



## Vegetation, ground cover, soil, rainfall simulation, and overland flow experiments before and after tree removal in woodland-encroached sagebrush steppe: the hydrology component of the Sagebrush Steppe Treatment Evaluation Project (SageSTEP)

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**Abstract.** Rainfall simulation and overland-flow experiments enhance understanding of surface hydrology and erosion processes, quantify runoff and erosion rates, and provide valuable data for developing and testing predictive models. We present a unique dataset (1021 experimental plots) of rainfall simulation (1300 plot runs) and overland flow (838 plot runs) experimental plot data paired with measures of vegetation, ground cover, and surface soil physical properties spanning point to hillslope scales. The experimental data were collected at three sloping sagebrush (*Artemisia* spp.) sites in the Great Basin, USA, each subjected to woodland-encroachment and with conditions representative of intact wooded-shrublands and 1-9 yr following wildfire, prescribed fire, and/or tree cutting and shredding tree-removal treatments. The methodologies applied in data collection and the cross-scale experimental design uniquely provide scale-dependent, separate measures of interrill (rainsplash and sheetflow processes) and concentrated overland-flow runoff and erosion rates along with collective rates for these same processes combined over the patch scale (tens of meters). The dataset provides a valuable source for developing, assessing, and calibrating/validating runoff and erosion models applicable to diverse plant community dynamics with varying vegetation, ground cover, and surface soil conditions. The experimental data advance understanding and quantification of surface hydrologic and erosion processes for the research domain and potentially for other patchy-vegetated rangeland landscapes elsewhere. Lastly, the unique nature of repeated measures spanning numerous treatments and time scales delivers a valuable dataset for examining long-term landscape vegetation, soil, hydrology, and erosion responses to various management actions, land use, and natural disturbances. The dataset is available from the National Agricultural Library at <https://data.nal.usda.gov/search/type/dataset> (DOI: <https://doi.org/10.15482/USDA.ADC/1504518>; Pierson et al., 2019).

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rainfall simulation; rangeland hydrology; runoff; sagebrush steppe; tree cutting; tree shredding;  
45 tree removal; woody plant encroachment

## 1 Introduction

Rangelands are one of the most common occurring sparsely-vegetated wildland landscapes  
50 around the world. These lands cover about half of the world's land surface and about 31% (> 300  
million ha) of the land surface in the US (Havstad et al., 2009). The patchy vegetation structure  
typical to these water-limited landscapes regulates connectivity of runoff and erosion sources and  
processes and thus controls hillslope scale runoff and sediment transport (Pierson et al., 1994;  
Wainwright et al., 2000; Wilcox et al., 2003; Ludwig et al., 2005). Runoff and erosion in isolated  
55 bare patches on well-vegetated rangelands occur as splash-sheet (rainsplash and sheetflow)  
processes. Sediment entrained by raindrops and shallow sheetflow in bare patches typically  
moves a limited distance downslope before deposition immediately upslope of and within  
vegetated areas (Emmett, 1970; Reid et al., 1999; Puigdefábregas, 2005; Pierson and Williams,  
2016). Disturbances such as intensive land use, plant community transitions, and wildfire can  
60 alter this resource-conserving vegetation structure and thereby facilitate increases in runoff and  
soil loss through enhanced connectivity of overland flow and sediment sources during rainfall  
events (Davenport et al., 1998; Wilcox et al., 2003; Pierson et al., 2011; Williams et al., 2014a,  
2014b, 2018a). The negative ramifications of woody plant encroachment and wildfire have been  
extensively studied on rangelands around the World and have advanced understanding of runoff  
65 and erosion processes for these commonly occurring ecosystems (Schlesinger et al., 1990;  
Wainwright et al., 2000; Shakesby and Doerr, 2006; Shakesby, 2011; Pierson and Williams,  
2016). Recent widespread plant community transitions and trends in wildfire activity and  
associated amplified runoff and erosion rates spanning rangelands to dry forests throughout the  
western US (Williams et al., 2014a) and elsewhere (Shakesby, 2011) underpin a need for  
70 compiling data sources that further contribute to process understanding and improved  
parametrization of rangeland hydrology and erosion predictive technologies.

Sagebrush rangelands in the western US are an extensive (> 500 000 km<sup>2</sup>) and important  
vegetation type that have undergone substantial degradation associated with encroachment by  
pinyon (*Pinus* spp.) and juniper (*Juniperus* spp.) woodlands, invasions of fire-prone annual  
75 cheatgrass (*Bromus tectorum* L.), and altered fire regimes (Davies et al., 2011; Miller et al.,  
2011, 2019). Pinyon and juniper woodland encroachment of sagebrush vegetation can have  
negative hydrologic impacts (Miller et al., 2005; Petersen and Stringham, 2008; Pierson et al.,  
2007; Petersen et al., 2009; Pierson et al., 2010; Williams et al., 2014a, 2018a). Encroaching  
trees outcompete understory sagebrush and herbaceous vegetation over time and thereby increase  
80 bare ground and connectivity of runoff and sediment sources (Bates et al., 2000; Miller et al.,  
2000; Bates et al., 2005; Petersen et al., 2009; Pierson et al., 2010; Roundy et al., 2017).  
Extensive well-connected bare patches in the later stages of woodland encroachment propagate  
broad-scale runoff generation and soil loss during storms events. Runoff from splash-sheet  
processes during these events combine along hillslopes to form concentrated overland flow with  
85 high sediment detachment rates and ample transport capacity (Pierson et al., 2010; Williams et



al., 2014a, 2016a). Amplified soil loss over time perpetuates a woodland ecological state and long-term site degradation (Petersen et al., 2009). Land managers commonly employ various mechanical treatments and prescribed and natural fires to reduce tree cover and re-establish sagebrush vegetation and associated resource-conserving hydrologic function (Bates et al., 2000, 2005; Pierson et al., 2007; Bates et al., 2014; Miller et al., 2014; Roundy et al., 2014; Bates et al., 90 2017; Williams et al., 2018a). However, managers are challenged with predicting potential vegetation and ecohydrologic effects of tree removal across diverse woodland landscapes and with determining the appropriate type and timing of available treatment options. Invasions of fire-prone cheatgrass following prescribed and natural fires are particularly problematic. This annual grass commonly invades open patches on woodlands at lower elevations or on warmer 95 sites, subsequently increases wildfire frequency, and potentially promotes long-term loss of surface soil and nutrients associated with recurrent burning and fire-induced runoff events (Pierson et al., 2011; Wilcox et al., 2012; Williams et al., 2014a).

Land managers around the World need improved understanding of runoff and erosion 100 processes for the various disturbances common to rangelands and need improved tools for predicting responses to and making decisions on a host of management alternatives. Managers rely on local understanding and conceptual and quantitative science-based models to aid management decisions. Local knowledge is often limited and data necessary to populate conceptual and science-based models are likewise limited given vast rangeland domain. 105 Vegetation and ground cover inventories and field-based experiments are primary resources for informing conceptual models (Petersen et al., 2009; Chambers et al., 2014; Williams et al., 2016a; Chambers et al., 2017). Rainfall simulation and overland flow experiments likewise provide data for developing, evaluating, and enhancing quantitative hydrology and erosion predictive technologies (Flanagan and Nearing, 1995; Robichaud et al., 2007; Wei et al., 2009; 110 Nearing et al., 2011; Al-Hamdan et al., 2012a, 2012b, 2013, 2015, 2017; Hernandez et al., 2017). To this need, we present an ecohydrologic dataset containing 1021 experimental plots. The dataset consists of rainfall simulation (1300 plot runs, 0.5 m<sup>2</sup> to 13 m<sup>2</sup> scales) and overland flow (838 plot runs, ~9 m<sup>2</sup> scale) experimental data with paired measures of vegetation and ground cover, and surface soil physical properties spanning point to hillslope scales (Pierson et al., 115 2019). The experimental data were collected at multiple sagebrush rangelands in the Great Basin, USA, each with woodland encroachment and sampled in untreated conditions and following fire and mechanical tree-removal treatments over a 10 yr period. The dataset therefore represents diverse vegetation, ground surface, and surface soil conditions common to undisturbed and disturbed rangelands in the western US and elsewhere. The resulting dataset contributes to both 120 process-based knowledge and provision of data for populating, evaluating, and improving conceptual and quantitative hydrology and erosion models.

## 2 Study Sites and Experimental Design

125 A series of vegetation, soils, rainfall simulation (Figures 1 and 2a-2c), and overland flow experiments (Figure 2d-2e) were completed at three pinyon and juniper woodlands historically vegetated as sagebrush shrublands. The study sites were selected from a network of sites as part of a larger study on the ecological impacts of invasive species and woodland encroachment into



130 sagebrush ecosystems and the effects of sagebrush restoration practices, the Sagebrush Steppe  
Treatment Evaluation Project (SageSTEP, [www.sagestep.org](http://www.sagestep.org)). Study site climate, physical, and  
vegetation attributes are provided in Table 1. The data were collected in years 2006-2015, with  
sampling years varying by site and by treatment area within each site (see Table 2). Vegetation  
and ground cover were patchy and sparse at the sites when the study began in 2006 (Table 1).  
135 Tree-removal treatments (prescribed fire, tree cutting, tree shredding [bullhog]) were applied at  
the Marking Corral and Onaqui sites in 2006 (late summer and autumn) to evaluate effectiveness  
of pinyon and juniper removal in re-establishing sagebrush vegetation and ground cover,  
improving hydrologic function, and reducing erosion rates. The Castlehead site burned by  
wildfire in summer 2007 before tree-removal treatments could be applied, and, wildfire was  
assessed as a prescribed natural-fire tree-removal treatment for that site. At all three sites, a cut-  
140 tree (downed tree) treatment was placed across a subset of large-rainfall and overland-flow plot  
bases (Figure 2d-2e) within the various treatments to measure effects of downed trees on surface  
hydrology and erosion processes. This additional treatment was applied in 2007 and 2015 to  
some plots in cut treatment areas at Marking Corral and Onaqui and in 2008 and 2009 in  
unburned areas at Castlehead. Treatment applications and descriptions and the study  
145 experimental design are explained in earlier papers by Pierson et al. (2010, 2013, 2014, 2015)  
and by Williams et al. (2014a, 2018b, 2019a) and all treatments for each site each year are  
provided in Table 2.

