

Wildfire and Hydrological Processes

Elizabeth W. Boyer, Joseph W. Wagenbrenner, and Lu Zhang

¹ Penn State University, Department of Ecosystem Science and Management, University Park, PA, 16802 USA, ewb100@psu.edu

² USDA Forest Service, Pacific Southwest Research Station, Arcata, CA, USA, joseph.wagenbrenner@usda.gov

³ CSIRO Land and Water, Canberra, Australia, Lu.Zhang@csiro.au

* Corresponding author

Note: this is a pre-print of this manuscript that was accepted and minorly revised for publication. The citation for the final accepted version is: Boyer EW, JW Wagenbrenner, and Lu Zhang (2022). Wildfire and Hydrological Processes. Hydrological Processes, 36(7), e14640, DOI: 10.1002/hyp.14640.

Abstract

Climate change is a crucial factor in increasing wildfire risks, where warmer and drier conditions, increased drought periods, and increased lightning strikes have made many areas more susceptible to burning. This special issue focuses on *Wildfire and Hydrological Processes*, exploring how wildfire has impacted watersheds and water resources. The manuscripts in this collection underscore how wildfire can change the nature of vegetation, characteristics of soils, hydrological flow paths, and residence times of water in the critical zone, and provide new insights toward predictability of wildfire impacts on watersheds. The studies reveal that wildfire can affect water quantity and quality over varying timescales, from during the active burning to years and decades afterward.

Preface

Climate change is a crucial factor in increasing wildfire risks, given warmer and drier conditions, increased drought periods, and increased lightning strikes affecting initiation and burn severity (Veraverbeke et al., 2017). Many vegetated areas worldwide have become more susceptible to wildfires; due to a combination of factors such as low precipitation, earlier snow melt, high air temperatures, low humidity, strong wind, land cover change, and increases in accumulated fuels. In recent decades, unprecedented wildfires have burned extensive areas worldwide, with significant societal implications, including effects on hydrological processes and water resources (Figure 1).



Figure 1. In many areas of the world, wildfires have become more common, with major societal implications. Public domain photo of a wildfire in Montana, by John McColgan, U.S. Forest Service.

This special issue focuses on *Wildfire and Hydrological Processes*, exploring how wildfire has impacted watersheds and water resources. The manuscripts in this collection underscore how wildfire can change the nature of vegetation, characteristics of soils, hydrological flow paths, and

residence times of water in the critical zone. Wildfire can affect water quantity and quality over varying timescales, from during the active burning to years and decades afterward. For example, in their important warning on extreme wildfire risks to water supply, Robinne et al. (2021) highlight that post-fire hazards such as source water contamination, flash flooding, and mudslides can represent long-term risks to drinking water production, aquatic life, and socio-economic activity. Pre- and post-fire land management can help to mitigate the impacts.

Numerous papers in this issue are focused on how wildfires affect streamflow generation and water quality from burned areas of the landscape. Vore et al. (2020) explored interrelationships in British Columbia, Canada, between climate, extreme forest fire seasons, mountain pine beetle outbreaks, and runoff in eight large watersheds within the Fraser and Peace drainage basins. Caldwell et al. (2020) showed that water yields in the Appalachian region of the southeastern United States (USA) were much greater in burned than unburned reference watersheds. Guo et al. (2021) explored the impacts of wildfires and climatic variability on streamflow from 14 catchments in Australia, where the 2009 Victoria wildfires caused a significant increase in mean annual streamflow for an immediate post-wildfire period. Tramier et al. (2021) explored the impacts of wildfires and invasive mammals on hydrological regimes in the tropical island valley of New Caledonia in the southwest Pacific Ocean, demonstrating the linkage between land cover and hydrological responses. Wilson et al. (2021) explored how streamflow and sediment delivery from hillslopes to streams is affected by stream channel networks and watershed connectivity, studying stormflow responses to the 2012 High Park Fire in Colorado. Nunes et al. (2020) explored the impacts of wildfire and post-fire management on watershed responses in a catchment in the Mediterranean Rim region of Iberia in southwestern Europe. In an agricultural catchment that was ~10% burned in a wildfire, sediment generation greatly increased, though streamflow did not, in the years directly following the fire. In their study of wildfire responses in the southern Appalachian Mountain region of the US, Caldwell et al. (2020) found that nitrate and total suspended solids concentrations were higher in burned watersheds and increased with increasing high burn severity extent, especially during storm events. In a laboratory experiment, Boyer et al. (2022) showed that smoke deposition onto water surfaces can transiently impact water quality.

