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A Literature Review

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National Institute of
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Applied Economics Office
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Photo Credit: Lake City, Fla., May 15, 2007 -- The Florida Bugaboo Fire still rages out of control in some locations. FEMA Photo by Mark Wolfe - May 14, 2007 - Location: Lake City, FL: https://www.fema.gov/media-library/assets/images/51316

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Abstract

This report enumerates all possible costs of wildfire management and wildfire-related losses. It, further, compiles estimates or proposes methods for estimating the costs and losses identified. These estimates can be used for C+NVC (cost plus net value change) modeling, and can also be used to produce an estimate of the 'economic burden' of wildfire for the United States. The economic burden represents the impact wildfire has on the U.S. economy. Tracking the economic burden of wildfire could be used to assess return-on-investment into wildfire interventions. The economic burden is decomposed into: 1. intervention costs; 2. prevention/preparedness, mitigation, suppression, and cross-cutting; 2. and into direct and indirect wildfire related (net) losses. The annualized economic burden from wildfire is estimated to be between $71.1 billion to $347.8 billion ($2016 US). Annualized costs are estimated to range from $7.6 billion to $62.8 billion. Annualized losses are estimated to range from $63.5 billion to $285.0 billion.

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1. Introduction: The Economics of Wildland/WUI Fire Management

The economics of wildfire, particularly the idea of efficient wildfire management, is not new. Headley introduced the discussion of the effectiveness, efficiency, and waste of effort in relation to fire suppression.[1] Sparhawk presented his (graphical) economic 'cost plus loss' (C+L) model depicting the tradeoff between primary protection (e.g., prevention and pre-fire suppression expenditures), suppression cost, and wildfire losses.[2] The C+L model illustrates that primary protection expenditures can be chosen to minimize the sum of the primary protection expenditures plus the ensuing 'total liability' (suppression costs plus wildfire losses) of wildfire management. The minimum is optimal because for any other combination of primary protection expenditures, more will be spent on management and/or lost to fire damage.

The C+L model has been revised several times (e.g., Gorte 2013 and Gorte, 1979).[3, 4] Simard recognizes that some impacts from wildfire can be beneficial (e.g., ecological benefits).[5] The modern C+L model has been since replaced by the 'cost plus net value change' or 'C+NVC' model.[6] Donovan and Rideout reformulate Sparhawk's original C+L model to allow for both primary protection ('presuppression') and suppression to be independent inputs into the C+NVC model.[7] (Only primary protection is independent in the Sparhawk model.)

Figure 1.1 depicts the Donovan and Rideout C+NVC model. For illustration purposes, presuppression expenditures are held constant; thus, as suppression expenditures increase, NVC (net damage) falls. (Alternatively, the figure could be generated holding suppression constant and allowing presuppression to vary.) Summing presuppression, suppression, and NVC, produces the C+NVC line. The minimum of the C+NVC line corresponds with the optimal level of suppression (point A) – i.e., the level of suppression that minimizes the cost plus net value change (net damage) of wildland/WUI fire. Increases in spending on suppression beyond point A (to the right) are not fully offset by the reduction in net damages. Decreases in spending below point A (to the left) result in increases in net damages that exceed the savings in suppression.

While the graphical depiction of the C+NVC is useful for illustration, it is less so for identifying the minimum C+NVC when presuppression expenditures are allowed to remain unconstrained.

[1] Headley, R. 1916. "Fire Suppression District 5." USDA Forest Service. Washington, DC. 58 pages.
[2] Sparhawk, W.N. 1925. "The Use of Liability Ratings in Planning Forest Fire Protection." Journal of Agricultural Research 30(8):693-792.
[3] Gorte, Ross. 2013. "The Rising Cost of Wildfire Protection," Headwater Economics.
[4] Gorte, J.K., and R.W. Gorte. 1979. "Application of Economic Techniques to Fire Management—A Status Review and Evaluation." USDA Forest Service Technical Report. INT-53. 26 pages.
[5] Simard, A.J. 1976. "Wildland Fire Management: The Econoimcs of Policy Alternatives." Canadian Forest Service Technical Report 15. Ottawa, Ontario. 52 pages.
[6] Rideout, D.B., and P.N. Omi. 1990. "Alternative Expressions for the Economic Theory of Forest Fire Management." Forest Science 36(3): 614-624.
[7] Rideout, D.B., and P.N. Omi. 1990. "Alternative Expressions for the Economic Theory of Forest Fire Management." Forest Science 36(3): 614-624.

Mathematically, the C+NVC model, adapted from Donovan and Rideout,[8] can be written as:

Equation 1

$$MIN: C + NVC = \sum_{i=1}^{I}\sum_{j=1}^{J}\sum_{k=1}^{K} w_i^p p_i + w_j^s s_j + f_k(p_i, s_j)$$

where the *w*'s are unit prices, *p* is presuppression, *s* is suppression, *i* indexes presuppression activities, *j* indexes suppression activities, and *f*() is the set of *k* net value change (net damage) functions, which depend on presuppression and suppression.

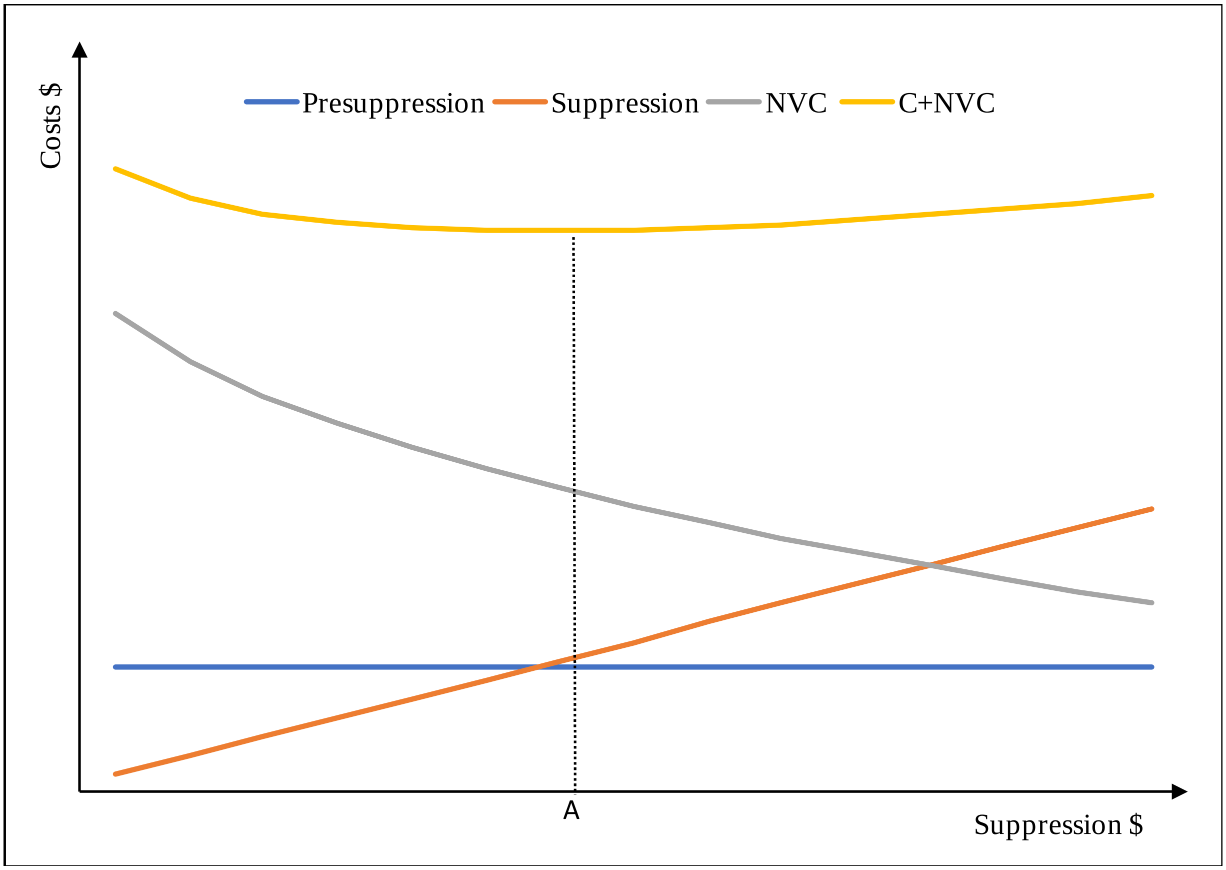

Figure 1.1: Donovan and Rideout C+NVC Model

The first-order conditions to minimize C+NVC are:

Equation 2

$$\frac{\partial(C + NVC)}{\partial p_i} = w_i^p + \frac{\partial f_k(p_i, s_j)}{\partial p_i} = 0,$$

[8] Donovan, G.H., and D.B. Rideout. 2003. "A Reformulation of the Cost Plus Net Value Change (C+NVC) Model of Wildfire Economics." Forest Science 49(2): 318-323.

and

$$\frac{\partial(C + NVC)}{\partial s_i} = w_i^s + \frac{\partial f_k(p_i, s_j)}{\partial s_i} = 0.$$

Therefore, optimality conditions imply:

Equation 3

$$-\frac{\partial f_k(p_i, s_j)}{\partial p_i} = w_i^p,$$

and

$$-\frac{\partial f_k(p_i, s_j)}{\partial s} = w_i^s.$$

Thus, C+NVC is minimized when the marginal benefit from reducing net damages from wildfires equals the unit price (i.e., marginal cost) of intervention. Again, as was the case with the graphical depiction, at the optimal level of intervention, any increase in intervention will not be fully offset by additional avoided damages, while decreases result in damages in excess of the expenditure savings.

Two challenges exist that make identification of the optimal levels of intervention difficult to determine. First, an understanding of the functional relationship between fire interventions and the resulting net damages is needed. Second, measuring all possible interventions, their unit prices (costs), and the damages related to wildland/WUI fires is a significant effort, regardless of scale (e.g., national, state, community). This latter concern is the primary focus of this report.

Another issue is the scale of analysis is not often discussed in the C+NVC literature. Sparhawk (1925) focuses on individual national forests. Although substantially more complex, the C+NVC could be applied more broadly (e.g., United States). An advantage of a smaller scale analysis is the lower data requirement. For a national forest or WUI community, the comprehensive dataset required may be easier to obtain. However, representing the functional relationship between costs and the net damages (NVC), for a specific area, might be difficult. An advantage of a larger scale analysis is the availability of more data to parameterize the net damage equation (*f*() above). A smaller scale analysis may also fail to account for spatial externalities—impacts to third parties outside the analysis area. Methodologically, however, the C+NVC model is appropriate for a variety of spatial scales.

1.1. Wildfire Production (Net Damage) Functions

While not a focus of this report, there exists a relatively broad range of literature that has examined the relationship between wildfire behavior and factors, including climate and weather, topography, land use and land cover, socio-economics and demographics, fire weather indices, fuel treatment, other wildland/WUI management interventions, law enforcement, and locational characteristics (e.g., distance to road). Table 1.1 provides a summary of a sample of the literature. The sample is not exhaustive; rather, it is meant to provide representation of the types of studies previously undertaken.

Based on Table 1.1, the majority of the literature is focused on understanding wildfire occurrence (e.g., likelihood of ignition – see Grala et al., 2012) and wildfire extent (e.g., acres burned – see Syphard et al., 2008). A few have accounted for wildfire flame intensity (e.g., Mercer et al., 2007), wildfire burned area size distribution (e.g., Moreira et al., 2010), ignition density (e.g., Ganteaume and Long-Fournel, 2015), and structure loss (e.g., Ager et al., 2010). Very few studies have considered economic, as opposed to physical, measures of loss. Prestemon et al. (2008) and Hesseln et al. (2010) evaluated suppression costs and firefighting expenditures. While not a loss function, but also included in Table 1.1, are examples of production functions focused on fireline (suppression) production (e.g., Holmes and Calkin, 2013).

Across the literature, the study periods and study areas are varied. Few comparisons have been made to assess the generalizability of findings, although some survey papers exist (e.g., Thompson and Calkin, 2011). In terms of modeling the effect of wildfire management interventions, fuel treatments are the most common (Fernandes and Botelho, 2003, provide an overview of the literature), while studies focusing on suppression (e.g., Butry, 2009) and prevention (e.g, Abt et al., 2015) are fewer.

Table 1.1: Summary of the Wildfire Damage Function Literature

Wildfire Measure	Study Area	Study Type	Factors Examined	Source
Occurrence	US Bureau of Indian Affairs tribal units; 1996 to 2011	Empirical	Prevention program, law enforcement, weather, fire weather indices, previous wildfire activity	Abt et al., 2015
Occurrence, Extent	Ft. Benning, GA; 1982 to 2012	Empirical	Fuel treatments, fire weather index, previous wildfire activity	Addington et al., 2015.
Extent, flame length, structure loss	Blue Mountains province, OR	Simulation	Fuel treatments	Ager et al., 2010
Occurrence	Carranglan, Nueva, Ecija, Philippines; 2002 to 2014	Empirical	Topography, weather, location, land cover	Ancog et al., 2016
Occurrence, extent	Galicia, Spain; 2001 to 2010	Empirical	Weather, socio-economic, land cover, forest protection	Barreal and Loureiro, 2015
Occurrence	Mark Twain National Forest, MO; 1986 to 2002	Empirical	Topography, land cover, weather, location, socio-economic	Brosofske et al., 2007
Occurrence	Bariloche, Argentina; 2002 to 2005	Empirical	Socio-economic	Bühler, et al., 2013
Flame intensity-weighted extent	St. Johns River Water Management District, FL; 1996 to 2001	Empirical	Suppression, fuel treatment, weather, fire weather indices, land cover, previous wildfire activity, ignition cause	Butry, 2009
Occurrence	San Carlos de Bariloche, Patagonia, Argentina; 2001 to 2005	Empirical	Socio-economic, land cover	Curth et al., 2012
Occurrence, Extent	Administrative Region of Ligura, Italy and Alachua Country, FL	Simulation	Land cover, previous wildfire activity	D’Andrea et al., 2010
Intensity, extent, damage	Various	Literature Review	Fuel treatment	Fernandes and Botelho, 2003
Occurrence, reoccurrence	Portugal; 1981 to 2010	Empirical	Topography, weather, socio-economic, land cover	Ferreira-Leite et al., 2016
Occurrence density	South-eastern France; 1960 to 2011	Empirical	Socio-economic, land cover, topography, weather	Ganteaume and Long-Fournel, 2015
Occurrence	Mississippi; 1991 to 2005	Empirical	Socio-economic, location	Grala et al., 2017
Occurrence density	Canada; 1980 to 2006	Empirical	Location	Gralewicz et al., 2012
Occurrence	United States; 2000 to 2006	Empirical	Land cover, weather, topography, socio-economic	Hawbaker et al., 2013

