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Evaluating Watershed Response Using WEPPcloud—EU for Wildfire Burned Areas in Portugal

Marta Basso[1,2] | Erin Brooks[2] | Anurag Srivastava[2] | Jacob Keizer[3] | R. Peter Robichaud[4]

[1]Department of Forest Ecosystems and Society, Oregon State University, Corvallis, Oregon, USA | [2]Department of Soil and Water Systems, University of Idaho, Moscow, Idaho, USA | [3]GeoBioTec, Department of Environment and Planning, University of Aveiro, Aveiro, Portugal | [4]USDA Forest Service, Rocky Mountain Research Station, Moscow, Idaho, USA

Correspondence: Marta Basso (mbasso@uidaho.edu)

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ABSTRACT

WEPPcloud—European Union (EU) is an online interface of the Water Erosion Prediction Project (WEPP) model designed to predict streamflow and sediments in European forested watersheds. Although designed to be run in any location in Europe, its performance has not yet been evaluated against observed data. This study evaluates WEPPcloud—EU's performance in simulating streamflow and suspended sediment yield for two burned catchments, Ermida and Serra de Cima, in continental Portugal during the first year after the fire. The default parameters significantly underestimated streamflow and suspended sediment yield at the outlet of both catchments, suggesting the need for catchment-specific parameterization. Selected model input parameters (bulk density, sand, clay, organic matter and rock content) were changed based on existing information on local conditions at the beginning of an autocalibration procedure. This combined re-parameterization and autocalibration procedure (based on saturated hydraulic conductivity, anisotropy and baseflow coefficient) improved the performance of WEPPcloud—EU model, yielding satisfactory results for both streamflow and suspended sediment yield for both catchments. The autocalibration improved model accuracy, with predicted average streamflow from the default 3.3 to 6.3 mm day^{-1} (observed 6.9 mm day^{-1}) and suspended sediment yield from 0.5 to 8.2 kg ha^{-1} day^{-1} (observed 11.7 kg ha^{-1} day^{-1}) in the Ermida catchment. In Serra de Cima, predicted average streamflow improved from 1.8 to 1.9 mm day^{-1} (observed 1.8 mm day^{-1}) and suspended sediment yield from 1.4 to 35.4 kg ha^{-1} day^{-1} (observed 28.5 kg ha^{-1} day^{-1}). This study demonstrated WEPPcloud—EU potential as a decision-support tool for post-fire emergency stabilization in catchments in Europe. Future studies in different eco-regions in Europe are needed for a broader assessment of the model's potential, including for emergency stabilization scenarios and with an emphasis on the importance of existing local information for achieving satisfactory predictions.

1 | Introduction

Wildfires have been a natural phenomenon present in the Mediterranean region since the Holocene (Burjachs and Expósito 2015; Carrión et al. 2003). Although essential for the shaping of the Mediterranean ecosystem, in the last decades wildfires have become a threat, mainly due to climate changes and the progressive abandonment of the areas previously used for agriculture (Moreira et al. 2020; Moreira et al. 2009; San-Miguel-Ayanz et al. 2022; Silva et al. 2011; Turco et al. 2016; Viedma et al. 2015). Furthermore, the widespread planting of fire-prone timber species on these abandoned agricultural lands and the often reduced fuel-load management of these plantations has created a highly flammable environment in a large part of the Iberian Peninsula (Fernandes et al. 2019; Pausas and Fernández-Muñoz 2012; Silva et al. 2009; Viedma et al. 2015).

Wildfires can deeply affect the hydrological and erosion responses of forested watersheds, due to the consumption of vegetation and litter layer combined with heating-induced changes in topsoil properties as a function of the burn severity (Certini 2005; DeBano 2000; Fernández 2023; Keeley 2009; Shakesby and Doerr 2006; Vieira et al. 2015). The consumption of the vegetation and litter reduces interception capacity, leaving the soil exposed to the direct impacts of rainfall drops and overland flow and, thereby, enhancing the detachment of soil particles by raindrops and overland flow (Cerdá and Doerr 2005; Shakesby and Doerr 2006). In addition, heating can reduce soil aggregation, altering its structure by depleting organic matter and breaking mineral bonds and, ultimately, turning the soil more erodible (DeBano et al. 1998; Mataix-Solera et al. 2011; Parsons et al. 2010). Depending on the soil heating regime (DeBano 2000), infiltration capacity can be markedly reduced (Vieira et al. 2015). Such reduction is typically attributed to the formation of a water-repellent layer, with hydrophobic hydrocarbons coating soil particles and disrupting mineral bindings (DeBano et al. 1998; Mataix-Solera et al. 2011; Parsons et al. 2010). However, temperatures above 270°C–400°C can destroy pre-existing soil water repellency or reduce its severity (Doerr 1998; Doerr et al. 2009; Santín and Doerr 2016).

The above-mentioned fire-induced changes can lead to secondary impacts such as increased overland flow and soil erosion. The overland flow response of recently burnt areas is commonly observed to be faster and characterized by larger volumes than that of nearby unburnt areas (Ebel et al. 2012; Malvar et al. 2011; Moody et al. 2013; Neary et al. 2003; Shakesby and Doerr 2006). Even so, the post-fire hydrological response can vary markedly between burnt areas and with time-since-fire, as this response typically depends on a complexity of factors. Key factors are the degree of burn severity (Fernández 2023; Keeley 2009; Vieira et al. 2015), post-fire rainfall regime (Moody et al. 2013; Murphy et al. 2015; Neary et al. 2003; Wagenbrenner et al. 2021), topography (DeBano et al. 1998; Dillon et al. 2011; Neary et al. 2003), pre- and post-fire vegetation and land management practises, including emergency stabilization measures (Fernández and Vega 2016a; Girona-García et al. 2021; Holden et al. 2007; Malvar et al. 2016; Malvar et al. 2013; Parente et al. 2021; Robichaud et al. 2020; Vieira et al. 2016) and soil characteristics (Cerdan et al. 2010; Coelho et al. 1995).

Fire impacts resulting from the enhanced runoff and erosion responses are often not limited to the burned areas but can pose a threat to downstream locations. Fire-enhanced hydrological and erosive responses can produce flash floods and debris flows (Cannon et al. 2008; Moody et al. 2013), and can jeopardize the water quality of downstream waterbodies, including water reservoirs (Basso et al. 2022a; Bladon et al. 2014; Emelko et al. 2011; Smith et al. 2011).

A large variety of hydrological and erosion models have been tested to predict wildfire impacts on water quantity and quality, ranging from empirical to physical models (Lopes et al. 2021). Empirical models such as the (Revised) Universal Soil Loss Equation ((R)USLE; Renard et al. 1991; Wischmeier and Smith 1978), and semi-empirical models such as the Morgan–Morgan–Finney model (MMF; Morgan 2001) have been tested most comprehensively (Fernández et al. 2010; Fernández and Vega 2016b; Larsen and MacDonald 2007; Litschert et al. 2014; Lopes et al. 2021; Myronidis and Arabatzis 2009; Parente et al. 2022), while physically based models have been tested less frequently and mainly focus on catchment responses at (sub-)hourly to daily resolutions (Basso et al. 2024; Basso et al. 2022b; Basso et al. 2019; De Girolamo et al. 2022; Dobre et al. 2022; Havel et al. 2018; Lew et al. 2022; Loiselle et al. 2020; Nunes et al. 2018). Although the application of models to burned areas is being studied by the scientific community, the use of models to support operational land and water management decision-making after wildfires is not yet widely adopted in Europe.

Operational emergency stabilization is often conditioned by a lack of time between a wildfire and the first significant post-fire rainfall event(s). Therefore, models that do not require time-consuming data collection and/or important calibration efforts to obtain reliable predictions are essential. The WEPPcloud—EU (European Union) interface (Lew et al. 2022) may be the first such model for the EU, offering a user-friendly, online platform to run the model. Based on the Water Erosion Prediction Project (WEPP) (Flanagan and Nearing 1995), WEPPcloud—EU was developed in collaboration between the University of Idaho and the U.S. Department of Agriculture Forest Service at the Rocky Mountain Research Station. The Forest Service WEPP Interfaces platform (Elliot 2000), which includes WEPPcloud, counts for more than 100 000 runs annually, being used by stakeholders to assess the implications of different types of disturbances as well as the effectiveness of selected erosion mitigation treatments. WEPPcloud provides predictions of post-fire hydrological and erosion response at watershed scale (up to 5000 ha), using as input a user-supplied soil burn severity map and data from existing databases (Dobre et al. 2022; Lew et al. 2022). While WEPPcloud has been extensively parameterized and calibrated for burned areas across the USA (Brooks et al. 2016; Dobre et al. 2022; East et al. 2024; Srivastava et al. 2018), WEPPcloud—EU had not yet been tested for Europe, at least at the start of this study.

To evaluate the applicability of WEPPcloud—EU as a post-fire management tool, the model was tested on two recently burned catchments in Portugal. The aim of the study was to compare results obtained using WEPPcloud—EU with default parameter values against the results obtained from model parameterization with local field measurements and model calibration. The specific objectives were: (i) Assess the model performance of the default configuration of WEPPcloud—EU to simulate the hydrological and erosive response for two recently burned catchments in the Central region of Portugal; (ii) Assess WEPPcloud—EU performance to simulate daily streamflow and suspended sediment yield at the outlet of the burned catchments after including locally measured input parameters and performing a calibration limited to a small number of parameters and (iii) compare the differences in the modeled responses of the two catchments.

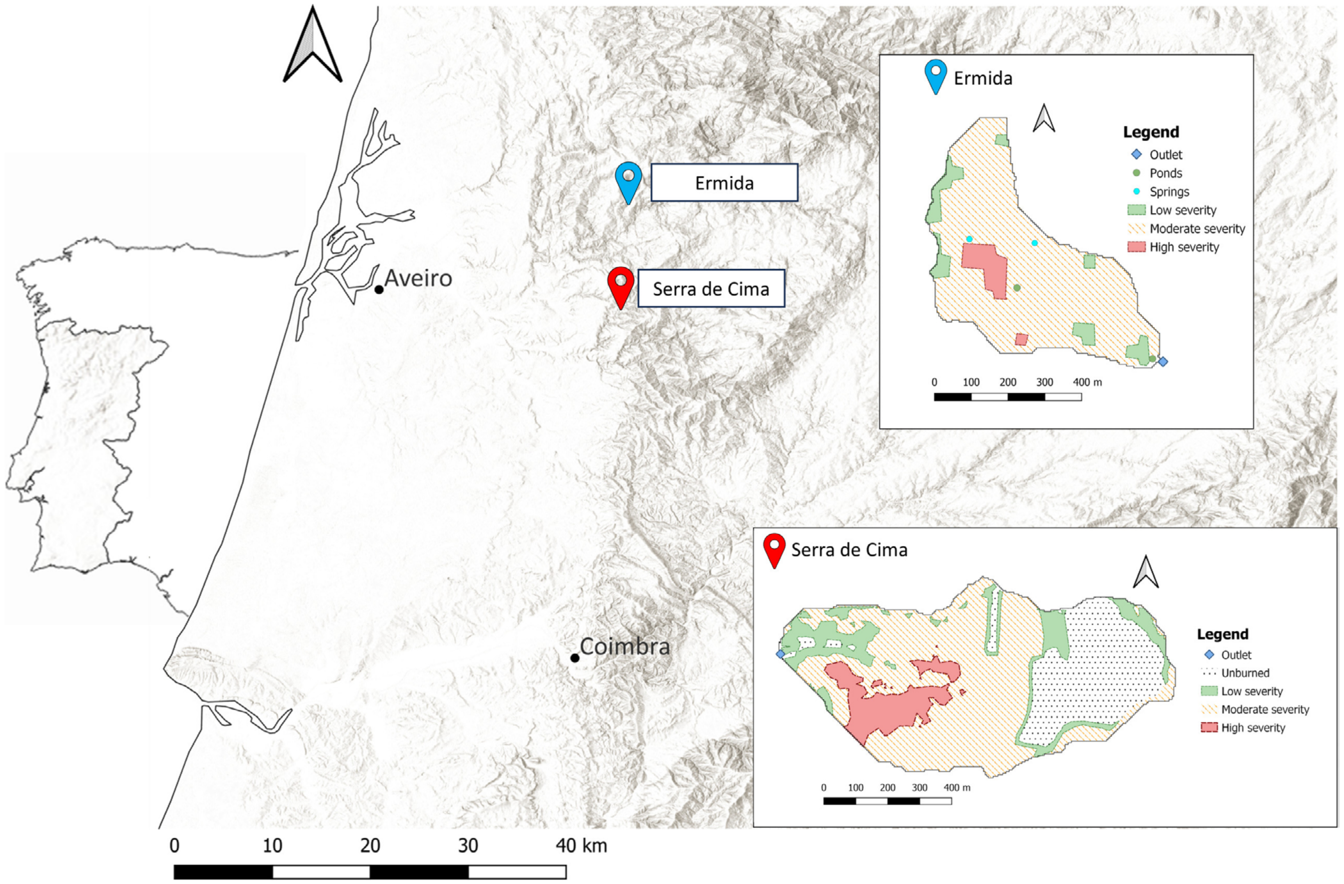

FIGURE 1 | Study areas and burn severity maps.

