The Past and Future of Wildfire in the Colorado Springs Wildland-Urban Interface

A Thesis

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Introduction

This past summer marked the five-year anniversary of the Waldo Canyon Wildfire in Colorado Springs, Colorado, which consumed over 18,000 acres, 346 homes and took the lives of two individuals. The fire's destruction persisted long after the last of the embers smoldered out; downstream of Waldo's burnscar, the city of Manitou Springs and sections of the Highway 24 corridor, a major Colorado highway, experienced numerous flood events and debris flows the following year. Though homes are being rebuilt and the forest is recovering, how can Colorado Springs and the greater Pikes Peak region reconcile its extensive wildfire history to better prepare for the next catastrophic fire?

Adding to wildfire's complexity towards society, wildfires have been, and continue to be, significantly modified by anthropogenic influences by making them burn hotter, longer and extending the length of the fire season itself (Gorte 2013). Perhaps the most immediate effect of anthropogenic influence is on vegetation density and type in North American forests. In the twentieth century, economic pressure from the logging industry as well as the biblically destructive "Big Burn of 1910", spurred the newly formed United States Forest Service to develop a strict wildfire exclusion policy. This lofty campaign mandated that all wildfire on national forest were to be suppressed as quickly possible, regardless if the ignition source was naturally occurring or not. As a consequence, the naturally occurring fire regimes of forests were halted, leading to overgrowth of vegetation that would have normally been consumed by fire. This change in vegetation density has drastically increased the fuel load for wildfires increasing "the likelihood of unusually severe and extensive wildfires" (Arno et al., 227).

Fuel loads of forests are also increased by insect and disease epidemics which are more likely due to decreased vegetation resiliency from the added competition of overgrowth (Ibid). Though the extent of influence is not clear, the unusually high severity of the Front Range's Hayman Wildfire of 2002 was undoubtedly influenced by decades of fire expression, leading Front Range forests' to "have developed a very different stand structure during the 20th century" (Romme et al., 198). Currently, mitigation efforts such as prescribed burning or vegetation chipping reduce fuel loads in forests, however performing these efforts on large scales is unfeasible.

The next significant source of anthropogenic influence on wildfire is from global climate change. Climate change increases the severity and frequency of wildfires through three mechanisms: hotter temperatures, earlier mountain snowpack melt, and drought (Gorte, 2013). Hotter temperatures and drought make wildfires burn hotter and increase the chances of ignition through the decrease of water content of vegetation. Earlier spring snowmelts lengthen the fire season itself by extending the period of time Western forests rely on summer precipitation for moisture. (Ibid) Both the Hayman and Waldo Canyon wildfires occurred during summers of extreme drought and hot temperatures on the Front Range. Another climatic influence, though understudied, is the increase of insect outbreaks (mentioned above) with rising temperatures. Increasing epidemics in Western forests could influence wildfire severity due to greater fuel loads from mortality and less fire-resilient tree stands (Ibid). Though the extent is not fully understood, climatic influence on wildfire needs to be considered when preparing for the annual fire season

As a natural occurrence in our ecosystem, wildfires are an inherent burden to those living in the West. Yet, fires play a key role in healthy forest dynamics by clearing out layers of vegetation, and at times entire tree stands, thereby decreasing competition and promoting succession within the fire-adapted ecosystem. Where Eastern plains meet Western mountains, the Front Range's forests are characterized by a mixture of Ponderosa Pine and Douglas-fir trees, which are adapted to annual wildfire regimes. Wildfire assists seedlings by clearing out competing shrubs and grasses as well as creating fertile, nutrient rich soil for Douglas-fir and Ponderosa Pine seeds to grow (Colorado State University 2012). The Rocky Mountain's iconic Aspen tree-stands are also dependent on fire as being the primary successional species to rapidly grow following a burn (USDA-Forest Service). The duality of wildfires, as a source of both destruction and regeneration within forests, creates difficult and complex policy issues for communities living in landscapes where wildfires are a natural phenomenon. Colorado Springs is no exception. Wildfires are not influenced by jurisdictional boundaries yet people and policy decisions are. The difficulty of living with wildfire necessitates research to better assist ecosystem managers, policy makers, and private citizens alike.

Over the past twenty years, the Pikes Peak region has experienced the costly and lethal consequences of catastrophic wildfires, namely the Hayman, Waldo Canyon, and Black Forest wildfires. As evidenced by the Waldo Canyon Wildfire of

2012, burnscars alter the hydrology of a landscape and significantly increase the likelihood of flooding and debris flows (Young et al., 2012). Again, the destructive perimeter of a wildfire expands spatially and temporally beyond the burnscar itself, endangering homes, roads and lives that are downstream. Increased erosion and chemical transport following a burn damages the health of aquatic ecosystems as well as vital water resource infrastructure such as reservoirs and water treatment plants.

The Waldo Canyon Wildfire was particularly potent due to its proximity to Colorado Springs' wildland-urban interface (WUI), which in this study is defined as the margins between Pike National Forest and Colorado Springs. While no technical boundaries are defined, the term is more generally used in this study as a working definition for areas of Colorado Springs primarily at risk from wildfire and the focus of management efforts.

To prepare for the next catastrophic wildfire effecting Colorado Springs, this report uses qualitative 'lessons learned' and quantitative data from the Pikes Peak region's extensive wildfire history. Using the Hayman and Waldo Canyon wildfires as model wildfires, this research extracted remotely-sensed, physical data from the burns' pre-fire landscape and correlated it to the resultant burn severity. From this correlation, a predictive model was made that is used to simulate both the magnitude and spatial extent of a potential wildfire within the research's area of interest (AOI) encompassing the Colorado Springs WUI. To understand the impacts of post-fire flooding, elevation data from the AOI was then used to measure potential hydrologic flow power, which is used to identify areas with highest potential for debris flows. Using geographic information systems (GIS), a composite model of both burn-severity and erosive potential was processed over the AOI. The results display areas most susceptible to severe burn and erosion intensity.

The AOI is, overall, bounded by Colorado Springs' WUI. Further, to interpret the results of the predictive model more clearly, Colorado Springs' WUI was subdivided by watersheds. The predictive model overlaid on a watershed scale allows for comparison between different areas of the WUI.

By mapping areas within Colorado Springs of highest concern, our research can be used to prioritize mitigation efforts and resources. Further, by highlighting the high number of people, property, and infrastructure at risk, our research can be used to stimulate policy and management decisions.