Suppression costs, firefighting expenditures, extent, fire duration	Northern Rocky Mountains; 2000 to 2003	Empirical	Suppression, geospatial technology, topography, wildfire factors	Hesseln et al., 2010
Fireline	United States; 2008	Empirical	Suppression input, weather, fire factors	Holmes and Calkin, 2013
Fireline	United States; 2010 to 2011	Empirical	Suppression input, weather, fire factors, previous wildfire activity, land cover	Katuwal et al., 2016
Non-specific	Non-specific	Theoretical	Suppression	Mendes, 2010
Flame intensity-weighted extent, extent	Volusia County, FL; 1981 to 2001	Empirical, Simulation	Fuel treatment, previous wildfire activity, timber removal, socio-economic, climate	Mercer et al., 2007
Occurrence, flame intensity-weighted extent, extent	Florida; 1981 to 2001	Empirical	Fuel treatment, previous wildfire activity, socio-economic, climate	Mercer and Prestemon, 2005
Various	Various	Literature Review	Various	Miller and Ager, 2013
Size distribution	Portugal; 2001 to 2003	Empirical	Land cover, demographics	Moreira et al., 2010
Occurrence	Western United States; 1980 to 2004	Empirical	Weather, climate, fire weather indices	Preisler and Westerling, 2007
Occurrence	Various Locations, Florida; 1994 to 2001	Empirical	Law enforcement, socio-economic, previous wildfire activity, fuel treatment, fire weather indices	Prestemon and Butry, 2005
Extent	Florida; 1995 to 1999	Empirical	Previous wildfire activity, fuel treatment, timber removal, climate, socio-economic	Prestemon et al., 2002
Suppression costs	United States; 1997 to 2006	Empirical	Climate, fire weather indices	Prestemon et al., 2008
Extent	Southeastern United States; 1992 to 2010	Empirical	Weather, land cover, socio-economic	Prestemon et al., 2016
Occurrence, extent	California; 1960 to 2000	Empirical	Socio-economic, land cover, previous wildfire activity	Syphard et al., 2007
Occurrence	Santa Monica Mountains, CA; 1925 to 2003	Empirical	Topography, location, weather, land cover	Syphard et al., 2008
Various	Various	Literature Review	Various	Thompson and Calkin, 2011
Extent	Southern Sierra, CA	Simulation	Fuel treatment	Wei et al., 2008
Extent	Ozarks Highlands, MO	Simulation	Land cover, topography, location, demographic	Yang et al., 2008

1.2. Purpose

The purpose of this report is to enumerate all possible costs of wildfire management and wildfire-related losses. The report compiles estimates or propose methods for estimating costs and losses to produce an accounting that can 1) be used for C+NVC modeling and 2) produce an estimate of the 'economic burden' of wildfire for the United States.[9] The economic burden represents the impact wildfire has on the U.S. economy. Tracking the economic burden of wildfire could be used to assess the return-on-investment into wildfire interventions.

1.3. Scope and Approach

The categories of costs and (net) losses from wildfire are shown in Table 1.2 and Table 1.3 **below**. Costs are categorized into 1. **Prevention**, 2. **Mitigation**, 3. **Suppression**, and 4. **Cross-Cutting** (i.e., those categories that fit within multiple categories). Losses are categorized into 1. **Direct** and 2. **Indirect** categories. The costs and losses are mapped to the responsible stakeholders who bear the economic burden. The stakeholders are separated into: 1. **Homeowners**, 2. **Government/Tax-Payers**, 3. **Citizens/Consumers/Occupants**, 4. **Firefighters, and 5. Fire Departments**, 6. **Local Business Owners**, 7. **Suppliers**, **Local Employees**, and 8. **Standards and Code Organizations**. Of course, these stakeholder groups are not mutually exclusive. For example, a homeowner might also be a tax payer and building occupant.

Table 1.2 and Table 1.3 were the basis for a literature and data survey. The findings of those are summarized in Sections 2 and 3. These sections present what is known along with the values that are currently still unknown. Section 4 summarizes the total costs and losses. Section 5 summarizes the current data gaps and unknown values.

[9] Throughout this report, the term 'wildfire' is used generally to include both wildland and wildland-urban interface (WUI) fires, unless otherwise noted.

Table 1.2: The Costs Associated with Wildfire Management by Responsible Stakeholder

Who Bears the Cost?	Homeowners	Gov't / Tax payers	Citizens/ Consumers/ Occupants	Firefighters and Fire Department	Local Business Owners	Suppliers	Local Employees	Standard and Code Organizations
Costs								
Prevention								
Education & Training		x		x				
Detection		x	x	x				
Enforcement / Policing / Patroling / Permitting / Inspections		x		x				
Equipment (e.g., Spark Arrestor, Child-Proof Lighter)	x	x	x					x
Mitigation								
Fuels Management		x						
Fuel treatments (Rx fire, thinnings)		x						
Defensible Space / Firewise	x				x			
Environmental Impact (Smoke, Landscape modification)			x					
Insurance	x				x			
Disaster Assistance		x						
Suppression								
Fire Departments (Labor, Equipment, Training)		x						
Federal		x		x				
State		x		x				
Municipal (Professional)		x		x				
Rural (Volunteer)		x		x				
Cross-Cutting								
Legal								
Prosecution		x						
Incarceration		x						
Civil / Liability	x	x	x		x			
Science / Research & Development		x		x				x
Building Codes & Standards	x	x			x			
Regulations (e.g., Zoning)	x	x	x		x			

Table 1.3: The Value Change (Net Losses) From Wildfire by Responsible Stakeholder

Who Bears the Cost?	Homeowners	Gov't / Tax payers	Citizens/ Consumers/ Occupants	Firefighters and Fire Department	Local Business Owners	Suppliers	Local Employees	Standard and Code Organizations
Losses								
Direct								
Deaths and Injuries (Civilian and Firefighter)			x	x				
Psychological Impacts (PTSD)			x	x				
Structure and Infrastructure Loss	x	x	x		x			
Environmental impact		x	x					
Habitat & Wildlife loss		x	x					
Timber Loss			x		x			
Agriculture Loss			x		x			
Remediation/cleanup	x	x			x			
Indirect								
General Economic Impacts (Business Interruption, Tourism, Supply Chain)		x	x		x	x	x	
Evacuation Costs	x	x	x	x	x		x	
Accelerated Economic Decline of Community		x	x		x		x	
Utility and Pipeline Interruption (Elec, Gas, Water, Oil)		x	x		x			
Transportation interruption (e.g., Roads and Rail)		x	x		x	x		
Government Service Interruption (inc. Education)	x	x	x		x			
Psychological Impacts (Loss of Natural Amenities)	x		x					
Housing Market Impact (Loss Due to Fire Risk)	x							
Interference with military operations		x						
Loss of Ecosystem Services (e.g., Watershed/Water Service)		x	x					
Increased Risk of Other Hazards (e.g., mudslide, invasive species)		x	x	x				
Decrease in Tax Base (Structure Loss or Decline in Value of Structure)		x						
Decrease in Government Services	x	x	x	x	x	x	x	
Health/Environmental Impacts from Use of Fire Retardants / Suppressants		x	x					

2. The Costs Associated with Wildfires

Wildfires occurring near urban areas threaten lives and property. The risk that they pose spurs communities to prevent or reduce the resulting damage. This chapter discusses the costs of the actions taken to reduce losses and health impacts of wildfires. It discusses prevention, mitigation, suppression and costs that cut across a number of categories. Prevention includes items such as education and detection while mitigation includes items such as fuels management and disaster assistance. The cross-cutting category includes several items, including legal costs, research, building codes, and regulations. Each section has a subsection labeled “Unknown” that discusses what is unknown about this cost/loss. Some cost categories have more details available than others; therefore, more discussion is warranted. For example, preparedness has limited data available, so only a short section is devoted to it. Mitigation has much more information available, so there are multiple subsections within the mitigation section.

2.1. Preparedness

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 “any activity that leads to a safe, efficient, and cost-effective fire management program, and includes the range of tasks necessary to build, sustain, and improve the capability to protect against, respond to, and recover from domestic incidents.”[10] In FY2015, preparedness spending exceeded $1.4 billion dollars, split between US Forest Service (78 %) and the Department of Interior (22 %).[11] Preparedness does not include hazardous fuels management.

Unknown: The data on preparedness is not complete; thus, the total cost is unknown. Estimates similar to those at the federal level are not available for state and local governmental agencies.

2.2. Mitigation

Mitigation is the action of reducing the severity of the impact from a fire. For wildfires, mitigation actions include fuels management, insurance, and disaster assistance. The following sections discuss the costs associated with mitigation.

2.2.1. Fuels Management

Fuels management includes two different sets of costs. The first cost is the implementation of defensible space, an area around a structure designed to reduce fire

[10] Hoover, Katie and Kelsi Bracmort. 2015. “Wildfire Management: Federal Funding and Related Statistics,” Congressional Research Service, R43077.
[11] Ibid

ignition and spread. The second is in-forest fuels management, including controlled burns.

There is a growing body of literature looking at qualitative factors that impact whether people engage in defensible space behaviors. Much of the literature is aimed at identifying who implements defensible space measures and understanding the barriers to implementing them. Several studies[12,13,14] survey residents along the front range in Colorado and ask whether they have implemented defensible space measures, their intentions to do so, and barriers to implementing such measures. They found that a majority of survey respondents had implemented the measures and the most commonly cited barrier to implementation was cost. However, a few listed aesthetics as a barrier as well: in one study[15] some 11 % thought that defensible space measures would make their property look worse; some 20 % considered aesthetics to be either a moderate or extreme barrier to implementing defensible space measures; and 26 % felt that privacy considerations were either a moderate or extreme barrier.

A similar effort in Oregon[16] attempted to identify the extent to which beliefs in climate change affect participation in defensible space behaviors. That study found that “the belief that climate change caused wildfires made one more likely to participate in Firewise behaviors, and the relationship between beliefs and behaviors was partially mediated by risk perception.”

McCaffrey[17] in her review of the literature found that typically a majority of people surveyed in the WUI had implemented defensible space measures. The notable exception to that was California which was the only state with active defensible space ordinances and where the participation rate was 91 %. She observed that beliefs about effectiveness were strong predictors of participation. She also observed a strong association between familiarity and acceptance, an association she interpreted as causal.

The only study that estimated the costs of defensible space mitigation measures looked at the cost-effectiveness of mitigation measures at the foot of the Bitterroot Mountains in

[12] Absher, James D., Jerry J. Vaske, and Katie M. Lyon. 2013 “Overcoming Barriers to Firewise Actions by Residents. Final Report to Joint Fire Science Program,” http://www.treesearch.fs.fed.us/pubs/44796.
[13] Absher, James D., Jerry J. Vaske, and Lori B. Shelby. 2010. *Residents’ Responses to Wildland Fire Programs: A Review of Cognitive and Behavioral Studies*. DIANE Publishing.
[14] Kyle, Gerard T., Gene L. Theodori, James D. Absher, and Jinhee. 2010. “The Influence of Home and Community Attachment on Firewise Behavior.” *Society & Natural Resources.* 23(11): 1075-1092.
[15] Absher, James D., Jerry J. Vaske, and Katie M. Lyon. 2013. “Overcoming Barriers to Firewise Actions by Residents. Final Report to Joint Fire Science Program.” http://www.treesearch.fs.fed.us/pubs/44796.
[16] Wolters, Erika Allen, Brent S. Steel, Daniel Weston, and Mark Brunson. 2017 “Determinants of Residential Firewise Behaviors in Central Oregon.” *The Social Science Journal*. 54(2): 168-178.
[17] McCaffrey, Sarah. “Crucial Factors Influencing Public Acceptance of Fuels Treatments.” 2009. http://www.treesearch.fs.fed.us/pubs/download/36075.pdf.

Montana.[18,19] That study estimated the costs of a variety of mitigation measures "in consultation with fire hazard reduction professionals local to the study area." Thomas and Butry estimate for the 2001 to 2010 decade that there were on average 3.2 million residential structures at risk of wildfire annually.[20] Assuming that each of these structures required 0.366 acres of defensible space (the average lot size for a new home[21]); that 91 % of the structures have implemented defensible space, as seen in California; and that Montana estimates apply nationally, the cost would be between $1.7 billion and $53.3 billion to comply with FireWise.

Cost estimates to convert different terrains are listed in Table 2.1. At the federal level, US Forest Service and the Department of Interior spent $532.3 million on hazardous fuel treatments in FY2015.[22] Over 83 000 prescribed fires treated four million acres in 2015.[23]

Unknown: It is not known to what extent these estimates for Western Montana are applicable to the rest of the WUI. It is also not known how much land of each type must be modified each year.

2.2.2. Insurance

The cost of insurance has typically been calculated as the difference between premiums paid in and claims paid out.[24] Insurance is a system where funds are pooled to pay for the losses that occur among the insured. The cost of insurance, that is, the amount not paid back to the insured, is the overhead costs. That would include employees' wages, underwriting expenses, administrative expenses, taxes, real-estate expenses, legal expenses, and cost of capital.

Supply for insurance is determined by the amount of reserves that insurance providers have—the reserves ensure that the insurance providers have the resources available to cover any claims that may be received. The levels of reserves required for a given level of supply will depend on the variability in the amount of claims. Insurance lines with low variance will require fewer reserves than insurance lines with high variance. In particular,

[18] Stockmann, Keith. 2007. "A Cost Effectiveness Analysis of Preventative Mitigation Options for Wildland Urban Interface Homes Threatened by Wildfire." *Graduate Student Theses, Dissertations, & Professional Papers*. http://scholarworks.umt.edu/etd/260.
[19] Stockmann, Keith, James Burchfield, Dave Calkin, and Tyron Venn. 2010. "Guiding Preventative Wildland Fire Mitigation Policy and Decisions with an Economic Modeling System." *Forest Policy and Economics*. 12(2): 147-154.
[20] Thomas, Douglas and David Butry. 2014 "Areas of the US Wildland-Urban Interface Threatened by Wildfire During the 2001-2010 Decade." Natural Hazards. 71(3): 1561-1585.
[21] US Census Bureau. Characteristics of New Single-Family Houses Sold. 2017. https://www.census.gov/construction/chars/pdf/soldlotsize.pdf
[22] Hoover, Katie and Kelsi Bracmort. "Wildfire Management: Federal Funding and Related Statistics," 2015. Congressional Research Service, R43077.
[23] National Interagency Fire Center. "Prescribed Fires and Acres by Agency." https://www.nifc.gov/fireInfo/fireInfo_stats_prescribed.html. Accessed 10 July 2017.
[24] Hall, John R. *The Total Cost of Fire in the United States*. National Fire Protection Association. 2014.

Table 2.1: Estimated costs to convert different types of terrain to comply with FireWise requirements are listed in Table 1. This table is modified from Stockmann, 2007 (Figure 15).

