CHAPTER 5 DIRECT DAMAGES FROM WILDLAND FIRE

5.1 INTRODUCTION

The primary focus of this assessment is a quantitative analysis of the smoke impacts, on both air quality and health, from wildland fires. As detailed in the conceptual framework outlined in Chapter 2, in the process of examining the trade-offs between prescribed fire and wildfire it is also important to consider the potential effects, both positive and negative, of the fire itself. Although it is not possible in this assessment to quantify these effects because location-specific data are limited, the qualitative characterization of these additional effects helps add context to the overall examination of the trade-offs of smoke impacts due to different fire management strategies.

This chapter discusses the direct fire damages (value of economic loss) that are often experienced as a result of wildland fire. As detailed in Chapter 6 and quantitatively examined in Chapter 8, the health effects and overall population impacts of smoke exposure are well characterized. Although there are ecological benefits to fire (see Chapter 3), severe wildfires can adversely affect ecosystems, lead to substantial effects on public welfare, and incur societal costs (Table 5-1). In considering the costs incurred from wildfires, preparedness, mitigation, and suppression efforts are included, along with numerous losses that have substantial effects on society. The following chapter provides a broad discussion of these additional effects often experienced because of wildfires.

5.2 ECONOMIC BURDEN OF WILDFIRE

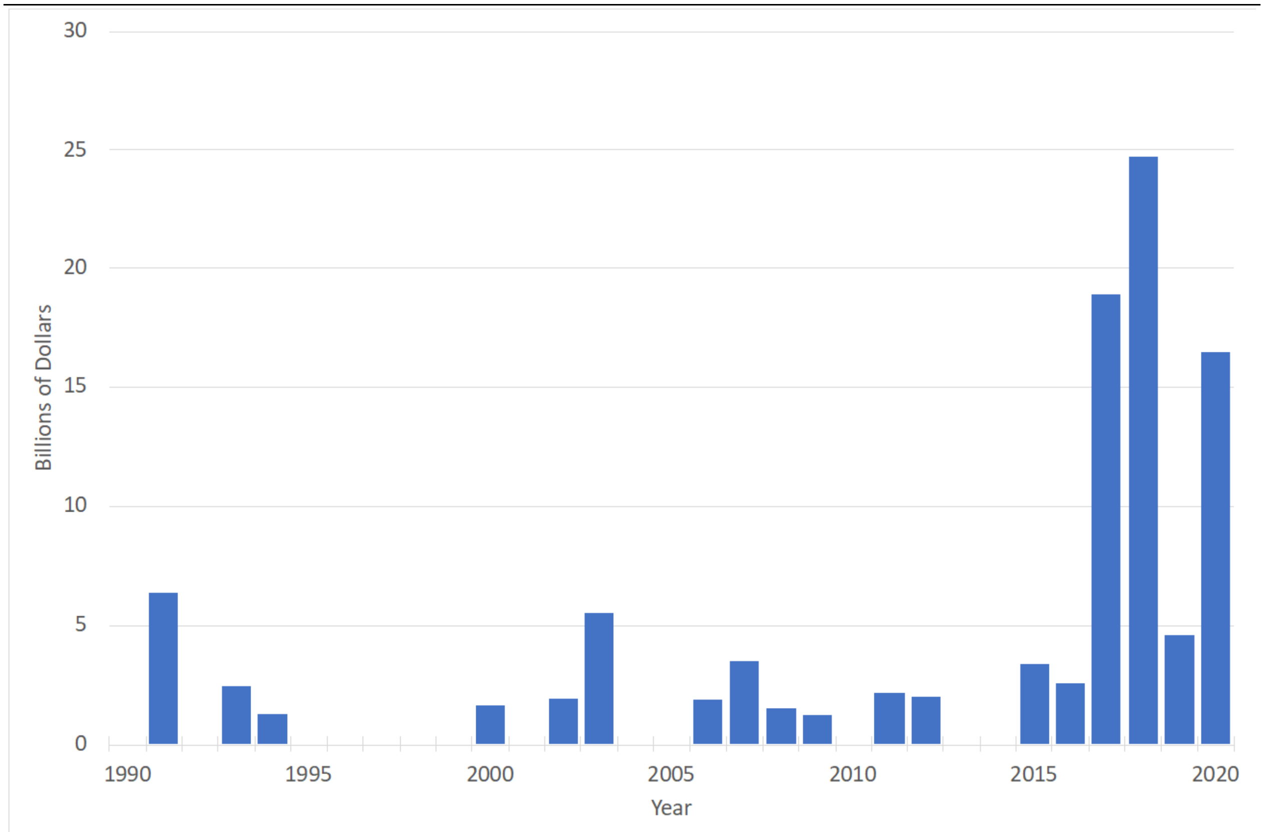
The National Institute of Standards and Technology (NIST) Special Publication 1215 (Thomas et al., 2017) quantified the burden on the U.S. economy from wildfires. The economic burden includes wildfire-induced damages and losses, and also the management costs to suppress and mitigate ignition and fire spread (see Table 5-1). The annualized burden was estimated to be between $71.1 billion to $347.8 billion in 2016 dollars ($77.4 billion to $378.7 billion in 2020 dollars). The estimates were based on literature or data available in early to mid-2017. Not included, for example, were recent catastrophic wildfire incidents. [Note, however, the estimates in Thomas et al. (2017) were significantly larger than the previous estimates found in the NIST Special Publication 1130 Hamins et al. (2012)].

Table 5-1 The economic burden of wildland fires.

Costs	Losses
Prevention	***Direct***
• Education and training	• Deaths and injuries
• Detection	• Psychological effects
• Enforcement	• Structure and infrastructure loss
• Equipment	• Environmental impact
Mitigation	• Habitat and wildlife loss
• Fuels management	• Timber loss
• Insurance	• Agricultural loss
• Disaster assistance	***Indirect***
Suppression	• General economic impacts
• Federal	• Evacuation costs
• State	• Accelerated economic decline
• Municipal (paid)	• Utility and pipeline interruption
• Rural (volunteer)	• Transportation interruption
Cross-cutting	• Government service interruption
• Legal	• Psychological effects (loss of amenities)
• R&D	• Housing market impact
• Building codes and standards	• Loss of ecosystem service
• Regulations	• Increase risk of other hazards
	• Loss of tax base
	• Health effects from fire retardant use

R&D = research and development.

