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Meteorological, snow, streamflow, topographic, and vegetation height data from four western juniper-dominated experimental catchments in southwestern Idaho, USA

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Abstract. Meteorological, snow, streamflow, topographic, and vegetation height data are presented from the South Mountain experimental catchments. This study site was established in 2007 as a collaborative, long-term research laboratory to address the impacts of western juniper encroachment and woodland treatments in the interior Great Basin region of the western USA. The data provide detailed information on the weather and hydrologic response from four highly instrumented catchments in the late stages of woodland encroachment in a sagebrush steppe landscape. Hourly data from six meteorologic stations and four weirs have been carefully processed, quality-checked, and are serially complete. These data are ideal for hydrologic, ecosystem, and biogeochemical modeling. Data presented are publicly available from the USDA National Agricultural Library administered by the Agricultural Research Service (https://data.nal.usda.gov/dataset/data-weather-snow-and-streamflow-data-four-western-juniper-dominated-experimental-catchments, doi:10.15482/USDA.ADC/1254010).

1 Introduction

Across the interior western US, native western juniper (*Juniperus occidentalis* Hook.) is encroaching into sagebrush-dominated (*Artemisia* spp.) landscapes. These fire-sensitive native conifers in the western US have greatly expanded in response to changing fire regimes (increased woody fuels in response to fire suppression efforts) following European settlement (Miller and Wigand, 1994; Miller and Rose, 1995; Weisberg et al., 2007; Miller et al., 2000). Western juniper now dominates over 3.6 million ha of rangeland in the Intermountain Region of the western US. Juniper (*Juniperus* spp.) expansion into sagebrush ecosystems influences the vegetation community (Bates et al., 2000; Miller et al., 2005; Miller and Tausch, 2001) and the hydrology and soil resources of an area (Pierson et al., 2007, 2010; Williams et al., 2014), which in turn also affects the wildlife habitat. For example, research in similar study sites demonstrate that juniper encroachment diminishes understory biomass (Bates et al., 2000, 2014; Pierson et al., 2013), which serves as a soil stabilization mechanism, forage for livestock, and habitat diversity. At mid-to-high elevations, expansion of native conifer species is viewed as a major threat to sagebrush obligates such as the greater sage grouse (*Centrocercus urophasianus*) (Braun, 1998; Connelly and Braun, 1997). Because of the associated impacts on the ecosystem quality and local economy (Aldrich et al., 2005), juniper encroachment has become a critical issue to the region's resource managers and ranchers.

Table 1. Hydrometeorological variable, type of instrument, and instrument height from the South Mountain Experimental Catchments. Locations are denoted with a WS for weather station or W for weir; "n/a" denotes not applicable.

Hydrometeorological variable	Instrument/ method	Instrument height (m)
Precipitation (WS)	8 in. Belfort-type gauge with Alter shield	3
Wind speed (WS)	Met One WS 013	3
Wind direction (WS)	Met One WD 023	3
Air temperature (WS)	Vaisala HMP45AC	3
Relative humidity (WS)	Vaisala HMP45AC	3
Vapor pressure (WS)	Calculated from air temperature and relative humidity	3
Dew point temperature (WS)	Marks et al. (2013)	3
Incoming solar radiation (WS)	Kipp and Zonen CMP3	3
Snow depth (WS)	Judd ultrasonic depth sensor	3
Snow water equivalent (WS)	Federal-type snow tube, mean of 6 samples per site	n/a
Stream discharge (W)	Druck PDCR1830 in drop-box V-notch weir	n/a

Although the deleterious impact of juniper encroachment is widely reported through field studies, there are limited datasets available to quantify that impact on larger scales through modeling. To address the need for monitoring data, the South Mountain Experimental Catchments were established in 2007 in a juniper-dominated region of southwestern Idaho, USA (Kormos et al., 2017). A period of background data collection spans the 2008–2015 water years. The catchments are now being treated to remove juniper so comparative studies can be conducted. Catchment M was burned in the fall of 2015 and catchment G is scheduled to burn in the spring of 2017. The long-term treatment plan includes burning catchments F and then E.