A suite of biological and physical attributes at each site were measured at point, small-  
rainfall plot (0.5 m<sup>2</sup>), overland-flow plot (~9 m<sup>2</sup>), large-rainfall plot (13 m<sup>2</sup>), and hillslope plot  
150 (990 m<sup>2</sup>) scales. Soil bulk density of the near-surface (0-5 cm depth) was sampled as a point  
measure in interspace microsites between plants, shrub coppice microsites underneath shrub  
canopies, and tree coppice microsites underneath three canopies. The bulk density sampling was  
conducted by compliant cavity method within all treatment areas 1-2 yr after respective  
treatments. Surface soil texture was quantified as a point measure using grab samples (0-2 cm  
155 depth) from interspace, shrub coppice, and tree coppice microsites within all treatment areas at  
Marking and Onaqui in 2006 prior to treatments and within unburned and burned treatment areas  
at Castlehead in 2008. Vegetation and ground cover were measured at small-rainfall, large-  
rainfall, and overland-flow plot scales and at the hillslope scale pre- and post-treatment in all  
treatment areas at Marking Corral and Onaqui and in unburned and burned treatment areas at  
160 Castlehead. Vegetation and ground cover measures at the hillslope scale (site characterization  
plots) were conducted to describe site-level cover conditions prior to and over time after  
treatment. Site characterization plots were installed and sampled prior to treatment (2006) in all  
treatment areas at Marking Corral and Onaqui and were re-sampled 1 yr (2007) and 9 yr (2015)  
after treatment. Castlehead site characterization plots were installed and sampled in unburned  
165 and burned areas 1 yr after the fire (2008) and were re-sampled the 2<sup>nd</sup> year post-fire (2009).  
Vegetation and ground cover measures on rainfall simulation and overland flow plots were used  
to evaluate resisting and driving forces on surface hydrology and erosion processes and to  
quantify treatment effects on cover components at those plot scales. Sampling of vegetation and  
ground cover on rainfall simulation and overland flow plots in untreated areas (control and  
170 unburned) and treated areas varied by site and year as described in Table 2.



Rainfall simulations and overland flow experiments were employed at the different plot scales to quantify specific scale-dependent runoff and erosion processes (Pierson et al., 2010; Williams et al., 2014a). Small-plot rainfall simulations (Figure 1) were applied to quantify runoff and erosion by splash-sheet processes. Each small rainfall plot was installed, as described by  
175 Pierson et al. (2010) and Williams et al. (2014a), to occur on either a tree coppice, shrub coppice, or interspace microsite (Figure 1b-1e). Small plots at Marking Corral and Onaqui were installed and sampled in control and all other treatment areas in 2006 before application of the tree-removal treatments and were left in place for subsequent sampling 1 yr (2007), 2 yr (2008), and 9 yr (2015) after treatment. Small plots at Castlehead were installed and sampled in unburned  
180 and burned areas 1 yr after the fire (2008) and left in place for subsequent sampling the 2<sup>nd</sup> year after fire (2009). Large-plot rainfall simulations (Figure 2a-2b) were used to quantify runoff and erosion from combined splash-sheet and concentrated overland flow processes. Each plot was installed, as described by Pierson et al. (2010) and Williams et al. (2014a), on either a tree zone (tree coppice and area just outside tree canopy drip line) or a shrub-interspace zone (intercanopy area between tree canopies) inclusive of shrub coppice and interspace microsities (Figure 2).  
185 Large plots at Marking Corral and Onaqui were installed and sampled in all treatment areas in 2006 immediately before treatment application (controls) and were extracted following sampling. New plots were installed and sampled in treatment areas at Marking Corral and Onaqui in 2007, 1 yr post-treatment, and were then extracted. Large rainfall plots at Castlehead  
190 were installed and sampled in unburned and burned areas in 2008, 1 yr after the fire, and were then extracted. Overland flow simulations (Figure 2d-de) were conducted on large rainfall plots (Figure 2a-2c) at Marking Corral and Onaqui in 2006 and 2007 immediately following respective rainfall simulations. Overland flow simulations were conducted in control and treated areas at those sites in 2008, but those plots were not subjected to rainfall simulation. Castlehead  
195 overland flow simulations in 2008, 1 yr post-fire, were run on large rainfall simulation plots following rainfall simulations and, in 2009, 2 yr post-fire, were run on newly installed plots without rainfall simulations. Overland flow experiments conducted on large-rainfall simulation plots had borders on all sides and contained a collection trough for runoff measurement at the plot base (Figure 2c; Pierson et al., 2010, 2013, 2015; Williams et al., 2014a). Overland flow  
200 simulations run independent of rainfall-simulation experiments were conducted on borderless plots, but contained a runoff collection trough at the downslope plot base (Figure 2d-2e; Pierson et al., 2013, 2015; Williams et al., 2014a, 2018b, 2019a).

### 3 Field Methods

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#### 3.1 Hillslope scale site characterization plots

Understory vegetation and ground cover and overstory tree cover at the hillslope scale at each site were sampled on 30 m × 33 m site characterization plots using a suite of line-point and belt  
210 transect methods and various tree measures (see Pierson et al., 2010; Williams et al., 2014a). Foliar and ground cover on each site characterization plot were recorded for 60 points (50 cm spacing) along each of five line-point transects (30 m in length; spaced 5-8 m apart) for a total of 300 sample points per plot. Percent cover by each sampled cover type was derived for each plot



as the number of respective cover type hits divided by the total number of points sampled.  
215 Multiple canopy layers were possible and therefore the total foliar cover across all sampled cover  
types potentially exceeded 100%. The number of live tree seedlings 5-50 cm height and shrubs  
exceeding 5-cm height were quantified along three belt transects on each plot. Each of the three  
belt transects on each plot were centered along a foliar/ground cover line-point transect, sized 2  
220 m wide  $\times$  30 m long, and spaced 6 m apart. Shrub and tree seedling densities were calculated for  
each plot as the total number of respective individuals tallied along the three belt transects  
divided by total belt transect area (180 m<sup>2</sup>). The number of live trees  $>$  0.5 m in height was  
quantified for each plot, and tree height and minimum and maximum crown diameters were  
measured for each live tree. A crown radius for each live tree was derived as one-half the  
225 average of measured minimum and maximum crown diameters. Individual tree crown area (tree  
cover) was calculated as equivalent to the area of a circle, derived with the respective crown  
radius. Total tree cover for each plot was quantified as the sum of measured tree cover values on  
the plot.

### 230 3.2 Small-rainfall simulation plots and experiments

Foliar cover, ground cover, and ground surface roughness on all small-rainfall plots were  
quantified using point frame methods explained in Pierson et al. (2010). Foliar and ground cover  
on each plot were sampled at 15 points spaced 5 cm apart along each of seven transects spaced  
10 cm apart and oriented parallel to hillslope contour (105 sample points per plot). Percent cover  
235 for each cover type sampled on each plot was derived from the frequency of respective cover  
type hits divided by the total number of points sampled. Multiple canopy layers were allowed  
and therefore total foliar cover across all cover types potentially exceeded 100%. A relative  
ground surface height at each sample point on each plot was determined by metal ruler as the  
distance between the ground surface and a level-line (top of point frame). Ground surface  
240 roughness for each plot was then derived as the mean of standard deviations of ground surface  
heights for each of the transects sampled on the respective plot. Litter depth on each plot was  
measured along the outside edge of the two plot borders located perpendicular to the hillslope  
contour. Measurements were made to the nearest 1 mm using a metal ruler at four evenly spaced  
points (15-cm apart) along the two plot borders. An average litter depth was derived for each plot  
245 as the averaged of the eight litter depth measures.

Soil water repellency of the mineral soil surface and at depths near the mineral soil  
surface (0-5 cm depths) was measured immediately adjacent ( $\sim$  50 cm away) to each small-  
rainfall plot immediately before rainfall simulation using the water drop penetration time  
(WDPT) method (see Pierson et al., 2010). Litter and ash cover were carefully removed from the  
250 mineral soil surface prior to application of the WDPT. Eight water drops ( $\sim$  3-cm spacing) were  
then placed on the mineral soil surface and the time required for infiltration of each drop was  
recorded up to a 300-s maximum. The WDPT was then repeated at 1-cm soil depth increments  
until 5-cm soil depth was reached. For each sampled depth, 1 cm of soil was excavated  
immediately underneath the previously sampled area and the WDPT procedure was repeated  
255 with eight drops. A mean WDPT for each sampled soil depth on each plot was recorded as the  
average of the eight WDPT (s) samples at the respective depth. Soils were classified as wettable



where mean WDPT < 5 s, slightly water repellent where mean WDPT ranged 5 s to 60 s, and strongly water repellent where mean WDPT > 60 s.

260 Surface soil moisture and aggregate stability were also sampled for each small-rainfall plot prior to rainfall simulations. Soil samples were collected at 0-5 cm depth immediately adjacent to each small rainfall plot and were subsequently analyzed in the laboratory for gravimetric soil water content. Some samples were excluded from the dataset due to poor sealing of soil cans in the field. Aggregate stability of the surface soil on each plot was determined using a modified sieve test on six soil peds approximately 2-3 mm thick and 6-8 mm in diameter (see  
265 Pierson et al., 2010). Each soil ped sampled on each plot was assigned to one of the following classes, as defined by Herrick et al. (2005): (1) > 10% stable aggregates, 50% structural integrity lost within 5 s, (2) > 10% stable aggregates, 50% structural integrity lost within 5-30 s, (3) > 10% stable aggregates, 50% structural integrity lost within 30-300 s, (4) 10-25% stable aggregates, (5) 25-75% stable aggregates, or (6) 75-100% stable aggregates. An average  
270 aggregate stability was derived for each plot as the arithmetic average of the classes assigned to the six aggregate samples for the respective plot.