	$/16ft^2	cells/acre	$/acre	$/100ft^2
Surface Litter	$ 0.50	2722.5	$ 1,361.25	$ 3.13
Short Grass	$ 3.50	2722.5	$ 9,528.75	$ 21.88
Medium Grass	$ 5.00	2722.5	$ 13,612.50	$ 31.25
Tall Grass	$ 5.50	2722.5	$ 14,973.75	$ 34.38
Shrubs (0-5)	$ 3.00	2722.5	$ 8,167.50	$ 18.75
Shrubs (5-20)	$ 3.50	2722.5	$ 9,528.75	$ 21.88
Shrubs (20+)	$ 5.00	2722.5	$ 13,612.50	$ 31.25
Underbrush	$ 6.00	2722.5	$ 16,335.00	$ 37.50
Trees (0-20)(1)	$ 8.00	2722.5	$ 21,780.00	$ 50.00
Trees (0-20) Multiple	$ 8.50	2722.5	$ 23,141.25	$ 53.13
Trees (21-40)(1)	$ 9.00	2722.5	$ 24,502.50	$ 56.25
Trees (21-40) Multiple	$ 9.50	2722.5	$ 25,863.75	$ 59.38
Trees (41-60)(1)	$ 10.00	2722.5	$ 27,225.00	$ 62.50
Trees (41-60) Multiple	$ 10.50	2722.5	$ 28,586.25	$ 65.63
Trees (61-80)(1)	$ 11.00	2722.5	$ 29,947.50	$ 68.75
Trees (61-80) Multiple	$ 11.50	2722.5	$ 31,308.75	$ 71.88
Trees (80+)(1)	$ 15.00	2722.5	$ 40,837.50	$ 93.75
Trees (80+) Multiple	$ 16.00	2722.5	$ 43,560.00	$ 100.00
Wood Pile (chopped)	$ 4.00	2722.5	$ 10,890.00	$ 25.00
Wood Pile (bucked)	$ 3.00	2722.5	$ 8,167.50	$ 18.75
Wood Pile (logs)	$ 10.00	2722.5	$ 27,225.00	$ 62.50
Debris Pile	$ 1.50	2722.5	$ 4,083.75	$ 9.38

insurance lines subject to occasional catastrophes will require much higher levels of reserves than lines with more stable streams of claims.

For example, consider two hypothetical insurance lines. In the first line 10 % of the insured exposure is paid out in claims every year. In the second line, nine years out of ten no claims are paid, but one year out of ten 100 % of the insured exposure is paid out in claims. The average claim paid per year for each insurance line is the same. But in the case of the first line, the insurers must maintain sufficient reserves to be able to pay out 10 % of their exposure each year, while in the second case they must maintain sufficient reserves to be able to pay out 100 % of their exposure in any given year.

Wildfire can result in catastrophes that significantly affect local populations. For example, in California the number of structures destroyed in wildland fires between 2001 and 2015 range from 94 in 2010 to 5394 in 2003.[25]

[25] California Department of Forestry and Fire Protection. *2015 Wildfire Activity Statistics.* 2016.

There are a number of insurance markets that are exposed to wildland fire. These include: homeowners insurance, commercial insurance, automobile insurance,[26] health and life insurance. Regarding health and life insurance, there is a growing literature identifying health effects from smoke from wildland fires.[27, 28, 29, 30] The consensus of the literature is that smoke from wildland fires has deleterious effects on the health of people exposed to it, but the severity of that effect is still not well understood.

Unknown: There are a number of unknowns involved with estimating the cost of insuring against wildfire risk.

- It is not clear how much of the cost (and claims) for each policy line is attributable to fire. Hall estimates that 21% of multiple-peril homeowners policies are attributable to fire.[31] No such estimates exist for other lines.

- It is not clear how much of the cost of each policy is attributable to *wildfire*.

The main data source for aggregate information on the insurance industry is the National Association of Insurance Commissioners. Two sources used here are the *"Dwelling Fire, Homeowners Owner-Occupied, and Homeowners Tenant and Condominium/Cooperative Unit Owner's Insurance Report*[32] and the *Statistical Compilation of Annual Statement Information for Property/Casualty Insurance Companies*.[33]

2.2.3. Disaster Assistance

In November of 2016, a wildfire broke out in the Great Smoky Mountain National Park, Tennessee. This fire killed 14 people and destroyed 2400 homes.[34] This wildfire, like many others, resulted in a disaster declaration by the president[35], which resulted in the disbursement of taxpayer funds to residents and businesses for recovery efforts. When

[26] Ibid
[27] Henderson, Sarah B., and Fay H. Johnston. 2012. "Measures of Forest Fire Smoke Exposure and Their Associations with Respiratory Health Outcomes:" *Current Opinion in Allergy and Clinical Immunology* 12(3): 221–27. doi:10.1097/ACI.0b013e328353351f.
[28] Kochi, Ikuho, et al. 2012. "Valuing Mortality Impacts of Smoke Exposure from Major Southern California Wildfires." *Journal of Forest Economics* 18(1): 61–75.
[29] Kochi, Ikuho, et al. 2010. "The Economic Cost of Adverse Health Effects from Wildfire-Smoke Exposure: A Review." *International Journal of Wildland Fire*. 19(7): 803. doi:10.1071/WF09077.
[30] Richardson, L. A., P. A. Champ, and J. B. Loomis. 2012. "The Hidden Cost of Wildfires: Economic Valuation of Health Effects of Wildfire Smoke Exposure in Southern California." *Journal of Forest Economics.* 18(1): 14–35.
[31] Hall, John R. 2014 The Total Cost of Fire in the United States. National Fire Protection Association. http://www.nfpa.org/news-and-research/fire-statistics-and-reports/fire-statistics/fires-in-the-us/overall-fire-problem/total-cost-of-fire
[32] National Association of Insurance Commissioners. 2017 *"Dwelling Fire, Homeowners Owner-Occupied, and Homeowners Tenant and Condominium/Cooperative Unit Owner's Insurance Report: Data for 2014."*
[33] National Association of Insurance Commissioners. *"Statistical Compilation of Annual Statement Information for Property/Casualty Insurance Companies in 2015."* 2017.
[34] Satterfield, Jamie. 2016. "Teens toying with matches started Tennessee wildfire," USA Today, Dec 9. http://www.usatoday.com/story/news/nation-now/2016/12/09/sources-teens-toying-matches-started-tennessee-wildfire/95223326/
[35] FEMA. "Tennessee Wildfires (DR-4293)." https://www.fema.gov/disaster/4293

estimating these costs, it is important to consider the possibility of double-counting. For instance, FEMA disaster assistance can be used for several resilience-related items, including: 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 FEMA. Potentially, one might double-count the costs and losses of a wildfire by adding losses and disaster assistance together.

National disaster assistance costs can be ascertained from FEMA's monthly report, which is published on the 5th of each month. It provides predicted obligations and actual obligations.[36] The FEMA website also provides a searchable database of disaster declarations by year and disaster type.[37] In 2016, there were 37 disaster declarations related to fire with FEMA indicating that seven resulted in public assistance:

- California Blue Cut Fire $11 266.61
- California Clayton Fire: $20 929.88
- California Pilot Fire: $15 896.71
- California Sand Fire: $13 825.73
- California Erskine Fire: $185 295.00
- California Border 3 Fire: $54 309.01
- Kansas Anderson Creek Fire: $1 249 825.60

According to the FEMA values, a total of $1.551 million in public assistance was disbursed for fire disaster declarations occurring in 2016. Note that funds can be disbursed in years following a disaster.

Unknown: Despite the tracking of federal disaster declarations, there are some unknowns regarding disaster assistance costs. State and local governments might also be contributing disaster assistance. At this time, these costs do not appear to be available in an aggregated form, making it difficult to estimate the total.

2.3. Suppression

At the federal level, in FY2015, suppression spending exceeded $1.0 billion dollars, split between US Forest Service (70 %) and the Department of Interior (30 %), with FLAME account appropriations (i.e., wildfire suppression reserve accounts) adding another $383 million.[38] The Federal Land Assistance, Management, and Enhancement Act of 2009 (FLAME Act) provides for emergency funding for wildfire suppression.[39] Related is

[36] FEMA. "Disaster Relief Fund: Monthly Report," https://www.fema.gov/media-library/assets/documents/31789
[37] FEMA. Disaster Declarations, https://www.fema.gov/disasters
[38] Hoover, Katie and Kelsi Bracmort. 2015. "Wildfire Management: Federal Funding and Related Statistics," Congressional Research Service, R43077.
[39] Forests and Rangelands. "The Federal Land Assistance, Management and Enhancement Act of 2009 Report to Congress." https://www.forestsandrangelands.gov/strategy/documents/reports/2_ReportToCongress03172011.pdf.

another $130 million in wildfire management accounts not explicitly labeled for suppression, preparedness, fuel treatment, or rehabilitation purposes. State suppression expenditures are estimated at $1 to $2 billion a year.[40]

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 2013, it is estimated that career fire department expenditures amounted to $41.9 billion, and the value of volunteer (rural) fire departments is estimated at $94.9 billion.[41] Based on call volume (31.6 million calls) and on National Fire Incident Reporting System (NFIRS) data from 2013 (0.6 % of all calls), natural vegetation fires comprised 19 % of all fire incidents. This yields an estimate of $2.1 billion after adjusting to 2016 dollars, but it should be noted this would include suppression and preparedness-type activities. Note that wildfires tend to occur in more rural areas, which may have a lower participation rate for data reporting. This tendency may underestimate the number of incidents involving wildfires when using NFIRS data.

Unknown: Although an estimate for suppression at the municipal level can be estimated, the actual value is unknown.

2.4. Cross-Cutting

There are several costs that cut across various organizations and categories. These include legal costs, research, and regulations. The following sections discuss these costs.

2.4.1. Legal

The wildfire at Great Smoky Mountain National Park in 2016 was set by teens who were latter charged with arson.[42] The prosecution and defense of individuals such as these along with the associated law enforcement, result in both individual and government costs. If an individual is convicted, there can also be costs of incarceration. Additionally, civil court cases for liability incur additional costs. The motivation for arsonists can include profit (e.g., collecting insurance), crime concealment, revenge, vandalism, and even job security for firefighters.

The Bureau of Justice Statistics has periodically published a special report on local jail inmates with the most recent one being from 2002.[43] This data source provides estimates on the total number of jail inmates for arson offenses, including those convicted and unconvicted. In 2002, there were 342 372 convicted inmates of which 0.3 % were

[40] Gorte, Ross. 2013. "The Rising Cost of Wildfire Protection," Headwater Economics.
[41] Zhuang, J. et al. (Forthcoming). 'Measurement of the Economic Impact of Fire.' National Fire Protection Association.
[42] Satterfield, Jamie. 2016. "Teens toying with matches started Tennessee wildfire," USA Today, Dec 9. http://www.usatoday.com/story/news/nation-now/2016/12/09/sources-teens-toying-matches-started-tennessee-wildfire/95223326/
[43] Doris J. James, "Profile of Jail Inmates,2002," Bureau of Justice Statistics Special Report, October 12, 2004, https://www.bjs.gov/content/pub/pdf/pji02.pdf

convicted of arson. An additional 178 035 inmates were unconvicted with 0.5 % being charged with arson. This information can be combined with NFPA estimates on the proportion of intentional fires that are outside fires (75 %)[44] to approximate the number of inmates being charged with or convicted of arson associated with wildlands.

Equation 4

$$WAIJ = P_{Out-Fire}\left[\left(I_{Jail,Conv,15} * \ P_{Jail,Conv,Ars,02}\right) + \left(I_{Jail,Unconv,15} * P_{Jail,Unconv,Ars,02}\right)\right]$$

Where:
$WAIJ$ = Wildfire arsonists in jail
$P_{Out-Fire}$ = Proportion of arson fires that are outside from the NFPA
$I_{Jail,Conv,15}$ = Number of convicted jail inmates in 2015 from the Bureau of Justice Statistics
$P_{Jail,Conv,Ars,02}$ = Proportion of convicted jail inmates that are convicted of arson in 2002 from the Bureau of Justice
$I_{Jail,Unconv,15}$ = Number of unconvicted jail inmates in 2015 from the Bureau of Justice
$P_{Jail,Unconv,Ars,02}$ = Proportion of unconvicted jail inmates that are being charged with arson in 2002 from the Bureau of Justice

This is an estimate of the number of individuals in local jails for arson associated with wildfires and excludes those in state and federal prisons. Unfortunately, prison offense data does not include a category for arson; therefore, some assumptions need to be made to calculate an approximation. One can use the proportion of the jail population associated with wildfire arson combined with prison population data to estimate the prison population associated with wildfire arson:

Equation 5

$$WAIP = \frac{P_{Jail,Conv,Ars,02} * P_{Out-Fire}}{P_{Jail,Conv,Prop,02}} * \left(P_{Prison,Prop,15} * I_{Prison,15}\right)$$

Where:
$WAIP$ = Wildfire arsonists in prison
$P_{Jail,Conv,Prop,02}$ = Proportion of convicted inmates that are convicted of property crimes in 2002 from the Bureau of Justice
$P_{Prison,Prop,15}$ = Proportion of prisoners for property crimes in 2015 from the Bureau of Justice
$I_{Prison,15}$ = Number of prison inmates in 2015 from the Bureau of Justice

Prison data is available from the Bureau of Justice Statistics with the most recent being data for 2015.[45] Using Equation 4, the total wildfire arsonists in jail is estimated to be

[44] NFPA. 2014. "Intentional Fires," April. http://www.nfpa.org/news-and-research/fire-statistics-and-reports/fire-statistics/fire-causes/arson-and-juvenile-firesetting/intentional-fires
[45] Carson, E. Ann and Elizabeth Anderson. 2016. "Prisoners in 2015," Bureau of Justice Statistics, December. https://www.bjs.gov/content/pub/pdf/p15.pdf

2212 individuals and, using Equation 5, the total number of individuals in prison for wildfire arson is 2621. The prison estimate assumes that the proportion of wildfire arsonists in jail is similar to the proportion of those in prison. There is likely some error in making this assumption; however, it is the best estimate available at this time.

The estimated number of those incarcerated can be multiplied by the cost per inmate. A cost estimate is provided annually in the Federal Register or one could use an estimate from another source such as the VERA Institute of Justice. The Federal Register estimates that the average cost of incarceration for a federal inmate in fiscal year 2014 was $30 619.85 while the VERA Institute of Justice estimates an average of $31 286 for state prisons. Using the Federal Register estimate and assuming that the cost of inmates in jail pose the same cost, the total cost associated with wildfire arsonists adjusted to 2016 dollars is $149.9 million.

