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Strategies for Assessing Post-Wildfire Geomorphic Resilience in Semiarid Rivers

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ABSTRACT

We review and summarize diverse components of a catchment that can be monitored after wildfire to assess the geomorphic resilience of the river corridor in semiarid regions. We distinguish upland portions of river catchments from river corridors. Upland components influence inputs of water, solutes, sediment, and organic matter to river corridors. Upland components following wildfire can be assessed with respect to topography (erosion, deposition, rilling, channel head position, drainage density, water and sediment connectivity), snowpack (peak snow water equivalent, snow disappearance date, snowmelt rate), runoff ratio, soils (repellency, infiltration capacity, sorptivity, soil moisture), and vegetation (community composition, density or percent cover). River corridor components following wildfire can be assessed via hydrograph characteristics, sediment supply and transport, channel morphology, floodplain morphology, river corridor connectivity, and aquatic and riparian habitat. We list specific parameters for each of these components and review methods used to measure these parameters. The ability to evaluate geomorphic resilience of a river catchment or corridor may depend on understanding of (i) baselines against which to assess resilience, (ii) responses of system components through time after disturbance, (iii) choice of specific components within a catchment or river corridor, and (iv) recognition of human interactions within the catchment or river corridor. We discuss the basis for choices regarding spatial and temporal resolution and extent of measurements, using the Cache la Poudre River catchment in Colorado, USA as an example.

1 | Introduction

Wildfires are increasing in frequency, extent, and severity in many fire-prone regions of the world, including the western United States (Abatzoglou and Williams 2016; Wohl 2025). High-severity fires in steep terrain typically trigger a disturbance cascade in which post-fire increases in water and sediment yields to river networks cause multiple secondary effects including channel and floodplain instability and changes in habitat, resources, trophic cascades, and community composition within river corridors (Moody et al. 2013; Santi et al. 2013; Kemter et al. 2021; Paul et al. 2022; Ortega-Becerril et al. 2024). Rivers may exhibit only transient responses or persistent changes (Brunsden and Thornes 1979) to increased water and sediment yields; these differing responses can be described in the context of resistance, resilience, and sensitivity (Table 1). We approach resilience in the context of physical processes and forms within river catchments, with an emphasis on the river corridor.

A substantial body of literature examines various aspects of river resilience (e.g., McCluney et al. 2014; Fuller et al. 2019; Van Looy et al. 2019; Piégay et al. 2020; Greene et al. 2023; Thoms

TABLE 1 | Definitions for terms used in this paper.

Term	Definition	Relevant references
Catchment	The drainage area above a reference point, including upland and river corridor areas	
Disturbance	A relatively discrete event in time that alters a catchment or stream corridor (e.g., intense rainfall that triggers hillslope mass movements and floods)	White and Pickett 1985; Montgomery 1999
Historical range of variability	The range through time of a specified parameter (e.g., channel width or peak flow) during the period after human alteration of a catchment	
Natural range of variability	Analogous to the historical range of variability but referring to the period prior to intensive human alteration of a catchment	
Resilient	Resilience is present when a specified component (process or form) returns to the pre-disturbance state within a timespan shorter than the return interval of the disturbance	Thoms et al. 2018
Resistant	Resistance is present when a specified characteristic does not change following disturbance	Thoms et al. 2018
River corridor	The active channel(s), floodplain, and underlying hyporheic zone	Harvey and Gooseff 2015
Sensitive	In sensitive systems, disturbance creates change that persists longer than the return interval of the disturbance	Brunsden and Thornes 1979; Fryirs 2017
Upland	All contributing portions of the catchment outside of the river network	
Wildfire	Fires outside of human-built environments started by processes not directly associated with humans or by deliberate or accidental human-generated ignitions of fire	Wohl 2025

and Fuller 2024; Wohl et al. 2023; Wohl, Fryirs, et al. 2024). We define resilience of a riverine process or form as being present when the specified process or form returns to its pre-disturbance state over a shorter timespan than the return interval of the disturbance (Figure 1). Resilience thus depends on the magnitude and duration of the disturbance and the change caused by the disturbance. Assessing whether a specified process or form (hereafter referred to as components) has returned to a pre-disturbance state is not necessarily straightforward because adjustments after disturbance may follow a trend of declining fluctuations through time. For example, in a resilient system the first rainstorms following a wildfire may trigger exceptionally high pulses of water and sediment delivery to the river corridor. Comparable storms in subsequent years may still produce elevated responses, but the magnitude of those responses will tend to decline steadily through time as upland vegetation and infiltration capacity recover (e.g., Mayor et al. 2007; Wilson et al. 2018). The natural or historical range of variability, if known, can be used as a baseline pre-disturbance state, along with other sources of information discussed in Section 4. Resilience can also be assessed for a very specific component, such as channel width/depth ratio, or for a river corridor as a whole based on the resilience of multiple components within a reach.

We use a specific, yet broad, physical setting—river catchments in semiarid regions responding to the disturbance of a wildfire—to (i) review the physical components that could be examined to assess resilience, (ii) discuss considerations when characterizing pre-disturbance state, and (iii) discuss considerations when choosing appropriate spatial and temporal resolution and extent of measurements. We use the Cache la Poudre (Poudre) River catchment in Colorado, USA to illustrate these three topics. The Poudre River exemplifies challenges faced by many river corridors in semiarid regions, including increasingly frequent and severe wildfires; growing human population and consumptive water demands; a history of human alterations of the catchment and river corridor; at-risk aquatic species; and changing flow and disturbance regimes caused by climate warming. As such, the Poudre River catchment represents characteristics shared by many other river catchments in the western United States and other fire-prone regions of the world.

2 | Geomorphic Context for Post-Fire Resilience

We focus on reach-scale responses to the wildfire disturbance cascade. A reach is a continuous length of river corridor with progressive increase in drainage area and discharge (i.e., no

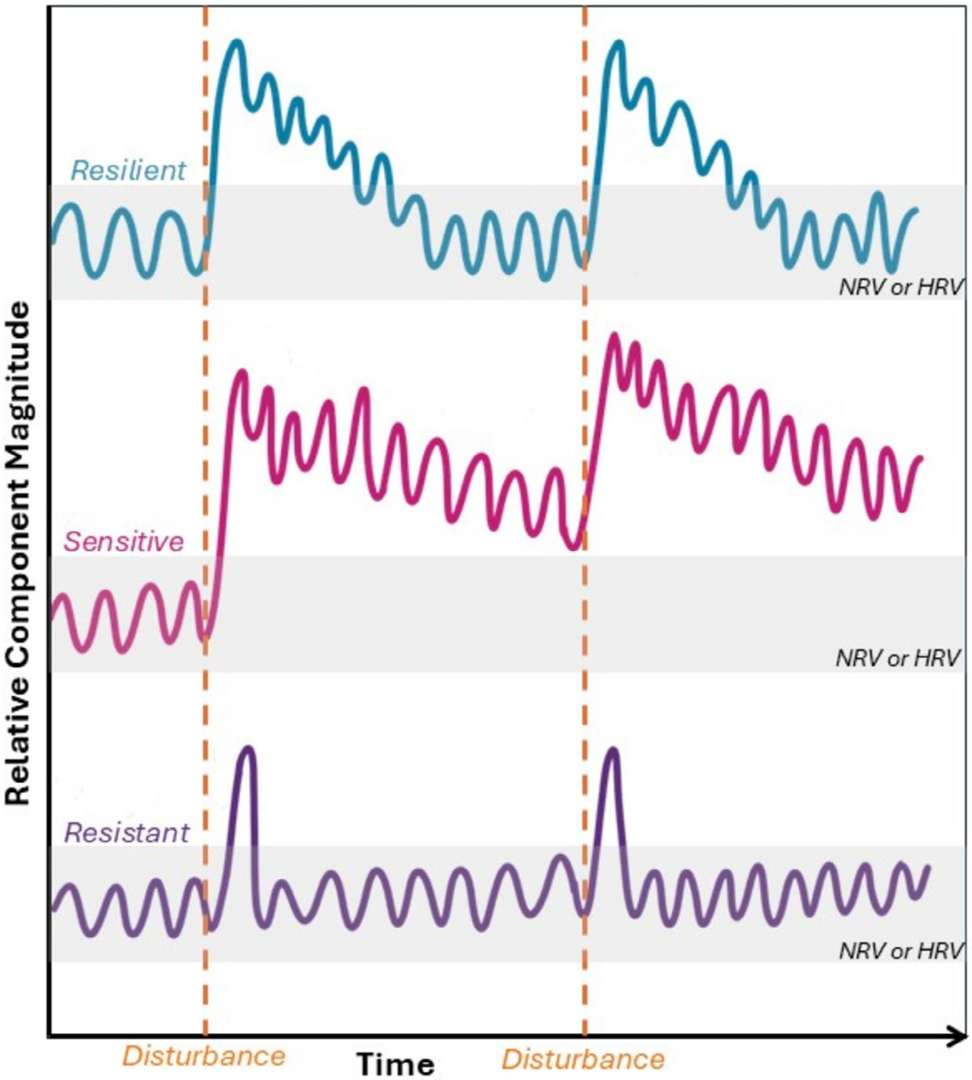

FIGURE 1 | Conceptual illustration of resilient, sensitive, and resistant system components following disturbances (e.g., wildfires). A resilient system component (blue) returns to its natural or historical range of variability (NRV or HRV, gray shaded areas) over a shorter timespan than the return interval of the disturbance. A sensitive system component (magenta) does *not* return to its HRV or NRV over a shorter timespan than the disturbance recurrence interval. A resistant system component (purple) changes very briefly or not at all following disturbance, remaining mostly within NRV or HRV. [Color figure can be viewed at wileyonlinelibrary.com]

substantial tributary confluences) and consistent channel and valley-floor geometry. A reach may be tens of meters long in a headwater stream and tens of kilometers in length in a larger river. A reach may also be bounded at the upstream and downstream ends by a substantial tributary confluence.

A river consists of multiple successive reaches, a river network includes all the contributing channels above a specified point, and a catchment includes all the contributing area above a specified point. A reach exists within the context of these spatial scales and is influenced by processes upstream and by downstream conditions such as base level stability (e.g., Musselman 2011). The reach is characterized by (i) a physical template created by the valley-floor geometry, (ii) inputs of material to the river corridor and fluxes of these materials through the river corridor—materials include water, solutes, sediment, and particulate organic matter, and (iii) biophysical interactions associated with aquatic and riparian vegetation and animals such as beaver (*Castor* spp.) in the northern hemisphere or hippos (*Hippopotamus amphibius*) in parts of the southern hemisphere (Wohl, Rathburn, et al. 2024). At any point in time, the morphology of the river corridor in a reach reflects the history of continuing interactions between the physical template, inputs and fluxes, and biophysical features (Wohl 2018).

The catchment, the river network, and individual reaches each include numerous features and thus have numerous potential pathways of adjustment following a disturbance such as a wildfire (Figure 2), as well as different types and return intervals for disturbances. Each of these components can be evaluated in the context of resilience. We identify the components that we expect to be most useful in assessing resilience, although not all the components will be either applicable or feasible to characterize for any particular site in a river catchment, and not all the components will be equally important. The Poudre River,

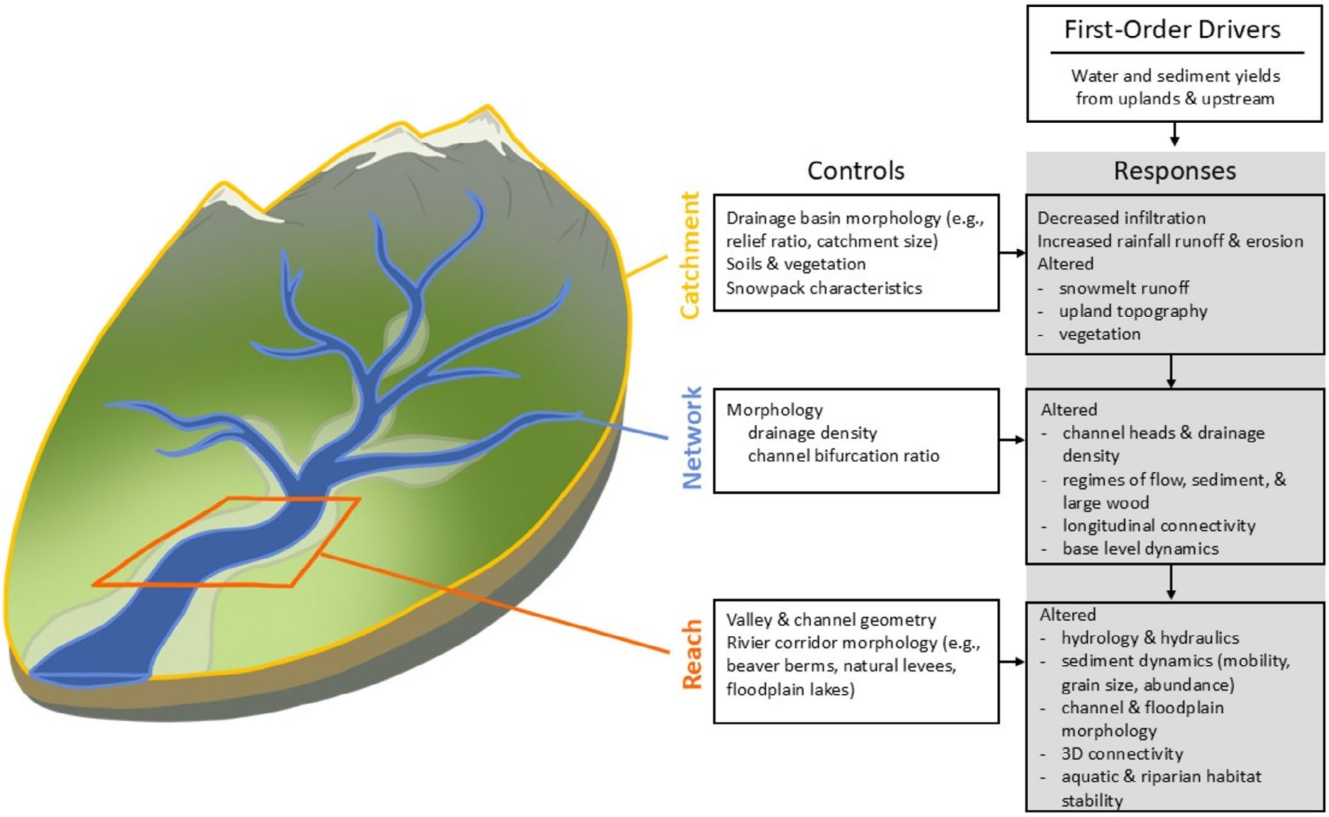

FIGURE 2 | Schematic illustration of the catchment, river network, and river reach scales at which geomorphic components can be measured to assess resilience after wildfire. [Color figure can be viewed at wileyonlinelibrary.com]

for example, starts in the Southern Rocky Mountains and then flows eastward onto the Great Plains. Changes in upland topography caused by sheetwash, rilling, and mass movements are likely to be more impactful in the steep terrain of the mountainous portion of the river network than in the lowland portion in the context of assessing resilience.

3 | Quantifiable Landscape Components Affected by Wildfire

We assume that all the components discussed in this section may change over time and thus should be measured over time; we address duration and temporal resolution of measurements in Section 5. Wildfires can ignite within the uplands or within a river corridor. Wildfires that burn upland environments can indirectly affect river corridors by changing inputs of materials to the river corridor. Wildfires that ignite in either uplands or river corridors may or may not spread between these environments. Wildfires that burn river corridors can directly alter process and form within the river corridor, for example by removing riparian vegetation and downed wood and thereby indirectly altering erosional resistance of the channel banks and floodplain surface (Eaton et al. 2010). Human presence, in the form of infrastructure, property boundaries, changes in land cover, and management actions before, during, and after wildfire can potentially influence all the components discussed in this section. Topographic change in uplands, for example, may be enhanced or retarded by human modifications such as post-fire application of mulch (Girona-García et al. 2021).

3.1 | Uplands

Upland components strongly influence geomorphic resilience in river corridors by regulating the timing, magnitude, and character of water, sediment, and solute delivery. Following wildfire, changes in upland processes can amplify or dampen downstream responses. Upland components relevant to geomorphic resilience in river corridors include upland topography, snowpack, runoff, soils, and vegetation (Table 2).

Upland topographic change following wildfire reflects shifts in how water and sediment are delivered to river networks. Sheetwash and rilling enhance water inputs to a river, while debris flows rapidly deliver large sediment inputs to the river. Upland topographic change can also influence subsequent inputs to a river by altering downslope pathways, or upland-river corridor connectivity (e.g., Wilson et al. 2021), for movement of materials. Changes in upland topography can be measured using DEM differencing based on sufficiently high resolution repeat terrestrial or airborne lidar or Structure from Motion (SfM) surveys (Rengers, Tucker, et al. 2016; Ellett et al. 2019); SfM or lidar imagery to locate new erosional features such as rills (Alessio et al. 2021); erosion pins (Smith and Dragovich 2008); sediment fences (Robichaud et al. 2020); and field-based mapping of channel heads and rills (Wohl 2013a).

Upland snow characteristics influence water, solute, and sediment inputs to the river corridor, as well as the regrowth of upland vegetation. Relevant snow characteristics include the peak snow water equivalent, the date of snow disappearance,

TABLE 2 | Components of uplands that can be assessed for resilience.

Component	Characteristics	Relevant references
Topography	Overall erosion and deposition (via sheetwash, mass movement, soil creep, dry ravel)	Rengers, Tucker, et al. 2016
	Rilling	Berg and Azuma 2010
	Channel head position	Wohl and Scott 2017
	Drainage density	Moody and Kinner 2006
	Water and sediment connectivity	Cavalli et al. 2013; Wilson et al. 2021
Snowpack	Peak snow water equivalent	McGrath et al. 2023
	Snow disappearance date	Gersh et al. 2022
	Snowmelt rate	McGrath et al. 2023
Runoff	Runoff ratio	Sheridan et al. 2007
Soils	Repellency (hydrophobicity)	Doerr et al. 2000
	Infiltration capacity	Nyman et al. 2014
	Sorptivity	Balfour 2015
	Soil moisture	González-Pelayo et al. 2024
Vegetation	Community composition (species, age)	Engel and Abella 2011
	Density or percent cover	Lentile et al. 2007

and the rate of snowmelt. Techniques that can be used to assess snow characteristics include snowpack telemetry (e.g., the SNOTEL network in the western United States, which includes precipitation gauges and snow pillows to record the weight of the overlying snowpack every 24 h; Serreze et al. 2001; Giovando and Niemann 2022); sensors and dataloggers deployed in the field (e.g., Capelli et al. 2022; Le Breton et al. 2023); satellite-acquired data such as the US National Aeronautics and Space Administration's MODIS (Moderate Resolution Imaging Spectroradiometer) data sets, including MODSCAG (MODIS snow covered area and grain size) and MODDRF (MODIS dust radiative forcing in snow); Airborne Snow Observatory (a coupled imaging spectrometer and scanning lidar) measurements used to estimate snow water equivalent at regular time intervals (Painter et al. 2016); cosmic-ray neutron sensing via various ground-based platforms (Schrön et al. 2021); and ground-based field surveys of snow depth, snow density, snow water equivalent, and other properties using depth measurement rods and rulers, snow sampling tubes, and snowpit observations (Kinar and Pomeroy 2015).

Runoff from uplands influences water, solute, and sediment inputs to river corridors. Runoff ratio—the amount of runoff as a proportion of total precipitation—is a primary characteristic of runoff. The runoff ratio can be estimated from precipitation and streamflow data (e.g., Robichaud et al. 2008) and from rainfall-runoff models (e.g., Rengers, McGuire, et al. 2016) that include infiltration modeling such as Green-Ampt, Smith-Parlange, or the Richards equation (Ebel and Moody 2020). Plot-scale rainfall simulations are also used to measure post-fire runoff (e.g., Johansen et al. 2001). Rainfall-runoff relationships may be modified by wildfire-induced changes in upland soil and vegetation characteristics (e.g., Ebel et al. 2012; Partington et al. 2022).

