# Drivers of Wildfire Suppression Costs

## Literature Review and Annotated Bibliography

*AUTUMN ELLISON, CASSANDRA MOSELEY, AND R. PATRICK BIXLER*

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## About the authors

***Autumn Ellison*** is a faculty research assistant in the Ecosystem Workforce Program, Institute for a Sustainable Environment, University of Oregon.

***Cassandra Moseley*** is director of the Ecosystem Workforce Program and the Institute for a Sustainable Environment, University of Oregon.

***R. Patrick Bixler*** is a faculty research associate in the Ecosystem Workforce Program, Institute for a Sustainable Environment, University of Oregon.

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**About the Northwest Fire Science Consortium**

The Northwest Fire Science Consortium is part of a national network of consortia established by the Joint Fire Science Program to accelerate the awareness, understanding, and adoption of wildland fire science information by federal, tribal, state, local, and private stakeholders. The geographic region of the NW Consortium includes Oregon and Washington, except for the basin and range of southeastern Oregon.

For additional information about the Northwest Fire Science Consortium, contact:

Janean Creighton
Oregon State University
321 Richardson Hall
Corvallis, OR 97331
541-737-1049
nw.fireconsortium@oregonstate.edu
www.nwfirescience.org/

For additional information about this report, contact:

Ecosystem Workforce Program
Institute for a Sustainable Environment
5247 University of Oregon
Eugene OR 97503-5247
541-346-4545
ewp@uoregon.edu
http://ewp.uoregon.edu


UNIVERSITY OF OREGON

Over the past century, wildland fire management has been core to the mission of federal land management agencies. In recent decades, however, federal spending on wildfire suppression has increased dramatically; suppression spending that on average accounted for less than 20 percent of the USFS's discretionary funds prior to 2000 had grown to 43 percent of discretionary funds by 2008 (USDA 2009), and 51 percent in 2014 (USDA 2014). Rising suppression costs have created budgetary shortfalls and conflict as money "borrowed" from other budgets often cannot be paid back in full, and resources for other program areas and missions are subsumed by suppression expenditures (Thompson et al. 2013). Significant policy making over the past 15 years has been designed, at least in part, to address these issues and temper wildfire costs. Effective political efforts and strategies to control public spending on suppression rely on a thorough and comprehensive understanding of the drivers of suppression costs and recent trends.

Currently, scholars and policymakers have little understanding or agreement on the diversity of drivers behind wildfire suppression costs, how drivers vary in different situations, or what specific tactics or approaches might best reign in rising costs. There is great variability in costs between comparable wildfires in the same season, as well as between comparable fire seasons. Problematically, much of this variation is unexplained by frequently noted drivers. As speculation and scrutiny around potential drivers has increased, so too has a growing body of scholarly literature investigating the correlates and influences driving suppression costs.

A more comprehensive understanding of the full suite of factors affecting suppression costs can inform how land management agencies can best leverage limited resources for wildfire management, and how budget allocations could more accurately accommodate annual suppression costs. This working paper gathers together existing scholarly literature on wildfire suppression cost drivers. The purpose of the paper is to provide an overview of the diversity of drivers examined in scholarly literature that may influence suppression costs; be a resource for documenting the growth, parameters, and directions in this field of research; and serve as a central collection annotating this literature to date.

# Approach

To provide an overview and annotated bibliography of literature that examines drivers of wildfire suppression spending, we gathered peer-reviewed government reports, journal articles, and book chapters. We sought scholarly literature from any discipline, using any methodological approach so long as the main focus of the literature was the drivers of wildfire suppression expenditures. We focused on literature premised on the relatively recent trend of rising suppression costs. Although there is some earlier literature examining causal factors of suppression expenditures, it does not focus on drivers behind the recent trend of increasing costs. To capture literature only relevant to the recent trends, we limited our annotation to literature published after 2000. We excluded resources that analyzed policy or circumstances around suppression spending if they did not explicitly analyze drivers of spending, as well as resources that examined only increasing wildfire activity with no link to suppression spending.

To identify literature, we conducted keyword searches in the University of Oregon library catalog of peer-reviewed literature and on Google Scholar, which produced the first round of resources. As we began to annotate these resources, we reviewed the publications that were cited throughout them to identify other relevant sources that may not have been yielded through the initial searches. Finally, we reviewed several pieces of "grey" literature that provide an overview of suppression spending to confirm that we had included all relevant sources. We identified 18 peer-reviewed articles and reports in total, and three book chapters, which are arranged primarily by date and secondarily in alphabetical order in the annotated bibliography (see page 12). Annotated literature is also summarized in Appendix 1 (page 32).

This review does not include any grey literature; all of the literature reviewed was subject to peer review and published in a scientific journal, a book, or a peer-reviewed technical report. Citations for sources that are contextually related to suppression spending but not peer-reviewed investigations into drivers of spending (e.g. non peer-reviewed government reports on suppression spending; peer-reviewed articles providing contextual premise only) are not annotated. Citations for these can be found in the references section at the end of the paper.

# Findings

## Recent wildfire suppression spending trends

In general, the literature on wildfire suppression spending is focused on federal spending, particularly U.S. Forest Service spending. Although suppression expenditures have likely increased across agencies at other levels, federal agencies pay for the large majority of wildfire suppression expenditures each year, and the Forest Service is responsible for approximately 70 percent of the federal spending (Calkin et al. 2011). Forest Service spending on wildfire suppression began to steadily increase in the late 1980s, with dramatic increases beginning in 2000 (Calkin et al. 2005, Gebert and Black 2012). The 2000 wildfire season was the first to cost the U.S. Forest Service more than $1 billion, and the 2002 fire season set yet another new record for suppression spending. Adjusting all previous annual expenditures to year 2002 dollar-values, no other season prior to 2000 was close to $1 billion in suppression costs (Calkin et al. 2005).

Suppression costs have continued to rise. In 2014, suppression costs consumed 40 percent of the Forest Service's total annual budget, compared to 13 percent of the budget in 2004 (USDA 2014). Comparing the 1985-1999 period to the 2000-2012 period nationwide, the average number of fires per year remained the same (76,491 to 76,874 fires). However, the average number of acres burned more than doubled (3.2 to 7.0 million acres), and the Department of Interior plus U.S. Forest Service annual suppression spending increased 3.4-fold ($426 million to $1.46 billion) (National Interagency Fire Center 2013). In essence, wildfires have become larger and much more expensive.

## Drivers of wildfire suppression costs

After the Forest Service's first billion-dollar suppression year in 2000 and the subsequent adoption of the National Fire Plan (2001), research into drivers of wildfire expenditures became more prevalent (Hand et al. 2014). The academic literature explores drivers that range from climate and environmental variables to human settlement patterns, institutional influences, and decision-making logic in fire management scenarios. Investigation for many drivers remains exploratory. This review groups drivers into three categories: physical and environmental drivers, socio-environmental drivers, and management and decision-making drivers. Most of the annotated literature focuses on drivers in a single category though a few consider drivers across categories.

## Physical and environmental drivers

Physical characteristics are the most measurable and empirically substantiated drivers of suppression costs. These drivers are most commonly included in equations and regression models that seek to better predict, or forecast, suppression costs, and include larger trends such as climate as well as more local fire and environment characteristics.

### Wildfire size

Suppression expenditures have consistently correlated with area burned over time, and this correlation has implications for the scholarly investigations annotated in this paper. Both historically and today, annual suppression expenditures increase with the total number of acres burned (Calkin et al. 2005, Abt et al. 2008), and despite being a small minority of all fires suppressed, large wildfires ac-

count for the large majority of acres burned. From 1970 to 2002, only 1.1 percent of the wildfires suppressed by the Forest Service burned 300 or more acres, yet these fires accounted for 97.5 percent of the area burned (Calkin et al. 2005). Likewise, these large wildfires create the bulk of expenditures. A USDA Office of Inspector General audit found that in 2003 and 2004, just 2 percent of wildfires accounted for more than 80 percent of suppression costs (USDA OIG 2006). Large wildfires are occurring with greater frequency (Dennison et al. 2014) despite advanced land management efforts to stem them (Williams 2013), and rising suppression spending has mirrored this trend.

Although area burned is not considered a true driver of suppression costs because both are "contemporaneously determined...the relationship implies that if area burned could be forecast two or three years in advance, then forecasts of expenditures could be developed using area burned forecasts" (Abt et al. 2008, 343). Because large wildfires consistently create the majority of suppression expenditures, investigations into the drivers of suppression expenditures generally focus only on large wildfire events. For the literature annotated in this paper, investigations that examine individual wildfire events consider only large wildfire events, most commonly defined as 300 acres or greater.

### Climate

Climate is a well-known driver of wildfire behavior. Littell et al. (2006) explain, "despite the possible influence of fire suppression, exclusion, and fuel treatment, wildfire burn area is still substantially controlled by climate" (1003). Among the literature examining suppression spending, climate change is commonly acknowledged as a significant driver

of increasing wildfire activity and associated costs. Across this literature, it is generally accepted that ongoing climate change will continue to affect wildfire occurrences, severity, and cost. Climate indices such as ocean temperature, pressure systems, and drought indices are considered in regression analyses within the literature that seek to explain spending trends and forecast future suppression costs (e.g., Calkin et al. 2005, Prestemon et al. 2008, Abt et al. 2009, Preisler et al. 2011).

### Fire environment and characteristics

Characteristics of individual wildfires and local fire environment variables are also known to affect wildfire suppression costs. The influence of weather patterns on wildfire season severity is well established, and weather (e.g., wind, relative humidity) is often considered the dominant variable affecting wildfire activity, with implications for spending (Calkin et al. 2005). Fire terrain, fuel, behavior, and location have also been indicated as drivers of suppression costs. In an analysis including variables for fire size, fuel moisture, suppression resource availability, nearby private property, and whether fire managers rated the terrain of the wildfire as extreme for 58 wildfires in Oregon and Washington, only extreme terrain and fire size were significantly correlated with suppression costs (Donovan et al. 2004). Gebert et al. (2007) show that landscape aspect, slope, fuel type (timber, brush, grass, etc.), fire behavior based on flame length, and the available energy at the head of a wildfire front (considering fuel moisture in both live and dead fuels) all have an impact on individual wildfire suppression costs. They also show significant differences in both total fire costs and cost per acre between Forest Service regions, with Regions 5 and 6 having significantly higher costs than Regions 1, 2, 3, 4, and Regions 8 and 9 having significantly lower costs.