Rainfall was applied to small-rainfall plots at approximate intensities of 64 mm h<sup>-1</sup> (dry run) and 102 mm h<sup>-1</sup> (wet run) for 45 min as explained in Pierson et al. (2010). The dry run was applied to dry antecedent soil conditions, and the wet run was applied to wet soil conditions, ~  
275 30 min after the dry run. Rainfall was applied to small-rainfall plots by a Meyer and Harmon-type portable oscillating-arm rainfall simulator with 80-100 Veejet nozzles (Figure 1a; Meyer and Harmon, 1979; Pierson et al. 2010, 2013, 2014; Williams et al., 2014a, 2018b, 2019a). The applied rainfall kinetic energy (200 kJ ha<sup>-1</sup> mm<sup>-1</sup>) and raindrop size (2 mm) were within approximately 70 kJ ha<sup>-1</sup> mm<sup>-1</sup> and 1 mm respectively of values reported for natural convective  
280 rainfall (Meyer and Harmon, 1979). Rainfall amount applied to each plot during rainfall simulation was estimated by integrating a pan catch of a 5-min calibration run prior to each rainfall simulation plot run. Total rainfall amount was estimated on plots where debris and/or vegetation prevented placement of calibration pans. In such cases, the estimated rainfall amount was derived as the average of all calibration runs for the respective simulation date. Timed plot  
285 runoff samples were collected at 1-3-min intervals throughout each 45-min rainfall simulation and were subsequently analyzed in the laboratory for runoff volume and sediment concentration. Cumulative runoff and sediment amounts were obtained for each runoff sample by weighing the sample before and after drying at 105°C. A mean runoff rate (mm h<sup>-1</sup> and L min<sup>-1</sup>) was derived for each sample interval as the interval runoff divided by the interval time. Sediment discharge (g  
290 s<sup>-1</sup>) for each sample interval was calculated as the cumulative sediment for the sample interval divided by the interval time. Sediment concentration for each sample interval was obtained by dividing cumulative sediment by cumulative runoff (g L<sup>-1</sup>). Some field samples were discarded from the final dataset because of laboratory errors or various issues noted on field datasheets (i.e., spillage, bottle overrun, etc.).

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### 3.3 Large-rainfall simulation plots and experiments

Vegetation and ground cover were measured on large-rainfall simulation plots using line-point methods as described by Pierson et al. (2010) and Williams et al. (2014a). Foliar cover and



300 ground cover on large-rainfall plots were recorded for 59 points with 10-cm spacing along each  
of five transects (6 m long, spaced 40 cm apart) oriented perpendicular to the hillslope contour,  
295 sample points per plot. The percentage cover by each sampled cover type for each plot was  
derived as the number of point contacts or hits for each respective life form divided by the total  
number of points sampled on the respective plot. Multiple canopy layers were allowed and  
305 therefore total foliar cover across all sampled cover types potentially exceeded 100%. Cut trees  
placed on a subset of rainfall simulation plots (see experimental design above) were excluded  
from foliar and ground cover measurements. However, various attributes of downed trees (i.e.,  
length [height], crown width, etc.) were measured and are reported. Ground surface roughness  
for each plot was calculated as the average of the standard deviations of ground surface heights  
310 measured across the line-point cover transects. The relative ground-surface height at each sample  
point was calculated as the distance between a survey transit level-line above the point and the  
ground surface. Distances in excess of 20 cm between plant canopies (canopy gaps) and plant  
bases (basal gaps) were measured along each of the line-point transects on each plot. Average  
canopy and basal gap sizes were calculated for each plot as the mean of all respective gaps  
315 measured in excess of 20 cm. Additionally, maximum canopy and basal gap sizes were  
calculated for each plot as the maximum of all respective gaps measured in excess of 20 cm.  
Percentages of canopy gaps and basal gaps representing 50-cm incremental gap classes (e.g., 51-  
100 cm, 101-150 cm, etc.) were derived for each transect and averaged across the transects on  
each plot to determine gap-class plot means.

320 Rainfall was applied to pairs of large-rainfall plots (Figure 2a-2b) at the same dry-run and  
wet-run target rates and sequence and durations as described above for small-rainfall plots  
(Pierson et al., 2010; Williams et al., 2014a). Each paired-rainfall simulation was run with a  
Colorado State University (CSU) type rainfall simulator (Figure 2a-2b; Holland, 1969). The  
CSU-type design delivers rainfall energy at approximately 70% of that for a natural convective  
325 rainfall event and produces rainfall drop diameters within approximately 1 mm of natural rainfall  
(Holland, 1969; Neff, 1979). The applied simulator design consists of seven stationary  
sprinklers evenly spaced along each of the outermost borders of the respective rainfall-plot pair,  
with each sprinkler elevated 3.05 m above the ground surface. Total rainfall applied to large-  
rainfall plots was quantified from the average of six plastic rainfall depth gages organized in a  
330 uniform grid within each plot. Runoff from direct rainfall on the large-plot collection troughs  
(trough catch, Figure 2b) was quantified by sampling collection trough runoff before plot-  
generated runoff occurred. Once plot runoff occurred, timed samples of runoff were collected at  
1-3-min intervals throughout each 45-min simulation run and were subsequently analyzed in the  
laboratory for runoff volume and sediment concentration as with small-plot rainfall simulation  
335 samples. Sample weights were adjusted to appropriately account for trough catch, as described  
by Pierson et al., 2010. Some field samples were discarded from the final dataset because of  
laboratory errors or various issues noted on field datasheets (i.e., spillage, bottle overrun, etc.).  
Runoff and erosion rates were determined consistent with methods for small-plot rainfall  
simulations.

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### 3.4 Overland-flow simulation plots and experiments

345 Vegetation and ground cover on overland-flow plots were measured using methods consistent  
with those on large-rainfall simulation plots. For overland-flow plots that underwent rainfall  
simulation, foliar and ground cover measures were derived from the large-rainfall plot line-point  
transect data, but were restricted to the lower 4 m of the respective plots. Foliar and ground cover  
on overland-flow plots not subjected to rainfall simulations were recorded at 24 points with 20-  
350 cm spacing, along each of nine line-point transects (4.6 m in length, spaced 20 cm apart) oriented  
perpendicular to the hillslope contour, for a total of 216 points per plot. Percentage cover for  
each cover type sampled on each plot was derived from the number of point contacts or hits for  
each respective cover type divided by the total number of points sampled within the plot. As on  
large-rainfall plots, total foliar cover across all cover types potentially exceeded 100% given  
355 multiple canopy were allowed. Cut trees placed on a subset of overland-flow plots (see  
experimental design above) were excluded from foliar and ground cover measurements.  
However, various attributes of downed trees (i.e., length [height], crown width, etc.) were  
measured and are reported. The ground surface roughness for each overland-flow plot was  
calculated as the average of the standard deviations of the ground surface heights across the  
360 foliar/ground cover line-point transects. The relative ground-surface height at each cover sample  
point was calculated as the distance between a survey transit level line above the respective  
sample point and the ground surface. Canopy and basal gaps exceeding 20 cm on overland-flow  
plots were recorded along each line-point transect. Average and maximum canopy and basal  
gaps were derived consistent with methods for large-rainfall simulation plots. Percentages of  
365 canopy and basal gaps representing 50-cm incremental gap classes (e.g., 51-100 cm, 101-150  
cm, etc.) were derived for each transect and averaged across the transects on each plot to  
determine gap-class plot means, similar as on large-rainfall plots.

Datalogger-controlled flow regulators (see Pierson et al., 2010, 2013, 2015; Williams et  
al., 2014a, 2018b, 2019a) were used to apply concentrated flow release rates of 15, 30, and 45 L  
370  $\text{min}^{-1}$  to each overland-flow plot. Flow was routed into and through a metal box filled with  
Styrofoam pellets and was released through a 10-cm wide mesh-screened opening at the box  
base (Figure 2d; see Pierson et al., 2010). Each flow release on each plot was applied for 12 min  
from a single release-point located 4 m upslope of the collection trough apex. Flow release rate  
progression on each plot was consecutive from 15 L  $\text{min}^{-1}$  to 30 L  $\text{min}^{-1}$  to 45 L  $\text{min}^{-1}$ . Flow  
375 samples were collected at various time intervals (usually 1-min to 2-min) for each 12-min  
simulation at each release rate. As with rainfall simulation samples, runoff samples were taken to  
the laboratory, weighed, oven-dried at 105°C, and then re-weighed to determine the runoff rate  
and sediment concentration. Also as noted above for rainfall simulation samples, a small number  
of runoff samples were discarded because of laboratory errors or various issues noted on field  
380 datasheets (i.e., spillage, bottle overrun, etc.). Runoff and sediment variables for each flow  
release rate were calculated for an 8-min time period starting at runoff initiation. The resulting 8-  
min runoff and sediment variables were derived as explained for the 45-min rainfall simulations.  
The velocity of overland flow was measured using a concentrated salt tracer applied into the  
flow and electrical conductivity probes to track the mean transit time of the tracer over a set flow  
385 path length (usually 3 m; Pierson et al., 2010, 2013, 2015; Williams et al., 2014a, 2018b, 2019a).



The width, depth, and a total rill area width (TRAW) of overland flow were measured along flow cross-sections 1 m, 2 m, and 3 m downslope from the flow release point. The TRAW variable represents the total width between the outermost edges of the outermost flow paths at the respective cross section (Pierson et al., 2010). Overland flow simulations conducted on large-rainfall simulation plots at Marking Corral and Onaqui in 2006 and 2007 and at Castlehead in 2008 were run approximately two hours after respective rainfall simulations. Overland flow simulations on plots not subjected to rainfall simulation at Marking Corral and Onaqui in 2008 and 2015 and at Castlehead in 2008 were conducted on soils pre-wet with a gently misting sprinkler (see Pierson et al., 2013, 2015; Williams et al., 2014, 2018, 2019a).

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#### 4 Data Application

Subsets of the dataset have been used to improve understanding of rangeland hydrologic and erosion processes, assess the ecohydrologic impacts of wildland fire and management practices on sagebrush rangelands, and improve and enhance rangeland hydrology and erosion models. Examples of data use for such applications are presented in Figures 3-5. Pierson et al. (2010) applied pre-treatment data across all plot-scales and experiment types from Marking Corral and Onaqui to evaluate the ecohydrologic impacts of woodland encroachment on sagebrush rangelands. Studies by Pierson et al. (2014, 2015) assessed the initial (1<sup>st</sup> and 2<sup>nd</sup> year) effects of prescribed fire and mechanical tree removal treatments on vegetation, ground cover, and hydrology and erosion processes at Marking Corral and Onaqui. Williams et al. (2014a) applied vegetation, ground cover, rainfall simulation and overland flow experiments from unburned and burned areas at Castlehead to evaluate the utility of fire to reverse the negative ecohydrologic impacts of juniper encroachment on rangelands and to frame conceptual concepts on process connectivity for burned and degraded rangelands (Figure 4). Pierson et al. (2013 and 2015) evaluated the immediate effects of cut-downed trees on runoff and erosion processes on woodlands. Williams et al. (2018b, 2019a, 2019b) applied data from all experimental plot scales and methods in untreated and treated areas at Marking Corral and Onaqui to evaluate the long-term ecohydrologic impacts of prescribed fire and mechanical tree-removal treatments on woodland-encroached sagebrush steppe (Figure 5). Al-Hamdan et al. (2012a, 2012b, 2013, 2015, 2017) applied subsets of the data to develop, test, and enhance various parameter estimation equations for flow hydraulics and erodibility parameters in the Rangeland Hydrology and Erosion Model (RHEM). Collectively, these studies have improved understanding of rangeland hydrology and erosion processes and informed both conceptual and quantitative models applicable to assessment and management of diverse rangelands (McIver et al., 2014; Pierson and Williams, 2016; Williams et al., 2016a, 2016b, 2016c; Hernandez et al., 2017; Williams et al., 2018a).