Upland soil characteristics influence infiltration and runoff, sediment inputs to river corridors, and upland vegetation. The key soil characteristics following wildfire include (i) repellency or hydrophobicity, which reduces the affinity of soils to water such that they resist wetting for periods from a few seconds to hours, days, or weeks (Doerr et al. 2000); (ii) infiltration capacity, which can be reduced after wildfire by soil-water repellency, soil sealing, ash particle clogging, ash crust formation, heat effects that reduce soil structure, and alterations in soil-water retention (Ebel and Moody 2017); (iii) sorptivity, which is a measure of how readily a soil absorbs water due to capillary forces (e.g., Akin and Akinleye 2021); and (iv) soil moisture, which typically decreases after fire, influencing soil and water inputs to river corridors and upland vegetation regrowth (Ebel and Moody 2020). These characteristics can be estimated through: satellite-borne optical, thermal, passive microwave, and active microwave sensors for soil moisture (Wang and Qu 2009); stationary, car-borne, or rail-borne cosmic ray neutron sensing (Altdorff et al. 2023); field samples analyzed in the lab for soil texture and bulk density (Moody and Nyman 2013); and field measurements such as use of an infiltrometer (Nestingen et al. 2018), mini-disk infiltrometer (Moody et al. 2009) or water drop penetration time test (Dekker et al. 2009).

Upland vegetation influences (i) infiltration and runoff (Dunne et al. 1991) by decreasing the average velocity of overland flow, intercepting raindrop energy and preventing surface sealing, and creating macropores that increase local hydraulic conductivity; (ii) surface stability and sediment inputs to river corridors (Bracken 2010) by providing surface roughness that may help concentrate overland flow into rills and increasing soil erosional resistance; (iii) snowpack retention and melt rate by intercepting snow and shading the ground, depending on the type and density of the vegetation (e.g., Pomeroy and Brun 2001); and (iv) solute and organic matter inputs to rivers by altering downslope flow paths and rates, creating organic matter through plant litterfall, providing solutes directly to downslope flows, and influencing upland soil organic matter and leaching of this material (e.g., Sebestyen et al. 2008; Van Stan and Stubbins 2018). Relevant post-fire vegetation characteristics include plant community composition (species and ages present), and density or percent cover of vegetation. These characteristics can be assessed using remote imagery such as normalized difference vegetation index (NDVI), which measures the amount of potential photosynthetic activity of vegetation (Leon et al. 2012), and leaf area index (LAI; Serbin et al. 2013; Graber et al. 2023); normalized burn ratio (NBR, a quantitative measure of burn severity; Hislop et al. 2018) or differenced NBR (dNBR, based on pre- versus post-fire differences; Ponomarev et al. 2022); drone- or satellite-based remote imagery for percent cover (e.g., Martinez et al. 2021); and field measurements with quadrat plant surveys (Taylor et al. 2021).

3.2 | River Corridors

Here, river corridors include all parts of the river network, whether considered at the scale of the entire network, an entire river, or a single reach. River corridor components relevant to post-fire geomorphic resilience include flows within the active channel(s), sediment transport, channel morphology, floodplain morphology, river corridor hydrologic connectivity, and aquatic and riparian habitat (Table 3).

Wildfires in moderate to steep terrain typically cause increased fluxes of water and sediment to river corridors in the first few years after the fire (e.g., Shakesby and Doerr 2006; Wohl 2025). Increased fluxes can appear as changes in the hydrograph and sediment dynamics within the active channel(s) and can also cause changes in channel and floodplain morphology (Benda et al. 2003; Eaton et al. 2010; Hahn et al. 2025). Hydrograph characteristics can change with respect to magnitude of total flow and peak flows, as well as duration, frequency, seasonal timing, and flashiness of peak flows (Caldwell et al. 2020; White et al. 2022) (Figure 3). Hydrograph characteristics can be assessed using existing stream gauges (e.g., Mahat et al. 2015) or stream gauges installed after a fire using equipment such as pressure transducers, staff gauges and remote-interval cameras, and other indirect recording devices (White et al. 2022). Discharge can also be assessed using measurements such as salt tracers and conductivity sensors to estimate reach-averaged velocity (e.g., Planchon et al. 2005), or installations of temporary weirs (e.g., Lane et al. 2006). Satellite and/or UAV imagery or field-measured high-water marks can be used with topographic data in hydraulic modeling (Bandini et al. 2021; Huang et al. 2022; Durand et al. 2023). Post-fire relationships for flow magnitude and frequency can be compared to regional relationships (e.g., the US Geological Survey program StreamStats) or calibrated pre-fire hydrologic models.

Sediment dynamics after wildfire can change with respect to the magnitude, duration, and frequency of transport of dissolved, suspended, and bedload (Moody and Martin 2009). Spatial and temporal patterns of bedload mobilization and transport can be assessed using existing stream gauges that include measurements of dissolved and/or suspended sediment (e.g., Jumps et al. 2022). Where gauges for time-series measurements are not present, either in situ, direct field measurements with handheld or bridge- or boat-mounted samplers or automated field sampling can be used. Examples of direct field measurements include collecting suspended load via DH84 sampler or a Secchi disk or turbidity probe for turbidity as a proxy for suspended sediment concentration (e.g., Lane et al. 2006), and the Helley-Smith sampler for bedload (Ryan et al. 2011). Examples of automated field sampling included

TABLE 3 | Components of river corridors that can be assessed for resilience.

Component	Characteristics	Relevant references
Hydrograph characteristics	Magnitude, duration, frequency, timing, flashiness	White et al. 2022
Sediment transport	Magnitude, duration, frequency of dissolved, suspended, and bedload	Ryan et al. 2011, 2024
Channel morphology	Width/depth ratio; cross-sectional area and symmetry; bed grain size; bank stability; bedforms (type, amplitude, wavelength); bed gradient; pool volume; sinuosity and channel planform; large wood (abundance, distribution, mobility); beaver modifications; relative roughness coefficient; channel stability (lateral—migration and avulsion, vertical); spatial heterogeneity	Benda et al. 2003; Eaton et al. 2010; Florsheim et al. 2017; Busby and Wilcox 2024
Floodplain morphology	Floodplain/channel width ratio; grain size and thickness/depth; depth of ash deposition; vegetation (community composition, density); large wood load and distribution; spatial heterogeneity	Brogan et al. 2019; Iskin and Wohl 2021; Hahn et al. 2025
River corridor connectivity	Lateral (channel-floodplain and peak flow attenuation); vertical (hyporheic exchange flows, groundwater recharge); longitudinal; hydraulic complexity of channel and floodplain	Sutfin and Wohl 2019; Wilson et al. 2021; Wohl, Marshall, et al. 2024
Aquatic and riparian habitat	Abundance, diversity, stability, connectivity, complexity	Isaak et al. 2010; Kleindl et al. 2015; Whitney et al. 2015

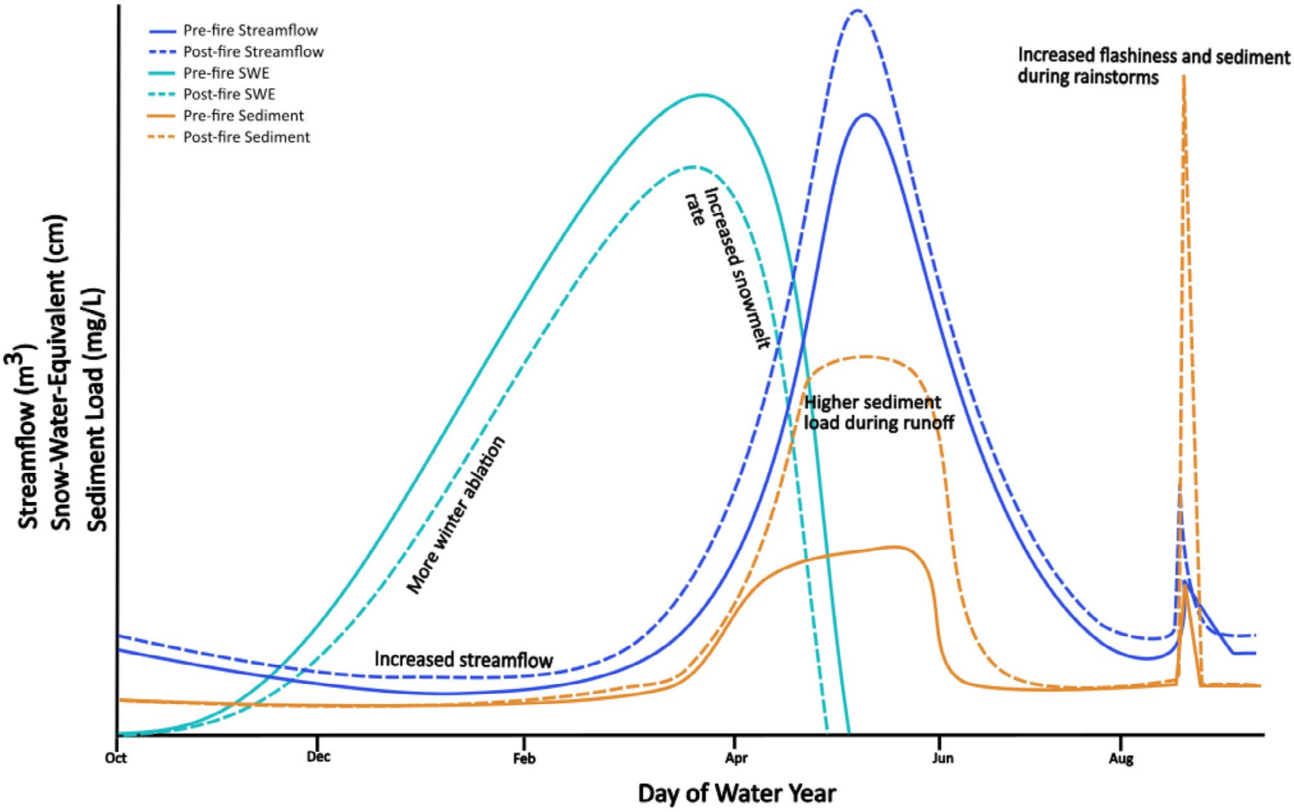

FIGURE 3 | Schematic illustration of generic changes in streamflow, snow water equivalent (SWE), and suspended sediment before and after wildfire in a semiarid mountain river catchment. Source references for conceptualizing these changes in stream flow (Kinoshita and Hogue 2015; Zhou et al. 2015; Ebel et al. 2016; Partington et al. 2022); for changes in SWE (Koshkin et al. 2022), and for changes in suspended sediment load (Murphy et al. 2015; Paul et al. 2022; Wohl et al. 2022). [Color figure can be viewed at wileyonlinelibrary.com]

automatic water samplers for suspended load (Petticrew et al. 2006) and slot samplers (Liébault et al. 2022), geophones, and other passive acoustic methods for bedload (Rickenmann 2017), as well as indirect bedload estimations based on seismic signals (e.g., Bakker et al. 2020). Satellite imagery can be used to estimate dissolved and suspended loads on medium to large-sized rivers (Stroud et al. 2021). Bedload is perhaps the most difficult form of sediment transport to measure, but post-fire measurements can employ repeat surveys of bed geometry (Trayler and Wohl 2000), including via bathymetry, or particle tracking of a subset of clasts marked with RFID (Liébault et al. 2024), paint, or magnetic tags (Eaton et al. 2010).

Channel morphology can change after wildfire in response to the combined effects of altered water and sediment fluxes into and through river corridors, along with increased large wood mobility, and altered bank erosional resistance if riparian vegetation burns (Eaton et al. 2010; Busby and Wilcox 2024). Changes in the morphology of active channel(s) can involve changes in channel width/depth ratio; cross-sectional area and symmetry; bed grain size distribution; bedform type, amplitude, and wavelength; bed gradient; pool volume; bank morphology and stability; sinuosity and channel planform; the relative roughness coefficient for flows; abundance, distribution, and mobility of large wood; the presence of beaver modifications (e.g., dams, canals); channel stability in both the lateral (channel migration and avulsion) and vertical (incision, aggradation) dimensions; and spatial heterogeneity (Figure 4).

Most of the potential changes in channel cross-sectional area and shape and planform can be assessed using repeat surveys of channel form with traditional surveys (e.g., total station, autolevel; for example, Eaton et al. 2010), RTK or other GPS-based platforms, boat-based bathymetry, imagery obtained from UAV or satellite platforms (Canfield et al. 2005), or remote elevation data from lidar or green lidar (DiBiase and Lamb 2020). Changes in grain-size distribution can be measured using direct pebble counts, automated grain-size detection software with drone- or ground-based imagery for coarse sediment and sample collection and sieving, laser particle size analysis, or hydrometer measurements for finer sediment (Chardon et al. 2022). Bank erosion can be assessed using erosion pins of various types (Papanicolaou et al. 2017) and bank stability modeling (Stryker et al. 2017). Pool volume can be assessed from repeat surveys of direct field measurements with the V* technique (Lisle and Hilton 1992). The distribution of large wood and changes in large wood position can be assessed using DEM differencing, supervised classification with remote imagery, and filtered lidar returns (e.g., Sendrowski and Wohl 2021; Sanhueza et al. 2022). Roughness coefficients can be estimated from reach-average velocity measurements (Planchon et al. 2005) or from hydraulic modeling (e.g., Knight et al. 2018). Spatial heterogeneity can be characterized using a metric such as planform complexity (the number of separate functional surfaces per unit of channel

FIGURE 4 | Examples of post-fire channel changes along Little Beaver Creek, a mountain tributary of the Poudre River, Colorado, USA. The 2020 photos were taken in July 2020, prior to a wildfire later that calendar year. The 2022 photos were taken in late July 2022, following a substantial flood that created extensive erosion and deposition along the river corridor. Blue and yellow ovals indicate the same location in each set of 2020/2022 photos. [Color figure can be viewed at wileyonlinelibrary.com]

length; Graf 2006) or channel complexity (sum of areal extents of active bar and secondary water features over consistent lengths of valley; Curtis et al. 2015).

As with channel morphology, changes in floodplain morphology can occur after wildfire in response to changes in water and sediment fluxes through the river corridor, changes in channel mobility and channel-floodplain connectivity, combustion of riparian vegetation, and changed mobility and distribution of large wood (Brogan et al. 2019; Hahn et al. 2025). Altered floodplain morphology takes the form of changes in the ratio of floodplain width/channel width (McLin et al. 2001); the grain-size distribution and thickness of alluvium in the floodplain (Wohl et al. 2020); the depth of ash deposition (wildfire ash alters physical properties and hydraulic properties of sediment; Bodí et al. 2014); the community composition and cover density of floodplain vegetation (Bendix and Cowell 2010); and the spatial heterogeneity of the floodplain associated with floodplain topography, beaver modifications, and large wood (Kleindl et al. 2015). Most of the techniques described for characterizing channel morphology also apply to floodplain morphology—repeat surveys using diverse ground-based and aerial platforms (Brogan et al. 2019). Floodplain grain-size distribution and alluvial thickness can be assessed via coring or shallow geophysical techniques such as ground penetrating radar or seismic reflectivity (Malenda et al. 2019). Thickness, depth, and spatial extent of ash deposition can be measured using sediment cores, cutbank exposures along the active channel, and from spectral indices in satellite imagery (Chafer et al. 2016). Vegetation characteristics can be estimated via field measurements in quadrats (Bendix and Cowell 2010) and remotely using aerial or satellite imagery (White et al. 1996; Pérez-Cabello et al. 2021).

River corridor hydrologic connectivity can be assessed in lateral, longitudinal, and vertical dimensions. Lateral (channel-floodplain) connectivity can change after wildfire in response to changes in both the dimensions of channel and floodplain and the fluxes of water into and through the river corridor (Benda et al. 2003; Wohl, Marshall, et al. 2024). These changes, which can either enhance or reduce the attenuation of peak flows, can be estimated using 2D hydraulic modeling (Chen et al. 2020); digital elevation models with delineated floodplains that include topographic thresholds for floodplain inundation (Brinkerhoff 2024); arrays of sensors or remote imagery to detect the presence of water on the floodplain (Hudson et al. 2013), or floodplain staff gauges and cameras to record overbank flows; field surveys of high water marks and the presence of post-fire, fluvially created erosional and depositional features on the floodplain (Wohl, Marshall, et al. 2024); SWOT and satellite imagery for larger catchments (Pavelsky et al. 2014); and the presence, location, and characteristics (age, species) of wetland and phreatophyte vegetation communities (Pike and Scatena 2010).

Vertical (surface-hyporheic-groundwater) connectivity can change after fire in response to changes in upland infiltration, as well as the grain-size distribution and surface configuration of the channel and floodplain (Benda et al. 2003; Rey et al. 2023). Hyporheic exchange flows can be mapped using salt tracers and electrical resistivity (Ward et al. 2010; Gambill et al. 2025); dye or radon tracers (Bourke et al. 2014); and patterns of streambed temperature (Westhoff et al. 2011). Groundwater recharge and upwelling can be mapped using shallow wells (Coluccio and Morgan 2019); seepage meters (Brunner et al. 2017); isotopic signatures and tracers (Johnson et al. 2024); measures of soil moisture content over time via automatic recorders such as electrical conductivity sensors or satellite imagery (Soylu and Bras 2021); measurements of streambed water temperature (Bianchin et al. 2010); integrated surface and subsurface hydrological flow models (Brunner et al. 2017); mapping of spring-head channels; mapping of wetland and phreatophyte vegetation (Crossman et al. 2012); and thermal imagery (Casas-Mulet et al. 2020).

Longitudinal connectivity can change after fire in response to altered water and sediment fluxes into and through river corridors, as well as changes in channel and floodplain morphology, including topographic irregularities and obstructions such as logjams and beaver dams (Benda et al. 2003; Wohl et al. 2022). Similar to the techniques applicable to lateral hydrologic connectivity, longitudinal hydrologic connectivity can be assessed using sensors that record the presence and/or depth of flow in channels and on the floodplain (Jaeger and Olden 2012); staff gauges and time-interval cameras; calibrated 1D static and 2D hydraulic models (e.g., Choi et al. 2015); and indirect assessments based on the presence of geomorphic features such as tributary fans, floodouts, or floodplains that could attenuate peak flows, or the distribution and genetic characteristics of aquatic populations (Cote et al. 2009; Fullerton et al. 2010).

Hydraulic complexity of river corridors can be assessed using direct hydraulic measurements with acoustic Doppler velocity measurements (Wallis et al. 2012); estimates of hydraulic complexity based on particle image velocimetry (Bandini et al. 2021) or geometric characterization of topography, grain size, and other sources of roughness as a first approximation of relative hydraulic differences (e.g., Buffington and Montgomery 1999); characterization of mechanisms for flow energy dissipation and of the distribution and characteristics of flow separation features such as secondary channels, logjams, and channel expansions or constrictions (Addy and Wilkinson 2019); and 2D and 3D hydraulic modeling (Olsen and Stokseth 1995).

The abundance, diversity, stability, connectivity, and complexity of aquatic and riparian habitat can be altered by post-fire changes in water and sediment fluxes, the configuration and stability of the river corridor, and factors such as food resources, trophic cascades, and connectivity for diverse organisms in the river corridor (Benda et al. 2003; Bixby et al. 2015; Ward et al. 2022). The characteristics of habitat can be assessed using tools such as habitat suitability models (Yi et al. 2017) and the presence or absence of species and characteristics of populations (Dunham et al. 2007).

3.3 | Assessment of Catchment-To Reach-Scale Resilience

Existing resilience evaluations based on multiple components commonly use a categorical objective and/or subjective weighting system (e.g., Nemec et al. 2014) in which the determination of indicator weight is a key step (e.g., Han et al. 2023). Choice of components to include is also a key step, especially in the context of assessing the resilience of a reach or entire length of river corridor. Choice of components and assignment of weights reflect both practical considerations of what can be measured and monitored and identification of the most important components at a specific site. If turbidity is particularly important because of water-supply intakes or aquatic habitat, for example, then direct measurement of turbidity and/or suspended sediment concentrations at varying flows and locations along a river may be the top priority for monitoring. Assessment of potential sources for fine sediment via measurement of upland erosion and ground cover, stream bank stability, and floodplain erosion and ground cover, as well as precipitation and stream flow thresholds for mobilizing these sediments, might be a secondary priority to facilitate understanding potential controls on observed turbidity. These more extensive measurements require greater time and effort but can also make resilience monitoring less of a “black box” by providing insights into the thresholds that trigger increases in turbidity and the potential for continuing changes in turbidity as vegetation regrows and stabilizes sediment or as potential sediment sources are exhausted. Assessing more variables for resilience increases the complexity, expense, and time of monitoring, but can also increase the insight into interactions among variables that control outcomes of interest, such as bed substrate stability, sediment yield to downstream areas, turbidity, or habitat diversity.