In this paper we present hourly pretreatment weather, precipitation, snow, and streamflow data, along with lidar-derived topographic and vegetation cover, that detail the hydrologic function of a western juniper-dominated (*Juniperus occidentalis* Hook.) study area. Table 1 summarizes the hydrometeorological variables presented in this paper with the instrument used to collect the data and instrument height. These data represent a relatively complete background hydrologic dataset that has been collected from 1 October 2007 through 30 September 2013 (six water years, WY2008 to WY2013). This time period is sufficient to provide a range of precipitation and temperature conditions typical for this region. These data are appropriate to force and evaluate models that investigate the hydrologic function and change in these systems. For example, Kormos et al. (2017) utilized this dataset to evaluate the changes in ecosystem water availability between juniper-dominated and sagebrush-dominated landscapes by simulating snow dynamics with and without juniper trees.

2 Site description

The South Mountain Experimental Catchments are located on South Mountain (42.67° N, 116.90° W) in the Owyhee Mountains just east of the Idaho–Oregon border, in the northwestern USA (Fig. 1). The research catchments were established in 2007 as a collaborative, long-term research laboratory to assess the hydrologic and ecologic impacts of juniper encroachment and removal in the Great Basin region. Four west-draining catchments are defined by the locations of drop-box weirs (Bonta and Pierson, 2003). The catchments share one or two borders with each other, which may be beneficial to hydrologic modeling efforts to describe lateral connectivity of basins or woodland treatment impacts beyond watershed divides. Contributing areas range in size from 21.0 to 70.2 ha for a total of 204.5 ha (Table 2). Elevation ranges from 1665 to 1898 m a.s.l. (meters above sea level) and mean catchment slope ranges from 10 to 13°. Vegetation is typical of woodland-encroached sagebrush steppe ecosystems. Diminished understory consists of sparse shrubs, grasses, and forbs, while overstory is exclusively western juniper. Juniper cover ranges from 42 to 61 % based on a 10 m pixel classification where maximum vegetation height greater than 1.5 m is classified as juniper (Kormos et al., 2017). Juniper density is approximately 288 stems ha^{-1} with a mean height of 7.3 m (Sankey et al., 2013).

Table 2. Watershed areas, the percent of the pixels classified as juniper dominated, elevation ranges, and mean slopes. Mean catchment elevations are in parentheses.

Watershed	Area (ha)	Juniper cover (%)	Elevation range (m)	Mean slope (degree)
E	56.7	42	1704–1898 (1793)	13
F	56.6	61	1687–1815 (1748)	13
G	70.2	53	1693–1814 (1758)	12
M	21.0	54	1665–1791 (1723)	10

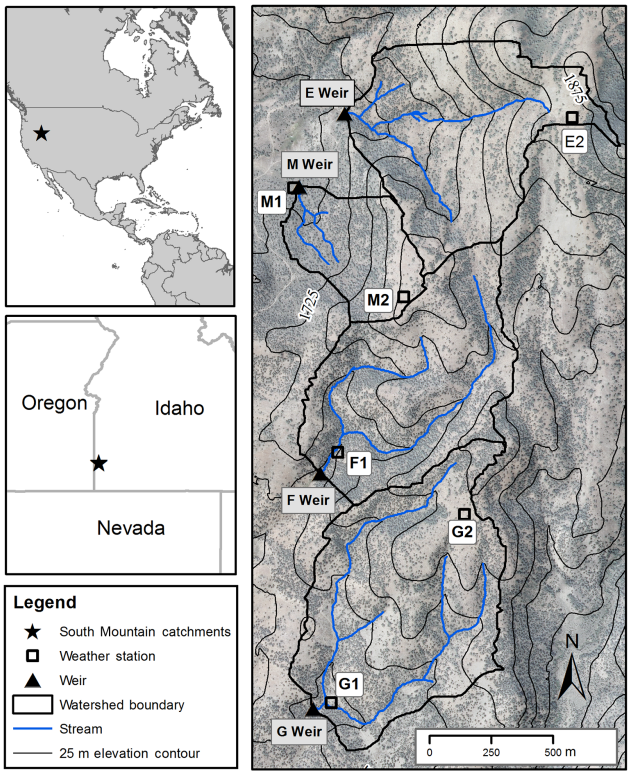

Figure 1. Location map of the South Mountain Experimental Catchments showing the locations of weather stations and weirs. The base map shows the distribution of western juniper. The contour interval is 25 m, with the 1875 and 1725 m contours labeled for reference.