Based on National Oceanic and Atmosphere Administration (NOAA) billion-dollar weather and climate disaster data (Smith, 2020), which include direct losses from insured and uninsured sources, the largest losses from billion-dollar wildfire disasters have all come since 2017 (Figure 5-1; note: there were no billion-dollar events prior to 1991). Since 1980, no year experienced more than a single billion-dollar wildfire disaster (direct losses from a single-event), meaning each year represents a single event in Figure 5-1. Accounting for more than just direct losses, Wang et al. (2020) measured the economic ramifications of the 17 largest wildfires in California during 2018 and estimated their direct, indirect, and health costs. The study authors estimated wildfires to have caused $148.5 billion ($126.1 billion to $192.9 billion, 95% confidence interval) in losses associated with direct capital losses ($27.7 billion), health effects ($32.2 billion), and indirect economic effects [$88.6 billion; Wang et al. (2020)].



Source: Developed from data presented in Smith (2020)

Figure 5-1 Billion-dollar wildfire event losses (1980−2020).

The economic burden from wildfire seems to have been increasing over time. Although the wildfires of the last few years have been particularly devastating, the increasing ability in measurement science to better account for the effects of wildfires can also partly explain the increase in reported costs and losses. In particular, until recently, the economic loss due to human-health effects from wildfire smoke has been underappreciated.

The next section discusses economic issues related to wildfire management, followed by a section on management costs, and then a section covering economic issues related to valuing wildfire net value change (NVC).

5.2.1 ECONOMICS OF WILDFIRE: MANAGEMENT IMPLICATIONS

Economics is a discipline concerned with the allocation of scare resources and the understanding of trade-offs. Central to the economics of wildfire management is the search for the understanding of trade-offs between management inputs (e.g., prevention and suppression) and the consequences of unwanted wildfire ignitions (e.g., life-safety, acres burned, structure loss). The economics of wildfire management is not a new concept. Headley (1916) discussed ideas of suppression effectiveness, efficiency, and waste of effort. Sparhawk (1925) introduced the idea of the "Cost plus Loss" (C+L) model as the management trade-off between prevention and "prefire suppression activities" (e.g., fuels management) expenditures, suppression expenditures, and wildfire losses. A central finding of the C+L model is that prevention and prefire suppression expenditures can be selected to minimize the sum of all costs (i.e., prevention, prefire suppression activities, and suppression spending) plus the resulting wildfire losses to identify the optimal level of management effort. The optimal level corresponds with the C+L minimum, and it can be shown that at the minimum, any other allocation of management resources will result in either (1) an increase in spending that exceeds the expected avoided loss or (2) a reduction in spending that surpasses an increase in expected loss. This concept of the C+L model is depicted in Figure 5-2, where the inputs of prefire suppression activities and suppression are independent inputs, and prefire suppression activities expenditures are held constant (Donovan and Rideout, 2003; Sparhawk, 1925). Suppression costs increase with increases in suppression effort, while the value of corresponding loss decreases. The minimum point of the (suppression) cost plus loss curve reveals the economically optimal level of suppression effort (holding prefire suppression activities constant).

The C+L model has been revised several times [e.g., Gorte (2013); Gorte and Gorte (1979)], with modern depictions acknowledging the potential for positive effects of wildfires, necessitating a change in the term "loss" to "NVC" (Rideout and Omi, 1990; Simard, 1976). Although the graphical depiction of the C+NVC is useful for illustration, it is less useful for identifying the minimum C+NVC when presuppression expenditures are allowed to be unconstrained. Further, because management activities and recent wildfire activity can have lasting effects on the fuels, affecting future wildfire risk (Prestemon et al., 2002), intertemporal optimization is required. Intertemporal optimization introduces additional considerations such as discounting and risk perception, which affect the optimal timing of forest management activities (Mercer et al., 2007; Amacher et al., 2005a, b).

There are two immediate challenges making the optimal levels of intervention difficult to determine. First, an understanding of the functional relationship between wildfire management activities and the resulting NVC is needed. Second, and perhaps more fundamental, is that many of the effects from wildfire are not well known or measured, particularly indirect or cascading effects. However, additional challenges include (1) the costs and losses are not incurred by the same subsets of the population, creating equity concerns and barriers to aligning economic interests and (2) the spatial, temporal, and economic boundaries of the C+L loss model are hard to define. Many of the sections that follow build from work detailed in the NIST Special Publication 1215 (Thomas et al., 2017) and describe categories of the costs and losses associated with wildland fire for the U.S.

