Hydrology and stream water quality of fire-prone watersheds

Fernando A. L. Pacheco¹ and Luís F. Sanches Fernandes²

Abstract

This study reviewed current research on the nexus ‘wildfires-watershed hydrology-stream water quality’. Various studies used remote sensed Earth observation data to improve the understanding of soil erosion and water balance in burned watersheds and their relationships with fire variables (e.g., severity). It was noteworthy the application of computer models to assess fire-related hydrologic processes (e.g., soil-water repellence) and their control over runoff generation. The discussions about short-term and long-term impacts of wildfires were prominent, including streamflow reductions following vegetation resprouts or mobilization of metals. The controls of wildfire impacts drove studies about the role of spatial scale in the rainfall thresholds for postfire runoff and sediment delivery or the role of snowpack decline in the anticipation of peak flows in Boreal latitudes. Finally, it is worth mentioning the research on fire management, as a measure to restore stream water yields in forested watersheds and prevent subsequent fires.

Addresses

¹ Centro de Química de Vila Real, Universidade de Trás-os-Montes e Alto Douro, Ap 1013, 5001-801, Vila Real, Portugal

² Centro de Investigação e Tecnologias Agroambientais e Biológicas, Universidade de Trás-os-Montes e Alto Douro, Ap 1013, 5001-801, Vila Real, Portugal

Corresponding author: Pacheco, Fernando A.L. (fpacheco@utad.pt)

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Wildfires, Watershed hydrology, Stream water quality, Impact assessment, Impact control factors, Restoration to prefire conditions.

Introduction

Wildfires are a natural phenomenon that always affected aquatic ecosystems [1,2]. Given the complex interplay between the natural environment and spatiotemporal patterns of burned areas, the assessment of wildfire impacts on the hydrology and water quality of catchments required multiple standpoints of observation. This has fragmented the scientific literature into

studies that mostly addressed the hydrologic impacts (e.g., postfire runoff and flood-peak increases combined with infiltration decreases) and studies that looked into the consequences of sediment and ash discharge into the water masses, including turbidity, nutrient, and metal contamination. In both cases, the topics to address were quite large. This has led some authors to concentrate the scientific effort on developing models capable to track the impacts back and forth, while other authors encountered research niches on factors controlling the impacts or in the hydrologic restoration postfire. Water resources planning in fire-prone watersheds was also the focus of many scientific publications.

The present review tackles a number of issues relevant to the ‘wildfire-watershed hydrology-stream water quality’ nexus, highlighting the current research. [Figure 1](#) captures the review structure. The term ‘wildfires’ occupies the center of the figure because wildfires are the focus of this review. The statement ‘Watershed hydrology and stream water quality’ surrounds the word ‘wildfires’ to alert the readers to the nexus. We separated hydrology from water quality because this division was common in the consulted papers. Within these broad sections, we addressed various topics as highlighted in the studies, namely the assessment and monitoring of wildfire impacts, factors controlling wildfire impacts, restoration from wildfires, modeling approaches, and water resources management in fire-prone watersheds. In [Figure 1](#), these topics appear as keywords placed outside the hexagram. The review structure portrayed in this figure and described above reflects the ways the selected studies approached the several topics and subtopics. We captured those approaches and transposed them into the subsections of this presentation. The review ends up with a table that summarizes general outcomes. The selection of papers followed the journal guidelines of including about 50 papers published in the past 2–3 years and resulted from a consult to SCOPUS database. The search for papers involved the use of search strings ‘wildfires’, ‘fire-prone watersheds’, ‘watershed hydrology’, and ‘stream water quality’.

Hydrology of fire-prone watersheds

Impacts of wildfires on watershed hydrology:

I – assessment and monitoring

Hydrologic processes and water balance components are both sensitive to land cover changes caused by wildfires.

Figure 1

Summary of topics and subtopics discussed in recent literature about hydrology, water quality and burned watersheds.

A hydrologic process commonly amplified by wildfires is water erosion. Recently developed technologies, such as time-lapse cameras and terrestrial laser scanning, allowed to map erosion features developed on a severely burned landscape located in the Chiricahua Mountains (Arizona, USA) [3]. The features included rills and gullies, sediment-laden flows, and debris flows. On a wildland–urban interface area (the Rafina catchment located in Attica, Greece), innovative multitemporal remotely sensed Earth Observation data allowed to compare prefire and postfire erosion rates considering fire severity [4*]. The eroded materials ultimately reach the watercourses contributing to sediment loads. In a study following the largest and most deadly forest fire in Portugal (Pedrógão Grande, 2017), which caused a sudden and drastic removal of vegetation cover in the Mondego River basin, the analysis of river sediment composition allowed to understand sediment sources (granite, metasediment) and control factors (orography) of sediment transport [5].