Stand composition is another important consideration in wildfire activity and costs. Much of the literature takes as given that past suppression efforts have led to increased fuel loads and changes in forest stand structure that have in turn led to more intense wildfire activity, particularly in drier forests. Calkin et al. (2005) show significant increases in area burned during drier fire seasons, but also a significant increase in area burned when the previous season was more moist, suggesting that moist growing seasons increase plant growth, fuel loading, and consequently area burned in the next season. Many empirical analyses correlating costs include measures for forest and fuel conditions (Gebert et al. 2007, Gebert and Black 2012, Liang et al. 2008, Preisler 2011).

Despite the known influence of many physical and environmental variables, significant unexplained variability in costs persists between wildfires after these influences are accounted for. Regression analyses aiming to better predict suppression expenditures that consider variables for climate, wildfire size, wildfire activity and environment characteristics, significant unexplained variability (Donovan and Brown 2005, Donovan et al. 2011, Preisler et al. 2011). In addition, many of these variables are uncontrollable by land managers, and cannot be altered to evaluate different effects on suppression spending (Gebert et al. 2007).

## Socio-environmental drivers

Wildfires often affect large landscapes that have a mix of land ownership. The literature on socio-environmental drivers explores the link between rising wildfire suppression expenditures and development in the area known as the wildland-urban interface (WUI), where private property abuts public lands in wildfire-prone landscapes. Private property in the WUI is rapidly expanding; the National Academy of Public Administration (NAPA 2002) predicted a 40 percent increase in WUI homes between 2001 and 2030. A spatial analysis of western lands indicates the potential for increased development in the WUI, with just 14 percent of available interface developed and severe implications for escalating suppression expenditures with further development in the remaining 86 percent (Gude et al. 2008).

This is a crucial piece to the expenditure puzzle because the majority of wildfire suppression expenditures come from public funds, with little private funding. Although the Federal Wildland Fire Policy mandates that private property and natural resources be valued equally in resource deployment deci-

sions, federal reports suggest that private property protection is the highest priority in suppression efforts after protection of human life (NAPA 2002), and a main driver behind aggressive and expensive suppression efforts (USDA OIG 2006). Within the USDA, there is broad agreement that increased development in the WUI has contributed to rising suppression costs (USDI/USDA 1995, USDA 2003, USDA OIG 2006, GOA 2009). A 2006 audit of large wildfires determined that the protection of private property was the primary reason for suppression efforts in the majority (87 percent) of fires audited, and identified the WUI as the primary factor behind escalating suppression costs (USDA OIG 2006). Despite this recognition, measuring the effects of private property on wildfire costs can be difficult. Socio-environmental drivers are intricately entwined with policy and managerial drivers that inform resource decision-making during large wildfire events (MacGregor and Haynes 2005), and influences are often difficult to isolate.

An analysis of 58 wildfires that burned during the 2002 fire season in Oregon and Washington found no correlation between either total housing or housing density near wildfire perimeters and suppression costs (Donovan et al. 2004). Of the variables examined, only fire size and extreme terrain predicted suppression costs. The authors suggest that although their analysis found no correlation, the small sample size and significant risk to housing for all of the fires in the sample may have limited the analysis. Alternatively, they suggest that greater accessibility to areas with more housing and roads may have negated any increased cost effect in suppression.

Subsequent research on private property proximity in wildfire events that considers larger samples of fires has found significant correlations between private property and suppression costs. An analysis of 1,550 large wildfires and expenditures found that along with fire size and fire intensity, the amount


of housing located within 20 miles of large wildfire ignition locations was one of the most significant factors influencing suppression costs (Gebert et al. 2007). In an analysis of the effects of 16 non-managerial factors on the suppression costs of 100 large wildfires in the Northern Rocky Mountains, Liang et al. (2008) found that besides fire size, only the amount of private property in the burned area had a strong effect on suppression costs. The influence of private property and fire size together was greater than the influences of forest and fuel conditions or geographic region, and explained 58 percent of the variation in expenditures across the wildfires. The authors suggest that remaining variability may be explained by managerial variables that were not considered. Accordingly, more recent research has advanced some of the equations presented in Gebert et al. (2007) to include variables for management strategies and cost-affecting influences on suppression decision-making.

## Management and decision-making drivers

Suppression expenditure studies have consistently found that physical characteristics alone do not explain observed variations in costs (Donovan and Brown 2005, Liang et al. 2008, Donovan et al. 2011, Preisler et al. 2011). On an individual wildfire basis, analyses of climatic, physical, and demographic influences leave half or more of the variability unexplained (Donovan et al. 2004, Gebert et al. 2007, Liang et al. 2008, Preisler et al. 2011). Unexplained variability is often attributed to human decision-making, or managerial factors that are less quantifiable (Canton-Thompson 2006, Liang et al. 2008), but also theoretically more controllable by land managers (Gebert et al. 2007). Suppression decisions, resources, and approaches can greatly affect the cost of suppression efforts, and these decisions, resource allocations, and strategies can differ considerably between wildfire events, explaining some of the variability in wildfire expenditures remaining after biophysical drivers are accounted for.

### Suppression strategies

Gebert and Black (2012) found that different fire management objectives and strategies had significant influences on suppression costs in 1,330 large wildfires, although results for cost-efficiency depended on the timeframe considered and the cost-efficiency metric used. On a per-fire basis, more aggressively suppressed fires cost less, while less aggressive strategies generally resulted in longer burn durations, more burned acres, and greater management costs overall. The authors suggest, however, that less aggressive strategies may be more cost-effective in the long-term if current and future ecological objectives were considered along with potentially lower future suppression costs as a result of less aggressive strategies. In another study, Houtman et al. (2013) estimated the effect that letting a wildfire burn would have on future suppression costs through a process-based simulation model. They used existing models to simulate fire and suppression costs over 100 years in a Central Oregon landscape, and found that, in some cases, the cost savings in future suppression efforts as a result of letting wildfires burn was substantial. When lost timber value was considered, the benefit of letting a wildfire burn still exceeded losses in a small sample of wildfires, suggesting that a better understanding of the conditions under which the benefits of letting a wildfire burn exceed the losses can help guide wildfire management for long-term cost efficiency.

### Decision-making influences and incentives

Ultimately, wildfire management strategies and resource allocation are based on decisions made by fire managers. A handful of studies have focused on better understanding the factors that influence decision-making during wildfire suppression events, including the incentives that managers face to spend efficiently. Empirical evidence for decision-making influences and the impact of management decisions on suppression costs is particularly limited because there are little or no existing data for many conceivable non-biophysical drivers of management decision-making. To illustrate the importance of non-biophysical influences on suppression costs, Donovan et al. (2011) developed measures for two variables: newspaper coverage and political pressure. Both variables were shown to have significant impacts on suppression costs after known biophysical cost variables were considered, suggesting that the variables influenced manager decisions, affected suppression spending, and explained some of the considerable variation in costs unexplained by biophysical variables.

Canton-Thompson et al. (2008) conducted interviews with 48 Incident Management Team (IMT) members that indicated some of the perplexing dynamics of suppression decision-making. The researchers in this study found "an overwhelming amount of information" (418) on a variety of external pressures, or factors that the IMTs felt were beyond their control, but that they felt substantially limited their ability to make cost-efficient decisions. Overall, IMT members felt frustrated by increasingly complex rules, policies, procedures, and regulations aimed at a variety of objectives that were often conflicting, and a lack of agency support in coping with negative fire-related outcomes such as lawsuits or potential litigation in response to decisions made under pressure. IMT members reported that in combination with resource shortages resulting from agency financial centralization, shifting sociocultural values at large, and cultural shifts within the agency, they felt constrained and inhibited in decision-making processes that could allow them to more effectively use resources.

These studies illustrate how drivers that influence forest management and suppression strategy decisions can significantly affect expenditures during wildfire suppression events. In a review of progress and barriers towards a shift to more of a risk management framework in federal wildfire policy, Calkin et al. (2011) note "pressures faced by managers to select aggressive, and possibly expensive, strategies do not appear to be counteracted through pressure to avoid unnecessary expenditures of federal taxpayer dollars" (385). The sentiment that incentives to spend aggressively outweigh those to spend efficiently is mirrored in much of the reviewed literature that investigates suppression spending drivers within a framework of federal wildfire management and decision-making.

Individually, different investigations find that: federal wildfire budgeting processes need restructuring to reward efficient spending (Hesseln 2001, Thompson et al. 2013); wildfire managers have compelling reasons to avoid wildfire damage but do not have compelling reasons to consider the potential benefits of wildfire or the true costs of suppression expenditures while making decisions about suppression resources (Donovan and Brown 2005); federal suppression spending directives continue to encourage aggressive suppression and spending with little incentive to spend less or recognize the ecological value of wildfire (Donovan and Brown 2007); funding mechanisms that provide unlimited emergency suppression funds and federal performance measures encourage inefficient spending (Donovan et al. 2008); wildfire managers make high-cost decisions because they fear adverse outcomes regarding career and personal liability if property damages are accrued and exposed under their management, while they face few adverse outcomes from overspending (Donovan et al. 2011); incident management objectives are typically incompatible with reducing suppression costs (Canton-Thompson et al. 2008, Thompson et al. 2013); wildfire managers are faced with unclear agency direction on the importance of containing costs and little financial accountability for management actions, leading to risk-averse, aggressive-suppression tactics versus risk-based approaches to planning, budgeting, and management (Thompson et al. 2013).

