Post-Wildfire Hydrologic Hazards in the Wildland Urban Interface of Colorado and the Western United States

Introduction

Following a wildfire, such as the 2002 Missionary Ridge fire (fig. 1), a number of hydrologic hazards may develop that can have an important impact on water resources, businesses, homes, reservoirs, roads, and utilities in the wildland urban interface (areas where homes and commercial developments are interspersed with wildlands) in mountainous areas of the Western United States. This fact sheet describes these hazards and identifies approaches to quantify them, thus enabling land and resource managers to plan for and mitigate the effects of these hazards. The fact sheet has been produced in association with the U.S. Geological Survey (USGS) Fire Science Thrust program and the Colorado Front Range Demonstration Project (CFRDP). The current (2007) focus of the CFRDP is on the Three Lakes watershed in Grand County, Colorado (fig. 2), which has applicability to many similar forested, mountain areas in the Western United States.

Wildfires are natural, recurring events in most terrestrial ecosystems in the United States. Historical land-management practices (including fire suppression) and expansion of urban development into wildland areas have altered these ecosystems so that present-day wildfires tend to be larger and more destructive than decades ago. For example, the Hayman fire of 2002, near Deckers, Colorado (about 35 miles southwest of Denver, Colorado), is the largest known wildfire in Colorado history, burning nearly 138,000 acres (Graham, 2003) and affecting many nearby communities, including the Denver metropolitan water supply.

Post-wildfire effects may persist for years and can negatively affect ecology, flood-control, and drinking-water resources, and pose hazards to life and property in burned watersheds (figs. 2–3). Water-supply reservoirs for metropolitan and small rural communities in or downstream from burned areas are at risk when forested watersheds burn.

Figure 1. Missionary Ridge fire threatens Vallecito Reservoir, near Durango, Colorado. Photograph courtesy of NOAA National Weather Service http://www.crh.noaa.gov/Image/gjt/images/ImageGallery/WildFires/misfire8.jpg.

Post-Wildfire Hazards

Post-wildfire hydrologic hazards can be divided into three general categories: flooding, debris flows, and water-quality changes. These hazards are described in the following section and methods used by the USGS to quantify them are discussed.

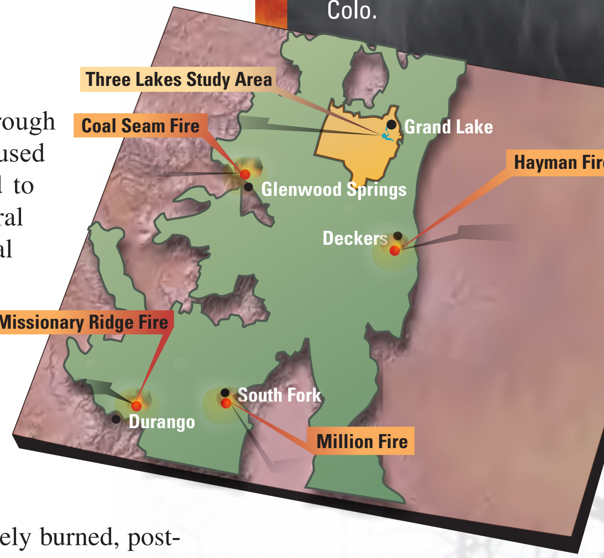

Figure 2. Locations of major Colorado wildfires in 2002, and the Colorado Front Range Demonstration Project area in Grand County, Colo.

Post-Wildfire Floods

Post-wildfire flooding can damage property and infrastructure through inundation, erosion, and deposition of debris (figs. 3–5). The USGS has used flood-frequency equations to predict post-wildfire flood magnitudes and to delineate changes in flood elevation and flood-plain boundaries for several watersheds burned by Colorado fires in 2002, including the Hayman, Coal Seam, Missionary Ridge, and Million fires (Elliott and others, 2005) (fig. 2).