The changes to water balance components are another prominent consequence of wildfires in catchments around the globe. For example, following the large fires of January 2017 that burned over 500,000 ha of native forest around the Quivolgo locality in central Chile, streamflow reduced significantly triggered by increased evapotranspiration of vigorously resprouted forest [6]. Wildfires also decreased evapotranspiration relative to unburned and prefire controls in California's Sierra Nevada, an impact that sometimes lasted 15 years after the fire and varied with burn severity, prefire canopy

density, and hydro-topographic environment [7*]. Another example reported infiltration declines in the Kudremukh national forest (Western Ghats of India) following the 2017 fires, estimated from historical satellite hydro-climatic datasets and hydrologic modeling (SWAT) [8]. In the mountainous areas of the Shingle Creek watershed within the Twitchell Canyon fire complex (USA), where snow is a fundamental contributor of streamflow, wildfires caused earlier disappearance of snowpack in burned areas relative to unburned areas, particularly on south-facing slopes [9]. The study of François-Nicolas Rafael Pimentel and Berit Arheimer [10*] evaluated the impact of a large forest fire that occurred in 2014 in the Västmanland County, south-central Sweden, highlighting the shorter and delayed snow season in the burned areas relative to neighbor nonburned forests, as well as the reduction in the duration of high and low flow conditions. In a scoping review, François-Nicolas Robinne et al. summarized the results of postfire hydrologic studies in high-latitude forests of Canada and Alaska, also highlighting the role of wildfires on the seasonal timing of flow [11].

Many studies dedicated attention to the monitoring of hydrologic processes and water balance conditions to get the long-term response of watersheds to wildfires. The seven-year monitoring of runoff generation thresholds following the 2010 Fourmile Canyon fire (Boulder, Colorado, USA), showed a progressive decrease of runoff generation for identical precipitation events as the time after the fire has passed [12]. For example, beyond the first three years, only 30–100 return period events generated surface runoff. The five years after the 2003 Lost Creek forest fire that burned a vast region in the eastern slopes of the Rocky Mountains (southern Alberta, Canada), showed a 20–220% higher mean annual water yield and peak flows from burned relative to unburned watersheds [13]. Other studies included projections of future hydrologic catchment response to wildfires. Using the SWAT model in the Elbow River watershed (Alberta, Canada), Danielle Loiselle et al. simulated streamflow changes resulting from wildfires compounded with climate change scenarios until 2062 [14]. The results suggested higher streamflow yields due to increased surface runoff relative to nonforest fire simulations. The SWAT was also the hydrologic model used to project stream-flow components in a Sabor River watershed (Northeast of Portugal) devastated by a large forest fire [15]. In this case, the simulations revealed increases in surface flow and decreases of lateral and groundwater flows.

The assessment of hydrologic impacts related to wildfires resorts to measurements and models. The SWAT model embeds a diversity of hydrologic processes and has the capability to handle land-use changes, including wildfires; however, it fails to account for hydraulic effects specifically related to vegetation burns, such as soil-water

repellence. The study of Jun Wang et al. developed the PFHydro to explicitly simulate vegetation interception and soil-water repellence effects for high, medium, and low burn severities [16*]. Because of soil-water repellence, the runoff was about three to six times after the fire than before the fire. With the advent of free and abundant remotely sensed Earth observation data, as well as of globally available datasets, basin-wide to worldwide studies evaluated various water-fire nexus. A study of Waldo Canyon fire that burned about 74 km² of land near Colorado Springs in 2012 related reductions in the normalized burn ratio calculated from MODIS satellite imagery and due to the fire, with concurrent increases in runoff production under similar external conditions (event precipitation depths, intensities, and antecedent soil moisture) [17]. The study of François-Nicolas Robinne et al. presented a global diagnosis on forest fire-water risk based on the Driving forces-Pressures-State-Impacts-Response risk analysis framework and the necessary global environmental databases [18].

The disturbance of catchment hydrology by wildfires has societal implications addressed in various studies, such as drinking water supply or watershed management. The decrease of aquifer recharge in the 'Serra do Rola Moça State Park' (Minas Gerais, Brazil), related to loss of vegetation cover by wildfire, caused deficits in the replenishment of headsprings that supply drinking water to Belo Horizonte and surrounding urban centers [19].

Impacts of wildfires on watershed hydrology: II – control factors and feedbacks

The consequences of wildfires for catchment hydrology differ as a function of spatial scale, fire severity, postfire land cover, time postfire, mulch treatments, climate change, among other factors. In turn, the modified hydrologic conditions in the burned watershed may change the risk of forest fire besides other feedbacks. Rainfall thresholds for postfire runoff and sediment delivery increased significantly across spatial scales after the Colorado Front Range fires (USA) [20*]. For example, two years after the 2000 Bobcat fire the minimum thresholds were 4.4, 7.3, and 12 mm/h in unmulched plots (≤ 0.06 ha), hillslopes (0.07–5.2 ha), and watersheds (100–1500 ha), respectively. Evapotranspiration decreased as function of soil burnt severity and postfire land cover after the 2011 Las Conchas fire in New Mexico (USA) [21]. The postfire evapotranspiration was 19.9–36.1%, 15–34.1%, and 8.7–29.1% lower than the prefire counterparts in high, moderate, and low soil burnt severity areas, respectively. Evapotranspiration in the postfire grassland cover was 18–51% lower than the prefire conifer cover values. Forest residue mulch (chopped eucalyptus bark and twigs fibbers) reduced soil loss by water erosion by as much as 91% during the five postfire years of 2010 Sever do Vouga (Portugal) moderate severity fire [22]. A coupled hydrologic-

erosion model applied to the Salmon River Basin (Idaho, USA) predicted the anticipation of peak flows (1–2 months) in response to a declining snowpack under warming temperatures, projected in the future climate scenarios [23].