Mean water year precipitation from the six precipitation gauges was 627 mm for the 6-year dataset (Fig. 2). The majority of precipitation occurs in the fall, winter, and spring, with little accumulation in June, July, and August (Fig. 3). A seasonal snow pack commonly accumulates in November and melts out in March and April. Six weather stations are arranged to capture the spatial variability in weather across the study area (Fig. 1). To capture elevation gradients, three weather stations are located on ridges (designated with a 2 in the name) and three are located at lower catchment elevations (designated with a 1 in the name). All weather stations are equipped with identical instrumentation (Table 1). Snow water equivalent is measured at snow courses, which are located within 30 m of each of the weather stations.

3 Spatial data: digital elevation and vegetation models

One-meter bare-earth elevation and vegetation height data were derived from a snow-free airborne lidar survey (Fig. 4) acquired in November 2007. The lidar point density was 7 points per square meter, resulting in a vertical accuracy of approximately 3 cm. The lidar dataset extends beyond the

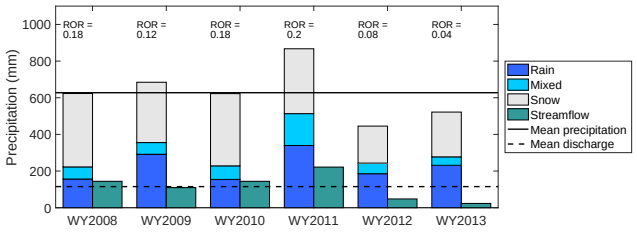

Figure 2. Total water year precipitation split up into phase at the South Mountain Experimental Catchments showing that the precipitation regime is snow dominated. Mean water year precipitation was 627 mm as depicted by the solid black line. Mean total catchment streamflow is shown as green bars. The 6-year mean water year stream flow was 115 mm as shown with the dashed black line. Runoff ratios (ROR) are displayed for each water year above the bars.

catchment boundaries by approximately 200 m in most cases, although improved catchment boundaries extend to the end of the dataset in the northwest of the study area. Processing of the lidar dataset to obtain the bare-earth elevation and canopy height models was done using tools developed by the Boise Center Aerospace Laboratory (BCAL, 2016) as described by Streutker and Glenn (2006). These data provide an accurate 1 m snapshot (3276 rows and 1754 columns, 5 746 104 pixels with data) of bare-earth elevation and mean and maximum vegetation height for each of the study catchments (Sankey et al., 2013). In addition, we provide a 10 m digital elevation model obtained by aggregating elevation data from the 1 m dataset (Fig. 5). Similarly, we provided a 10 m maximum vegetation height dataset created by taking the mean of the 1 m maximum vegetation pixel heights contained in the 10 m pixels. These data provide an accurate 10 m snapshot (329 rows and 176 columns, 37 310 pixels with data) of bare-earth elevation and maximum vegetation height for each of the study catchments that can be utilized in modeling projects (Kormos et al., 2017).

The raw lidar point cloud is available through the Idaho Lidar Consortium (https://www.idaholidar.org/data/data-map/south-mountain/) in the case that additional spatial data is required, such as leaf area index or vegetation shape parameters. Additional spatial data include shapefiles of weather station and weir locations, the delineations of catchment boundaries, and an estimate of the locations of the ephemeral stream network. All geographic data are in the Universal Transverse Mercator projected coordinate system using zone 11 and 1983 North American Datum (UTM, zone 11, NAD83). Catchment delineations, stream channels, mean catchment slope, and elevations were derived directly from the 1 m bare-earth digital elevation model.