In addition to the incarceration costs, there are also the legal costs, including legal defense and judicial costs. The Bureau of Justice Statistics provides estimates on the expenditures on public defenders and judicial costs.[46] Combining these with estimates from the Uniform Crime Reporting system for the number of arrests for arson, an approximation can be made for the legal costs associated with arson:

Equation 6

$$Legal\ Defense = A_{ars} * P_{Out-Fire}\left(\frac{E_{PD,SC}}{C_{SC}}\right)$$

Where:
A_{ars} = Number of arrests for arson in 2014 from the Uniform Crime Reporting system
$E_{PD,SC}$ = Expenditures for public defenders at the state and county level for 2007 from the Bureau of Justice Statistics
C_{SC} = Number of cases received by public defenders at the state and county level for 2007 from the Bureau of Justice Statistics

Equation 7

$$Judicial\ Costs = A_{ars} * P_{Out-Fire}\left(\frac{E_{J,S}}{C_S}\right)$$

Where:
$E_{J,S}$ = Expenditures for judicial costs at the state level for 2007 from the Bureau of Justice Statistics
C_S = Number of cases received at the state level for 2007

Using Equation 6, the approximated cost of public of legal defense for those arrested for arson is $3.4 million after adjusting to 2016 dollars. This estimate is a lower bound estimate, as it assumes that all defendants use public defenders, which are, generally, less

[46] Bureau of Justice Statistics. 2012. Census of Public Defender Offices, 2007. September. NCJ 228229. https://www.bjs.gov/content/pub/pdf/spdp07.pdf

expensive than a private lawyer. Using Equation 7, the associated judicial costs were $29.5 million after adjusting to 2016 dollars.

Unknown: The approximations of the cost discussed above utilize several assumptions due to a lack of data. The actual number of wildfire arsonists in jail or prison are unknown. Additionally, the forms of legal defense for arsonists and judicial costs are unknown; however, making some assumptions allows for an approximation of the legal and incarceration costs. Additionally, the estimates above do not take into account the cost of arresting an arsonist.

2.4.2. Science, Research, and Development

Many public and non-profit organizations are involved in research and development to reduce the costs and losses associated with wildland fires. These efforts, themselves, have costs that should be considered for wildland fires.

The US Forest Service provides an estimate for research and development associated with wildland fire management. In fiscal year 2016, the USDA reports that approximately $19.8 million was spent on these items.[47]

Unknown: A number of other state and federal government entities along with universities and colleges have expenditures related to wildland fire. Some of them may specify these expenditures in their budgets; however, an aggregated estimate would require substantial effort in collecting this data. In 2012-2013 there were an estimated 7253 degree granting institutions in the United States with an unknown number of them having fire science programs conducting research on wildland fire.[48]

2.4.3. Regulations and Building Codes

Regulations and building codes have been developed at the local, state, and federal levels to reduce the risk of damage to life and property. For instance, California law requires homeowners to clear flammable vegetation within 30 feet of a building.

Unknown: There is no comprehensive list of regulations covering fire and wildland fire. While building codes are compiled by the 50 states, there is no complete sense of which portions are related to fire (and wildfire) and which are not. Nor is there any estimate of how much of the costs of building codes are associated with fire (and wildfire) protection.

Each state has its own building codes and fire regulations. Cost estimates are often developed for the adoption of new regulations and building codes by states. Local

[47] US Department of Agriculture. 2016. Fiscal Year 2017 Budget Overview. February. B-2. https://www.fs.fed.us/sites/default/files/fy-2017-fs-budget-overview.pdf
[48] U.S. Department of Education, National Center for Education Statistics. 2016. Digest of Education Statistics, 2014 (NCES 2016-006), Chapter 2.

governments can also have their own building codes and regulations as well. In many cases these will not have cost estimates for their rules.

3. The Losses Associated with WUI Fires

Despite the extensive efforts to prevent, suppress, and mitigate wildfires, they continue to cause damage to life and property. These damages include direct losses such as deaths, injuries, and structure damage along with indirect damage such as business interruption, utility loss, and ecosystem impacts. This chapter discusses the various losses due to wildland fires.

3.1. Direct Losses

Direct losses include those items that are lost as a direct result of a fire. For instance, homes that are burned, civilians that are injured, and timber that is destroyed. The following sections discuss these losses.

3.1.1. Deaths

Fire Exposure Related Deaths: The primary safety concern during a wildfire are the lives of the civilians in the fire's path and the firefighters attempting to contain the fire. Historically speaking, the civilian casualties due to wildfires have been relatively low. In 2012, an estimated 15 civilians died as a direct result of a wildfire,[49] close to the average of 13 people per year. Data on civilian mortality due specifically to WUI fires are not available, but treating WUI fires as a subset of wildfires that encroach on populated areas would suggest that the 13 fatalities per year is a respectable initial estimate.

The rate of wildland firefighter deaths per year is higher, though not by much. From 1990 to 1998, 133 people died while involved in fighting wildfires.[50] Of these deaths, 29 % were a result of burnover and 21 % were heart attacks. The largest cause of death was vehicle related (23 % due to aircraft accidents, 19 % related to other vehicles). An updated version of the report, which included data up to 2006, found a total of 310 deaths over a 17-year period.[51] The percentages of cause of death remained relatively constant with the addition of the new data. The findings on cardiovascular mortality in firefighters responding to a fire are well documented.

Smoke Exposure Related Deaths: The health effects of a wildfire are not confined temporally or geographically to the fire event itself. Smoke from a fire can be carried hundreds of miles away, and the effects of smoke exposure may persist well after the fire has been extinguished. These impacts are not insignificant, nor are they simple to quantify. The effects of acute exposure to wildfire smoke is well studied, however studies on chronic exposure are not well represented in the literature.

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[49] Thomas, Douglas S., and David T. Butry. 2012. "Wildland fires within municipal jurisdictions." Journal of Forestry 110(1): 34-41.
[50] Mangan, Richard. 1999. "Wildland Fire Fatalities in the United States." https://www.fs.fed.us/fire/safety/ref_material/content/fatalities.pdf
[51] Mangan, Richard J. 2007. Wildland firefighter fatalities in the United States: 1990-2006. National Wildfire Coordinating Group. https://www.fs.fed.us/t-d///pubs/pdfpubs/pdf07512814/pdf07512814dpi72.pdf

Wildfire smoke contains several chemicals that can possibly cause adverse health effects. Particulate matter less than 2.5 micrometers ($PM_{2.5}$) and less than 10 micrometers (PM10) are the most commonly researched components of smoke in the literature. These fine particles have been found to lead to an increased risk of cardiopulmonary and lung cancer related mortality.[52] Rappold et al. found an excess relative risk of 66 % and 42 % for congestive asthma and congestive heart failure respectively.[53] These values increased to 85 % and 124 % respectively when incorporating socio-economic factors.

Johnston et al. estimated the global mortality from landscape fires using a chemical transport model coupled with satellite data.[54] Using a figure provided in the document, an estimate for the United States can be bounded between 2940 and 21 095 people annually. The wide range is a result of the bounds used in the heat map provided in Johnston et al; no point estimate was provided in the article.

The clear majority of articles on smoke exposure related deaths focus on individual fire events. Individual fire examples are useful in providing evidence of the impact wildfire smoke has on mortality rates, but they are not generalizable across the entire United States. For instance, Analitis et al. found that small forest fires had no impact on mortality, while medium and large fires increased the number of respiratory and cardiovascular related deaths.[55] Analitis et al. noted that PM concentrations were not sufficient to completely explain their findings. These findings are aligned with what is found in the literature survey of Liu et al, although they found that cardiovascular related deaths had mixed evidence for a significant effect.[56] This finding is corroborated by Adetona et al.[57] while Kochi et al. found that there were 133 excess deaths in the 2003 southern California wildfires due to cardiorespiratory causes.[58]

Other Causes of Mortality: While long-term effects of wildfires on civilian health are not well-understood, some studies have attempted to determine what effects there may be for firefighters. Although most literature focuses on all firefighters, or only urban firefighters, the work of Liu et al. found that the respiratory effects for wildland firefighters were similar to urban firefighters.[59] Daniels et al. found an increased risk of

[52] Pope III, C. Arden, et al. 2002. "Lung cancer, cardiopulmonary mortality, and long-term exposure to fine particulate air pollution." Jama 287(9): 1132-1141.
[53] Rappold, Ana G., et al. 2012. "Cardio-respiratory outcomes associated with exposure to wildfire smoke are modified by measures of community health." *Environmental Health* 11(71): 1-9.
[54] Johnston, Fay H., et al. 2012. "Estimated global mortality attributable to smoke from landscape fires." Environmental health perspectives 120(5): 695.
[55] Analitis, Antonis, Ioannis Georgiadis, and Klea Katsouyanni. 2011. "Forest fires are associated with elevated mortality in a dense urban setting." Occupational and environmental medicine: oem-2010.
[56] Liu, J.C., Pereira G., Uhl, S.A., Bravo, M.A., and Bell, M.L. 2015. A systematic review of the physical health impacts from non-occupational exposure to wildfire smoke. Environmental Research 136: 120-132
[57] Adetona, Olorunfemi, et al. 2016. "Review of the health effects of wildland fire smoke on wildland firefighters and the public." Inhalation toxicology 28(3): 95-139.
[58] Kochi, Ikuho, et al. 2012. "Valuing mortality impacts of smoke exposure from major southern California wildfires." Journal of Forest Economics 18(1): 61-75.
[59] Liu, Diane, et al. 1992. "The effect of smoke inhalation on lung function and airway responsiveness in wildland fire fighters." American Review of Respiratory Disease 146: 1469-1469.

respiratory and digestive cancers mortality. Excess malignant mesothelioma was also reported, however exposure to asbestos is less common for wildland firefighters.[60] Vehicle accidents are a prevalent cause, by percentage, of death for wildland firefighters responding to a fire as well.[61]

Economic Losses: The economic losses due to the deaths of civilians and firefighters have not been adequately analyzed in the literature,[62] however there are some national estimates. An estimate for all firefighters (including wildfire) puts the number around $31.7 billion annually (excluding smoke exposure related deaths) assuming a $5 million dollar value of a statistical life (VSL) and a $166 000 Value of a Statistical Injury (VSI).

Using a justifiable VSL, a very rough estimate of the overall mortality losses can be achieved for just wildland fires. There are additional considerations that arise from fatalities (i.e., cost of emergency health care, impact of losing a firefighter on the effectiveness of a fire department), but many of these are either difficult to quantify, or are better rolled into another loss category. Given the wide range of estimated deaths derived from the heat map in Johnston et al., a point estimate should be checked against actual estimates from a specific fire, the southern California wildfires of 2003, which had an estimated $172.9 million to $1.729 billion dollars of economic losses due to wildfire related mortality.[63]

Using the estimates of 15 civilians and 18 firefighters direct wildfires deaths, between 2940 and 21 095 indirect deaths, and a $9.6 million value of a statistical life, there is an estimate of between $28.5 billion and $202.8 billion lost.

Unknown: Due to the nature of smoke related deaths, the long-term mortality due to wildfire smoke is not well understood. Short-term effects can only be estimated based on modeling or using hospital admissions.

3.1.2. Injuries and Health Impacts

Injuries: Injuries due to wildland fires are not uncommon. While firefighters experience the bulk of them due to the hazards of their profession, civilians can also be injured. These may be the result of attempting to flee the scene of the fire, car accidents during evacuations, slips, trips, falls, and acute smoke inhalation, among other causes.

Injuries related directly to wildfires, other than smoke exposure, are relatively infrequent when compared with urban fires. In 2012, 88 civilian injuries due to wildland fires were

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[60] Daniels, Robert D., et al. 2014. "Mortality and cancer incidence in a pooled cohort of US firefighters from San Francisco, Chicago and Philadelphia (1950–2009)." Occupational and Environmental Medicine. 71(6): 388-397.
[61] Mangan, Richard. 1999 "Wildland Fire Fatalities in the United States." https://www.fs.fed.us/fire/safety/ref_material/content/fatalities.pdf
[62] Kochi, Ikuho, et al. 2010. "The economic cost of adverse health effects from wildfire-smoke exposure: a review." International Journal of Wildland Fire 19(7): 803-817.
[63] Kochi, Ikuho, et al. 2012. "Valuing mortality impacts of smoke exposure from major southern California wildfires." Journal of Forest Economics 18(1): 61-75.

reported,[64] which is estimated using the National Fire Incident Reporting System (NFIRS). The same paper estimated the total cost due to fatalities and injuries in wildfires as roughly $148 million. Estimates for the number of wildland firefighter injuries can be obtained from the Incident Management Situation Report system, which tracks data on wildfires in federal jurisdictions. From 2003 to 2007, an average of roughly 260 injuries per year were reported in such incidents.[65] It may be possible to extrapolate this value to the nation as a whole by utilizing the equivalent rate of injury per person-days (13.316 average over the selected years).[66] Getting an estimate of total person-hours for a responding wildland firefighters and using a viable value of statistical injury, a rough estimate can be obtained.

Smoke Exposure: Liu et al.[67] found strong evidence (43 of 45 studies with statistically significant results) for an increase in respiratory morbidity due to wildfires. Higher instances of asthma attacks were commonly reported, along with coughing, wheezing, and other respiratory symptoms, as well as dispensation or use of medication. Liu et al. found no studies that directly examined lags longer than 5 days between exposure and hospital admission day. Some cross-sectional studies did note increases in primary care visits for a 12-week[68] and a 5-week[69] exposure period, although no conclusion on whether these visits were because of acute short-term, or lower-level long-term exposure was reached. Other effects that were found consistent in the literature survey of Liu et al. are, ophthalmic related symptoms, rescue medication use, and asthma related symptoms. Cardiovascular symptoms (six significant findings out of 14 studies) and birth weight (one significant finding out of two studies) showed inconsistent results in the literature.

Economic Losses: The economic impacts of smoke related health impacts can be substantial. Most literature estimates include mortality, but the values give some sense of scale to the total health impacts for individual fires. For the Chisolm fire in 2001, the total health impacts were estimated to be around 12 137 043 dollars Canadian based on monitoring station data and willingness to pay estimates.[70] It is estimated that 95 % of this value was due to increased mortality risk.

[64] Thomas, Douglas S., and David T. Butry. 2012 "Wildland fires within municipal jurisdictions." Journal of Forestry 110(1): 34-41.
[65] Britton, Carla Lea. 2010. "Risk factors for injury among federal wildland firefighters in the United States."
[66] ibid
[67] Liu, J.C., Pereira G., Uhl, S.A., Bravo, M.A., and Bell, M.L. 2015. A systematic review of the physical health impacts from non-occupational exposure to wildfire smoke. Environmental Research 136: 120-132
[68] Lee, T. S., Falter, K., Meyer, P., Mott, J., & Gwynn, C. 2009. Risk factors associated with clinic visits during the 1999 forest fires near the Hoopa Valley Indian Reservation, California, USA. International journal of environmental health research, 19(5): 315-327.
[69] Moore, D., Copes, R., Fisk, R., Joy, R., Chan, K., & Brauer, M. 2006. Population health effects of air quality changes due to forest fires in British Columbia in 2003: estimates from physician-visit billing data. Canadian Journal of Public Health/Revue Canadienne de Sante'e Publique, 105-108.
[70] Rittmaster, R., et al. 2006. "Economic analysis of health effects from forest fires." Canadian Journal of Forest Research 36(4): 868-877.