The loss of vegetation because of wildfires means more runoff entering the streams in the shorter term because the burned trees and bushes are not using that water; however, as the forest resprouts and the growing trees consume more water, substantial reductions in the water yield from the catchments will occur over the coming decades, intensifying droughts. In turn, the occurrence of more prolonged and severe extreme meteorological conditions amplifies the risk of summer wildfires [24]. Other feedbacks from catchments affected by wildfires relate to dry ravel, the transport of sediment by gravity, which transfers material from steep hillslopes to valley bottoms during dry conditions. Burned catchments are prone to dry ravel, and hence, more susceptible to short-term sediment delivery in response to storms. Dry-ravel processes following the 2013 Springs Fire occurred in the Big Sycamore Canyon (southern California), produced deposits distributed irregularly at the margins of stream channels, which, in turn, dominated the postwildfire sediment yields [25].

Hydrologic recovery from wildfires or in the forest environment

Recovery of vegetation tends to bring watersheds toward their prefire conditions normalizing the basin-wide hydrologic parameters. The time for recovery depends on many factors but natural conditions can return 4–6 years after the fire. This recovery period occurred in the Upper Nahal Oren basin (Mt. Carmel, Israel) following the 2010 fire that consumed nearly one-third of the basin's vegetation cover [26*]. This was accomplished besides the drastic hydrologic changes caused by the fire in the 2010–2013 period. In these years, the threshold rainfall amounts for flow generation decreased by 50%, the number of flow events increased by 180%, base flows practically disappeared or lasted for just a few days, and suspended sediment concentrations increased by 2–3 orders of magnitude. In semiarid regions where water shortages are frequent, the recovery of watersheds to prefire conditions enhances where perennial springs populate the forested areas. Following the 2014 forest fire in the Asaayi Creek Watershed and Royal Gorge Park (Colorado, USA), springs provided a critical source of water that directly affected soil moisture, and in turn, protected roots and buds allowing native vegetation to regenerate [27].

In the meantime between fire occurrence and natural recovery, mitigation of flooding and elevated sediment loads can protect downstream water resources. Straw-bale check dams are an option to reduce sediment yields

in small ephemeral catchments where rainfall intensities are low and soils are less erodible. This type of treatment trapped 50% of sediments delivered from catchments in the Twitchell Canyon (Utah, USA) during the two years following the 2010 fire [28]. Post-fire straw mulching is another measure especially justified in the case of postfire recovery from high burn severity fires. In these cases, soil organic matter needs to rebuild while the mulch protects soil from erosion. The study of Prats et al. developed in Monchique (Portugal) and Casares (Spain) after the 2018 fires evidenced a 65–76% reduction of soil erosion accomplished by application of straw-biochar mulching over high to moderate burn severity areas [29*]. Straw mulching has protected the soil from erosion even where the burned areas experienced salvage logging, but had no real impact on runoff control, as pointed out by Lucas-Borja et al. working in Lietor (Spain) after the 2016 fire burned about 830 ha of forest land [30].

Forest fire management may be a preventive measure to restore stream water yields in forested watersheds, at the same time that avoids subsequent fires. Trees are deep-rooted vegetation capable to consume large volumes of water. If fire reduces this demand by a reasonable predefined amount (e.g., 20%), it frees up some water to recharging groundwater resources and subsequently to surface water supplies as streamflow. Besides, fire management acts through reducing fuel loads and hence the risk of severe fires. In the Illilouette Creek Basin (Upper Merced Watershed, Yosemite National Park, California, USA), there seems to be a signal of enhanced streamflow production following the institution of managed wildfire regime in 1972 [31,32]. Moreover, forcing the ecohydrological model developed for this basin with an ensemble of downscaled future climate predictions, showed identical hydrological impacts of fire use to those observed under present-day climate conditions [33*]. Ecohydrologic enhancement also occurred in the Great Basin in the USA, where pinyon and juniper removal by prescribed fire effectively re-established a successional trajectory towards sagebrush-steppe vegetation structure and thereby reduced runoff and sediment yield from high-intensity rainfall by > 2 fold [34]. Despite the potential virtues of protective (e.g., straw mulching) and preventive (e.g., managed fire) measures taken separately, the discussion about hydrologic resilience of fire-prone areas is still ongoing and authors tend to integrate wildfire, water, and society into common research [35].