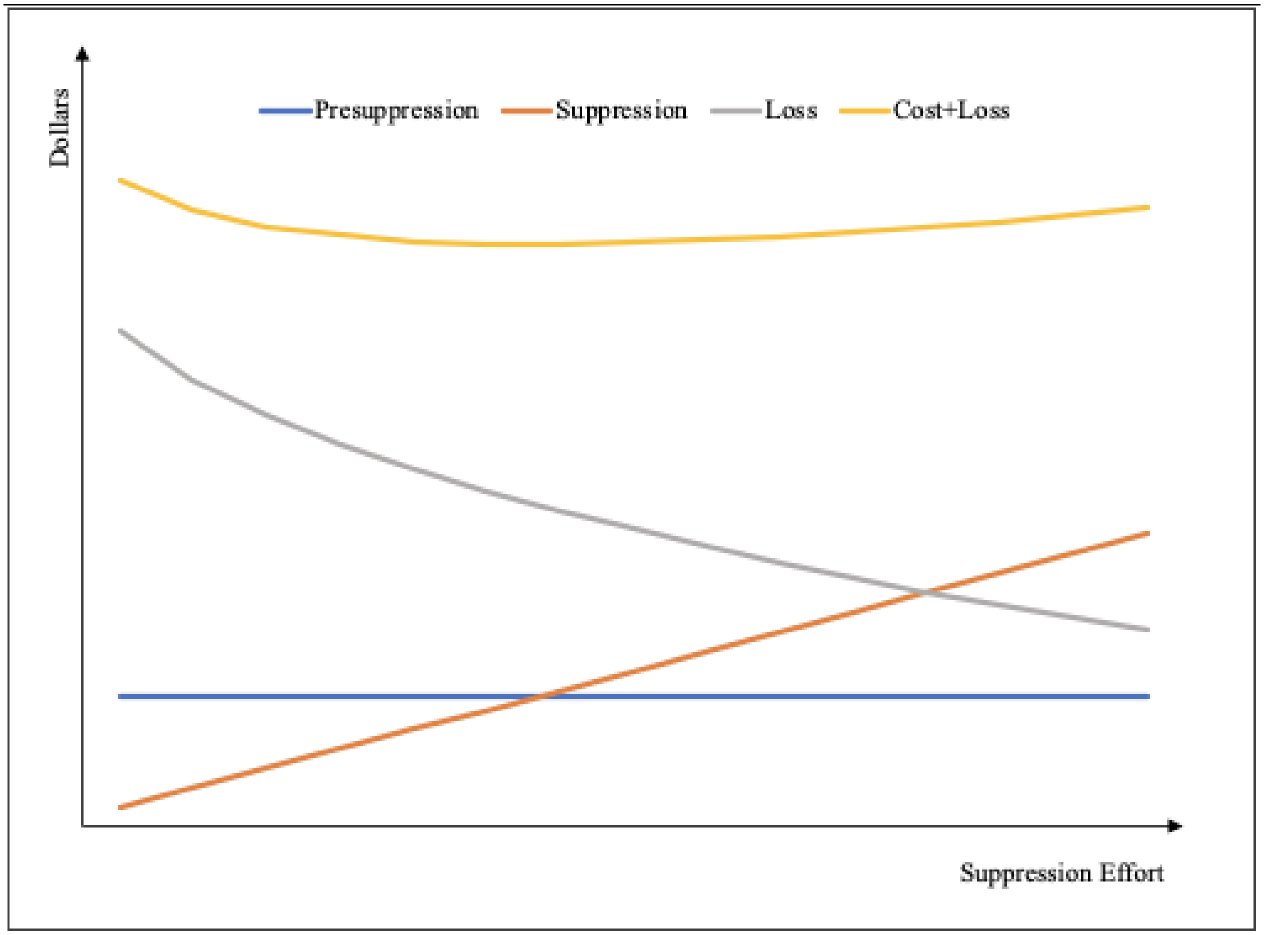


Figure 5-2 **Illustrative example of the Cost plus Loss (C+L) Model of wildfire management.**

5.2.2 MANAGEMENT COST CATEGORIES

Management cost categories include those expenditures spent on preparing for, mitigating, suppressing, and recovering from wildfires. Presuppression activities include prevention and preparedness. Suppression accounts for firefighter labor, equipment, firefighter training and wellness programs, as well as the monetary equivalence of volunteer time from local, nonpaid fire departments. Post-fire rehabilitation and recovery include efforts to return lands to prefire functionality. The "cross-cutting" cost category includes activities that impact multiple management activities; for example, research and development efforts result in more effective suppression technologies, improved building codes, and fire-resistant building products.

5.2.2.1 PREPAREDNESS AND PREVENTION

At the federal level, prevention and mitigation activities, including wildfire detection and education, are aggregated together in budget line items as "preparedness." Preparedness is considered to be "comprise[d] [of] a range of tasks to ensure readiness for wildfire response, including workforce preparation, equipment and resource management, and wildfire outlook conditions for forecasting" (Hoover, 2020). For Fiscal Year (FY) 2020, preparedness spending was $1.672 billion dollars in total for the U.S. Forest Service (USFS; 80%) and the Department of the Interior [DOI; 20%; Hoover (2020)].

Wildfire prevention activities include awareness efforts to promote fire safety to reduce unintentional wildfire ignitions. Awareness programs, such as public service announcements and media spots, community townhall-style presentations by wildfire prevention specialists, distribution of brochures and flyers containing educational messaging, and community wildfire hazard assessment performed by risk specialists have all been shown to reduce the number of human-caused unintentional wildfire starts and generate positive economic return on investment (Prestemon et al., 2010). For example, Prestemon et al. (2010) estimated that the benefit-cost ratio of prevention to be 35 to 1 on the margin. Abt et al. (2015), who also accounted for law enforcement efforts and intentionally set wildfires, found benefits were 5 to 38 times larger than prevention costs. Prevention efforts have been shown to have differential effects that vary by ignition cause type [e.g., escaped campfire, debris fire; Butry and Prestemon (2019); Abt et al. (2015)], and the timing of activities can be exploited to yield larger economic benefits (Butry et al., 2010b; Butry et al., 2010a) or coupled with other risk reduction activities, such as fuels management (Butry et al., 2010b).

Early wildfire warning and detection systems, including aerial and satellite technologies, can lead to improved firefighting response time, limiting fire growth after ignition or assist in monitoring wildfire progression, and increase suppression effectiveness (Cardil et al., 2019). Satellite-based wildfire detection information has been shown to improve fire commanders' decision making during suppression activities, yielding better firefighting safety and economic outcomes (Herr et al., 2020). Steele and Stier (1998) found that wildfire surveillance from fixed lookouts yielded benefit-cost ratios of 6 to 1 in terms of reduced suppression costs and property losses.

Wildfire risk assessments and related tools can be used to identify occurrences of elevated temporal or spatial (landscape-level) risks, by examining factors such as prior wildfire history, weather, climate, fuel conditions, and socioeconomic factors. Such information can be used to inform decisions on the prepositioning of mitigation and suppression resources (Bayham et al., 2020; Thomas et al., 2011; Prestemon and Butry, 2005). Improved suppression response time can yield economic benefits by reducing burned areas (Cardil et al., 2019).