Taken together, a lack of incentives among wildfire managers to contain costs during wildfire management and decision-making is attributed to oversights in overarching wildfire management philosophy, policy directives, resource valuation, budgetary structures, management practices, and personal liability protection. The authors of these studies also acknowledge, however, that significant limitations exist in shifting to wildfire management with a greater emphasis on reducing costs, for instance: public acceptance of budgetary cutoffs and increased property damage as a result of reduced


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suppression spending is unlikely even if public disapproval of escalating costs is high (Donovan et al. 2011). Recommendations for moving toward more cost-efficient decision-making among suppression managers include: incorporating an incentive structure within wildfire budgeting and resource allocation that features a fixed base suppression budget (Donovan and Brown 2005, Donovan and Brown 2007); political messaging that works toward a fundamental shift in the expectations of wildfire suppression at the federal level to build a more tolerant attitude toward wildfire (Donovan and Brown 2007); a more holistic approach to forest and wildfire management and budgeting processes (Hesseln 2001, Donovan and Brown 2005, Donovan and Brown 2007, Thompson et al. 2013); greater attention to the pressures and challenges facing Incident Management Teams to practice effective cost-containment, as well as personal liability protection against damages accrued during approved risk-based approaches (Canton-Thompson et al. 2006, Canton-Thompson et al. 2008); the incorporation of performance measures that encompass the full complexity of wildfire management, including ecological values and future costs and conditions (Donovan and Brown 2005, Donovan and Brown 2007, Gebert and Black 2012); and the application of risk-based actuarial principals to wildfire budgetary planning (Hesseln 2001, Thompson et al. 2013).

## Summary and conclusions

Controlling wildfire suppression costs has become a major public policy concern. Since the mid-1980s, annual suppression expenditures have been increasing steadily, consuming greater and greater proportions of federal land management budgets, and creating substantial issues for the Forest Service and the program objectives it manages. Scholarly investigation into the suppression spending dilemma have focused on understanding the drivers of suppression costs, and analyzing how they may be manipulated to better control costs. Suppression expenditure drivers can be broken down into physical, socio-environmental, and management drivers. Physical drivers include fire characteristics such wildfire size and intensity, larger influences such as climate, and fire environment variables such as terrain, vegetation type, and weather while burning. Physical drivers are the most readily correlated drivers of suppression costs, but these drivers are generally uncontrollable prior to or during wildfire incidents. Socio-environmental drivers include characteristics relating to private property development and values at risk in wildfire-prone areas near public land. Although these drivers are potentially somewhat controllable, they have considerable policy implications such as widespread regulations for certain types of development or action at significant scales to alter the fire-risk environment, which may be infeasible across political and geographic boundaries.

Even after biophysical and socio-environmental values at risk drivers are considered, much of the variation in wildfire suppression expenses remains unexplained, suggesting that management strategies and decisions that differ between wildfires significantly drive suppression costs and variation. Although the drivers of wildfire decision-making that influence cost are more difficult to find data for and test empirically, these drivers are theoretically more controllable through alterations in wildfire management directives, budgets, performance measures, and practices.

As policymakers search for solutions to growing suppression expenditures and the budget challenges they create, it is important that the full suite of suppression spending drivers is considered. Cost-containment measures of any type are likely to face significant pressure during large wildfire events, and progressive approaches will need to consider all of the influences on wildfire behavior and suppression decision-making in order to best align efficient spending with risk management. This paper provides an overview of the drivers of suppression spending, and serves as a resource for gathering and summarizing the academic literature to date in this field.

# Annotated bibliography

For a summary of this literature, see Appendix 1 (page 32).

**2001**

**Hesseln, Hayley. 2001. "Refinancing and Restructuring Federal Fire Management." *Journal of Forestry* 99(11): 4–8.**

This article highlights the problem of rising federal suppression expenditures by noting the dramatic example of the 2000 fire year alongside trends during the five years prior. Hesseln suggests three issues in particular as drivers behind the expenditure increases: 1) fuel loading due to past suppression policies that suppressed fires as soon as possible; 2) development in the wildland-urban interface (WUI) with the majority of increased costs to protect this development falling on federal fire management; and 3) an inefficient federal budget system that does not incentivize efficient spending. To address rising expenditures, Hesseln focuses on inefficiencies in federal budgeting, and suggests restructuring federal wildfire management budgets, programs, and processes to create a focus on fire management as a whole versus preparation and suppression individually. In particular, she suggests using private capital markets to: 1) fund a national fire management organization versed in all aspects of fire management and fuels treatment, and 2) to finance emergency suppression expenditures through catastrophic bonds that financially secure underlying risk. She highlights the need for combining presuppression and suppression spending budgets for a more holistic approach to battling rising costs, as well as the need to have people in the WUI assume financial responsibility. Hesseln concludes by explaining that a capital approach to federal funding could build human capital and expertise as well as reallocate funds based on effectiveness, enabling agencies to shift focus from regional suppression to optimal, long-term and landscape scale wildfire management.
**Driver(s) investigated:** Institutional drivers at federal budgetary level on increasing suppression costs.
**Methods:** Policy commentary
**Main finding:** To curb suppression expenditures, federal suppression budgets need restructuring for more efficient spending; a promising approach to this can be found in private capital markets.

## 2004

**Donovan, Geoffrey H., Peter Noordijk and Radeloff Volker. 2004. "Estimating the Impact of Proximity of Houses on Wildfire Suppression Costs in Oregon and Washington." Proceedings of 2nd Symposium on Fire Economics, Planning and Policy: A Global View: 19-22.**

This article presents research that empirically explores the relationship between WUI development and suppression costs by evaluating the relationship between housing proximity and suppression costs for 58 wildfires that burned in Oregon and Washington during the 2002 fire season. To relate costs to housing, the authors superimposed GIS layers of the wildfire perimeters with housing density layers derived from 2000 census data, which allowed calculation of the housing density and total housing within perimeters. They also considered total housing and housing density within 2-, 5-, 10-, and 20-mile buffers around the fire perimeters to capture the effect of houses threatened but not destroyed by the fires. Finally, they also considered variables for fuel moisture, fire size, terrain difficulty, and relative scarcity of suppression resources—based on the number of uncontained acres burning in Oregon and Washington on the day that each fire started. Regression analysis found no significant correlation between total suppression expenditures and any of the total housing or housing density variables they considered. Of the other variables considered, only total fire size and terrain extremity significantly affected suppression costs. When the model was re-estimated with per-acre costs versus total costs, all of the variables—housing-related and otherwise—were insignificant. The authors offer several explanations for the inability of the analysis to show a significant relationship between housing and suppression costs: 1) the relatively small 58-fire sample; 2) correlations between housing density and road density, which can make suppression easier and less costly due to improved access; and 3) a sample of fires that may have all been affected by nearby housing due to population density in the region as a whole. In conclusion, the authors suggest that per-acre wildfire costs may be affected most by variables unique to each fire versus variables common to all wildfires, meaning that "a generic approach to cost containment would be inappropriate and likely ineffective."

**Driver(s) investigated:** Correlations between total housing and housing density in and near wildfire perimeters on individual wildfire suppression costs

**Methods:** Regression analysis

**Main finding:** Across fires in the sample, housing measures had no significant influence on suppression costs.

## 2005

**Calkin, David E., Krista M. Gebert, J. Greg Jones, and Ronald P. Neilson. 2005. "Forest Service Large Fire Area Burned and Suppression Expenditure Trends, 1970–2002." *Journal of Forestry* 103(4): 179–183.**

This article presents empirical analyses of USDA Forest Service wildfire suppression expenditure trends using data for annual emergency suppression expenditures, number of fires, and acres burned in statistical models to estimate area burned based on drought indices from 1970-2002. Included in the analysis are data from the first two fire seasons with over $1 billion in Forest Service suppression costs (2000 and 2002). The analysis finds: 1) large wildfires (300acres or larger) were responsible for the vast majority of burned acres and emergency expenditures despite being a very small percentage of all fires; 2) emergency suppression expenditures increased and became erratic as acres burned increased and became erratic, starting notably in 1987; 3) cost-per-acre for suppression actually declined as overall suppression expenses increased, and; 4) area burned increased when the fire season was drier in all regions, and when the previous season was wetter in all but 2 regions. The authors suggest that, based on their analysis, the recent increase in suppression expenditures is related to an increase in acres burnt, spurred by a long-term weather regime shift. They note that other factors such as fuel loading, WUI development, and increased resources for structural protection do not account for a significant shift in area burned after 1987. Conversely, a long-term weather regime shift beginning in 1987 increased the length and intensity of wet and dry seasons: in wet periods

fine fuel growth adds to already over-accumulated fuel loads from fire exclusion, and in dry periods these fuels encourage larger and more intense wildfires. The authors conclude by warning against assumptions and strategies to contain costs based on anecdotal information without careful analysis.
**Driver(s) investigated:** Correlations between total number of wildfires, total acres burned, and drought severity before and during wildfire seasons on annual emergency suppression expenditures during each season
**Methods:** Regression analysis
**Main finding:** Increases in suppression expenditures are tied to weather-related shifts that began in 1987 and led to an increase in the number of acres burned.