Lessons Learned

Though over a decade has passed since the Hayman Wildfire of 2002, it remains the geographically largest wildfire in Colorado's history and become a pivotal event in shaping the relationship between the Front Range and wildfire. The fire consumed approximately 138,000 acres of Pike National Forest and the South Platte River corridor and 'moonscaped' vast swaths of land, leaving areas so intensely burned that the landscape, devoid of any vegetation, resembled the surface of the moon (Graham 2003). The fire ignited on June 8^{th}, 2002 from a campfire near Lake George, Colorado and burned until June 28^{th} (Ibid). In total, the wildfire completely destroyed 132 homes, damaged another 662, and scorched Cheeseman Reservoir, a vital link in a chain of water resource infrastructure utilized by the City of Denver (Ibid). The fire was also responsible for the deaths of six individuals. Many lessons can be extrapolated from the Hayman wildfire, including being an example of a mega fire whose behavior was undoubtedly exacerbated by anthropogenic influence.

The most striking feature of Hayman's burnscar is the continuous amount of severely burned landscape where the fire's intensity was able to burn entire tree stands. Though the Hayman burnscar is considered a mosaic of burn severity ranging from unburned to severe, a post-burn analyses by the USFS concluded that the majority of the landscape ranked 35%, or 48,000 acres, as severely burned (Robichaud et al., 2003). Wildfire intensity classification is measured through the condition of the landscape's physical characteristics, such as vegetation and soil. In general, a burned area where all the biomass at ground level and entire tree-stands are consumed is classified as 'high severity', whereas 'low severity' is characterized by the fire's consumption of vegetation only at the ground level and not whole tree-stands (Ibid). The USFS has a standardized method of measuring this using pre- and post-fire satellite imaging. The scale and intensity of the Hayman wildfire brings into question of the role that 20th century fire exclusion and animal agricultural practices played in the fire's behavior. Dendrochronology records show that the high intensity as well as total fire perimeter was consistent with historic fire of the region (Romme et al., 2003). However, the unprecedented feature of Hayman to consider is the size of severely burned areas, that no "fires documented from the early 1300s through 1880 created such a large contiguous patch of severe stand-replacing fire" (Romme et al.,193). That the fire reached stand-replacing intensity is not unprecedented, however it is unprecedented that 35% of the total area was severely burnt in contiguous pieces.

20th century fire exclusion has occurred in the Hayman landscape: before the summer of 2002, the last large fire in the area occurred in 1880 while the one before that burned in 1851 (Ibid). The time period between Hayman and the last large wildfire in the area is over three times longer than the previous fire interval of only 29 years. While the extent to which fire suppression and human activity contributed to the fire's behavior and magnitude is uncertain, the high vegetation density within Hayman's landscape directly contributed to the fire's growth and intensity. Historical photographs of the Cheeseman Reservoir show "in 1900… a canopy cover of 30 percent or less, and only 7 percent was dense enough to support a crown fire "and thus "it is clear that the contemporary forest and landscape structure contributed to the size and severity of the fire" (Romme et al., 200).

Another unprecedented aspect of the Hayman fire was its burn speed. Fires of similar size took up to months to burn whereas Hayman burned on the order of mere weeks (Ibid). Colloquially referred to as 'the blowout day', on June 9th extreme wind caused the fire to grow from "1,200 acres to approximately 61,000" (Finney et al., 59), close to half of the total burned area. Like other wildfires, Hayman's behavior was most strongly influenced by local weather and climate. However, anthropogenic influences like climate change need to be considered when analyzing Hayman's behavior. These influences may be indirect but are still contributing factors, especially when considering Hayman's unprecedented burn-severity and the blowout day of June 9th. The summer of 2002 marked the fourth year of acute drought in the Front Range where "fuel moisture conditions were among the driest seen in at least the past 30 years" (Graham, 4) which greatly contributed to the severity and size of Hayman. Anthropogenic climate change increases a landscape's predisposition to wildfire through magnified drought and decreased vegetation resilience (Gorte 2013). Further, once a wildfire has started, hotter temperatures can contribute to the severity of the fire directly, providing more ambient heat energy. (Quadrennial Fire Review, 2014).

The Hayman wildfire is, in part, a product of two anthropogenic influences: 20th century fire exclusion practices and climate change. For the Pikes Peak community, the unprecedented size of the Hayman wildfire acted as a major wake-up call. Since 2002, wildfire awareness by private homeowners and management by the USFS and municipalities has improved. USFS wildland fire crews have improved their effectiveness by using a standardized procedure for organizing resources and people most efficiently between themselves and other responding agencies (Botts, Markalunas, personal communication 2017). In 2011, the City of Colorado Springs issued its Community Wildfire Protection Plan (CWPP) that includes fuels mitigation projects, at-risk neighborhood mapping, and promotes sound homeowner practices and awareness. Unfortunately, the Pikes Peak region was reminded of their vulnerability to wildfire when the Waldo Canyon wildfire burned in June of 2012, a decade after Hayman. The Waldo Canyon wildfire stands as the current model fire occurring closest to Colorado Springs.

The Waldo Canyon wildfire was markedly different than Hayman in size, intensity, and effect. Though Hayman remains catastrophic in its own right, the

Waldo Canyon wildfire is comparatively more destructive despite being significantly smaller in size and intensity. The fire started on June 26th, 2012 on Pike National Forest land between Colorado Springs and Woodland Park and was fully contained by July 10th. In total, the fire burned 18,247 acres, completely destroyed 347 homes, and took the lives of two people (City of Colorado Springs, 2013). The fire also scorched the perimeter of Rampart Reservoir, one of the major drinking water sources of Colorado Springs. A post-fire analysis by the USFS concluded that the majority of the burnscar, 41.6%, to be unburned to low in severity, with only 18.6% classified as high (Young et al., 2012).