2 | Materials and Methods

2.1 | Study Sites

This study was conducted in two experimental catchments affected by wildfire in the Central region of continental Portugal (Figure 1). The Ermida catchment (0.22 km^2; 40.730500°, −8.345296°) was dominated by plantations of eucalypt (*Eucalyptus globulus* Labill.) but included a maritime pine (*Pinus pinaster* Ait.) stand and a riparian stand of cork oak (*Quercus suber* L.). The watershed elevation ranges from 88 to 302 m above m.s.l. The Serra de Cima catchment (0.52 km^2, 40.60915°, −8.34037°) was also dominated by eucalypt plantations, except for a small area of riparian forest close to the outlet. The watershed elevation ranges between 275 and 485 m above m.s.l. Both catchments were part of the Hesperic Massif in the Central Iberian Zone, and the parent material is (predominantly) pre-Ordovician schist (Boulet et al. 2015; Ferreira et al. 2016; Martins et al. 2013; Serpa et al. 2020). The soils in both catchments were predominantly Humic Cambisols combined with different types of Leptosols (Cardoso 1974; Pereira and FitzPatrick 1995). The Ermida topsoil was characterized by a sandy loam to sandy clay texture (Ferreira et al. 2016; Serpa et al. 2020), while the Serra de Cima topsoil had a silty loam texture (Boulet et al. 2015). The topsoil in both catchments had high stone content, in the order of 50% in the case of the Serra de Cima catchment (Boulet et al. 2015) and 55% in the case of the Ermida catchment (Prats et al. 2016). However, there was a small portion of the Ermida catchment with Leptosols, which exhibited a reduced rock content (10%). Soil depth ranged from 200 to 800 mm in the Serra de Cima catchment (Boulet et al. 2015) and from 250 to 750 mm in the Ermida catchment. The climate of the two catchments was similar, being characterized by mean annual temperature and rainfall during the last 25 years of 14.9°C and 1609 mm year^{-1} in the Ermida catchment, and 14.4°C and 1330 mm year^{-1} in the Serra de Cima catchment (SNIRH 2020). The Ermida catchment was characterized by two springs and two retention ponds, the latter used in the past for irrigation and flow control (Keizer et al. 2015) (Figure 1). The aquifer of the area is predominantly unconfined and recharges mainly through precipitation. The main natural discharge process involves groundwater flow occurring in fault zones. The flow of one of the springs was negligible in the summer season, while the flow behaviour of the spring located in the upper part of the watershed appears to have a strong correlation with the amount of precipitation during the wet season (October–March). In years when the total rainfall for these months was less than 1000 mm, the flow from the spring decreased significantly, although it generally did not dry up during prolonged dry summers.

In July 2010, the Ermida catchment was entirely burned by a wildfire, predominantly at moderate severity (Ferreira et al. 2016) (Figure 1). In August 2016, a wildfire affected approximately 74% of the Serra de Cima catchment. Due to the presence of unburned areas, the burn severity at the Serra de Cima catchment was mapped using Sentinel 2 imagery, computing the difference Normalised Burn Ratio from the near-infrared and shortwave infrared bands (Figure 1) (Lutes et al. 2006).

2.2 | Catchment Instrumentation

The Ermida and Serra de Cima hydrometric stations both consisted of an H-flume with maximum discharge capacities of 0.12 and 0.86 $m^3 s^{-1}$, respectively. The Ermida station also included a second, cut-throat flume with a maximum discharge capacity of 1.11 $m^3 s^{-1}$, but peak discharges never exceeded the maximum capacity of the H-flume (Keizer et al. 2015; Basso et al. 2022b). The Ermida station was set up on September 18th 2010, before the occurrence of post-fire rainfall, equipped with a Campbell CR1000 data logger and one pressure water level sensor in each flume. The Serra de Cima station was re-installed on August 20th, 2016, also before the occurrence of post-fire rainfall, and equipped with a Campbell Scientific CS451 pressure water level sensor connected to a Campbell CR1000 datalogger. Both stations included a 24-bottle automatic ISCO 3700 sampler which was triggered by the data logger to collect water samples in the flume during runoff events. For each station, a series of 12 successive triggers were defined, ranging from the station's baseflow to its maximum discharge capacity. This approach ensured that the 24 samples would capture the peak of the event, with samples equally distributed between the rising and falling limbs of the hydrograph. To avoid collecting samples in response to minor fluctuations in flow, a minimum pause of 5 min was enabled between triggers. The samples were collected during 1- to 2-weekly fieldtrips, and their total suspended solids (TSS) contents analyzed in the laboratory through filtration of 50 mL of water by a glass fiber filter, followed by drying until constant weight at 105°C (APHA 1998). Because of WEPPcloud—EU's daily modeling step, a regression analysis was performed to establish the relationship between observed flow and TSS discrete values, which was then used to obtain continuous TSS data. The predicted TSS values were subsequently summed to calculate the total daily TSS yield (kg day^{-1}) for comparison with model outputs. This was done for a total of 16 days in the case of the Ermida catchment and for a total of 6 days in the case of the Serra de Cima catchment (Table S1).

The precipitation in the Ermida catchment was measured using two tipping-bucket rainfall gauges (Pronamic Professional Rain Gauge with 0.2 mm resolution), while in the Serra de Cima precipitation data were obtained by four automatic rainfall gauges: two located on top of the catchment, one in the hamlet of Serra de Cima (40.609°, −8.322°), and another at the Pousada meteorological station (40.615°, −8.316°, 425 m above m.s.l.). Data on wind speed and direction, air temperature and dew point temperature were compiled from the Barragem de Castelo Burgães meteorological station (40.853°, −8.379°) for the Ermida and from the Pousada meteorological station for the Serra de Cima. Solar radiation data were obtained from the CAMS radiation service for both catchments (Granier et al. 2019).

2.3 | Disturbed WEPP Model and WEPPcloud

The WEPP is a process-based model initially developed to simulate the hydrological and erosion response at the scale of hillslopes up to small catchments (Flanagan and Nearing 1995). The incorporation of channel routing methods has extended the applicability of the model to larger watersheds (Elliot 2013). WEPP models hydrological and erosive processes for each hillslope and channel segment, subsequently routing flow and sediment through channels to the watershed outlet (Brooks et al. 2016). The surface hydrology components include evapotranspiration, infiltration, saturation-excess runoff, depression storage and peak discharge. Evapotranspiration is simulated using the FAO Penman–Monteith–IN method, where actual evapotranspiration is computed from potential evapotranspiration of a grass reference crop based on vegetation growth and environmental conditions (Allen 2000). Infiltration-excess runoff is simulated using the modified Green-Ampt-Mein-Larson equation (Mein and Larson 1973), while overland flow and peak discharge are computed using the modified kinematic wave equation (Flanagan and Nearing 1995; Lew et al. 2022). Lateral subsurface flow from hillslopes into channels is calculated using Darcy's law, while potential evapotranspiration is estimated using the Penman equation. Channel flow routing can be simulated using the Kinematic Wave, Muskingum-Cunge and Muskingum-Cunge variable options (Wang et al. 2010).

Soil erosion at hillslope scale is simulated from the detachment and delivery by raindrop impacts and shallow sheet flow in slope sections with interrill erosion and from soil detachment, transport and deposition in slope sections with rill erosion (Flanagan and Nearing 1995). Soil detachment in rills is simulated to occur when the hydraulic shear stress of the flow exceeds the critical shear stress of the soil or when sediment load is less than sediment transport capacity, the latter being calculated using a modified Yalin equation (Foster and Meyer 1972; Yalin 1963). Channel erosion routine is similar to what is computed for rill erosion on the hillslope, except that flow is considered spatially varied. Channel detachment is simulated to occur from the bottom of the channel until the non-erodible layer has been reached, after which the channel begins to widen. The erosion rate is simulated to decrease with time until the flow is too shallow to cause detachment. Model input data files are categorized by mediums (climate, soil, land management, channel and groundwater) and allow easy and comprehensive access to the files and the parameters. The WEPP model generates daily outputs for each watershed element, including hillslopes/overland flow elements and channels (Flanagan and Livingston 1995; Lew et al. 2022). Specifically, the model provides daily values for each element related to plant growth (above- and belowground live biomass, canopy cover, height, leaf area index and root depth), as well as surface and submerged residue. The water balance components include precipitation (rain and snowmelt), soil evaporation, plant transpiration, surface runoff, subsurface lateral flow, deep percolation, soil and frozen water content and snow-water equivalent. Soil erosion and sediment characteristics are reported for individual storm events.

The WEPP model has an online interface called 'WEPPcloud—Disturbed' adapted for forest applications with an additional ability to simulate baseflow (Lew et al. 2022). The online version allows users to predict post-fire streamflow and erosion, by uploading a burn severity map as model input (Dobre et al. 2022). Wildfire impacts on vegetation and soils are parameterized from a 'disturbed' database, considering pre-fire land use and surface soil texture and soil burn severity. To parameterize the local conditions of the area, WEPPcloud—Disturbed relies on publicly available databases (Table 1 for Europe), being supported in United States, Europe and Australia. The online version allows the user to select their climate from different climate databases or generate it from the closest meteorological stations to the study area available in the interface by using the CLIGEN weather generator (Meyer 2011). In this study, the 'User Defined Climate' option was used, which allows user to upload their climate file built from local meteorological weather stations.

2.4 | WEPPcloud—EU Disturbed Parameterization

In the default post-fire soil file (Lew et al. 2022) created by WEPPcloud—EU for the Ermida and Serra de Cima catchments, several parameters were found to be 0 (Table S2). This occurrence was presumed to be a result of incomplete information in the European Soil Data Centre database (Table 1). To locally parameterize the model to the watershed of interest, the simulation design was downloaded using the wepp-win-bootstrap utility tool (https://github.com/rogerlew/wepppy-win-bootstrap; accessed 15 Jun 2024) to refine parameters based on field-sampled soil data (Table 2). Portuguese mountain soils are typically shallow, especially due to the weather conditions and the steep slopes that characterize a large portion of the Portuguese mountainous territory, which does not favour the formation of deep soils (Pereira and FitzPatrick 1995). Cambisols—the predominant soil type of both watersheds—are defined as poorly developed soils, with a maximum depth between 500 and 1000 mm (IUSS Working Group WRB 2022). Based on this information and field measurements in the Serra de Cima catchment (Boulet et al. 2015), the depth of the first and second soil layers was set to 250 and 500 mm, respectively, for both catchments. Bulk density in Ermida was set to 0.98 and 1.20 g cm^{-3} for the first and second layers, respectively, based on the auto-calibrated value obtained from this watershed by Basso et al. (2022b) (0.98 g cm^{-3}) and the range 0.71–1.2 g cm^{-3} measured in the field (Ferreira et al. 2016; Prats et al. 2016; Serpa et al. 2020). Unpublished bulk density data for the Serra de Cima catchment were collected in the field for the first layer, ranging between 0.75 and 1.20 g cm^{-3}, varying with vegetation type before the fire and soil type. The missing values in the second layer were replaced with the value of the nearest slope located in the same soil type. To account for the fire impact on the vegetation, the model directly parameterizes different coefficients. However, the maximum leaf area index was manually modified according to the burn severity (2—high, 3—moderate, 4—low) to simulate the reduced transpiration.