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#### 5 Data Availability

The full dataset is available from the National Agricultural Library website at <https://data.nal.usda.gov/search/type/dataset> (DOI: <https://doi.org/10.15482/USDA.ADC/1504518>; Pierson et al., 2019). The suite of files therein



430 includes an abbreviated description and field methods; a data dictionary; geographic information  
for study sites; photographs of the study sites, field experiments, and experimental plots; and  
datafiles for vegetation, ground cover, soils, and hydrology and erosion time series measures  
spanning the associated plots scales. Subset examples of the datafiles are shown in Tables 4 (site  
level soil particle size and bulk density), 5 (site characterization plots), 6 (small-rainfall plot  
attributes), 7 (large-rainfall plot attributes), 8 (overland-flow plot attributes), 9 (small-plot  
435 rainfall simulation time series), 10 (large-plot rainfall simulation time series), and 11 (overland-  
flow simulation time series).

## 6 Summary and Conclusions

440 Rangelands are uniquely managed using ecological principles. As such, our functional  
understanding of regulating ecohydrologic processes, such as soil conservation and runoff  
moderation, are limited by our ability to track these processes in the context of interdependent  
land management decisions. Pinyon-juniper encroachment into sagebrush shrublands and the  
resulting management actions provide a model system for observing hydrologic processes under  
445 disturbances and interventions typical of extensively managed rangelands. To provide detailed  
understanding of ecohydrologic processes under realistic management conditions, we collected  
long-term data at multiple sites, spatial scales, and treatments. The combined dataset includes  
1021 experimental plots and contains vegetation, ground cover, soils, hydrology, and erosion  
data spanning multiple spatial scales and diverse vegetation, ground cover, and surface soil  
450 conditions from three study sites and five different study years. The dataset includes 57 plots  
from the hillslope scale (site characterization plots), 528 small rainfall simulation plots, 146 large  
rainfall simulation plots, and 290 overland-flow simulation plots. The hydrology and erosion  
experiments provide time series data for small-rainfall plot, large-rainfall plot, and overland-flow  
plot simulations. After excluding some time series rainfall- and overland-flow simulation data  
455 due to various lab and equipment failures, the final time series dataset contains 1020 small-  
rainfall, 280 large-rainfall, and 838 overland-flow plot-run hydrographs and sedigraphs if plots  
without runoff are retained. Retaining only plots that generated runoff results in a time series  
dataset of 749 small-rainfall, 251 large-rainfall, and 719 overland-flow plot simulation  
hydrographs and sedigraphs. Overall, the hydrology and erosion time series dataset totals to 2138  
460 hydrographs/sedigraphs including plots with no runoff and 1719 hydrographs/sedigraphs for  
plots that generated runoff. The methodology employed and resulting experimental data improve  
understanding of and provide quantification of separate scale-dependent (e.g., rainsplash and  
sheetflow) and combined (e.g., interrill and concentrated flow/rill) surface hydrology and erosion  
processes for sagebrush rangelands and pinyon and juniper woodlands in the Great Basin before  
465 and after tree removal and for sparsely vegetated sites elsewhere. This separate and combined  
experimental approach yields a valuable data source for testing and improving isolated process  
parameterizations in quantitative hydrology and erosion models. The long-term nature of the  
dataset is unique and provides a substantial database for populating conceptual ecological models  
of changes in vegetation, ground cover conditions, and soils resulting from management  
470 practices and disturbances. Likewise, the combined data on short-term and long-term



ecohydrologic impacts of management practices and fire provide valuable insight on trends in  
ecohydrologic recovery of rangeland ecosystems.

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Z. Al-Hamdan participated in the experimental design, data collection and reduction, and  
compilation of the dataset and manuscript. Justin C. Johnson contributed to data reduction and  
compilation of the dataset and manuscript. All authors contributed to revisions of the submitted  
manuscript.

480 **Competing interests.** The authors declare that they have no conflict of interest.

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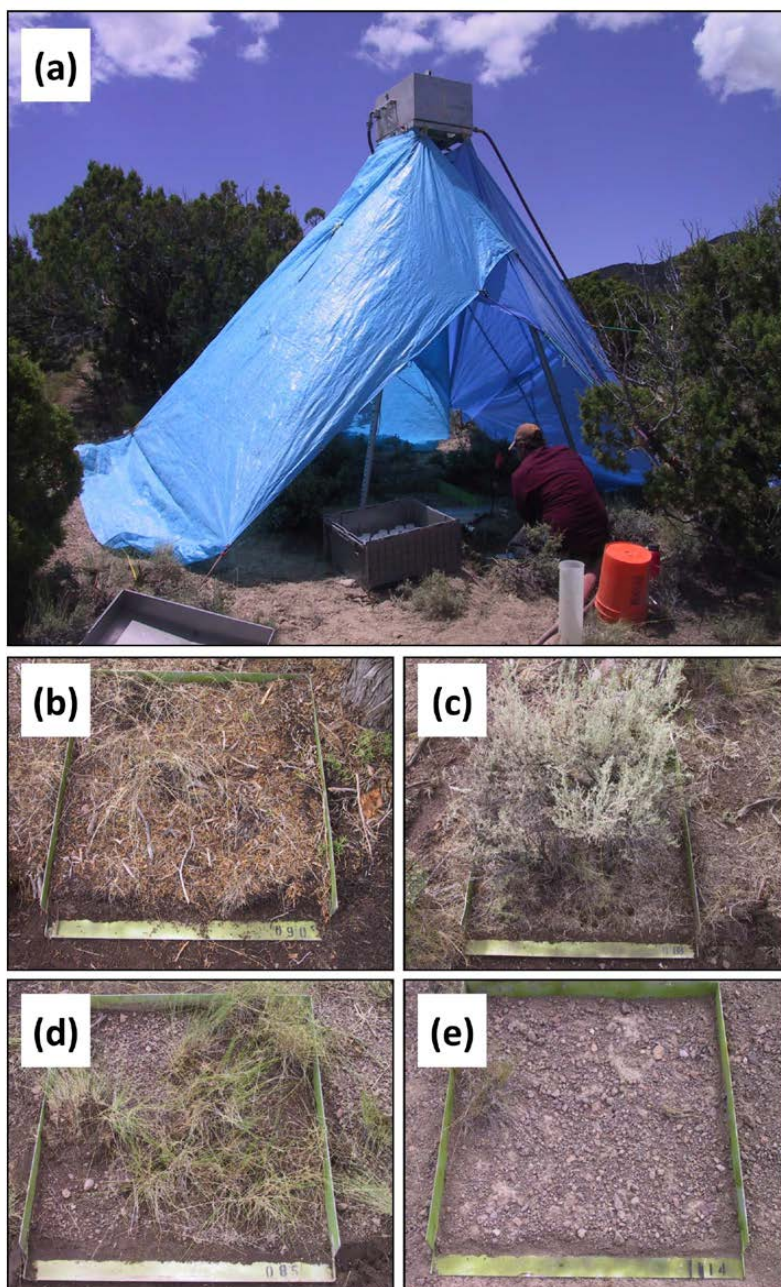


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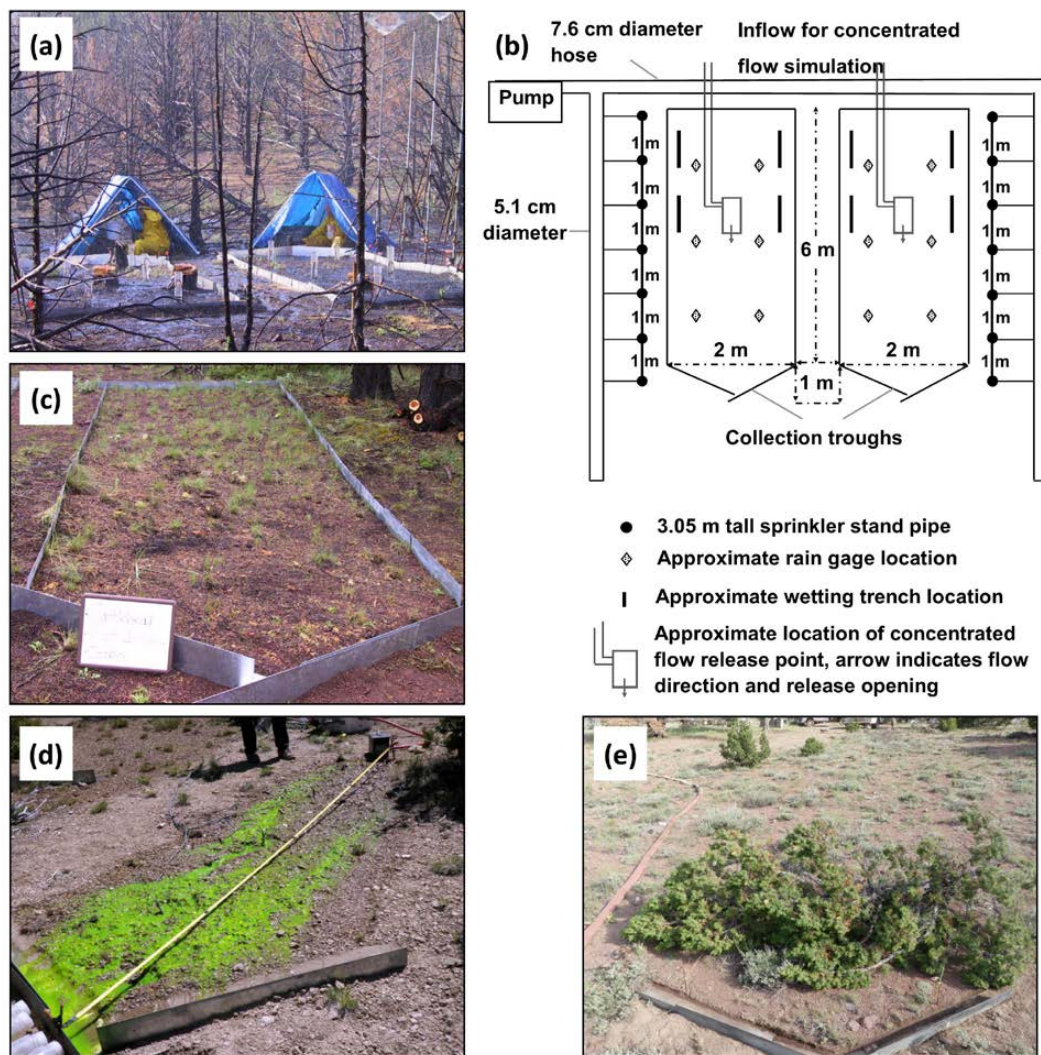