Stream water quality in fire-prone watersheds

Impacts of wildfires on stream water quality

Wildfires impact water quality as severely as they modify the hydrology of affected watersheds, with potential sequels for aquatic biota [36–38]. Fortunately, the

quality changes seem to last shorter than the hydrologic impacts. The study of three fires that occurred in the Northern California Coastal Ranges in 2015 evidenced high levels of turbidity (e.g., 871 ± 747 NTU for the Rocky fire), color (6014 ± 6098 Pt–Co), and suspended solids (613 ± 626 mg/L) during the first rainy season postfire [39*]. Then, they decreased to reference values in the second year (36 ± 47 NTU, 362 ± 478 Pt–Co, and 96 ± 158 mg/L, respectively). The fluxes of dissolved organic carbon, dissolved organic nitrogen, and ammonium were also larger in the first year after the burns ($67 \pm 40\%$, $418 \pm 125\%$, $192 \pm 120\%$, and $31 \pm 17\%$, respectively) and recovered to reference values in the second year. Nitrate concentrations were, however, practically undetected in the first year but increased significantly in fire-impacted streams during the second rainy season, probably owing to delayed nitrification. Contrarily to the short time scales of forest fire impacts on stream water quality, spatial scales can be very large. Following the devastating 2016 Fort McMurray wildfire in western Canada, ash transport in rivers has been signaled in river basins as large as $100,000 \text{ km}^2$ following rainfall events [40].

Wildfires can mobilize metals in runoff reducing the benefits of high-quality potable water provision from forested watersheds. Globally, preserving these watersheds in a pristine state supports the economy of approximately US\$ 4.1 trillion/yr by limiting the cost of expensive drinking water treatments and provision of unnecessary infrastructure [41*]. One particularly relevant issue regarding metal mobilization from burnt soils and ashes relates to mercury (Hg) washout by postfire rainfall that can reach streams and lakes via runoff transport. After the 2010 fires occurred in Ermida and São Pedro do Sul (Portugal), Isabel Campos et al. reported 0.5 g Hg/ha exported from burnt areas towards adjacent areas [42]. The mobilization of metals from wildfire-affected watersheds is, however, not restricted to Hg. In a comparative study about lead (Pb) and iron (Fe) leaching from burnt forests and urban areas, Paulina Pinedo-Gonzalez et al. highlighted the larger proportions of soluble Pb and Fe in storm runoff from the fire-affected (58% and 24% of total dissolved, respectively) than from urbanized watersheds (17% and 8%) [43]. The study of the 2010 Fourmile Canyon Fire near Boulder (Colorado, USA) revealed how the exposure of mine tailings and waste rock due to the burn of vegetation cover, along with hydrologic changes induced by the wildfire, have accelerated the mobilization and dispersal of arsenic and metals to local streams [44].

The impacts of wildfires on stream water quality can trigger water security problems, which may negatively influence source water quality and treatment [45,46]. The study of Regina Santos et al. showed large stream flows overlapped with large phosphorus concentrations in the Beça River basin (Portugal) and showed how

Table 1

Summary of general outcomes reported in scientific studies that recently addressed the nexus 'wildfires – watershed hydrology – stream water quality'. The outcomes are valid for the case studies indicated below the heading 'source'. They are not generalizable.

Forest fire impacts on watersheds				
Research topic	Hydrology	Source(s)	Water quality	Source(s)
Assessment	Use of time-lapse cameras and terrestrial laser scanning to map water erosion	[3]	Investigating the sources of high phosphorus concentrations in forested watersheds approaching the problem from the 'pressures-pathways-receptors' conceptual model	[49]
	Use of remotely sensed Earth Observation data to compare prefire and postfire erosion rates considering fire severity	[4]	Use empirical deterministic spatiotemporal relationships between land cover, nonpoint pollution sources, and erosion to estimate accumulations from the overland flow within the watershed	[50]
	Use of historical satellite hydro-climatic datasets to assess infiltration declines postfire	[8]	Combine physically described processes with stochastic models to assess water quality risk in wildfire-prone catchments	[51]
	Use of global environmental databases to assess forest fire-water risk on Earth	[18]	Creation of a dataset containing relevant information to develop spatial indicators of wildfire risk for water security	[48]
	Use of general hydrologic models (e.g., SWAT) to project water balance components in fire-prone watersheds in the near future	[14,15]		
	Use of specific hydrologic models (e.g., PFHydro) to account for hydraulic effects specifically related to vegetation burns (e.g., water repellence)	[16]		
Short-term impacts	Streamflow reduction is triggered by increased evapotranspiration of vigorously resprouted forest	[6]	Quality changes seem to last no longer than 1–2 years, i.e. less than the hydrologic impacts	[39]
	Evapotranspiration decreases relative to prefire and unburned catchments, lasting for 15 years postfire and depending on burn severity, prefire canopy density, and hydro-topographic environment	[7]	Nitrate concentrations can be undetected in the first year but increase significantly in fire-impacted streams during the second rainy season, probably owing to delayed nitrification	[39]
	Earlier disappearance of snowpack in burned areas relative to unburned areas	[9]	Fire-related ash transport in rivers can be signaled in river basins as large as 100,000 km ² following rainfall events	[40]
	Shorter and delayed snow season in the burned areas relative to neighbor nonburned forests	[10]	Forest fires can mobilize metals in the runoff, such as Hg, Pb, Fe, As, among others	[41–44]
	Soil-water repellence increased runoff about three to six times after fire	[16]		
	Decrease of aquifer recharge caused deficits in the replenishment of headsprings that supply drinking water to urban centers	[19]		
Long-term impacts	Progressive decrease of runoff generation for identical precipitation events in a seven-year period	[12]	Recurrent wildfires and damming can keep nutrient concentrations periodically high threatening water security	[47]
	A report of 20%–220% higher mean annual water yield and peak flows from burned relative to unburned watersheds, 5 years postfire	[13]		
Control factors	Rainfall thresholds for postfire runoff and sediment delivery increased significantly across spatial scales	[20]	Globally, preserving forest watersheds in the pristine state supports the economy of approximately US\$ 4.1 trillion/yr by limiting the cost of expensive drinking water treatments and provision of unnecessary infrastructure	[41]
	Evapotranspiration decreased as a function of soil burnt severity and postfire land cover	[21]		