2.5 | WEPPcloud—EU Disturbed Calibration

WEPPcloud—EU Disturbed was calibrated at the catchment outlet at a daily time step for simulating streamflow of both catchments. A 1-year calibration period for the Serra de Cima catchment was selected starting on the day of the fire (August 20th, 2016). A shorter calibration period was available for the Ermida catchment (September 18th, 2010) and the creation of terraces within the catchment area, which alter the hydrological response (March 1st, 2011) (Basso et al. 2022b; Coelho et al. 1995). During the simulated year, the flow from the spring was found to be constant, and the value of 2.94 mm day^{-1} was assigned based on the minimum discharge observed at the end of the dry period. The model considered the spring an external water input and could not accurately simulate its presence with the current model structure. To avoid erroneous model calibration, as well as reduce the problem of equifinality, this constant value was omitted from the total streamflow. Calibration

TABLE 1 | Public database used in WEPPcloud—EU Disturbed for the European interface.

Input	Dataset	Resolution
DTM	EU-DEM v1.1 (EEA 2021)	30 m
Soil	European Soil Data Centre (ESDAC 2018; Ballabio et al. 2016)	1000 m
Land use	Corine Land Cover (European Environmental Agency (EEA) 2018)	100 m
Climate	User generated climate built with WEPPCLIFF tool (McGehee et al. 2020)	Precipitation—hourly, remaining parameters—daily
Soil burn severity	User map (.img or .tif)	10–30 m

TABLE 2 | Local parameterization of WEPPcloud-EU soil file for the Ermida and Serra de Cima catchments.

	Ermida catchment		Serra de Cima catchment	
	Value	References	Value	References
Bulk density (g cm^{-3})	0.98	Basso et al. (2022b)	0.75–1.20	Field data
Sand (%)	61	Ferreira et al. (2016)	21	Boulet et al. (2021) and Boulet et al. (2015)
Clay (%)	14	Ferreira et al. (2016)	23	Boulet et al. (2021) and Boulet et al. (2015)
OM (%)	10	Prats et al. (2016)	13	Boulet et al. (2021) and Boulet et al. (2015)
Rock (%)	55	Prats et al. (2016)	10–60	Field data, Boulet et al. (2021) and Boulet et al. (2015)

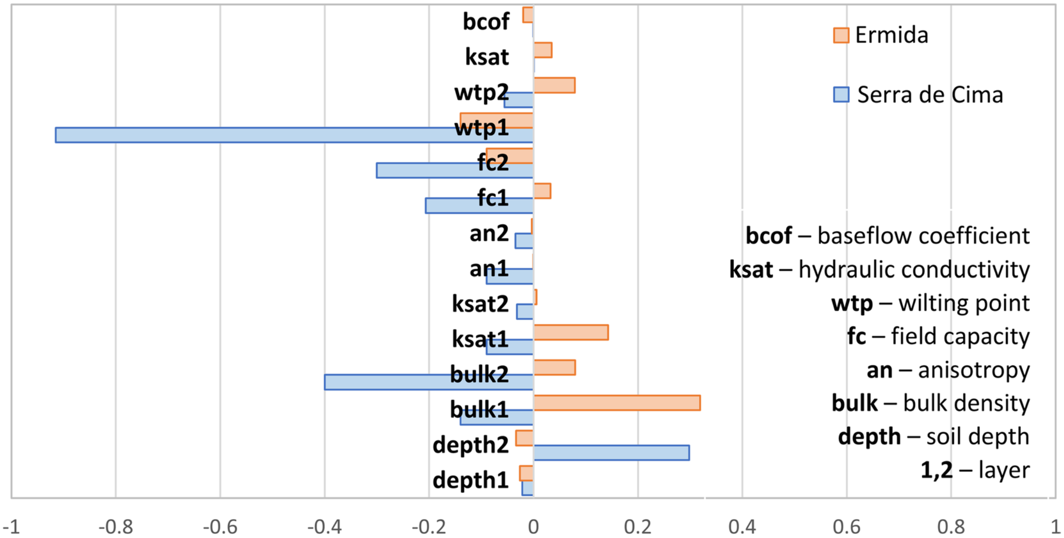

FIGURE 2 | Local sensitivity for the streamflow in the Ermida and Serra de Cima catchment. 1 and 2 indicate the values for each soil layer.

of total suspended sediments was done considering the model output corresponding to the date on which the analytical sample was obtained. To mitigate bias related to model instability, a warm-up period of 2 years was considered.

Before the calibration, a local sensitivity analysis was performed to assess the impacts of small changes in the values of key input parameters on the model predictions for daily streamflow and daily suspended sediment yield. The input parameters analyzed in the sensitivity analysis for streamflow were those parameterized for local conditions, except for soil texture and those used for calibration (Figure 2). The analysis was performed using the sensFUN function included in the FME package in R (R Core Team 2021; Soetaert and Petzoldt 2010). The analysis included soil and groundwater parameters for which the value was not measured in the field. Bulk density was included due to its significant spatiotemporal variability (Alletto and Coquet 2009; Mzuku et al. 2005; Wang et al. 2014) and its sensitivity to wildfire conditions (Ebel and Moody 2020; Moody et al. 2016). Additionally, soil depth was considered since limited field depths were measured in a portion of the watershed, emphasizing the need to understand its influence on the hydrologic response. The sensitivity analysis of the model results for the total suspended sediments was based on three key input parameters that determine the erosion response at the hillslope: critical shear stress, rill and interrill erodibility.

The calibration procedure was based on an autocalibration performed using the *modFit* function of the FME package in R (R Core Team 2021; Soetaert and Petzoldt 2010). The function runs 1000 simulations by changing the parameter values inside a pre-defined range, providing the best prediction for the watershed response based on NSE. The autocalibration of daily streamflow was based on the following soil parameters: effective hydraulic conductivity, anisotropy and saturated hydraulic conductivity of the bedrock. Effective hydraulic conductivity adjustment to post-fire conditions is frequently used (Beeson et al. 2001; Chen et al. 2013; Semenova et al. 2015; Thomas et al. 2021; Vieira et al. 2022; Wu, Nunes, et al. 2021; Wu, Baartman, et al. 2021) to simulate the increase in surface runoff usually observed in burned areas (Neary et al. 2003; Robichaud 2000; Shakesby and Doerr 2006). Anisotropy was also included in the calibration since the value provided by WEPPcloud-EU is not based on the European soil database and the parameter is important for simulating subsurface lateral flow. Finally, the calibration of Ermida catchment also included the baseflow coefficient (per day), due to the sensitivity of the simulation to this parameter.

The calibration of the suspended sediment yield was based on the calibrated hydrological response and the critical shear stress erodibility parameters for the hillslopes together with the rill and interrill erodibility. The critical shear stress at the hillslope scale was parameterized to calibrate the threshold at which the rill detachment occurs. The rill and interrill erodibility were calibrated to simulate the sediments generated by splash and overland flow erosion.

Uncertainty analysis was performed for streamflow and suspended sediment yield predictions using the Markov Chain Monte Carlo method (MCMC) with the *modMCMC* function of the FME package (R Core Team 2021; Soetaert and Petzoldt 2010). A set of 1000 simulations was run using a random selection of the calibrated parameters from a range of values.

3 | Results

3.1 | WEPPcloud—EU Disturbed Streamflow Predictions

3.1.1 | Ermida Catchment

The results of WEPPcloud—EU Disturbed simulation using the default configuration showed that WEPPcloud—EU missed several peak flow events during the first year (Figure S1). The available European databases in the WEPPcloud—EU were missing soil texture, organic matter, rock content and bulk density values for the second soil layer, affecting the correct representation of the hydrological response. This incorrect parameterization of the model likely explained the underestimation of the streamflow, with a predicted average of 3.3 ± 2.4 mm day^{-1} compared to the observed 6.9 ± 2.8 mm day^{-1}, resulting in unsatisfactory performance (Table 4).

The local sensitivity analysis revealed that the daily streamflow in the Ermida catchment was mainly sensitive to bulk density, wilting point and effective hydraulic conductivity of the first layer (Figure 2). After the autocalibration (Table 3), the predicted streamflow average was 6.3 ± 3.1 mm day^{-1}, resulting in an overall satisfactory WEPPcloud—EU Disturbed performance in terms of R^2 and NSE, and good for PBIAS (Table 4). Calibrated values for saturated hydraulic conductivity (5 mm h^{-1}) and anisotropy (50) were constant in the soil profile (Table 3). The saturated hydraulic conductivity for the bedrock was 0.43 mm h^{-1}, while the baseflow coefficient was 0.018. Negligible variation was observed in the predicted daily streamflow, with an average streamflow of 14.2 ± 1.3 mm day^{-1} during rainfall events (coefficient of variation of 9%), and 6.2 ± 0.4 mm day^{-1} (coefficient of variation of 7%) during dry periods (Figure 3). From the WEPPcloud—EU analysis of the water balance in Ermida catchment, referring to the Fall and the Winter after the fire, it has been determined that 29% of precipitation during the simulation period was lost through evapotranspiration (13% through transpiration and 16%

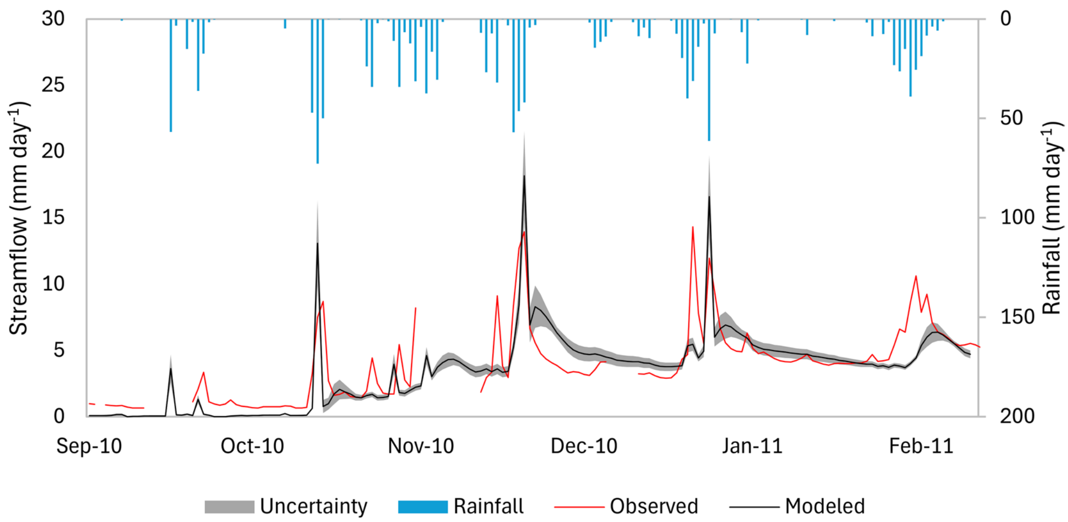

FIGURE 3 | WEPPcloud—EU calibrated prediction of the streamflow at Ermida catchment outlet.

TABLE 3 | WEPPcloud—EU calibrated parameters.

		Ermida			Serra de Cima		
		Layer 1	**Layer 2**	**Autocalibration range**	**Layer 1**	**Layer 2**	**Autocalibration range**
Hydrological parameters	Saturated hydraulic conductivity (mm h^{-1})	5	5	0–200	30–60	5	0–100[a]
	Anisotropy (–)	50	50	0.1–10[a]	10	10	0.1–10[a]
	Saturated hydraulic conductivity of bedrock (mm h^{-1})	0.43		0.005–0.5	0.005		0.005–0.5
	Baseflow coefficient (–)	0.018		0.001–0.1	0.04[b]		—
Erosion parameters	Critical shear stress (Pa)	0.5		0.5–10	0.6–1.2		0.1–1[a]
	Rill erodibility	8e-05[b]		0.1–10[a]	8e-05–1e-03		0.1–10[a]
	Interrill erodibility	1e06[b]		0.1–10[a]	4e05–1e06[b]		0.1–10[a]

[a]Multiplier.
[b]Default value from WEPPcloud—EU Disturbed.

TABLE 4 | WEPPcloud—EU Disturbed performance statistics.

		R^2	NSE	PBIAS
Ermida				
WEPPcloud-EU	Streamflow	0.2	−1.08	10.60
	Suspended sediment yield	0.002	−0.33	95.38
WEPPcloud-EU calibrated	Streamflow	0.57	0.47	5.20
	Suspended sediment yield	0.81	0.72	−22.62
Serra de Cima				
WEPPcloud-EU	Streamflow	0.07	0.01	0.28
	Suspended sediment yield	0.09	−0.24	95.14
WEPPcloud-EU calibrated	Streamflow	0.73	0.68	−32.38
	Suspended sediment yield	0.99	0.89	24.04

evaporation) and 55% through deep percolation. Streamflow consisted mainly of baseflow, which accounts for 45% of the total volume. Surface runoff contribution to the streamflow was minor (4%), with the upper subbasins contributing the most to the predicted runoff at the outlet.