We suggest the following steps for developing a resilience index:

1. Assess available information on baseline condition and available pre-fire data; these may dictate which variables are worth monitoring to assess post-fire changes.
2. Choose and rank the response variable(s) of interest and potential underlying controls; as a hypothetical example, direct response variables might be channel substrate grain-size distribution and stability, and controls on these response variables might be instream sediment supply versus sediment transport capacity.
3. Identify the spatial extent and duration and the spatial and temporal resolution and technology that are feasible to use for measuring the response variable(s); in the hypothetical example in the previous step, this might

involve repeat photographic measurements of bed particle size and use of tracer clasts to assess bed stability, measured twice yearly at 10 locations within a reach for at least 2 years.

4. Revisit choices for extent, duration, and resolution of monitoring after the initial runoff season or other specified time period to assess whether initial choices are adequate for desired purposes.

4 | Considerations for Evaluating Resilience

The ability to evaluate geomorphic resilience of a river catchment or corridor may depend on an understanding of (i) baselines against which to assess resilience, (ii) responses of system components through time after disturbance, (iii) choice of specific components within a catchment or river corridor, and (iv) recognition of human interactions with the catchment or river corridor. We review each of these factors below.

4.1 | Baselines Against Which to Assess Resilience

Baselines here refers to pre-wildfire conditions. At some sites, records of pre-disturbance conditions may exist in the form of quantitative measurements such as stream gauging records (Mahat et al. 2015; Saxe et al. 2018) or remote imagery from which characteristics such as upland land cover or channel planform can be extracted (Wells et al. 2024). Where pre-fire data are limited, conditions prior to disturbance may be inferred from adjacent, undisturbed but otherwise comparable sites based on ground measurements, remote sensing, or published studies (Nigro et al. 2024); hydrologic and hydraulic modeling conducted prior to the disturbance or conducted based on assumed/inferred pre-disturbance conditions (Mahat et al. 2015; Havel et al. 2018); stratigraphic and sedimentary geochemical indirect indicators of pre-disturbance conditions (MacDonald et al. 1991; Reneau et al. 2007); topography of the river corridor as this indicates pre-disturbance forms (García et al. 2020); historical records from before the disturbance, such as topographic maps or ground-based photographs (Cousins 2001; Fuchs et al. 2015); and personal communications from residents and others familiar with the site prior to disturbance (Goforth and Minnich 2007).

When using any of these methods to infer pre-disturbance conditions, it is important to conceptualize the catchment or river corridor as dynamic, with a disturbance regime (Montgomery 1999) and continual adjustments. The concepts of natural or historical range of variability are useful in this context. Although sometimes used interchangeably, natural range of variability describes the conditions of a natural system prior to intensive human alteration of that system, whereas historical range of variability may describe conditions after human alteration. In either case, the intent is to understand the range of variations in relevant components during a specified timespan (typically, many decades or longer) (e.g., Cissel et al. 1994; Morgan et al. 1994). If the natural range of variability is used to characterize pre-disturbance conditions, then return to those conditions occurs when river corridor components pushed beyond this range by wildfire once again fall within the natural range of variability.

4.2 | Responses of System Components Through Time

Response curves or recovery trajectories of system components following disturbance can also be used to evaluate whether the magnitude and/or frequency of changes in a particular variable are declining through time (Warrick and Rubin 2007; Ebel et al. 2022), as well as whether changes are returning the component to a pre-disturbance condition (Gibson and Shelley 2020). Disturbance can force a river corridor into an alternate state that then remains stable; examples include beaver meadows that become elk grasslands because of intensive ungulate browsing and loss of riparian willows (Wolf et al. 2007) and wood-poor corridors in which removal of large wood causes a braided or anastomosing channel with a spatially heterogeneous floodplain to become a single-thread channel with a more homogeneous floodplain (Collins et al. 2012; Livers et al. 2018). In these examples, system components may change relatively rapidly and then exhibit little change. Alternatively, substantial changes immediately following wildfire—increased peak flows and sediment transport following precipitation, for example—may gradually decline in magnitude with time despite similar precipitation inputs and eventually reach input-response characteristics similar to those present prior to the disturbance. Trends in system components through time can thus be used to indirectly assess whether the component is resilient.

Ebel et al. (2022) distinguish statistical and functional evaluations of recovery. Statistical evaluations are based on central tendencies, variances, statistical distributions, or quantitative statistical relations such as linear regression. These are used to define pre- and post-fire states; sequential temporal comparisons form the basis for assessing a return to the pre-fire state. Functional recovery assessments rely on the re-establishment, or documentation of no change, of hydrologic functions such as soil moisture or discharge.

4.3 | Choice of Components

Resilience to wildfire disturbance can be evaluated for a specific component, such as sediment yield to a reach of river corridor, annual peak flow, bedform amplitude and wavelength, or hydrologic connectivity of floodplain wetlands. Resilience can also be evaluated for multiple components in a catchment or river corridor, with some type of weighting used to assess resilience of the catchment or river corridor as a system. The use of multiple components to create a resilience index has mostly been used thus far to evaluate river biotic communities, water quality, or urban flooding (Nemec et al. 2014; Han et al. 2023), but such an approach might also be useful for geomorphic components, as discussed in the context of the Poudre River in Section 6. Realistically, component choice is likely to reflect the objectives of monitoring (e.g., suspended sediment concentrations are a primary concern because of water-supply intakes) and feasibility (budget, spatial extent of measurement area, duration of measurements, access to remote data or field measurements).

4.4 | Human Effects

Resilience of river catchments and river corridors is most likely to be evaluated in the context of human needs, desires, and expectations, whether these relate to ecosystem services, hazards, or protection and restoration of native species, communities, or ecosystems. Although we focus here on the geomorphic resilience of river systems, this can be closely related to the resilience of infrastructure and human communities. The State of Colorado, for example, defines resilience as "the ability of communities to rebound, positively adapt to, or thrive amidst changing conditions or challenges—including human-caused and natural disasters—and to maintain quality of life, healthy growth, durable systems, economic vitality, and conservation of resources for present and future generations." (Colorado Resiliency Framework 2025). The Colorado Department of Transportation (CDOT Risk and Resilience Site, n.d.) and the State of Colorado (Colorado House Bill 18-1394, n.d.) define resilience as the ability to keep roads open and functional in the face of unexpected events and challenges (Colorado House Bill 18-1394, n.d.).

Geomorphic resilience of river catchments and river corridors may also be constrained by direct and deliberate or indirect and inadvertent human alterations of natural systems. Examples include mulching burned uplands with hay that has led to unintended introduction of nonnative cheatgrass (*Bromus tectorum*) (Bontrager et al. 2019), an annual grass that increases fire fuels and can promote a change in the wildfire regime to more frequent fires (Balch et al. 2013). This may in turn cause sustained post-fire increases in water and sediment yields to river corridors. Steep sections of unpaved roads can be locations of substantial rilling after wildfire and can enhance sediment delivery from uplands to river corridors (Sosa-Pérez and MacDonald 2017). Another example comes from catchments with consumptive water withdrawals that limit peak river flows and therefore the ability of the river to export excess post-fire sediment (Peat et al. 2005; Katz et al. 2026).

5 | Extent, Duration, and Resolution of Measurements

In addition to choosing specific components to measure and appropriate measurement techniques, choices regarding spatial and temporal resolution for measurements and spatial extent and duration of measurements will influence the ability to assess geomorphic resilience. Moody et al. (2013) identified the need to characterize the temporal and spatial distributions of major processes of precipitation, infiltration, runoff, and sediment erosion and transport as a critical theme for understanding post-wildfire landscape responses.

5.1 | Spatial and Temporal Resolution for Measurements

Spatial and temporal resolution for measurements will vary with the component and the location of interest, as well as the measurement technique used. Measurements of the spatial extent and duration of snow cover using MODIS data, for example, have a 500 × 500 m spatial resolution and are collected on a daily basis; this spatial and temporal resolution is imposed by the use of a standardized dataset. Repeat, ground-based surveys of channel dimensions may include individual survey points with spatial resolution governed by equipment capabilities (e.g., centimeters if the field crew uses an RTK GPS unit) and temporal resolution governed by the frequency of field visits and repeat surveys.

Among the important considerations in selecting spatial and temporal resolution are that needed resolution may (i) decline with time since the wildfire as uplands and river corridors gradually adjust to the effects of the fire (e.g., Sheridan et al. 2007; Orem and Pelletier 2015); (ii) vary with ongoing events and inputs, such as intense or prolonged precipitation that triggers inputs of water, solutes, and sediment to the river corridor or redistributes material within the river corridor (Liu et al. 2022); (iii) depend on the scale of inputs or changes—an example includes the spatial and temporal variability of rainfall, with some threshold rainfall intensity or volume required to trigger substantial upland runoff and associated changes (e.g., Rengers, Tucker, et al. 2016); and (iv) depend on the seasonality of potential changes, such as greater spatial and temporal measurements of vegetation characteristics during the growing season (e.g., Van Leeuwen et al. 2010) or of snow during the winter and spring. Appropriate spatial and temporal resolution can be estimated based on the expected magnitude, frequency, and duration of inputs and changes.

5.2 | Spatial Extent and Duration of Measurements

The spatial extent of measurements in a burned catchment and the length of time over which measurements are made also depend on the component being measured, the location of interest, and the measurement technique used. Remotely sensed data, for example, may be limited by spatial and temporal resolution but they can typically cover large spatial areas (e.g., Argentiero et al. 2021). Ground-based field measurements may have higher spatial and temporal resolution but limited spatial extent and duration of measurements (e.g., Van Eck et al. 2016).

Additional considerations with regard to spatial extent and duration of measurements include the following:

1. The spatial extent depends on the scale of events and inputs and the extent of the study area. The scale of events and inputs may vary in relation to the size of storm cells creating rainfall and associated runoff and sediment mobilization, for example, as well as whether measurements are to be made only in burned areas or also in unburned areas that can provide a comparison to the response of burned areas. In large catchments or spatially extensive wildfires, it may not be feasible to include all burned areas and either representative (e.g., Johansen et al. 2001) or particularly responsive portions of a catchment (e.g., Triantafillou and Wohl 2024) may be selected for measurements.

2. Measurement duration may depend on the intensity of the wildfire and the characteristics of the catchment. Low-intensity wildfire and low-relief terrain may not create elevated levels of runoff or solute or sediment fluxes from uplands, for example, and therefore may not create substantial responses in river corridors (Bonell and Williams 1987; Wohl 2025).

3. Duration of measurements may also depend on evidence of decreasing magnitude of response. Runoff yields from rainfall (e.g., Liu et al. 2022; Partington et al. 2022), suspended sediment concentrations (e.g., Desilets et al. 2007), and sediment yields (e.g., Shin et al. 2013) commonly decrease with time following fire and this may limit the duration of measurements as these components approach pre-fire levels.

4. Measurement duration may depend on evidence of either self-arresting feedbacks that limit the duration of response and monitoring or self-enhancing feedbacks that may extend the duration of response and monitoring. Regrowth of vegetation or limited supply of upland sediment may cause abrupt or rapid declines in sediment yields to river corridors with time (Wohl and Pearthree 1991; DiBiase and Lamb 2013), creating self-arresting feedback in post-fire channel change that limits the duration of monitoring necessary to measure post-fire landscape trajectory. Alternatively, self-enhancing feedbacks can create persistent post-fire channel changes. In Montana's Sleeping Child Creek catchment, for example, post-fire debris flows caused channel aggradation upstream from each debris-flow fan, incision across the fan, and aggradation downstream during the first 5 years after the fire (Hoffman and Gabet 2007). After 11 years, however, increased instream wood loads and a beaver dam had caused continuous aggradation that will likely persist over longer timespans (Short et al. 2015). This self-enhancing feedback indicates the extended duration of measurements required to understand the recovery trajectory.

5. Finally, expectations based on documented responses in the scientific literature may influence the spatial extent and duration of post-fire measurements. A synthesis of 51 studies indicates that post-fire increases in suspended sediment typically persist for at most 5 years, although some studies indicated elevated yields for 14 years or more (Paul et al. 2022).

6 | The Cache la Poudre River, Colorado Case Study

6.1 | Catchment Characteristics

The Poudre River heads in the Southern Rocky Mountains at 4145 m elevation and flows eastward approximately 200 km to its confluence with the South Platte River on the Great Plains at 1399 m elevation, draining 4895 km^2 (Figure 5). Climate is semi-arid, with increasing mean annual temperature (−4°C to 10°C) and decreasing mean annual precipitation (1000 to 380 mm) at lower elevations (NOAA 2024). Upland vegetation includes tundra (> 3460 m elevation), subalpine conifer forest (3360–2850 m elevation), montane conifer forest (2850–1835 m elevation), and shortgrass prairie (< 1800 m elevation).

The mountainous portion of the catchment can be divided into snow zones that are persistent (> ~3000 m elevation; deep, lasting snow throughout winter months), transitional (~3000 to 2600 m; consistent winter snow, but snow persistence and snow water equivalent less than in the persistent zone), and intermittent (< 2600 m; continual snow cover only periodically throughout winter) (Moore et al. 2015). Portions of the catchment above 2300 m elevation have predominantly snowmelt peak flows with peak unit discharge typically of 1.1 m^3/s/km^2 (Jarrett 1990). Below 2300 m, the river network also experiences flash floods from summer convective storms. These floods can have unit peak discharge up to 40 m^3/s/km^2 (Jarrett 1990), although the unit peak discharge declines in larger rivers such as the Poudre River mainstem. Although no major dams are present along the mainstem, numerous diversions reduce peak and base flow through the City of Fort Collins (in the prairie portion of the catchment) by 59% and 57%, respectively, from pre-development levels (Shanahan et al. 2014).

Three general types of wildfire regimes occurred historically in the mountain portion of the Poudre catchment (Veblen and Donnegan 2005). Frequent, low-severity fires burned mainly the ground surface over areas of ~100 ha and recurred at intervals of 5–30 years in the lower elevations of the montane zone. Infrequent, high-severity fires that killed all canopy trees over areas of hundreds to thousands of hectares recurred at intervals of > 100 years in the subalpine zone. A complex pattern of both low- and high-severity fires that burned areas of ~100 ha and recurred at intervals of 40–100 years occurred in the middle and upper montane zone (Veblen and Donnegan 2005).

As with other regions of the world, the wildfire regime of the Poudre River catchment is changing rapidly in response to a warming climate and human effects (e.g., Schoennagel et al. 2017). We focus on the two most recent major wildfires in the catchment, which occurred in 2012 and 2020. The 2012 fire was ignited by a lightning strike and burned nearly 35,380 ha, mostly in the montane zone. The 2020 fire was likely human-caused and burned nearly 84,550 ha in the montane and subalpine zones; for now, it is the largest wildfire in Colorado's history. Multiple studies document the geomorphic effects of these wildfires in uplands and river corridors within and downstream from the burned areas (Table 4).

6.2 | Assessing Geomorphic Resilience of the Cache la Poudre River Catchment and River Corridor

A key consideration for this river catchment is the longitudinal variation in catchment characteristics from the mountainous upper catchment to the plains portion of the lower catchment (Figure 6). Assessment of upland resilience will focus on the mountainous upper catchment that is likely to be the site of wildfires, whereas assessment of river corridor resilience can focus on any and all portions of the river network. Among the issues of concern post-wildfire are (i) increased water and sediment yields to river corridors that cause flash flooding and debris flows during summer convective rainfall (Moody and Martin 2001; Triantafillou and Wohl 2024); (ii)

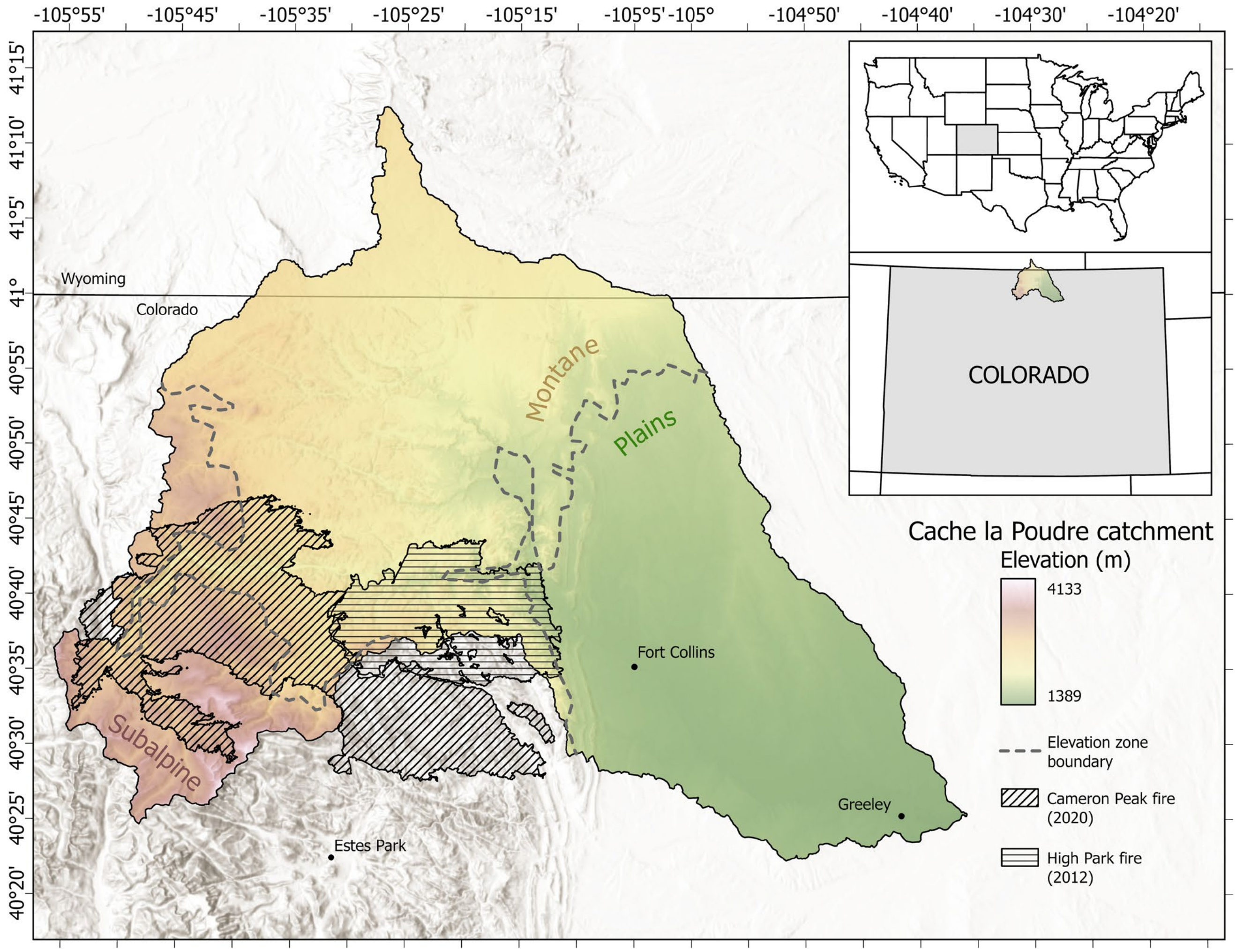

FIGURE 5 | Location map of the Poudre River catchment, indicating the extent of the 2012 and 2020 wildfires and the elevation zones described in the text. The map was created with ArcGIS Pro (3.1.2) using elevation data from the US Geological Survey (2021) and fire perimeters from the National Interagency Fire Center (2022). [Color figure can be viewed at wileyonlinelibrary.com]

degraded water quality associated with increased turbidity (Clow et al. 2024) and increased yields of phosphate (Hohner et al. 2016), nitrate (Mast et al. 2016), and dissolved organic carbon (Writer et al. 2012) to downstream water-supply reservoirs; (iii) fish kills and degraded aquatic habitat from the combined effects of turbidity, fine sediment accumulation in channels, and increased water temperatures from loss of riparian shading (Dunham et al. 2007; Preston et al. 2023); and (iv) channel instability and damage to infrastructure associated with excessive erosion or sedimentation (Chin et al. 2016). Ability to identify issues of greatest concern post-wildfire facilitates identifying appropriate components of the catchment and river network for resilience assessment, as well as relevant spatial and temporal characteristics of resilience assessment.

6.2.1 | Catchment-Scale Resilience

Wildfires in the mountainous uplands have demonstrably influenced the five components of upland topography, snowpack, runoff, soils, and vegetation (Table 4), but ongoing climate warming and drying in the region are also influencing snowpack and vegetation characteristics. Interactions between wildfire and climate change (Calder and Shuman 2017) may preclude return to pre-fire conditions of snowpack (Gergel et al. 2017; Bolinger et al. 2024) and vegetation communities (Fornwalt et al. 2024), in particular. A catchment-scale resilience assessment could focus on any one of the five basic components listed above or focus on a subset of these components.