Unlike Hayman, the Waldo Canyon wildfire's destructive potency is due to its proximity to communities and human infrastructure. The most poignant lesson learned from Waldo Canyon is that Colorado Springs has a WUI problem: one of the largest in the nation, the Colorado Springs' WUI comprises of 28,800 acres, 24% of the population, and 36,485 homes (Colorado Springs Fire Department, 2014). During the fire, all of the homes destroyed were located in the Mountain Shadows neighborhood, which was previously classified as being located in the WUI (Fire Adapted Communities, 2012). Not only are many lives and homes at risk within the WUI, fire protection against homes during a burn can be largely ineffective. In an analysis of home destruction within the Mountain Shadows community, 54% of homes ignited were from fire embers blown downwind from the burn while only 8% of home ignitions were sourced from the fire front itself (Colorado Springs Fire Department, 2014). Further, "90% of homes ignited were completed destroyed"

(Fire Adapted Communities, 10). These two alarming findings further highlight the Springs' WUI problem.

The Waldo Canyon wildfire also reflects the lasting, destructive implications after the fire itself has burnt out. In an initial assessment of watershed burn severity, a USFS hydrologic response team found that "large runoff producing storms will likely create increased surface flow volumes and velocities that can transport available sediment from the slopes" (Moore et al., 7). This prediction came true as major flooding and sedimentation events occurred just weeks after the fire and in the following summer of 2013 within the City of Manitou Springs and the Highway 24 corridor.

Ultimately, the Hayman wildfire represents the apocalyptic potential lurking in the Front Range's forests while the Waldo Canyon wildfire represents a behaviorally less severe yet more destructive fire due to its proximity to a WUI. If a 'Hayman' level of wildfire were to occur in the same geographic location as Waldo Canyon, its destructive potential would dwarf that of Waldo Canyon and be unprecedented to any Western city living with wildfire.

Methods

The purpose of this work was to create a map of wildfire severity in the wildland-urban interface based on the ecosystem characteristics of the Waldo Canyon wildfire. The quantitative focus of the research primarily utilized ArcGIS, a popular GIS software. Per our objective of using GIS techniques to compare the Hayman and Waldo Canyon pre-fire landscapes to the resultant burn severity, the first step in our research was compiling historical data from both fires. The United States Geological Survey's (USGS) *Earth Explorer* website provided open access to federal research satellite imaging from which Raster type files were downloaded. Images from the National Aeronautical and Space Administration's (NASA) Landsat 5 and Landsat 7 satellites were used, which provided 30-meter resolution images in both the visible color and infrared spectra. Image searches were filtered by geographic area and date using *Earth Explorer's* user interface. Only images encompassing the entire Hayman or Waldo pre-fire landscape were used. Further, image dates were refined to June through August and up to three years prior to each wildfire. Images with excessive cloud and snow cover had to be omitted due to processing challenges encountered later on.

The Normalized Difference Vegetation Index (NDVI) was selected as a key landscape characteristic to measure and correlate to burn severity. NDVI is a calculation derived from the relative amounts of red and near-infrared spectral reflectance from vegetation which, in turn, is a measure of the 'greenness' of the photosynthetically active vegetation (NASA, 2017). NDVI was selected as a variable to measure for a variety of reasons. In accounting for wildfire fuel conditions, NDVI can be used as an approximation of live fuel moisture content (Dennison et al., 2005). As acute drought was shown to be a major factor in the Hayman wildfire, an interpolation of vegetation health was desired to be used in our model. Further, NDVI could be calculated from our available data set in GIS.

The next pre-fire landscape features calculated were topographical slope and aspect, using digital elevation models (DEM). For both the Hayman and Waldo

Canyon wildfires, the steepness of the terrain and the orientation of hillsides relative to the Sun were variables effecting wildfire behavior (Finney 2003, Botts personal communication 2017). Topographic data would also be used later on in flood and sedimentation modeling.

The USFS's *Monitoring Trends in Burn Severity* (MTBS) program provided geospatial burn severity data for the Hayman and Waldo Canyon wildfires. The MTBS program uses the differenced Normalized Burn Ratio (dNBR) to classify burn severity. dNBR is a calculation of the difference in pre- and post-fire thermal reflectance in the infrared spectrum (United States Forest Service, 2017).

Having compiled pre-fire data on NDVI, slope, aspect as well as burn severity data post-fire, we then geospatially aligned the four data points. Within each burnscar, every 30x30 meter pixel had attached numerical values of the pre-fire landscape variables and of resultant burn severity, resulting in a dataset with ~500,000 pixels for each imaging day for 10 days. Aligning the data this way allowed compiled data to be represented and manipulated in a tabular format, a necessary step towards burn severity modeling.

Two tabular data sets, one for Hayman and the other for Waldo, were input into *R*, a statistical computing software. The software was used for statistical comparison between burn severity and individual variables. The software was also used to create two linear regression models, correlating each fire's burn severity to NDVI, slope, and aspect. Because the hillside aspect variable is not mathematically linear, the dataset was split into different aspect groups and then the model was ran for each aspect grouping.

The two respective burn severity equations could then input back into the GIS software. Using current data on the AOI's NDVI, slope, and aspect as the input variables, the models computed a predictive burn severity spectrum overlaid on the AOI. A range of potential burn severity was visually depicted over a map of Colorado Spring's WUI. To better interpret the results, the models were depicted over the watersheds comprising the WUI, specifically the North & South Cheyenne, Bear, Sutherland, and Ruxton Creek watersheds. Further, the burn severity models were filtered to depict only the areas with the highest potential for a severe burn.

While no technical definition of wildland-urban interface (WUI) was established by our research project, a parcel-scale WUI map created by University of Wisconsin's SILVIS Lab was used in conjunction with the burn severity model to calculate the proportions of Colorado Springs' WUI subject to varying degrees of potential burn severity. The proportions of the Springs' WUI (bounded by the AOI) overlapping with the burn severity potential, broken into a four-point scale, was calculated in ArcGIS. Tabular data was then extracted from the spatial overlap of the two maps.

Because this analysis required geospatial calculations in ArcGIS, Colorado Springs' WUI was implicitly defined through the WUI map used from UW's SILVIS Lab. The WUI map is also distinguished into two WUI types, intermix WUI and interface WUI. The technical definitions for each designation are as follows: a parcel is first considered WUI if it contains a minimum density of one structure per 40 acres (Stewart et al 2007). Next, if a parcel is also covered by greater than 50% wildland vegetation, it is considered intermix WUI. If a parcel is not covered by at least 50% wildland vegetation, but is within 1.5 miles of significant wildland vegetation, then it is considered interface WUI. This distance is established to account for the distance a fire ember can travel during a wildfire (Ibid).