**Calkin, David, Kevin Hyde, Krista M. Gebert, and Greg Jones. 2005. "Comparing resource values at risk from wildfires with Forest Service fire suppression expenditures: Examples from 2003 western Montana wildfire season." Research Note RMRS-RN-24WWW.**
This article explores the economic effectiveness of wildfire suppression expenditures in relation to the private property market values at risk in a case study of two large wildfires from the 2003 fire season in western Montana. The authors identify the likely direction of spread of the wildfires had they not been suppressed, determine the value of surrounding land and structure value, and employ a break-even analysis to identify the size of an expanded fire perimeter where the value of private property contained within would equal the suppression expenditures of the wildfire (the break even point). They find that because taxable residential value adjacent to the Black Mountain Fire was very high, with dense development if the fire perimeter expanded, the amount spent suppressing the fire was economically justifiable even if it reduced the fire perimeter only modestly. In contrast, because private property market value around the perimeter of the Crazy Horse Wildfire was less than the money spent suppressing it, the potential perimeter would have needed to be much larger than it actually was to economically justify the money spent suppressing it. However, there were significant non-market resource values such as bull trout spawning habitat adjacent to the Crazy Horse Wildfire perimeter. While the positive and negative effects of wildfire on bull trout habitat are not fully understood, bull trout habitat provides an example of the kinds of non-market values that could be included in analysis. The authors suggest that incorporating ecosystem considerations into the analytic approach is a challenging but necessary step in further analysis. They conclude by noting that spatial mapping of values at risk—market and non-market resources alike—can be a valuable tool for wildfire managers in strategic planning, but that application of the approach for non-market resource values must be undertaken with caution.
**Driver(s) investigated**: Private property market values at risk near wildfire perimeters as a measure of justifiable suppression expenditures
**Methods**: Break-even economic analysis in a case-study approach
**Main finding**: Mapped known market resource values can provide a valuable resource tool for strategic wildfire management; incorporation of non-market resources is possible with additional efforts to determine value change in wildfire management contexts.

**Donovan, Geoffrey H., and Thomas C. Brown. 2005. "An alternative incentive structure for wildfire management on national forest land." *Forest Science* 51(5): 387-395.**
This article investigates the influence of the incentive structure facing Forest Service fire managers on rising suppression expenditures. It considers prior literature on presuppression and suppression expenditures that illustrates physical characteristics alone do not explain cost differences, and that managerial and individual fire manager attitudes also impact costs. The authors show—through mathematical equations, decision-making process explanation, and theoretical example—how the funding mechanism for wildfire suppression has two flaws that encourage inefficient spending: 1) the potential benefits of wildfire are largely ignored when fire managers determine suppression strategies; and 2) the costs of suppression

are not fully considered because an emergency suppression budget allows deficit spending and no incentive for money savings to be used elsewhere or on other fires by fire managers. Thus, managers are set-up to inefficiently spend on suppression even if the damage reduction is incremental, ultimately increasing the net value costs of suppression. The authors propose an alternative incentive structure that features a fixed base suppression budget supplemented by a variable for the expected magnitude of the individual fire season to encourage the use of limited funds where they would be most effective. To address uncertainty about each fire year's severity, they propose that surpluses and deficits be carried over between years to account for more severe fire years when needed. To account for the beneficial effects of wildfire, they propose a budget adjustment based on the amount of forest burned in the wildfire, or more accurately, the benefits lost by protecting hectares from natural wildfires/ fuels reduction. The authors note that a shift to this type of incentive structure would require a fundamental change in public expectations for wildfire suppression, and suggest that the shift could therefore happen incrementally, in stages, and over time. They also note difficulties in determining the base budget stemming from historical cost consideration and changing values at risk from WUI development that would require more attention. In conclusion, the authors emphasize that the success of any alternative structure is dependent on fire manager's perception of government behavior for enforcing the structure.
**Driver(s) investigated**: Cost-containment incentives within the Forest Service wildfire budgeting policy
**Methods**: Economic model
**Main finding**: The current incentive structure faced by Forest Service fire managers is inefficient; a budgeting structure that limits deficit spending and considers the ecological benefits of wildfire will yield greater long-term spending efficiencies.

## 2006

**Canton-Thompson, Janie, Brooke Thompson, Krista Gebert, David Calkin, Geoff Donovan, and Greg Jones. 2006. "Factors Affecting Fire Suppression Costs as Identified by Incident Management Teams." Research Notes Rocky Mountain Research Station RMRS-RN-30.**
This research reports the results of interviews with incident management team (IMT) command and general staff members on the decision-making variables that influence suppression expenditures. The authors report many factors that were repeatedly presented during interviews as affecting costs: "lack of decision space; outside costs over which IMTs have no control; rigid policies and rules limiting the ability to manage effectively, including cost-effectively mitigating safety dangers on the ground; external decisions affecting costs; use of sophisticated technology; expanding public demand for information related to sophisticated technology; increased use of contracting for equipment and services; other demands on the agency; increased aircraft use; agency reorganizations affecting workforce availability; and new rules and regulations limiting flexibility needed for geographic differences" (from abstract). The authors suggest that deeper examination of IMTs' relationships to local land managers is necessary, as well as a better understanding of the other players involved in making wildfire decisions such as dispatchers and dispatch coordinators, Fire Use Management Teams (FUMTs), and Type 1 suppression resources such as smokejumpers and hotshot crews. Additional investigation, results, and conclusions around from these qualitative interviews around the external influences noted are presented in Canton-Thompson et al. (2008), annotated below.
**Driver(s) investigated**: Variables that influence Incident Management Team member decisions and associated wildfire suppression costs
**Methods**: Qualitative analysis; in-depth interviews
**Main finding**: Incident Management Team command and general support staff members reported a large variety of factors that influence wildfire suppression costs; these factors need greater consideration and investigation to fully understand their influence on rising suppression costs.

**2007**

**Donovan, Geoffrey H., and Thomas C. Brown. 2007. "Be Careful What You Wish For: The Legacy of Smokey Bear."** ***Frontiers in Ecology and the Environment*** **5(2): 73–79.**

This article offers a review of federal institutional history, practices, and policies around wildfire suppression and presents an overview of current concerns to suggest an alternative approach that balances short- and long-term costs and benefits of wildfire and wildfire exclusion. The authors examine historical perspectives of forest management and wildfire suppression that led to policies promoting wildfire exclusion and, subsequently, overabundance of fuels in forest systems. They explore current policies that encourage treatments such as thinning and prescribed burning to remedy the overloaded fuels, but which they contend do not adequately consider the benefits of wildfire or continued costs of ongoing aggressive suppression. The authors explain how mechanical thinning efforts to correct wildfire risk cannot adequately address overstocked fuels because of inadequate fuel management budgets to carry out the efforts at the necessary scale. In addition, they note how current wildfire management environment encourages continued aggressive suppression with insufficient incentives for cost containment, which continues to elevate wildfire risk and costs. Furthermore, as strict suppression is continually practiced, it encourages increased density in at-risk WUI fire zones, and essentially subsidizes individuals living in those areas through suppression costs paid by the public. Finally, they contend that suppression spending guidelines overlook the ecological value of wildfire. Ultimately, Donovan and Brown propose a fundamental shift in how wildfires are managed and how suppression is funded, which would force managers to consider ecological benefits of wildfire. This shift would eliminate emergency funding but allow carry over surpluses or deficits between fire seasons in areas, giving incentive to limit costs and value ecological benefits of wildfire. The authors conclude that although a shift in wildfire policies, practices, and funding is highly needed, such a shift will require a dramatic change in how the public views wildfires and suppression expectations, and inevitably raise opposition; thus Smokey Bear "needs a more nuanced message and substantial campaign funds."

**Driver(s) investigated**: The effect of historic wildfire management on the current wildfire suppression environment; the effect of current culture, policies, on rising wildfire risk and suppression costs

**Methods**: Policy review

**Main finding**: To curb excessive wildfire activity and associated spending, a significant effort to shift public and institutional views of and approaches to wildfire and wildfire suppression is necessary.

**Gebert, Krista M., David E. Calkin, and Jonathan Yoder. 2007. "Estimating Suppression Expenditures for Individual Large Wildland Fires." *Western Journal of Applied Forestry* 22(3): 188–196.**
This article presents an empirical investigation into a variety of fire characteristics that influence expenditure amounts in large wildfire events in an effort to find correlations for forecasting future expenditures. The authors develop and test a theoretical regression model to estimate expenditures for individual wildfires as a function of fire size, fire environment, values at risk, resource availability, and detection time in Forest Service regions. Fire characteristics/ variables were chosen as those often employed to explain rising suppression costs, and were tested on 1,550 large wildfires (defined as greater than 100 acres before FY2003 and greater than 300 acres after FY2003) across the United States from FY 1995-2004. The authors find that all of these variables did indeed have significant impacts on wildfire suppression costs. Variables with the largest influence were: wildfire intensity level (a measure of fire environment, based on flame length during initial burn period), total acres burned (fire size), and total housing within 20 miles of the ignition location (values at risk). They also find that both cost per acre and cost per fire differed significantly between regions, with Regions 5 and 6 have significantly higher costs, and Regions 8 and 9 having significantly lower costs, than Regions 1, 2, 3, and 4. Because the main objective of the study was to produce equations useful for predicting individual wildfire expenditures, the authors then used the equations to predict expenditures for a set of 2005 wildfires. They used the equations to flag "outliers", or wildfires with suppression expenditures falling significantly outside the normal expected range, and suggest further review of these fires to determine why they differ from other fires with similar characteristics. The authors conclude by noting that while the isolated variables all have viable roles in equations to forecast wildfire costs and identify outliers, they for the most part measure characteristics that are not within land manager control. They suggest that useful future research might therefore look at other factors that are more easily controlled, such as managerial factors, to determine their impacts on wildfire suppression costs, in addition to the variables explored in this article.
**Driver(s) investigated**: The influence of fire size, fire environment, values at risk, resource availability, and detection time on individual wildfire suppression costs.
**Methods**: Regression analysis
**Main finding**: All of the tested drivers had a significant influence on costs, with wildfire intensity, fire size, and values at risk having the most significant influence.