Interactions among the five components are of interest in a geomorphic context as they influence water and sediment yields to river corridors, so a resilience assessment might focus on the factors limiting return to pre-fire yields, such as regrowth of ground cover as this influences response to rainfall (Graber et al. 2023). Assessment of snowpack resilience is likely to require repeat measurements over a longer timespan because of the slower regrowth rate of forest cover and the potential for factors such as wet and dry deposition of dust from distant locations that can influence snowmelt rates (McGrath et al. 2023). Assessment of either ground cover or snowpack

TABLE 4 | Some of the documented hydrologic and geomorphic effects of the 2012 and 2020 wildfires in the Poudre River catchment.

Hydrologic and geomorphic effects	References
17%–25% decrease in peak snow water equivalent, 82%–144% greater melt rates, and 11–13 days earlier disappearance of snow during first winter and spring after 2020 fire	McGrath et al. 2023
Rainfall intensity thresholds for post-fire runoff during summer convective storms increased with time after 2012 fire	Wilson et al. 2018
Following 2020 fire, sites in persistent snow zone more responsive to rainfall (measurable stream flow response) than sites in other snow zones and burned sites more responsive than unburned sites, but persistent snow zone sites had longer lags between peak rainfall and peak discharge, indicating infiltration excess overland flow at intermittent snow zone sites	Miller 2022
Hillslope-to-stream sediment delivery ratios and area-normalized cross-sectional channel change increased with the percentage of catchment that burned at high severity during the 2012 fire	Wilson et al. 2021
Sediment transport from excess overland flow dominated sediment entrainment and delivery to small, ephemeral tributaries in the 2012 burn area, which did not experience net channel cross-sectional change despite evidence of multiple episodes of scour and fill during first runoff season after fire; perennial tributaries delivered sediment that accumulated on alluvial fans at each confluence with the South Fork Poudre River	Rathburn et al. 2018
Mean drainage area above channel heads decreased by > 2 orders of magnitude immediately after 2012 fire, but returned to pre-fire levels within 4 years	Wohl 2013a Wohl and Scott 2017
After 2020 fire, anomalous winter flooding over ice during temporary warming in spring 2021 Increased base flow during first year after 2020 fire	White et al. 2022 Wohl et al. 2022
Suspended sediment concentrations on South Fork Poudre River during summer storms declined monotonically to background conditions over 3 years after the 2012 fire, despite a major flood in 2013	Ryan et al. 2024
Net sediment accumulation in the valley floors of tributaries to the Poudre River over a 4-year period after the 2012 fire, especially in wider and flatter valley floors during the first 2 years, despite substantial erosion during the 2013 flood	Brogan et al. 2019
Net in-channel and floodplain sediment accumulation following 2020 fire until 2022 major flood caused substantial channel erosion; channel-spanning logjams attenuated in-channel sediment fluxes until 2022 flood redistributed most logjams to the floodplain	Wohl et al. 2022; Wohl, Marshall, et al. 2024
Substantial post-fire debris flows and flash floods in small (< 40 km^2 drainage area) catchments	Triantafillou and Wohl 2024
Channel and floodplain change greatly increased in magnitude after the first runoff season following the 2020 fire but returned to the historical range of these metrics 3 years after the fire; geomorphic change included secondary channel infilling, reduced pool area, and increased area of bars and islands	Hahn et al. 2025
Portions of the Poudre River mainstem on the Great Plains experienced substantial sedimentation following the 2020 fire; flow regulation and lack of peak flows have allowed marginal sediment deposits to persist and become partly stabilized by riparian vegetation as of the 2023 runoff season	Katz et al. 2026

characteristics could rely on remote data for the entire mountainous portion of the catchment or focus on subcatchments or elevation zones that are likely to produce the greatest water and/or sediment yields. In the Poudre catchment, the intermittent snow-covered zone (snow persistence, or snow on the ground, 25%–50% of time between 1 January and 3 July) at elevations below ~3000 m is likely to be the most sensitive to change in snow characteristics and vegetation (Harrison et al. 2021) and is a logical choice for more intensive or spatially limited monitoring. Post-fire declines in evapotranspiration rates may have a larger effect on water yield than fire-related changes in snowpack in portions of the catchment without persistent snowpack (e.g., Poon and Kinoshita 2018). Existing work suggests that ground cover may return to levels that limit water and sediment yields within circa 5 years of wildfire (Graber et al. 2023) but recovery of the forest canopy will require decades (Kampf et al. 2022). Monitoring the resilience of snowpack characteristics can inform understanding

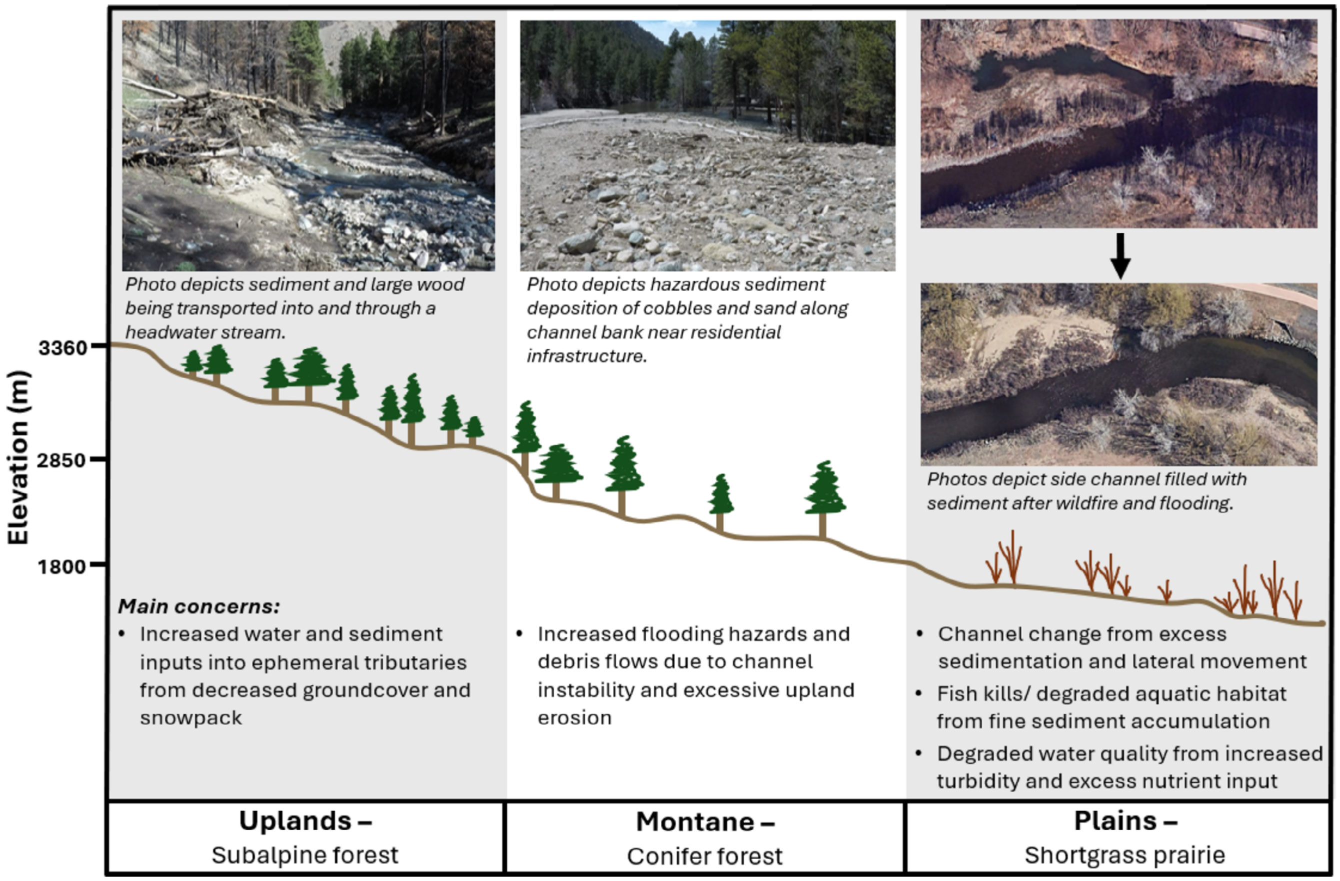

FIGURE 6 | Schematic illustration of primary elevation zones in the Poudre River catchment affected by wildfire and some of the primary post-fire concerns in each zone. [Color figure can be viewed at wileyonlinelibrary.com]

of the processes underlying water yield to river corridors and thus the basic energy and fluvial transport capacity available for ongoing change within the river corridor.

6.2.2 | River Corridor Resilience

Mountain wildfires have also demonstrably influenced the components of the river corridor in both the mountains and plains portions of the Poudre River catchment (Table 4) although the magnitude, duration, and nature of post-fire changes in the river corridor vary throughout the river network. Portions of the Poudre River network that could be affected by mountain wildfires include ephemeral headwaters, perennial tributaries, and the mainstem river in the mountains, as well as the mainstem in the plains portion of the network.

Ephemeral mountain headwaters may be of concern primarily as a conduit or source (via bed and bank erosion) for increased sediment yield to downstream portions of the river network. Resilience assessments that indicate areas of erosion or deposition could include direct measurements of sediment transport, or repeated ground-based/remote measurements of channel morphology (e.g., Ridgway et al. 2024). Channel instability may continue after water and sediment yields have declined to pre-fire levels. Ephemeral headwater channels may stabilize within a few years (e.g., Minshall et al. 2004; Rathburn et al. 2018), although this is poorly constrained because most studies focus on the immediate channel response within a year or two of a wildfire.

Perennial mountain tributaries may be of most concern as locations of (i) flash flooding, (ii) sediment transport, sourcing, or storage, and (iii) aquatic habitat. Resilience assessments could focus on: flow measurements (Ebel et al. 2022; Wohl et al. 2022); measurements of sediment transport (Ryan et al. 2024); change in channel geometry (Benda et al. 2003; Legleiter et al. 2003; Florsheim et al. 2017), large wood accumulations (Zelt and Wohl 2004), and other channel characteristics as these indicate erosion or deposition; longitudinal connectivity as this indicates the potential to attenuate downstream fluxes of water, sediment, and phosphate (Triantafillou and Wohl 2024); vertical connectivity (Pugh et al. 2022) as this indicates potential for nutrient (nitrate) uptake; and/or direct metrics of habitat such as pool volume and spawning gravels (Florsheim and Chin 2024). More attention has been given to recovery times of perennial mountain streams than to ephemeral streams because of the direct effects of perennial streams on water quality and aquatic habitat throughout the larger river network.

These studies suggest that changes in perennial stream morphology in response to wildfire can be more sustained over many years (e.g., Minshall et al. 2004), especially where (i) a threshold is crossed with respect to incision or aggradation and change in channel planform, or (ii) feedbacks among tributary channels, alluvial fans, and axial channels (e.g., Benda et al. 2003; Florsheim et al. 2017), fluvial and debris-flow processes (Murphy et al. 2019), or physical processes and living vegetation (e.g., Eaton et al. 2010) or downed wood (e.g., Short et al. 2015) create nonlinear and time-lagged responses to the fire. Again, however, the exact timespan over which fire-induced changes may persist is poorly constrained because of both site-specific considerations that limit extrapolations across rivers and the paucity of long-term studies.

The mainstem Poudre River in the mountainous portion of the river network is also of most concern with respect to sediment transport or storage and aquatic habitat. Resilience assessments could thus focus on channel change, habitat abundance and quality (pool volume, bed substrate, areas of flow separation), and longitudinal connectivity for organisms. The Poudre River in the mountains is a relatively steep (average gradient 0.006 m/m) river with high transport capacity for the sediments introduced to the mainstem from adjacent uplands and tributaries following wildfire, but the longitudinal profile alternates downstream between steep (gradient 0.01–0.02 m/m), laterally confined reaches and lower gradient (0.003–0.006 m/m) reaches in which floodplains, backwaters, and secondary channels can accumulate and store sediment. The steeper, transport-dominated reaches (sensu Montgomery and Buffington 1997) appear to experience minimal change in channel morphology, habitat, or longitudinal connectivity after wildfire. Channel-margin sediment deposits of sand-size and finer, as well as greater embeddedness of riffle gravels, are more likely to form after wildfire in the lower gradient response reaches, and these effects may persist for several years to decades (Wohl and Cenderelli 2000; Katz et al. 2026). This suggests that it would be most effective to monitor post-fire river corridor resilience by focusing on lower-gradient segments, particularly with respect to channel marginal areas and embeddedness of coarser sediment.

Wildfire-related effects in the prairie portion of the mainstem Poudre River relate mainly to sediment dynamics (primarily deposition) as this influences channel change and hazards to infrastructure and aquatic habitat. The prairie portion of the river corridor historically had a meandering to anastomosing channel with floodplain wetlands, high lateral connectivity, cottonwood (*Populus* spp.) riparian gallery forests, and beaver modifications (Sexton 1998; Wohl 2013b; Katz et al. 2026). This was the upstream-most extent of many native, endemic fishes of the Great Plains (Fausch and Bestgen 1997). The contemporary river is a single channel with limited sinuosity and channel-floodplain connectivity. Water diversions reduce peak and base flows by 59% and 57%, respectively, from predevelopment levels. These extensive flow withdrawals have altered the annual hydrograph. In-channel structures such as low dams and weirs interrupt longitudinal connectivity. The combined effects of declining flow due to flow regulation and water withdrawals, as well as lower transport capacity due to lower channel gradients, exacerbate deposition of fire-related sediment loads in the lower reaches of the mainstem Poudre River, especially in backwaters and secondary channels, and create greater embeddedness in the mainstem thalweg relative to the mountain portion of the river (Katz et al. 2026). This loss of habitat has contributed to declines in native fish species diversity, distribution, and abundance since the 1990s (Haworth and Bestgen 2024).

Post-fire resilience assessments in the prairie portion of the Poudre River could focus on changes in channel cross-sectional geometry and bed substrate, especially in reaches that contain potentially sensitive infrastructure (e.g., irrigation headgates) and fish habitat. These assessments could include mainstem bed grain-size distribution, channel width/depth ratio, channel planform heterogeneity, and lateral connectivity within the river corridor. Given the lack of snowmelt peak flows of historically occurring magnitudes, which might at least flush fine sediment from spawning gravels, the fire-related changes in sedimentation in the prairie portion of the mainstem river are likely to persist for decades, but resilience monitoring at intervals longer than a single year could be used to check this assumption.

7 | Discussion

There are at least two reasons to assess post-wildfire geomorphic resilience in a catchment or river corridor—for basic understanding of disturbance and response in the system, and to assess whether specific management responses such as upland mulching or addition of structures (e.g., engineered logjams) to the river corridor are desirable. Although this paper examines components of the catchment and river corridor that can be used to assess resilience following wildfire, it is important to note that some situations do not require any monitoring because wildfire has minimal geomorphic effects. Examples include grasslands, low-relief catchments, and low intensity fires. Each of these situations may not result in substantially increased water and sediment yields to river corridors following wildfire (Bonell and Williams 1987; Wohl 2025). In addition, the magnitude of post-fire change that might be of concern and warrant monitoring depends on whether the change in water and sediment dynamics and thus processes, forms, and functions in the river corridor necessitate a management response.

A lack of resilience is not inherently bad. Dryland channels are sometimes most accurately characterized as disequilibrium systems that change substantially in response to disturbance and maintain the new configuration for decades to centuries, as in channels of the semiarid steppe that change abruptly during large floods from sinuous, single channels lined with woodland to unvegetated, braided river corridors (Friedman and Lee 2002). Management actions designed to increase resilience in these river corridors may be of limited use unless they are mitigating previous human alterations that have made the river corridor even less resilient to disturbance.

Conversely, resilience is not inherently good, as when a river corridor returns to an undesirable state following disturbance. Examples come from semiarid river corridors with dense riparian vegetation because of past human actions. Some dryland river corridors have dense exotic woody vegetation, such as *Tamarix* spp. and *Elaeagnus angustifolia* in the western United States, that have facilitated substantial narrowing and simplification of the active channel over a period of decades (Graf 1978; Jaeger and Wohl 2011). Native riparian species that have grown densely across the floodplain in response to flow regulation can similarly constrict and simplify the active channel (Williams 1978; Nadler and Schumm 1981). In each scenario, the change in river corridor form can severely restrict habitat for diverse native species from fishes to birds (NRC 2004). A quick return to this densely vegetated state of the floodplain after disturbance, although indicating resilience, may be undesirable in these river corridors.

Resilience is beneficial if it maintains desirable characteristics and services provided by the river corridor, such as flood attenuation, nutrient uptake, sediment retention, or habitat. Characteristics considered to be desirable, however, may vary substantially between individuals or groups of people and specific contexts. Spatial heterogeneity in headwater river corridors can attenuate downstream fluxes and enhance resilience to post-fire floods in downstream portions of a river network (Wohl et al. 2022, 2025), for example, but property owners of headwater river corridors may view attenuation associated with beaver ponds as an undesirable feature (Jonker et al. 2006; Morzillo and Needham 2015).

Resilience has commonly been assessed with respect to either the natural or historical range of variability (Morgan et al. 1994; Seidl et al. 2016) but changing climate may alter or negate the ability of catchments and river corridors to return to past system states. Ecologists describe novel ecosystems (Hobbs et al. 2009) and the need to define reference points that trigger management action (Samhouri et al. 2010), although the latter concept is controversial (Johnson 2013). Ongoing rapid changes in natural systems suggest that an Anthropocene baseline defined in terms of human needs—which can include preservation of native species—may be a particularly useful basis on which to assess resilience.

7.1 | Prioritizing Geomorphic Monitoring Before and After a Wildfire

Based on the considerations discussed in previous sections, we propose a generalized approach that can assist in prioritizing monitoring of individual catchments or subcatchments following wildfire (Figure 7). In the immediate aftermath of wildfire, priorities for monitoring and mitigation tend to emphasize protection of life and property. Having pre-fire data on the spatial distribution of upland and river corridor characteristics that influence post-fire geomorphic adjustments can assist with these efforts and inform prioritization of post-fire monitoring efforts.

We suggest that relevant pre-fire data for uplands include spatially explicit representations of vegetation communities, soil characteristics, water and sediment connectivity, and bedrock lithology. Vegetation maps can assist in identifying areas where vegetation is likely to regrow relatively rapidly after fire (e.g., grasses) or where fire-destruction of canopy cover may most strongly alter snowpack and rainfall-runoff processes. Soils maps that include hydrologic parameters such as hydrophobicity, vertical hydraulic conductivity, and sorptivity can highlight areas that may be especially susceptible to post-fire increases in water and sediment yields (Moody et al. 2009). Metrics of water and sediment connectivity can indicate portions of the catchment likely to transmit post-fire increases in water and sediment yield down to river corridors (e.g., Cavalli et al. 2013; Shore et al. 2013) and these metrics should explicitly include the presence of infrastructure such as unpaved roads that can substantially influence downslope water and sediment yields (e.g., Jing et al. 2022) or any roadway embankment that can pond water and sediment in valley floors. Bedrock lithologies can be categorized as those likely to produce abundant sand-size and finer sediment and calcareous versus non-calcareous lithologies (Wohl et al. 2007). Abundant fine sediment can adversely impact channel stability, aquatic habitat abundance and stability, and drinking-water supplies (e.g., Benda et al. 2003; Emelko et al. 2011; Ward et al. 2022). Calcareous rocks produce biologically reactive solutes that can support greater abundance and diversity of stream organisms (Allan et al. 2021). The presence of these rocks can signal highly productive stream waters that might be prioritized for mitigation and monitoring if there is concern for at-risk aquatic species.