Additional papers focused on how post-wildfire conditions impact watershed response, informing land management that promotes vegetation re-growth and maintains ecosystem functions. For example, after wildfires, salvage logging is sometimes conducted to minimize economic losses of burned timber and generate logging slash that can be used as part of a land management strategy. Cole et al. (2021) explored sediment yields issuing from watersheds following the 2015 Valley Fire in the northern California Coast Range, investigating the effects of post-fire salvage logging and sub-soiling after salvage logging. Robichaud et al. (2020) studied the impacts of the 2015 wildfires in Washington, USA, finding that skid trails without logging slash produced significantly more sediment than the skid trails having a logging-slash cover treatment. Olsen et al. (2021) quantified post-fire and post-salvage logging sediment yields following the 2013 Rim Fire in the Sierra Nevada mountains of California, using rill patterns to identify sediment source areas; showing that adding ground cover on skid trails and between areas disturbed by post-fire logging and stream channels may reduce sediment yields. In Washington, USA, Robichaud et al. (2021) explored the use of leaving undisturbed stream buffer zones between the upland post-fire logging areas and the stream, showing that a standard 15 m buffer zone was sufficient to contain surface runoff and reduce sediment concentration on unburned sites, but the buffer width must be larger to be effective in burned areas (Robichaud et al., 2021). Prats et al. (2021) conducted rainfall simulation experiments after a high-severity wildfire in the Boggs Mountain Demonstration State Forest of the northern Coast Range in California, USA demonstrating that soil compaction (e.g., from post-fire salvage logging skidder traffic) can greatly decrease soil infiltration and increase soil erosion, while covering the compacted soil with logging slash can decrease soil degradation and sediment yield. Rakhmatulina et al. (2020) and Stiefel et al. (2021) discuss how wildfire can enhance areas of water repellent soils, which can increase runoff and associated water quality loadings during follow-on precipitation events. Stiefel et al. (2021) studied the impacts of the 2016 Chestnut Knob Fire in the Appalachian Forest region of North Carolina, USA, showing the extent of soil hydrophobicity and water repellency varies significantly with burn severity and between ecosystems. Rakhmatulina et al. (2020) studied hydrophobic soils in the Sierra Nevada region of California, USA, showing how repeated post-fire freeze/thaw processes affect soil water repellency and hydrophobicity, and highlighting the importance of this process in soil recovery from fire.

Several papers focused on improving the prediction capability of the impacts of wildfire on post-fire streamflow or water quality, identifying important model concepts and parameters. Ebel et al. (2020) focused on quantifying post-wildfire flooding and debris flow hazards, showing that wildfire effects on soil water-retention were dominated by reductions in hydraulic conductivity, soil moisture, soil-water retention, and soil bulk density in burned soils, which in turn was attributed to fire-induced decreases in soil structure. Cao et al. (2021) simulated the effects of rural road networks on surface runoff generation and soil erosion, and sediment delivery to streamflow from the 2016 Emerald Fire in the Lake Tahoe basin of California, USA highlighting management opportunities to detain eroded sediments. Wilder et al. (2021) demonstrated that machine learning methods using information on watershed characteristics performed better than simple empirical methods for predicting post-fire peak streamflow; and provided a new analytical solution for rapid prediction of post-fire streamflow rates.