## 2008

**Abt, Karen L., Jeffrey P. Prestemon, and Krista Gebert. 2008. "Forecasting Wildfire Suppression Expenditures for the United States Forest Service." In *The Economics of Forest Disturbances*, edited by Thomas P. Holmes, Jeffrey P. Prestemon, and Karen L. Abt, 341–360. Netherlands: Springer Netherlands.**
As part of a book on the economics of forest disturbances, this chapter evaluates new methods for forecasting suppression expenditure budgets, premised on the reality that with the 10-year moving average model (using a 3-year out data forecast), forecasted expenditures had fallen short in 8 of the last 10 years. The authors develop simple time series regression models forecasting USFS suppression spending by national forest regions and evaluate them at two- and three-year out forecast horizons. They suggest the 3-year horizon as a useful tool during budget requests, and the 2-year horizon for updating budget requests several months later. They also use the models to develop a distribution to provide an estimate of confidence intervals for the forecasts. The authors evaluate forecasts from the models against forecasts from the 10-year moving average method. They find that actual expenditures are more volatile than any of the forecasts, regardless of the model used, implying that there is important information for forecasting costs that is not contained in time trends of cost lags. The 3-year out time series model had the lowest error, followed by the 2-year out time series model; however no model had statistically significant superiority

to the others at the 5 percent error level. All models demonstrated a poorer fit in more recent years with greater expenditures. Due to data constraints, short time series added further difficulty in determining the model of best fit. The authors then demonstrate the importance of considering loss functions and costs of both over- and under-budgeting, and describe a set of procedures that could help agency personnel to design a budget request tool that balances needs for accuracy and stability with reducing error costs. In conclusion, they suggest that development of more sophisticated time series models that consider variations in fire activity and costs beyond the variation explained in lags of cost and time trends would likely improve the accuracy of forecast models. Ultimately, they suggest factors to consider in the choice of which forecast to use, as well as variables from climate science that with recent research advances might also be incorporated for more sophisticated models.

**Driver(s) investigated**: The influence of historic seasonal suppression costs on future costs; i.e., the ability of time series models based on past seasonal suppression costs to accurately forecast suppression costs.

**Methods**: Regression analysis

**Main finding**: None of the time series models accurately predicted actual volatility of agency-wide suppression expenditures; more sophisticated time series models that consider variables beyond time trends and lags of cost with longer time-series data are needed.

**Canton-Thompson, Janie, Krista M. Gebert, Brooke Thompson, Greg Jones, David Calkin, and Geoff Donovan. 2008. "External Human Factors in Incident Management Team Decisionmaking and Their Effect on Large Fire Suppression Expenditures." *Journal of Forestry* 106(8): 416–424.**

This article presents an array of external factors that influence incident management team (IMT) decisions and associated suppression expenditures in large wildfire events, gleaned from in-depth qualitative interviews with 48 IMT and command and general staff members. External factors are those that influence decisions and expenditures, but which IMT members felt were are also outside of their control. The authors found "an overwhelming amount of information" on a variety of external pressures that the IMT members felt substantially limited their ability to make decisions influencing cost control. The most important factors from the IMT viewpoint were in the areas of: 1) risk management; 2) interaction with agency administrators; 3) policies, regulations, and rules; 4) resource availability; and 5) social–political pressures. Overall, IMT members felt frustrated by increasingly complex rules, policies, procedures, and regulations aimed at objectives that were often conflicting; and a lack of agency support in coping with negative fire-related outcomes such as lawsuits or potential litigation in response to decisions made under pressure. In combination with resource shortages resulting from agency financial centralization, shifting sociocultural values at large, and cultural shifts within the agency, IMT members reported that overall they felt constrained and inhibited in decisionmaking processes. The authors suggest that these external decisionmaking influences have been generally overlooked in the recent array of fire-cost reviews and studies aimed at containing suppression costs, exemplifying an incomplete understanding of the full suite of factors behind rising costs. They conclude by suggesting that attention to these factors is essential in developing policies to mitigate costly wildfire suppression, and recommend similar interviews with agency administrators to gain a more complete picture of the external influences on decisionmaking and costs during wildfire management.

**Driver(s) investigated**: The influence of external factors on Incident Management Team member's decisionmaking and associated expenditures during wildland fire management

**Methods**: Qualitative analysis; in-depth interviews

**Main finding**: Incident Management Team members reported many factors that they felt were beyond their control but that constrained their ability to make the most cost-efficient suppression decisions.

**Donovan, Geoffrey H., Thomas C. Brown, and Lisa Dale. 2008. "Incentives and Wildfire Management in the United States." In *The Economics of Forest Disturbances*, edited by Thomas P. Holmes, Jeffrey P. Prestemon, and Karen L. Abt, 323–340. Netherlands: Springer Netherlands.**

This book chapter examines how incentive structures within suppression funding mechanisms influence wildfire managers and their spending decisions. The authors provide a brief history of U.S. wildfire management and an overview of suppression budgeting, with the conclusion that emergency suppression funds essentially eliminate any incentive to contain costs or consider the long-term benefits of wildfire. The authors then examine how efforts for increased accountability among federal agencies have led to the development of performance measures that shape incentive structures. They suggest that the performance measures addressing suppression costs are problematic in that they encourage aggressive suppression (which may actually increase costs), ignore long-term benefits of wildfire on forest health and future suppression costs, have desired outcomes that are difficult to measure, and are based on unclear reward systems. Ultimately, the authors suggest a shift in wildfire suppression budgeting to a system that does not measure managers' performance, but encourages managers to spend their budgets efficiently in light of the costs and benefits of wildfire suppression using their professional judgment. In conclusion, they note that the proposed shift does not help determine total optimal wildfire suppression budgets, but that total budget is more of a political than an economic question: savings in suppression will likely create other losses, such as property and recreation opportunities that although economically measurable, would need be politically tolerable.

**Driver(s) investigated**: The influence of incentive structures embedded within suppression funding mechanisms on suppression costs

**Methods**: Policy analysis

**Main finding**: Funding mechanisms for wildfire suppression and suppression expenditure performance measures ultimately encourage inefficient spending; both should be reconsidered to incorporate incentives for both near- and long-term cost-efficiency during wildfire management decision-making.

**Gebert, Krista M., David E. Calkin, Robert J. Huggett Jr., and Karen L. Abt. 2008. "Economic Analysis of Federal Wildfire Management Programs." In *The Economics of Forest Disturbances*, edited by Thomas P. Holmes, Jeffrey P. Prestemon, and Karen L. Abt, 295–322. Netherlands: Springer Netherlands.**

This book chapter describes the model generally used to economically evaluate federal wildfire management programs, discusses when and where economic analysis enters wildfire program decision-making during pre-fire, fire event, and post-fire processes, and highlights difficulties in economically analysis of federal wildfire management, with suggestions for future research. The cost-plus-net value change (C+NVC) model considers fire benefits and costs to determine efficient levels of spending in fire management programs. The authors describe how the model often suffers from difficulties in accounting for net value change with consideration for both market and non-market resources, and note that the model has thus far been used mainly in determining appropriate presuppression spending levels. However, the model may also be used to determine optimal levels of spending for prevention actions, restoration and recovery activities, and suppression. The authors then explore how, when, and to what extent economic analysis enters decision-making in activities that happen before a fire (during planning, pre-positioning resources, prevention, and fuels management programs, decisions, and budgets), as a result of actual fire events and associated suppression spending (during the initial plan for suppression after fire escapes initial attack, and during the ex-post analysis of suppression costs), and for activities that happen after a fire (in decisions around rehabilitation and restoration, performance measures, and impact studies). The authors find that, in general, availability of accurate expenditure data makes time series economic analysis of wildfire management programs difficult. They note differences in accounting systems and record keeping over time, practices not designed to aid systematic investigation of suppression spending, mismatches between expenditures and fire activity, overly coarse budget object codes for some types of suppression spending,

issues with fire specific data, and lack of common data repository or fire identifier among systems as some of the key obstacles in performing economic assessment of wildfire management. In closing, the authors note steps being taken toward easier and more reliable fire data access, and suggest directions for future research that include: examining the relative effectiveness of different suppression resource types; the effect of encroaching populations into the WUI; the effect of formal policies, informal policies, and social/political pressures on suppression strategies and resources; and the effectiveness of fuel treatments on affecting fire behavior and suppression expenditures.
**Driver(s) investigated**: How economic analyses and considerations (or lack thereof) during different aspects of wildfire management may affect wildfire management costs from presuppression to suppression and post-suppression expenditures.
**Methods**: Policy analysis
**Main finding**: Complexity, unavailability, and inaccuracy of expenditure data limits time series economic analysis of many aspects of wildland fire management; there are many opportunities for future research and efforts to increase reliability of and access to fire data that can help build greater understanding around the economics of fire management

**Gude, Patricia, Ray Rasker, and Jeff van den Noort. 2008. "Potential for Future Development on Fire-prone Lands."** ***Journal of Forestry*** **106(4): 198-205.**
This article explores residential development in the wildland urban interface (WUI) as a driver of wildfire suppression costs, and critically investigates future costs by considering the potential for additional development in WUI areas with associated suppression costs. The study measures development trends and development potential by mapping buffers around public forests in 11 western states, and measuring existing development, lot sizes, housing density, and characteristics such as seasonal or non-seasonal home status of the development within buffers. The authors find that, compared to housing patterns on other western lands, housing patterns in the WUI were skewed toward lower density development, resulting in much greater per capita land consumption. WUI residences were also much more likely to be seasonal homes or cabins. The authors determine and rank the states and counties with the highest levels of WUI area, and the highest levels of developed and undeveloped WUI areas, which they portray in maps and charts. They find that overall, 4 percent of all western homes were built in the WUI by the year 2000, with 14 percent of the forested WUI developed. The authors determine that with the large majority (86 percent) of the mapped WUI undeveloped, great potential for additional WUI development is evident. They suggest that additional development in similar patterns of large lot sizes with seasonal homes will lead to rapidly expanding developed areas in the WUI, and firefighters tasked with protecting large areas of dispersed housing in these fire-prone areas. When combined with increased incidence of catastrophic wildfires from climate change, this additional development is likely to result in suppression costs that continue to rise and strain budgets. They estimate that if 50 percent of the WUI were developed, suppression costs would consume 100 percent of the Forest Service's annual budget. The authors then provide a brief review of major federal wildland fire policies and state policies around WUI development, and highlight embedded problems for producing more sustainable suppression expenditures. They suggest that to effectively reduce wildfire risk, policies must be implemented at multiple levels of government so that local, state, and federal policies are aligned. They conclude that, ultimately, policies that address wildland fuels must also be coupled with policies that address development in fire-prone lands, with an understanding of the ramifications of current development trends and incorporation of wildfire risk into planning and governance.
**Driver(s) investigated**: The influence of additional WUI development on future wildfire suppression costs
**Methods**: Geospatial analysis
**Main finding**: There is great potential for additional development in the wildland urban interface across the west; additional development following observed trends will lead to further escalating suppression costs.