Relevant pre-fire data for the river network include reach-scale gradient, flow regime types, river corridor connectivity, and

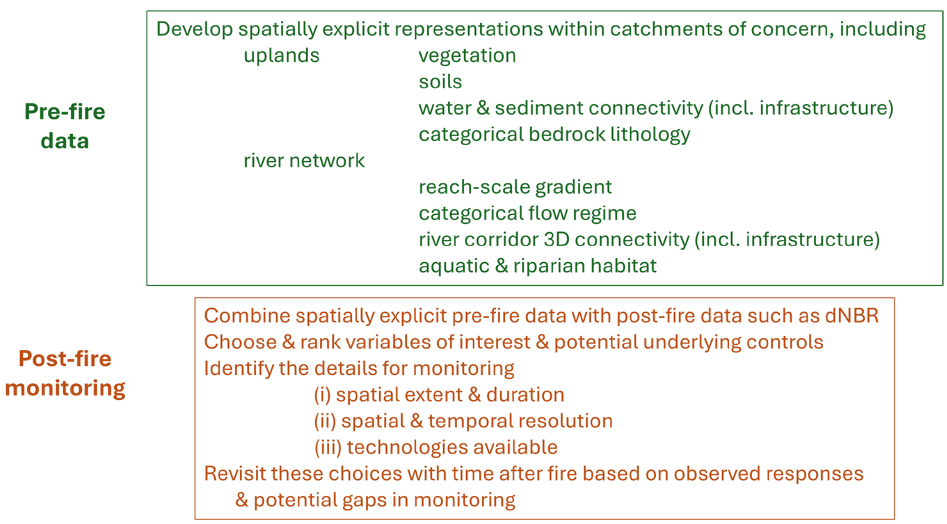

FIGURE 7 | Suggested approach to using pre- and post-fire data for prioritizing monitoring and mitigation after wildfire. [Color figure can be viewed at wileyonlinelibrary.com]

aquatic and riparian habitat. Reach-scale stream gradient in high- to moderate-relief terrain typically reflects underlying bedrock erosional resistance and geologic history. Gradient can be regarded as a master variable that correlates with multiple variables including channel morphology, grain-size distribution, lateral confinement, potential influence of debris flows, and transport vs. response river segments (Montgomery and Buffington 1997; Wohl and Merritt 2005; Buffington and Tonina 2009). Categorical flow regime reflects differences in magnitude, duration, frequency, and flashiness of stream flow that strongly influence the geomorphic responses of river corridors after fire. In mountainous regions of the western US, for example, distinguishing portions of the river network dominated by snowmelt flow and those dominated by rainfall-runoff can inform understanding of potential river corridor resilience after fire. Metrics or relative ranking of each of the three primary dimensions of longitudinal, lateral, and vertical connectivity can indicate portions of the river network likely to transmit post-fire increases in water and sediment efficiently downstream, portions of the network likely to create at least transient storage for water and sediment, and portions of the network likely to transform excess nutrients such as nitrate via hyporheic exchange flows. These can be based on a range of river network variables, including catchment- to reach-scale characteristics such as spatial heterogeneity and accommodation space on the valley floor for transient storage (e.g., Triantafillou and Wohl 2024). Evaluation of connectivity must include diverse forms of infrastructure such as culverts, flow regulation, or road embankments that currently limit connectivity or that might do so following wildfire (e.g., Neville et al. 2009; Blanton and Marcus 2014; Wohl et al. 2017). Spatially explicit data on basic aspects (abundance or quality) of habitat for specific organisms or communities can help to identify portions of the river network to prioritize for post-fire monitoring or mitigation if these areas are rare or either particularly sensitive or resistant (and thus providing refugia) to fire-related changes (e.g., Whitney et al. 2016). Many of these suggested pre-fire datasets overlap or reinforce each other. Spatially explicit data on vegetation, soils, and bedrock lithology can inform inferences about water and sediment connectivity, for example, and help to identify portions of a catchment that are likely to be most susceptible to post-fire changes. Reach-scale gradient, flow regime, and 3D connectivity interact to govern the magnitude and speed of post-fire changes in the river corridor.

Spatially explicit pre-fire data can be combined with fire-related spatially explicit data such as the differenced normalized burn ratio (dNBR; French et al. 2008) to identify portions of a catchment most likely to experience substantial geomorphic response to wildfire. Examples focused on a specific process include post-fire debris flows and debris floods (Kern et al. 2017; Sturzenegger et al. 2021), flash floods (Sutanto et al. 2024), and snow avalanches (Yariyan et al. 2022). Local to regional governmental agencies may also maintain hazard maps that can be used to prioritize monitoring and mitigation after wildfire. Following the 2020 wildfires in north-central Colorado, for example, steep gradient tributaries that had previously exhibited pre-fire hydrologic responses to short duration, intense convective rainfall were commonly observed to exhibit some of the more significant increases in post-wildfire flows of sediment, woody material, and ash in the first few years after the fires. Easily identifiable physical characteristics of the landscape such as alluvial fans at tributary confluences had been identified as creating risks to property and infrastructure before the fire, as indicated on hazard maps created by Colorado Geological Survey. Some of these sites experienced debris flows and flash floods following the 2020 wildfires.

8 | Conclusions

Geomorphic resilience of a river corridor or river network following wildfire reflects upland and upstream components as well as components within the river corridor itself. A large number of components can be measured to assess resilience. Choices of which components to measure, as well as their spatial and temporal resolutions, will reflect priorities and concerns as well as resources available for ongoing monitoring programs. We have suggested use of a multi-component resilience index based on (i) available information on pre-fire conditions, (ii) choosing and ranking response variables of interest, (iii) identifying the spatial extent and duration and the spatial and temporal resolution and technology that are available for measuring response variables, and (iv) revisiting choices for monitoring strategy after the initial runoff season. Assessment of geomorphic resilience in rivers after wildfire should also consider the specific context with respect to ongoing climate change and human alterations and whether even relatively recent pre-fire conditions provide an appropriate baseline against which to assess resilience.

Data Availability Statement

Data sharing not applicable to this article as no datasets were generated or analysed during the current study.

References

Abatzoglou, J. T., and A. P. Williams. 2016. "Impact of Anthropogenic Climate Change on Wildfire Across Western US Forests." *Proceedings of the National Academy of Science* 113: 11770–11775. https://doi.org/10.1073/pnas.1607171113.

Addy, S., and M. E. Wilkinson. 2019. "Representing Natural and Artificial In-Channel Large Wood in Numerical Hydraulic and Hydrological Models." *WIREs Water* 6: e1389. https://doi.org/10.1002/wat2.1389.

Akin, I. D., and T. O. Akinleye. 2021. "Water Vapor Sorption Behavior of Wildfire-Burnt Soil." *Journal of Geotechnical and Geoenvironmental Engineering* 147: 04021115. https://doi.org/10.1061/(ASCE)GT.1943-5606.0002648.

Alessio, P., T. Dunne, and K. Morell. 2021. "Post-Wildfire Generation of Debris-Flow Slurry by Rill Erosion on Colluvial Hillslopes." *Journal of Geophysical Research. Earth Surface* 126: e2021JF006108. https://doi.org/10.1029/2021JF006108.

Allan, J. D., M. M. Castillo, and K. A. Capps. 2021. "Streamwater Chemistry." In *Stream Ecology*, edited by J. D. Allan, M. M. Castillo, and K. A. Capps, 3rd ed., 75–100. Springer. https://doi.org/10.1007/978-3-030-61286-3_4.

Altdorff, D., S. E. Oswald, S. Zacharias, et al. 2023. "Toward Large-Scale Soil Moisture Monitoring Using Rail-Based Cosmic Ray Neutron Sensing." *Water Resources Research* 59: e2022WR033514. https://doi.org/10.1029/2022WR033514.

Argentiero, I., G. F. Ricci, M. Elia, et al. 2021. "Combining Methods to Estimate Post-Fire Soil Erosion Using Remote Sensing Data." *Forests* 12: 1105. https://doi.org/10.3390/f12081105.

Bakker, M., F. Gimbert, T. Geay, C. Misset, S. Zanker, and A. Recking. 2020. "Field Application and Validation of a Seismic Bedload Transport Model." *Journal of Geophysical Research* 125: e2019JF005416. https://doi.org/10.1029/2019JF005416.

Balch, J. K., B. A. Bradley, C. M. D'Antonio, and J. Gomez-Dans. 2013. "Introduced Annual Grass Increases Regional Fire Activity Across the Arid Western USA (1980-2009)." *Global Change Biology* 19: 173–183. https://doi.org/10.1111/gcb.12046.

Balfour, V. N. 2015. "Determining Wildfire Ash Saturated Hydraulic Conductivity and Sorptivity With Laboratory and Field Methods." *Catena* 135: 358–368. https://doi.org/10.1016/j.catena.2014.01.009.

Bandini, F., B. Luthi, S. Pena-Haro, et al. 2021. "A Drone-Borne Method to Jointly Estimate Discharge and Manning's Roughness of Natural Streams." *Water Resources Research* 57: e2020WR028266. https://doi.org/10.1029/2020WR028266.

Benda, L., D. Miller, P. Bigelow, and K. Andras. 2003. "Effects of Post-Wildfire Erosion on Channel Environments, Boise River, Idaho." *Forest Ecology and Management* 178: 105–119. https://doi.org/10.1016/S0378-1127(03)00056-2.

Bendix, J., and C. M. Cowell. 2010. "Impacts of Wildfire on the Composition and Structure of Riparian Forests in Southern California." *Ecosystems* 13: 99–107. https://doi.org/10.1007/s10021-009-9303-z.

Berg, N. H., and D. L. Azuma. 2010. "Bare Soil and Rill Formation Following Wildfires, Fuel Reduction Treatments, and Pine Plantations in the Southern Sierra Nevada, California, USA." *International Journal of Wildland Fire* 19: 478–489. https://doi.org/10.1071/WF07169.

Bianchin, M., L. Smith, and R. Beckie. 2010. "Quantifying Hyporheic Exchange in a Tidal River Using Temperature Time Series." *Water Resources Research* 46: W07507. https://doi.org/10.1029/2009WR008365.

Bixby, R. J., S. D. Cooper, R. E. Gresswell, L. E. Brown, C. N. Dahm, and K. A. Dwire. 2015. "Fire Effects on Aquatic Ecosystems: An Assessment of the Current State of the Science." *Freshwater Science* 34: 1340–1350. https://doi.org/10.1086/684073.

Blanton, P., and W. A. Marcus. 2014. "Roads, Railroads, and Floodplain Fragmentation due to Transportation Infrastructure Along Rivers." *Annals of the Association of American Geographers* 104: 413–431. https://doi.org/10.1080/00045608.2014.892319.

Bodí, M. B., D. A. Martin, V. N. Balfour, et al. 2014. "Wildland Fire Ash: Production, Composition and Eco-Hydro-Geomorphic Effects." *Earth-Science Reviews* 130: 103–127. https://doi.org/10.1016/j.earscirev.2013.12.007.

Bolinger, B., J. Lukas, R. Schumacher, and P. Goble. 2024. *Climate Change in Colorado*. Colorado State University. https://mountainscholar.org/items/99896af1-0564-4531-9628-be1e13dbc4cd.

Bonell, M., and J. Williams. 1987. "Infiltration and Redistribution of Overland Flow and Sediment on a Low Relief Landscape of Semi-Arid, Tropical Queensland." In *Forest Hydrology and Watershed Management*, edited by R. H. Swanson, P. Y. Bernier, and P. D. Woodward, vol. 167, 199–211. IAHS-AISH Publication.

Bontrager, J. D., P. Morgan, A. T. Hudak, and P. R. Robichaud. 2019. "Long-Term Vegetation Response Following Post-Fire Straw Mulching." *Fire Ecology* 15: 22. https://doi.org/10.1186/s42408-019-0037-9.

Bourke, S. A., P. G. Cook, M. Shanafield, S. Dogramaci, and J. F. Clark. 2014. "Characterisation of Hyporheic Exchange in a Losing Stream Using Radon-22." *Journal of Hydrology* 519: 94–105. https://doi.org/10.1016/j.jhydrol.2014.06.057.

Bracken, L. J. 2010. "Overland Flow and Soil Erosion." In *Sediment Cascades: An Integrated Approach*, edited by T. P. Burt and R. J. Allison, 181–216. Wiley. https://doi.org/10.1002/9780470682876.ch7.

Brinkerhoff, C. B. 2024. "The Importance of Source Data in River Network Connectivity Modeling: A Review." *Limnology and Oceanography* 69: 3033–3060. https://doi.org/10.1002/lno.12706.

Brogan, D. J., P. A. Nelson, and L. H. MacDonald. 2019. "Spatial and Temporal Patterns of Sediment Storage and Erosion Following a Wildfire and Extreme Flood." *Earth Surface Dynamics* 7: 563–590. https://doi.org/10.5194/esurf-7-563-2019.

Brunner, P., R. Therrien, P. Renard, C. T. Simmons, and H. J. H. Franssen. 2017. "Advances in Understanding River-Groundwater Interactions." *Reviews of Geophysics* 55: 818–854. https://doi.org/10.1002/2017RG000556.

Brunsden, D., and J. B. Thornes. 1979. "Landscape Sensitivity and Change." *Transactions of the Institute of British Geographers* 4: 463–484.

Buffington, J. M., and D. R. Montgomery. 1999. "Effects of Hydraulic Roughness on Surface Textures of Gravel-Bed Rivers." *Water Resources Research* 35: 3507–3521. https://doi.org/10.1029/1999WR900138.

Buffington, J. M., and D. Tonina. 2009. "Hyporheic Exchange in Mountain Rivers II: Effects of Channel Morphology on Mechanics, Scales, and Rates of Exchange." *Geography Compass* 3: 1038–1062. https://doi.org/10.1111/j.1749-8198.2009.00225.x.

Busby, D. M., and A. C. Wilcox. 2024. "Hydrogeomorphic Response of Steep Streams Following Severe Wildfire in the Western Cascades, Oregon." *Earth Surface Processes and Landforms* 49: 4570–4586. https://doi.org/10.1002/esp.5982.

Calder, W. J., and B. Shuman. 2017. "Extensive Wildfires, Climate Change, and an Abrupt State Change in Subalpine Ribbon Forests, Colorado." *Ecology* 98: 2585–2600. https://doi.org/10.1002/ecy.1959.

Caldwell, P. V., K. J. Elliott, N. Liu, J. M. Vose, D. R. Zietlow, and J. D. Knoepp. 2020. "Watershed-Scale Vegetation, Water Quantity, and Water Quality Responses to Wildfire in Southern Appalachian Mountain Region, United States." *Hydrological Processes* 34: 5188–5209. https://doi.org/10.1002/hyp.13922.

Canfield, H. E., C. J. Wilson, L. J. Lane, K. J. Crowell, and W. A. Thomas. 2005. "Modeling Scour and Deposition in Ephemeral Channels After Wildfire." *Catena* 61: 273–291. https://doi.org/10.1016/j.catena.2005.03.013.

Capelli, A., F. Koch, P. Henkel, et al. 2022. "GNSS Signal-Based Snow Water Equivalent Determination for Different Snowpack Conditions Along a Steep Elevation Gradient." *Cryosphere* 16: 505–531. https://doi.org/10.5194/tc-16-505-2022.

Casas-Mulet, R., J. Pander, D. Ryu, M. J. Stewardson, and J. Geist. 2020. "Unmanned Aerial Vehicle (UAV)-Based Thermal Infra-Red (TIR) and Optical Imagery Reveals Multi-Spatial Scale Controls of Cold-Water Areas Over a Groundwater-Dominated Riverscape." *Frontiers in Environmental Science* 8: 64. https://doi.org/10.3389/fenvs.2020.00064.

Cavalli, M., S. Trevisani, F. Comiti, and L. Marchi. 2013. "Geomorphometric Assessment of Spatial Sediment Connectivity in Small Alpine Catchments." *Geomorphology* 188: 31–41. https://doi.org/10.1016/j.geomorph.2012.05.007.

CDOT Risk and Resilience Site. n.d. "CDoOT Risk and Resilience Site." Accessed 25 September, 2025. https://www.codot.gov/programs/planning/cdot-resilience-program.

Chafer, C. J., C. Santin, and S. H. Doerr. 2016. "Modelling and Quantifying the Spatial Distribution of Post-Wildfire Ash Loads." *International Journal of Wildland Fire* 25: 249–255. https://doi.org/10.1071/WF15074.

Chardon, V., G. Piasny, and L. Schmitt. 2022. "Comparison of Software Accuracy to Estimate the Bed Grain Size Distribution From Digital Images: A Test Performed Along the Rhine River." *River Research and Applications* 38: 358–367. https://doi.org/10.1002/rra.3910.

Chen, X., L. Chen, M. C. Stone, and K. Acharya. 2020. "Assessing Connectivity Between the River Channel and Floodplains During High

Flows Using Hydrodynamic Modeling and Particle Tracking Analysis." *Journal of Hydrology* 583: 124609. https://doi.org/10.1016/j.jhydrol.2020.124609.

Chin, A., L. An, J. L. Florsheim, et al. 2016. "Investigating Feedbacks in Human-Landscape Systems: Lessons Following a Wildfire in Colorado, USA." *Geomorphology* 252: 40–50. https://doi.org/10.1016/j.geomorph.2015.07.030.

Choi, C. C., G. Constantinescu, and R. Mantilla. 2015. "Implementation of a Hydraulic Routing Model for Dendritic Networks With Offline Coupling to a Distributed Hydrological Model." *Journal of Hydrologic Engineering* 20: 04015023. https://doi.org/10.1061/(ASCE)HE.1943-5584.0001152.

Cissel, J. H., F. J. Swanson, W. A. McKee, and A. L. Burditt. 1994. "Using the Past to Plan the Future in the Pacific Northwest." *Journal of Forestry* 92: 30–46. https://doi.org/10.1093/jof/92.8.30.

Clow, D. W., G. A. Akie, S. F. Murphy, and E. J. Gohring. 2024. "Dynamic Water-Quality Responses to Wildfire in Colorado." *Hydrological Processes* 38: e15291. https://doi.org/10.1002/hyp.15291.

Collins, B. D., D. R. Montgomery, K. L. Fetherston, and T. B. Abbe. 2012. "The Floodplain Large-Wood Cycle Hypothesis: A Mechanism for the Physical and Biotic Structuring of Temperate Forested Alluvial Valleys in the North Pacific Coastal Ecoregion." *Geomorphology* 139-140: 460–470. https://doi.org/10.1016/j.geomorph.2011.11.011.

Colorado House Bill 18-1394. n.d. "Colorado House Bill 18-1394." Accessed 25 September, 2025. https://leg.colorado.gov/bills/hb18-1394.

Colorado Resiliency Framework. 2025. "Colorado Resiliency Framework." https://coresiliency.colorado.gov/2025-colorado-resiliency-framework-update.

Coluccio, K., and L. K. Morgan. 2019. "A Review of Methods for Measuring Groundwater-Surface Water Exchange in Braided Rivers." *Hydrology and Earth System Sciences* 23: 4397–4417. https://doi.org/10.5194/hess-23-4397-2019.

Cote, D., D. G. Kehler, C. Bourne, and Y. F. Wiersma. 2009. "A New Measure of Longitudinal Connectivity for Stream Networks." *Landscape Ecology* 24: 101–113. https://doi.org/10.1007/s10980-008-9283-y.

Cousins, S. A. O. 2001. "Analysis of Land-Cover Transitions Based on 17th and 18th Century Cadastral Maps and Aerial Photographs." *Landscape Ecology* 16: 41–54. https://doi.org/10.1023/A:1008108704358.

Crossman, J., C. Bradley, J. N. W. David, and A. M. Milner. 2012. "Use of Remote Sensing to Identify Areas of Groundwater Upwelling on Active Glacial Floodplains: Their Frequency, Extent and Significance on a Landscape Scale." *Remote Sensing of Environment* 123: 116–126. https://doi.org/10.1016/j.rse.2012.03.023.

Curtis, J. A., S. A. Wright, J. T. Minear, and L. E. Flint. 2015. "Assessing Geomorphic Change Along the Trinity River Downstream From Lewiston Dam, California, 1980–2011." US Geological Survey Scientific Investigations Report2015–5046, Reston, VA. https://doi.org/10.3133/sir20155046.

Dekker, L. W., C. J. Ristema, K. Oostindie, D. Moore, and J. G. Wesseling. 2009. "Methods for Determining Soil Water Repellency on Field-Moist Samples." *Water Resources Research* 45: W00D33. https://doi.org/10.1029/2008WR007070.

Desilets, S. L. E., B. Nijssen, B. Ekwurzel, and T. P. A. Ferré. 2007. "Post-Wildfire Changes in Suspended Sediment Rating Curves: Sabino Canyon, Arizona." *Hydrological Processes* 21: 1413–1423. https://doi.org/10.1002/hyp.6352.

DiBiase, R. A., and M. P. Lamb. 2013. "Vegetation and Wildfire Controls on Sediment Yield in Bedrock Landscapes." *Geophysical Research Letters* 40: 1093–1097. https://doi.org/10.1002/grl.50277.

DiBiase, R. A., and M. P. Lamb. 2020. "Dry Sediment Loading of Headwater Channels Fuels Post-Wildfire Debris Flows in Bedrock Landscapes." *Geology* 48: 189–193. https://doi.org/10.1130/G46847.1.