3.1.2 | Serra de Cima Catchment

The simulation run using the default WEPPcloud—EU Disturbed configuration underestimated the runoff peaks during the first year after the fire (Figure S3). Similar to the Ermida catchment, the lack of complete soil information for different hillslopes likely affected the response of the watershed simulated by the model. The incorrect bulk density value of zero for several hillslopes caused the model to predict low to no measurable overland flow during rainfall events, explaining the behaviour of the predicted hydrological response (Figure S3). The underprediction of runoff peaks is reflected in the standard deviation value in the predicted streamflow (1.8 ± 1.3 mm day^{-1}) compared to the observed streamflow (1.8 ± 2.7 mm day^{-1}), leading to poor model performance in terms of R^2 and NSE (Table 4).

The local sensitivity analysis for the hydrological response in the Serra de Cima catchment revealed a large sensitivity to the wilting point for the upper layer, followed by the bulk density and the field capacity for both layers (Figure 2). The soil depth of the second layer appeared to be a sensitive parameter, while the sensitivity to the baseflow coefficient and the saturated hydraulic conductivity of the restrictive layer were not particularly important.

After autocalibration (Table 3), WEPPcloud-EU Disturbed predictions of streamflow improved (1.9 ± 2.3 mm day^{-1}), revealing satisfactory model performance in terms of R^2, NSE and PBIAS (Table 4). Calibrated saturated hydraulic conductivity (mm h^{-1}) was higher in the first soil layer (30–60 mm h^{-1}) than in the second layer (5 mm h^{-1}), while anisotropy values were constant through the soil profile (10) (Table 3). Saturated hydraulic conductivity of bedrock was calibrated at 0.005 mm h^{-1}, while the baseflow coefficient did not change from the default value (0.04).

The lower variations in simulated streamflow from the uncertainty analysis (coefficient of variation of 13%) revealed overall consistent simulation results (Figure 4), probably due to the lower sensitivity of the model results to the values used for calibration. The water balance analysis in the Serra de Cima catchment simulated by WEPPcloud—EU showed that 26% of the precipitation during the simulation period is lost in evapotranspiration (13% through transpiration and 13% evaporation), while 4% accounts for deep percolation. Lateral flow accounts for 54% of the streamflow, while surface runoff and baseflow represented 11% and 5% of the total volume, respectively. The spatial distribution of total runoff in the Serra de Cima watershed appeared homogeneous, with a lower contribution from sub-catchments with lower soil burn severity or small areas.

3.2 | WEPPcloud—EU Disturbed Suspended Sediment Yield Predictions

3.2.1 | Ermida Catchment

WEPPcloud—EU Disturbed results, using the default configuration, underpredicted suspended sediment yield, especially during rain events (Figure S2). The underprediction of streamflow is probably the main reason for the underestimation of the average predicted sediment yield (0.5 ± 0.3 kg ha^{-1} day^{-1}), compared to the observed (11.7 ± 19.6 kg ha^{-1} day^{-1}), resulting in poor model performance (Table 4).

Local sensitivity analysis revealed a higher sensitivity of the total suspended sediments to the critical shear stress (0.5 Pa) (Figure 5), while the other parameter remained unchanged from the default values (Table 3). The autocalibration of the parameters specific to the erosion response improved model performance, obtaining a good agreement with observed data, with predicted average of 8.2 ± 19.5 kg ha^{-1} day^{-1} (Table 4). Uncertainty analysis showed a good fit of model prediction,

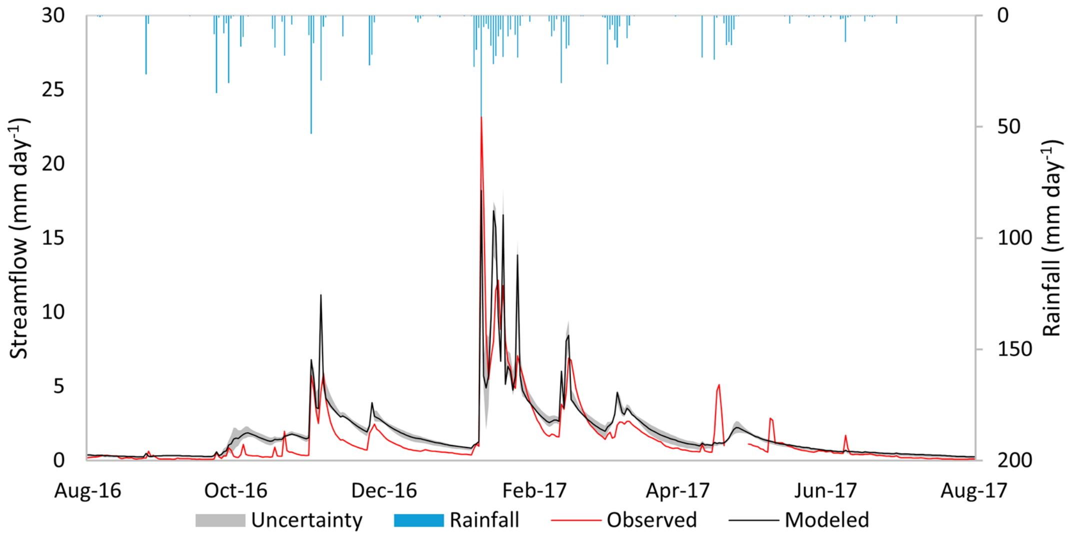

FIGURE 4 | WEPPcloud—EU calibrated prediction of the streamflow at Serra de Cima catchment outlet.

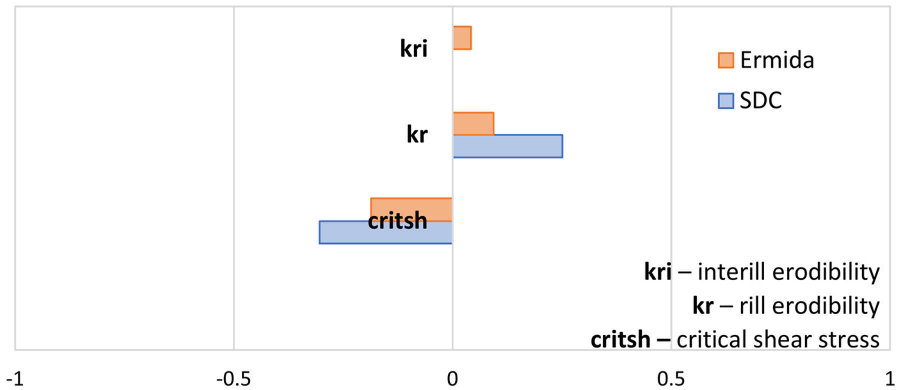

FIGURE 5 | Local sensitivity for the sediment yield for Ermida and SDC catchment.

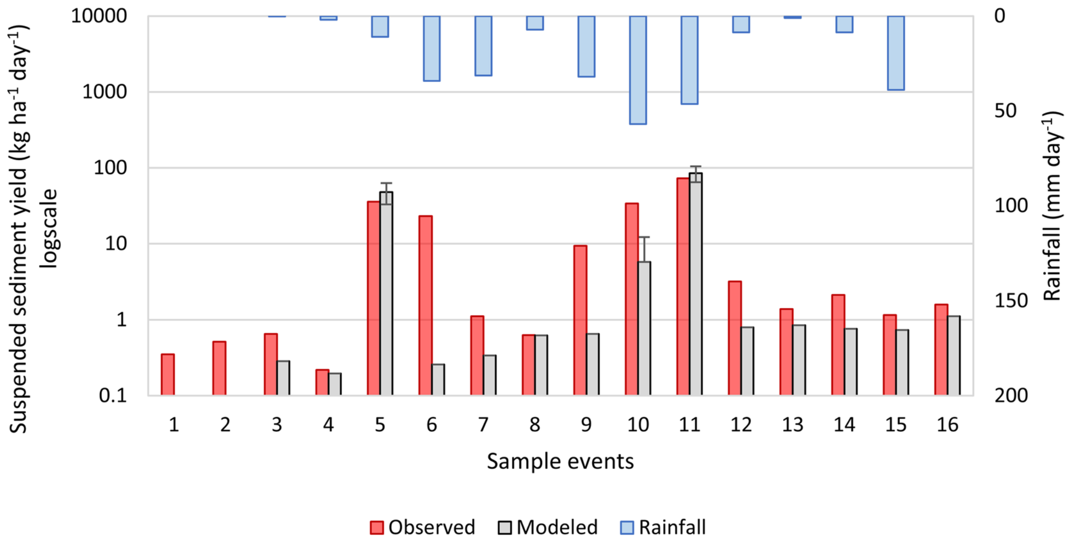

FIGURE 6 | WEPPcloud—EU calibrated prediction of the sediment yield at Ermida catchment.

with detectable uncertainty at the events that generate runoff (Figure 6—event 5, 11).

3.2.2 | Serra de Cima Catchment

The results of the default configuration of WEPPcloud—EU Disturbed underestimated the suspended sediments at the outlet for the Serra de Cima catchment (Figure S4), especially for the largest rainfall event (November 20th, 2016—53.2 mm day^{-1}). Similar to the Ermida catchment, the underprediction of the streamflow is likely the reason for the poor performance of the model (Table 4). Predicted sediment yield average was 1.4 ± 0.8 kg ha^{-1} day^{-1}, while observed average was 28.5 ± 56.7 kg ha^{-1} day^{-1}. The local sensitivity for the suspended sediment yield at the outlet of the Serra de Cima catchment revealed a higher sensitivity to the hillslope critical shear stress (0.6–1.2 Pa) and the rill erodibility (8e-05–1e-03) (Figure 5). The autocalibration (Table 3) improved model performance, with predicted average of 35.4 ± 73.9 kg ha^{-1} day^{-1}, obtaining very good statistics in terms of R^2 and NSE respectively (Table 4). A higher uncertainty was observed in correspondence to the two largest rainfall/runoff events (Figure 7, event 1, 53.2 mm day^{-1}—November 20th, 2016, and event 4, 17.6 mm day^{-1}—December 15th, 2016).

4 | Discussion

4.1 | Calibration and Model Performance of WEPPcloud—EU Disturbed

The default configuration of WEPPcloud—EU Disturbed unpredicted streamflow and total suspended sediments at the catchment outlet for both watersheds. The main limitation of the online tool seemed to be the coarser resolution of the soil database used for characterizing soil parameters. The 1000 m resolution ESDAC soil database (Table 1) likely led to incorrect parameterization of the catchment characteristics, as the database was not representative of local conditions. For example, although the default soil layers were set at 1200 and 1500 mm for both watersheds, it was determined that the soils were shallower in the area (Boulet et al. 2015; IUSS Working Group WRB 2022). As observed in the sensitivity analysis for the streamflow (Figure 2), especially for the Serra de Cima catchment, simulation results were highly sensitive to soil depth and available water storage, emphasizing the critical importance of accurate parameterization. The auto-calibrated effective hydraulic conductivity values of the first soil layer for both watersheds were of the same order of magnitude as the default values of WEPPcloud—EU Disturbed and as those calibrated and measured in other burned areas (Basso et al. 2024; Ebel and Martin 2017; Moussoulis et al. 2015; Pradhan and Floyd 2021; Rengers et al. 2016). The values for the second layers were two orders of magnitude lower than the default ones, likely reflecting the transition to a restrictive layer underneath. This restrictive layer could be due to prior management activities in the area, as soils in eucalyptus plantations are highly water repellent (Doerr and Thomas 2000; Keizer et al. 2005). Research indicated that eucalyptus plantation soils were equally water repellent from the surface to 30 cm depth (Doerr et al. 1996), probably aided by the rip-ploughing of the soil before planting (Shakesby et al. 1994). The calibrated value of schists bedrock hydraulic conductivity for both watersheds was typical for this type of bedrock (APHA 1998).

Baseflow played a major role in the streamflow for the Ermida catchment, reflected in the calibrated baseflow coefficient of the groundwater parameters (Table 3). Streamflow in the Serra de Cima catchment, on the other hand, consisted mostly of lateral flow as observed by field measurements (Boulet et al. 2015), increasing the sensitivity of modeled results to anisotropy (Figure 2). The higher sensitivity of wilting points and field capacity coefficients in the Serra de Cima catchment was also likely related to the importance of available soil water storage and water release through lateral flow.

