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COMMENTARY

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Key Points:

- Globally, wildfires affect surface water supplies, but fire-related natural and social interactions are often unknown
- Interactions between water domains —ecohydrology, hydrological services, society and water risks, and global water resources—are complex
- Future assessments of wildfire threats to water supply resilience must acknowledge impacts on these water domain interactions

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Reframing the Challenge of Global Wildfire Threats to Water Supplies

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Abstract The timing, extent, and severity of forest wildfires have increased in many parts of the world in recent decades. These wildfires can have substantial and devastating impacts on water supply, ecohydrological systems, and sociohydrosystems. Existing frameworks to assess the magnitude and spatial extent of these effects generally focus on local processes or services and are not readily transferable to other regions. However, there is a growing need for regional, continental, and global scale indices to assess the potential effect of wildfires on freshwater availability and water supply resilience. Such indices must consider both the individual and compound effects of wildfires. In so doing, this will enable comprehensive insights on the water security paradigm and the value of hydrological services in fire-affected areas around the globe.

Plain Language Summary The number of large forest fires and the length of the wildfire season have both increased globally in the past few decades. Wildfire trends are expected to continue due to increasing occurrence of drought and denser forests associated with historical forest management and fire suppression. This development has raised concerns for water supplies because most water used for irrigation, industry, hydropower, recreation, and community drinking water comes from rivers draining watersheds that are prone to wildfires. As such, it is critical to improve our understanding of the capacity of watersheds and downstream communities to absorb or mitigate fire impacts. In this commentary, we emphasize the need for new continental and global scale indices to assess the full range of wildfire hazards to water supply and society. This will ultimately contribute to sustainable policies and land management plans for safeguarding water supplies and community health.

1. Introduction

The timing, extent, and severity of forest wildfires have increased in many parts of the world in recent decades, aggravating the potential impacts on water supplies (Flannigan et al., 2013; Martin, 2016). In particular, wildfire seasons have been longer and wildfires have become more severe, in part, due to drier conditions associated with climate change (Flannigan et al., 2009; Jolly et al., 2015). In addition, decentralized urbanization has led to a rapid increase in areas that are part of the wildland-urban interface, where residences are built among fire-prone forests or grasslands (Radeloff et al., 2005). To protect these structures and human safety, wildfire policy and management have focused heavily on fire suppression, which has unintentionally increased fuel availability and the potential for more destructive wildfires (Balch et al., 2017; Schoennagel et al., 2017). In turn, this has increased the threats to water supply in fire-affected regions such as North America, Australia, and the Mediterranean (Bladon, 2018; Hallema et al., 2018; Robinne et al., 2018).

The implications of this coupled wildfire and water resource risk for the sustainability of surface freshwater supplies are not well understood, even though millions of people depend on water production in wildfire-affected basins that may be vulnerable, in various degrees, to postfire water pollution, water stress, or floods (Robinne et al., 2016, 2018). Recent studies suggest that wildfire risk must be incorporated into future assessments of surface water supplies (Kinoshita et al., 2016; Martin, 2016); however, we currently lack a general framework for connecting local fire impacts to water security metrics. The challenge is to properly quantify how wildfire impacts on water resources translate into water-related risk over time and disperse and propagate from one location to another.