Doerr, S. H., R. A. Shakesby, and R. P. D. Walsh. 2000. "Soil Water Repellency: Its Causes, Characteristics and Hydro-Geomorphological Significance." *Earth-Science Reviews* 51: 33–65. https://doi.org/10.1016/S0012-8252(00)00011-8.

Dunham, J. B., A. E. Rosenberger, C. H. Luce, and B. E. Rieman. 2007. "Influences of Wildfire and Channel Reorganization on Spatial and Temporal Variation in Stream Temperature and the Distribution of Fish and Amphibians." *Ecosystems* 10: 335–346. https://doi.org/10.1007/s10021-007-9029-8.

Dunne, T., W. Zhang, and B. F. Aubry. 1991. "Effects of Rainfall, Vegetation, and Microtopography on Infiltration and Runoff." *Water Resources Research* 27: 2271–2285. https://doi.org/10.1029/91WR01585.

Durand, M., C. J. Gleason, T. M. Pavelsky, et al. 2023. "A Framework for Estimating Global River Discharge From the Surface Water and Open Topography Satellite Mission." *Water Resources Research* 59: e2021WR031614. https://doi.org/10.1029/2021WR031614.

Eaton, B. C., C. A. E. Andrews, T. R. Giles, and J. C. Phillips. 2010. "Wildfire, Morphologic Change and Bed Material Transport at Fishtrap Creek, British Columbia." *Geomorphology* 118: 409–424. https://doi.org/10.1016/j.geomorph.2010.02.008.

Ebel, B. A., and J. A. Moody. 2017. "Synthesis of Soil-Hydraulic Properties and Infiltration Timescales in Wildfire-Affected Soils." *Hydrological Processes* 31: 324–340. https://doi.org/10.1002/hyp.10998.

Ebel, B. A., and J. A. Moody. 2020. "Parameter Estimation for Multiple Post-Wildfire Hydrologic Models." *Hydrological Processes* 34: 4049–4066. https://doi.org/10.1002/hyp.13865.

Ebel, B. A., J. A. Moody, and D. A. Martin. 2012. "Hydrologic Conditions Controlling Runoff Generation Immediately After Wildfire." *Water Resources Research* 48: W03529. https://doi.org/10.1029/2011WR011470.

Ebel, B. A., F. K. Rengers, and G. E. Tucker. 2016. "Observed and Simulated Hydrologic Response for a First-Order Catchment During Extreme Rainfall Three Years After Wildfire Disturbance." *Water Resources Research* 51: 9367–9389. https://doi.org/10.1002/2016WR019110.

Ebel, B. A., J. W. Wagenbrenner, A. M. Kinoshita, and K. D. Bladon. 2022. "Hydrologic Recovery After Wildfire: A Framework of Approaches, Metrics, Criteria, Trajectories, and Timescales." *Journal of Hydrology and Hydromechanics* 70: 388–400. https://doi.org/10.2478/johh-2022-0033.

Ellett, N. G., J. L. Pierce, and N. F. Glenn. 2019. "Partitioned by Process: Measuring Post-Fire Debris-Flow and Rill Erosion With Structure From Motion Photogrammetry." *Earth Surface Processes and Landforms* 44: 3128–3146. https://doi.org/10.1002/esp.4728.

Emelko, M. B., U. Silins, K. D. Bladon, and M. Stone. 2011. "Implications of Land Disturbance on Drinking Water Treatability in a Changing Climate: Demonstrating the Need for Source Water Supply and Protection Strategies." *Water Research* 45: 461–472. https://doi.org/10.1016/j.watres.2010.08.051.

Engel, E. C., and S. R. Abella. 2011. "Vegetation Recovery in a Desert Landscape After Wildfires: Influences of Community Type, Time Since Fire and Contingency Effects." *Journal of Applied Ecology* 48: 1401–1410. https://doi.org/10.1111/j.1365-2664.2011.02057.x.

Fausch, K. D., and K. R. Bestgen. 1997. "Ecology of Fishes Indigenous to the Central and Southwestern Great Plains." In *Ecology and Conservation of Great Plains Vertebrates*, edited by F. L. Knopf and F. B. Samson, vol. 125, 131–166. Springer. https://doi.org/10.1007/978-1-4757-2703-6_6.

Florsheim, J. L., and A. Chin. 2024. "Disturbance and Recovery of Physical Elements of Habitat in Relation to Post-Wildfire Channel Sedimentation, Southern California Transverse Ranges." In *Biogeomorphic Responses to Wildfire in Fluvial Ecosystems*, edited by J. L. Florsheim, A. P. O'Dowd, and A. Chin, vol. 562, 57–77. Geological Society of America. https://doi.org/10.1130/2024.2562(04).

Florsheim, J. L., A. Chin, A. M. Kinoshita, and S. Nourbakhshbeidokhti. 2017. "Effect of Storms During Drought on Post-Wildfire Recovery of Channel Sediment Dynamics and Habitat in Southern California Chaparral, USA." *Earth Surface Processes and Landforms* 42: 1482–1492. https://doi.org/10.1002/esp.4117.

Fornwalt, P. J., A. P. Wion, A. W. Schoettle, et al. 2024. "Vulnerability of Major Colorado Front Range Tree Species to Climate Change." In *Colorado Front Range Climate Change Vulnerability Assessment for National Forests*, edited by B. Hanberry, 123–243. USDA General Technical ReportRMRS-GTR-438, Rocky Mountain Research Station.

French, N. H. F., E. S. Kasischke, R. J. Hall, et al. 2008. "Using Landsat Data to Assess Fire and Burn Severity in North American Boreal Forest Region: An Overview and Summary of Results." *International Journal of Wildland Fire* 17: 443–462. https://doi.org/10.1071/WF08007.

Friedman, J. M., and V. J. Lee. 2002. "Extreme Floods, Channel Change, and Riparian Forests Along Ephemeral Streams." *Ecological Monographs* 72: 409–425. https://doi.org/10.1890/0012-9615(2002)072[0409:EFCCAR]2.0.CO;2.

Fryirs, K. A. 2017. "River Sensitivity: A Lost Foundation Concept in Fluvial Geomorphology." *Earth Surface Processes and Landforms* 42: 55–70. https://doi.org/10.1002/esp.3940.

Fuchs, R., P. H. Verburg, J. G. P. W. Clevers, and M. Herold. 2015. "The Potential of Old Maps and Encyclopaedias for Reconstructing Historic European Land Cover/Use Change." *Applied Geography* 59: 43–55. https://doi.org/10.1016/j.apgeog.2015.02.013.

Fuller, I. C., D. J. Gilvear, M. C. Thoms, and R. G. Death. 2019. "Framing Resilience for River Geomorphology: Reinventing the Wheel?" *River Research and Applications* 35: 91–106. https://doi.org/10.1002/rra.3384.

Fullerton, A. H., K. M. Burnett, E. A. Steel, et al. 2010. "Hydrological Connectivity for Riverine Fish: Measurement Challenges and Research Opportunities." *Freshwater Biology* 55: 2215–2237. https://doi.org/10.1111/j.1365-2427.2010.02448.x.

Gambill, I., A. Marshall, D. A. Benson, et al. 2025. "Exploring the Influence of Morphologic Heterogeneity and Discharge on Transient Storage in Stream Systems: 1. Insights From the Field." *Water Resources Research* 61: e2023WR036031. https://doi.org/10.1029/2023WR036031.

García, J. H., S. Dunesme, and H. Piégay. 2020. "Can We Characterize River Corridor Evolution at a Continental Scale From Historical Topographic Maps? A First Assessment From the Comparison of Four Countries." *River Research and Applications* 36: 934–946. https://doi.org/10.1002/rra.3582.

Gergel, D. R., B. Nijssen, J. T. Abatzoglou, D. P. Lettenmaier, and M. R. Stumbaugh. 2017. "Effects of Climate Change on Snowpack and Fire Potential in the Western USA." *Climatic Change* 141: 287–299. https://doi.org/10.1007/s10584-017-1899-y.

Gersh, M., K. E. Gleason, and A. Surunis. 2022. "Forest Fire Effects on Landscape Snow Albedo Recovery and Decay." *Remote Sensing* 14: 4079. https://doi.org/10.3390/rs14164079.

Gibson, S., and J. Shelley. 2020. "Flood Disturbance, Recovery, and Inter-Flood Incision on a Large Sand-Bed River." *Geomorphology* 351: 106973. https://doi.org/10.1016/j.geomorph.2019.106973.

Giovando, J., and J. D. Niemann. 2022. "Wildfire Impacts on Snowpack Phenology in a Changing Climate Within the Western U.S." *Water Resources Research* 58: e2021WR031569. https://doi.org/10.1029/2021WR031569.

Girona-García, A., D. C. S. Vieira, J. Silva, C. Fernández, P. R. Robichaud, and J. J. Keizer. 2021. "Effectiveness of Post-Fire Soil Erosion Mitigation Treatments: A Systematic Review and Meta-Analysis." *Earth-Science Reviews* 217: 103611. https://doi.org/10.1016/j.earscirev.2021.103611.

Goforth, B. R., and R. A. Minnich. 2007. "Evidence, Exaggeration, and Error in Historical Accounts of Chaparral Wildfires in California." *Ecological Applications* 17: 779–790. https://doi.org/10.1890/06-0831.

González-Pelayo, O., S. A. Prats, E. van den Elsen, et al. 2024. "The Effects of Wildfire Frequency on Post-Fire Soil Surface Water Dynamics." *European Journal of Forest Research* 143: 493–508. https://doi.org/10.1007/s10342-023-01635-z.

Graber, A. P., M. A. Thomas, and J. W. Kean. 2023. "How Long Do Runoff-Generated Debris-Flow Hazards Persist After Wildfire?" *Geophysical Research Letters* 50: e2023GL105101. https://doi.org/10.1029/2023GL105101.

Graf, W. L. 1978. "Fluvial Adjustments to the Spread of Tamarisk in the Colorado Plateau Region." *Geological Society of America Bulletin* 89: 1491–1501. https://doi.org/10.1130/0016-7606(1978)89%3C1491:FATTSO%3E2.0.CO;2.

Graf, W. L. 2006. "Downstream Hydrologic and Geomorphic Effects of Large Dams on American Rivers." *Geomorphology* 79: 336–360. https://doi.org/10.1016/j.geomorph.2006.06.022.

Greene, R. H., M. C. Thoms, and M. Parsons. 2023. "We Cannot Turn Back Time: A Framework for Restoring and Repairing Rivers in the Anthropocene." *Frontiers in Environmental Science* 11: 1162908. https://doi.org/10.3389/fenvs.2023.1162908.

Hahn, A. J., N. D. Christensen, D. C. White, E. Wohl, and R. R. Morrison. 2025. "Trajectories of River-Floodplain Morphology and Hydraulics Following Compounding Wildfire-Flood Disturbances." *Earth Surface Processes and Landforms* 50: e70057. https://doi.org/10.1002/esp.70057.

Han, H., X. Li, X. Gu, and G. Li. 2023. "Urban Rivers Health Assessment Based on the Concept of Resilience Using Improved FCM-EWM, MABAC Model." *Ecological Indicators* 154: 110833. https://doi.org/10.1016/j.ecolind.2023.110833.

Harrison, H. N., J. C. Hammond, S. Kampf, and L. Kiewiet. 2021. "On the Hydrological Difference Between Catchments Above and Below the Intermittent-Persistent Snow Transition." *Hydrological Processes* 35: e14411. https://doi.org/10.1002/hyp.14411.

Harvey, J., and M. Gooseff. 2015. "River Corridor Science: Hydrologic Exchange and Ecological Consequences From Bedforms to Basins." *Water Resources Research* 51: 6893–6922. https://doi.org/10.1002/2015WR017617.

Havel, A., A. Tasdighi, and M. Arabi. 2018. "Assessing the Hydrologic Response to Wildfires in Mountainous Regions." *Hydrology and Earth System Sciences* 22: 2527–2550. https://doi.org/10.5194/hess-22-2527-2018.

Haworth, M. R., and K. R. Bestgen. 2024. "Low-Head Dam Fragmentation, Habitat Alteration, and Invasive Predators Degrade a Western United States Stream Fish Assemblage." *Ecology of Freshwater Fish* 33: e12773. https://doi.org/10.1111/eff.12773.

Hislop, S., S. Jones, M. Soto-Berelov, A. Skidmore, A. Haywood, and T. H. Nguyen. 2018. "Using Landsat Spectral Indices in Time-Series to Assess Wildfire Disturbance and Recovery." *Remote Sensing* 10: 460. https://doi.org/10.3390/rs10030460.

Hobbs, R. J., E. Higgs, and J. A. Harris. 2009. "Novel Ecosystems: Implications for Conservation and Restoration." *Trends in Ecology & Evolution* 24: 599–605. https://doi.org/10.1016/j.tree.2009.05.012.

Hoffman, D., and E. J. Gabet. 2007. "Effects of Sediment Pulses on Channel Morphology in a Gravel Bed River." *Geological Society of America Bulletin* 119: 116–125. https://doi.org/10.1130/B25982.1.

Hohner, A. K., K. Cawley, J. Oropeza, R. S. Summers, and F. L. Rosario-Ortiz. 2016. "Drinking Water Treatment Response Following a Colorado Wildfire." *Water Research* 105: 187–198. https://doi.org/10.1016/j.watres.2016.08.034.

Huang, Q., D. Long, Z. Han, and P. Han. 2022. "High-Resolution Satellite Images Combined With Hydrological Modeling Derive River Discharge for Headwaters: A Step Toward Discharge Estimation in Ungauged Basins." *Remote Sensing of Environment* 277: 113030. https://doi.org/10.1016/j.rse.2022.113030.

Hudson, P. F., M. A. Sounny-Slitine, and M. LaFevor. 2013. “A New Longitudinal Approach to Assess Hydrologic Connectivity: Embanked Floodplain Inundation Along the Lower Mississippi River.” *Hydrological Processes* 27: 2187–2196. https://doi.org/10.1002/hyp.9838.

Isaak, D. J., C. H. Luce, B. E. Rieman, et al. 2010. “Effects of Climate Change and Wildfire on Stream Temperatures and Salmonid Thermal Habitat in a Mountain River Network.” *Ecological Applications* 20: 1350–1371. https://doi.org/10.1890/09-0822.1.

Iskin, E. P., and E. Wohl. 2021. “Wildfire and the Patterns of Floodplain Large Wood on the Merced River, Yosemite National Park, California, USA.” *Geomorphology* 389: 107805. https://doi.org/10.1016/j.geomorph.2021.107805.

Jaeger, K. L., and J. D. Olden. 2012. “Electrical Resistance Sensor Arrays as a Means to Quantify Longitudinal Connectivity of Rivers.” *River Research and Applications* 28: 1843–1852. https://doi.org/10.1002/rra.1554.

Jaeger, K. L., and E. Wohl. 2011. “Channel Response in a Semiarid Stream to Removal of Tamarisk and Russian Olive.” *Water Resources Research* 47: W02536. https://doi.org/10.1029/2009WR008741.

Jarrett, R. D. 1990. “Paleohydrologic Techniques Used to Define the Spatial Occurrence of Floods.” *Geomorphology* 3: 181–195. https://doi.org/10.1016/0169-555X(90)90044-Q.

Jing, Y., Q. Zhao, M. Lu, et al. 2022. “Effects of Road and River Networks on Sediment Connectivity in Mountainous Watersheds.” *Science of the Total Environment* 826: 154189. https://doi.org/10.1016/j.scitotenv.2022.154189.

Johansen, M. P., T. E. Hakonson, and D. D. Breshears. 2001. “Post-Fire Runoff and Erosion from Rainfall Simulation: Contrasting Forests With Shrublands and Grasslands.” *Hydrological Processes* 15: 2953–2965. https://doi.org/10.1002/hyp.384.

Johnson, C. J. 2013. “Identifying Ecological Thresholds for Regulating Human Activity: Effective Conservation or Wishful Thinking?” *Biological Conservation* 168: 57–65. https://doi.org/10.1016/j.biocon.2013.09.012.

Johnson, K., J. N. Christensen, W. P. Gardner, et al. 2024. “Shifting Groundwater Fluxes in Bedrock Fractures: Evidence From Stream Water Radon and Water Isotopes.” *Journal of Hydrology* 635: 131202. https://doi.org/10.1016/j.jhydrol.2024.131202.

Jonker, S. A., R. M. Muth, J. F. Organ, R. R. Zwick, and W. M. Siemer. 2006. “Experiences With Beaver Damage and Attitudes of Massachusetts Residents Toward Beaver.” *Wildlife Society Bulletin* 34: 1009–1021. https://doi.org/10.2193/0091-7648(2006)34[1009:EWBDAA]2.0.CO;2.

Jumps, N., A. B. Gray, J. J. Guilinger, and W. C. Cowger. 2022. “Wildfire Impacts on the Persistent Suspended Sediment Dynamics of the Ventura River, California.” *Journal of Hydrology: Regional Studies* 41: 101096. https://doi.org/10.1016/j.ejrh.2022.101096.

Kampf, S. K., D. McGrath, M. G. Sears, S. R. Fassnacht, L. Kiewiet, and J. C. Hammond. 2022. “Increasing Wildfire Impacts on Snowpack in the Western U.S.” *Proceedings of the National Academy of Sciences* 119: e2200333119. https://doi.org/10.1073/pnas.2200333119.

Katz, A. C., E. Wohl, K. Bestgen, and M. Haworth. 2026. “Fine Sediment Depositional Patterns and Fish Habitat Following Wildfire and Debris Flow.” *River Research and Applications* 42: 149–161. https://doi.org/10.1002/rra.70064.

Kemter, M., M. Fischer, L. V. Luna, et al. 2021. “Cascading Hazards in the Aftermath of Australia's 2019/2020 Black Summer Wildfires.” *Earth's Future* 9: e2020EF001884. https://doi.org/10.1029/2020EF001884.

Kern, A. N., P. Addison, T. Oommen, S. E. Salazar, and R. A. Coffman. 2017. “Machine Learning Based Predictive Modeling of Debris Flow Probability Following Wildfire in the Intermountain Western United States.” *Mathematical Geosciences* 49: 717–735. https://doi.org/10.1007/s11004-017-9681-2.

Kinar, N. J., and J. W. Pomeroy. 2015. “Measurement of the Physical Properties of the Snowpack.” *Reviews of Geophysics* 53: 481–544. https://doi.org/10.1002/2015RG000481.

Kinoshita, A. M., and T. S. Hogue. 2015. “Increased Dry Season Water Yield in Burned Watersheds in Southern California.” *Environmental Research Letters* 10: 014003. https://doi.org/10.1088/1748-9326/10/1/014003.

Kleindl, W. J., M. C. Rains, L. A. Marshall, and F. R. Hauer. 2015. “Fire and Flood Expand the Floodplain Shifting Habitat Mosaic Concept.” *Freshwater Science* 34: 1366–1382. https://doi.org/10.1086/684016.

Knight, D. W., C. Hazlewood, R. Lamb, P. G. Samuels, and K. Shiono. 2018. *Practical Channel Hydraulics*. 2nd ed. CRC Press.

Koshkin, A. L., B. J. Hatchett, and A. W. Nolin. 2022. “Wildfire Impacts on Western United States Snowpacks.” *Frontiers in Water* 4: 971271. https://doi.org/10.3389/frwa.2022.971271.

Lane, P. N. J., G. J. Sheridan, and P. J. Noske. 2006. “Changes in Sediment Loads and Discharge From Small Mountain Catchments Following Wildfire in South Eastern Australia.” *Journal of Hydrology* 331: 495–510. https://doi.org/10.1016/j.jhydrol.2006.05.035.

Le Breton, M., E. Larose, L. Baillet, Y. Lejeune, and A. van Herwijnen. 2023. “Monitoring Snow Water Equivalent Using the Phase of RFID Signals.” *Cryosphere* 17: 3137–3156. https://doi.org/10.5194/tc-17-3137-2023.

Legleiter, C. J., R. L. Lawrence, M. A. Fonstad, W. A. Marcus, and R. Aspinall. 2003. “Fluvial Response a Decade After Wildfire in the Northern Yellowstone Ecosystem: A Spatially Explicit Analysis.” *Geomorphology* 54: 119–136. https://doi.org/10.1016/S0169-555X(02)00332-X.

Lentile, L. B., P. Morgan, A. T. Hudak, et al. 2007. “Post-Fire Burn Severity and Vegetation Response Following Eight Large Wildfires Across the Western United States.” *Fire Ecology* 3: 91–108. https://doi.org/10.4996/fireecology.0301091.