**Liang, Jingjing, David E. Calkin, Krista M. Gebert, Tyron J. Venn, and Robin P. Silverstein. 2008. "Factors Influencing Large Wildland Fire Suppression Expenditures." *International Journal of Wildland Fire* 17(5): 650–659.**

This article investigates correlations between non-managerial factors and Forest Service suppression expenditures in 100 large wildfires within the Northern Rocky Mountains. The authors consider 16 specific variables for their causal effects on suppression costs including variables for fire size and shape, private property, public land attributes/ jurisdictions, forest and fuel conditions, and geographic settings. For private property, variables tested included the percentage of private land in the fire perimeter, total structure value within 8 km of the fire perimeter, and percentage of the wildland-urban interface within 8 km of the fire perimeter. The authors tested the significance of each of the 16 variables while controlling all other variables, then removed insignificant terms until a parsimonious final model was achieved. They found that only the size of the fire and private land in the burned area had strong effects on costs; when variables in these categories were accounted for no other variable had a significant effect of suppression costs. Fire size and private property together explained 58 percent of the variation in expenditures across the wildfires. The authors tested several statistical hypotheses, and determined that of the three variables measuring private property, total structure value and percentage of WUI within 8km of the fire perimeter had no effect when percentage of private property in the fire perimeter and fire size were accounted for. For the average fire size, suppression expenditures increased as proportions of private land in the perimeter increased up to 20 percent. Once private land exceeded 20 percent of the burned area, expenditures gradually declined to zero and stabilized when private land reached 50 percent of the burned area. Although this study did not examine why the effect of private land declined and stabilized, the authors presume that it was due to cost-share agreements between the Forest Service and other state and local governments, as fires with higher proportions of affected private land were close to towns. The authors conclude that efforts to decrease suppression expenditures will need to focus on the complex and politically sensitive topic of wildfires on private lands, and that the 42 percent of variation in expenditures not accounted for by the spatial factors of this study could likely be explained by management factors like incident management team type and fire experience.

**Driver(s) investigated**: The influence of 16 non-managerial factors representing fire size and shape, private property, public land attributes, forest/fuel conditions, and geographic settings on individual large wildfire suppression costs.

**Methods**: Regression analysis

**Main finding**: Of the non-managerial factors examined, only fire size and private land in the burned area had significant impacts on suppression expenditures.

**Prestemon, Jeffrey P., Karen Abt, and Krista Gebert. 2008. "Suppression Cost Forecasts in Advance of Wildfire Seasons." *Forest Science* 54(4): 381–396.**

This article describes a forecast method that can be used by the USFS to monitor suppression costs and plan for possible budgetary shortfalls. Specifically, it explores empirical models developed for forecasting wildfire suppression expenditures during two lead-times (spring and fall) before upcoming fire seasons, and compares performance to the 10-year moving average model used by the US Forest Service for budget requests. The authors suggest that fall estimates prior to the next year's fire season are necessary to provide an overall budget outlook in order to secure funding in advance of the fire season, while spring forecasts could use the latest climate information to be useful for shifts in resource repositioning or warning of potential budget shortfalls or excess. The developed models include indices for ocean temperatures, sea level pressure, and regional drought with considerations for past regional costs and time trends in each USFS region for fall and spring pre-fire-season forecasts. The authors find that the developed models are far more accurate and have significantly lower error (reducing forecast errors by approximately 60 percent) than the 10-year moving average for forecasting upcoming season costs. However, the spring forecasts,

despite inclusion of additional climate information, were not significantly better than the fall forecasts. The results suggest that climate-related changes in weather and drought may be able to explain much of the variation in suppression costs over the previous three decades. The authors also note, however, that a systemically increasing cost trend is also apparent and separate from the effects of observed effects of observed climate and weather patterns. They note that the likely drivers behind this trend (changing fuels, input costs, contracts, and population) are collinear and difficult to isolate. They suggest that further modeling at finer spatial scales is necessary to tease apart reasons for rising cost trends. They also note that improved data sets, such as with availability of for-region expenditures time series, would aid in improved understanding of costs. The authors conclude by suggesting methods, alternate variable explorations, and approaches that might further reduce uncertainties to improve the usefulness of models and yield further advances in forecasting accuracy.

**Driver(s) investigated**: The influence of climate, drought, historic costs, and time trends on seasonal costs, regionally and in aggregate

**Methods**: Regression analysis

**Main finding**: Both fall and spring models developed with consideration for climate-related changes in weather and drought significantly outperformed the 10-year moving average model in forecasting suppression expenditures, but there was no statistic difference in performance between fall and spring forecast models.

## 2009

**Abt, Karen L., Jeffrey P. Prestemon, and Krista M. Gebert. 2009. "Wildfire Suppression Cost Forecasts for the US Forest Service." *Journal of Forestry* 107(4): 173-179.**

This article explores results from regression models developed for forecasting U.S. Forest Service expenditures with 1-, 2-, and 3-year lead times, and compares model results with the 10-year moving average forecast model. The authors note that regression models used in this analysis are improved versions of models reported by Abt et al. 2008 and Prestemon et al. 2008, which are also included in this annotated bibliography. The developed models consider ocean temperature and ocean pressure indices as well as localized drought indices, a trend variable to capture systemic changes in capital, labor prices, and regional populations, and expenditures from previous years to capture persistent spending patterns. They also include an adjustment from earlier models that accounts for the significant shift in wildfire activity that occurred in the mid-80s with a control variable. Models considered different geographic regions for each of the different lead-time forecast, and insignificant variables were dropped. Sea surface and pressure were significant in the large majority of equations, drought was significant in the majority, and previous costs were insignificant in nearly all equations. Ultimately, all of the developed models were significantly more accurate than the 10-year moving average method for forecasting expenditures over the time horizons examined. The 1-year ahead model produced the lowest error rate, which was 60 percent smaller than the error derived from the 10-year moving average method. The 2- and 3-year ahead models had 40 percent and 35 percent smaller error, respectively, than the 10-year moving average over the examined time spans. The authors illustrate how the 10-year moving average method had deteriorated over time, due to its inherent slowness at responding to change in wildfire conditions. The developed regression models included external influencing physical, biological, and managerial information, and were particularly better at forecasting in more recent years when expenditures jumped dramatically. The authors suggest that while the developed regression models are significantly more accurate, the forecasted volatility would likely present a challenge to agencies and Congress under the current budget appropriations system. They note the need for appropriation mechanisms that can accommodate variability, rather than budget stability, for suppression funding. The authors conclude by suggesting that future models might develop more spatially explicit models to allow inclusions for hazardous fuel, population, development, and local weather effects.
**Driver(s) investigated**: The influence of climatic indices (sea surface and pressure), localized drought indices, systematic trends, and previous expenditure patterns on seasonal costs per geographic region.
**Methods**: Regression analysis
**Main finding**: The developed models, with inclusions for physical, biological, and managerial information/drivers, were significantly more accurate than the 10-year moving average model at forecasting suppression expenditures.

## 2011

**Donovan, Geoffrey H., Jeffrey P. Prestemon, and Krista Gebert. 2011. "The Effect of Newspaper Coverage and Political Pressure on Wildfire Suppression Costs." *Society and Natural Resources* 24(8): 785–798.**

This article explores non-biophysical drivers of wildfire suppression expenditures. Specifically, it examines how newspaper coverage and political pressure affect USFS suppression costs to provide insight on the full suite of cost drivers and show how policy remedies seeking to effectively reduce costs need to consider more than biophysical drivers. The authors highlight previous studies that fail to explain significant portions of the variability in suppression expenditures. They then explore the cost plus net value change (C+NVC) model that seeks to determine efficient levels of wildfire suppression by minimizing the sum of all wildfire-related costs and damages, and hypothesize that the model fails to consider costs borne by fire managers personally, such as adverse career consequences and personal lawsuits. They extend the model described in Gebert et al. 2007 (also annotated in this bibliography) to accommodate variables for news-

paper coverage and political pressure in net-value change (NVC), in addition to the biophysical variables included in the original model. The authors find that variables for both newspaper coverage and political pressure significantly influenced suppression costs. Newspaper coverage and political pressure variables, when positive, increased suppression costs per acre, suggesting that managers increase suppression spending in response to newspaper coverage and political pressure, and demonstrating the existence of costs borne by fire managers when making suppression decisions. The authors suggest that fire management policies that reduce these personal costs by indemnifying managers from the consequences of their decisions could help reduce expenditures. They also suggest developing guidelines about when it is appropriate to refrain from suppressing wildfires as aggressively as possible, shifting some liability from managers to agency leaders, and some decision making away from individual managers that may fear adverse outcomes if they do not spend to aggressively fight a wildfire. The authors note that some of these policy remedies (such as guidelines) could be adopted at very little cost compared to biophysical approaches such as fuel management. They conclude, however, by questioning whether agencies, policymakers, and the public will in actuality accept the consequences of reduced suppression expenditures, despite general agreement that costs and benefits of wildfire need to be balanced, and note that calls to reduce spending are often replaced by calls for more resources during wildfire events.

**Driver(s) investigated**: The influence of newspaper coverage and political pressure on individual wildfire costs

**Methods**: Regression analysis

**Main finding**: Variables for both newspaper coverage and political pressure increased wildfire suppression costs, illuminating the role of non-biophysical variables in driving suppression costs.