Results

Figure 1 shows results of the burn-severity model processed over the research's AOI, comprised of the Ruxton, Sutherland, Bear, and North and South Cheyenne Creek watersheds. The burn-severity spectrum ranges from the lowest, in blue, through the highest potential, in orange. In general, the highest burn-severity potential is concentrated in the foothills of Pikes Peak, at the transition of plains to mountains and also penetrates into some of the Springs' parks and open spaces. Burn-severity potential then extends westward into Pikes Peak, concentrated on slopes surrounding roads and creeks. Burn-severity potential is proportionally higher on steeper areas versus flatter areas.   In the event of a wildfire in the Pikes Peak area, the fire would prominently burn into the hills of Colorado Springs' WUI due to its heavily saturated burn-severity potential. The fire would also heavily burn into the drainages surrounding the creeks and rural roads that extent into Pikes Peak, leaving substantial repercussions for the precipitation events that follow.

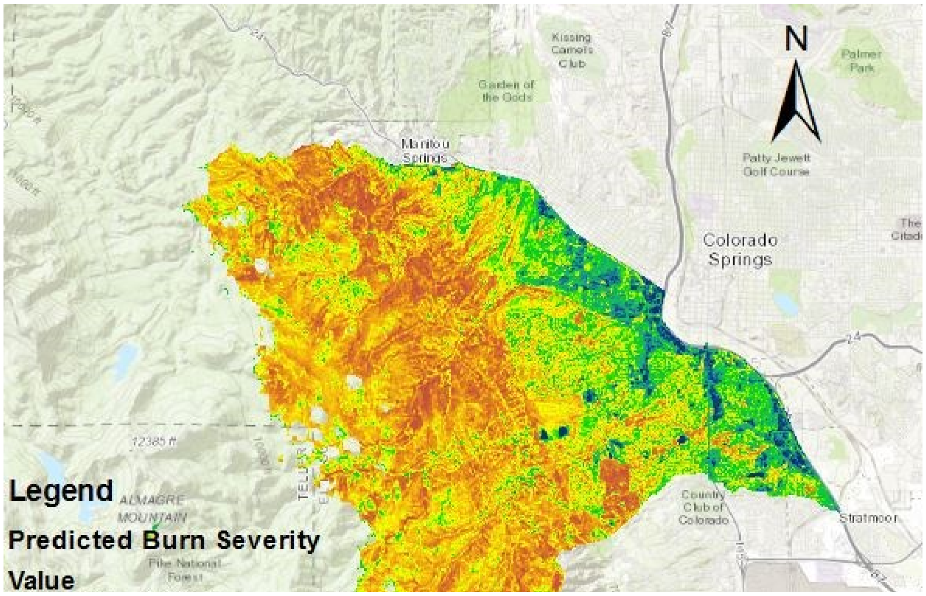

Figure 1. Burn-Severity Potential

Figure 2 depicts a stream power index (SPI) of the AOI, where the highest erosive potentials are highlighted in dark blue while the areas with the least erosive potential are highlighted in light green. Exacerbated by the brittle composition of Pike's Peak Granite and steep gullies, the potential for debris flows is very high for communities situated on alluvial planes.

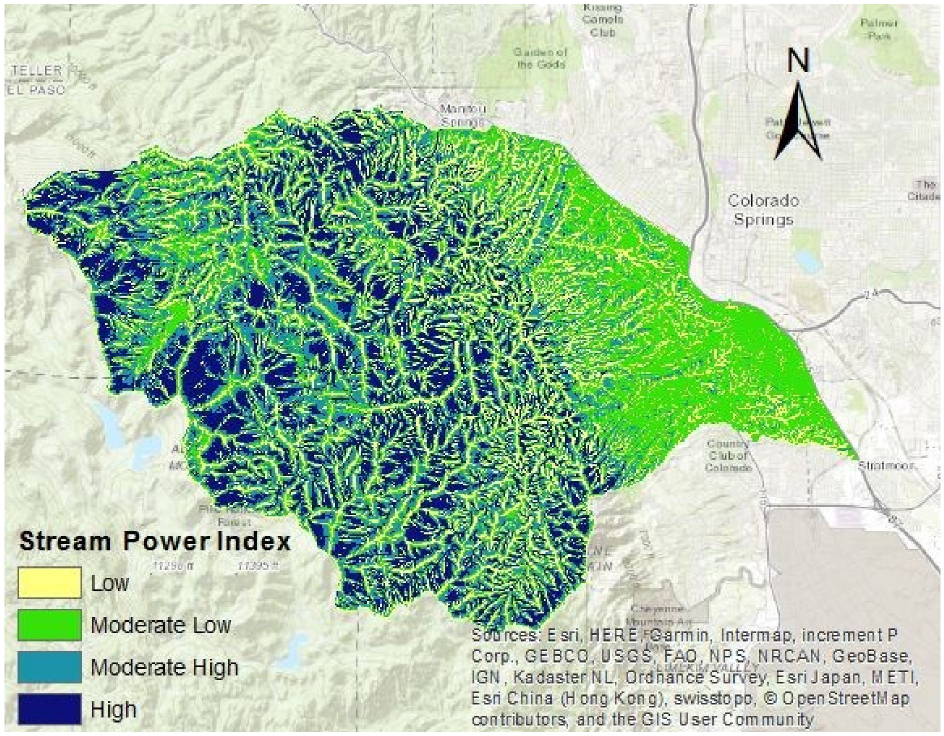

Figure 2. Stream Power Index

In order to account for both erosive potential and burn-severity potential, the two models were combined and filtered to show overlapping areas of highest and intermediate composite burn-erosive potential. The results were then split into two groups of watersheds comprising the AOI to display the results at a finer scale. Figure 3 depicts areas of intermediate to highest composite burn severity-erosive potential over the Ruxton and Sutherland Creeks watersheds, and Bear and Cheyenne Creek Watersheds. The results of the composite model show that the two groups of watersheds act as case studies in different, yet nonetheless destructive, outcomes of a wildfire in the Colorado Springs WUI.