The calibrated value for the hillslope soil critical shear stress for both catchments (Table 3) was found to be lower than that used in other WEPP applications (Dobre et al. 2022; Srivastava et al. 2018). Although lower than the values suggested by WEPPcloud-EU Disturbed and the values generally used by other authors, a critical shear stress of 0.5 N m^{-2} can be found in different types of soils (Elliot 1990) and can be reached at temperatures > 275°C after fire, regardless of soil type (Moody et al. 2005). In addition, the

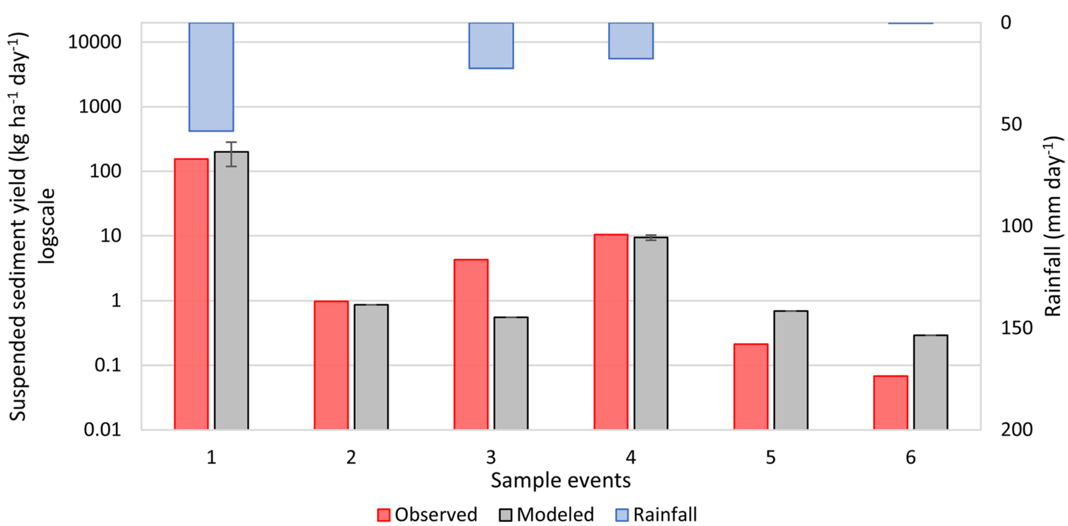

FIGURE 7 | WEPPcloud—EU calibrated prediction of the sediment yield at Serra de Cima catchment.

observed suspended sediment yield did not distinguish between ash and soil particles, potentially influencing the auto-calibrated critical shear stress value. This value may have reflected the presence of a highly loose and easily transported ash material along with the sediment. The higher sensitivity in both catchments to rill erodibility compared to interrill erodibility was due to a compensative process between the contributions. This resulted in low sensitivity to interrill erodibility when rill erosion is active and dominates the hillslope erosion process (Nearing et al. 1990).

In comparison to other WEPPcloud applications, the model performance for both catchments was consistent with other studies simulating streamflow and suspended sediment yield at catchment outlets (Brooks et al. 2016; Dobre et al. 2022; East et al. 2024; Srivastava et al. 2018).

4.1.1 | Calibration and Model Performance for Ermida Catchment

After model parameterization and calibration in Ermida catchment, performance in simulating daily streamflow increased compared to the default WEPPcloud—EU Disturbed configuration. Compared with the results obtained from the Soil and Water Assessment Tool (SWAT) modeling exercise by Basso et al. (2022b) for streamflow in the same watershed, WEPPcloud—EU Disturbed did not perform as well. However, in this study, the number of calibrated parameters was intentionally minimized to test the ability of WEPPcloud—EU Disturbed to simulate daily streamflow. Although this caused a small decrease in the performance of WEPPcloud—EU Disturbed, it increased the possibility of model applications to ungauged watersheds with minimum calibration. The higher uncertainty during the recession highlighted the importance of a corrected simulation of the baseflow dynamics in this watershed. Baseflow was best simulated using the non-linear reservoir theory, as opposed to the linear reservoir assumption used in WEPPcloud—EU Disturbed (Sánchez-Murillo et al. 2015; Srivastava et al. 2013). This could have affected the final performance of the model. In addition, not including the spring in the model could have resulted in an inaccurate calibration, since its flow, which is influenced by rainfall, could play a critical role in shaping the hydrograph. The decision to consider the spring flow constant limited the model calibration to the simulated period, as the flow was sensitive to rainfall during the wet season. To extend the simulation to a longer period, an accurate analysis of the fluctuation of the spring flow due to the rainfall would be required.

Nevertheless, WEPPcloud—EU Disturbed was successful in simulating daily streamflow patterns. While successful in predicting the general trend, it slightly underestimated the baseflow during the initial dry period and did not predict the first runoff peaks of two events (Figure 3). Observed data in Figure 3 showed a higher sensitivity of the watershed response to rain events compared to what was simulated, as can be observed during the February 10th 2010 and January 7th 2011 events. Regarding total suspended sediments prediction at Ermida catchment outlet, good model performance was obtained after calibration. Compared with the SWAT application by Basso et al. (2022b), WEPPcloud—EU better predicted suspended sediment yield. The model accurately predicted sediment yield corresponding to most sample events (Figure 6). However, occasional underprediction occurred, mainly due to the omission of the spring flow and the underprediction of streamflow on specific dates.

4.1.2 | Calibration and Model Performance for Serra de Cima Catchment

Model parameterization and calibration of the Serra de Cima catchment resulted in satisfactory daily streamflow prediction. The model performance was similar to another modeling exercise in the same catchment run using OpenLISEM and MOHID Land models (Basso et al. 2024). WEPPcloud—EU Disturbed was able to simulate the peak flow and the baseflow in the second part of the hydrograph, but it slightly overpredicted the trend during the first part (Figure 4). The rainfall event during January 2017 could have biassed the calibration of the model. The uniqueness of the January 2017 rainfall event was also observed by Basso et al. (2022b), wherein the model was unable to simulate the streamflow increase due to its calibration being based on a period characterized by lower rainfall. The temporally constant parameterization of the model could be the reason WEPPcloud—EU better predicted a portion of the hydrograph. A time-constant parameterization of a model did not correctly incorporate soil properties that were affected by weather conditions (Baartman et al. 2012; Basso et al. 2022b; Boulet et al. 2015; Doerr and Thomas 2000; Ferreira et al. 2000; Malvar et al. 2016; Santos et al. 2016) and time-since-fire in the case of a burned area (Canfield et al. 2005; Ebel and Martin 2017; Vieira et al. 2022).

Model performance in predicting suspended sediment yield increased after model calibration, resulting in correct estimates of total suspended sediment transported during high-intensity rainfall events. Although the model slightly underpredicted suspended sediment yield during heavy rainfall events, it also overpredicted the sediment transported during drier periods (Figure 7). This discrepancy could reflect the model attempt to account for the higher mobile ash and soil layer during heavy rainfall, alongside its effort to simulate the reduced sediment transport during the drier periods.

4.2 | Comparison of the Post-Fire Response of Ermida and Serra de Cima Catchments

The Ermida and Serra de Cima catchments presented similar land-use and soil characteristics previous to the wildfires. The main differences between the two catchments were their size and the presence of two springs as well as two retention ponds in the Ermida catchment and their absence in the Serra de Cima catchment. Field observations and the water balance analysis from WEPPcloud—EU Disturbed showed the key role of the baseflow in the Ermida catchment. Rainfall events produced a negligible amount of runoff (amounting to 2% of the water balance), likely attenuated by the presence of two retention ponds upstream of the flume. The average runoff coefficient (0.079) during rainfall events in the Ermida catchment was significantly lower than the average runoff coefficient for the

Serra de Cima (0.199), where runoff accounted for 11% of the water balance. Except for the January 31st 2017 event, which presented a sudden increase in streamflow (81 mm day^{-1} rainfall, 16 mm day^{-1} runoff), the Serra de Cima catchment generally had a reduced response to rainfall events compared to the Ermida catchment (Figures 3 and 4). The rapid response to rainfall events observed in the Ermida catchment suggested that overland flow was initiated by infiltration exceedance, likely simulated through the lower effective hydraulic conductivity value of the first soil layer in the Ermida than in the Serra de Cima catchment (Table 3). In the Serra de Cima catchment, the higher effective hydraulic conductivity values for the first layer and the generally milder watershed response to precipitation events indicated that overland flow was initiated by the saturation excess mechanism. The rainfall lost in evapotranspiration was similar for the Ermida (19%) and Serra de Cima (26%) catchments. Those values are similar to the lowest value reported by Nolan et al. (2014) for a damp eucalyptus stand following a high burned severity. Häusler et al. (2018) reported that differences in daily evapotranspiration rates between unburned and moderate-to-high-severity burnt eucalypt stands in the study region were highest during the first post-fire year, ranging from 1.5 mm day^{-1} during early autumn and early spring to less than 0.5 mm day^{-1} in winter. Assuming an average decrease of 1 mm day^{-1} in the burned area, and using the annual evapotranspiration values of Boulet et al. (2021) for an unburnt eucalypt-dominated catchment in the study region, evapotranspiration estimates for the first year following a moderate-to-high-severity fire would range from 16% to 37%, with a median of 24%. The sensitivity analysis of the erosive response for both catchments showed a higher sensitivity to the critical shear stress and the rill erodibility (Figure 5), presenting similar auto-calibrated values for the coefficients related to sediment response (Table 3). However, during more intense rainfall events, higher suspended sediment yields (November 20th, 2016–53.2 mm day^{-1} rainfall, 155 kg ha^{-1} day^{-1}) were observed at the outlet of the Serra de Cima compared with the Ermida catchment (December 5th, 2010–57 mm day^{-1} rainfall, 33.76 kg ha^{-1} day^{-1}; December 6th—46.4 mm day^{-1} rainfall, 72.5 kg ha^{-1} day^{-1}). The lower observed suspended sediment yield transported in the Ermida catchment could be attributed to the presence of the ponds, which likely disrupted the connectivity between hillslopes and the outlet (Keizer et al. 2015). Regarding the model prediction for these two events, the lower values obtained at the outlet of the Ermida basin could be due to the inability of the model to simulate the corresponding peak. For values measured outside of rain events, Ermida presented a higher TSSs yield than Serra de Cima. The greater sediment transport observed in the Ermida basin during dry periods, compared to the Serra de Cima, can be explained by the continuous flow from the springs, which move sediment trapped in the ponds, causing delayed transport (Keizer et al. 2015).

4.3 | Optimising WEPPcloud—EU Disturbed for Accurate Simulations of Burned Areas in the Central Region of Portugal

The strength of WEPPcloud—EU Disturbed online tool lies in setting model inputs with a user-friendly interface. The creation of a simulation does not require watershed parameterization, as input parameters are already stored in a database readily accessible by the software. This feature simplifies the simulation setup, enabling users to efficiently input data and initiate simulations.

However, from this study, a notable weakness of the current WEPPcloud—EU Disturbed online version was found to be its dependence on a lower resolution soil database, which presented limitations when trying to accurately simulate local watershed scales. The underprediction of the WEPPcloud—EU Disturbed default configuration for streamflow and suspended sediment yields (Figures S1–S4), highlighted the importance of a proper parameterization of soil and groundwater parameters to better reflect the local characteristics of individual watersheds. The use of national databases would already improve the quality and the resolution of input parameters. However, accessibility to these data is challenging due to data ownership and language barriers. In addition, national databases could provide a greater network of weather stations to be implemented in WEPPcloud—EU Disturbed and allow for a greater representation of the local weather conditions of the relevant area.

Another limitation of WEPPcloud—EU is that it does not simulate water quality constituents dynamics, such as nutrients cycling or contaminants mobilisation. This limits its applicability for comprehensive post-fire water quality assessments, where prediction of dissolved and particulate nutrient transport is crucial to understanding potential impacts on downstream water supplies. A new tool integrated into the model, called Wildfire Ash Transport and Risk, allows the user to predict the potential pollutants in ash and soil (Neris et al. 2021). This tool will include ash transport routines from hillslopes into channels and predict water quality parameters at the watershed outlet. This model will need to be calibrated with observed data.

The use of a user-defined climate did not yield better results, highlighting the importance of correct soil parameterization. It was not possible to satisfactorily incorporate the presence of the spring in the Ermida catchment into the model, necessitating its exclusion from the total streamflow. An option was to consider the spring as a reservoir that constantly provided water to the stream network. However, this approach would have complicated model parameterization and conflicted with the study's objective to minimize parameterization and calibration. Future research should aim to incorporate these features in WEPPcloud—EU Disturbed, as they are not uncommon and could alter watershed responses.