Some specific wildfires of focus in this issue include: the 2009 Victoria wildfire in Australia (Guo et al., 2021), wildfires in British Columbia, Canada (Vore et al., 2020); and wildfires in the Mediterranean Rim region of Iberia (Nunes et al., 2020). Additional papers focused on wildfires in California, USA -- including the 2013 Sierra Nevada Rim Fire (Olsen et al., 2021), the 2015 Valley Fire in the northern Coast Range (Cole et al., 2020; Pratts et al., 2021), the 2016 Emerald Fire in the Lake Tahoe region (Cao. et al., 2021), and the 2017 Thomas Fire (Ebel et al. 2020). Further studies addressed the 2015 and 2016 fires in the Okanogan Highlands of Washington, USA which consisted of several fires, including the Cayuse Mountain, Tunk Block, and North Star Fires (Robichaud et al. 2020, 2021), the 2012 High Park Fire in Colorado, USA (Wilson et al., 2021), and the 2016 Chestnut Knob and other wildfires in the southern Appalachian Mountains region of the USA (Caldwell et al. 2020, Stiefel et al., 2021).

Another common theme in this collection is that despite advancements in understanding how wildfires affect hydrological and critical zone processes across heterogeneous landscapes, there is more to learn. For example, papers identified the need for further research on the following topics: effects of soil properties and catchment connectivity on runoff generation, impacts of post-fire conditions on stormflow and extreme events, the duration of the post-fire recovery

period, increased wildfire risk under climate change and the effect on ecology, and advancing predictability at regional scales.

Acknowledgements

This synthesis was supported by NSF award # EAR-2012893 (to EWB). We thank journal editor-in-chief Dörthe Tetzlaff for her contributions. View the special issue on *Wildfire and Hydrological Processes* at: [https://onlinelibrary.wiley.com/doi/toc/10.1002/\(ISSN\)1099-1085.wildfire-hydrological-processes](https://onlinelibrary.wiley.com/doi/toc/10.1002/(ISSN)1099-1085.wildfire-hydrological-processes).

References

- Boyer, EW, MA Moritz, MG Brown (2022). Smoke Deposition to Water Surfaces Drives Hydrochemical Changes. *Hydrological Processes* 36: <https://doi.org/10.1002/hyp.14626>
- Cao, L, W Elliot, JW Long (2021). Spatial simulation of forest road effects on hydrology and soil erosion after a wildfire. *Hydrological Processes* 35:e14139. <https://doi.org/10.1002/hyp.14139>
- Caldwell, PV, KJ Elliott, N Liu, JM Vose, DR Zietlow, JD Knoepp (2020). Watershed-scale vegetation, water quantity, and water quality responses to wildfire in the southern Appalachian Mountain region, United States. *Hydrological Processes* 34: 5188– 5209. <https://doi.org/10.1002/hyp.13922>
- Cole, RP, KD Bladon, JW Wagenbrenner, DBR Coe (2020). Hillslope sediment production after wildfire and post-fire forest management in northern California. *Hydrological Processes* 34: 5242– 5259. <https://doi.org/10.1002/hyp.13932>
- Ebel, BA, JA Moody (2020). Parameter estimation for multiple post-wildfire hydrologic models. *Hydrological Processes* 34: 4049– 4066. <https://doi.org/10.1002/hyp.13865>
- Guo, Y., Zhang, L., Zhang, Y., Wang, Z., & Zheng, H. X. (2021). Estimating impacts of wildfire and climate variability on streamflow in Victoria, Australia. *Hydrological Processes* 35(12): e14439. <https://doi.org/10.1002/hyp.14439>
- Nunes, JP, L Bernard-Jannin, ML Rodríguez-Blanco, A-K Boulet, JM Santos, JJ Keizer (2020). Impacts of wildfire and post-fire land management on hydrological and sediment processes in a humid Mediterranean headwater catchment. *Hydrological Processes* 34: 5210– 5228. <https://doi.org/10.1002/hyp.13926>
- Olsen, WH, JW Wagenbrenner, PR Robichaud (2021). Factors affecting connectivity and sediment yields following wildfire and post-fire salvage logging in California's Sierra Nevada. *Hydrological Processes* 35:e13984. <https://doi.org/10.1002/hyp.13984>