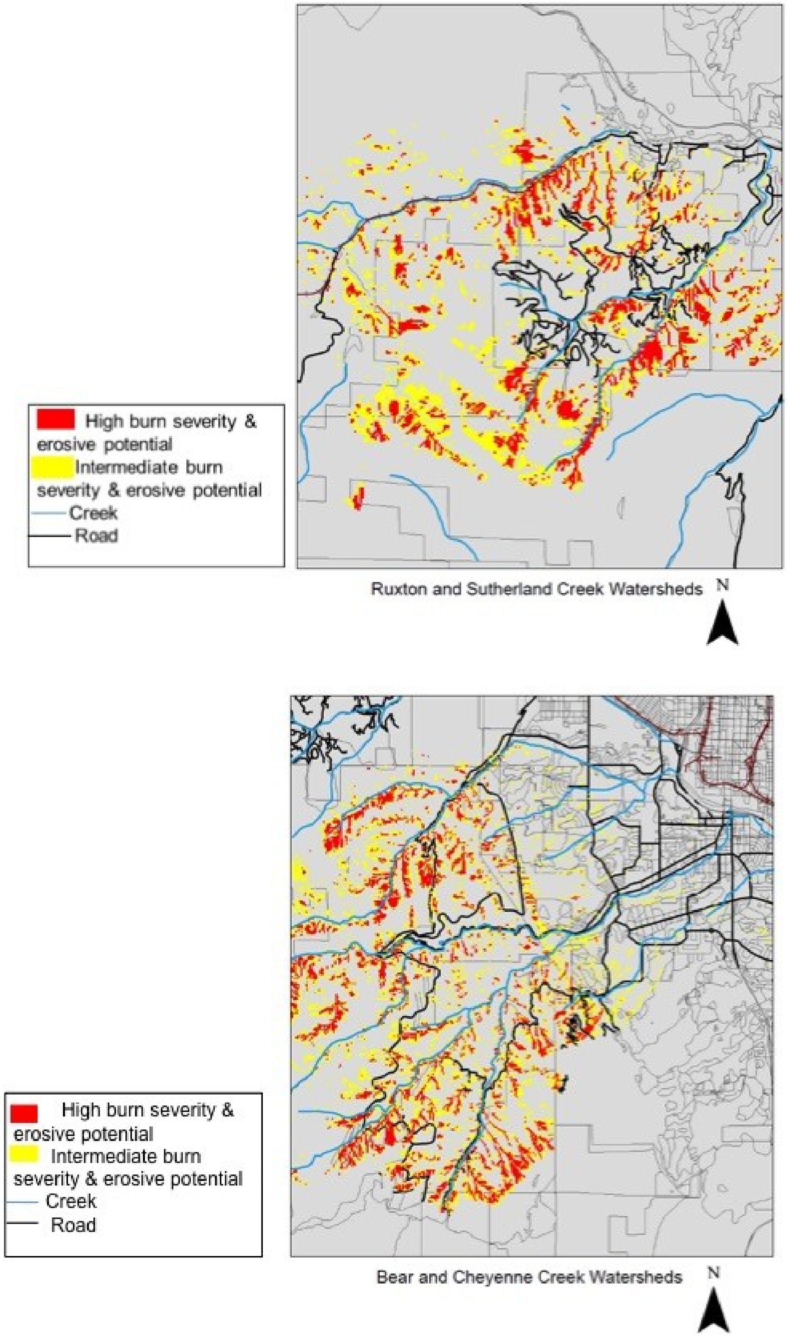

Figure 3. Composite Burn-Severity and Erosive Potential

Overall, the upper portion of Sutherland Creek and the lower portions of both Ruxton and Sutherland watersheds display the potential for acute burn and erosive severity. The upper portion of the Ruxton watershed reflects lesser burn-erosion potential, which, in the aftermath of a wildfire in the area, may have a lesser flood risk. However the lower portion of the Ruxton watershed show a different story: Manitou's iconic Cog Railway, hydroelectric plant and the surrounding homes and other infrastructure at the top of Ruxton Avenue are all located in areas of severe burn-erosion potential. Further, Ruxton watershed's lower side drainages reflect acute burn-erosive potential. These drainages increase the magnitude of debris flows into Manitou Springs following a fire. For an area still at risk of flooding and debris flow from the Waldo Canyon burnscar, Manitou Spring's infrastructure, including some of its critical economic sources, are at extreme risk from another wildfire and precipitation events.

The model depicts large, contiguous swaths of severe burn-erosion potential in the upper portion of the Sutherland Creek watershed. This elevates the magnitude of post-burn flooding and debris flow, posing indefinable risk downstream of the Sutherland Creek watershed. Of particular note is the Crystal Park community, which abuts against Sutherland Creek itself. The model shows Crystal Park neighborhoods as well as sections of Crystal Park road as being directly compromised by wildfire. Crystal Park's steep terrain and limited road access exacerbates this risk to individual's homes and lives.

The model depicts severe burn and erosive potential for the Bear and Cheyenne Creek areas that extend into the steep canyons on the southeastern flanks of Pikes Peak. Infrastructure directly at risk includes neighborhoods of West Stratton, Gold Camp, Old Stage, and Cheyenne Canyon Roads, as well as Helen Hunt Falls and the Seven Falls recreation areas, two popular tourist sites for Colorado

Springs. Relative to the Ruxton and Sutherland watershed analysis, the model depicts less at-risk human infrastructure within the Bear and Cheyenne Creek watersheds. However, due to the high and widespread burn-erosion potential in the upper portions of each watershed, a flood event would have catastrophic consequences from the Broadmoor/Cheyenne area and as far down as the Nevada Bridge, at the junction of Highway 25 and Nevada Avenue. The steep, rugged terrain of Cheyenne Canyon prevents feasibly performing wildfire mitigation efforts, such as tree-thinning. (Botts, personal communication 2017). Limitations such as this need to be considered for communities living with wildfire.

Using the burn-severity potential model in conjunction with a Colorado Springs WUI map, proportions of burn potential, on a four point scale, were spatially analyzed into two categories of WUI: intermix and interface. Figure 4 shows a WUI map of Colorado Springs with differentiated intermix and interface WUI. Areas within the Colorado Springs WUI are considered intermix WUI if the area of human development also contains 50% or more wildland vegetation (Stewart et al. 2007) Areas within the Colorado Springs WUI are considered interface WUI if areas of human development contain less than 50% wildland vegetation but are within 1.5 miles of wildland (Ibid).