To estimate pre-fire peak flows, flood-frequency equations were used with watershed properties, such as watershed slope, drainage area, and mean-annual precipitation. Pre-fire streamflows were used to calibrate hydrologic models, such as the Hydrologic Engineering Center–Hydrologic Modeling System (U.S. Army Corps of Engineers, 2001a), which were further modified to reflect burn severity, allowing an estimate of post-wildfire peak streamflows. Among Hayman fire subwatersheds having greater than 50 percent of the area described as moderately to severely burned, post-wildfire peak streamflows are expected to be 28 to 91 times higher than pre-fire peak streamflows, depending on the subwatershed (Elliott and others, 2005). Based on year-to-year changes in peak flows, the USGS has estimated that burned watersheds require about 4 to 5 years to return to stable hydrologic conditions (Elliott and others, 2005).

Predicted post-wildfire streamflows are usually much higher than pre-fire streamflows. These predictions are used for practical purposes, such as flood-plain studies and flood-insurance mapping. Flood profiles can be developed using a stream-channel routing model (Hydrologic Engineering Center–River Analysis System) to estimate the height of the water surface along the stream (U.S. Army Corps of Engineers, 2001b). High peak streamflows would cause water-surface elevations during floods to be higher and flood-plain boundaries wider compared to pre-fire streamflows. This information is critical to residents, community planners, and emergency personnel who must be prepared to respond to storm and flood warnings and also to determine where future development in areas adjacent to flood plains might occur or be restricted.

Figure 3. Flooding in a watershed burned by the Hayman fire near Deckers, Colo., threatens homes along Fourmile Creek. Photograph by M.R. Stevens, USGS, 2003.

Figure 4. Highway destroyed by post-wildfire flooding in the West Creek area of the Hayman fire near Deckers, Colo. Photograph by M.R. Stevens, USGS, 2006.

Post-Wildfire Debris Flows

Debris flows are fast-moving mixtures of water, sediment, and debris caused by periods of intense rain or rapid snowmelt on steep hillsides that are mantled with loose material. Debris flows can move huge amounts of material and be can be very destructive (fig. 6).

The USGS has used predictive models (Rupert and others, 2003; Cannon and others, 2004, 2006) to estimate the probability of debris flows and the volume of water and material that could be moved in areas recently burned by wildfire. Logistic regression statistical methods were used to assess the probability of a given watershed to produce post-wildfire debris flows as a function of a combination of soil properties, watershed characteristics, burn severity, and rainfall conditions (Rupert and others, 2003). Multiple regression methods were used to develop a predictive model that estimates the volume of debris-flow material expected at a watershed outlet (Gartner, 2005). Variables used in this model are the area of the watershed burned, watershed gradient, soil properties, and rainfall intensity.

Other models, such as the FLO-2D model (O'Brien, 2006), can be used to predict and delineate the inundation area that a flood or debris flow will affect as it emerges from a burned tributary watershed onto an alluvial fan or flood-plain surface. The model uses a specified input hydrograph, volumetric sediment concentrations, and watershed topography to route a debris flow from the originating tributary to the depositional zone.

Using the results from these models, emergency responders can set priorities in areas recently burned or that have the potential to burn. Managers can focus on areas that pose the greatest danger to human life and infrastructure.

Post-Wildfire Water Quality

Wildfire may negatively affect water quality by releasing large quantities of nutrients (nitrogen and phosphorus); metals, such as lead, manganese, and mercury; and organic carbon (total and dissolved) into the environment where they can persist for years (Ranalli, 2004). The large post-wildfire increases in the concentration of these chemicals as well as sediment in streams and reservoirs may negatively affect aquatic life, aquatic habitat, and drinking-water supplies. Large increases in concentrations of nutrients in post-wildfire runoff (2 to 100 times greater than pre-wildfire conditions) (Ranalli and Stevens, 2004) may cause algal blooms, which can deplete dissolved oxygen to levels below those that are needed by fish. Increased mercury that can result from post-wildfire runoff is a concern because it is toxic when it is converted to methylmercury under conditions of low oxygen, such as in lake and reservoir sediments in summer. Manganese is a concern to the water-treatment industry because at high concentrations it can create esthetic problems and requires intensive treatment (National Drinking Water Clearing House, 1998). Organic carbon is composed of particulate and dissolved organic matter and is a concern to the water-treatment industry because post-wildfire increases of organic matter can increase treatment costs and can form disinfection byproducts, such as trihalomethanes, when water is chlorinated, posing potential health risks (Rostad, 2004). Organic compounds also may be formed during a wildfire, some of which may be toxic to aquatic life and humans.