The good model performance achieved after parameterization to local conditions coupled with autocalibration underscored the potential of using WEPPcloud—EU Disturbed in effectively simulating daily streamflow and suspended sediment yield in burned areas in the European continent. In particular, the autocalibration, using a reduced number of parameters, highlighted the viability of the model not only for research purposes but also as a practical management tool. Looking ahead to a WEPPcloud—EU Disturbed use, future research should prioritise minimizing the number of parameters needed for calibration while ensuring robust parameterization to local conditions. Given the significant role of soil depth in modeling hydrological processes, special emphasis should be placed on accurate representation of this variable for European soils. In addition, the online version of WEPPcloud—EU Disturbed databases should be regularly updated with newly available data. The CLIGEN climate option was unrepresentative of weather conditions in large parts of Europe, due to the limited number of stations available in the interface dataset. WEPPcloud—EU Disturbed should expand the range of stations when they become available, while still keeping the simple parameterization of the model.

5 | Conclusions

In this study, WEPPcloud—EU model was tested on two recently burned catchments in Portugal to assess its applicability as a post-fire management tool. This modeling exercise highlighted the significance of incorporating national and local databases into the model's default parameterization. This refinement of input data could lead to improved model performance even before calibration, as the improved parameterization to local conditions could reduce discrepancies between the uncalibrated and calibrated simulation. As experienced with the model parameterization for the Ermida watershed, local knowledge of the presence of the spring and ponds helped reduce equifinality during calibration, a challenging issue in modelling when field conditions are unknown. The main findings of this study further emphasize the value of locally informed input data:

i. WEPPcloud—EU default simulations in the online interface, which lacked local input data, underestimated the daily streamflow and suspended sediment yield at the outlet of both catchments.

ii. Catchment-specific parameterization combined with autocalibration markedly improved the performance of WEPPcloud—EU, resulting in satisfactory prediction of both daily streamflow and suspended sediment yield at the outlet of both catchments.

iii. Restricting autocalibration to a small number of parameters did not compromise the satisfactory performance of WEPPcloud—EU, highlighting the value of locally informed parameterization.

iv. The contrasting characteristics as well as diverging post-fire hydrological and erosion responses of the two catchments demonstrated the elevated potential of WEPPcloud—EU as a valuable tool for post-fire emergency stabilization, particularly if a local input dataset is available.

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Data Availability Statement

The data that support the findings of this study are available on request from the corresponding author. The data are not publicly available due to privacy or ethical restrictions.

References

Allen, R. G. 2000. "Using the FAO-56 Dual Crop Coefficient Method Over an Irrigated Region as Part of an Evapotranspiration Intercomparison Study." *Journal of Hydrology* 229: 27–41. https://doi.org/10.1016/S0022-1694(99)00194-8.

Alletto, L., and Y. Coquet. 2009. "Temporal and Spatial Variability of Soil Bulk Density and Near-Saturated Hydraulic Conductivity Under Two Contrasted Tillage Management Systems." *Geoderma* 152: 85–94. https://doi.org/10.1016/j.geoderma.2009.05.023.

APHA. 1998. "Total Suspended Solids Dried at 105 Degrees Celsius Method 2540D." In *Standard Methods for the Examination of Water and Waste Water*. APHA.

Baartman, J. E. M., V. G. Jetten, C. J. Ritsema, and J. de Vente. 2012. "Exploring Effects of Rainfall Intensity and Duration on Soil Erosion at the Catchment Scale Using openLISEM: Prado Catchment, SE Spain." *Hydrological Processes* 26: 1034–1049. https://doi.org/10.1002/hyp.8196.

Ballabio, C., P. Panagos, and L. Monatanarella. 2016. "Mapping Topsoil Physical Properties at European Scale Using the LUCAS Database." *Geoderma* 261: 110–123. https://doi.org/10.1016/j.geoderma.2015.07.006.

Basso, M., J. Baartman, M. Martins, J. Keizer, and D. Vieira. 2024. "Predicting Post-Fire Hydrological and Erosive Catchment Response During Rainfall Events. A Comparison of OpenLISEM and MOHID Land Models." *Journal of Hydrology* 636: 131258. https://doi.org/10.1016/j.jhydrol.2024.131258.

Basso, M., D. Serpa, M. Mateus, J. J. Keizer, and D. C. S. Vieira. 2022a. "Advances on Water Quality Modeling in Burned Areas: A Review." *PLOS Water* 1: e0000025. https://doi.org/10.1371/journal.pwat.0000025.

Basso, M., D. Serpa, J. Rocha, M. A. S. Martins, J. Keizer, and D. C. S. Vieira. 2022b. "A Modelling Approach to Evaluate Land Management Options for Recently Burnt Catchments." *European Journal of Soil Science* 73: e13275. https://doi.org/10.1111/ejss.13275.

Basso, M., D. C. S. Vieira, T. Brito Ramos, and M. Mateus. 2019. "Assessing the Adequacy of the Soil and Water Assessment Tool (SWAT) to Simulate Post-Fire Effects on the Watershed Hydrological Regime and Water Quality." *Land Degradation & Development* 31: 619–631. https://doi.org/10.1002/ldr.3476.

Beeson, P. C., S. N. Martens, and D. D. Breshears. 2001. "Simulating Overland Flow Following Wildfire: Mapping Vulnerability to Landscape Disturbance." *Hydrological Processes* 15: 2917–2930. https://doi.org/10.1002/hyp.382.

Bladon, K. D., M. B. Emelko, U. Silins, and M. Stone. 2014. "Wildfire and the Future of Water Supply." *Environmental Science & Technology* 48: 8936–8943. https://doi.org/10.1021/es500130g.

Boulet, A.-K., S. A. Prats, M. C. Malvar, et al. 2015. "Surface and Subsurface Flow in Eucalyptus Plantations in North-Central Portugal." *Journal of Hydrology and Hydromechanics* 63: 193–200.

Boulet, A.-K., M. E. Rial-Rivas, C. Ferreira, et al. 2021. "Hydrological Processes in Eucalypt and Pine Forested Headwater Catchments

Within Mediterranean Region." *Water* 13: 1418. https://doi.org/10.3390/w13101418.

Brooks, E. S., M. Dobre, W. J. Elliot, J. Q. Wu, and J. Boll. 2016. "Watershed-Scale Evaluation of the Water Erosion Prediction Project (WEPP) Model in the Lake Tahoe Basin." *Journal of Hydrology* 533: 389–402. https://doi.org/10.1016/j.jhydrol.2015.12.004.

Burjachs, F., and I. Expósito. 2015. "Charcoal and Pollen Analysis: Examples of Holocene Fire Dynamics in Mediterranean Iberian Peninsula." *Catena* 135: 340–349. https://doi.org/10.1016/j.catena.2014.10.006.

Canfield, H. E., D. C. Goodrich, and I. S. Burns. 2005. "Selection of Parameters Values to Model Post-Fire Runoff and Sediment Transport at the Watershed Scale in Southwestern Forests." In *Managing Watersheds for Human and Natural Impacts: Engineering, Ecological, and Economic Challenges*, edited by G. E. Moglen, 1–12. American Society of Civil Engineers. https://doi.org/10.1061/40763(178)48.

Cannon, S. H., J. E. Gartner, R. C. Wilson, J. C. Bowers, and J. L. Laber. 2008. "Storm Rainfall Conditions for Floods and Debris Flows From Recently Burned Areas in Southwestern Colorado and Southern California." *Geomorphology* 96: 250–269. https://doi.org/10.1016/j.geomorph.2007.03.019.

Cardoso, J. C. 1974. "The Classification of Soils in Portugal – New Version (A Classificação dos Solos de Portugal–Nova Versão)." *Boletim de Solos* 17: 14–46.

Carrión, J. S., P. Sánchez-Gómez, J. F. Mota, R. Yll, and C. Chaín. 2003. "Holocene Vegetation Dynamics, Fire and Grazing in the Sierra de Gádor, Southern Spain." *Holocene* 13: 839–849. https://doi.org/10.1191/0959683603hl662rp.

Cerdá, A., and S. H. Doerr. 2005. "Influence of Vegetation Recovery on Soil Hydrology and Erodibility Following Fire: An 11-Year Investigation." *International Journal of Wildland Fire* 14: 423–437. https://doi.org/10.1071/WF05044.

Cerdan, O., G. Govers, Y. Le Bissonnais, et al. 2010. "Rates and Spatial Variations of Soil Erosion in Europe: A Study Based on Erosion Plot Data." *Geomorphology* 122: 167–177. https://doi.org/10.1016/j.geomorph.2010.06.011.

Certini, G. 2005. "Effects of Fire on Properties of Forest Soils: A Review." *Oecologia* 143: 1–10. https://doi.org/10.1007/s00442-004-1788-8.

Chen, L., M. Berli, and K. Chief. 2013. "Examining Modeling Approaches for the Rainfall-Runoff Process in Wildfire-Affected Watersheds: Using San Dimas Experimental Forest." *JAWRA Journal of the American Water Resources Association* 49: 851–866. https://doi.org/10.1111/jawr.12043.

Coelho, C., R. A. Shakesby, and R. P. D. Walsh. 1995. *Effects of Forest Fires and Post-Fire Land Management Practice on Soil Erosion and Stream Dynamics, Águeda Basin, Portugal: Soil and Groundwater Research Report V.* European commission.

De Girolamo, A. M., O. Cerdan, T. Grangeon, G. F. Ricci, R. Vandromme, and A. Lo Porto. 2022. "Modelling Effects of Forest Fire and Post-Fire Management in a Catchment Prone to Erosion: Impacts on Sediment Yield." *Catena* 212: 106080. https://doi.org/10.1016/j.catena.2022.106080.

DeBano, L. F. 2000. "The Role of Fire and Soil Heating on Water Repellency in Wildland Environments: A Review." *Journal of Hydrology* 231: 195–206. https://doi.org/10.1016/S0022-1694(00)00194-3.

DeBano, L. F., D. G. Neary, and P. F. Ffolliott. 1998. *Fire Effects on Ecosystems*. John Wiley & Sons.

Dillon, G. K., Z. A. Holden, P. Morgan, M. A. Crimmins, E. K. Heyerdahl, and C. H. Luce. 2011. "Both Topography and Climate Affected Forest and Woodland Burn Severity in Two Regions of the Western US, 1984 to 2006." *Ecosphere* 2: 130. https://doi.org/10.1890/ES11-00271.1.

Dobre, M., A. Srivastava, R. Lew, et al. 2022. "WEPPcloud: An Online Watershed-Scale Hydrologic Modeling Tool. Part II. Model Performance Assessment and Applications to Forest Management and Wildfires." *Journal of Hydrology* 610: 127776. https://doi.org/10.1016/j.jhydrol.2022.127776.

Doerr, S. H. 1998. "On Standardizing the 'Water Drop Penetration Time' and the 'Molarity of an Ethanol Droplet' Techniques to Classify Soil Hydrophobicity: A Case Study Using Medium Textured Soils." *Earth Surface Processes and Landforms* 23: 663–668. https://doi.org/10.1002/(SICI)1096-9837(199807)23:7<663::AID-ESP909>3.0.CO;2-6.

Doerr, S. H., R. A. Shakesby, and L. H. MacDonald. 2009. "Soil Water Repellency: A Key Factor in Post-Fire Erosion." In *Fire Effects on Soils and Restoration Strategies*, edited by A. Cerda, 213–240. CRC Press.

Doerr, S. H., R. A. Shakesby, and R. P. D. Walsh. 1996. "Soil Hydrophobicity Variations With Depth and Particle Size Fraction in Burned and Unburned Eucalyptus Globulus and *Pinus pinaster* Forest Terrain in the Águeda Basin, Portugal." *Catena* 27: 25–47. https://doi.org/10.1016/0341-8162(96)00007-0.

Doerr, S. H., and A. D. Thomas. 2000. "The Role of Soil Moisture in Controlling Water Repellency: New Evidence From Forest Soils in Portugal." *Journal of Hydrology* 231–232: 134–147. https://doi.org/10.1016/S0022-1694(00)00190-6.

East, A. E., J. B. Logan, H. W. Dow, et al. 2024. "Post-Fire Sediment Yield From a Central California Watershed: Field Measurements and Validation of the WEPP Model." *Earth and Space Science* 11: e2024EA003575. https://doi.org/10.1029/2024EA003575.