5.2.2.2 MITIGATION

Mitigation activities are designed to reduce the consequences from wildfire (e.g., area burned, value of economic loss). For wildfires, the primary mitigation approaches are fuels management, insurance, and disaster assistance.

5.2.2.2.1 FUELS MANAGEMENT

Fuels management activities result in the reduction of hazardous fuels in forests. This can be accomplished by a number of methods, including prescribed burning and mechanical and chemical thinning of materials (as discussed in Chapter 3). In FY 2020, the federal government spent $194.0 million on the line item "hazardous fuels/fuels management" on federal lands and the line item "other Forest Service wildfire appropriations," which also includes fuels management that amounted to $545.3 million (Hoover, 2020). Fuels management spending is not readily available at the state, local, and private levels, nationally.

There is statistical evidence that fuel treatments can impact wildfire behavior (Mercer et al., 2007; Prestemon et al., 2002), resulting in suppression cost savings in excess of treatment costs (Thompson et al., 2017; Taylor et al., 2013; Butry, 2009). However, some research suggests that fuel treatments may lead to increased suppression spending, due to more aggressive suppression strategies as an option in treated landscapes [e.g., see Belval et al. (2019); Loomis et al. (2019); Rideout and Ziesler (2008)]. Research into optimization has shown that with careful planning, fuel treatments can be leveraged to yield larger economics returns, when considering timing (Butry et al., 2010a) or when allowing for the sale of harvested materials after forest thinning (Prestemon et al., 2012). Beyond avoided suppression costs, Huang et al. (2013) identified additional benefits that included fatalities avoided, timber loss avoided, avoided regional economic impacts, rehabilitation costs avoided, and loss of carbon storage avoided. In addition, Houtman et al. (2013) considered the impact of "free" fuel treatments (i.e., wildfire that are allowed to continue to burn to achieve multiple objectives which can include resource benefits) on future suppression costs avoided and found instances of large economic returns. However, policies allowing for more wildfires to burn (wildland fire use), instead of immediate suppression actions, may be more economically favorable with a low or zero discount rate. Furthermore, wildland fire use is controversial and carries inherent risk. Current federal fire management policy, for example, allows for limited wildland fire use (i.e., as long as the managers determine that it would not endanger the public). To increase the amount of wildland fire use, the risk thresholds would need to be relaxed, potentially resulting in more unintended losses of people, structures, and resources [see Houtman (2011)].

Fuel modification also occurs on private land, often as part of a program to create an area around a structure designed to reduce wildfire ignition and spread (i.e., "defensible space"). The major barriers to use of defensible-space programs are related to cost, aesthetics, and privacy (Absher et al., 2013; Kyle et al., 2010; Absher et al., 2009). For some, climate change and risk perceptions have lessened some of the resistance (Wolters et al., 2017), while for others it is a familiarity with the programs and expectations of its effectiveness that have led to acceptance. Stockmann et al. (2010) evaluated the cost-effectiveness of various homeowner risk reduction strategies including fuels management and structure hardening. They found that fuel reduction within 61 m (200 ft) of the house was the most cost-effective. Nevertheless, homeowner actions to reduce wildfire risk are potentially limited by the homeowners' own inaccurate assessment of risk factors [e.g., Champ et al. (2009)].

5.2.2.2.2 INSURANCE

In measuring the U.S. fire problem, the cost of insurance has typically been calculated as the difference between premiums paid in and claims paid out (Hall, 2014), which constitutes overhead costs. These costs would include employees' wages, underwriting expenses, administrative expenses, taxes, real-estate expenses, legal expenses, and cost of capital. There are a number of insurance markets that are exposed to wildland fire, including homeowner's insurance, commercial insurance, automobile insurance (Hall, 2014), health and life insurance, and reinsurance markets. Frequently, wildfire losses are reported as direct, insured losses.

Although insurance could be part of the solution to increased efforts to reduce overall risk to wildland fire on private lands, very few firms offer insurance focused, in particular, on forests (Chen et al., 2014). A leading limiting factor to widespread adoption of such insurance is a lack of actuarial information on wildfire risk at fine spatiotemporal scales. There is additionally a need to develop a better understanding of the approaches for reducing moral hazard and adverse selection in the issuance of policies. As a result, policies tend to be expensive and out of reach of small forestland owners, meaning that an insurance-based incentive structure for reducing overall wildfire risks on private lands remains elusive.

5.2.2.2.3 DISASTER ASSISTANCE

Disaster assistance is financial assistance provided by the federal government following a disaster declaration. Because assistance can be used for things such as temporary housing, lodging expenses, repair, replacement, housing construction, child-care, medical expenses, household items, clean-up, fuel, vehicles, moving expenses, and other necessary expenses determined by the Federal Emergency Management Agency (FEMA), care needs to be taken in tracking the economic burden of wildfires because counting these costs or reimbursements directly and also as disaster assistance may result in double counting.

5.2.2.3 SUPPRESSION

In FY 2020, at the federal level, suppression spending exceeded $1.4 billion dollars, split between the USFS (73%) and the DOI [27%; Hoover (2020)]. These are resources used for firefighting. State suppression expenditures are estimated at $1 to 2 billion per year (Gorte, 2013).

An estimate for local (municipal) fire departments is more difficult to determine. An approximation can be calculated assuming the cost of wildfire prevention and suppression is proportional to the incident volume of fire involving wildland fuels. In 2014, based on Zhuang et al. (2017), it is estimated that career fire department expenditures amounted to $41.9 billion ($46.21 billion in 2020 dollars), and the value of volunteer (rural) fire departments is estimated at $46.9 billion [see “Method 5” used in Zhuang et al. (2017); $51.72 billion]. Based on call volume (27.8 million calls) reported to the National Fire Incident Reporting System (NFIRS) from 2018, fires involving natural vegetation represented 0.8% of all calls (20% of all fire incidents). In combination with fire department expenditures, this information could be used to estimate the amount spent to suppress wildland fires in local jurisdictions.