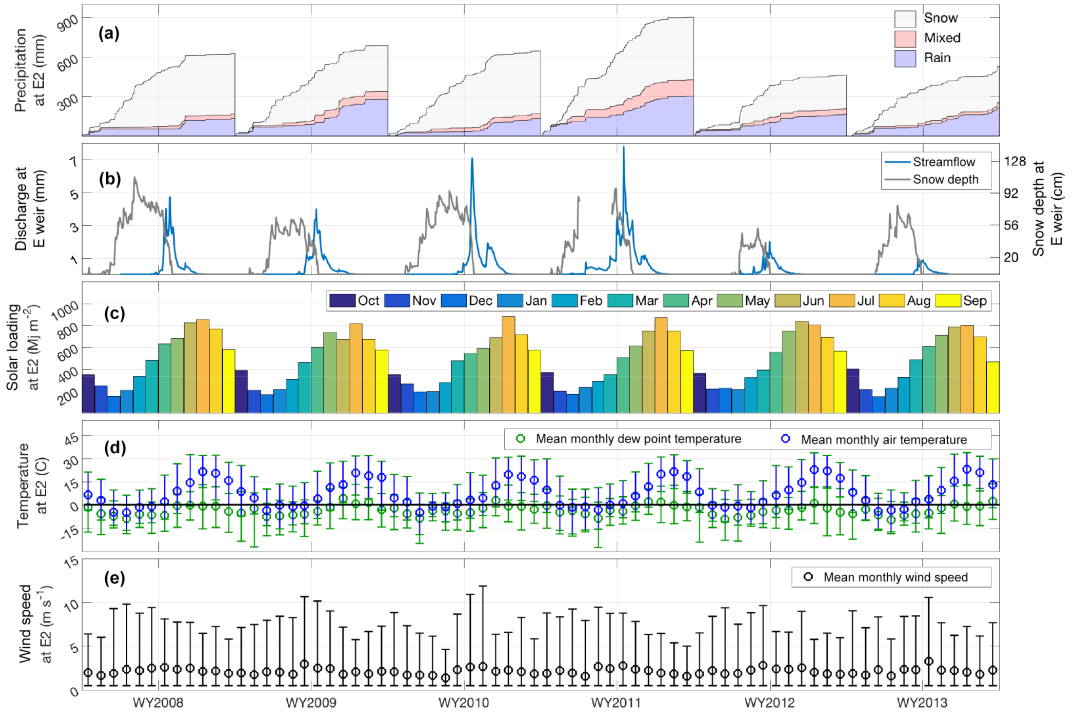

Figure 3. Example forcing data from catchment E and weather station E2 showing **(a)** precipitation amount and phase, **(b)** streamflow and snow depth, **(c)** monthly incoming solar radiation, **(d)** air and dew point temperature, and **(e)** wind speed.

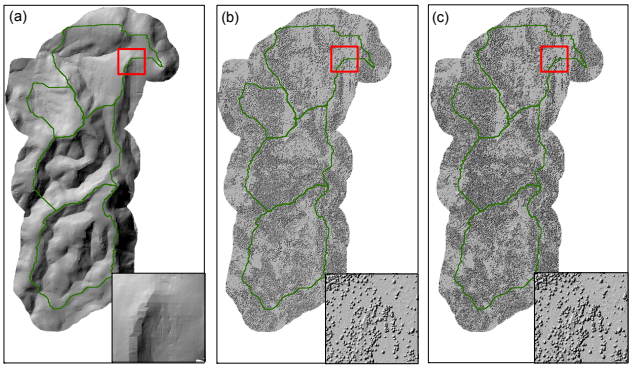

Figure 4. Hillshades of 1 m bare-earth model, 1 m mean vegetation heights, and 1 m maximum vegetation heights. The insets in the lower right-hand corners show close-up images of the area shown in the red boxes.