Ebel, B. A., and D. A. Martin. 2017. "Meta-Analysis of Field-Saturated Hydraulic Conductivity Recovery Following Wildland Fire: Applications for Hydrologic Model Parameterization and Resilience Assessment." *Hydrological Processes* 31: 3682–3696. https://doi.org/10.1002/hyp.11288.

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.

EEA, C. L. M. S. 2021. "EU-DEM v1. 1."

EEA, E. E. A. 2018. "Corine Land Cover." https://www.eea.europa.eu/publications/COR0-landcover.

Elliot, W. J. 1990. *A Compendium of Soil Erodibility Data From WEPP Cropland Soil Field Erodibility Experiments 1987 & 88*. Agricultural Research Service, US Department of Agriculture, National Soil Erosion Research Laboratory.

Elliot, W. J. 2000. Forest Service WEPP Interfaces. https://forest.moscowfsl.wsu.edu/fswepp/.

Elliot, W. J. 2013. "Erosion Processes and Prediction With WEPP Technology in Forests in the Northwestern US." *Transactions of the ASABE* 56: 563–579.

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.

ESDAC, E. S. D. C. 2018. "European Soil Database Maps." https://esdac.jrc.ec.europa.eu/resource-type/european-soil-database-maps.

Fernandes, P. M., N. Guiomar, and C. G. Rossa. 2019. "Analysing Eucalypt Expansion in Portugal as a Fire-Regime Modifier." *Science of the Total Environment* 666: 79–88. https://doi.org/10.1016/j.scitotenv.2019.02.237.

Fernández, C. 2023. "Soil Fire Severity Is More Relevant Than Fire Frequency in Explaining Soil, Carbon and Nitrogen Losses and Vegetation Recovery After Wildfire in NW Spain." *Journal of Environmental Management* 327: 116876. https://doi.org/10.1016/j.jenvman.2022.116876.

Fernández, C., and J. A. Vega. 2016a. "Effects of Mulching and Post-Fire Salvage Logging on Soil Erosion and Vegetative Regrowth in NW Spain." *Forest Ecology and Management* 375: 46–54.

Fernández, C., and J. A. Vega. 2016b. "Evaluation of RUSLE and PESERA Models for Predicting Soil Erosion Losses in the First Year After Wildfire in NW Spain." *Geoderma* 273: 64–72. https://doi.org/10.1016/j.geoderma.2016.03.016.

Fernández, C., J. A. Vega, and D. C. S. Vieira. 2010. "Assessing Soil Erosion After Fire and Rehabilitation Treatments in NW Spain: Performance of Rusle and Revised Morgan–Morgan–Finney Models." *Land Degradation & Development* 21: 58–67. https://doi.org/10.1002/ldr.965.

Ferreira, A. J. D., C. O. A. Coelho, R. P. D. Walsh, R. A. Shakesby, A. Ceballos, and S. H. Doerr. 2000. "Hydrological Implications of Soil Water-Repellency in *Eucalyptus Globulus* Forests, North-Central Portugal." *Journal of Hydrology* 231–232: 165–177. https://doi.org/10.1016/S0022-1694(00)00192-X.

Ferreira, R. V., D. Serpa, M. A. Cerqueira, and J. J. Keizer. 2016. "Short-Time Phosphorus Losses by Overland Flow in Burnt Pine and Eucalypt Plantations in North-Central Portugal: A Study at Micro-Plot Scale." *Science of the Total Environment* 551-552: 631–639. https://doi.org/10.1016/j.scitotenv.2016.02.036.

Flanagan, D. C., and S. Livingston. 1995. *Water Erosion Prediction Project (WEPP) User Summary. NSERL Report No. 11*. USDA-ARS National Soil Erosion Research Laboratory.

Flanagan, D. C., and M. A. Nearing. 1995. *USDA-Water Erosion Prediction Project: Hillslope Profile and Watershed Model Documentation. NSERL Rep. 10, 1–123*. USDA-ARS National Soil Erosion Research Laboratory.

Foster, G. R., and L. D. Meyer. 1972. "A Closed-Form Soil Erosion Equation for Upland Areas." In *Sedimentation: Symposium to Honor Professor H.A. Einstein*, edited by H. W. Shen, 12.1–12.19. Colorado State University.

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.

Granier, C., S. Darras, H. D. van der Gon, et al. 2019. "The Copernicus Atmosphere Monitoring Service Global and Regional Emissions (April 2019 Version)." Copernicus Atmosphere Monitoring Service (CAMS) Report. https://doi.org/10.24380/d0bn-kx16.

Häusler, M., J. P. Nunes, P. Soares, et al. 2018. "Assessment of the Indirect Impact of Wildfire (Severity) on Actual Evapotranspiration in Eucalyptus Forest Based on the Surface Energy Balance Estimated From Remote-Sensing Techniques." *International Journal of Remote Sensing* 39: 6499–6524. https://doi.org/10.1080/01431161.2018.1460508.

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.

Holden, Z. A., P. Morgan, M. A. Crimmins, R. K. Steinhorst, and A. M. S. Smith. 2007. "Fire Season Precipitation Variability Influences Fire Extent and Severity in a Large Southwestern Wilderness Area, United States." *Geophysical Research Letters* 34: L16708. https://doi.org/10.1029/2007GL030804.

IUSS Working Group WRB. 2022. "World Reference Base for Soil Resources." In *International Soil Classification System for Naming Soils and Creating Legends for Soil Maps*, 4th ed. International Union of Soil Sciences.

Keeley, J. E. 2009. "Fire Intensity, Fire Severity and Burn Severity: A Brief Review and Suggested Usage." *International Journal of Wildland Fire* 18: 116–126. https://doi.org/10.1071/WF07049.

Keizer, J. J., C. O. A. Coelho, R. A. Shakesby, et al. 2005. "The Role of Soil Water Repellency in Overland Flow Generation in Pine and Eucalypt Forest Stands in Coastal Portugal." *Soil Research* 43: 337–349. https://doi.org/10.1071/SR04085.

Keizer, J. J., M. A. S. Martins, S. A. Prats, et al. 2015. "Within-In Flume Sediment Deposition in a Forested Catchment Following Wildfire and Post-Fire Bench Terracing, North-Central Portugal." *Cuadernos de Investigación Geográfica* 41: 149–164. https://doi.org/10.18172/cig.2700.

Larsen, I. J., and L. H. MacDonald. 2007. "Predicting Postfire Sediment Yields at the Hillslope Scale: Testing RUSLE and Disturbed WEPP." *Water Resources Research* 43: W11412. https://doi.org/10.1029/2006WR005560.

Lew, R., M. Dobre, A. Srivastava, et al. 2022. "WEPPcloud: An Online Watershed-Scale Hydrologic Modeling Tool. Part I. Model Description." *Journal of Hydrology* 608: 127603. https://doi.org/10.1016/j.jhydrol.2022.127603.

Litschert, S. E., D. M. Theobald, and T. C. Brown. 2014. "Effects of Climate Change and Wildfire on Soil Loss in the Southern Rockies Ecoregion." *Catena* 118: 206–219. https://doi.org/10.1016/j.catena.2014.01.007.

Loiselle, D., X. Du, D. S. Alessi, K. D. Bladon, and M. Faramarzi. 2020. "Projecting Impacts of Wildfire and Climate Change on Streamflow, Sediment, and Organic Carbon Yields in a Forested Watershed." *Journal of Hydrology* 590: 125403. https://doi.org/10.1016/j.jhydrol.2020.125403.

Lopes, A. R., A. Girona-García, S. Corticeiro, R. Martins, J. J. Keizer, and D. C. S. Vieira. 2021. "What Is Wrong With Post-Fire Soil Erosion Modelling? A Meta-Analysis on Current Approaches, Research Gaps, and Future Directions." *Earth Surface Processes and Landforms* 46: 205–219. https://doi.org/10.1002/esp.5020.

Lutes, D. C., R. E. Keane, J. F. Caratti, et al. 2006. *FIREMON: Fire Effects Monitoring and Inventory System. Gen. Tech. Rep. RMRS-GTR-164*. U.S. Department of Agriculture Forest Service—Rocky Mountain Research Station.

Malvar, M. C., M. A. S. Martins, J. P. Nunes, P. R. Robichaud, and J. J. Keizer. 2013. "Assessing the Role of Pre-Fire Ground Preparation Operations and Soil Water Repellency in Post-Fire Runoff and Inter-Rill Erosion by Repeated Rainfall Simulation Experiments in Portuguese Eucalypt Plantations." *Catena* 108: 69–83. https://doi.org/10.1016/j.catena.2012.11.004.

Malvar, M. C., S. A. Prats, and J. J. Keizer. 2016. "Runoff and Inter-Rill Erosion Affected by Wildfire and Pre-Fire Ploughing in Eucalypt Plantations of North-Central Portugal." *Land Degradation & Development* 27: 1366–1378. https://doi.org/10.1002/ldr.2365.

Malvar, M. C., S. A. Prats, J. P. Nunes, and J. J. Keizer. 2011. "Post-Fire Overland Flow Generation and Inter-Rill Erosion Under Simulated Rainfall in Two Eucalypt Stands in North-Central Portugal." *Environmental Research* 111: 222–236. https://doi.org/10.1016/j.envres.2010.09.003.

Martins, M. A. S., A. I. Machado, D. Serpa, et al. 2013. "Runoff and Inter-Rill Erosion in a Maritime Pine and a Eucalypt Plantation Following Wildfire and Terracing in North-Central Portugal." *Journal of Hydrology and Hydromechanics* 61: 261–268. https://doi.org/10.2478/johh-2013-0033.

Mataix-Solera, J., A. Cerdà, V. Arcenegui, A. Jordán, and L. M. Zavala. 2011. "Fire Effects on Soil Aggregation: A Review." *Earth-Science Reviews* 109: 44–60. https://doi.org/10.1016/j.earscirev.2011.08.002.

McGehee, R., D. Flanagan, and P. Srivastava. 2020. "WEPPCLIFF: A Command-Line Tool to Process Climate Inputs for Soil Loss Models."

Journal of Open Source Software 5, no. 49: 2029. https://doi.org/10.21105/joss.02029.

Mein, R. G., and C. L. Larson. 1973. "Modeling Infiltration During a Steady Rain." *Water Resources Research* 9, no. 2: 384–394. https://doi.org/10.1029/WR009i002p00384.

Meyer, C. 2011. *General Description of the CLIGEN Model and Its History*, 690. USDA-ARS National Soil Erosion Research Laboratory.

Moody, J. A., B. A. Ebel, P. Nyman, D. A. Martin, C. Stoof, and R. McKinley. 2016. "Relations Between Soil Hydraulic Properties and Burn Severity." *International Journal of Wildland Fire* 25: 279–293.

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.

Moody, J. A., J. D. Smith, and B. W. Ragan. 2005. "Critical Shear Stress for Erosion of Cohesive Soils Subjected to Temperatures Typical of Wildfires." *Journal of Geophysical Research: Earth Surface* 110: F01004. https://doi.org/10.1029/2004JF000141.

Moreira, F., D. Ascoli, H. Safford, et al. 2020. "Wildfire Management in Mediterranean-Type Regions: Paradigm Change Needed." *Environmental Research Letters* 15: 11001.

Moreira, F., P. Vaz, F. Catry, and J. S. Silva. 2009. "Regional Variations in Wildfire Susceptibility of Land-Cover Types in Portugal: Implications for Landscape Management to Minimize Fire Hazard." *International Journal of Wildland Fire* 18: 563–574. https://doi.org/10.1071/WF07098.

Morgan, R. P. C. 2001. "A Simple Approach to Soil Loss Prediction: A Revised Morgan–Morgan–Finney Model." *Catena* 44: 305–322. https://doi.org/10.1016/S0341-8162(00)00171-5.

Moussoulis, E., G. Mallinis, N. Koutsias, and I. Zacharias. 2015. "Modelling Surface Runoff to Evaluate the Effects of Wildfires in Multiple Semi-Arid, Shrubland-Dominated Catchments." *Hydrological Processes* 29: 4427–4441. https://doi.org/10.1002/hyp.10509.

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.

Myronidis, D., and G. Arabatzis. 2009. "Evaluation of Greek Post-Fire Erosion Mitigation Policy Through Spatial Analysis." *Polish Journal of Environmental Studies* 18: 865–872.

Mzuku, M., R. Khosla, R. Reich, D. Inman, F. Smith, and L. MacDonald. 2005. "Spatial Variability of Measured Soil Properties Across Site-Specific Management Zones." *Soil Science Society of America Journal* 69: 1572–1579.

