitable for inclusion in building codes and other documents. In addition, this publication includes a detailed commentary with explanatory and supplementary information designed to assist building code staff and regulatory authorities. asce.org

Rocky Mountain Insurance Information Association

RMIIA is a non-profit insurance communications organization representing property and casualty insurers in Colorado, New Mexico, Utah, and Wyoming. RMIIA compiles overall estimates of insured losses and number of claims filed for catastrophes (insured natural disasters that cause more than $25 million in damages).

- Hail: rmiia.org/catastrophes_and_statistics/hail.asp
- Tornadoes: rmiia.org/catastrophes_and_statistics/tornado.asp

National Weather Service (NWS)

The NWS is the official provider of U.S. weather, marine, fire, and aviation forecasts. The NWS issues warnings and provides data, products, forecasts, and information related to meteorology. The NWS is a component of the National Oceanic and Atmospheric Administration (NOAA). The NWS maintains a glossary of information on more than 2,000 terms, phrases, and abbreviations used by the NWS. weather.gov/glossary

APPLICABLE PLANNING TOOLS AND STRATEGIES

The table below cites applicable planning tools and strategies that are profiled in this guide.

APPLICABLE PLANNING TOOLS AND STRATEGIES – WIND HAZARDS	
Addressing Hazards in Plans and Policies	• Comprehensive plan • Climate plan • Hazard mitigation plan • Pre-disaster planning
Strengthening Incentives	*N/A*
Protecting Sensitive Areas	*N/A*
Improving Site Development Standards	*N/A*
Improving Buildings and Infrastructure	• Building code • Critical infrastructure protection
Enhancing Administration and Enforcement	*N/A*

SEVERE WINTER STORM

DESCRIPTION

A **severe winter storm** is defined as a prolonged event involving snow or ice. The characteristics of severe winter storms are determined by the amount and extent of snow or ice, air temperature, wind, and event duration (*National Weather Service*, 2009).

- **Heavy snow** is snowfall accumulating to four inches or more in depth in 12 hours or less, or snowfall accumulating to six inches or more in depth in 24 hours or less. A snow squall is an intense, but limited-duration period of moderate to heavy snowfall, also known as a snowstorm, accompanied by strong, gusty surface winds, and possibly lightning.
- **Blizzards** are characterized by low temperatures, wind gusts of 35 mph or more, and falling and/or blowing snow that reduces visibility to ¼-mile or less for three or more hours.
- **Sleet** is defined as pellets of ice composed of frozen or mostly frozen raindrops or refrozen partially melted snowflakes. These pellets of ice usually bounce after hitting the ground or other hard surfaces. Freezing rain is rain that falls as a liquid but freezes into glaze upon contact with the ground. Both types of precipitation, even in small accumulations, can cause significant hazards to a community.
- **Ice storms** are occasions when damaging accumulations of ice are expected during freezing rain situations. Significant accumulations of ice pull down trees and utility lines, resulting in loss of power and communication. These accumulations of ice make walking and driving extremely dangerous.

SEVERE WINTER WEATHER IN COLORADO

All areas of Colorado are vulnerable to the adverse impacts of Colorado's severe winter weather. Average snowfall is 72 inches or greater in the central (including the Front Range foothills) and western areas of the state (*Colorado Natural Hazards Mitigation Plan,* 2013, p. 3-120). While Colorado blizzards are less frequent and drop less snow in areas further east and north, they can still be devastating. As recently as 1997, several fatalities in northeastern Colorado were directly attributable to an October blizzard that caught many travelers unprepared. Heavy snows in the high mountains are common (p. 3-120).

RELATED HAZARDS

Heavy snowstorms in the high mountains are common and can lead to avalanches. Each year several lives are lost due to avalanches. Avalanches pose a serious problem to residents, road maintenance crews, and backcountry travelers.

Colorado's spring flood potential results from melting snow pack at higher elevations. In a year of near-normal snow accumulation in the mountains and normal spring temperatures, river stages become high, but there is no general flooding. In years when snow cover is heavy, or when there is widespread lower elevation snow accumulation and a sudden warming in the spring, there may be higher than normal amounts of runoff that can lead to flooding.