Leon, J. R. R., W. J. D. Van Leeuwen, and G. M. Casady. 2012. “Using MODIS-NDVI for the Modeling of Post-Wildfire Vegetation Response as a Function of Environmental Conditions and Pre-Fire Restoration Treatments.” *Remote Sensing* 4: 598–621. https://doi.org/10.3390/rs4030598.

Liébault, F., J. B. Laronne, S. Klotz, and C. Bel. 2022. “Seasonal Bedload Pulses in a Small Alpine Catchment.” *Geomorphology* 398: 108055. https://doi.org/10.1016/j.geomorph.2021.108055.

Liébault, F., H. Piégay, M. Cassel, and F. Arnaud. 2024. “Bedload Tracing With RFID Tags in Gravel-Bed Rivers: Review and Meta-Analysis After 20 Years of Field and Laboratory Experiments.” *Earth Surface Processes and Landforms* 49: 147–169. https://doi.org/10.1002/esp.5704.

Lisle, T. E., and S. Hilton. 1992. “The Volume of Fine Sediment in Pools: An Index of Sediment Supply in Gravel-Bed Streams.” *Journal of the American Water Resources Association* 28: 371–383. https://doi.org/10.1111/j.1752-1688.1992.tb04003.x.

Liu, T., L. A. McGuire, N. Oakley, and F. Cannon. 2022. “Temporal Changes in Rainfall Intensity-Duration Thresholds for Post-Wildfire Flash Floods in Southern California.” *Natural Hazards and Earth System Sciences* 22: 361–376. https://doi.org/10.5194/nhess-22-361-2022.

Livers, B., E. Wohl, K. J. Jackson, and N. A. Sutfin. 2018. “Historical Land Use as a Driver of Alternative States for Stream Form and Function in Forested Mountain Watersheds of the Southern Rocky Mountains.” *Earth Surface Processes and Landforms* 43: 669–684. https://doi.org/10.1002/esp.4275.

MacDonald, G. M., C. P. S. Larsen, J. M. Szeicz, and K. A. Moser. 1991. “The Reconstruction of Boreal Forest Fire History From Lake Sediments: A Comparison of Charcoal, Pollen, Sedimentological, and Geochemical Indices.” *Quaternary Science Reviews* 10: 53–71. https://doi.org/10.1016/0277-3791(91)90030-X.

Mahat, V., A. Anderson, and U. Silins. 2015. "Modelling of Wildfire Impacts on Catchment Hydrology Applied to Two Case Studies." *Hydrological Processes* 29: 3687–3698. https://doi.org/10.1002/hyp.10462.

Malenda, H. F., N. A. Sutfin, G. Guryan, et al. 2019. "From Grain to Floodplain: Evaluating Heterogeneity of Floodplain Hydrostratigraphy Using Sedimentology, Geophysics, and Remote Sensing." *Earth Surface Processes and Landforms* 44: 1799–1815. https://doi.org/10.1002/esp.4613.

Martinez, J. L., M. E. Lucas-Borja, P. A. Plaza-Alvarez, et al. 2021. "Comparison of Satellite and Drone-Based Images at Two Spatial Scales to Evaluate Vegetation Regeneration After Post-Fire Treatments in a Mediterranean Forest." *Applied Sciences* 11: 5423. https://doi.org/10.3390/app11125423.

Mast, M. A., S. F. Murphy, D. W. Clow, C. A. Penn, and G. A. Sexstone. 2016. "Water-Quality Response to a High-Elevation Wildfire in the Colorado Front Range." *Hydrological Processes* 30: 1811–1823. https://doi.org/10.1002/hyp.10755.

Mayor, A. G., S. Bautista, J. Llovet, and J. Bellot. 2007. "Post-Fire Hydrological and Erosional Responses of a Mediterranean Landscape: Seven Years of Catchment-Scale Dynamics." *Catena* 71: 68–75. https://doi.org/10.1016/j.catena.2006.10.006.

McCluney, K. E., N. L. Poff, M. A. Palmer, et al. 2014. "Riverine Macrosystems Ecology: Sensitivity, Resistance, and Resilience of Whole River Basins With Human Alterations." *Frontiers in Ecology and the Environment* 12: 48–58. https://doi.org/10.1890/120367.

McGrath, D., L. Zeller, R. Bonnell, et al. 2023. "Declines in Peak Snow Water Equivalent and Elevated Snowmelt Rates Following the 2020 Cameron Peak Wildfire in Northern Colorado." *Geophysical Research Letters* 50: e2022GL101294. https://doi.org/10.1029/2022GL101294.

McLin, S. G., E. P. Springer, and L. J. Lane. 2001. "Predicting Floodplain Boundary Changes Following the Cerro Grande Wildfire." *Hydrological Processes* 15: 2967–2980. https://doi.org/10.1002/hyp.385.

Miller, Q. 2022. "Streamflow Generation Across an Elevation Gradient After the 2020 Cameron Peak Fire." Master's thesis, Colorado State University, Fort Collins, CO.

Minshall, G. W., T. V. Royer, and C. T. Robinson. 2004. "Responses to Fire: The First Ten Years." In *After the Fires: The Ecology of Change in Yellowstone National Park*, edited by L. L. Wallace, 165–188. Yale University Press.

Montgomery, D. R. 1999. "Process Domains and the River Continuum." *Journal of the American Water Resources Association* 35: 397–410. https://doi.org/10.1111/j.1752-1688.1999.tb03598.x.

Montgomery, D. R., and J. M. Buffington. 1997. "Channel-Reach Morphology in Mountain Drainage Basins." *Geological Society of America Bulletin* 109: 596–611. https://doi.org/10.1130/0016-7606(1997)109%3C0596:CRMIMD%3E2.3.CO;2.

Moody, J. A., and D. A. Kinner. 2006. "Spatial Structures of Stream and Hillslope Drainage Networks Following Gully Erosion After Wildfire." *Earth Surface Processes and Landforms* 31: 319–337. https://doi.org/10.1002/esp.1246.

Moody, J. A., D. A. Kinner, and X. Ubeda. 2009. "Linking Hydraulic Properties of Fire-Affected Soils to Infiltration and Water Repellency." *Journal of Hydrology* 379: 291–303. https://doi.org/10.1016/j.jhydrol.2009.10.015.

Moody, J. A., and D. A. Martin. 2001. "Initial Hydrologic and Geomorphic Response Following a Wildfire in the Colorado Front Range." *Earth Surface Processes and Landforms* 26: 1049–1070. https://doi.org/10.1002/esp.253.

Moody, J. A., and D. A. Martin. 2009. "Synthesis of Sediment Yields After Wildland Fire in Different Rainfall Regimes in the Western United States." *International Journal of Wildland Fire* 18: 96–115. https://doi.org/10.1071/WF07162.

Moody, J. A., and P. Nyman. 2013. "Variations in Soil Detachment Rates After Wildfire as a Function of Soil Depth, Flow Properties, and Root Properties." US Geological Survey Scientific Investigations Report2012–5233, Reston, VA. https://doi.org/10.3133/sir20125233.

Moody, J. A., R. A. Shakesby, P. R. Robichaud, S. H. Cannon, and D. A. Martin. 2013. "Current Research Issues Related to Post-Wildfire Runoff and Erosion Processes." *Earth-Science Reviews* 122: 10–37. https://doi.org/10.1016/j.earscirev.2013.03.004.

Moore, C., S. Kampf, B. Stone, and E. Richer. 2015. "A GIS-Based Method for Defining Snow Zones: Application to the Western United States." *Geocarto International* 30: 62–81. https://doi.org/10.1080/10106049.2014.885089.

Morgan, P., G. H. Aplet, J. B. Haufler, H. C. Humphries, M. M. Moore, and W. D. Wilson. 1994. "Historical Range of Variability: A Useful Tool for Evaluating Ecosystem Change." *Journal of Sustainable Forestry* 2: 87–111. https://doi.org/10.1300/J091v02n01_04.

Morzillo, A. T., and M. D. Needham. 2015. "Landowner Incentives and Normative Tolerances for Managing Beaver Impacts." *Human Dimensions of Wildlife* 20: 514–530. https://doi.org/10.1080/10871209.2015.1083062.

Murphy, B. P., J. A. Czuba, and P. Belmont. 2019. "Post-Wildfire Sediment Cascades: A Modeling Framework Linking Debris Flow Generation and Network-Scale Sediment Routing." *Earth Surface Processes and Landforms* 44: 2126–2140. https://doi.org/10.1002/esp.4635.

Murphy, S. F., J. H. Writer, R. B. McCleskey, and D. A. Martin. 2015. "The Role of Precipitation Type, Intensity, and Spatial Distribution in Source Water Quality After Wildfire." *Environmental Research Letters* 10: 084007. https://doi.org/10.1088/1748-9326/10/8/084007.

Musselman, Z. A. 2011. "The Localized Role of Base Level Lowering on Channel Adjustment of Tributary Streams in the Trinity River Basin Downstream of Livingston Dam, Texas, USA." *Geomorphology* 128: 42–56. https://doi.org/10.1016/j.geomorph.2010.12.021.

Nadler, C. T., and S. A. Schumm. 1981. "Metamorphosis of South Platte and Arkansas Rivers, Eastern Colorado." *Physical Geography* 2: 95–115. https://doi.org/10.1080/02723646.1981.10642207.

National Interagency Fire Center. 2022. "Inter Agency Fire Perimeter History." https://data-nifc.opendata.arcgis.com/datasets/e02b85c0ea784ce7bd8add7ae3d293d0_0/explore.

Nemec, K. T., J. Chan, C. Hoffman, et al. 2014. "Assessing Resilience in Stressed Watersheds." *Ecology and Society* 19: 34. https://doi.org/10.5751/ES-06156-190134.

Nestingen, R., B. C. Asleson, J. S. Gulliver, R. M. Hozalski, and J. L. Nieber. 2018. "Laboratory Comparison of Field Infiltrometers." *Journal of Sustainable Water in the Built Environment* 4: 04018005. https://doi.org/10.1061/JSWBAY.0000857.

Neville, H., J. Dunham, A. Rosenberger, J. Umek, and B. Nelson. 2009. "Influences of Wildfire, Habitat Size, and Connectivity on Trout in Headwater Streams Revealed by Patterns of Genetic Diversity." *Transactions of the American Fisheries Society* 138: 1314–1327. https://doi.org/10.1577/T08-162.1.

Nigro, M., D. Penna, I. Baneschi, et al. 2024. "The Selection of Paired Watersheds Affects the Assessment of Wildfire Hydrological Impacts." *Science of the Total Environment* 941: 173488. https://doi.org/10.1016/j.scitotenv.2024.173488.

NOAA (National Oceanic and Atmospheric Administration). 2024. "Colorado Climate Center." https://climate.colostate.edu/.

NRC (National Research Council). 2004. "Endangered and Threatened Species of the Platte River." Committee on Endangered and Threatened Species in the Platte River Basin, National Research Council, The National Academies Press, Washington, D.C.

Nyman, P., G. J. Sheridan, H. G. Smith, and P. N. J. Lane. 2014. "Modeling the Effects of Surface Storage, Macropore Flow and Water

Repellency on Infiltration After Wildfire." *Journal of Hydrology* 513: 301–313. https://doi.org/10.1016/j.jhydrol.2014.02.044.

Olsen, N. R. B., and S. Stokseth. 1995. "Three-Dimensional Numerical Modelling of Water Flow in a River With Large Bed Roughness." *Journal of Hydraulic Research* 33: 571–581. https://doi.org/10.1080/00221689509498662.

Orem, C. A., and J. D. Pelletier. 2015. "Quantifying the Time Scale of Elevated Geomorphic Response Following Wildfires Using Multi-Temporal LiDAR Data: An Example From the Las Conchas Fire, Jemez Mountains, New Mexico." *Geomorphology* 232: 224–238. https://doi.org/10.1016/j.geomorph.2015.01.006.

Ortega-Becerril, J. A., C. Suarez, D. Vazquez-Tarrio, J. Garrote, and M. Gomez-Heras. 2024. "Sediment Response After Wildfires in Mountain Streams and Their Effects on Cultural Heritage: The Case of the 2021 Navalcruz Wildfire (Avila, Spain)." *Fire* 7: 52. https://doi.org/10.3390/fire7020052.

Painter, T. H., D. F. Berisford, J. W. Boardman, et al. 2016. "The Airborne Snow Observatory: Fusion of Scanning Lidar, Imaging Spectrometer, and Physically Based Modeling for Mapping Snow Water Equivalent and Snow Albedo." *Remote Sensing of Environment* 184: 139–152. https://doi.org/10.1016/j.rse.2016.06.018.

Papanicolaou, A. N. T., C. G. Wilson, A. G. Tsakiris, et al. 2017. "Understanding Mass Fluvial Erosion Along a Bank Profile: Using PEEP Technology for Quantifying Retreat Lengths and Identifying Event Timing." *Earth Surface Processes and Landforms* 42: 1717–1732. https://doi.org/10.1002/esp.4138.

Partington, D., M. Thyer, M. Shanafield, et al. 2022. "Predicting Wildfire Induced Changes to Runoff: A Review and Synthesis of Modeling Approaches." *WIREs Water* 9: e1599. https://doi.org/10.1002/wat2.1599.

Paul, M. J., S. D. LeDuc, M. G. Lassiter, L. C. Moorhead, P. D. Noyes, and S. G. Leibowitz. 2022. "Wildfire Induces Changes in Receiving Waters: A Review With Considerations for Water Quality Management." *Water Resources Research* 58: e2021WR030699. https://doi.org/10.1029/2021WR030699.

Pavelsky, T. M., M. T. Durand, K. M. Andreadis, et al. 2014. "Assessing the Potential Global Extent of SWOT River Discharge Observations." *Journal of Hydrology* 519: 1516–1525. https://doi.org/10.1016/j.jhydrol.2014.08.044.

Peat, M., H. Chester, and R. Norris. 2005. "River Ecosystem Response to Bushfire Disturbance: Interaction With Flow Regulation." *Australian Forestry* 68: 153–161. https://doi.org/10.1080/00049158.2005.10674961.

Pérez-Cabello, F., R. Montorio, and D. B. Alves. 2021. "Remote Sensing Techniques to Assess Post-Fire Vegetation Recovery." *Current Opinion in Environmental Science & Health* 21: 100251. https://doi.org/10.1016/j.coesh.2021.100251.

Petticrew, E. L., P. N. Owens, and T. R. Giles. 2006. "Wildfire Effects on the Quantity and Composition of Suspended and Gravel-Stored Sediments." In *The Interactions Between Sediments and Water*, edited by B. Kronvang, J. Faganeli, and N. Ogrinc, 283–292. Springer. https://doi.org/10.1007/978-1-4020-5478-5_29.

Piégay, H., A. Chabot, and Y. F. le Lay. 2020. "Some Comments About Resilience: From Cyclicity to Trajectory, a Shift in Living and Nonliving System Theory." *Geomorphology* 367: 106527. https://doi.org/10.1016/j.geomorph.2018.09.018.

Pike, A. S., and F. N. Scatena. 2010. "Riparian Indicators of Flow Frequency in a Tropical Montane Stream Network." *Journal of Hydrology* 382: 72–87. https://doi.org/10.1016/j.jhydrol.2009.12.019.

Planchon, O., N. Silvera, R. Gimenez, et al. 2005. "An Automated Salt-Tracing Gauge for Flow Velocity Measurement." *Earth Surface Processes and Landforms* 30: 833–844. https://doi.org/10.1002/esp.1194.

Pomeroy, J. W., and E. Brun. 2001. "Physical Properties of Snow." In *Snow Ecology: An Interdisciplinary Examination of Snow-Covered Ecosystems*, edited by H. G. Jones, J. W. Pomeroy, D. A. Walker, and R. W. Hoham, 45–126. Cambridge University Press.

Ponomarev, E., A. Zabrodin, and T. Ponomareva. 2022. "Classification of Fire Damage to Boreal Forests of Siberia in 2021 Based on the dNBR Index." *Fire* 5: 19. https://doi.org/10.3390/fire5010019.

Poon, P. K., and A. M. Kinoshita. 2018. "Spatial and Temporal Evapotranspiration Trends After Wildfire in Semi-Arid Landscapes." *Journal of Hydrology* 559: 71–83. https://doi.org/10.1016/j.jhydrol.2018.02.023.

Preston, D. L., J. L. Trujillo, M. P. Fairchild, R. R. Morrison, K. D. Fausch, and Y. Kanno. 2023. "Short-Term Effects of Wildfire on High Elevation Stream-Riparian Food Webs." *Oikos* 2023, no. 8: e09828. https://doi.org/10.1111/oik.09828.

Pugh, B. E., M. Colley, S. J. Dugdale, et al. 2022. "A Possible Role for River Restoration Enhancing Biodiversity Through Interaction With Wildfire." *Global Ecology and Biogeography* 31: 1990–2004. https://doi.org/10.1111/geb.13555.

Rathburn, S. L., S. M. Shahverdian, and S. E. Ryan. 2018. "Post-Disturbance Sediment Recovery: Implications for Watershed Resilience." *Geomorphology* 305: 61–75. https://doi.org/10.1016/j.geomorph.2017.08.039.

Reneau, S. L., D. Katzman, G. A. Kuyumijan, A. Lavine, and D. V. Malmon. 2007. "Sediment Delivery After a Wildfire." *Geology* 35: 151–154. https://doi.org/10.1130/G23288A.1.

Rengers, F. K., L. A. McGuire, J. W. Kean, D. M. Staley, and D. E. J. Hobley. 2016. "Model Simulations of Flood and Debris Flow Timing in Steep Catchments After Wildfire." *Water Resources Research* 52: 6041–6061. https://doi.org/10.1002/2015WR018176.

Rengers, F. K., G. E. Tucker, J. A. Moody, and B. A. Ebel. 2016. "Illuminating Wildfire Erosion and Deposition Patterns With Repeat Terrestrial Lidar." *Journal of Geophysical Research: Earth Surface* 121: 588–608. https://doi.org/10.1002/2015JF003600.

Rey, D. M., M. A. Briggs, M. A. Walvoord, and B. A. Ebel. 2023. "Wildfire-Induced Shifts in Groundwater Discharge to Streams Identified With Paired Air and Stream Water Temperature Analyses." *Journal of Hydrology* 619: 129272. https://doi.org/10.1016/j.jhydrol.2023.129272.

Rickenmann, D. 2017. "Bed-Load Transport Measurements With Geophones and Other Passive Acoustic Methods." *Journal of Hydraulic Engineering* 143: 03117004. https://doi.org/10.1061/(ASCE)HY.1943-7900.0001300.

Ridgway, P., B. Lane, H. Canham, B. P. Murphy, P. Belmont, and F. K. Rengers. 2024. "Wildfire, Extreme Precipitation and Debris Flows, Oh My! Channel Response to Compounding Disturbances in a Mountain Stream in the Upper Colorado River Basin, USA." *Earth Surface Processes and Landforms* 49: 3855–3872. https://doi.org/10.1002/esp.5942.

Robichaud, P. R., S. A. Lewis, J. W. Wagenbrenner, R. E. Brown, and F. B. Pierson. 2020. "Quantifying Long-Term Post-Fire Sediment Delivery and Erosion Mitigation Effectiveness." *Earth Surface Processes and Landforms* 45: 771–782. https://doi.org/10.1002/esp.4755.

Robichaud, P. R., J. W. Wagenbrenner, R. E. Brown, P. M. Wohlgemuth, and J. L. Beyers. 2008. "Evaluating the Effectiveness of Contour-Felled Log Erosion Barriers as a Post-Fire Runoff and Erosion Mitigation Treatment in the Western United States." *International Journal of Wildland Fire* 17: 255–273. https://doi.org/10.1071/WF07032.

Ryan, S. E., K. A. Dwire, and M. K. Dixon. 2011. "Impacts of Wildfire on Runoff and Sediment Loads at Little Granite Creek, Western Wyoming." *Geomorphology* 129: 113–130. https://doi.org/10.1016/j.geomorph.2011.01.017.

Ryan, S. E., C. M. Shobe, S. L. Rathburn, and M. K. Dixon. 2024. "Suspended Sediment Response to Wildfire and a Major Post-Fire Flood on the Colorado Front Range." *River Research and Applications* 40: 1256–1272. https://doi.org/10.1002/rra.4286.

Samhouri, J. F., P. S. Levin, and C. H. Ainsworth. 2010. "Identifying Thresholds for Ecosystem-Based Management." *PLoS One* 5: e8907. https://doi.org/10.1371/journal.pone.0008907.