(continued on next page)

Table 1. (continued)

Forest fire impacts on watersheds		
Research topic	Hydrology	Water quality
Restoration	Forest residue mulch (chopped eucalyptus bark and twigs fibers) reduced soil loss by water erosion	Source(s)
	Decline of snowpack under warming temperatures are thought to anticipate peak flows by 1–2 months	[22]
	Prefire conditions can return 4–6 years after the fire	[23]
	Recovery of watersheds to prefire conditions enhance where perennial springs populate the forested areas	[26]
	Strawbale check dams are an option to reduce sediment yields in small ephemeral catchments where rainfall intensities are low and soils are less erodible	[27]
	Postfire straw mulching is especially justified in the case of postfire recovery from high burn severity fires	[28]
	Forest fire management may be a preventive measure to restore stream water yields in forested watersheds, at the same time that avoids subsequent fires	[29,30]
	Integrating wildfire, water, and society into common research is essential to successfully restore prefire conditions in watersheds	[31–34]
		[35]

recurrent wildfires and damming can threaten water security in the long term [47]. The conscience of wildfire impacts on water security led François-Nicolas Robinne to create a dataset for Canada and Alaska that contains relevant information to develop spatial indicators of wildfire risk to water security [48]. This useful database would be helpful to water resources managers anywhere around the globe.

Modeling approaches for impact assessment

The accomplishment of a catchment-wide view about the impacts of wildfires on stream water quality usually resorts to models that combine spatiotemporal distributions of environmental variables (e.g., topography, hydrology, and climate) and burnt areas. For example, a study by Regina Santos et al. investigated the sources of high phosphorus concentrations in Portuguese forested watersheds approaching the problem from the ‘pressures-pathways-receptors’ conceptual model [49]. The results showed postfire soil erosion among the leading factors of phosphorus exports across the watersheds and precipitation intensity as a key variable of erosion, not ruling out the role of forest management (hardwood clear cuttings). The study outcomes also suggested sediment deposition along the pathway from burned areas to water masses as attenuating factor of phosphorus yields. Other models rely on empirical deterministic spatiotemporal relationships between land cover, nonpoint pollution sources, and erosion to estimate accumulations from the overland flow within the watershed. In the Santa Lucia Range (northern portion of Los Padres National Forest, California, USA), an empirical runoff-erosion model indicated average postfire concentration increases in phosphorus, sediments, and total suspended solids by 161%, 350%, and 53% above prefire years, respectively [50]. Models that are more sophisticated can combine physically described processes (e.g., debris flow initiation, fire spread) with stochastic models (e.g., Monte Carlo simulations) and assess water quality risk in wildfire-prone catchments in the sequel. Using a model of this kind in central Victoria (Australia), Christoph Langhans et al. estimated recurrent risks (e.g., every 15 years) of turbidity in the water supply of Upper Yarra reservoir near Melbourne, caused by periodic inflows of clay-sized wildfire-related debris [51].

Summary

Table 1 summarizes the general outcomes of studies described in the previous sections. The aim was to grant the readers with a systematized list of recently reported methods, impacts, and restoration results, in studies of wildfires concerned with watershed hydrology and stream water quality. Like the review, the table is far from exhaustive.

Author contributions

Fernando António Leal Pacheco and Luís Filipe Sanches Fernandes participated equally in the tasks necessary to

produce the present review. The two authors have read and agreed to publish the current version of the manuscript.

Declaration of competing interest

The authors declare no conflicts of interest. The funders had no role in the design of the study, in writing the manuscript and revising the text, or in the decision to publish it.