Gebert et al. (2007) found suppression spending to be impacted by burned area, suppression strategy, and region of the country. Statistical models developed to forecast USFS suppression costs by region of the country show that forecasted suppression spending is influenced by factors such as prior suppression expenditures, sea surface temperatures, and weather [e.g., temperature and precipitation; Gebert and Black (2012); Abt et al. (2009)]. The models found that suppression strategy influences total suppression costs for large wildfires, with direct suppression being the most expensive on a per-acre-burned and per-day basis but leads to smaller wildfire sizes and duration. However, studies have found that overall suppression strategy can be complicated by other factors, which also impact total suppression expenditures. For example, Liang et al. (2008) found that the percentage of private land within the burned area influenced suppression expenditures on large wildfires, while Rossi and Kuusela (2020) indicated that management risk attitudes (risk aversion) affected expenditures.

5.2.2.4 POST-FIRE REHABILITATION AND RECOVERY

Post-fire rehabilitation is funded at the federal level as part of "other activities," and in FY 2020 the other activities amounted to $41.9 million. This accounts for costs associated with landscape-level restoration activities. Also included in this line item are activities related to research and development, construction and maintenance of fire facilities, and forest health management (Hoover, 2020).

5.2.2.5 CROSS-CUTTING COST CATEGORIES

Some costs cut across various organizations and categories. These include legal costs, research, and regulations. Legal costs include the prosecution, defense, and incarceration of fire-setters. In 2019, there were 785,500 prisoners in local prisons [all crimes; Zeng and Minton (2021)]. In 2019, there were 1,430,805 prisoners in federal and state facilities, with 0.9% sentenced for "other" property crimes, which include arson [all types; Carson (2020)]. The Bureau of Prisons (2018) estimated that the average cost of incarceration for a federal inmate in FY 2016 was $36,299.25 ($39,566.18 in 2020 dollars).

Many public and nonprofit organizations are involved in research and development to reduce the costs and losses associated with wildland fires. For federal research and science agencies, some of these costs are included in the $41.9 million "other activities" listed above (Hoover, 2020).

Each state has its own building codes and fire regulations, based on the international model codes. In addition, some consumer products are built for fire safety. Zhuang et al. (2017) estimated in 2014 that fire-safety related costs for building construction were $57.4 billion ($63.30 billion in 2020 dollars) and for consumer products were $54.0 billion ($59.55 billion in 2020 dollars). This includes fire safety from all ignition and risk sources. In a study comparing the construction costs of a typical house with a "wildfire-resistant" house, Quarles and Pohl (2018) found that the costs of components are slightly less expensive for the wildfire-resistant house ($79,230 vs. $81,140). The cost components included the roof, exterior walls, deck, and landscaping. The largest savings were found for the exterior walls, which more than offset increases to the other components.

5.2.3 WILDFIRE LOSS CATEGORIES

Wildfire-induced losses are grouped into two categories: direct and indirect. Direct losses are those that occur as a primary result of wildfire (e.g., structure loss), while indirect losses are those that occur as a secondary, or cascading, result of wildfire (e.g., economic downturn due to business structure loss). Indirect losses are often more difficult to quantify due to latency and many may only be realized years after the wildfire.

5.2.3.1 DIRECT LOSSES

5.2.3.1.1 FATALITIES AND INJURIES

The National Fire Protection Association (NFPA) reported 80 civilian (nonfire-service) fatalities and 700 injuries in 2019 from fire incidents reported as "outside and other fires" (Ahrens and Evarts, 2020). The "outside and other fire" incident type includes wildland, grass, crop, timber, and rubbish fires. The estimates are based on a survey to U.S. fire departments, meaning the fatalities and injuries would tend to include those observed or reported immediately following the fire incident. Long-term health consequences made worse due to fire exposure, but not known until well after the incident, would not be captured. In 2017, there were 10 firefighter deaths associated with wildland suppression activities (USFA, 2018). The Incident Management Situation Report system, which tracks data on wildfires in federal jurisdictions, includes firefighter injuries. From 2003 to 2007, an average of 260 injuries per year were reported (Britton, 2010).

5.2.3.1.2 PSYCHOLOGICAL EFFECTS

Studies from wildfires have found depression, post-traumatic stress disorder (PTSD), and other anxiety disorders to have resulted from exposure to wildfire events. Estimates for civilian rates of PTSD and other anxiety disorders after a disaster range from 30% (Cole, 2011) to 60% (Kuligowski, 2017), with effects sometimes taking years to manifest (Kuligowski, 2017). For first responders, rates of PTSD have been estimated to occur in up to 20% of firefighters and paramedics (Rahman, 2016).

5.2.3.1.3 STRUCTURE AND INFRASTRUCTURE LOSS

The National Interagency Coordination Center (NICC) reported 963 structures lost by wildfire in 2019, under the annual average of 2,593 (NICC, 2019). NICC reported 25,790 structures lost in 2018 (NICC, 2018) and 12,306 structures lost in 2017 (NICC, 2017). NICC does not provide dollar lost estimates.

5.2.3.1.4 ENVIRONMENTAL EFFECTS

Environmental effects can take many forms, including effects on vegetation, soil as well as erosion, watershed including increased sediment deposition, and carbon sequestration. Vegetation loss can create the need to reseed and regrow forest and grasslands. Soil degradation can result in poor soil nutrients and vegetation growth. Both vegetation and soil loss can result in erosion and increase the risk of flooding and debris flow (Ren et al., 2011; Benda et al., 2003). Trees sequester carbon and provide oxygen, but carbon can be released to the atmosphere if trees are burned. Wildfires can decrease water quality by introducing carbon, metals, other containments, and changes to nutrients, which can affect aquatic ecosystems and drinking water (Rhoades et al., 2019b). In addition to increased treatment costs for potable water, poor water quality can impact agricultural and industrial operations (Bladon et al., 2014). Treatment costs include the increased need to remove solids and dissolved organic carbon in water impacted by discharge from burned forests and wildlands (Emelko et al., 2011). However, traditional water quality protection strategies may fail to recognize the effects from wildfire that would result in the need for water treatment (Emelko et al., 2011).