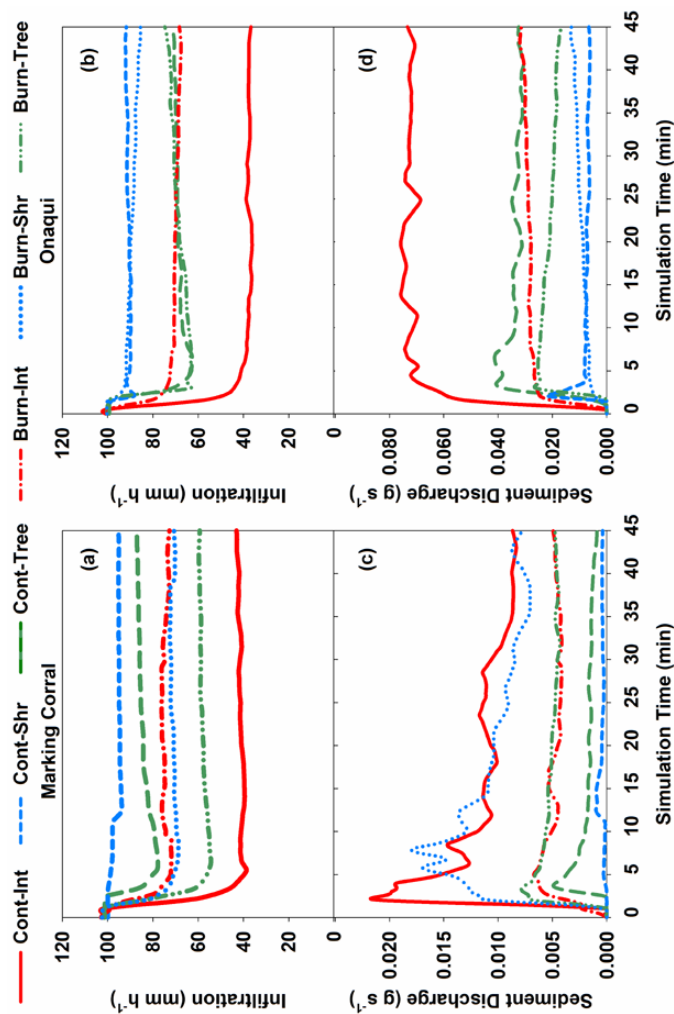
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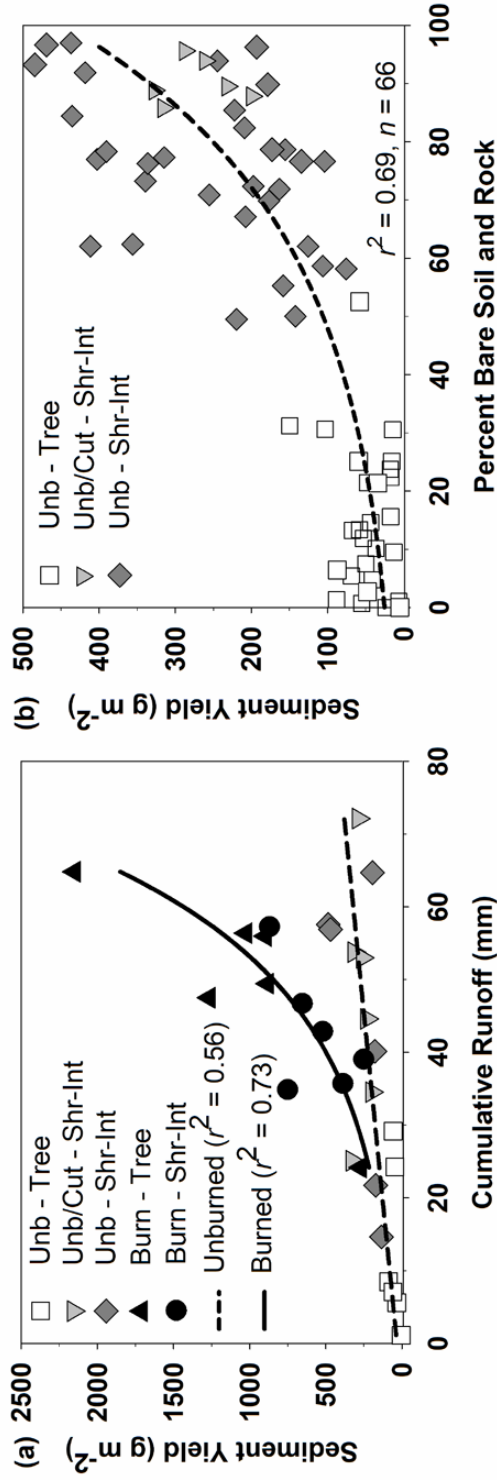
**Figure 1.** Photographs of small-plot rainfall simulator (a) and example small-rainfall plots on tree coppice (b), shrub coppice (c), and interspace (d and e) microsites as applied in this study.



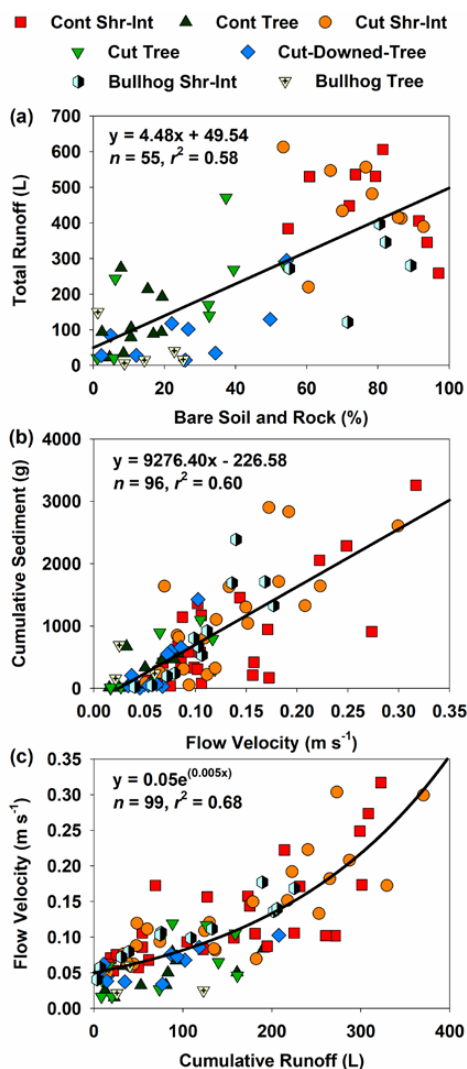
**Figure 2.** Images showing paired large-rainfall plots during rainfall simulations (a), experimental set-up of paired large-rainfall plot simulation experiments (b), a fully-bordered large-rainfall simulation plot on a tree coppice microsite (c), a borderless overland-flow simulation plot and experiment on an intercanopy (shrub-interspace) microsite (d), and a borderless overland-flow simulation plot with a cut, downed tree on an intercanopy microsite, all as respective examples as applied in this study.



**Figure 3.** Example infiltration (a and b), calculated as applied rainfall minus measured runoff, and sediment discharge (c and d) time series data generated from a subset of the small-plot rainfall simulation dataset. Example sub-dataset is from wet-run rainfall simulations in untreated (Cont) and burned (Burn) interspace (Int), shrub coppice (Shr), and tree coppice (Tree) microsites at the Marking Corral and Onaqui study sites 9 yr following prescribed fire. The data illustrate the long-term impacts of burning and associated changes in surface conditions on infiltration and sediment discharge. Figure modified from Williams et al. (2018b).



**Figure 4.** Example relationships/correlations in large-rainfall plot cumulative runoff and sediment yield for unburned (untreated [Unb] and [Cut] treatments) and burned (Burn) tree (Tree) and intercanopy (shrub-interspace, Shr-Int) plots at the Castlehead site (a) and bare ground (bare soil plus rock cover) and sediment yield for unburned (Unb) and cut treatment (Cut) tree and intercanopy plots across all study sites (Castlehead, Marking Corral, and Onaqui) (b). The relationship in runoff and sediment yield (a) demonstrates the initial (1 yr) impact of burning on sediment availability and elevated sediment delivery (for tree coppices in this study) as commonly reported in fire studies (Pierson and Williams, 2016). The relationship in bare ground and sediment yield (b) shows the typical increase in sediment yield where bare ground exceeds 50-60% as commonly reported for rangelands (Pierson et al., 2008, 2009; Williams et al., 2014b). Figures modified from Pierson et al. (2013) and Williams et al. (2014a).



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2

3 **Figure 5.** Example relationships/correlations in runoff and bare ground (bare soil plus rock  
4 cover; a), cumulative sediment and overland flow velocity (b), and overland flow velocity and  
5 runoff (c) derived from a subset of the overland flow dataset for Marking Corral and Onaqui  
6 sites, as presented in Williams et al. (2019a). Data from overland flow simulations on  
7 untreated/control (Cont) plots, cut treatment (Cut) plots without and with a cut, downed tree  
8 (Cut-Downed Tree), and bullhog plots (Bullhog, Onaqui site only) in tree (Tree) and intercanopy  
9 (shrub-interspace, Shr-Int) microsites 9 yr after respective tree removal treatments. The data  
10 demonstrate that, for the studied conditions, runoff is largely regulated by bare ground, sediment  
11 delivery is controlled by flow velocity, and flow velocity is strongly correlated with the amount  
12 or runoff.



**Table 1** Topography, climate, soil, tree cover, and understory vegetation at the Castlehead, Marking Corral, and Onaqui sites prior to treatments. Data from Pierson et al. (2010, 2015) or Williams et al. (2014a) except where indicated by footnote.