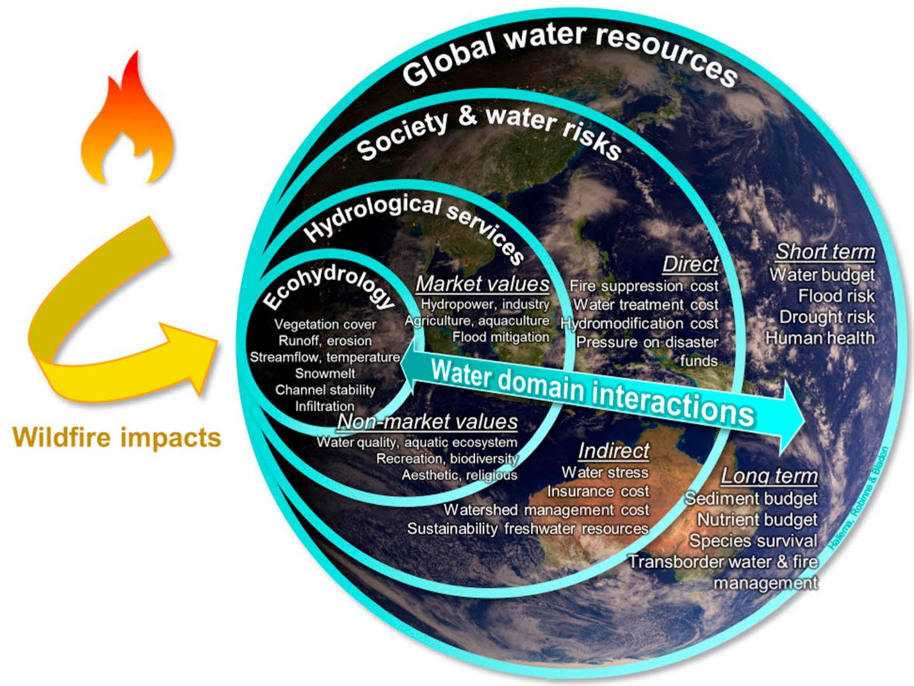

Figure 1. Water supply is impacted by wildfire via water domain interactions, but much remains unclear about the magnitude and direction of these interactions (background image credit: NASA Earth Observatory, 2002).

We postulate that (1) continental and global scale indices are needed to assess the potential role of wildfire hazards on freshwater availability and water supply resilience, here defined as the adaptive capacity to maintain present and future water supply in the face of postfire hydrological disturbance (Emelko et al., 2011; Wang & Blackmore, 2009). Furthermore, we argue that (2) finer-scale data and model adaptations (e.g., coupled fire-water balance models, postfire land cover changes and flow recovery, and ecosystem service valuation) accounting for a diversity of parameters shaping sociohydrosystems (e.g., natural environment, political factors, culture, and society) must be integrated within global analyses. In so doing, we emphasize a forward-looking view of the coupled wildfire and water resource risk, integrating both natural and social aspects of large-scale risk assessment (Wesselink et al., 2017).

2. The Challenge of Determining Global Wildfire Threats to Water Supplies

There is a great deal of uncertainty about the nature of wildfire threats to water supplies and their implications for sustainable development, regional and national economies, and responsibilities of the various respective stakeholders in water governance and water use. This uncertainty, combined with the expected impacts of climate trends on wildfire hazard and water availability, emphasizes the need to consider larger scale environmental and social factors controlling for the likelihood of a local event to trigger bottom-up adverse consequences (Sivapalan et al., 2014). Inclusion of these factors will yield more accurate assessments of the coupled wildfire and water resource risk to downstream values, thereby enhancing stakeholder capacity to identify vulnerabilities.

Furthermore, wildfires of comparable size and severity occurring in different areas can pose dissimilar threats to water resources based on the sociohydrologic characteristics of affected areas (Di Baldassarre et al., 2018). It is commonly believed that postfire impacts on local water supplies can diminish regional water supplies if environmental thresholds are exceeded. This can happen when the postfire decline in forest cover accelerates storm runoff, reducing the amount water storage in the ground. The downstream propagation of wildfire threats to water supplies can have far-reaching implications for water governance in fire-affected regions and downstream areas around the planet (Bladon et al., 2014). Fire threats to surface water may be amplified in regions with greater population density and/or lower economic wealth, those regions being among the most vulnerable to the envisioned impacts of global environmental change (Flannigan et al., 2013; Schlosser et al., 2014).

Historically, wildfires burned extensively but were often less concerning due to comparatively low population densities. However, the recent growth of the wildland-urban interface linked to worldwide urban sprawl has raised concerns about the impacts of wildfire on the quality of upstream source waters. Recognizing and measuring fire impacts on source water supply is a daunting task, partly because of a lack of scalable data on the extent and severity of wildfires alongside an absence of water resource monitoring in most fire-affected countries. Additionally, models used to help understand patterns and processes reflected by the data are usually constrained to one particular watershed and the ecosystem services it provides (e.g., water supply, erosion control, and support for ecosystems) and explain little about interactions with existing socio-hydrological factors or the connection of the watershed to regional water security.

3. Complex Interactions Between Water Domains

Specific challenges for data and models are best addressed by subdividing global hydrological functioning into what we call water domains (Figure 1), viz., the ecohydrological domain, ecosystem service domain, sociohydrologic domain, and water security domain. These water domains are nested and partially overlap; however, our knowledge within and across domains is incomplete and unequally distributed.

The majority of research on fire effects on surface water resources is within the ecohydrological domain and has occurred at the small plot to watershed scale (Hallema, Sun, Bladon, et al., 2017). However, even within this water domain, interactions are complex and not fully understood. For example, several studies have illustrated strong discrepancies between measurements of postfire infiltration, hydraulic conductivity, and scaling of runoff generation due to interactions between flow processes, soil properties, and surface characteristics (Ebel & Moody, 2017; Langhans et al., 2016). As a result, many basic ecohydrological processes are poorly represented in models, creating substantial challenges for assessments of impacts on hydrological services, society, and global water resources.