Sanhueza, D., L. Picco, A. Paredes, and A. Iroume. 2022. "A Faster Approach to Quantify Large Wood Using UAVs." *Drones* 6: 218. https://doi.org/10.3390/drones6080218.

Santi, P., S. Cannon, and J. DeGraff. 2013. "Wildfire and Landscape Change." In *Treatise on Geomorphology, v 13, Geomorphology of Human Disturbances, Climate Change, and Natural Hazards*, edited by L. A. James, C. P. Harden, and J. J. Clague, 262–287. Academic Press.

Saxe, S., T. S. Hogue, and L. Hay. 2018. "Characterization and Evaluation of Controls on Post-Fire Streamflow Response Across Western US Watersheds." *Hydrology and Earth System Sciences* 22: 1221–1237. https://doi.org/10.5194/hess-22-1221-2018.

Schoennagel, T., J. K. Balch, H. Brenkert-Smith, and C. Whitlock. 2017. "Adapt to More Wildfire in Western North American Forests as Climate Changes." *Proceedings of the National Academy of Sciences* 114: 4582–4590. https://doi.org/10.1073/pnas.1617464114.

Schrön, M., S. E. Oswald, S. Zacharias, M. Kasner, P. Dietrich, and S. Attinger. 2021. "Neutrons on Rails: Transregional Monitoring of Soil Moisture and Snow Water Equivalent." *Geophysical Research Letters* 48: e2021GL093924. https://doi.org/10.1029/2021GL093924.

Sebestyen, S. D., E. W. Boyer, J. B. Shanley, et al. 2008. "Sources, Transformations, and Hydrological Processes That Control Stream Nitrates and Dissolved Organic Matter Concentrations During Snowmelt in an Upland Forest." *Water Resources Research* 44: W12410. https://doi.org/10.1029/2008WR006983.

Seidl, R., T. A. Spies, D. L. Peterson, S. L. Stephens, and J. A. Hicke. 2016. "REVIEW: Searching for Resilience: Addressing the Impacts of Changing Disturbance Regimes on Forest Ecosystem Services." *Journal of Applied Ecology* 53: 120–129. https://doi.org/10.1111/1365-2664.12511.

Sendrowski, A., and E. Wohl. 2021. "Remote Sensing of Large Wood in High-Resolution Satellite Imagery: Design of an Automated Classification Work-Flow for Multiple Wood Deposit Types." *Earth Surface Processes and Landforms* 46: 2333–2348. https://doi.org/10.1002/esp.5179.

Serbin, S. P., D. E. Ahl, and S. T. Gower. 2013. "Spatial and Temporal Validation of the MODIS LAI and FPAR Products Across a Boreal Forest Wildfire Chronosequence." *Remote Sensing of Environment* 133: 71–84. https://doi.org/10.1016/j.rse.2013.01.022.

Serreze, M. C., M. P. Clark, and A. Frei. 2001. "Characteristics of Large Snowfall Events in the Montane Western United States as Examined Using Snowpack Telemetry (SNOTEL) Data." *Water Resources Research* 37: 675–688. https://doi.org/10.1029/2000WR900307.

Sexton, J. M. 1998. "Historical Changes in the Cache la Poudre River, Fort Collins, Colorado." Master's thesis, Colorado State University, Fort Collins.

Shakesby, R. A., and S. H. Doerr. 2006. "Wildfire as a Hydrological and Geomorphological Agent." *Earth-Science Reviews* 74: 269–307. https://doi.org/10.1016/j.earscirev.2005.10.006.

Shanahan, J. O., D. W. Baker, B. P. Bledsoe, et al. 2014. "An Ecological Response Model for the Cache la Poudre River Through Fort Collins." City of Fort Collins Natural Areas Department, Fort Collins, CO. https://www.fcgov.com/naturalareas/eco-response.php.

Sheridan, G. J., P. N. J. Lane, and P. J. Noske. 2007. "Quantification of Hillslope Runoff and Erosion Processes Before and After Wildfire in a Wet Eucalypt Forest." *Journal of Hydrology* 343: 12–28. https://doi.org/10.1016/j.jhydrol.2007.06.005.

Shin, S. S., S. D. Park, and K. S. Lee. 2013. "Sediment and Hydrological Response to Vegetation Recovery Following Wildfire on Hillslopes and the Hollow of a Small Watershed." *Journal of Hydrology* 499: 154–166. https://doi.org/10.1016/j.jhydrol.2013.06.048.

Shore, M., P. N. C. Murphy, P. Jordan, et al. 2013. "Evaluation of a Surface Hydrological Connectivity Index in Agricultural Catchments." *Environmental Modelling and Software* 47: 7–15. https://doi.org/10.1016/j.envsoft.2013.04.003.

Short, L. E., E. J. Gabet, and D. F. Hoffman. 2015. "The Role of Large Woody Debris in Modulating the Dispersal of a Post-Fire Sediment Pulse." *Geomorphology* 246: 351–358. https://doi.org/10.1016/j.geomorph.2015.06.031.

Smith, H. G., and D. Dragovich. 2008. "Post-Fire Hillslope Erosion Response in a Sub-Alpine Environment, South-Eastern Australia." *Catena* 73: 274–285. https://doi.org/10.1016/j.catena.2007.11.003.

Sosa-Pérez, G., and L. MacDonald. 2017. "Wildfire Effects on Road Surface Erosion, Deposition, and Road-Stream Connectivity." *Earth Surface Processes and Landforms* 42: 735–748. https://doi.org/10.1002/esp.4018.

Soylu, M. E., and R. L. Bras. 2021. "Global Shallow Groundwater Patterns From Soil Moisture Satellite Retrievals." *IEEE Transactions on Geoscience and Remote Sensing* 15: 89–101. https://doi.org/10.1109/JSTARS.2021.3124892.

Stroud, M. K., G. H. Allen, M. Simard, D. Jensen, B. Gorr, and D. Selva. 2021. "Optimizing Satellite Mission Requirements to Measure Total Suspended Solids in Rivers." *IEEE Transactions on Geoscience and Remote Sensing* 62: 4200409. https://doi.org/10.1109/TGRS.2023.3337641.

Stryker, J., B. Wemple, and A. Bomblies. 2017. "Modeling Sediment Mobilization Using a Distributed Hydrological Model Coupled With a Bank Stability Model." *Water Resources Research* 53: 20151–22073. https://doi.org/10.1002/2016WR019143.

Sturzenegger, M., K. Holm, C. A. Lau, and M. Jakob. 2021. "Debris-Flow and Debris-Flood Susceptibility Mapping for Geohazard Risk Prioritization." *Environmental and Engineering Geoscience* 27: 179–194. https://doi.org/10.2113/EEG-D-20-00006.

Sutanto, S. J., M. Janssen, M. de Madruga Brito, and M. del Pozo Garcia. 2024. "The Effect of Wildfires on Flood Risk: A Multi-Hazard Flood Risk Approach for the Ebro River Basin, Spain." *Natural Hazards and Earth System Sciences* 24: 3703–3721. https://doi.org/10.5194/nhess-24-3703-2024.

Sutfin, N. A., and E. Wohl. 2019. "Elevational Differences in Hydrogeomorphic Disturbance Regime Influence Sediment Residence Times Within Mountain River Corridors." *Nature Communications* 10: 2221. https://doi.org/10.1038/s41467-019-09864-w.

Taylor, A. H., H. M. Poulos, J. Kluber, R. Issacs, N. Pawlikowski, and A. M. Barton. 2021. "Controls on Spatial Patterns of Wildfire Severity and Early Post-Fire Vegetation Development in an Arizona Sky Island, USA." *Landscape Ecology* 36: 2637–2656. https://doi.org/10.1007/s10980-021-01260-4.

Thoms, M., and I. Fuller. 2024. *Resilience and Riverine Landscapes*. Elsevier.

Thoms, M. C., H. Piegay, and M. Parsons. 2018. "What Do You Mean, 'Resilient Geomorphic Systems'?" *Geomorphology* 305: 8–19. https://doi.org/10.1016/j.geomorph.2017.09.003.

Trayler, C. R., and E. E. Wohl. 2000. "Seasonal Changes in Bed Elevation in a Step-Pool Channel, Rocky Mountains, Colorado, USA." *Arctic, Antarctic, and Alpine Research* 32: 95–103. https://doi.org/10.1080/15230430.2000.12003343.

Triantafillou, S., and E. Wohl. 2024. "Geomorphic Characteristics Influencing Post-Fire River Response in Mountain Streams." *Geomorphology* 466: 109446. https://doi.org/10.1016/j.geomorph.2024.109446.

United States Geological Survey. 2021. "United States Geological Survey 3D Elevation Program 1/3 Arc-Second Digital Elevation Model." Distributed by OpenTopography. https://doi.org/10.5069/G98K778D.

Van Eck, C. M., J. P. Nunes, D. C. S. Vieira, S. Keesstra, and J. J. Keizer. 2016. "Physically Based Modelling of the Post-Fire Runoff Response of a Forest Catchment in Central Portugal: Using Field Versus Remote Sensing-Based Estimates of Vegetation Recovery." *Land Degradation & Development* 27: 1535–1544. https://doi.org/10.1002/ldr.2507.

Van Leeuwen, W. J. D., G. M. Casady, D. G. Neary, et al. 2010. "Monitoring Post-Wildfire Vegetation Response With Remotely Sensed Time-Series Data in Spain, USA and Israel." *International Journal of Wildland Fire* 19: 75–93. https://doi.org/10.1071/WF08078.

Van Looy, K., J. D. Tonkin, M. Floury, et al. 2019. "The Three Rs of River Ecosystem Resilience: Resources, Recruitment, and Refugia." *River Research and Applications* 35: 107–120. https://doi.org/10.1002/rra.3396.

Van Stan, J. T., and A. Stubbins. 2018. "Tree-DOM: Dissolved Organic Matter in Throughfall and Stemflow." *Limnology and Oceanography Letters* 3: 199–214. https://doi.org/10.1002/lol2.10059.

Veblen, T. T., and J. A. Donnegan. 2005. "Historical Range of Variability for Forest Vegetation of the National Forests of the Colorado Front Range." Final Report, USDA Forest Service Agreement 1102–0001–99-033, Golden, CO. https://www.researchgate.net/publication/242613875_Historical_Range_of_Variability_for_Forest_Vegetation_of_the_National_Forests_of_the_Colorado_Front_Range.

Wallis, C., I. Maddock, F. Visser, and M. Acreman. 2012. "A Framework for Evaluating the Spatial Configuration and Temporal Dynamics of Hydraulic Patches." *River Research and Applications* 28: 585–593. https://doi.org/10.1002/rra.1468.

Wang, L., and J. J. Qu. 2009. "Satellite Remote Sensing Applications for Surface Soil Moisture Monitoring: A Review." *Frontiers of Earth Science in China* 3: 237–247. https://doi.org/10.1007/s11707-009-0023-7.

Ward, A. S., M. N. Gooseff, and K. Singha. 2010. "Imaging Hyporheic Zone Solute Transport Using Electrical Resistivity." *Hydrological Processes* 24: 948–953. https://doi.org/10.1002/hyp.7672.

Ward, M., D. Southwell, R. V. Gallagher, et al. 2022. "Modelling the Spatial Extent of Post-Fire Sedimentation Threat to Estimate the Impacts of Fire on Waterways and Aquatic Species." *Diversity and Distributions* 28: 2429–2442. https://doi.org/10.1111/ddi.13640.

Warrick, J. A., and D. M. Rubin. 2007. "Suspended-Sediment Rating Curve Responses to Urbanization and Wildfire, Santa Ana River, California." *Journal of Geophysical Research. Earth Surface* 112: F02018. https://doi.org/10.1029/2006JF000662.

Wells, A. G., C. B. Yackulic, J. Kostelnik, et al. 2024. "Before the Fire: Predicting Burn Severity and Potential Post-Fire Debris-Flow Hazards to Conservation Populations of the Colorado River Cutthroat Trout (*Oncorhynchus clarkii pleuriticus*)." *International Journal of Wildland Fire* 33: WF23199. https://doi.org/10.1071/WF23199.

Westhoff, M. C., M. N. Gooseff, T. A. Bogaard, and H. H. G. Savenije. 2011. "Quantifying Hyporheic Exchange at High Spatial Resolution Using Natural Temperature Variations Along a First-Order Stream." *Water Resources Research* 47: W10508. https://doi.org/10.1029/2010WR009767.

White, D. C., R. R. Morrison, and E. Wohl. 2022. "Fire and Ice: Winter Flooding in a Southern Rocky Mountain Stream After a Wildfire." *Geomorphology* 413: 108370. https://doi.org/10.1016/j.geomorph.2022.108370.

White, J. D., K. C. Ryan, C. C. Key, and S. W. Running. 1996. "Remote Sensing of Forest Fire Severity and Vegetation Recovery." *International Journal of Wildland Fire* 6: 125–136. https://doi.org/10.1071/WF9960125.

White, P. S., and S. T. A. Pickett. 1985. "Natural Disturbance and Patch Dynamics: An Introduction." In *The Ecology of Natural Disturbance and Patch Dynamics*, edited by S. T. A. Pickett and P. S. White, 3–9. Academic Press.

Whitney, J. E., K. B. Gido, T. J. Pilger, D. L. Propst, and T. F. Turner. 2015. "Consecutive Wildfires Affect Stream Biota in Cold- and Warmwater Dryland River Networks." *Freshwater Science* 34: 1510–1526. https://doi.org/10.1086/683391.

Whitney, J. E., K. B. Gido, T. J. Pilger, D. L. Propst, and T. F. Turner. 2016. "Metapopulation Analysis Indicates Native and Non-Native Fishes Respond Differently to Effects of Wildfire on Desert Streams." *Ecology of Freshwater Fish* 25: 376–392. https://doi.org/10.1111/eff.12217.

Williams, G. P. 1978. "The Case of the Shrinking Channels – The North Platte and Platte Rivers in Nebraska." US Geological Survey Circular781, Arlington, VA.

Wilson, C., S. K. Kampf, S. Ryan, T. Covino, L. H. MacDonald, and H. Gleason. 2021. "Connectivity of Post-Fire Runoff and Sediment From Nested Hillslopes and Watersheds." *Hydrological Processes* 35: e13975. https://doi.org/10.1002/hyp.13975.

Wilson, C., S. K. Kampf, J. W. Wagenbrenner, and L. H. MacDonald. 2018. "Rainfall Thresholds for Post-Fire Runoff and Sediment Delivery From Plot to Watershed Scales." *Forest Ecology and Management* 430: 346–356. https://doi.org/10.1016/j.foreco.2018.08.025.

Wohl, E. 2013a. "Migration of Channel Heads Following Wildfire in the Colorado Front Range, USA." *Earth Surface Processes and Landforms* 38: 1049–1053. https://doi.org/10.1002/esp.3429.

Wohl, E. 2013b. *Wide Rivers Crossed: The South Platte and Illinois of the American Prairie*. University Press of Colorado.

Wohl, E. 2018. "Geomorphic Context in Rivers." *Progress in Physical Geography* 42: 841–857. https://doi.org/10.1177/0309133318776488.

Wohl, E. 2025. *Landscapes on Fire: Impacts on Uplands, Rivers, and Communities*. Wiley.

Wohl, E., D. Cooper, L. Poff, F. Rahel, D. Staley, and D. Winters. 2007. "Assessment of Stream Ecosystem Function and Sensitivity in the Bighorn National Forest, Wyoming." *Environmental Management* 40: 284–302. https://doi.org/10.1007/s00267-006-0168-z.

Wohl, E., K. Fryirs, R. C. Grabowski, R. R. Morrison, and D. Sear. 2024. "Enhancing the Natural Absorbing Capacity of Rivers to Restore Their Resilience." *Bioscience* 74: 782–796. https://doi.org/10.1093/biosci/biae090.

Wohl, E., K. B. Lininger, S. L. Rathburn, and N. A. Sutfin. 2020. "How Geomorphic Context Governs the Influence of Wildfire on Floodplain Organic Carbon in Fire-Prone Environments of the United States." *Earth Surface Processes and Landforms* 45: 38–55. https://doi.org/10.1002/esp.4680.

Wohl, E., A. Marshall, J. Scamardo, and S. Rathburn. 2023. "Biogeomorphic Processes, Spatial Heterogeneity, and River Corridor Resilience to Stand-Killing Wildfire." In *Biogeomorphic Responses to Wildfire in Fluvial Ecosystems*, edited by J. L. Florsheim, A. P. O'Dowd, and A. Chin, vol. 562. Geological Society of America. https://doi.org/10.1130/2024.2562(08).

Wohl, E., A. E. Marshall, J. Scamardo, D. White, and R. R. Morrison. 2022. "Biogeomorphic Influences on River Corridor Resilience to Wildfire Disturbances in a Mountain Stream of the Southern Rockies, USA." *Science of the Total Environment* 820: 153321. https://doi.org/10.1016/j.scitotenv.2022.153321.

Wohl, E., A. E. Marshall, S. Triantafillou, M. Mobley, M. Means-Brous, and R. R. Morrison. 2024. "Distribution of Logjams in Relation to Lateral Connectivity in the River Corridor." *Geomorphology* 451: 109100. https://doi.org/10.1016/j.geomorph.2024.109100.

Wohl, E., and D. M. Merritt. 2005. "Prediction of Mountain Stream Morphology." *Water Resources Research* 41: W08419. https://doi.org/10.1029/2004WR003779.

Wohl, E., S. Rathburn, S. Chignell, et al. 2017. "Mapping Longitudinal Stream Connectivity in the North St. Vrain Creek Watershed of Colorado." *Geomorphology* 277: 171–181. https://doi.org/10.1016/j.geomorph.2016.05.004.

Wohl, E., S. Rathburn, S. Dunn, et al. 2024. "Geomorphic Context in Process-Based River Restoration." *River Research and Applications* 40: 322–340. https://doi.org/10.1002/rra.4236.

Wohl, E., J. Scamardo, and R. R. Morrison. 2025. "James Buttle Review: Bed, Banks, and Beyond: River Flood Dynamics." *Hydrological Processes* 39: e70131. https://doi.org/10.1002/hyp.70131.

Wohl, E., and D. N. Scott. 2017. "Transience of Channel Head Locations Following Disturbance." *Earth Surface Processes and Landforms* 42: 1132–1139. https://doi.org/10.1002/esp.4124.

Wohl, E. E., and D. A. Cenderelli. 2000. "Sediment Deposition and Transport Patterns Following a Reservoir Sediment Release." *Water Resources Research* 36: 319–333. https://doi.org/10.1029/1999WR900272.

Wohl, E. E., and P. P. Pearthree. 1991. "Debris Flows as Geomorphic Agents in the Huachuca Mountains of Southeastern Arizona." *Geomorphology* 4: 273–292. https://doi.org/10.1016/0169-555X(91)90010-8.

Wolf, E. C., D. J. Cooper, and N. T. Hobbs. 2007. "Hydrologic Regime and Herbivory Stabilize an Alternative State in Yellowstone National Park." *Ecological Applications* 17: 1572–1587. https://doi.org/10.1890/06-2042.1.

Writer, J. H., R. B. McCleskey, and S. F. Murphy. 2012. "Effects on Wildfire Source-Water Quality and Aquatic Ecosystems, Colorado Front Range. In, Wildfire and Water Quality: Processes, Impacts and Challenges." IAHS Publication. 354, 117–122.

Yariyan, P., E. Omidvar, F. Minaei, R. A. Abbaspour, and J. P. Tiefenbacher. 2022. "An Optimization on Machine Learning Algorithms for Mapping Snow Avalanche Susceptibility." *Natural Hazards* 111: 79–114. https://doi.org/10.1007/s11069-021-05045-5.

Yi, Y., X. Cheng, Z. Yang, S. Wieprecht, S. Zhang, and Y. Wu. 2017. "Evaluating the Ecological Influence of Hydraulic Projects: A Review of Aquatic Habitat Suitability Models." *Renewable and Sustainable Energy Reviews* 68: 748–762. https://doi.org/10.1016/j.rser.2016.09.138.

Zelt, R. B., and E. E. Wohl. 2004. "Channel and Woody Debris Characteristics in Adjacent Burned and Unburned Watersheds a Decade After Wildfire, Park County, Wyoming." *Geomorphology* 57: 217–233. https://doi.org/10.1016/S0169-555X(03)00104-1.

Zhou, Y., Y. Zhang, J. Vaze, P. Lane, and S. Xu. 2015. "Impact of Bushfire and Climate Variability on Streamflow From Forested Catchments in Southeast Australia." *Hydrological Sciences Journal* 60: 1340–1360. https://doi.org/10.1080/02626667.2014.961923.