	Castlehead, Idaho, USA	Marking Corral, Nevada, USA	Onaqui, Utah, USA
Woodland community	western juniper <sup>1</sup>	single-leaf pinyon <sup>2</sup> /Utah juniper <sup>3</sup>	Utah juniper <sup>3</sup>
Elevation (m) - Aspect	1750 – SE facing	2250 – W to SW facing	1720 – N to NE facing
Mean annual precip. (mm)	364 <sup>4</sup>	299 <sup>4</sup>	298 <sup>4</sup>
Mean annual air temp. (°C)	7.4 <sup>4</sup>	6.9 <sup>4</sup>	9.2 <sup>4</sup>
Slope (%)	10-25	10-15	10-15
Parent rock	basalt and welded tuff <sup>5</sup>	andesite and rhyolite <sup>6</sup>	sandstone and limestone <sup>7</sup>
Soil association	Mulshoe-Squawcreek-Gaib <sup>5</sup>	Segura-Upatad-Cropper <sup>6</sup>	Borvant <sup>7</sup>
Depth to bedrock (m)	0.5-1.0 <sup>5</sup>	0.4-0.5 <sup>6</sup>	1.0-1.5 <sup>7</sup>
Soil surface texture	sandy loam, 59% sand, 37% silt, 4% clay	sandy loam, 66% sand, 30% silt, 4% clay	sandy loam, 57% sand, 37% silt, 7% clay
Tree canopy cover (%) <sup>8</sup>	26 <sup>1</sup>	15 <sup>2</sup> , 10 <sup>3</sup>	26 <sup>3</sup>
Trees per hectare <sup>8</sup>	158 <sup>1</sup>	329 <sup>2</sup> , 150 <sup>3</sup>	476 <sup>3</sup>
Mean tree height (m) <sup>8</sup>	5.2 <sup>1</sup>	2.3 <sup>2</sup> , 2.4 <sup>3</sup>	2.4 <sup>3</sup>
Juvenile trees per hectare <sup>9</sup>	28 <sup>1</sup>	296 <sup>2</sup> , 139 <sup>3</sup>	154 <sup>3</sup>
Shrubs per hectare <sup>10</sup>	2981	12065	4914
Intercanopy bare ground (%) <sup>11</sup>	88	64	79
Common understory plants	<i>Artemisia tridentata</i> Nutt. ssp. <i>wyomingensis</i> Beetle & Young; <i>Artemisia nova</i> A. Nelson; <i>Artemisia tridentata</i> Nutt. ssp. <i>vaseyana</i> (Rydb.) Beetle; <i>Purshia</i> spp.; <i>Poa secunda</i> J. Presl; <i>Pseudoroegneria spicata</i> (Pursh) A. Löve; <i>Festuca idahoensis</i> Elmer; and various forbs		

<sup>1</sup> *Juniperus occidentalis* Hook.

<sup>2</sup> *Pinus monophylla* Torr. & Frém.

<sup>3</sup> *Juniperus osteosperma* [Torr.] Little.

<sup>4</sup> Estimated from 4 km grid for years 1989-2018 from Prism Climate Group (2019).

<sup>5</sup> Natural Resources Conservation Service (NRCS) (2003).

<sup>6</sup> NRCS (2007).

<sup>7</sup> NRCS (2006).

<sup>8</sup> Trees ≥ 50 cm height, for Castlehead includes data from Williams et al. (2014a) and one additional year.

<sup>9</sup> Trees 5 to 50 cm height, for Castlehead mean based on data from Williams et al. (2014a) and one additional year.

<sup>10</sup> Shrubs ≥ 5 cm height, for Castlehead mean based on data from Williams et al. (2014a) and one additional year.

<sup>11</sup> Area between tree canopies consisting of shrubs, grasses, and interspaces between plants (shrub-interspace zone).



**Table 2.** Number of plots sampled by plot type (site characterization and small plot rainfall, large plot rainfall, and overland flow simulations) at each study site (Castlehead, Marking Corral, and Onaqui) by treatment and microsite (small plots - tree coppice, shrub coppice, and interspace; large plots and overland flow – tree zone and shrub-interspace zone [intercanopy]) combination each year of the study. Control refers to untreated areas at Marking Corral and Onaqui sites. Unburned refers to areas immediately adjacent to, but outside the wildfire area (burned treatment) at the Castlehead site. Downed tree sub-treatments (cut-downed tree and unburned-downed tree) refer to plots with a single downed tree across each respective plot within the specified associated treatment (cut or unburned). Tree and shrub coppice microsites are areas underneath or previously (prior to treatment) underneath tree and shrub canopy, respectively. Interspace microsites are areas between tree and shrub coppice microsites. Tree zone microsites are areas underneath, or previously underneath, and immediately adjacent (just outside canopy drip line) to a tree canopy. Shrub-interspace zones are the areas between tree canopies, collectively inclusive of shrub coppice and interspace microsites [the intercanopy].

Year	Treatment	Castlehead			Marking Corral			Onaqui		
2006	Control	-	-	-	6	-	-	9	-	-
	Bullhog	-	-	-	-	-	-	3	-	-
2007	Burned	-	-	-	3	-	-	3	-	-
	Cut	-	-	-	3	-	-	3	-	-
2008	Unburned	3	-	-	-	-	-	-	-	-
	Burned	3	-	-	-	-	-	-	-	-
2009	Unburned	3	-	-	-	-	-	-	-	-
	Burned	3	-	-	-	-	-	-	-	-
	Bullhog	-	-	-	-	-	-	3	-	-
2015	Burned	-	-	-	3	-	-	3	-	-
	Cut	-	-	-	3	-	-	3	-	-

Year	Treatment	Castlehead			Marking Corral			Onaqui		
		Tree Coppice	Shrub Coppice	Interspace	Tree Coppice	Shrub Coppice	Interspace	Tree Coppice	Shrub Coppice	Interspace
2006	Control	-	-	-	24	13	23	23	21	36
	Control	-	-	-	7	5	8	4	3	3
2007	Bullhog	-	-	-	-	-	-	10	10	30
	Burn	-	-	-	8	4	8	5	5	10
2008	Control/Unburned	8	8	8	4	2	4	4	3	3
	Burned	5	5	10	8	4	8	5	5	10
2009	Unburned	3	3	4	-	-	-	-	-	-
	Burned	5	5	10	-	-	-	-	-	-
2015	Control	-	-	-	8	4	6	8	6	6
	Bullhog	-	-	-	-	-	-	5	5	10
	Burned	-	-	-	8	4	6	5	5	10
	Cut	-	-	-	8	4	6	5	5	10

Year	Treatment	Castlehead		Marking Corral		Onaqui	
		Tree Zone	Shrub-Interspace Zone	Tree Zone	Shrub-Interspace Zone	Tree Zone	Shrub-Interspace Zone
2006	Control	-	-	12	12	18	18
	Bullhog	-	-	-	-	4	4
2007	Burned	-	-	6	6	6	6
	Cut	-	-	-	6	-	6
	Cut-Downed Tree	-	-	-	6	-	6
	Unburned	6	6	-	-	-	-
2008	Unburned-Downed Tree	-	6	-	-	-	-
	Burned	6	6	6	6	6	6

Year	Treatment	Castlehead		Marking Corral		Onaqui	
		Tree Zone	Shrub-Interspace Zone	Tree Zone	Shrub-Interspace Zone	Tree Zone	Shrub-Interspace Zone
2006	Control	-	-	12	12	18	18
	Bullhog	-	-	-	-	4	4
2007	Burned	-	-	6	6	6	6
	Cut	-	-	-	6	-	6
	Cut-Downed Tree	-	-	-	6	-	6
	Control Unburned	6	6	3	3	2	2
2008	Unburned-Downed Tree	-	6	-	-	-	-
	Burned	6	6	6	6	6	6
2009	Unburned	6	6	-	-	-	-
	Unburned-Downed Tree	-	6	-	-	-	-
	Burned	6	6	-	-	-	-
2015	Control	-	-	5	5	5	5
	Bullhog	-	-	-	-	5	5
	Burned	-	-	5	5	5	5
	Cut	-	-	5	5	5	5
	Cut-Downed Tree	-	-	-	5	-	5

- Indicates not applicable, no plots.





**Table 3.** Select foliar cover and ground cover measures on from hillslope-scale site characterization plots (990 m<sup>2</sup>) in cut and burned treatment areas at the Marking Corral and Onaqui sites 1 yr prior to tree removal (2006) and 1 yr (2007) and 9 yr (2015) after tree removal treatments.

Site characteristic	Marking Corral				Onaqui	
	Untreated 2006 <sup>1</sup>	Cut 2007 <sup>2</sup>	Cut 2015 <sup>2</sup>	Untreated 2006 <sup>1</sup>	Cut 2007 <sup>2</sup>	Cut 2015 <sup>2</sup>
Foliar Cover						
Shrub (%)	14.6	14.3	28.7	3.4	5.0	16.9
Grass (%)	12.4	21.4	30.2	7.3	13.7	27.1
Forb (%)	1.0	3.7	1.4	3.2	12.1	7.4
Ground Cover						
Litter (%)	46.1	46.0	47.6	26.2	41.6	35.8
Rock (%) <sup>3</sup>	22.0	11.3	1.3	29.8	22.3	17.0
Bare soil (%)	26.4	40.5	42.5	37.7	29.1	35.7
	Marking Corral				Onaqui	
	Untreated 2006 <sup>1</sup>	Burn 2007 <sup>4</sup>	Burn 2015 <sup>4</sup>	Untreated 2006 <sup>1</sup>	Burn 2007 <sup>4</sup>	Burn 2015 <sup>4</sup>
Site characteristic						
Foliar Cover						
Shrub (%)	17.7	6.2	8.7	0.9	0.4	10.7
Grass (%)	4.8	10.0	63.1	6.2	3.4	39.7
Forb (%)	0.1	10.6	0.9	3.3	6.0	14.3
Ground Cover						
Litter (%)	47.4	31.4	40.3	34.4	29.7	34.7
Rock (%) <sup>3</sup>	25.4	16.5	12.8	29.0	31.6	21.6
Bare soil (%)	26.8	52.0	39.7	31.1	35.9	29.5

<sup>1</sup> Data from Pierson et al. (2010), but restricted to plots in area subsequently cut or burned at the respective site × treatment combination.

<sup>2</sup> Data from Williams et al. (2019a).

<sup>3</sup> Rock fragments > 5 mm in diameter.

<sup>4</sup> Data from Williams et al. (2018b).