In 2015, an estimated 30 000 firefighters were mobilized to contend with wildland fires.[71] This data can be combined with a study of respiratory and cardiovascular health outcomes[72] that can be used to estimate the proportion of those exposed to smoke that have adverse respiratory outcomes (estimated to be 29 %) along with a study that examines smoke related health costs[73] (estimated to be $10 971 per treatment) to estimate a cost of injuries due to smoke exposure:

Equation 8

$$SHC = Exp * Rate * AvgCost$$

SHC = Smoke related health costs
Exp = Total number of exposed
$Rate$ = Estimated proportion of those exposed that have adverse health effects.
$AvgCost$ = Average cost of treating health impacts from smoke exposure

Combining this with the estimated 88 civilian injuries and the 260 firefighters multiplied by the value of a statistical injury ($189 000)[74] and adjusting to 2016 dollars provides an estimate of $177.4 million in economic loss.

Unknown: Injuries that occur as a result of wildland fires are not tracked comprehensively at the national level; however, national estimates can be made using existing datasets. No national estimates of the health impacts of smoke exposure exist, however using the estimate from Johnston et al. and an assumed VSI for the types of injuries associated with smoke exposure, an initial estimate is possible.[75] A more detailed estimate is possible through attempting to separate out the costs of treatment for specific smoke-related impacts and a literature-based distribution of health impacts.

3.1.3. Psychological Impacts

Exposure to a wildfire can have a traumatizing impact on civilians and firefighters. Witnessing the physical destruction from a wildfire can present emotional and mental hardships that may manifest in psychological disorders. Studies from wildfires have found depression, post-traumatic stress disorder (PTSD), and other anxiety disorders to

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[71] Mooney, Chris. 2015. With a stunning 7 million acres burned so far, the U.S. wildfire situation is looking dire. The Washington Post. August 19.
[72] Henderson, Sarah B. et al. 2011. “Three Measures of Forest Fire Smoke Exposure and their Associations with Respiratory and Cardiovascular Health Outcomes in a Population-Based Cohort.” Environmental Health Perspectives. 119: 1266-1271. https://ehp.niehs.nih.gov/1002288/
[73] Jones, Benjamin et al. 2016. “Wildfire Smoke Health Costs: A Methods Case Study for a Southwestern US ‘Mega-Fire’.” Joural of Environmental Economics and Policy. 5(2): 181-199. http://www.tandfonline.com/doi/full/10.1080/21606544.2015.1070765
[74] Thomas, Douglas S., and David T. Butry. 2012 "Wildland fires within municipal jurisdictions." Journal of Forestry 110(1): 34-41.
[75] Johnston, Fay H., et al. 2012. "Estimated global mortality attributable to smoke from landscape fires." Environmental health perspectives 120(5): 695.

have resulted from exposure to wildfire events. The focus of the remainder of this section is on PTSD, due to a greater amount of literature on its role post-wildfire.

Estimates for civilian rates of PTSD and other anxiety disorders after a disaster range from 30 %[76] to 60 %.[77] These effects have been observed to last long after the fire, with 40 % showing signs up to 1.5 years after the event.[78] Rates of PTSD among firefighters range from 13 %[79] to 20 %,[80] with 20 % experiencing burnout[81].

A national estimate can be achieved by estimating the population of civilians and firefighters exposed and using the rates form the literature to get a count of those exposed. For firefighters, an estimate for the exposed population is achievable from literature. At one point in 2015, a total of 30 000 firefighters were mobilized to contend with wildland fires.[82] This was the highest reported number since 2000. Assuming that this number represents the exposed firefighter population for a year, and assuming that the cost of PTSD treatment is $4075[83] based on estimates for military personnel, the estimated cost of PTSD for firefighters is roughly $24.5 million dollars.

Unknown: There are no national estimates for the civilian population exposed to wildfires, and at what exposure level (e.g., smoke, flames, lost loved ones, lost house, etc.). Therefore, it is not possible to get a credible estimate of the civilian rate of PTSD. Using PTSD also serves as a proxy for other disorders not as well developed in the literature.

3.1.4. Structure and Infrastructure

Wildfires frequently move into communities and burn buildings and infrastructure. The damage to these structures is tracked at varying degrees, but there is not a database that tracks this information comprehensively across the US.

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[76] Cole, Valerie. 2011. "PTSD and Natural Disasters, Defense Centers of Excellence for Psychological Health and Traumatic Brain Injury." DCoE. Webinar Aug. 25. http://www.dcoe.mil/content/Navigation/Documents/Cole%20%20PTSD%20and%20Natural%20Disasters.pdf

[77] Kuligowski, Erica. 2016. "Burning down the silos: integrating new perspectives from the social sciences into human behavior in fire research." Fire and Materials. Special Issue Paper. August 31. http://onlinelibrary.wiley.com/doi/10.1002/fam.2392/pdf

[78] ibid

[79] Katsavouni, F., et al. 2015. "The relationship between burnout, PTSD symptoms and injuries in firefighters." Occupational medicine 66(1): 32-37.

[80] Rahman, Fauzeya. 2016. New Study Estimates 20 Percent of Firefighters have PTSD. Houston Chronical. Aug 17.

[81] Katsavouni, F., et al. 2015. "The relationship between burnout, PTSD symptoms and injuries in firefighters." Occupational medicine 66(1): 32-37.

[82] Mooney, Chris. 2015. With a stunning 7 million acres burned so far, the U.S. wildfire situation is looking dire. The Washington Post. August 19.

[83] Galea, Sandro, et al. 2012. "Treatment for posttraumatic stress disorder in military and veteran populations: Initial assessment." Washington, DC: The National Academies.

The National Fire Incident Reporting System (NFIRS), a product of the National Fire Data Center which is at the U.S. Fire Administration (USFA), is broken into modules with the Basic Module as the primary one. In this module, general information is captured for every incident (emergency call). There are additional modules for different types of incidents. There is a Fire Module, Structure Fire Module, Civilian Fire Casualty Module, Fire Service Casualty Module, Wildland Fire Module, and an Arson Module. Information is generally obtained at the scene by emergency responder personnel. Within each module there are required fields and optional fields. This system records the types of materials burned and whether structures were involved; however, it is a voluntary system and not all fire departments participate. The overwhelming majority of departments that do participate are municipal fire departments, meaning that departments in the wildland, such as those in the Forest Service, do not typically report data to this system. A paper by Thomas and Butry used NFIRS data to estimate that between 2002 and 2006, an annual average of 1248 structures were damaged at an estimated loss of $160.2 million.[84] After adjusting for inflation using the consumer price index from the Bureau of Labor Statistics, the average per structure loss is $143 094.

In addition to the NFIRS data, the National Interagency Fire Center (NIFC) generates aggregated wildland fire data from forms filled out by wildland fire dispatch centers. According to NIFC, a total of 4312 structures were destroyed by wildfires in 2016, but it does not provide a dollar estimate of the losses.[85] Using the average per structure loss calculated from the NFIRS data above, an estimated $617 million was lost in 2016 to wildfires. Note that this estimate likely excludes many of the structures that occur in municipal jurisdictions since they are being reported by wildland fire dispatch centers.

There are additional databases that characterize wildfires; however, they tend to have a narrower scope geographically. For example, the California Department of Forestry and Fire Protection (CALFIRE) maintains fire perimeter data along with the number of structures burned; however, the data is only for California. Federal land managers, such as the Forest Service and Bureau of Land Management, also maintain databases, but only for their jurisdictions. Additionally, data from these organizations is likely incorporated in the NIFC data.

Unknown: There is not a comprehensive database tracking the number of structures burned and/or the value of property damaged. The NIFC data primarily contains information reported by wildland dispatch centers while the NFIRS data primarily contains data from municipal jurisdictions. Potentially, the two together might provide an estimate near the true loss; however, it is unclear to what extent these datasets overlap. There is not a known database that tracks the impact to infrastructure, such as power lines, roads, and pipelines.

[84] Thomas, Douglas S., and David T. Butry. 2012. "Wildland fires within municipal jurisdictions." Journal of Forestry 110(1): 34-41.
[85] National Interagency Fire Center. 2016. Wildland Fire Summary and Statistics Annual Report. https://www.predictiveservices.nifc.gov/intelligence/2016_Statssumm/intro_summary16.pdf

3.1.5. Environmental Impact

Wildfires are naturally occurring and play an important role in the life of a wildland area. As such many of the environmental impacts are naturally recovered as the wildland area returns to its pre-fire state. These impacts do have real costs in the immediate aftermath of a fire though and their effects can be exacerbated by human activity. Famously, trying to completely prevent forest fires had a negative effect. By not having regular sweeps of fire through forested areas, the underbrush grew to a point where the overabundance of fuel resulted in far more damaging fires.

Vegetation Loss: The most noticeable effect of a WUI fire is the loss of vegetation. Vegetation naturally returns on its own, however many parks actively work to reseed as soon as possible to help prevent future erosion. For instance, after the 1988 Yellowstone wildfires it cost roughly $2190 per hectare to reseed 440 hectares of land.[86] Using $2190 per hectare as a starting value and bringing it to present value dollars provides an initial estimate for the cost to reseed forest lands, provided an accurate estimate of forest land requiring reseeding per year can be found.

Unknown-Vegetation Loss: The acreage of land burned by vegetation type, which would allow an estimate to be derived based on some basic assumptions of seed type used and amount of seed per acre, is unknown.

Erosion: As mentioned, vegetation serves as a reliable way to prevent soil runoff. The total amount of runoff after a fire is dependent on the rainstorm sequence. An intense storm immediately after the fire will mobilize more soil than one after a substantial period of regrowth. Geography and soil type also play a role. This variability makes the total effects of runoff highly variable by climate and topology.[87] Grass seeding and straw mulch are typically applied after a fire to reduce erosion, with evidence showing straw mulch to be far more effective.[88] One component of an upper bound of the national estimate of soil erosion can be achieved by estimating the annual acreage burned and finding the required amount of straw mulch required to reduce erosion effects. An estimate of total erosion costs per year (including agricultural erosion) from Pimentel et al. puts the value at around $45 billion dollars.[89] It should be noted that Pimentel et al. deals primarily with agricultural erosion and includes wind erosion effects.

Unknown-Erosion: The percentage of erosion and runoff from wildfire effected lands, which could be used to reduce the Pimentel et al. estimate to a national estimate for

[86] Wenny, Daniel G. et al. The Need to Quantify Ecosystem Services Provided By Birds. American Ornithological Society.
[87] Moody, John A., Deborah A. Martin, and Susan H. Cannon. 2008. "Post-wildfire erosion response in two geologic terrains in the western USA." Geomorphology 95(3): 103-118.
[88] Groen, Amy H., and Scott W. Woods. 2008. "Effectiveness of aerial seeding and straw mulch for reducing post-wildfire erosion, north-western Montana, USA." International Journal of Wildland Fire 17(5): 559-571.
[89] Pimentel, David, et al. 1995. "Environmental and economic costs of soil erosion and conservation benefits." Science-AAAS-Weekly Paper Edition 267.5201: 1117-1122.

wildfire is unknown. Though not a true estimate given the extraneous types of erosion included, it would serve as an effective upper bound.

Effects on watershed: In many cases, the runoff from a wildfire-cleared area may end up in a waterway. This can produce negative effects for the aquatic ecosystem as well as for water treatment plants and other human users of the watershed. The impacts on water treatment can be estimated by developing a national average for the increase in turbidity due to wildfire runoff and using a general rule like "a 0.25 % increase in chemical cost for each 1 % increase in turbidity."[90] The effect on the environment is more difficult to quantify. As noted in Benda et al., the nature of a disruptive event, such as a wildfire, as well as the activities along the channel in question, may be a beneficial event or a detrimental one.[91]

The lack of vegetation near a watershed can lead to increased water flow into channels, potentially leading to greater downstream floods. A study by Neary et al. found that the watershed impacts of a large burnt area can produce peak flows to 10 to 100 times the baseflow for a watershed, with some being measured as high as 2300 times baseflow.[92] Unfortunately, data on floods which can be attributed to post-fire effects are not well documented, making valuation impossible.

Unknown-Watershed: The nature of the effects over the short-term, and long-term, are unknown and may be highly variable. Furthermore, the disruptive event may itself be a "restorative" one.[93] No national database on whether a flood was exacerbated by a wildfire is available.

Soil effects: Wildfire can affect soil properties in various ways. These include consuming the surface organic layer, exposing mineral soils, transforming nutrients, accumulating ash, soil particles lacking binding organics, and water repellency, some of which can last years.[94] Although fire is a natural forest process, improper forest management can increase fire severity, increasing the effects.

Unknown-Soil: The effects of wildfires on soil have been well studied, however there is currently no literature quantifying the economic impact.

Carbon sequestration: One of the benefits of vegetated areas is their ability to trap carbon as they grow. The creation of an organic layer of soil due to decay also serves this purpose. In a major fire, large areas of vegetation and soil may be lost, releasing any

[90] Dearmont et al. 1998. Costs of water treatment due to diminished water quality: A case study in Texas. Water Resources Research. 34(4): 849-853
[91] Benda, Lee, et al. 2003. "Effects of post-wildfire erosion on channel environments, Boise River, Idaho." Forest Ecology and Management 178(1): 105-119.
[92] Neary, Daniel G., Gerald J. Gottfried, and Peter F. Ffolliott. 2003 "Post-wildfire watershed flood responses." Proceedings of the 2nd International Fire Ecology Conference, Orlando, Florida.
[93] Benda, Lee, et al. 2003. "Effects of post-wildfire erosion on channel environments, Boise River, Idaho." Forest Ecology and Management 178(1): 105-119.
[94] Ice, George G., Daniel G. Neary, and Paul W. Adams. 2004. "Effects of wildfire on soils and watershed processes." Journal of Forestry 102(6): 16-20.

sequestered carbon into the atmosphere. If the forest is allowed to regrow, it will in theory recapture the carbon that was released during the fire. The time it takes to achieve that regrowth can be extensive though, especially for larger tree species and if the organic soil layer is lost, meaning an increase in greenhouse gases for decades.

The social cost of carbon (SCC) was developed specifically to put an economic value on carbon released into the atmosphere. The UK puts the SCC at around $5.44 per tonne CO_2 ($5.4 million per Tg of CO_2) for the central estimate for 2017, while the last EPA appraisal put the value at $36 per tonne of CO_2 ($36.0 million per Tg of CO_2).

Wiedinmyer and Neff provides an estimate for the amount of CO_2 released annually for the entire United States for all fires from 2002 to 2006.[95] Over the selected 5 years the average annual emissions are 213 (+/- 50) Tg CO_2 per year for the lower 48 states and 80 (+/- 89) Tg CO_2 per year for Alaska. The dominant sources were wildfires, however prescribed and agricultural burns were included as well. This is roughly 4 % to 6 % of the assumed anthropogenic emissions during that time, although at the state level the CO_2 emissions per year from fire exceeds those from fossil fuel usage in some states.