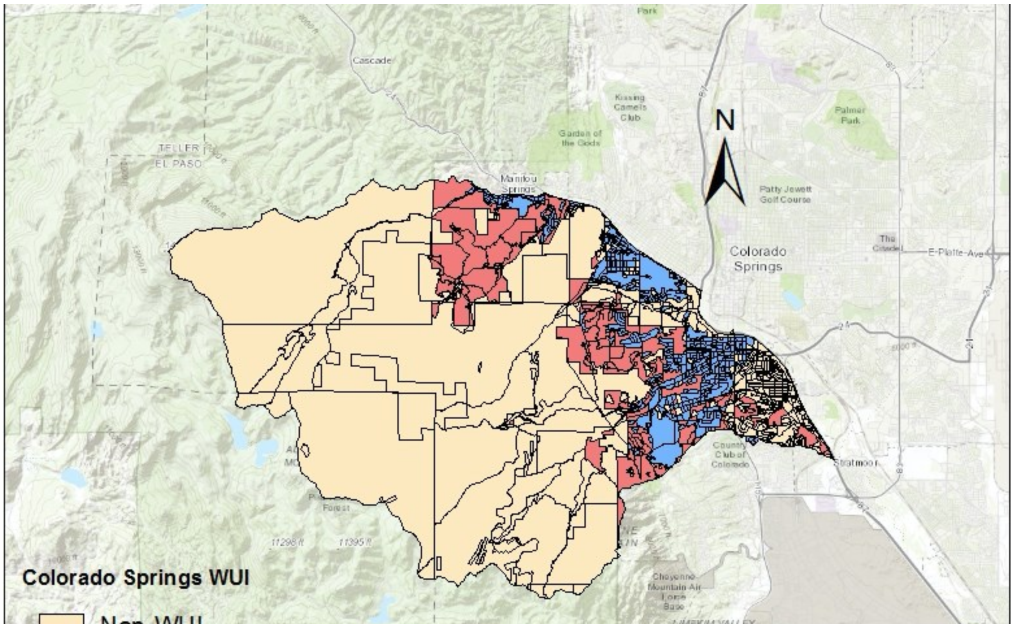

Figure 4. Colorado Springs' Wildland-Urban Interface

For the intermix WUI, shown in figure 5, the range of burn severity potential is relatively low where extreme burn potential encompasses ~27% of the area while low burn potential encompasses ~22% of the intermix area. High and intermediate burn potential account for ~23% and ~28%, respectively, of intermix area. During a potential wildfire, infrastructure within intermix WUI areas could be susceptible to ignition from both blowing fire embers and the fire front itself due to encircling vegetation that would burn in a mosaic of severity. Further a wildfire burning within the intermix WUI could push the burn as a whole farther down into Colorado Springs and act as a strong fire ember source.

The interface WUI, figure 6, displays more variability and a greater range in burn-severity composition where extreme burn potential encompasses ~9% of total interface area and low burn potential encompasses ~59% of the interface area. High and intermediate burn potential account for ~8% and ~24%, respectively, of interface area. While the composition of burn-severity potential is mostly low (59% of interface area), infrastructure within the interface WUI is susceptible to ignition from blowing fire embers rather than a direct fire front, as shown by the fate of the Mountain Shadows community during the Waldo Canyon fire.