5.2.3.1.5 TIMBER AND AGRICULTURAL LOSS

Wildfires on lands managed for timber and agricultural purpose result in business losses. The 1998 Florida wildfires resulted in pine timber damage of between $300 to $500 million in 1998 dollars ($479 to 798 million), which represented over half of the quantified costs and losses of the wildfire event (Butry et al., 2001). The timber losses were from two effects: (1) value from the physical loss of timber and (2) a price increase, due to scarcity, after all salvageable timber was sold. Prestemon et al. (2006) evaluated salvage harvest scenarios following the 2000 Bitterroot wildfire and found similar (direction of) effects to consumers, owners of damaged stands, and owners of undamaged stands. They demonstrated that the value of timber lost due to wildfire could be more than offset (in general welfare effects) through salvage.

5.2.3.2 INDIRECT LOSSES

5.2.3.2.1 GENERAL ECONOMIC IMPACTS

Wildfires, and disasters in general, can have long lasting impacts on an economy. They can include business interruption (temporary and permanent closures) and effects that disrupt the supply chain. Supply chain disruption can affect businesses and customers far removed from the wildfire threatened areas.

Butry et al. (2001) found the 1998 Florida wildfires impacted the tourism and service sectors. In an analysis of the 2002 Hayman Fire in Colorado, Kent et al. (2003) found the wildfire induced overall employment growth of 0.5%, by creating shifts in the economy resulting in a decline in average wages by 3%. Focusing on employment and wage dynamics, Davis et al. (2014) examined the impact of the 2008 large wildfires in Trinity County, CA. They found that employment in the natural resource sector increased by 30%, while average wages fell by 19%; whereas wage growth was experienced in the other sectors, again demonstrating disparate effects. Borgschulte et al. (In Press) found that wildfire smoke impacts annual labor income and employment in the U.S. and estimates the economic loss to be four times that from mortality ($83 billion in 2020 dollars).

Nielsen-Pincus et al. (2014) explored the economic impacts of large wildfires (fires where suppression exceed $1.0 million) in the western U.S. states by economic sector. For counties with populations under 250,000, they found sectors with employment increases included natural resources and mining; trade, transportation, and utilities; information services; financial services; and federal employment. Sectors that lost employment included construction, manufacturing, professional and business services, education and health services, and leisure and hospitality services. For larger counties, total employment was reduced after a large wildfire by 0.04%.

Loomis et al. (2001) found in a study of visitors to forests in Colorado that hikers and mountain bikers responded with fewer visits in areas with crown fires, but the time since the fire also played a role. Englin et al. (2008) and Englin et al. (2001) found the linkage to recreation demand is time dependent, with recent wildfires correlated with increased visitation and older wildfires linked to fewer, with Englin et al. (2001) also noting a rebound effect with the oldest wildfires. Hesseln et al. (2003) found crown and prescribed fires reduced visitation but consumer surplus differed between hikers (increased) and mountain bikers (decreased) in New Mexico. In Montana, Hesseln et al. (2004) found hikers decreased visitations after a crown fire, but increased visitations after a prescribed fire. They found mountain bikers displayed the opposite pattern.

5.2.3.2.2 EVACUATIONS

Evacuation costs include temporary lodging and travel to and from the impacted area. Kent et al. (2003) found the Hayman Fire in Colorado resulted in other expenditures, which included evacuation, that were estimated to be up to $14 million ($19.5 million in 2020 dollars). In addition to expenditures, McCaffrey et al. (2015) mentioned the nonmonetary expenditures, including the “logistical” and “emotional” toll of fire evacuation.

5.2.3.2.3 LOST NATURAL AMENITIES

National forests provide a stream of values including historic, use and recreational, and existence (value someone places on knowing something exists whether or not they may ever visit or use). Some of these values can be monetized in the form of entrance and use fees. The National Parks were estimated to be worth $92 billion dollars [$100 billion in 2020 dollars; Haefele et al. (2016)].

5.2.3.2.4 HOUSING MARKET

Hedonic analyses that relate home sales prices to nonmarket amenities and other property attributes can detect the values of environmental goods and services not directly traded in markets. Several studies have evaluated the effect of wildfire risk on home sales prices, with the expectation that higher risk lowers sales prices, all else being equal. Loomis (2004) compared housing sale prices before and after the 1996 Buffalo Creek Fire (Colorado) and found a price decline between 13 to 15% of undamaged homes near the wildfire. Kim and Wells (2005), in a study of the greater Flagstaff area (Arizona), found moderate crown canopy closure (40 to 69%) was preferred by home buyers; whereas high crown canopy closure (70% and higher), which posed a higher wildfire risk, was shown to decrease sale prices.

Meldrum et al. (2015) explored whether wildfire risk perceptions of residents of homes in Ouray County, in southwestern Colorado, aligned with professionals' data-based assessments of wildfire risk based on features of the home and property, including whether the property had vegetation nearby. Residents underestimated the risks of wildfire nearby. In many other aspects of the property's features, residents' perceptions were generally not highly correlated with the assessments of the professionals. The implication is that economic motivations to undertake risk-reduction efforts would be lower if risk were more accurately quantified by residents. Donovan et al. (2007) compared housing sales prices before and after homes were rated based on wildfire risk in Colorado Springs, CO. They found that the availability of risk information was correlated with a decrease of a representative home sales value by 13.7%. Champ et al. (2009) explored whether home prices in Colorado Springs, CO were aligned with risks of wildfire. They found that homebuyers prefer risky locations due to their favorable amenities (e.g., topography) but that homebuyers were less cognizant of wildfire risks than objective assessments would identify. Although these homebuyers preferred less fire-prone building materials, they tended to undervalue features of their properties from the perspective of wildfire risk reduction.

Hjerpe et al. (2016), in a study of house prices in four western cities, found that the sales of homes with medium forest density (34 to 66%) within 100 m of a house was associated with lower sales prices; yet, homes with high forest density (67% and greater) within 500 m of a house was associated with higher sales prices. Stetler et al. (2010) estimated home sales prices in Montana and found that distance to the wildfire, time since, size of fire, and whether the home was within sight distance of the wildfire affected home sales, for an average price loss of −13.7% for a home within 5 km of the fire.