Wiedinmyer and Neff acknowledges the high amount of variability and difficulties in obtaining a national estimate, however for the sake of an initial estimate their values are used. Assuming then that the averages hold (the total emissions are 293 Tg CO_2 per year) and CO_2 emissions from structural fires are dwarfed by those in wildland fires,[96] and WUI fires are not separated out, the total cost of lost carbon sequestration can be estimated to be roughly $1.6 trillion using the UK SCC.

Unknown-Carbon: The breakdown of WUI fires from Wiedinmyer and Neff, as well as the mentioned uncertainties in the estimate on total carbon released is unknown.

3.1.6. Timber and Agriculture Loss

The National Interagency Fire Center (NIFC) provides annual estimates of the number of acres that were burned in wildfires. This data is submitted by dispatch centers and largely excludes fires within municipal jurisdictions and does not specify whether the land is grass or wooded.[97] There are some federal agencies and/or states that collect data on timber loss; however, this information is only for their jurisdiction and is not consistently collected. For instance, Florida estimated its 1998 softwood timber loss to wildfire to be between $354 million and $605 million; however, it does not typically estimate annual

[95] Wiedinmyer, Christine, and Jason C. Neff. 2007. "Estimates of CO2 from fires in the United States: implications for carbon management." Carbon Balance and Management 2(1): 10.
[96] The authors acknowledge that this is an assumption made out of convenience, as data is lacking for just wildland fire CO_2 release.
[97] Thomas, Douglas and David Butry. 2011. Tracking the National Fire Problem: The Data Behind the Statistics. NIST Technical Note 1717: 32-33. <https://www.nist.gov/publications/tracking-national-fire-problem-data-behind-statistics>

timber losses.[98] During that year, 499 000 acres were burned in Florida, resulting in between $709.42 and $1212.42 per acre. In 2016, approximately 5 509 995 acres were burned according to NIFC estimates.[99] Using Florida's per acre timber loss and adjusting to 2016 dollars, one can approximate the total loss nationally to be between $5.8 billion and $9.8 billion. This calculation makes the strong assumption that the timber proportions in Florida are the same nationally and that the timber costs are similar as well; however, there are, currently, limited alternative methods for estimating timber loss nationally.

Unknown: A national database of timber loss does not exist despite it being one of the major impacts of wildfire.

3.1.7. Agriculture Loss

According to the Farm Service Agency, "wildfires have caused devastating losses for many farmers and rangers."[100] In 2017, agriculture losses due to a fire in Texas were estimated at $21 million.[101] The National Fire Incident Reporting System (NFIRS) has data on wildfires and on agriculture; however, it does not specify agricultural losses. Any losses in the NFIRS system would be included in the total losses discussed in Section 3.1.4.

Unknown: There is not a comprehensive database of national loss estimates for agriculture.

3.2. Indirect Losses

In addition to the direct losses of wildland fires, there are indirect losses. For instance, a business facility might be damaged in a fire, which results in the direct loss of the facility. There is an additional loss of the business that would have occurred in the facility had it not been damaged. The following sections discuss these indirect losses.

3.2.1. General Economic Impacts

Disasters have far reaching economic consequences beyond the initial damage. Businesses may be lost or closed for substantial lengths of time, vital infrastructure may be lost, the disaster may drive away a customer base, or completely alter the economy of

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98 Morton, Douglas C., Megan E. Roessing, Ann E. Camp, and Mary L. Tyrrell. 2003. Assessing the Environmental, Social, and Economic Impacts of Wildfire. GISF Research Paper 001. <http://gisf.yale.edu/sites/default/files/files/wildfire_report(1).pdf>

99 National Interagency Coordination Center. Wildland Fire Summary and Statistics Annual Report: 2016. https://www.predictiveservices.nifc.gov/intelligence/2016_Statssumm/annual_report_2016.pdf

100 US Department of Agriculture. 2015. USDA Offers Help to Fire-Affected Farmers and Ranchers. September. <https://www.usda.gov/media/press-releases/2015/09/15/usda-offers-help-fire-affected-farmers-and-ranchers>

101 Ledbetter, Kay. 2017 "Agriculture Damages from Wildfire Estimated at about $21 million." AgriLife Today. March 15. <https://today.agrilife.org/2017/03/15/agriculture-damages-wildfire-estimated-21-million/>

the region, workers may be dislocated, among many other indirect effects. While not obvious in the immediate aftermath, these losses can quickly add up to a substantial total.

Business Interruption: Business interruption, loss of customer base, loss of employment, and the loss of vital infrastructure all add to the economic losses for a community. Business interruption is the inability of a firm to operate, though it still exists. The causes can be direct damage to the business structure, loss of infrastructure, damage to stock, loss of employees due to death or displacement, among other factors. Not only does business interruption hurt a business by not selling products, it can also hurt a business if customers drift to other establishments during that time. These customers may not come back, creating long-term losses from a relatively short-term event.

The economic effects of business interruption due to wildland or WUI fires is not well documented, even for specific fires. A study on low-intensity hurricanes from 1996 to 1998 estimated an average of $79 billion in lost output due to business interruption.[102]

Business Interruption - Unknown: Business interruption losses are not extensively covered in the literature, and are typically folded into other categories, total indirect losses for instance. These indirect losses themselves are often done in HAZUS, a software product of the Federal Emergency Management Agency, which uses input-output coefficients to estimate impacts. While viable on a local scale and in relation to a specific disaster, generalizing such an analysis to the United States as a whole is not feasible.

Failed Infrastructure: A large disaster can cause substantial damage to the infrastructure of the region. While direct damage is categorized as a direct loss, there are subsequent impacts that result from infrastructure being down. Business interruption is one example, however lost infrastructure can also cripple transit, power, water, health and public safety, and telecommunications (all typically rolled into indirect losses). These have real human and economic costs associated with them. For instance, Rose et al. estimated that the loss of electricity lifelines occurring from a simulated earthquake in the New Madrid fault zone could result in production losses during recovery of 7 % of the gross regional product.[103]

Failed Infrastructure - Unknown: Unfortunately, national estimates do not exist for the cost of failed infrastructure during disasters, let alone WUI and wildland fires.

Population Decline: A disaster can have lingering impacts on a region, which can be felt for years after the event. Notably, the population may decline as people move away to start over somewhere else, or people may be averse to settle in the region due to the perceptions of safety in the wake of the disaster. In the wake of the Northridge

[102] Burrus Jr, Robert T., et al. 2002. "Impact of low-intensity hurricanes on regional economic activity." Natural Hazards Review 3(3): 118-125.
[103] Rose, Adam, et al. 1997. "The regional economic impact of an earthquake: Direct and indirect effects of electricity lifeline disruptions." Journal of Regional Science 37(3): 437-458.

earthquake tens of thousands are believed to have left the Northridge area, while the same can be said for Dade County Florida in the wake of multiple destructive hurricanes[104]. In the case of New Orleans, four months after Hurricane Katrina the population was 37 % of the pre-disaster population of 437 186.[105] Less people means typically means less jobs and less growth. These findings were true for the island of Kauai after Hurricane Iniki hit in 1992. Eighteen years after landfall Coffman and Noy estimated that the island had a 12 % smaller population than had the hurricane not occurred, with a proportional loss of jobs.[106]

Population Decline - Unknown: The economic impact of people leaving a region after a disaster is not well studied. Furthermore, to account for the national impact one would have to counter any losses in the immediate region with any compensatory gains from the emigration.

3.2.2. Supply Chain Impacts

In 2016, Toyota announced that it would suspend much of its production in factories in Japan due to a shortage of parts caused by earthquakes.[107] Natural disasters frequently threaten supply chains and can stop production in factories that are not directly affected by a disaster. Wildfires can pose the same risk to supply chains. If a factory is affected by a fire and there is no excess capacity at other factories to fill the gap, production can be stopped throughout a supply chain. A classic case of supply chain disruption is the fire that occurred at a Philips microchip plant, a supplier to Ericsson, in New Mexico in 2000. Lightning disrupted the electricity at the plant, which resulted in a fire. Although the fire was minor, a great deal of the semiconductor plant, which must remain spotlessly clean, was contaminated. This left Ericsson with a serious parts shortage, which was a fatal blow to the company's mobile phone venture.

Unknown: There is not a strong understanding of the extent that wildfires or other disasters disrupt supply chains on an annual basis. Input-output models and computable general equilibrium models can be used to estimate the general economic impacts of a disaster; however, these methods are applied on a case by case basis.

3.2.3. Evacuation Costs

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[104] Alesch, Daniel, et al. 2001. "Organizations at Risk: What Happens when Small Businesses and Not-for-Profits Encounter Natural Disasters." Public Entity Risk Institute. http://www.ecocalltoaction.com/images/Organizations_at_Risk.pdf

[105] Kates, R. W., C. E. Colten, S. Laska and S. P. Leatherman. 2006. "Reconstruction of New Orleans after Hurricane Katrina: a research perspective." Proceedings of the National Academy of Sciences 103(40): 14653-14660.

[106] Coffman, Makena, and Ilan Noy. 2012. "Hurricane Iniki: measuring the long-term economic impact of a natural disaster using synthetic control." Environment and Development Economics 17(2): 187-205.

[107] Tajitsu, Naomi, and Makiko Yamazaki. 2016. "Toyota, Other Major Japanese Firms hit by Quake Damage, Supply Disruptions." Reuters. April 17. <http://www.reuters.com/article/us-japan-quake-toyota-idUSKCN0XE08O>

The seminal paper[108] on evacuation costs is Whitehead,[109] which breaks evacuation costs into:

- Loss of income and capital depreciation
- Transportation costs and transportation time
- "Direct costs" while away (i.e., food, lodging, entertainment)

Whitehead surveys North Carolina households that were affected by Hurricane Bonnie in 1998 to obtain revealed and stated preference data. This data is used in a model of evacuation decisions that provides estimates of evacuation costs, computed as the household cost of evacuation (obtained from the survey) multiplied by the probability of evacuation (obtained from the empirical analysis). This approach yields the following estimates for hurricane evacuation costs (in 1998 USD), reproduced from Whitehead, Table 9 (see Table 3.1). However, the survey data does provide estimates of direct evacuation costs by destination (e.g., hotel, shelter, family) and broken down by type of cost (e.g., lodging, food, entertainment); see Table 8 in Whitehead. Thus, Whitehead estimates direct evacuation costs to be: $275 for hotel evacuees; $86 for shelter evacuees; $53 for evacuees who stay with family or friends; and $20 for other evacuees.

Table 3.1: Hurricane Evacuation Costs ($1988)

Hurricane Scale	Hurricane Watch	Voluntary Evacuation Order	Mandatory Evacuation Order
Category 1	$1.05 M	$1.22 M	$14.7 M
Category 2	$1.7 M	$1.96 M	$19.03 M
Category 3	$5.11 M	$5.75 M	$31.85 M
Category 4	$8.35 M	$9.22 M	$35.5 M
Category 5	$25.77 M	$27.23 M	$50.41 M

Source: Whitehead's analysis does include direct costs, as well as travel time and travel costs, but does not include less tangible costs such as loss of income.

[108] Among other papers reviewed, Kousky, Carolyn. 2012. Informing Climate Adaptation: A Review of the Economic Costs of Natural Disasters, their Determinants, and Risk Reduction Options. Discussion Paper. RFF DP 12-28.
[109] Whitehead, John C. 2003. "One Million Dollars per Mile? The Opportunity Costs of Hurricane Evacuation," Ocean and Coastal Management. 46(11-12): 1069-1083.

Other estimates in the literature on hurricane evacuation include:

- Pfurtscheller and Schwarze cites a paper by Joy (1993) that estimates evacuation costs for a hurricane in a small town of New South Wales to be 1.5 M (AUS$).[110]
- Lindell et al. model household hurricane evacuation and estimates the average daily cost per evacuee to be $111.84 (in 2002 USD).[111]

Unknown: The literature on fire is even more lacking in estimates of evacuation costs and we know nothing about wildfire-urban interface fires in particular.

Kent et al. study the Hayman Fire and note that "other related expenditures, such as rehabilitation, water treatment, and evacuation costs add up to another $14 million," but offer no breakdown or citation.[112]

Finally, McCaffrey et al. discuss the "logistical" and "emotional" costs of fire evacuation, but do not provide or cite any numbers.[113]

Morton et al., however, do note that "data on the number of persons and length of displacement are often part of the BAER fire summary."[114] Note that BAER consistes of teams that have been developed in order to address post-fire risks. Morton et al. provide several estimates of costs using BAER reports, including evacuation costs where available:

- Carlton, Florida fire (2011); 40 homes, 1 day;
- Cerro Grande fire: 18 000 people, approximately 1 week;
- Double Trouble Fire: 100 homes, 1-2 days;
- Hayman Fire: 38 000 people (no duration)

Similarly, Situation 209 reports include annual estimates on the number of persons evacuated, as shown in Table 3.2.[115] Back of the envelope estimates of fire evacuation costs may be obtained using the estimates of daily costs of hurricane evacuation together with estimates of the number of evacuees and the length of evacuation. For instance, the total evacuation cost per fire may be approximated as

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[110] Pfurtscheller, C and R Schwarze. 2008. "Estimating the Costs of Emergency Services During Flood Events." 4th International Symposium on Flood Defence: Managing Flood Risk, Reliability, and Vulnerability. Toronto, Canada.
[111] Lindell, Michael, Jung Eun Kang, and Carla Prater. 2011. "The Logistics of Household Hurricane Evacuation." Natural Hazards. 58: 1093-1109.
[112] Kent, Brian et al. 2003. "Social and Economic Issues of the Hayman Fire." USDA Forest Service Gen. Tech. Rep. RMRS-GTR-114. 2003. https://www.fs.usda.gov/treesearch/pubs/14904
[113] McCaffrey, Sarah, Alan Rhodes, and Melanie Stidham. 2015 "Wildfire Evacuation and its Alternatives: Perspectives from Four United States' Communities." International Journal of Wildland Fire. 24: 170-178.
[114] Morton, Douglas C., Megan E. Roessing, Ann E. Camp, and Mary L. Tyrrell. 2003. Assessing the Environmental, Social, and Economic Impacts of Wildfire. GISF Research Paper 001. <http://gisf.yale.edu/sites/default/files/files/wildfire_report(1).pdf>
[115] National Fire and Aviation Management Web Applications (FAMWEB). SIT-209. <https://fam.nwcg.gov/fam-web/>

Total Cost = (Direct daily cost + Indirect daily cost) x (Length of evacuation) x (Number of persons evacuated)

Note that the variation in the number of evacuees by fire (as seen in the BAER reports) and the number of annual fires makes it difficult to establish a relationship between number of fires and number of evacuees. Using this approach, an average $3.0 billion in costs are incurred due to evacuation.