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References

Papers of particular interest, published within the period of review, have been highlighted as:

- * of special interest
- ** of outstanding interest

1. Pompeani DP, McLauchlan KK, Chileen BV, Calder WJ, Shuman BN, Higuera PE: **The biogeochemical consequences of late Holocene wildfires in three subalpine lakes from northern Colorado.** *Quat Sci Rev* 2020, **236**:106293.
2. Jiménez-Moreno G, Anderson RS, Shuman BN, Yackulic E: **Forest and lake dynamics in response to temperature, North American monsoon and ENSO variability during the Holocene in Colorado (USA).** *Quat Sci Rev* 2019, **211**:59–72.
3. DeLong SB, Youberg AM, DeLong WM, Murphy BP: **Post-wildfire landscape change and erosional processes from repeat terrestrial lidar in a steep headwater catchment, Chiricahua Mountains, Arizona, USA.** *Geomorphology* 2018, **300**:13–30.
4. Efthimiou N, Psomiadis E, Panagos P: **Fire severity and soil erosion susceptibility mapping using multi-temporal Earth Observation data: the case of Mati fatal wildfire in Eastern Attica, Greece.** *Catena* 2020, <https://doi.org/10.1016/j.catena.2019.104320>.
- This study is of special interest because it assessed and mapped soil erosion susceptibility in a fire-prone watershed considering the severity and resorting to a sophisticated combination of diverse remote sensed data (see flow chart in Fig. 1), which can be used as a reference to other similar studies.
5. Dinis PA, Sequeira M, Tavares AO, Carvalho J, Castilho A, Cabral Pinto M: **Post-wildfire denudation assessed from compositional features of river sediments (Central Portugal).** *Appl Clay Sci* 2020, <https://doi.org/10.1016/j.clay.2020.105675>.
6. Balocchi F, Flores N, Neary D, White DA, Silberstein R, Ramírez de Arellano P: **The effect of the 'Las Maquinas' wildfire of 2017 on the hydrologic balance of a high conservation value Hualo (Nothofagus glauca (Phil.) Krasser) forest in central Chile.** *Ecol Manag* 2020, <https://doi.org/10.1016/j.foreco.2020.118482>.
7. Ma Q, Bales RC, Rungee J, Conklin MH, Collins BM, Goulden ML: **Wildfire controls on evapotranspiration in California's Sierra Nevada.** *J Hydrol* 2020, **590**:125364.
- This study is of special interest because it clearly reported the effects of wildfires on evapotranspiration in a large region, considering the separate roles of burn severity, prefire canopy density, and hydro-topographic environment, while it tackles restoration and fire management as measures to optimize the nexus vegetation cover - evapotranspiration - stream flow - ecosystem health. This study can be a reference for the implementation of management practices in fire-prone watersheds.
8. Venkatesh K, Preethi K, Ramesh H: **Evaluating the effects of forest fire on water balance using fire susceptibility maps.** *Ecol Indic* 2020, **110**:105856.
9. Maxwell JD, Call A, St Clair SB: **Wildfire and topography impacts on snow accumulation and retention in montane forests.** *Ecol Manag* 2019, <https://doi.org/10.1016/j.foreco.2018.09.021>.
10. Pimentel R, Arheimer B: **Hydrological impacts of a wildfire in a Boreal region: the Västmanland fire 2014 (Sweden).** *Sci Total Environ* 2021, **756**:143519.
- This study is of outstanding interest because it describes less understood wildfire impacts on hydrology, given the location of the study area in a Boreal region. In that regard, the study addresses problems like the variation in the duration and timing of snow season or in the dynamism of streamflow, which might have resulted from a large fire that occurred in 2014.
11. Robinne F-N, Hallema DW, Bladon KD, Buttle JM: **Wildfire impacts on hydrologic ecosystem services in North American high-latitude forests: a scoping review.** *J Hydrol* 2020, **581**:124360.
12. Ebel BA: **Temporal evolution of measured and simulated infiltration following wildfire in the Colorado Front Range, USA: shifting thresholds of runoff generation and hydrologic hazards.** *J Hydrol* 2020, **585**:124765.
13. Mahat V, Silins U, Anderson A: **Effects of wildfire on the catchment hydrology in southwest Alberta.** *Catena* 2016, **147**:51–60.
14. Loiselle D, Du X, Alessi DS, Bladon KD, Faramarzi M: **Projecting impacts of wildfire and climate change on streamflow, sediment, and organic carbon yields in a forested watershed.** *J Hydrol* 2020, <https://doi.org/10.1016/j.jhydrol.2020.125403>.
15. Santos RMB, Sanches Fernandes LF, Vitor Cortes RM, Leal Pacheco FA: **Hydrologic impacts of land use changes in the Sabor River basin: a historical view and future perspectives.** *Water* 2019, **11**:1464.
16. Wang J, Stern MA, King VM, Alpers CN, Quinn NWT, Flint AL, Flint LE: **PFHydro: a New watershed-scale model for post-fire runoff simulation.** *Environ Model Softw* 2020, <https://doi.org/10.1016/j.envsoft.2019.104555>.
- This study is of special interest because it developed a catchment-scale hydrologic model that incorporates fire-related hydrologic processes such as soil-water repellence. These processes are barely incorporated in more general hydrologic models such as the SWAT. In that regard, the PFHydro model is likely to simulate runoff more robustly in burned watersheds than the general models.
17. Moreno HA, Gourley JJ, Pham TG, Spade DM: **Utility of satellite-derived burn severity to study short- and long-term effects of wildfire on streamflow at the basin scale.** *J Hydrol* 2020, <https://doi.org/10.1016/j.jhydrol.2019.124244>.
18. Robinne FN, Bladon KD, Miller C, Parisien MA, Mathieu J, Flannigan MD: **A spatial evaluation of global wildfire-water risks to human and natural systems.** *Sci Total Environ* 2018, <https://doi.org/10.1016/j.scitotenv.2017.08.112>.
19. Rodrigues EL, Jacobi CM, Figueira JEC: **Wildfires and their impact on the water supply of a large neotropical metropolis: a simulation approach.** *Sci Total Environ* 2019, <https://doi.org/10.1016/j.scitotenv.2018.09.289>.
20. Wilson C, Kampf SK, Wagenbrenner JW, MacDonald LH: **Rain-fall thresholds for post-fire runoff and sediment delivery from plot to watershed scales.** *Ecol Manag* 2018, **430**:346–356.
- This study is of outstanding interest considering the multiple control factors that were accounted for in the assessment of rainfall thresholds for runoff generation, including fire location, year postfire, spatial scale, and mulch treatments. This holistic view incorporates important results, which are certainly a reference for other similar assessments.
21. Poon PK, Kinoshita AM: **Spatial and temporal evapotranspiration trends after wildfire in semi-arid landscapes.** *J Hydrol* 2018, <https://doi.org/10.1016/j.jhydrol.2018.02.023>.
22. Prats SA, Wagenbrenner JW, Martins MAS, Malvar MC, Keizer JJ: **Mid-term and scaling effects of forest residue mulching on post-fire runoff and soil erosion.** *Sci Total Environ* 2016, <https://doi.org/10.1016/j.scitotenv.2016.04.064>.
23. Gould GK, Liu M, Barber ME, Cherkauer KA, Robichaud PR, Adam JC: **The effects of climate change and extreme wildfire**