**Preisler, Haiganoush K., Anthony L. Westerling, Krista M. Gebert, Francisco Munoz-Arriola, and Thomas P. Holmes. 2011. "Spatially Explicit Forecasts of Large Wildland Fire Probability and Suppression Costs for California." *International Journal of Wildland Fire* 20(4): 508–517.**

This article explores spatially explicit forecasts of upcoming fire activity and costs that would enable more efficient suppression spending efforts by focusing resources where they would have the greatest effect. The authors present statistical models for forecasting upcoming wildfire numbers, locations, and costs 1-6 months prior to upcoming fire seasons. The presented models advance previous forecasting attempts by both using and outputting spatially explicit data for forecasts, versus overall season expenditures. Model estimation is done in 2 steps: first, a statistical model relating suppression costs per fire to fire size, vegetation, and topography; second, a probability model estimating probability of occurrence of large wildfires spatially using vegetation, topography, and climate variables as predictors. The two models are combined to produce spatially explicit forecasts of fires and suppression costs for the upcoming fire season. The authors then test the model on past wildfires in California to compare the forecast results with actual recorded wildfire occurrences and costs. They find that the models produced spatially explicit forecasts of large wildfires probabilities that matched the occurrence of large fires well with the exception of years during which there were widespread lightning events, which are difficult to predict. The models were able to differentiate between low- and high-cost fire years and regions when forecasting suppression expenditures, but they left a large degree of unexplained variability. The authors note that the unexplained variability in expenditures was expected, as non-biophysical managerial variables that are not easily captured in spatially explicit statistical models very likely contribute to variance in suppression expenses between wildfires. They conclude by noting that spatial representations of where large and costly wildfires are likely to occur each season could prove useful to wildfire managers and efforts to increase suppression efficiency by focusing resources where they are likely to have the greatest impact. They suggest that, with expansion of the presented methodology for testing beyond California, it may be useful for predicting nationwide suppression expenditures.

**Driver(s) investigated**: The influence of vegetation, topography, and hydroclimate on wildfire activity and costs; the ability of these influences to accurately and spatially explicitly predict upcoming wildfire season activity and costs

**Methods**: Regression analysis

**Main finding**: The models produced spatially explicit forecasts of large wildfires probabilities that matched the occurrence of large fires well; the models differentiated between low- and high-cost fire seasons but left a large degree of unexplained variability in suppression costs.

## 2012

**Gebert, Krista M., and Anne E. Black. 2012. "Effect of Suppression Strategies on Federal Wildland Fire Expenditures." *Journal of Forestry* 110(2): 65–73.**

This article examines the interplay between wildfire management strategies and objectives and federal emergency wildfire management expenditures. In close cooperation with field managers and personnel, the authors classify 1,330 large (300+ acre) federally managed wildfires to one of two management objectives (protection and resource benefit) consisting of five fire management strategies (direct, modified, limited, and 2 resource benefit strategies that were ultimately joined due to low sample numbers). They assess the effect of differing strategies on costs through a comparison of means approach followed by a regression analysis to test single variables independently from other explanatory variables (environmental characteristics, values at risk, and geographic region). The authors find that management strategies had a significant impact on costs, but the results varied by agency and the cost metric used. Through analyses of means they find that: 1) suppression strategy had a significant impact on total fire suppression cost, with modified suppression strategy fires having much higher average costs than other strategies; 2) suppression

strategy had a significant impact on suppression cost per acre, with the most aggressive strategy having significantly higher per acre costs than less aggressive strategies; 3) fire size was significantly lower for the most aggressive strategy compared to less aggressive strategies. Contrary to their hypothesis, the means analysis showed no difference in daily costs between the strategies, with longer events costing more and duration, rather than strategy, appearing to drive costs. Through regression analysis, the authors find again that management strategies affect costs, but the results vary by both agency and the costs metric used. On a per fire basis, more aggressively suppressed fires cost less. With cost per acre, the limited suppression strategy fires had cost 52 percent less per acre compared to direct suppression; however modified suppression strategy fires had similar cost per acre as direct suppression fires. Low sample size for fires classified as mixed resource benefit/ for resource benefit that had large variations in cost made significant differences between this strategy and others difficult to determine. Ultimately, on a per-year basis, aggressive efforts reduced costs by reducing acres burnt. Less aggressive strategies generally led to more acres burned and greater expenses. However, when current and future ecological objectives, plus potentially lower future suppression costs are considered, the authors note that less aggressive strategies may be more cost-effective long-term. They conclude by suggesting that to truly assess cost performance of federal agencies, additional investigations around fuel treatments, firefighter safety impacts, ecological outcomes, and processes for monitoring decision making that encompass the full complexity of wildfire management are necessary.
**Driver(s) investigated**: The influence of different fire management objectives and strategies on wildfire suppression expenditures.
**Methods**: Regression analysis
**Main finding**: Management strategies affect cost, but results vary by agency, cost metric, and time frame considered.

## 2013

**Houtman, Rachel M., Claire A. Montgomery, Aaron R. Gagnon, David E. Calkin, Thomas G. Dietterich, Sean McGregor, and Mark Crowley. 2013. "Allowing a Wildfire to Burn: Estimating the Effect on Future Suppression Costs."** ***International Journal of Wildland Fire*** **22(7): 871-882.**

This article examines the impact that intentionally letting wildfires burn may have on future suppression costs through process-based simulation modeling on a Central Oregon study area over 100 years. The authors note increased fuel loads from legacy policies that encouraged aggressive suppression, the prohibitive costs of landscape-scale fuel treatments to adequately address the unnaturally accumulated fuel levels, and the availability of existing fire behavior models to simulate fire and estimate future costs in different scenarios. They develop a least-cost-plus-net-value-change economic model that estimates one component of wildfire benefits—the value of a current wildfire in providing fuel treatment benefits that reduce future suppression costs. The authors combine models of fire behavior, forest vegetation, fire suppression effectiveness, and fire suppression costs to simulate fire on the landscape for a Central Oregon study area over 100 years. They then generated a set of scenarios for subsequent wildfire ignitions and weather events to estimate potential cost savings in subsequent fires. They find that the majority of the sample paths had modest but positive cost savings in future suppression costs, and in some cases, substantial potential savings were realized in subsequent suppression efforts. Simulations with the largest cost savings were those that followed a large initial fire relatively early in the time horizon during severe weather. Fires in the same scenario that occurred either later in the time horizon after the initial fire (allowing more fuels to accumulate) or during milder weather had small but still positive cost savings. The authors also undertook a preliminary estimate of net benefit by considering potential timber value losses in addition to suppression savings, and found that although in the large majority of wildfires this loss was much greater than the savings benefit in future suppression efforts, in 4.6 percent of the sample, the benefit of letting the fire burn still exceeded losses. They suggest that a better understanding of the conditions under which the net benefits of letting a wildfire burn exceed the costs will help guide wildfire management by identifying areas that meet those conditions. The authors conclude by reiterating that immediate suppression of all wildfires is no longer sustainable or feasible, and that with more comprehensive and credible models for measuring values at risk reflective of management objectives on particular landscapes, policy rules can be developed and applied to make informed let-burn decisions.

**Driver(s) investigated**: The influence that letting a wildfire burn has on future suppression costs

**Methods**: Process-based simulation model?

**Main finding**: Letting wildfires burn may produce substantial cost-savings in future wildfire suppression; additional research can improve cost estimates to consider comprehensive current and future benefits and losses for informed wildfire management decision-making.

**Thompson, Matthew P., David E. Calkin, Mark A. Finney, Krista M. Gebert, and Michael S. Hand. 2013. "A Risk-based Approach to Wildland Fire Budgetary Planning."** ***Forest Science*** **59(1): 63–77.**

This article analyzes the Forest Service's budgetary planning and processes to better understand embedded incentives and disincentives for cost containment. It focuses on the role of fire managers, their decisions, and overall agency direction in affecting suppression expenditures. The authors draw on previous literature to show how the incentive structure for wildfire managers rewards excessive spending to the detriment of cost containment. They then present a range of approaches for increasing financial accountability in suppression spending, emphasizing an approach that applies actuarial principles to wildfire budget planning and performance evaluations in a broad wildfire risk management scope. The approach introduces the use of statistical expectations for suppression expenses as a performance measure. Statistical expectations for forest-level expenditures are derived through a simulation model that outputs suppression cost probability distributions with the help of available models and tools. The suppression costs of output fires are then estimated using a regression model explained in previous research (Gebert et al.

2007, also annotated). The authors demonstrate proof of concept by generating annual suppression cost distributions for National Forest Regions 3 and 5, and comparing estimated suppression expenditures of fires from the simulation model with observed expenditures from 2000-2009. Simulated suppression costs were considerably lower than observed costs, with a range of possible explanations, but in relative terms, simulated costs were accurately assigned in that high- and low-cost forests were identified, and high-cost forests accurately captured a high percentage of spending. The authors detail modeling improvements in data, models, and methods that could refine estimates for expected forest-level expenditures accurate enough to be used in performance measures. The authors then illustrate how wildfire management could be extended to incorporate actuarial principles in a way that would further incentivize appropriate risk-management and cost containment across fire and fuels management holistically to account for actions that happen before and after, in addition to during, wildfire incidents. They illustrate how financial loss from large wildfire suppression is an insurable list according to seven criteria, suggest national forest "premiums", and outline the benefits of a wildfire budgetary planning framework premised on actuarial risk management principles. They acknowledge that application of such an insurance system would require an overhaul of fire and forest management at all levels, and suggest near-term positive incentives for cost-containment as well as considerations to weigh before adoption of proposed frameworks. The authors conclude by summarizing findings, offering recommendations for future agency direction, and reiterating that proper management of risk and incentives is essential for managing the escalating cost of wildfires.
**Driver(s) investigated**: The influence of incentives (or lack thereof) embedded within wildland fire budgetary processes.
**Methods**: Critical investigation of budgetary incentives; simulation modeling to estimate suppression costs probability distributions; empirical analysis to estimate suppression expenditures of fires and fire seasons derived from simulation model
**Main finding**: Wildfire management and budget planning could benefit from the application of risk-based actuarial principles with suppression-estimate-based performance measures to reduce escalating suppression costs.