**Table 4.** Soil texture and bulk density variables and data structure for those measures for all study sites.

Site	Microsite	Percent Sand	Percent Silt	Percent Clay	Bulk Density (g cm <sup>-3</sup> )
Castlehead	interspace	50.4	43.7	5.9	1.04
Castlehead	juniper_cop	65.3	31.5	3.2	0.72
Castlehead	shrub_cop	61.8	34.6	3.6	0.76
Marking Corral	interspace	63.5	32.3	4.3	1.35
Marking Corral	juniper_cop	74.4	23.2	2.3	1.05
Marking Corral	pinyon_cop	68.4	28.3	3.4	1.1
Marking Corral	shrub_cop	59.9	35.4	4.7	1.14
Onaqui	interspace	57.4	36.2	6.5	1.07
Onaqui	juniper_cop	58.9	35.6	5.4	0.83
Onaqui	shrub_cop	56.2	36.9	6.9	1.02



**Table 5.** Example (subset) of vegetation and ground cover variables and data structure for measures on hillslope-scale site characterization plots (990 m<sup>2</sup>) at the study sites.

Plot_ID	Site	Year	Treatment Area	Treated Yes or No	Fol. Cvr. Shrub (%)	Fol. Cvr. Grass (%)	Fol. Cvr. Forb (%)	...	Live Shrubs (>5 cm) Per Ha	Dead Shrub (>5 cm) per Ha	JUOC Trees		JUOC Trees (5-50 cm) Per Ha
											(>0.5 m) Per Ha	Per Ha	
SC_CH_BURN1	Castlehead	2008	Bum	Yes	0	5.3	6.3	...	0	722	0	0	0
SC_CH_BURN2	Castlehead	2008	Bum	Yes	0	3.7	5.7	...	0	611	0	0	0
SC_CH_BURN3	Castlehead	2008	Bum	Yes	0	5	4	...	0	1389	0	0	0
SC_CH_UNB1	Castlehead	2008	Unburned	No	0	13.3	6.7	...	222	278	222	5.5	5.5
SC_CH_UNB2	Castlehead	2008	Unburned	No	4	26.3	6.7	...	1944	778	162	4.7	4.7
SC_CH_UNB3	Castlehead	2008	Unburned	No	14.7	12.3	6.3	...	4056	1944	121	4.2	4.2
SC_CH_BURN1	Castlehead	2009	Bum	Yes	0	22	17	...	56	278	0	0	0
SC_CH_BURN2	Castlehead	2009	Bum	Yes	0	12.7	25.3	...	111	2500	0	0	0
SC_CH_BURN3	Castlehead	2009	Bum	Yes	0	16.3	26.3	...	0	1833	0	0	0
SC_CH_UNB1	Castlehead	2009	Unburned	No	1	19.3	2	...	5278	2056	212	5.9	5.9
SC_CH_UNB2	Castlehead	2009	Unburned	No	14.7	46.3	7	...	722	56	111	6.2	6.2
SC_CH_UNB3	Castlehead	2009	Unburned	No	18.3	39	14.3	...	5667	2056	121	4.6	4.6
...	...	...	...	...	...	...	...	...	...	...	...	...	...
SC_ON_CUT1	Onaqui	2015	Cut	Yes	8.9	41.6	11.3	...	6389	0	0	0	0
SC_ON_CUT2	Onaqui	2015	Cut	Yes	21	21	7.1	...	10667	0	0	0	0
SC_ON_CUT3	Onaqui	2015	Cut	Yes	20.8	18.7	3.9	...	10611	0	0	0	0



**Table 6.** Example (subset) of rainfall simulation, vegetation, ground cover, and soil variables and data structure for measures on small-rainfall simulation plots (0.5 m<sup>2</sup>) at the study sites.

Plot_ID	Site	Year	Treatment		Treated Yes or No	Microsite	Applied Rain		Slope (%)	Random Roughness (mm)	Fol. Cvr. Shrub (%)	Fol. Cvr. Grass (%)	Grd. Cvr. Bare Soil (%)	Grd. Rock (%)	WDPT at 0 cm (s)
			Area	WetRun			DryRun	WetRun							
SP_MC_CONT81	Marking Corral	2006	Control	76	No	shrub_cop	48	76	16.3	15	51.4	25.7	23.8	8.9	3
SP_MC_CONT82	Marking Corral	2006	Control	76	No	pinyon_cop	48	76	22.2	26	18.1	0	0	0	7
SP_MC_CONT83	Marking Corral	2006	Control	76	No	interspace	48	76	12.8	12	0	54.3	20.7	47.8	3
SP_MC_CONT84	Marking Corral	2006	Control	77	No	shrub_cop	48	77	12.8	29	78.1	19	13.6	4.9	3
SP_MC_CONT85	Marking Corral	2006	Control	76	No	interspace	48	76	20.7	12	0	34.3	38.1	30.9	3
SP_MC_CONT86	Marking Corral	2006	Control	76	No	pinyon_cop	47	76	13.6	15	0	2.9	0	0	3
SP_MC_CONT87	Marking Corral	2006	Control	77	No	interspace	44	77	9.6	14	4.8	35.2	48.9	13	3
SP_MC_CONT88	Marking Corral	2006	Control	76	No	shrub_cop	45	76	11.2	22	61.9	18.1	17	3.4	3
SP_MC_CONT89	Marking Corral	2006	Control	78	No	juniper_cop	48	78	9.9	10	0	1.9	0	0	38
SP_MC_CONT90	Marking Corral	2006	Control	78	No	juniper_cop	48	78	17.5	12	0	26.7	0	1	51
SP_MC_CUT91	Marking Corral	2006	Cut	78	No	interspace	48	78	9.5	4	0	0	37.1	61.9	3
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
SP_ON_CONT78	Onaqui	2015	Control	46	No	shrub_cop	46	74	18.1	17	42.9	8.6	14.4	27.8	30
SP_ON_CONT79	Onaqui	2015	Control	46	No	interspace	46	74	19.2	13	0	7.6	24.1	59.5	3
SP_ON_CONT80	Onaqui	2015	Control	47	No	shrub_cop	47	75	17.5	19	72.4	12.4	31.6	16.8	3



**Table 7.** Example (subset) of rainfall simulation, vegetation, ground cover, and soil variables and data structure for measures on large-rainfall simulation plots (13 m<sup>2</sup>) at the study sites.

Plot_ID	Site	Year	Treatment Area	Treated Yes or No	Microsite	Applied Rain		Slope (%)	Random Roughness (mm)	Fol. Cvr. Shrub (%)	Fol. Cvr. Grass (%)	Grd. Cvr. Bare Soil (%)	Grd. Cvr. Rock (%)	Avg. Canopy Gap (cm)	Avg. Basal Gap (cm)
						DryRun (mm)	WetRun (mm)								
LP_MC_CUT37	Marking Corral	2006	Cut	No	juniper_cop	39	65	11.1	19	9.2	8.8	16.3	6.1	100	164
LP_MC_CUT38	Marking Corral	2006	Cut	No	juniper_cop	47	87	12.2	19	7.5	8.8	5.4	2	77	157
LP_MC_CUT39	Marking Corral	2006	Cut	No	intercanopy	37	63	10.4	18	29.8	18	44.1	5.4	83	121
LP_MC_CUT40	Marking Corral	2006	Cut	No	intercanopy	50	96	9.6	14	11.5	8.8	28.1	49.2	59	94
LP_MC_CUT41	Marking Corral	2006	Cut	No	intercanopy	40	67	8.8	18	21.4	13.9	27.2	22.8	76	125
LP_MC_CUT42	Marking Corral	2006	Cut	No	intercanopy	46	88	9.5	15	18.6	19.7	24.1	31.2	86	131
LP_MC_CUT43	Marking Corral	2006	Cut	No	pinyon_cop	39	72	9.3	20	0.3	3.4	0	0.7	428	499
LP_MC_CUT44	Marking Corral	2006	Cut	No	pinyon_cop	50	93	8.1	18	0.7	1.7	0	1	427	435
LP_MC_CUT45	Marking Corral	2006	Cut	No	pinyon_cop	46	94	9.1	15	10.8	4.4	0	1.4	113	168
LP_MC_CUT46	Marking Corral	2006	Cut	No	pinyon_cop	47	83	1.3	21	9.8	8.5	1	3.7	127	243
LP_MC_CUT47	Marking Corral	2006	Cut	No	intercanopy	41	80	12.1	25	26.9	19.4	32.9	29.5	69	110
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
LP_CH_BURN28	Castlehead	2008	Burn	Yes	juniper_cop	43	77	15.2	12	0	3.7	33.6	50.2	43	101
LP_CH_BURN29	Castlehead	2008	Burn	Yes	intercanopy	48	87	14.8	22	0	5.8	54.2	44.7	36	56
LP_CH_BURN30	Castlehead	2008	Burn	Yes	intercanopy	42	83	14.7	17	0	6.8	33.6	54.2	31	42



**Table 8.** Example (subset) of overland flow, vegetation, and ground cover variables and data structure for measures on overland flow simulation plots (~9 m<sup>2</sup>) at the study sites.