AVAILABLE DATA SOURCES

Colorado Natural Hazards Mitigation Plan

The *Colorado Natural Hazards Mitigation Plan* is the State's FEMA-approved plan that serves as a foundation for the State's program to reduce risks to people, property, and infrastructure from natural hazards. The Plan is administered and updated by the Colorado Division of Homeland Security and Emergency Management. dhsem.state.co.us/emergency-management/mitigation-recovery/mitigation/state-colorado-natural-hazards-mitigation-plan

Colorado Climate Center

The Colorado Climate Center is housed in the Department of Atmospheric Science at Colorado State University. It is a source of useful information on natural hazards in Colorado and provides an excellent resource to learn about climate in Colorado. ccc.atmos.colostate.edu

National Centers for Environmental Information

The National Centers for Environmental Information (NCEI) was formed in 2015 as a merger of NOAA's three existing National Data Centers. This site is a rich data source for climate and historical weather information and contains historical event data on a host of natural hazards. A particularly helpful NCEI tool is the Storm Events Database which contains archived records on the nature and impact of notable storm events including blizzards, extreme cold, ice storms, and other winter weather as documented by NOAA's National Weather Service. ncdc.noaa.gov/stormevents

SHELDUS™

Developed by the Hazards & Vulnerability and Research Institute at the University of South Carolina SHELDUS™ provides a county-level hazard loss data and map set for 18 different natural hazard events types, including severe winter storms, and has been used by some Colorado communities in completing the risk assessments for their local or regional hazard mitigation plans. hvri.geog.sc.edu/SHELDUS

U.S. Department of Labor, Occupational Safety and Health Administration

One role of the Occupational Safety and Health Administration (OSHA) is to provide information to the public to protect them from various natural hazards, including winter weather. osha.gov/dts/weather/winter_weather/hazards_precautions.html

High Plains Regional Climate Center

The High Plains Regional Climate Center aims to increase the use and availability of climate data in the region that includes Colorado as well as Kansas, North Dakota, Nebraska, South Dakota, and Wyoming. The Center's website provides temperature and precipitation overviews that can be graphically depicted on a state-by-state basis by county boundaries. hprcc.unl.edu

Rocky Mountain Insurance Information Association

The Rocky Mountain Insurance Information Association (RMIIA) provides historical statewide data regarding damage resulting from natural hazards. The RMIIA website also contains recommendations for local planners to consider more specific ways to assess and reduce winter storm-related risks in their community, such as burst pipes, ice dams, wind damage, leaky roofs, and building collapse caused by the weight of ice or snow. rmiia.org/catastrophes_and_statistics/Winter_Storms.asp

National Weather Service

The National Weather Service (NWS) is the official U.S. weather, marine, fire and aviation forecasts, warnings, meteorological, products, climate forecasts, and information about meteorology. NWS is a component of the National Oceanic and Atmospheric Administration (NOAA). NWS maintains a glossary of information on more than 2000 terms, phrases, and abbreviations used by the NWS and accepted as an excellent source of definitions of hazards (*National Weather Service,* 2009).

ASSESSING THE RISK OF SEVERE WINTER STORM

Severe winter storms are a frequent occurrence and a source of major concern throughout Colorado. The combined perils of snow, ice, freezing temperatures, and high winds pose multiple risks, including threats to public safety and the potential to cause major property damage and disruption to commerce. For example, winter storm conditions can threaten transportation safety during the event and result in snow or ice accumulations that can collapse roofs or topple trees. Planners should also be mindful of the impacts that severe winter storms may have on vulnerable populations, especially the homeless or those living in households without heat. There is no simple or universal approach to assessing these risks; however, a variety of data sources and tools are available to assist in the process of understanding the likelihood and potential impact of future storm events on the community.

Similar to other hazards, the local or regional hazard mitigation plan should be among the first sources to look for data and/or information on severe winter storms. The risk assessments included within these plans should have information on historical events, as well as information on any particular risks or vulnerabilities the community faces. If the severe winter storm hazard is considered a real threat to the community, then potential risk reduction measures should also be included as part of the mitigation strategy or implementation section of the plan (e.g, strategies to deliver resources to vulnerable populations in a storm's aftermath or strengthening building codes to enable new construction to withstand severe winter storms). When seeking professional assistance and advice on severe winter storms, planners should also consider turning to meteorology experts from organizations such as the nearest local office of the National Weather Service or institution of higher education. Another valuable source of information is the Office of the State Climatologist at the Colorado Climate Center at Colorado State University (ccc.atmos.colostate.edu), which can provide additional weather and hazard risk-related data specific to each community.

APPLICABLE PLANNING TOOLS AND STRATEGIES

The table below cites applicable planning tools and strategies that are profiled in this guide.

APPLICABLE PLANNING TOOLS AND STRATEGIES – SEVERE WINTER STORM	
Addressing Hazards in Plans and Policies	• Comprehensive plan • Climate plan • Hazard mitigation plan • Pre-disaster planning
Strengthening Incentives	*N/A*
Protecting Sensitive Areas	*N/A*
Improving Site Development Standards	*N/A*
Improving Buildings and Infrastructure	• Building code • Critical infrastructure protection
Enhancing Administration and Enforcement	*N/A*