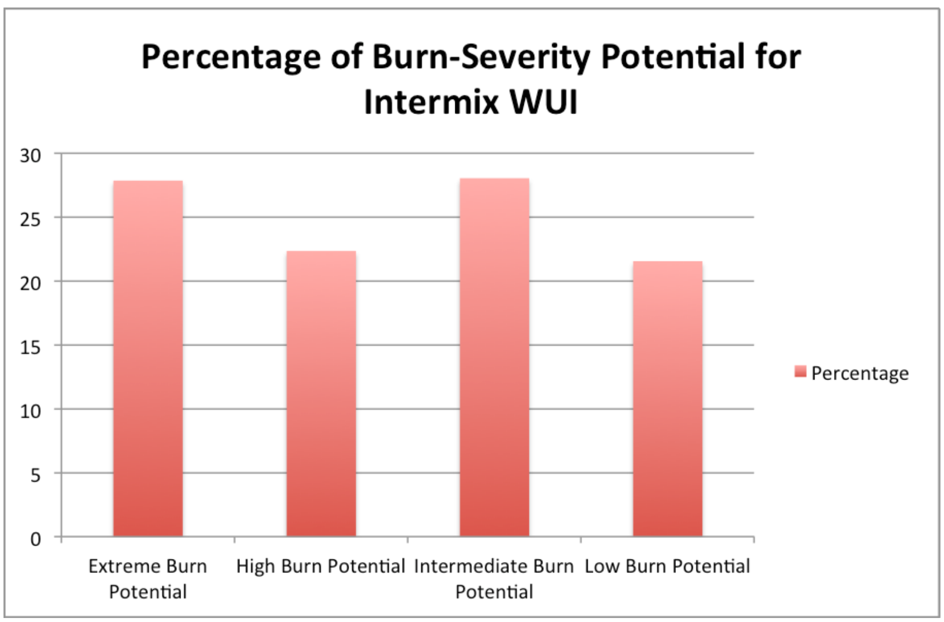

Figure 5. Intermix Burn-Severity Composition

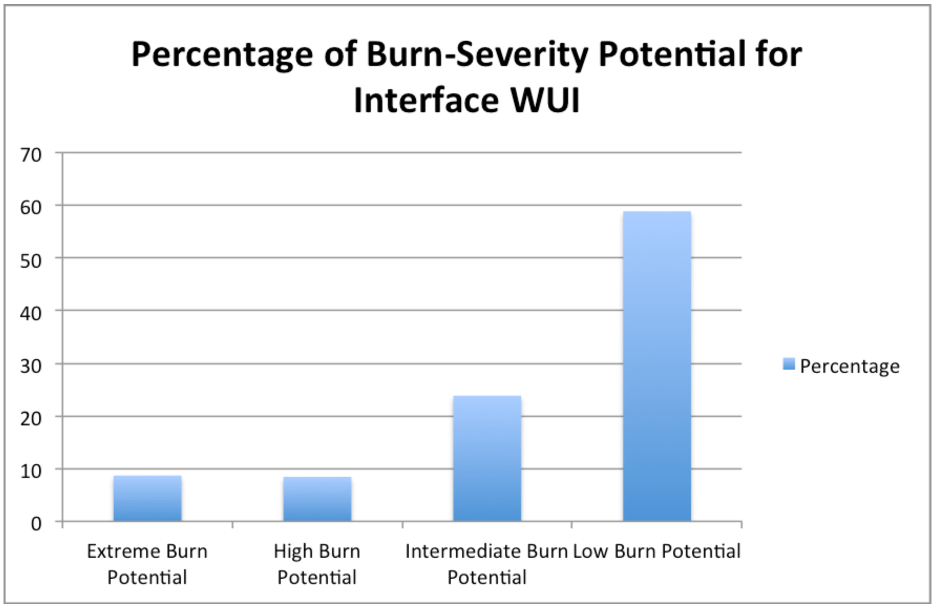

Figure 6. Interface Burn-Severity Compostion

While Colorado Springs' WUI as a whole necessitates wildfire management, the differences in burn-severity potential between the two WUI types could influence specific management practices. Because areas of intermix WUI show higher proportions of extreme burn severity than do areas of interface WUI, 28% and 9% respectively, fuels mitigation efforts could be prioritized in intermix areas to most efficiently use limited resources. Further, fire-resistant construction requirements and zoning laws could be refined to distinguish between human development in intermix versus interface.

An important feature to note of this analysis is that only areas of WUI that contain a minimum of human development at one structure per 40 acres were used (Stewart et al 2007). The analysis does not factor undeveloped WUI areas nor areas with particularly high infrastructure density. To further mitigate Colorado Springs'

WUI problem, potential growth in non-developed WUI areas as well as further growth in WUI areas overall must be managed to sustain annual wildfire risk.

The Future of Living with Wildfire

Five years from the Waldo Canyon wildfire, Colorado Springs is still reeling from its lasting effects. More recently, the West as a whole has also experienced the perennial devastation of wildfires that raged during the 2017 fire season, as seen in Southern California, Montana, Oregon, and British Columbia. Currently, the 2017 wildfire season is the most expensive on record, with suppression costs from the Forest Service alone exceeding $2 billion dollars (USDA 2017). As evidenced by the composite burn-erosion severity model, the Colorado Springs WUI and the surrounding community is saturated in extreme risk from the inevitability of the next wildfire. In preparing for the 2018 wildfire season and beyond, Colorado Springs and the Pikes Peak region must adapt to this risk to sustainably live with wildfire.

In October of 2017, the Pikes Peak Forest Health Symposium served to highlight the people, policies, and recent advances in addressing wildfire. The conference brought together the local leaders of wildfire management including historians, scientists, non-profit organizations, and wildland firefighters as well as three key stakeholders: the US Forest Service, Colorado Springs Utilities, and the City of Colorado Springs, represented Mayor John Suthers. Though many individuals across different fields contribute to understanding the issue, these three main stakeholders are primarily shaping Colorado Springs' future with wildfire. The efforts and policies put forth by each stakeholder need to be critically examined in their function across the checkerboard of jurisdiction that characterizes Colorado Spring's geography.

The most current and extensive wildfire mitigation project in the Pikes Peak area is the *Catamount Fuels Reduction Project* (CFRP) which is a dual-partnership between Colorado Springs Utilities and the USFS. The CFRP is a technical approach to address wildfire through the use of prescribed burning, tree-thinning, and other physical mitigation efforts with the primary goal of protecting CSU's various water resource infrastructures scattered across Pikes Peak. CFRP is also working to protect priority WUIs of the region (Catamount Environmental Assessment 2011). Of the project's ~100,000 acre scope, 70% is on federal land with the remaining consisting of private ownership (Ibid). The CFRP's project scope encompasses this research's AOI and also identified the research's watershed group as being of high priority. As of 2017, the CFRP has treated ~4500 acres with another proposed treatment of ~6500 acres in the immediate future (Howell 2017).

While the CFRP is a major component of Colorado Springs resilience to wildfire, physical solutions to mitigating wildfire risk are severely limited. In referring to the vast extent of at risk area of Pikes Peak, Eric Howell, spokesperson for the CFRP, concluded that "there is neither enough time, money or capacity to mitigate ourselves out of this situation". Colorado Springs' wildfire resilience cannot solely rely on physical mitigation and attempting to return Pike National Forest to its historical tree-stand density. Furthermore, even in the absence of anthropogenic influence on forest structure and climate, wildfires will naturally occur within the Pikes Peak ecosystem.

The City of Colorado Springs, including the Colorado Springs Fire Department and Office of Emergency Management, is the other key stakeholder in shaping Colorado Springs' wildfire resiliency through a variety of ways. In the event of a wildfire in the WUI, CSFD and the City's other emergency agencies will respond to structural fires, evacuation orders, and other necessary procedures in coordination with other responding agencies (see Appendix for detailed description of local and federal agency response during a wildfire). The City's proactive response to wildfire resiliency involves educational outreach, physical wildfire mitigation and, of particular note, policy. Colorado Springs' Community Wildfire Protection Plan engages the homeowner through stewardship education and extensive wildfire risk mapping down to a parcel-by-parcel scale. The City also uses resources for wildfire fuel mitigation in parks and open spaces, such as the extensive fuels reduction in Stratton Open Space in the Spring of 2017 (Will, personal communication 2017). The City's most prominent policy-based response to the wildfire issue is the Hillside Overlay design manual, adopted in 2011 and updated following the Waldo Canyon fire (City of Colorado Springs 2013). This legislation requires all homeowners residing in the WUI, as defined by the City, to adhere to the technical requirements as described by the fire code such as minimum vegetation clearance around structures and use of approved roofing materials.

When polled about the single most important step in wildfire mitigation, a 42% majority of wildfire speakers and attendees at the Pikes Peak Forest Health answered with **'Increase fuels reduction and forest restoration efforts'** while only 14% answered **'Manage wildland-urban interface'**. With a WUI that is 28,000 acres large and containing approximately a quarter of the total population, the City of Colorado Springs' extensive efforts to promote homeowner stewardship, along with the use of the Hillside Overlay ordinance, is a significant step. Ultimately, these efforts fall short of achieving a sustainable relationship with wildfire. Overall, the City's lack of a policy response is a significant gap in wildfire resilience and mirrors, anecdotally, the sentiment of local wildfire leaders and stakeholders.

The Waldo Canyon wildfire was devastating due to its proximity to the Colorado Springs' extensive WUI, not necessarily due to its abnormal intensity. Further, the results of the burn-erosion severity model of this research reflect a heavy reality for the future: the wildfire issue in Colorado Springs will get worse before it gets better.