Table 3.2: Situation 209 Data

Year	Number of evacuees	Number of fires
2014	33 247	136
2015	96 171	222
2016	299 790	395

Source: National Fire and Aviation Management Web Applications (FAMWEB). SIT-209. <https://fam.nwcg.gov/fam-web/>

3.2.4. Accelerated Economic Decline of Community

A disaster can often result in general economic decline for a period afterward. Many communities experience a decrease in economic output and population decline.

Unknown: Disentangling the impact of a disaster from the myriad of other causal factors that affect the economic decline of a community is challenging at best. According to Alesch et al.,[116] accelerated economic decline following a disaster may include:

- Changing economic conditions and accelerated pre-disaster trends
- Business disruption and changing customer base
- Outside firms increasing competition
- Business owner perceptions
- Loss of customers and staff shortages due to out-migration

Such losses are intangible and difficult to quantify. There exists little, if any, estimates on these losses in the broader disaster literature, let alone the fire (and WUI) literatures.

For fire in particular, the closest attempt is Kent et al.,[117] which studies the Hayman Fire. The study finds no evidence of the Hayman fire having an impact on the regional economy (in terms of wages, employment, and retail sales). It is possible that the effect of fire on accelerating economic trends is not easily identifiable.

[116] Alesch, Daniel, et al. 2001. "Organizations at Risk: What Happens when Small Businesses and Not-for-Profits Encounter Natural Disasters." Public Entity Risk Institute. http://www.ecocalltoaction.com/images/Organizations_at_Risk.pdf
[117] Kent, Brian et al. 2003. "Social and Economic Issues of the Hayman Fire." USDA Forest Service Gen. Tech. Rep. RMRS-GTR-114. 2003. https://www.fs.usda.gov/treesearch/pubs/14904

3.2.5. Utility, Transportation, and Government Service Interruption

There are a number of instances where wildfires disrupted various services. For example, in August of 2015 fires in Oregon and California left thousands without power.[118] In May of 2014, power was cut to several communities in California due to wildfire.[119] Frequently roads are impacted such as in the 2013 Silver Fire in New Mexico.[120] Reports from Burned Area Emergency Response teams frequently include information on road closures and some service interruptions; however, these reports tend to focus on individual fires and do not provide national annual estimates nor do they cover all of the service interruptions.

Unknown: The extent that wildfires disrupt services such as utilities, transportation, and government services is not well documented. Although there is frequently documentation for some of these interruptions for individual fires, there is not a national database or annual report.

3.2.6. Psychological Impacts from Lost Amenities

The effects of losing natural amenities is not limited to the physical loss of trees, brush, or wildlife. These features can also have effect people emotionally and mentally, typically through the loss of the natural beauty of the region. Other amenities, such as a clean watershed or widespread pollinators fit more into ecosystem services, which are discussed in a later section. These impacts are less tangible and extremely difficult to quantify. One method is to use the impacts on tangible assets, such as housing prices (discussed in the next section). Another means is to examine the effects on tourist and consumer behavior of the impacted area. This serves as a proxy for the economic "health" of the WUI area and how it's viewed.

Valuing state and national parks and wildlife refuges is routinely done. The total economic value of the National Park Service is estimated at roughly $92 billion dollars at a minimum.[121] Of the $62 billion related to geographic holdings, less than half represents recreational use. The difference is made up in the "value that American households place on just knowing that" these lands exist and will exist for subsequent generations.[122] Travel cost analysis puts the consumer surplus per trip in a wide range based on multiple

[118] Stelloh, Tim. 2015. "Western Wildfires Trigger Evacuations in California, Oregon." NBC News. August 17. <http://www.nbcnews.com/storyline/western-wildfires/western-wildfires-evacuations-power-outages-heavy-smoke-n410761>
[119] Lee, Morgan. 2014. "Wildfires Cut off Power to Thousands." May 14. <http://www.sandiegouniontribune.com/sdut-power-outages-wildfires-2014may14-htmlstory.html>
[120] US Forest Service. 2013. Silver Fire: Burned Area Emergency Response Team Executive Summary. <https://www.fs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb5430883.pdf>
[121] Haefele et al. 2016. "Total Economic Valuation of the National Park Service Lands and Programs: Results of a Survey of The American Public." Colorado State University. http://webdoc.agsci.colostate.edu/DARE/PubLinks/NPSTotalEconValue.pdf
[122] ibid

models, ranging from as low as $37.4 to as high as $327.5 in Zawacki et al.,[123] and from $52.58 to $193.74 in Mendes et al.[124]

While the benefits and value of natural amenities are well understood at a national level, the effects of wildland and WUI fires are not well documented. Regional level estimates are available however. Tourism revenue dropped by roughly $138 million in 1998 in the St. Johns River Water Management District due to wildfire, and $32.5 million in the San Diego region.[125,126] A travel cost study on the impact of wildland and prescribed fires in New Mexico by Hesselna et al. found that the value of a forest in terms of trips after a fire was not only dependent on time, but also the reason for the trip.[127] Both hikers and mountain bikers typically saw a decrease in the number of trips per hiker as the forest recovered from a crown fire, but the value per trip increased for hikers, while decreased for mountain bikers. No estimates for other reasons for visits (camping, day trips) were found, nor is it reasonable to assume that the significant factors in the New Mexico study are relevant nationwide.

Unknown: No national assessments of the overall losses in tourism value due to wildfire exist, and those studies that do exist are not capable of being scaled up to a national level.

3.2.7. Housing Market Impact

The risk of disaster tends to have an impact on the value of housing in the at-risk area. A number of studies exist that examine this issue. Mueller et al. estimate that an initial wildfire incident reduces house prices by about 10 %, while a second fire reduces house prices by nearly 23 %.[128] However, other research has suggested that homebuyers are, largely, unaware of wildfire risk. For instance, Champ et al. estimated in a Colorado Springs case study that only 27 % of homebuyers were aware of the risk to wildfire when purchasing their home.[129] In the same study, homeowners tended to underestimate their wildfire risk with 21 % believing they had a low risk when in fact only 1 % had a low risk. Only 13 % identified themselves as being in an extreme or high risk area when in

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[123] Zawacki, William T., Allan Marsinko, and J. Michael Bowker. 2000. "A travel cost analysis of nonconsumptive wildlife-associated recreation in the United States." Forest science 46(4): 496-506.
[124] Mendes, Isabel, and Isabel Proença. 2011. "Measuring the social recreation per-day net benefit of the wildlife amenities of a national park: a count-data travel-cost approach." Environmental management 48(5): 920.
[125] Butry, David T., et al. 2001. "What is the price of catastrophic wildfire?." Journal of Forestry 99(11): 9-17.
[126] Diaz, John M. 2012. “Economic Impacts of Wildfire”. Southern Fire Exchange. https://fireadaptednetwork.org/wp-content/uploads/2014/03/economic_costs_of_wildfires.pdf
[127] Hayley Hesselna, John B. Loomisb, Armando González-Cabánc, Susan Alexander. 2003. Wildfire effects on hiking and biking demand in New Mexico: a travel cost study. Journal of Environmental Management 69: 359–368
[128] Mueller, Julie M., John B. Loomis, and Armando González-Cabán. 2009. “Do Repeated Wildfires Change Homebuyers’Demand for Homes in High-Risk Areas? A Hedonic Analysis of the Short- and Long-Term Effects of Repeated Wildfires on House Prices in Southern California.” Journal of Real Estate Finance and Economics. 38(2): 155-172. DOI: 10.1007/s11146-007-9083-1.
[129] Champ, Patricia Ann, Geoffrey H. Donovan, and Christopher M. Barth. 2009. “Homebuyers and Wildfire Risk: A Colorado Springs Case Study.” Society & Natural Resources: An International Journal. 23(1): 58-70.

fact it was 27 %. This paper also identified that proximity to dangerous topography was, actually, associated with an increase in the sales price of a home; however, Donovan et al. illustrated that the dissemination of wildfire risk information can reverse this relationship.[130]

Thomas and Butry estimate that between 2001 and 2010 4.8 million residential structures were within the vicinity of a wildfire or 481 800 per year on average. An additional 2.5 million were within the vicinity of two or more fires or 247 500 per year on average.[131] Additionally, the National Association of Realtors estimates the mean sales price for a home in 2015 was $267 300.[132] Using these estimates along with Mueller et al (2009) house price reduction, one can approximate a potential house price impact of wildfires nationally:

Equation 9

$$HPR = M_F R_F A + M_{MF} R_{MF} A$$

Where
HPR = House price impact from wildfire
M_F = Percent price reduction for one fire incident
R_F = Number of residential structures within the vicinity of one wildfire

A = Mean house price
M_{MF} = Percent price reduction for two fire incidents
R_{MF} = Number of residential structures within the vicinity of more than one wildfire

Using Equation 9 and adjusting to 2016 dollars using the consumer price index, there is an estimated $28.3 billion in potential residential sales price impact.

Unknown: Although an approximation of sales price impact can be calculated, the true impact is unknown. The estimate above relies on a study of southern California. Impacts are likely to vary from region to region.

3.2.8. Interference with Military Operations

In 2015, a military flare ignited a wildfire at Camp Grayling in Michigan.[133] This is not an unusual event, given the nature of military training; however, these fires pose a risk to

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130 Donovan, Geoffrey H., Patricia A. Champ, and David T. Butry. 2007 "Wildfire Risk and Housing Prices: A Case Study from Colorado Springs." Land Economics. 83(2): 217-233.
131 Thomas, Douglas and David Butry. 2014 "Areas of the US Wildland-Urban Interface Threatened by Wildfire During the 2001-2010 Decade." Natural Hazards. 71(3): 1561-1585.
132 National Association of Realtors. Existing-Home Sales. <https://www.nar.realtor/topics/existing-home-sales>
133 Johnson, Mark. 2015. "Military Flare during Training Exercise Ignites Massive Wildfire at Camp Grayling." Gaylord Herald Times. April 27. <http://www.petoskeynews.com/gaylord/featured-ght/top-gallery/military-flare-during-training-exercise-ignites-massive-wildfire-at-camp/article_1681f36c-e65c-582d-8c57-c94adc7b87f7.html>

military operations. Military operations have even developed wildland fire management plans such as the one for training lands for the US Army in Hawaii.[134]

Unknown: Although wildland fire can disrupt military training and operations, there is not a public database that tracks the total cost of these incidents.

3.2.9. Loss of Ecosystem Services

Ecosystem services are generally defined as "any positive benefit that wildlife or ecosystems provides to people."[135] Examples include clean natural water services, pollination by insects or birds, and natural reseeding of areas. WUI and wildland fires destroy habitat, vital ecological features, and kill or displace local wildlife for potentially significant periods of time. These losses culminate in the loss of ecosystem services for the WUI region.

Generally speaking, ecosystem services are difficult to quantify in terms of monetary value. Specific studies exist for local regions, not all of which fall within the United States. Watershed health and river fauna are well represented in the literature. Loomis et al. found that the willingness to pay for better watershed services using a contingent valuation survey for a 45-mile section of the Platte river.[136] Similar studies found $196 million per person annually for lake preservation,[137] $526 to preserve the Mono Lake ecosystem,[138] and $415 per person to increase Salmon in the San Joaquin river.[139]

For coffee farms in Jamaica, birds have been found to elevate farm income by $75 per hectare-year[140] and $310 per hectare-year[141] by eating crop damaging insects. The ability of birds to naturally reseed has been valued at $2115 to $9450 per hectare based on a study for Eurasian Jays in Stockjolm National Urban Park in Sweden.[142] National

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[134] US Army. "Integrated Wildland Fire Management Plan Overview." <https://www.garrison.hawaii.army.mil/sbcteis/feis/Appendices/Appendix%20O.pdf>

[135] National Wildlife Federation. 2017. "Ecosystem Services." https://www.nwf.org/Wildlife/Wildlife-Conservation/Ecosystem-Services.aspx

[136] Loomis, John, et al. 2000. "Measuring the total economic value of restoring ecosystem services in an impaired river basin: results from a contingent valuation survey." Ecological economics 33(1): 103-117.

[137] Desvousges, W., Smith, V.K., McGivney, M., 1983. A Comparison of Alternative Approaches to Estimating Recreation and Related Benefits of Water Quality Improvements. Economic Analysis Division, US Environmental Protection Agency, Washington, DC.

[138] Moore, W., McCarl, B., 1987. Off-site costs of soil erosion: a case study of the Willamette valley. West. J. Agric. Econom. 12 (1): 42–49.

[139] Hanemann, M., Loomis, J., Kanninen, B.1991. Statistical efficiency of double-bounded dichotomous choice contingent valuation. American Journal of Agricultural Economics. 73(5): 1255–1263.

[140] Kellermann, J. L., M. D. Johnson, A. M. Stercho, and S. C. Hackett. 2008. Ecological and economic services provided by birds on Jamaican Blue Mountain coffee farms. Conservation Biology 22:1177–1185.

[141] Johnson, M. D., J. L. Kellermann, and A. M. Stercho. 2010. Pest reduction services by birds in shade and sun coffee in Jamaica. Animal Conservation 13:140–147.

[142] Hougner, C., J. Colding, and T. Soderqvist. 2006. Economic valuation of a seed dispersal service in the Stockholm National Urban Park, Sweden. Ecological Economics 59:364–374.

estimates for insect pollination are around $29 billion in farm income in 2010.[143] Various other studies on localized valuations exist in the literature.

Unknown: Despite the availability of individual studies, determining a national value is difficult due to the absence of nation-wide studies, and the localized nature of the services in question.

3.2.10. Increased Risk of Other Hazards

Following a fire, there are increased risks for flooding, debris flow, landslides, invasive species, erosion, and altered water quality.[144] The risk floods and debris flow increases due to the exposure of bare ground. Burned debris and chemicals affect water quality. Burned Area Emergency Rehabilitation (BAER) teams have been developed in order to address these post-fire risks. In addition to creating a plan of action, these teams also develop reports on the conditions that a wildfire has created.

Unknown: There is no national aggregated database tracking the occurrence of post fire incidents nor is there any national cost data associated with these incidents.

3.2.11. Decreased Tax Base

Section 3.2.7 discussed the decrease in price from a fire. A subsequent impact of a decrease in housing value is a decrease in the tax base. According to the Tax Foundation, state average property tax rates range between 0.28 % and 2.38 %. Applying these rates to the price decrease discussed in Section 3.2.7, there is between $79.2 million and $673.2 million in decreased property tax.

Unknown: There is not a strong understanding of the impact that wildfires have on tax bases. Additionally, there is not a database tracking this type of information. Housing prices can be impacted by wildfires; however, it is not clear to what extent it impacts housing assessments and taxes.