Figure 5. Post-wildfire flooding and debris-covered bridge on Trail Creek in the Hayman fire burn area, near Deckers, Colo. Photograph by M.R. Stevens, USGS, 2002.

Figure 6. Debris flow following the Missionary Ridge fire, near Durango, Colo. Photograph by Butch Knowlton, La Plata County Office of Emergency Management, 2002.

Since 2003, the USGS has been monitoring the water quality of Fourmile Creek, which drains a watershed near Deckers, Colo., that burned during the Hayman fire, and a nearby stream, Pine Creek, which drains a watershed that was not burned. The concentrations of total manganese in Fourmile Creek and Pine Creek are shown in figure 7. These plots show that the concentrations can be orders of magnitude higher in streams draining burned watersheds, and that the high concentrations can persist. Also, concentrations of total mercury were as much as 80 times greater in Fourmile Creek (burned) than in Pine Creek (unburned). More than 100 tentatively identified organic compounds were detected in Fourmile Creek but only a few were detected in Pine Creek (Ranalli and Stevens, 2004). The results of all chemical analyses obtained as part of this study reside in the National Water Information System (NWIS) database and can be accessed using the USGS Web interface to water data at URL http://waterdata.usgs.gov/co/nwis/qw/.

Watershed modeling tools, such as the Precipitation Runoff Modeling System (PRMS) developed by the USGS (Leavesley and others, 1983), can be used to estimate the potential for increased post-wildfire flooding, erosion, and sediment deposition. Reservoir models also can be used to simulate and predict reservoir-water circulation, transformation of nutrient species, dissolved-oxygen concentrations, transport of sediment within the reservoir, and the timing and potential magnitude of nuisance algal blooms, which can help water-supply managers develop plans to mitigate post-wildfire water-quality impacts.

Summary

Although wildfires are natural and recurring events, historic land-management practices and urban development into wildland areas are resulting in wildfires that tend to be larger and more destructive than those in the past. Post-wildfire conditions can produce a number of hydrologic hazards, including floods, debris flows, and impaired water quality, which can have harmful effects on the wildlands-urban interface and on water supplies that can be many miles downstream of the burned areas. The USGS and others have developed approaches to quantify these hazards, which will help land managers plan for and mitigate the effects of these hazards even before watersheds burn.

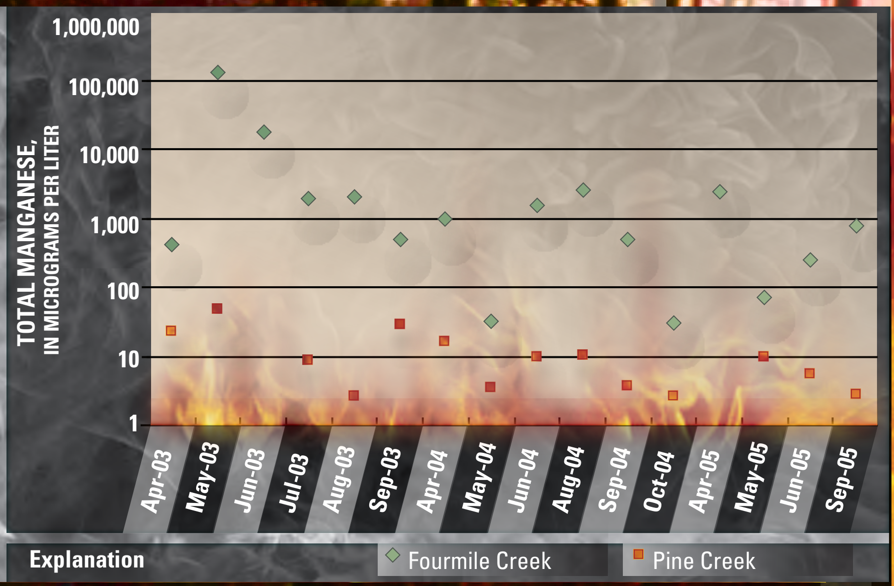

Figure 7. Post-Hayman fire total manganese concentrations at Fourmile Creek and Pine Creek near Deckers, Colo.

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