Nearing, M. A., L. Deer-Ascough, and J. M. Laflen. 1990. "Sensitivity Analysis of the WEPP Hillslope Profile Erosion Model." *Transactions of ASAE* 33: 839–849.

Neary, D. G., G. J. Gottfried, and P. F. Ffolliott. 2003. "Post-Wildfire Watershed Flood Responses." In *Proceedings of the 2nd International Fire Ecology Conference*, 16–20.

Neris, J., C. Santin, R. Lew, et al. 2021. "Designing Tools to Predict and Mitigate Impacts on Water Quality Following the Australian 2019/2020 Wildfires: Insights From Sydney's Largest Water Supply Catchment." *Integrated Environmental Assessment and Management* 17: 1151–1161. https://doi.org/10.1002/ieam.4406.

Nolan, R. H., P. N. J. Lane, R. G. Benyon, R. A. Bradstock, and P. J. Mitchell. 2014. "Changes in Evapotranspiration Following Wildfire in Resprouting Eucalypt Forests." *Ecohydrology* 7: 1363–1377. https://doi.org/10.1002/eco.1463.

Nunes, J. P., P. Naranjo Quintanilla, J. M. Santos, et al. 2018. "Afforestation, Subsequent Forest Fires and Provision of Hydrological Services: A Model-Based Analysis for a Mediterranean Mountainous Catchment." *Land Degradation & Development* 29: 776–788. https://doi.org/10.1002/ldr.2776.

Parente, J., A. Girona-García, A. R. Lopes, J. J. Keizer, and D. C. S. Vieira. 2021. "Post-Fire Soil Erosion Risk in Portugal–Prediction, Validation and Uncertainties of a Nation-Wide MMF Application." *Scientific Reports*. https://doi.org/10.21203/rs.3.rs-776845/v1.

Parente, J., A. Girona-García, A. R. Lopes, et al. 2022. "Prediction, Validation, and Uncertainties of a Nation-Wide Post-Fire Soil Erosion Risk Assessment in Portugal." *Scientific Reports* 12: 2945. https://doi.org/10.1038/s41598-022-07066-x.

Parsons, A., P. R. Robichaud, S. A. Lewis, C. Napper, and J. T. Clark. 2010. *Field Guide for Mapping Post-Fire Soil Burn Severity*. Citeseer.

Pausas, J. G., and S. Fernández-Muñoz. 2012. "Fire Regime Changes in the Western Mediterranean Basin: From Fuel-Limited to Drought-Driven Fire Regime." *Climatic Change* 110: 215–226. https://doi.org/10.1007/s10584-011-0060-6.

Pereira, V., and E. A. FitzPatrick. 1995. "Cambisols and Related Soils in North-Central Portugal: Their Genesis and Classification." *Geoderma* 66: 185–212. https://doi.org/10.1016/0016-7061(94)00076-M.

Pradhan, N. R., and I. Floyd. 2021. "Event Based Post-Fire Hydrological Modeling of the Upper Arroyo Seco Watershed in Southern California." *Water* 13: 2303. https://doi.org/10.3390/w13162303.

Prats, S. A., J. W. Wagenbrenner, M. A. S. Martins, M. C. Malvar, and J. J. Keizer. 2016. "Mid-Term and Scaling Effects of Forest Residue Mulching on Post-Fire Runoff and Soil Erosion." *Science of the Total Environment* 573: 1242–1254. https://doi.org/10.1016/j.scitotenv.2016.04.064.

R Core Team. 2021. *R: A Language and Environment for Statistical Computing*. R Foundation for Statistical Computing.

Renard, K. G., G. R. Foster, G. A. Weesies, and J. P. Porter. 1991. "RUSLE: Revised Universal Soil Loss Equation." *Journal of Soil and Water Conservation* 46: 30–33.

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.

Robichaud, P. R. 2000. "Fire Effects on Infiltration Rates After Prescribed Fire in Northern Rocky Mountain Forests, USA." *Journal of Hydrology* 231: 220–229. https://doi.org/10.1016/S0022-1694(00)00196-7.

Robichaud, P. R., S. A. Lewis, R. E. Brown, E. D. Bone, and E. S. Brooks. 2020. "Evaluating Post-Wildfire Logging-Slash Cover Treatment to Reduce Hillslope Erosion After Salvage Logging Using Ground Measurements and Remote Sensing." *Hydrological Processes* 34: 4431–4445.

Sánchez-Murillo, R., E. S. Brooks, W. J. Elliot, E. Gazel, and J. Boll. 2015. "Baseflow Recession Analysis in the Inland Pacific Northwest of the United States." *Hydrogeology Journal* 23: 287–303. https://doi.org/10.1007/s10040-014-1191-4.

San-Miguel-Ayanz, J., T. Durrant, R. Boca, et al. 2022. *Forest Fires in Europe, Middle East and North Africa 2021*. Publications Office of the European Union. https://doi.org/10.2760/34094.

Santín, C., and S. H. Doerr. 2016. "Fire Effects on Soils: The Human Dimension." *Philosophical Transactions of the Royal Society, B: Biological Sciences* 371: 20150171. https://doi.org/10.1098/rstb.2015.0171.

Santos, J. M., F. G. A. Verheijen, F. Tavares Wahren, et al. 2016. "Soil Water Repellency Dynamics in Pine and Eucalypt Plantations in Portugal—A High-Resolution Time Series." *Land Degradation & Development* 27: 1334–1343. https://doi.org/10.1002/ldr.2251.

Semenova, O., L. Lebedeva, N. Volkova, et al. 2015. "Detecting Immediate Wildfire Impact on Runoff in a Poorly-Gauged Mountainous

Permafrost Basin." *Hydrological Sciences Journal* 60: 1225–1241. https://doi.org/10.1080/02626667.2014.959960.

Serpa, D., R. V. Ferreira, A. I. Machado, M. A. Cerqueira, and J. J. Keizer. 2020. "Mid-Term Post-Fire Losses of Nitrogen and Phosphorus by Overland Flow in Two Contrasting Eucalypt Stands in North-Central Portugal." *Science of the Total Environment* 705: 135843. https://doi.org/10.1016/j.scitotenv.2019.135843.

Shakesby, R. A., C. d. O. A. Coelho, A. D. Ferreira, J. P. Terry, and R. P. D. Walsh. 1994. "Fire, Post-Burn Land Management Practice and Soil Erosion Response Curves in Eucalyptus and Pine Forests, North-Central Portugal." In *Soil Erosion Degradation as a Consequence of Forest Fires*, edited by M. Sala and J. L. Rubio, 111–132. Geoforma.

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.

Silva, J. S., F. Moreira, P. Vaz, F. Catry, and P. Godinho-Ferreira. 2009. "Assessing the Relative Fire Proneness of Different Forest Types in Portugal." *Plant Biosystems* 143: 597–608. https://doi.org/10.1080/11263500903233250.

Silva, J. S., P. Vaz, F. Moreira, F. Catry, and F. C. Rego. 2011. "Wildfires as a Major Driver of Landscape Dynamics in Three Fire-Prone Areas of Portugal." *Landscape and Urban Planning* 101: 349–358. https://doi.org/10.1016/j.landurbplan.2011.03.001.

Smith, H. G., G. J. Sheridan, P. N. J. Lane, P. Nyman, and S. Haydon. 2011. "Wildfire Effects on Water Quality in Forest Catchments: A Review With Implications for Water Supply." *Journal of Hydrology* 396: 170–192. https://doi.org/10.1016/j.jhydrol.2010.10.043.

SNIRH. 2020. Serviço Nacional de Informação Sobre Recursos Hídricos. https://snirh.apambiente.pt/.

Soetaert, K., and T. Petzoldt. 2010. "Inverse Modelling, Sensitivity and Monte Carlo Analysis in R Using Package FME." *Journal of Statistical Software* 33: 1–28.

Srivastava, A., M. Dobre, J. Q. Wu, et al. 2013. "Modifying WEPP to Improve Streamflow Simulation in a Pacific Northwest Watershed." *Transactions of the ASABE* 56: 603–611.

Srivastava, A., J. Q. Wu, W. J. Elliot, E. S. Brooks, and D. C. Flanagan. 2018. "A Simulation Study to Estimate Effects of Wildfire and Forest Management on Hydrology and Sediment in a Forested Watershed, Northwestern U.S." *Transactions of the ASABE* 61: 1579–1601. https://doi.org/10.13031/trans.12326.

Thomas, G., V. Rosalie, C. Olivier, D. G. Anna Maria, and L. P. Antonio. 2021. "Modelling Forest Fire and Firebreak Scenarios in a Mediterranean Mountainous Catchment: Impacts on Sediment Loads." *Journal of Environmental Management* 289: 112497. https://doi.org/10.1016/j.jenvman.2021.112497.

Turco, M., J. Bedia, F. Di Liberto, et al. 2016. "Decreasing Fires in Mediterranean Europe." *PLoS One* 11: e0150663. https://doi.org/10.1371/journal.pone.0150663.

Viedma, O., N. Moity, and J. M. Moreno. 2015. "Changes in Landscape Fire-Hazard During the Second Half of the 20th Century: Agriculture Abandonment and the Changing Role of Driving Factors." *Agriculture, Ecosystems and Environment* 207: 126–140. https://doi.org/10.1016/j.agee.2015.04.011.

Vieira, D. C. S., M. Basso, J. P. Nunes, J. J. Keizer, and J. E. M. Baartman. 2022. "Event-Based Quickflow Simulation With OpenLISEM in a Burned Mediterranean Forest Catchment." *International Journal of Wildland Fire* 31: 670–683. https://doi.org/10.1071/WF21005.

Vieira, D. C. S., C. Fernández, J. A. Vega, and J. J. Keizer. 2015. "Does Soil Burn Severity Affect the Post-Fire Runoff and Interrill Erosion Response? A Review Based on Meta-Analysis of Field Rainfall Simulation Data." *Journal of Hydrology* 523: 452–464. https://doi.org/10.1016/j.jhydrol.2015.01.071.

Vieira, D. C. S., M. C. Malvar, C. Fernández, D. Serpa, and J. J. Keizer. 2016. "Annual Runoff and Erosion in a Recently Burn Mediterranean Forest – The Effects of Plowing and Time-Since-Fire." *Geomorphology* 270: 172–183. https://doi.org/10.1016/j.geomorph.2016.06.042.

Wagenbrenner, J. W., B. A. Ebel, K. D. Bladon, and A. M. Kinoshita. 2021. "Post-Wildfire Hydrologic Recovery in Mediterranean Climates: A Systematic Review and Case Study to Identify Current Knowledge and Opportunities." *Journal of Hydrology* 602: 126772. https://doi.org/10.1016/j.jhydrol.2021.126772.

Wang, L., J. Q. Wu, W. J. Elliot, et al. 2010. "Implementation of Channel-Routing Routines in the Water Erosion Prediction Project (WEPP) Model." In *Proceedings of the 2009 SIAM Conference on "Mathematics for Industry" the Art of "Mathematics for Industry"*, 120–127. SIAM.

Wang, Y., M. Shao, Z. Liu, and C. Zhang. 2014. "Prediction of Bulk Density of Soils in the Loess Plateau Region of China." *Surveys in Geophysics* 35: 395–413. https://doi.org/10.1007/s10712-013-9249-8.

Wischmeier, W. H., and D. D. Smith. 1978. *Predicting Rainfall Erosion Losses: A Guide to Conservation Planning*. Department of Agriculture, Science and Education Administration.

Wu, J., J. E. M. Baartman, and J. P. Nunes. 2021. "Testing the Impacts of Wildfire on Hydrological and Sediment Response Using the OpenLISEM Model. Part 2: Analyzing the Effects of Storm Return Period and Extreme Events." *Catena* 207: 105620. https://doi.org/10.1016/j.catena.2021.105620.

Wu, J., J. P. Nunes, J. E. M. Baartman, and C. A. Faúndez Urbina. 2021. "Testing the Impacts of Wildfire on Hydrological and Sediment Response Using the OpenLISEM Model. Part 1: Calibration and Evaluation for a Burned Mediterranean Forest Catchment." *Catena* 207: 105658. https://doi.org/10.1016/j.catena.2021.105658.

Yalin, M. S. 1963. "An Expression for Bed-Load Transportation." *Journal of the Hydraulics Division* 89: 221–250.

Supporting Information

Additional supporting information can be found online in the Supporting Information section.