Plot ID	Site	Year	Treatment Area	Treated Yes or No	Microsite	Avg. Width 15 L min <sup>-1</sup> at 3m (cm)	Avg. Width 30 L min <sup>-1</sup> at 3m (cm)	Avg. Width 45 L min <sup>-1</sup> at 3m (cm)	...	Avg. Velocity 15 L min <sup>-1</sup> (m s <sup>-1</sup> )	Avg. Velocity 30 L min <sup>-1</sup> (m s <sup>-1</sup> )	Avg. Velocity 45 L min <sup>-1</sup> (m s <sup>-1</sup> )	Avg. Canopy Gap (cm)	Avg. Basal Gap (cm)
RI_MC_CUT37	Marking Corral	2006	Cut	No	juniper_cop	2	10	28	...	-999	0.029	0.036	67	92
RI_MC_CUT38	Marking Corral	2006	Cut	No	juniper_cop	0	30	32	...	0	-999	0.058	78	156
RI_MC_CUT39	Marking Corral	2006	Cut	No	intercanopy	42	33	43	...	0.07	0.122	0.148	70	93
RI_MC_CUT40	Marking Corral	2006	Cut	No	intercanopy	50	38	53	...	0.085	0.127	0.131	55	100
RI_MC_CUT41	Marking Corral	2006	Cut	No	intercanopy	37	61	59	...	0.028	0.067	0.107	59	106
RI_MC_CUT42	Marking Corral	2006	Cut	No	intercanopy	47	61	52	...	0.05	0.066	0.1	86	109
RI_MC_CUT43	Marking Corral	2006	Cut	No	pinyon_cop	0	52	102	...	0	-999	0.038	333	333
RI_MC_CUT44	Marking Corral	2006	Cut	No	pinyon_cop	0	-999	-999	...	0	-999	-999	284	292
RI_MC_CUT45	Marking Corral	2006	Cut	No	pinyon_cop	0	0	-999	...	0	0	-999	131	172
RI_MC_CUT46	Marking Corral	2006	Cut	No	pinyon_cop	0	24	32	...	0	0.033	0.044	88	175
RI_MC_CUT47	Marking Corral	2006	Cut	No	intercanopy	64	64	52	...	0.062	0.098	0.127	79	85
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
RI_ON_CUT131	Onaqui	2015	Cut	Yes	intercanopy	144	148	158	...	0.051	0.084	0.182	46	46
RI_ON_CUT133	Onaqui	2015	Cut	Yes	intercanopy	0	165	82	...	0	0.054	0.073	65	34
RI_ON_CUT134	Onaqui	2015	Cut	Yes	intercanopy	0	29	36	...	0	0.062	0.086	48	58



**Table 9.** Example (subset) of time series runoff and sediment data from small-plot rainfall simulations (0.5 m<sup>2</sup>) at the study sites.

Plot_ID	Site	Year	Treatment Area	Treated Yes or No	Microsite	Run Type	Runoff Yes or No	Rainfall Rate (mm h <sup>-1</sup> )	Runoff			Sample			
									Start Time (mm:ss)	Simulation Time (mm:ss)	Fill Time (s)	Runoff (L min <sup>-1</sup> )	Sediment Conc. (g L <sup>-1</sup> )	Runoff (mm h <sup>-1</sup> )	Sediment Discharge (g s <sup>-1</sup> )
SP_MC_CONT81	Marking Corral	2006	Control	No	shrub_cop	Dry_Run	No	64	00:00	00:00	0	0.000	0.00	0.000	0.0000
SP_MC_CONT81	Marking Corral	2006	Control	No	shrub_cop	Dry_Run	No	64	44:00	44:00	0	0.000	0.00	0.000	0.0000
SP_MC_CONT81	Marking Corral	2006	Control	No	shrub_cop	Wet_Run	Yes	102	05:11	00:00	0	0.000	0.00	0.000	0.0000
SP_MC_CONT81	Marking Corral	2006	Control	No	shrub_cop	Wet_Run	Yes	102	05:11	05:10	0	0.000	0.00	0.000	0.0000
SP_MC_CONT81	Marking Corral	2006	Control	No	shrub_cop	Wet_Run	Yes	102	05:11	05:36	49	0.096	0.38	11.520	0.0006
SP_MC_CONT81	Marking Corral	2006	Control	No	shrub_cop	Wet_Run	Yes	102	05:11	06:30	60	0.095	0.10	11.436	0.0002
SP_MC_CONT81	Marking Corral	2006	Control	No	shrub_cop	Wet_Run	Yes	102	05:11	07:30	60	0.080	0.13	9.552	0.0002
SP_MC_CONT81	Marking Corral	2006	Control	No	shrub_cop	Wet_Run	Yes	102	05:11	08:30	60	0.074	0.00	8.840	0.0000
SP_MC_CONT81	Marking Corral	2006	Control	No	shrub_cop	Wet_Run	Yes	102	05:11	09:30	60	0.068	0.30	8.110	0.0003
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
SP_ON_CONT80	Onaqui	2015	Control	No	shrub_cop	Wet_Run	Yes	100	01:50	26:00	120	0.075	6.42	8.968	0.0080
SP_ON_CONT80	Onaqui	2015	Control	No	shrub_cop	Wet_Run	Yes	100	01:50	29:00	120	0.077	6.29	9.250	0.0081
SP_ON_CONT80	Onaqui	2015	Control	No	shrub_cop	Wet_Run	Yes	100	01:50	32:00	120	0.073	6.58	8.751	0.0080
SP_ON_CONT80	Onaqui	2015	Control	No	shrub_cop	Wet_Run	Yes	100	01:50	35:00	120	0.065	6.55	7.783	0.0071
SP_ON_CONT80	Onaqui	2015	Control	No	shrub_cop	Wet_Run	Yes	100	01:50	41:00	120	0.067	6.50	8.026	0.0073



**Table 10.** Example (subset) of time series runoff and sediment data from large-plot rainfall simulations (13 m<sup>2</sup>) at the study sites.

Plot_ID	Site	Year	Treatment Area	Treated Yes or No	Microsite	Downed Cut Tree Yes or No	Run Type	Rainfall Rate (mm h <sup>-1</sup> )	Runoff Start Time (mm:ss)	Simulation Time (mm:ss)	Sample Fill Time (s)	Runoff (L min <sup>-1</sup> )	Sediment Conc. (g L <sup>-1</sup> )	Runoff (min h <sup>-1</sup> )	Sediment Discharge (g s <sup>-1</sup> )
LP_MC_CUT37	Marking Corral	2006	Cut	No	juniper_cop	No	Dry_Run	52	08:15	00:00	0	0	0	0	0
LP_MC_CUT37	Marking Corral	2006	Cut	No	juniper_cop	No	Dry_Run	52	08:15	08:14	0	0	0	0	0
LP_MC_CUT37	Marking Corral	2006	Cut	No	juniper_cop	No	Dry_Run	52	08:15	09:05	20	0.294	19.08	1.357	0.094
LP_MC_CUT37	Marking Corral	2006	Cut	No	juniper_cop	No	Dry_Run	52	08:15	10:08	15	0.464	14.56	2.142	0.113
LP_MC_CUT37	Marking Corral	2006	Cut	No	juniper_cop	No	Dry_Run	52	08:15	12:08	15	0.627	8.74	2.894	0.091
LP_MC_CUT37	Marking Corral	2006	Cut	No	juniper_cop	No	Dry_Run	52	08:15	14:08	16	0.476	11.11	2.196	0.088
LP_MC_CUT37	Marking Corral	2006	Cut	No	juniper_cop	No	Dry_Run	52	08:15	16:08	15	0.625	10.69	2.883	0.111
LP_MC_CUT37	Marking Corral	2006	Cut	No	juniper_cop	No	Dry_Run	52	08:15	18:08	15	0.554	10.47	2.556	0.097
LP_MC_CUT37	Marking Corral	2006	Cut	No	juniper_cop	No	Dry_Run	52	08:15	20:08	15	0.609	12.21	2.812	0.124
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
LP_CH_BURN30	Castlehead	2008	Burn	Yes	intercanopy	No	Wet_Run	110	01:09	30:08	15	15.647	4.68	72.216	1.22
LP_CH_BURN30	Castlehead	2008	Burn	Yes	intercanopy	No	Wet_Run	110	01:09	33:08	15	13.819	4.41	63.781	1.015
LP_CH_BURN30	Castlehead	2008	Burn	Yes	intercanopy	No	Wet_Run	110	01:09	36:08	15	14.198	5.78	65.529	1.368
LP_CH_BURN30	Castlehead	2008	Burn	Yes	intercanopy	No	Wet_Run	110	01:09	39:08	15	16.666	5.65	76.919	1.569
LP_CH_BURN30	Castlehead	2008	Burn	Yes	intercanopy	No	Wet_Run	110	01:09	42:08	15	14.282	5.48	65.915	1.305





**Table 11.** Example (subset) of time series runoff and sediment data from overland flow simulations (~9 m<sup>2</sup>) at the study sites.

Plot_ID	Site	Year	Treatment Area	Treated Yes or No	Microsite	Plot Bordered All Sides Yes or No	Runoff 15 L min <sup>-1</sup> Yes or No	Runoff 30 L min <sup>-1</sup> Yes or No	Runoff 45 L min <sup>-1</sup> Yes or No	Applied Overland Flow Rate (L min <sup>-1</sup> )	Simulation Time (min:ss)	Sample Fill Time (s)	Runoff (L min <sup>-1</sup> )	Sediment Conc. (g L <sup>-1</sup> )
RL_MC_CUT37	Marking Corral	2006	Cut	No	juniper_cop	Yes	Yes	Yes	Yes	15	00:00	30	0.181	13.49
RL_MC_CUT37	Marking Corral	2006	Cut	No	juniper_cop	Yes	Yes	Yes	Yes	15	00:41	15	0.47	1.62
RL_MC_CUT37	Marking Corral	2006	Cut	No	juniper_cop	Yes	Yes	Yes	Yes	15	01:11	15	0.628	0.7
RL_MC_CUT37	Marking Corral	2006	Cut	No	juniper_cop	Yes	Yes	Yes	Yes	15	02:31	15	1.265	0.66
RL_MC_CUT37	Marking Corral	2006	Cut	No	juniper_cop	Yes	Yes	Yes	Yes	15	03:06	15	1.662	1.04
RL_MC_CUT37	Marking Corral	2006	Cut	No	juniper_cop	Yes	Yes	Yes	Yes	15	03:41	15	1.976	0.2
RL_MC_CUT37	Marking Corral	2006	Cut	No	juniper_cop	Yes	Yes	Yes	Yes	30	00:00	15	11.181	15.97
RL_MC_CUT37	Marking Corral	2006	Cut	No	juniper_cop	Yes	Yes	Yes	Yes	30	00:45	15	14.551	0.61
RL_MC_CUT37	Marking Corral	2006	Cut	No	juniper_cop	Yes	Yes	Yes	Yes	30	02:40	15	18.795	0.29
...	...	...	...	...	...	...	...	...	...	...	...	...	...	...
RL_ON_CUT134	Onaqui	2015	Cut	Yes	intercanopy	No	No	Yes	Yes	45	04:05	20	14.5	5.51
RL_ON_CUT134	Onaqui	2015	Cut	Yes	intercanopy	No	No	Yes	Yes	45	04:55	20	15.215	5.56
RL_ON_CUT134	Onaqui	2015	Cut	Yes	intercanopy	No	No	Yes	Yes	45	05:45	20	15.694	5.49
RL_ON_CUT134	Onaqui	2015	Cut	Yes	intercanopy	No	No	Yes	Yes	45	08:35	20	17.426	5.41
RL_ON_CUT134	Onaqui	2015	Cut	Yes	intercanopy	No	No	Yes	Yes	45	10:35	20	18.678	5.44