Moreover, our knowledge of fire effects on water supplies at the regional to global scales is less complete and has received less attention (Emelko et al., 2016; Hunsinger et al., 2008). However, some statistical models have proven useful in scaling postfire effects on limited parameters (e.g., water yield and sediment) from the watershed scale to the regional scale (Sankey et al., 2017; Wine et al., 2018), especially when combined with process-based climate models (Hallema et al., 2018). As scale increases, the complexity of interactions across the four water domains also likely increase; however, it is critical for future research to address these challenges and improve our understanding and models of the complex interactions between the water domains.

Models will be indispensable in addressing these challenges because of their practical value for rapid assessment of wildfire effects, postfire watershed management, and their intrinsic value in helping us to understand underlying mechanisms of hydrologic responses. However, advancement in models "depends on supporting new experimental work, new field observations, and new data collection networks" (Kennedy et al., 2017; Kirchner, 2006). In particular, we require more field-based experiments on the effects wildfire on water quantity and quality in understudied regions. Reports of the relative decline of field studies (Burt & McDonnell, 2015) are troubling given the scarcity of hydrological data (Blair & Buytaert, 2016). There is now an abundance of hydrological, erosion, and sediment transport models that can account for a variety of small-scale processes (e.g., runoff) and large-scale processes (e.g., the global water cycle; Hallema, Sun, Caldwell, et al., 2017). However, the demand for larger scale models able to deal not only with finer-scale processes but also with sociohydrological consequences of wildfire is increasing rapidly (Robinne et al., 2018). The results from such models would help identify regions at risk and better inform international water policies according to wildfire hazards. This represents an essential economic requirement for bringing down the cost of regional water treatment, reservoir management, flood insurance, and disaster funding. The nature and duration of wildfire impacts on hydrological processes, as well as their consequences on the provision of water-related ecosystem services, and the effectiveness of watershed restoration have not yet been quantified across temporal and spatial scales (Hallema, Sun, Bladon, et al., 2017).

To address the challenge of future wildfire threats to freshwater production and distribution, we must also account for compound effects of local and regional wildfire threats to water security in fire-affected areas.

This compound effect of continental and global scale drivers of fire activity and distribution is greater than the sum of their impacts within smaller-scale sociohydrosystems. That is to say, scaling wildfire impacts in sociohydrological systems to dynamics on water stress at the continental and global scale is not the only translation issue. The other challenge is to determine how the cumulative impacts of fire on hydrologic ecosystem services (e.g., water quality impairment, limited flood control, water supply seasonality, and decline aquatic ecosystems) affect sociohydrology and regional water governance (Brauman, 2015).

4. Incorporating Natural and Social Interactions Into Future Fire-Water Risk Assessments

Practical knowledge of top-down and bottom-up interactions between water domain functions is critical for improving the fundamental understanding of compound wildfire impacts on water security. The key to learning is to focus simultaneously on combining data and models for each water domain and on scaling data and models between domains. Understanding transient wildfire impacts on water resources cannot be achieved with either field data or models in isolation—we must integrate both to formulate critical hypotheses that can be tested against field experiments. The knowledge generated from field studies can then help improve our models, providing important keys to better integrate controlling social and environmental factors. Comparatively, models can provide insights into the range of variables that may affect water resources. For example, machine learning techniques have the ability to learn specific wildfire impacts on water supply and interactions with environmental and sociohydrological processes across different scales (Hallema et al., 2018). This demonstrates the mutual benefit of real-world data collection and data-driven modeling of water supply within individual water domains (Olden et al., 2012). Such understanding will promote the use of adapted techniques to better design long-term water governance in fire-prone regions without compromising socioeconomic development and ecosystem functions (Kondolf et al., 2014).

There is a pressing need to understand the effects of wildfire on water resources, aquatic ecosystem health, and human uses of water at a range of spatial and temporal scales. Upscaling wildfire impacts in finer-scale systems (i.e., ecohydrological and hydrological services domains) to sociohydrologic and regional/continental/global water supply systems and vice versa will yield practical knowledge (e.g., model choice and parameterization) that will prove beneficial to all water domains and is essential to formulating indices of the role of fire in the quest for water security at a worldwide scale (Kumar, 2015). This will enable policy researchers to identify international implications: We will be better equipped to address transnational water security issues (e.g., boundary waters, human health, flood risk, and water pollution). By combining natural and social factors in a single coupled data-modeling approach, we will foster transdisciplinary scientific efforts and become able to perform integrated assessments of the coupled wildfire and water resource risk to downstream values, ranging from local water supply protection to the governance of regional water pressures. In this manner, we will achieve a more comprehensive view of the water security paradigm that accounts for sociohydrologic considerations pertaining to the value of hydrological services in fire-affected areas.

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