Kalhor et al. (2018) evaluated the impact of visible fire scars from the 2000 Cerro Grande Fire (New Mexico) on assessed house values in 2013. They found the impact of the previous damage equated to a 1.7 to 4.4% decline in assessed house value, while measures of future wildfire risk were found to be correlated to an increase in assessed house value by 0.3 to 0.4%. The latter impact was attributed to the crown area likely accounting for the aesthetic value of vegetation.

5.2.3.2.5 LOSS OF ECOSYSTEM SERVICES

Ecosystem services are generally defined as "any positive benefit that wildlife or ecosystems provides to people" (NWF, 2017). Few studies exist on a national scale. Most tend to be regional in scope and not specific to wildfire. For example, Loomis et al. (2000) evaluated the value of better watershed services for a 45-mile section of the Platte River, Desvousges et al. (1983) valued lake preservation, Moore and McCarl (1987) valued the preservation of the Mono Lake ecosystem, and Hanemann et al. (1991) valued increased salmon stock in the San Joaquin River. Such examples provide methods that could be used to value avoided losses to ecosystem services from wildfire mitigation.

Wildfire Fire and Prescribed Fire Effects on Forest Health and Wildlife

Studies in the ponderosa pine ecoregion of California, Oregon, and Washington have shown that fire management based on low-intensity prescribed fire coupled with mechanical thinning can, over time, approximate historical landscape conditions that are much less susceptible to catastrophic fires (Prichard et al., 2017a; Prichard et al., 2017b; Allen et al., 2002). Where it is feasible to use such practices, low-severity fires can promote important wildlife habitat and forest health benefits (Pausas and Keeley, 2019). These ecological benefits include improvements in habitat quality for threatened and endangered species (Pausas and Keeley, 2019); reductions in ground layer and understory "ladder" fuels; reduced losses of forest floor nutrient capital and water holding capacity (Murphy et al., 2006); and increased forest resistance to drought, pests, and diseases, all of which are being exacerbated by climate change (Spies et al., 2019; Vose et al., 2019).

To date, prescribed low-intensity fire and thinning treatments have not been adopted into local, state, and federal forest management practices at a scale necessary to affect the overall fire deficit, and associated fuel load excess, in western forests. The potential effects of ignoring the fire deficit is underscored by the growing body of evidence for the role of climate change in amplifying recent increases in the frequency and intensity of wildland fires (Kolden, 2019; Abatzoglou and Williams, 2016) and consequent effects on ecological benefits associated with low-intensity fire regimes.

Water Resources

Wildfire can both directly and indirectly affect water resources as well. Direct effects can occur via downwind smoke and ash deposition on the surface of water bodies (see Section 6.4), and damage to drinking water infrastructure. Indirectly, fire affects water resources primarily through increased runoff of water and other materials into nearby water bodies. Together, these direct and indirect effects can alter the physical, chemical, and biological characteristics of water resources, and by doing so, impact their end use, such as for recreation, aquatic life, and drinking water.

The direct effects of fire on drinking water infrastructure is an area of rising concern. For example, fires can damage water treatment facilities or water supply lines. In two locations in California (Santa Rosa and Paradise), benzene and other volatile organic compounds (VOCs) were detected in tapwater post-fire, with concentrations of benzene exceeding federal and state drinking water standards (Proctor et al., 2020). This was likely caused by the partial melting of plastic water-supply lines to homes and infiltration of hot gas and other materials when the supply system became depressurized (Proctor et al., 2020). As fires become more frequent, they are increasingly likely to burn into urbanized areas, and direct effects on drinking water infrastructure could become more common.

The indirect effects of fire are more widespread, including the indirect effects on water bodies used as drinking water sources. Fire-prone ecosystems are major sources of the national water supply. Fire effects on forested watersheds are particularly concerning because these watersheds provide much of the drinking water consumed in the lower 48 states (Liu et al., In Press). Most of these watersheds are at high risk from wildfire now or in the near future (Hallema et al., 2018).

Fire can impact the physical supply and timing of water delivery by altering runoff and streamflow. The loss of ground layer vegetation and canopy leaf biomass reduces interception and evapotranspiration, increasing runoff (Stevens, 2013; Seibert et al., 2010). Moreover, on some soil types, intense wildfires can dramatically increase runoff by increasing water repellency of near-surface soil layers, a condition that can persist for years (Certini, 2005). Depending on fire severity, rainfall patterns, and watershed soil and land cover characteristics, post-fire streamflow can increase in the days, months, and years following fire (Niemeyer et al., 2020). Severe fires can also increase the risk of downstream flooding (Stevens, 2013). Additionally, fire can alter the amount and timing of snowmelt. For instance, mountain snowpack beneath charred forests absorbed more solar energy, causing earlier melt and snow disappearance in >11% of forests in the western seasonal snow zone over the past two decades (Gleason et al., 2019). Fire and climate change effects on snowpack can also have a substantial impact on late summer runoff when it is most needed by fish and wildlife (Pausas and Keeley, 2019).

By increasing runoff and flow, fires can also increase erosion and delivery of sediments, ash, and other constituents to downslope ecosystems. The increased sediment loads and land destabilization that can occur post-fire (Ren et al., 2011; Benda et al., 2003) may be characterized by a large influx of suspended solids to headwater streams (Rinne, 1996). Although not always (Cawson et al., 2013), effects can often depend on fire severity, with greater sediment erosion associated with higher severity fires (Benavides-Solorio and MacDonald, 2005). A wide variety of chemical constituents are often mobilized along with the sediments and ash. This includes nutrients and cations, heavy metals, organic compounds, like polycyclic aromatic hydrocarbons (PAHs), and dissolved organic carbon (Smith et al., 2011). Besides direct additions to water resources, fire can indirectly increase disinfection byproducts (DBPs), compounds that form during drinking water treatment when disinfectants (e.g., chlorine, chloramine) react with organic carbon and nitrogen compounds present in higher concentrations post-fire (Bladon et al., 2014). Some DBPs pose health risks, with the potential to cause certain cancers, reproductive issues, and anemia.