- Prats, SA, MC Malvar, JW Wagenbrenner (2021). Compaction and cover effects on runoff and erosion in post-fire salvage logged areas in the Valley Fire, California. *Hydrological Processes* 35:e13997. <https://doi.org/10.1002/hyp.13997>
- Rakhmatulina, E, S Thompson (2020). Freeze–thaw processes degrade post-fire water repellency in wet soils. *Hydrological Processes* 34: 5229– 5241. <https://doi.org/10.1002/hyp.13931>
- Robichaud, PR, SA Lewis, RE Brown, ED Bone, ES Brooks (2020). Evaluating post-wildfire logging-slash cover treatment to reduce hillslope erosion after salvage logging using ground measurements and remote sensing. *Hydrological Processes* 34: 4431– 4445. <https://doi.org/10.1002/hyp.13882>
- Robichaud, PR, ED Bone, SA Lewis, ES Brooks, RE Brown (2021). Effectiveness of post-fire salvage logging stream buffer management for hillslope erosion in the U.S. Inland Northwest Mountains. *Hydrological Processes* 35:e13943. <https://doi.org/10.1002/hyp.13943>
- Robinne, F-N, DW Hallema, KD Bladon, MD Flannigan, G Boisramé, CM Bréthaut, SH Doerr, G Di Baldassarre, LA Gallagher, AK Hohner, SJ Khan, AM Kinoshita, R Mordecai, JP Nunes, P Nyman, C Santín, G Sheridan, CR Stoof, MP Thompson, JM Waddington, Y Wei (2021). Scientists' warning on extreme wildfire risks to water supply. *Hydrological Processes* 35:e14086. <https://doi.org/10.1002/hyp.14086>
- Stiefel, LC, SC Cooley, BG Johnson (2021). Increased colluvial hollow discharge and subsequent recovery after a low intensity wildfire in the Blue Ridge Mountains, USA. *Hydrological Processes* 35:e13971. <https://doi.org/10.1002/hyp.13971>
- Tramier, CMC, P Genthon, QRC Delvienne, NL Sauvan, JJO Cassan, E Ebrard, PS Dumas, Y Quefféleau (2021). Hydrological regimes in a tropical valley of New Caledonia (SW Pacific): Impacts of wildfires and invasive fauna. *Hydrological Processes* 35:e14071. <https://doi.org/10.1002/hyp.14071>
- Veraverbeke, S., Rogers, B., Goulden, M. et al. (2017). Lightning as a major driver of recent large fire years in North American boreal forests. *Nature Climate Change* 7, 529–534. <https://doi.org/10.1038/nclimate3329>
- Vore, ME, Déry, SJ, Hou, Y, Wei, X (2020). Climatic influences on forest fire and mountain pine beetle outbreaks and resulting runoff effects in large watersheds in British Columbia, Canada. *Hydrological Processes* 34: 4560– 4575. <https://doi.org/10.1002/hyp.13908>
- Wilder, BA, JT Lancaster, PH Cafferata, DBR Coe, BJ Swanson, DN Lindsay, WR Short, AM Kinoshita (2021). An analytical solution for rapidly predicting post-fire peak streamflow for small watersheds in southern California. *Hydrological Processes* 35:e13976. <https://doi.org/10.1002/hyp.13976>

Wilson, C, Kampf, SK, Ryan, S, Covino, T, MacDonald, LH, Gleason, H. (2021). Connectivity of post-fire runoff and sediment from nested hillslopes and watersheds. *Hydrological Processes* 35:e13975. <https://doi.org/10.1002/hyp.13975>