Policy based land-use planning decisions that manage Colorado Springs' WUI could significantly improve our long-term resiliency to wildfire. The growth of the WUI into at-risk lands in the West is primarily responsible for the rising costs of wildfire, though the extent to which this is true in Colorado Springs and the Pikes Peak region is unclear (Headwaters Economics 2014). Further, analyses show that 84% of WUI land in the West has yet to be developed (Ibid). These trends show that the West, including Colorado Springs, is at a tipping point regarding the future consequences of wildfire: the massive potential for growth and development in the WUI also carries the massive burden of increased wildfire risk. Though responsibility of wildfire is shared across many different stakeholder utilizing an array of effective strategies however, effective land-use planning in the WUI needs to be implemented to sustainably live with wildfire.

Appendix

The following are identified as the main stakeholder entities regarding wildfire management in Colorado Springs and the greater Pikes Peak Region. A mixture of interviews and stakeholder websites provided stakeholder information.

United States Forest Service & Pike and San Isabel National Forest- Cimarron and Comanche National Grasslands Regional District (PSICC)

At a national scale the USFS is responsible for all wildfire management on national forest and wildland areas, including both suppression and pre-fire mitigation activities. The 2017 fiscal year for the USFS was the most expensive on record by spending over $2 billion dollars on suppression costs alone (USDA 2017). Over the past two decades, the USFS has experienced a major paradigm shift regarding absolute wildfire suppression. USFS firefighting personal now utilize a more flexible decision making process in suppressing- or not suppressing wildfires (Markalunas, personal communication 2017). In the event of a wildfire, the USFS utilizes specialty personal such as *Burned Area Emergency Response Teams* to conduct immediate risk assessments on watersheds. The USFS also provides extensive, open-sourced online data for other landscape managers on active fires and major past fires, such as the *Monitoring Trends in Burn Severity Program*, used in this report

At the regional level, the Pike and San Isabel National Forest- Cimarron and Comanche National Grasslands is the Forest Service's regional district for Colorado Springs and the Pikes Peak region. While many local, state and federal agencies responded to the Waldo Canyon wildfire, Pikes Peak USFS personnel were the first to respond and remained in overall command throughout the duration of the blaze under the authority of Incident Commander Rich Harvey (City of Colorado Springs 2013). During the escalation in size and intensity of the fire, the FS command team designated Waldo to its highest level of emergency (Ibid). This designation authorized the consolidation of resources and personnel across responding agencies to the authority of the USFS command team.

The PSICC is part of a dual partnership for the *Catamount Fuels Reduction Project (CFRP)*, the most current and extensive wildfire management project for the Pikes Peak region

Colorado Springs Utilities (CSU)

CSU is a publicly owned four-service utility company serving Colorado Springs' and surrounding communities' energy and water needs. CSU, and other Western water providers, hold a major steak in maintaining healthy forests due to the ecosystem services they provide to water resource infrastructure. CSU's own Rampart Reservoir experienced increased sediment and nutrient loads following the Waldo fire. CSU's series of water infrastructures pocketed in Pike National Forest is at an even enhanced risk due to the high erodibility of Pikes Peak Granite, the distinctive coarse, red soil of the Front Range. Denver Water's Cheeseman Reservoir further evidences this issue, which continues to be heavily sedimented following the Hayman fire. CSU has spearheaded many erosion mitigation efforts in the Waldo Canyon area, such as sediment catch basins and ditches. In the event of a wildfire, CSU also employs its own emergency wildland firefighting personnel. CSU is the other major partner of the CFRP.

The Catamount Fuels Reduction Project (CFRP)

The CFRP is a dual partnership between CSU and USFS' Pikes Peak Ranger District to mitigate against the detrimental effects of wildfire, focused primarily in the Highway 24 WUI and around water infrastructure across Pikes Peak. Following an environmental assessment conducted by a third party, JW Associates, the CFRP was authorized to,

> "create more sustainable forest conditions that are more resilient to fire, and insects and diseases, while providing for diverse wildlife habitat, recreational opportunities, sustainable watershed conditions and increased fire fighter safety. The objectives are to restore sustainable forest conditions to reduce fuel for wildfires" and to protect "the municipal watershed reserves for the cities of Colorado Springs, Green Mountain Falls, Cascade, Chipita Park and Manitou Springs,"

Within its 100,000 acre project area over public and private lands, the CFRP proposes to treat 21,200 acres using activities such as tree-thinning and prescribed burning (Catamount Environmental Assessment 2011).

The City of Colorado Springs Fire Department (CSFD) & Office of Emergency Management (OEM)

Responding to structural fires within the municipality, CSFD also trains personnel and maintains resources for the objective of wildland firefighting. During the Waldo Canyon fire, CSFD, OEM and other municipal agencies played a pivotal role in responding to the fire in the WUI through suppression, evacuation efforts, and resource coordination (City of Colorado Springs, 2013). Overall, CSFD acts as a hub that responds directly to fire emergencies and also works with the City in developing ordinances and wildfire mitigation efforts.

The Waldo Canyon wildfire spurred the city to update its housing ordinance requirements to better protect homes and infrastructure. Specified communities in the WUI, or what the City calls the “Hillside Overlay Zone”, must be constructed up to code as described by the Hillside Design Manual, published in 2014 by CSFD. The Hillside Design Manual gives the technical requirements for ignition-resistant building materials and vegetation surrounding the homes to which the ordinance effects. For instance, the ordinance bans wood-shake roofs, requires decks to be made of non-wood material, and specifies 15 feet of clearance between primary structures and combustible vegetation (Colorado Springs Fire Department, 2014).

Created in 2011, The City of Colorado Springs’ Community Wildfire Protection Plan (CWPP) is the City’s most recent, noncompulsory wildfire management strategy. Along with extensive risk mapping for neighborhoods within the WUI, the Springs’ CWPP authorizes fuels reduction projects and promotes wildfire stewardship and education to its citizens. The CWPP also authorizes a neighborhood-chipping program, where the City removes mitigated fuels from homes free of charge, provided that certain requirements are met. To further incentivize homeowner responsibility, the Wildfire Mitigation Measures Subtraction works in conjunction with the CWPP by authorizing a federal income tax deduction for the costs incurred by a homeowner performing mitigation efforts. The tax deduction covers up to $2500, provided that the homeowner performs the technical recommendations prescribed in Colorado Springs' CWPP (Colorado Spring Fire Department, 2014).

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