Encroachment of wildfire into the wildland-urban interface (WUI) can also release largely unknown types and quantities of anthropogenic contaminants into streams. Combustion of houses, buildings, vehicles, waste sites and other infrastructure present risks from hazardous chemicals, such as benzene and VOCs, as well as heavy metals (Proctor et al., 2020; Uzun et al., 2020). Finally, the use of fire retardants may also increase nutrient and chemical loading to post-fire landscapes.

Beyond physical and chemical changes, fires can also indirectly alter biological assemblages in downstream waters. Fire can increase coarse woody debris in streams (Young, 1994), positively impacting long-term habitat for fish, yet over the shorter term, fish and macroinvertebrate populations typically decline post-fire [e.g., Rinne (1996)]. Concomitantly, burning in riparian areas can increase light levels to streams, and studies have often recorded increases in stream temperatures post-fire [e.g., Dunham et al. (2007)]. This could negatively affect cold-water fish species, like salmonids (Beakes et al., 2014). Combined with the increased light and temperature, an influx of nutrients and sediment can also promote harmful algal blooms and the production of cyanotoxins (Bladon et al., 2014; Smith et al., 2011). These cyanotoxins both contaminate drinking water and negatively affect aquatic life.

While wildfire has been a part of the natural ecology of many ecosystems for millennia, an increase in fire frequency, area burned, and/or severity can have deleterious effects on water resources, altering their physical, chemical, and biological characteristics. In general, the more severe the fire, the more likely downstream waters will be affected, with greater potential for flooding, higher sediment loads, and other effects on water quality. By contrast, lower severity fires could positively effect downstream water users because the effect on water quality may be lower while water supply is temporarily increased. Effects following fire are generally most pronounced in the first few years but may persist for more than a decade in some cases (Rhoades et al., 2019a; Smith et al., 2011). Increased concentrations of nutrients, heavy metals, organic compounds like benzene, and DBPs pose particular risks, along with increased algal blooms and cyanotoxins. Communities will need to be aware—and plan for—the potential for post-fire contamination of water resources, especially following severe fire. The provisioning of safe drinking water from burned watersheds may require additional treatment infrastructure and increased operations and maintenance costs to remediate effects.

5.2.3.2.6 OTHER EFFECTS

Other effects of wildfire include accelerated economic decline, loss of utilities and transportation systems, disruption to government services, interference with military operations (e.g., smoke visibility issues), cascading natural hazard risks (e.g., increase risk of mudslide or growth of invasive species), loss of tax base due to housing and building stock, and health and environmental effects from fire retardants.

Many of these effects are not well defined or monetized. (Focused on California, CCST (2020) provides a discussion on some of these categories and others.)

5.2.4 MAGNITUDES, GAPS, AND UNCERTAINTY

Table 5-2 shows estimated magnitudes of value of the costs and losses and levels of uncertainty in their measurement or ability to measure at a national scale [reproduced from Thomas et al. (2017)]. The estimated magnitudes and uncertainties were based on the values found in the report, and where not available, were estimated using expert judgment of the report authors. The largest cost and loss categories were fuel treatments and defensible space, suppression, economic value of deaths and injuries, evacuation costs, and effects on the housing market. The largest sources of uncertainty tended to be indirect economic effects, insurance, and some of the cross-cutting categories (e.g., building codes and standards, regulations).

Although there is significant literature detailing components of the costs and losses associated with wildland fire, producing an annual national estimate, which could be tracked over time to evaluate management success, is difficult at this time without introducing large sources of uncertainty in the estimates. However, it does appear that the economic burden from wildland fire is increasing over time.

Table 5-2 Magnitude and uncertainty associated with the economic burden of wildfire at the national level.

	Order of Magnitude	Uncertainty
Costs		
Preparedness	$$$$	?
Mitigation		
Fuels management		
Fuel treatments (Rx fire, thinning)	$$$	?
Defensible space/firewise	$$$$	???
Insurance	$$	????
Disaster assistance	$	??
Suppression		
Fire departments (labor, equipment, training)		

Table 5-2 (Continued): Magnitude and uncertainty associated with the economic burden of wildfire at the national level.

	Order of Magnitude	Uncertainty
Federal	$$$$	?
State	$$$$	?
Municipal (professional)	$$$$	???
Rural (volunteer)	$$$$	???
Cross-cutting		
Legal		
Prosecution	$$	??
Incarceration	$$$	??
Civil/liability	$$	????
Science/research and development	$$	???
Building codes and standards	$$	????
Regulations (e.g., zoning)	$$	????
Losses		
Direct		
Deaths and injuries (civilian and firefighter)	$$$$	??
Psychological effects (PTSD)	$$	???
Structure and infrastructure loss	$$$	???
Environmental impact	$$$	????
Habitat and wildlife loss	$$	????
Timber loss	$$$$	???
Agriculture loss	$$$	????
Remediation/cleanup	$$	???
Indirect		
General economic impacts (business interruption, tourism, supply chain)	$$$	????
Evacuation costs	$$$$	???

Table 5-2 (Continued): Magnitude and uncertainty associated with the economic burden of wildfire at the national level.

	Order of Magnitude	Uncertainty
Accelerated economic decline of community	$$$	????
Utility and pipeline interruption (electricity, gas, water, oil)	$$$	????
Transportation interruption (e.g., roads and rail)	$$	????
Government service interruption (including education)	$$	????
Psychological effects (loss of natural amenities)	$$	????
Housing market impact (loss due to fire risk)	$$$$	???
Loss of ecosystem services (e.g., watershed/water service)	$$$	????
Increased risk of other hazards (e.g., mudslide, invasive species)	$$$	????
Decrease in tax base (structure loss or decline in value of structure)	$$$	???
Decrease in government services	$$$	????
Health/environmental effects from use of fire retardants/suppressants	$$$	????

PTSD = post-traumatic stress disorder; Rx = prescribed.

Note: Classification of “order of magnitude”: $ = <millions; $$ = 10s millions; $$$ = 100s millions; $$$$ = billions; “uncertainty”: ? = low; ?? = medium; ??? = high; ???? = unknown.

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