# Appendix 1: Summary of annotated literature

| Year | Title | Authors | Driver(s) investigated | Methods | Main finding |
|---|---|---|---|---|---|
| 2001 | "Refinancing and restructuring federal fire management" | Hesseln, Hayley | Institutional drivers at federal budgetary level on increasing suppression costs | Policy commentary | To curb suppression expenditures, federal suppression budgets need restructuring for more efficient spending; a promising approach may be in private capital markets. |
| 2004 | "Estimating the impact of proximity of houses on wildfire suppression costs in Oregon and Washington" | Donovan, Geoffrey H.<br>Noordijk, Peter H.<br>Radeloff, Volker | Correlations between total housing and housing density in and near wildfire perimeters with individual wildfire suppression costs | Regression analysis | Across fires in the sample, housing measures had no significant influence on suppression costs. |
| 2005 | "Forest Service large fire area burned and suppression expenditure trends, 1970–2002" | Calkin, David E.<br>Gebert, Krista M.<br>Jones, J. Greg<br>Neilson, Ronald P. | Correlations between number of wildfires, acres burned, and drought severity before and during wildfire seasons with annual emergency suppression expenditures during each season | Regression analysis | Increases in suppression expenditures are tied to weather-related shifts that began in 1987 and led to an increase in the number of acres burned. |
| 2005 | "Comparing resource values at risk from wildfires with Forest Service fire suppression expenditures: Examples from 2003 western Montana wildfire season" | Calkin, David E.<br>Hyde, Kevin<br>Gebert, Krista M.<br>Jones, J. Greg | Private property market values at risk near wildfire perimeters as a measure of justifiable suppression expenditures | Break-even economic analysis | Mapped known market resource values can provide a valuable resource tool for strategic wildfire management; incorporation of nonmarket resources is possible with additional efforts to determine value change in wildfire management contexts. |
| 2005 | "An alternative incentive structure for wildfire management on national forest land" | Donovan, Geoffrey H.<br>Brown, Thomas C. | Cost-containment incentives within the Forest Service wildfire budgeting policy | Optimization analysis | The current incentive structure faced by Forest Service fire managers is inefficient; a budgeting structure that limits deficit spending and considers ecological benefits of wildfire will yield greater long-term cost efficiencies. |
| 2006 | "Factors affecting fire suppression costs as identified by Incident Management Teams" | Canton-Thompson, Janie<br>Thompson, Brooke<br>Gebert, Krista M.<br>Calkin, David E.<br>Donovan, Geoffrey H.<br>Jones, J. Greg | Variables that influence Incident Management Team member decisions and associated wildfire suppression costs | Qualitative analysis; in-depth interviews | Incident Management Team command and general support staff members reported many factors as influencing wildfire management decisions and costs; these factors need greater consideration in rising suppression cost investigations. |
| 2007 | "Be careful what you wish for: The legacy of Smokey Bear" | Donovan, Geoffrey H.<br>Brown, Thomas C. | The effect of historic wildfire management on the current wildfire suppression environment; the effect of current culture, policies, on rising wildfire risk and suppression costs | Policy review | To curb excessive wildfire activity and associated spending, a significant effort to shift public and institutional views of wildfire and suppression is needed. |
| 2007 | "Estimating suppression expenditures for individual large wildland fires" | Gebert, Krista M<br>Calkin, David E.<br>Yoder, Jonathan | The influence of fire size, fire environment, values at risk, resource availability, and detection time on individual wildfire suppression costs | Regression analysis | All of the tested drivers had a significant influence on costs, with wildfire intensity, fire size, and values at risk having the most significant influence. |

| Year | Title | Authors | Driver(s) investigated | Methods | Main finding |
|---|---|---|---|---|---|
| 2008 | "Forecasting wildfire suppression expenditures for the United States Forest Service" (Book Chapter) | Abt, Karen L. Prestemon, Jeffrey P. Gebert, Krista M. | The influence of historic seasonal suppression costs on future costs; i.e., the ability of time series models based on past seasonal suppression costs to accurately forecast suppression costs | Regression analysis | None of the time series models accurately predicted actual volatility of agency-wide suppression expenditures; more sophisticated time series models that consider variables beyond time trends and lags of cost with longer time-series data are needed. |
| 2008 | "External human factors in Incident Management Team decisionmaking and their effect on large fire suppression expenditures" | Canton-Thompson, Janie Gebert, Krista M. Thompson, Brook Jones, J. Greg Calkin, David E. Donovan, Geoffrey H. | The influence of external factors on Incident Management Team member's decision-making and associated expenditures during wildland fire management. | Qualitative analysis, in-depth interviews | Incident Management Team members reported many factors that they felt were beyond their control but that constrained their ability to make the most cost-efficient suppression decisions. |
| 2008 | "Incentives and wildfire management in the United States" (Book Chapter) | Donovan, Geoffrey H. Brown, Thomas C. Dale, Lisa | The influence of incentive structures embedded within suppression funding mechanisms on suppression costs | Policy analysis | Funding mechanisms for wildfire suppression and suppression expenditure performance measures ultimately encourage inefficient spending; both should be reconsidered to incorporate incentives for both near- and long-term cost-efficiency during wildfire management decision-making. |
| 2008 | "Economic analysis of federal wildfire management programs" (Book Chapter) | Gebert, Krista M. Calkin, David E. Huggett, Robert J. Jr. Abt, Karen L. | How economic analyses and considerations (or lack thereof) during different aspects of wildfire management may affect wildfire management costs from presuppression to suppression and post-suppression expenditures | Policy analysis | Complexity, unavailability, and inaccuracy of expenditure data limits time series economic analysis in many aspects of wildland fire management; many opportunities exist for research and efforts to increase reliability and obtainability of fire data to build greater understanding around economics of fire management. |
| 2008 | "Potential for future development on fire-prone lands" | Gude, Patricia Rasker, Ray van den Noort, Jeff | The influence of additional WUI development on future wildfire suppression costs | Geospatial analysis | There is great potential for additional development in the wildland urban interface across the west; additional development following observed trends will lead to further escalating suppression costs. |
| 2008 | "Factors influencing large wildland fire suppression expenditures" | Liang, Jingjing Calkin, David E. Gebert, Krista M. Venn, Tyron J. Silverstein, Robin P. | The influence of 16 non-managerial factors representing fire size/shape, private property, public land attributes, forest/fuel conditions, and geographic setting on individual large wildfire suppression costs | Regression analysis | Of the non-managerial factors examined, only fire size and private land in the burned area had significant impacts on suppression expenditures. |

| Year | Title | Authors | Driver(s) investigated | Methods | Main finding |
|---|---|---|---|---|---|
| 2008 | "Suppression cost forecasts in advance of wildfire seasons" | Prestemon, Jeffrey P.<br>Abt, Karen L.<br>Gebert, Krista M. | The influence of climate, drought, historic costs, and time trends on seasonal costs, regionally and in aggregate | Regression analysis | Both fall and spring models developed with consideration for climate-related changes significantly outperformed the 10-year moving average model in forecasting suppression expenditures, but there was no statistic difference in performance between fall and spring forecast models. |
| 2009 | "Wildfire suppression cost forecasts for the US Forest Service" | Abt, Karen L.<br>Prestemon, Jeffrey P.<br>Gebert, Krista M. | The influence of climatic indices (sea surface and pressure), localized drought indices, systematic trends, and previous expenditure patterns on seasonal costs per geographic region | Regression analysis | The developed models, with inclusions for physical, biological, and managerial information/drivers, were significantly more accurate than the 10-year moving average model at forecasting suppression expenditures. |
| 2011 | "The effect of newspaper coverage and political pressure on wildfire suppression costs" | Donovan, Geoffrey H.<br>Prestemon, Jeffrey P.<br>Gebert, Krista M. | The influence of newspaper coverage and political pressure on individual wildfire costs | Regression analysis | Variables for both newspaper coverage and political pressure increased wildfire suppression costs, illuminating the role of non-biophysical variables in driving suppression costs. |
| 2011 | "Spatially explicit forecasts of large wildland fire probability and suppression costs for California" | Preisler, Haiganoush K.<br>Westerling, Anthony L.<br>Gebert, Krista M.<br>Munoz-Arriola, Francisco<br>Holmes, Thomas P. | The influence of vegetation, topography, and hydroclimate on wildfire activity and costs; the ability of these influences to accurately and spatially explicitly predict upcoming wildfire season activity and costs | Regression analysis | The models produced spatially explicit forecasts of large wildfires probabilities that matched the occurrence of large fires well; models differentiated between low- and high-cost fire seasons but left a large degree of unexplained variability in suppression costs. |
| 2012 | "Effect of suppression strategies on federal wildland fire expenditures" | Gebert, Krista M.<br>Black, Anne E. | The iinfluence of different fire management objectives and strategies on wildfire suppression expenditures | Regression analysis | Management strategies affect cost, but results vary by agency, cost metric, and time frame considered. |
| 2013 | "Allowing a wildfire to burn: Estimating the effect on future suppression costs" | Houtman, Rachel<br>Montgomery, Claire A.<br>Gagnon, Aaron R.<br>Calkin, David E.<br>Dietterich, Thomas G.<br>McGregor, Sean<br>Crowle, Mark | The influence that letting a wildfire burn has on future suppression costs | Simulation modeling | Letting wildfires burn may produce substantial cost-savings in future wildfire suppression; additional research can improve cost estimates to consider comprehensive current and future benefits and losses for informed wildfire management decision-making. |
| 2013 | "A risk-based approach to wildland fire budgetary planning" | Thompson, Matthew P.<br>Calkin, David E.<br>Finney, Mark A.<br>Gebert, Krista M.<br>Hand, Michael S. | The influence of incentives (or lack thereof) embedded within wildland fire budgetary processes | Simulation modeling | Wildfire management and budget planning could benefit from the application of risk-based actuarial principles with suppression-estimate-based performance measures to reduce escalating suppression costs. |

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Oregon State University OSU

Ecosystem Workforce Program

University of Oregon

Joint Fire Science Program

Sustainable Northwest

Center for Natural Lands Management

The Nature Conservancy
Protecting nature. Preserving life.

Forest Service
U.S. Department of Agriculture