- events on runoff erosion over a mountain watershed. *J Hydrol* 2016, <https://doi.org/10.1016/j.jhydrol.2016.02.025>.
24. Russo A, Gouveia CM, Páscoa P, DaCamara CC, Sousa PM, Trigo RM: **Assessing the role of drought events on wildfires in the Iberian Peninsula.** *Agric For Meteorol* 2017, **237–238**:50–59.
 25. Florsheim JL, Chin A, O'Hirok LS, Storesund R: **Short-term post-wildfire dry-ravel processes in a chaparral fluvial system.** *Geomorphology* 2016, <https://doi.org/10.1016/j.geomorph.2015.03.035>.
 26. Greenbaum N, Wittenberg L, Malkinson D, Inbar M: **Hydrological and sedimentological changes following the 2010-forest fire in the Nahal Oren Basin, Mt. Carmel Israel—a comparison to pre-fire natural rates.** *Catena* 2021, **196**:104891.
- This study is of special interest because of its long-term and systematic analysis of prefire and postfire hydrological and sedimentological variables, including threshold rainfall amounts for flow generation, frequency of flow events, peak discharges, flow duration, and postfire suspended sediment concentrations.
27. Tsinnajinnie LM, Frisbee MD, Wilson JL: **Groundwater from perennial springs provide refuge from wildfire impacts in mountainous semiarid watershed.** *J Hydrol* 2020, <https://doi.org/10.1016/j.jhydrol.2020.125701>.
 28. Robichaud PR, Storrar KA, Wagenbrenner JW: **Effectiveness of straw bale check dams at reducing post-fire sediment yields from steep ephemeral channels.** *Sci Total Environ* 2019, <https://doi.org/10.1016/j.scitotenv.2019.04.246>.
 29. Prats SA, Merino A, Gonzalez-Perez JA, Verheijen FGA, De la Rosa JM: **Can straw-biochar mulching mitigate erosion of wildfire-degraded soils under extreme rainfall?** *Sci Total Environ* 2021, **761**:143219.
- This study is of special interest because it presents a comprehensive analysis of the role of straw and straw + biochar mulching in the attenuation of soil losses in burned watersheds subject to intensive rainfall events. Given the systematics, it can be a reference to similar studies.
30. Lucas-Borja ME, González-Romero J, Plaza-Álvarez PA, Sagra J, Gómez ME, Moya D, Cerdà A, de las Heras J: **The impact of straw mulching and salvage logging on post-fire runoff and soil erosion generation under Mediterranean climate conditions.** *Sci Total Environ* 2019, <https://doi.org/10.1016/j.scitotenv.2018.11.161>.
 31. Boisramé G, Thompson S, Collins B, Stephens S: **Managed wildfire effects on forest resilience and water in the Sierra Nevada.** *Ecosystems* 2017, **20**:717–732.
 32. Boisramé G, Thompson S, Stephens S: **Hydrologic responses to restored wildfire regimes revealed by soil moisture-vegetation relationships.** *Adv Water Resour* 2018, **112**:124–146.
 33. Rakhmatulina E, Boisramé G, Stephens SL, Thompson S: **Hydrological benefits of restoring wildfire regimes in the Sierra Nevada persist in a warming climate.** *J Hydrol* 2021, <https://doi.org/10.1016/j.jhydrol.2020.125808>.
- This study is of outstanding interest because it is a very robust analysis of fire management as a measure to improve hydrologic regimes and ecosystem health in the long-term.
34. Williams CJ, Pierson FB, Nouwakpo SK, Al-Hamdan OZ, Kormos PR, Weltz MA: **Effectiveness of prescribed fire to re-establish sagebrush steppe vegetation and ecohydrologic function on woodland-encroached sagebrush rangelands, Great Basin, USA: Part I: vegetation, hydrology, and erosion responses.** *Catena* 2020, **185**:103477.
 35. Kinoshita AM, Chin A, Simon GL, Briles C, Hogue TS, O'Dowd AP, Gerlak AK, Alborno AU: **Wildfire, water, and society: toward integrative research in the "Anthropocene."** *Anthropocene* 2016, <https://doi.org/10.1016/j.ancene.2016.09.001>.