3.2.12. Health and Environmental Impacts from Fire Retardants

The health and environmental impacts of the fire retardants used in fighting WUI and wildland fires are well understood. The effects on terrestrial ecosystems is negligible based on actual use,[145,146] though some plants may be more sensitive.[147] There is little

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[143] Ramanujan, Krishna. 2012. Insect pollinators contribute $29 billion to U.S. farm income. Cornell. http://news.cornell.edu/stories/2012/05/insect-pollinators-contribute-29b-us-farm-income

[144] USGS. USGS. Newsletter. 2006. https://pubs.usgs.gov/fs/2006/3015/2006-3015.pdf

[145] Kostas D. Kalabokidis. 2000. Effects of Wildfire Suppression Chemicals on People and the Environment – A Review. Global Nest: The International Journal. 2 (2): 129-137.

[146] Dietrich, Joseph P., et al. 2014. "Toxicity of PHOS-CHEK LC-95A and 259F fire retardants to ocean- and stream-type Chinook salmon and their potential to recover before seawater entry." Science of the Total Environment 490: 610-621.

[147] Robyn Adams and Dianne Simmons. 1999. Ecological Effects of Fire Fighting Foams and Retardants. Conference Proceedings of the Australian Bushfire Conference, Albury, July.

impact on air quality, and no impact on human health unless chemical is deployed directly on people. The overall effect is throat irritation and breathing difficulty due to ammonia gas release, although these are usually temporary in nature. Pilots deploying the chemical have noted eye and nasal irritation, though chemical levels were below threshold values. The cause in these cases may simply be the chemical odor.[148]

Fire retardant chemicals for wildland fires have consistently been found to be toxic to aquatic ecosystems.[149] One study found ammonia to be the primary cause,[150] while Calfee and Little found the CTS-R chemical to be phototoxic to fathead minnows.[151]

Unknown: While the toxicity of fire retardants to aquatic ecosystems is established, the overall impacts, economically and in practice, of these effects are not well documented. All studies focused on short-term effects, with no mention of the long-term effects of exposure.

[148] Kostas D. Kalabokidis 2000. Effects of Wildfire Suppression Chemicals on People and the Environment – A Review. Global Nest: The International Journal. 2 (2): 129-137.
[149] Robyn Adams and Dianne Simmons. 1999. Ecological Effects of Fire Fighting Foams and Retardants. Conference Proceedings of the Australian Bushfire Conference, Albury, July.
[150] Kostas D. Kalabokidis. 2000. Effects of Wildfire Suppression Chemicals on People and the Environment – A Review. Global Nest: The International Journal. 2 (2): 129-137.
[151] Robin D. Calfee, Edward E. Little. 2003. Effects of a fire-retardant chemical to fathead minnows in experimental streams. Environmental Science and Pollution Research September, 10(5): 296–300

4. Estimation of Total Costs and Losses

Section 2 and Section 3 provided a narrative describing the available data on wildland fire costs and losses. Bringing this data together can facilitate aggregating all the costs and losses. Table 4.1 provides a list of the costs, the section where they were discussed, variables relevant to the cost, and an estimate of the cost. Costs that cannot be estimated are omitted from the table. There are eleven costs that can be estimated. Table 4.2 provides similar information for the losses associated with WUI fires, which has nine items that can be estimated.

The total of annualized costs and losses of wildfire, as seen in Table 4.3, is between $71.1 and $347.8 billion. The total estimate with the indicator “Low,” is a sum of all the low estimates combined with the “Estimate” value when the “Low” value is not available. The “Estimate/Low” is the sum of all the “Estimate” values combined with the “Low” values used when the “Estimate” value is not available. The “Estimate/High” value is the sum of all the “Estimate” values combined with the “High” values when the “Estimate” value is not available. The “High” value is the sum of all the “High” values along with the “Estimate” value when there is not a “High” value.

The “Low” estimate for the costs amounts to $7.6 billion while the “High” estimate is $62.8 billion (not shown in Table 4.3). The three largest values represent 65.1 % of the “Low” value and 93.3 % of the “High” value. The top three for the “Low” value are local fire department costs, defensible space costs, and federal suppression costs. For the “High” value, the largest three includes defensible space costs, local fire department costs, and state suppression costs.

The “Low” estimate for the losses alone (not shown in Table 4.3) is $63.5 billion and the “High” estimate is $285.0 billion. The three largest values for the “Low” losses estimate and the “High” losses estimate represent 98.6 % and 96.0 % of the total, respectively. For the “Low” losses value, the top three includes deaths, impact on housing prices, and timber loss. For the “High” value, the top three includes deaths, evacuation, and the impact on housing prices.

Table 4.1: Costs Associated with WUI Fires

Costs	Variables					Indicator	Estimated Total Cost
Section 2.1	USFS	DOI				Estimate	1 483 278 641
						5-YR Low	976 363 507
Preparedness	1 145 800 000	319 000 000				5-YR High	1 483 278 641
Section 2.2.1	Montana cost estimate per acre (low)	Montana cost estimate per acre (high)	participation	homes at risk	Acres per structure	Low	1 664 089 967
Defensible Space	1 361	43 560	91%	3 170 880	0.4	High	53 250 878 955
Section 2.2.1	USFS	DOI				Estimate	532 331 773
						5-YR Low	444 335 519
Fuels Management	361 500 000	164 000 000				5-YR High	539 622 602
Section 2.2.3	FEMA Disaster Assistance						
Disaster Assistance	1 551 349					Estimate	1 551 349
Section 2.3	USFS	USFS-FLAME	DOI	DOI-FLAME		Estimate	1 412 395 582
						5-YR Low	1 176 354 995
Federal: Suppression	708 000 000	303 100 000	291 700 000	92 000 000		5-YR High	1 767 823 492
Section 2.3	USFS	DOI				Estimate	131 538 705
						5-YR Low	12 353 905
Federal: Other	117 800 000	12 100 000				5-YR High	151 689 746
Section 2.3	Fire Protection					Estimate	2 060 526 192
State: Suppression and Protection	2 000 000 000					Low	1 030 263 096
						High	2 060 526 192

Section 2.3	Fire Department Career (dollars)	Fire Department Volunteer (dollars)	# of Fire dept calls	# Reported Fires	# Rep Natural Veg Fires	Apportion based on call volume				Estimate	2 129 015 866
	41 900 000 000	94 900 000 000	31 644 500	1 021 846	191 178	Unlike Feds, this includes all fire protection & suppression activity				5-YR Low	2 129 015 866
Local FD										5-YR High	3 345 596 361
Section 2.4.1	Number of Cases received (2007)	Expenditures - public defenders (2007)	Arson arrests (2014)	State Expenditures (2007)	State Judicial and legal expenditures (2007)	Number of cases - state (2007)	NFPA - proportion of arson that is outdoors (2007-2011)				
Legal Costs (judicial and defense)	5 572 450	2 310 040 000	9 463	833 358 000	6 183 948 000	1 491 420	75.0%			Estimate	32 878 928
Section 2.4.1	Prisoner Population (2015)	Prisoner Population - Property Crimes (2015)	Jail population - convicted (2015)	Jail Population - unconvicted (2015)	Jail, convicted of arson (2002)	Jail, unconvicted, arson (2002)	Jail, convicted of property offenses (2002)	NFPA - proportion of arson that is outdoors (2007-2011)	Cost per prisoner		
Incarceration - jail and prison	1 526 800	19.0%	258 800	434 600	0.3%	0.5%	24.9%	75.0%	30 620	Estimate	149 863 857
Section 2.4.2	US Forest Service research and development										
Research and Development	19 795 000									Estimate	19 795 000

Table 4.2: Losses Associated with WUI Fires

Losses	Variables						Indicator	Estimated Total Cost
Section 3.1.1	Estimated number of annual deaths from wildfire smoke (acute) - low estimate	Estimated number of annual deaths from wildfire smoke (acute) - high estimate	Estimated annual number of direct deaths from wildfire (civilian)	Estimated annual number of direct deaths from wildfire (firefighter)	Value of a statistical life (VSL)		Low	28 540 800 000
Deaths	2 940	21 095	15	18	$9 600 000		High	202 828 800 000
Section 3.1.2	Estimated exposed population (firefighter)	Rate of adverse health impact (firefighter)	Average cost to treat adverse health impact	Annual injuries (Firefighter)	Annual Injuries (Civilian)	Value of a statistical injury (VSI)		
Injuries	30 000	29%	10 971	260	88	189 198	Estimate	177 450 535
Section 3.1.3	Estimated exposed population (firefighter)	Rate of psychological impact (PTSD) in exposed population (firefighters)	Average cost to treat psychological impact (PTSD)					
Psychological Impacts	30 000	20%	4 075				Estimate	24 450 000
Section 3.2.3	Persons displaced	Length of displacement (days)	Direct costs	Annual fires				
	100	1	29	136			Low	400 502
	38 000	7	405	395			High	42 544 921 839
	18 700	4	160	251			Mean	2 999 448 168
Evacuation	18 000	4	102	222			Median	1 635 711 020

Section 3.1.4	NIFC: Minor structures	NIFC: Commercial	NIFC: mixed commercial/ residential	NIFC: residences		Direct damage - structures and content: Avg 2002-2006 NFIRS	# of Structures: NFIRS		
Structures	1 025	78	17	3 192		160 200 000	1 248	Estimate	617 021 796
Section 3.1.6	Florida 1998 timber loss (low)	Florida 1998 timber loss (high)	Florida 1998 acres burned	Total US acres burned					
Timber loss	354 000 000	605 000 000	499 000	5 509 995				low	5 755 594 981
								high	9 836 539 445
Section 3.1.8	DOI							Estimate	18 227 072
Burned Area Rehab								5-YR Low	12 455 166
	18 000 000							5-YR High	45 263 896
Section 3.2.7	Mueller et al. price impact for one fire	Mueller et al. price impact for a second fire	NAR estimate for the mean house price	Thomas and Butry estimate for annual # homes within one fire	Thomas and Butry estimate for annual # homes within two or more fires				
Potential Impact on housing price	10%	23%	267 300	481 800	247 500			Estimate	28 286 518 963
Section 3.2.11	Tax Foundation tax rate	Tax Foundation tax rate						Low	79 202 253
Tax base loss	0.28%	2.38%						High	673 219 151

Table 4.3: Estimated Total WUI Costs and Losses ($2016)

Losses	Indicator	Estimated Total Cost
Section 2.1	Estimate	1,483,278,641
	5-YR Low	976,363,507
Preparedness	5-YR High	1,483,278,641
Section 2.2.1	Low	1,664,089,967
Defensible Space	High	53,250,878,955
Section 2.2.1	Estimate	532,331,773
	5-YR Low	444,335,519
Fuels Management	5-YR High	539,622,602
Section 2.2.3		
Disaster Assistance	Estimate	1,551,349
Section 2.3	Estimate	1,412,395,582
	5-YR Low	1,176,354,995
Federal: Suppression	5-YR High	1,767,823,492
Section 2.3	Estimate	131,538,705
	5-YR Low	12,353,905
Federal: Other	5-YR High	151,689,746
Section 2.3	Estimate	2,060,526,192
	Low	1,030,263,096
State: Suppression and Protection	High	2,060,526,192
Section 2.3	Estimate	2,129,015,866
	5-YR Low	2,129,015,866
Local FD	5-YR High	3,345,596,361
Section 2.4.1		
Legal Costs (judicial and defense)	Estimate	32,878,928
Section 2.4.1		
Incarceration - jail and prison	Estimate	149,863,857
Section 2.4.2		
Research and Development	Estimate	19,795,000
Section 3.1.1	Low	28,540,800,000
Deaths	High	202,828,800,000
Section 3.1.2		
Injuries	Estimate	177,450,535
Section 3.1.3		
Psychological Impacts	Estimate	24,450,000
Section 3.2.3	Low	400,502
	High	42,544,921,839
	Mean	2,999,448,168
Evacuation	Median	1,635,711,020
Section 3.1.4		
Structures	Estimate	617,021,796
Section 3.1.6	low	5,755,594,981
Timber loss	high	9,836,539,445
Section 3.1.8	Estimate	18,227,072
	5-YR Low	12,455,166
Burned Area Rehab	5-YR High	45,263,896
Section 3.2.7		
Potential Impact on housing price	Estimate	28,286,518,963
Section 3.2.11	Low	79,202,253
Tax base loss	High	673,219,151
TOTAL	Low	71,130,760,185
TOTAL	Estimate/Low	73,116,931,963
TOTAL	Estimate/High	346,238,240,473
TOTAL	High	347,837,690,748

5. Gaps and Unknowns

Section 2 and Section 3 provided a narrative describing the available data on wildland fire costs and losses, exposing gaps in the data. Some cost/loss items have well documented data; thus, an estimate can be made with low uncertainty. Other cost/loss items can be estimated; however, these estimates require a great deal of assumptions and approximations, resulting in high uncertainty. Yet other cost/loss items cannot be estimated at all. Research in measuring those cost/loss items that have a combination of high cost and high uncertainty or are unknown, have a greater potential for facilitating cost effective policy decisions.

Table 5.1 provides an estimated order of magnitude for the costs and losses along with an assessment of the uncertainty in the estimate for the United States. In the case that a value is unknown, an assessment of the magnitude of the cost/loss was made. A number of cost items are estimated to be in the billions and have a high uncertainty, including rural and municipal suppression, defensible space, timber loss, evacuation costs, and the housing market impact.

Table 5.1: Magnitude of Cost/Loss and Uncertainty at National Level

	ORDER OF MAGNITUDE $ < Millions $$ 10s Millions $$$ 100s Millions $$$$ Billions	UNCERTAINTY ? Low ?? Medium ??? High ???? Unknown
Costs		
Preparedness	$$$$	?
Mitigation		
Fuels Management		
Fuel treatments (Rx fire, thinning)	$$$	?
Defensible Space / Firewise	$$$$	???
Insurance	$$	????
Disaster Assistance	$	??
Suppression		
Fire Departments (Labor, Equipment, Training)		
Federal	$$$$	?
State	$$$$	?
Municipal (Professional)	$$$$	???
Rural (Volunteer)	$$$$	???
Cross-Cutting		
Legal		
Prosecution	$$	??
Incarceration	$$$	??
Civil / Liability	$$	????
Science / Research & Development	$$	???
Building Codes & Standards	$$	????
Regulations (e.g., Zoning)	$$	????
Losses		
Direct		
Deaths and Injuries (Civilian and Firefighter)	$$$$	??
Psychological Impacts (PTSD)	$$	???
Structure and Infrastructure Loss	$$$	???
Environmental impact	$$$	????
Habitat & Wildlife loss	$$	????
Timber Loss	$$$$	???
Agriculture Loss	$$$	????
Remediation/cleanup	$$	???
Indirect		
General Economic Impacts (Business Interruption, Tourism, Supply Chain)	$$$	????
Evacuation Costs	$$$$	???
Accelerated Economic Decline of Community	$$$	????
Utility and Pipeline Interruption (Elec, Gas, Water, Oil)	$$$	????
Transportation interruption (e.g., Roads and Rail)	$$	????
Government Service Interruption (inc. Education)	$$	????
Psychological Impacts (Loss of Natural Amenities)	$$	????
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	$$$	????
Health/Environmental Impacts from Use of Fire Retardants / Suppressants	$$$	????

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