 36. Rust AJ, Randell J, Todd AS, Hogue TS: **Wildfire impacts on water quality, macroinvertebrate, and trout populations in the Upper Rio Grande.** *Ecol Manag* 2019, **453**:117636.
 37. Valenca R, Ramnath K, Ditttrich TM, Taylor RE, Mohanty SK: **Microbial quality of surface water and subsurface soil after wildfire.** *Water Res* 2020, **175**:115672.
 38. Oliveira-Filho EC, Brito DQ, Dias ZMB, Guarieiro MS, Carvalho EL, Fascineli ML, Niva CC, Grisolia CK: **Effects of ashes from a Brazilian savanna wildfire on water, soil and biota: an ecotoxicological approach.** *Sci Total Environ* 2018, <https://doi.org/10.1016/j.scitotenv.2017.11.051>.
 39. Uzun H, Dahlgren RA, Olivares C, Erdem CU, Karanfil T, Chow AT: **Two years of post-wildfire impacts on dissolved organic matter, nitrogen, and precursors of disinfection by-products in California stream waters.** *Water Res* 2020, <https://doi.org/10.1016/j.watres.2020.115891>.
- This study is of special interest because it robustly describes the short-term evolution of stream water quality (essentially common contaminants) from immediate post-fire times until two years after the fire occurrence when prefire conditions returned. Given the comprehensive assessment, it can be used as a reference for similar studies.
40. Emmerton CA, Cooke CA, Hustins S, Silins U, Emelko MB, Lewis T, Kruk MK, Taube N, Zhu D, Jackson B, et al.: **Severe western Canadian wildfire affects water quality even at large basin scales.** *Water Res* 2020, **183**:116071.
 41. Abraham J, Dowling K, Florentine S: **Risk of post-fire metal mobilization into surface water resources: a review.** *Sci Total Environ* 2017, **599–600**:1740–1755.
- This study is of special interest because it reviews an important water security problem, namely the mobilization of metals into surface water.
42. Campos I, Vale C, Abrantes N, Keizer JJ, Pereira P: **Effects of wildfire on mercury mobilisation in eucalypt and pine forests.** *Catena* 2015, **131**:149–159.
 43. Pinedo-Gonzalez P, Hellige B, West AJ, Sañudo-Wilhelmy SA: **Changes in the size partitioning of metals in storm runoff following wildfires: implications for the transport of bioactive trace metals.** *Appl Geochem* 2017, <https://doi.org/10.1016/j.apgeochem.2016.07.016>.
 44. Murphy SF, McCleskey RB, Martin DA, Holloway JM, Writer JH: **Wildfire-driven changes in hydrology mobilize arsenic and metals from legacy mine waste.** *Sci Total Environ* 2020, **743**:140635.
 45. Hohner AK, Cawley K, Oropeza J, Summers RS, Rosario-Ortiz FL: **Drinking water treatment response following a Colorado wildfire.** *Water Res* 2016, **105**:187–198.
 46. Hohner AK, Summers RS, Rosario-Ortiz FL: **Laboratory simulation of postfire effects on conventional drinking water treatment and disinfection byproduct formation.** *AWWA Water Sci* 2019, **1**.
 47. Santos RMB, Sanches Fernandes LF, Pereira MG, Cortes RMV, Pacheco FAL: **Water resources planning for a river basin with recurrent wildfires.** *Sci Total Environ* 2015, **526**:1–13.
 48. Robinne F-N: **A geospatial dataset providing first-order indicators of wildfire risks to water supply in Canada and Alaska.** *Data Br* 2020, **29**:105171.
 49. Santos RMB, Sanches Fernandes LF, Pereira MG, Cortes RMV, Pacheco FAL: **A framework model for investigating the export of phosphorus to surface waters in forested watersheds: implications to management.** *Sci Total Environ* 2015, **536**:295–305.
 50. Morrison KD, Kolden CA: **Modeling the impacts of wildfire on runoff and pollutant transport from coastal watersheds to the nearshore environment.** *J Environ Manag* 2015, **151**:113–123.
 51. Langhans C, Smith HG, Chong DMO, Nyman P, Lane PNJ, Sheridan GJ: **A model for assessing water quality risk in catchments prone to wildfire.** *J Hydrol* 2016, <https://doi.org/10.1016/j.jhydrol.2015.12.048>.