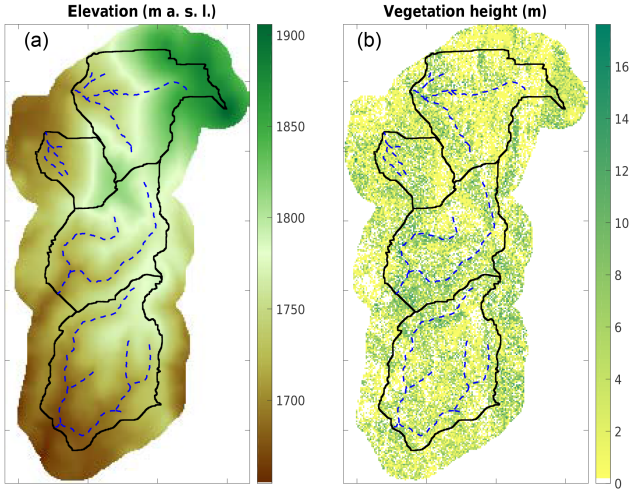

Figure 5. **(a)** Ten meter elevation map of the South Mountain Experimental Catchments showing the catchment boundaries and stream locations.**(b)** Ten-meter vegetation height map.

4 Weather data

Measured weather data are typical of forcing variables required to run hydrologic models, and include air temperature (°C), relative humidity (kPa kPa^{-1}), precipitation (mm), wind speed (m s^{-1}) and direction (degree), and incoming solar radiation (W m^{-2}). Vapor pressure and dew point temperature are calculated from air temperature and relative humidity using methods developed by Marks et al. (1999), described by Reba et al. (2011) and refined by Marks et al. (2013). Air temperature, vapor pressure, relative humidity, and precipitation from all stations were plotted together for every month to perform quality control. All weather data are hourly and have been cleaned and gap-filled, and, with the exception of wind direction, serially complete for WY2008 to WY2013. Data gaps and bad or noisy values have been filled using the most appropriate of either linear interpola-

tion, or multiple linear regression to nearby weather stations with the same measured variable. Raw data are also provided for all measured weather variables.

4.1 Precipitation

Shielded precipitation was measured at the six weather stations using 8-inch Belfort-type gauges with Alter shields (Hanson et al., 2001). Precipitation was filtered following Nayak et al. (2008) and wind corrected using the World Meteorological Organization protocol as described in Dingman (2002) (p. 109). Most of the annual precipitation falls in the cold winter season with dew point temperatures close to 0 °C (Fig. 3d). This creates a dynamic precipitation regime, where some years accumulate substantial snowpacks, and some years accumulate very little snow (Fig. 3b). Precipitation phase was computed using the dew point temperature methods as described by Marks et al. (2013). Though precipitation across the South Mountain Experimental Catchments is typically a mix of rain and snow, the region is snow-dominated, with 53 to 76 % of water year precipitation falling as snow or mixed-phase events (Fig. 2). The 6-year water year average is 627 mm (314 mm snow), with WY2011 being the wettest year with 867 mm (354 mm snow) and WY2012 being the driest year with 445 mm (202 mm snow). An example of the hourly cumulative precipitation, divided into phase from weather station E2, is shown in Fig. 3a.

4.2 Air temperature and humidity

Air temperature and relative humidity were measured at the six weather stations. Dew point temperature was calculated from measured values of air temperature and relative humidity (Marks et al., 2013). Average water year air temperature over the South Mountain research catchments for the six water years of this study is 7.0 °C, with WY2010 being the coldest (6.0 °C) and WY2012 being the warmest (8.0 °C). The mean water year dew point temperature was −3.0 °C, with WY2011 being the most humid and also the wettest (−1.9 °C) and WY2012 being the least humid and the driest (−3.7 °C) of the six water years in this study. Average water year air temperature during storms for the six water years of this study is 0.5 °C, with WY2008 being the coldest (−1.0 °C) and WY2012 being the warmest (1.6 °C). The mean water year dew point temperature during storms was −1.0 °C, with WY2008 having the greatest percent snow (−2.6 °C) and WY2011 having the least percent snow (−0.3 °C). An example of mean monthly air and dew point temperatures, with the monthly range from weather station E2 is shown in Fig. 3d.

4.3 Wind speed and direction

Wind speed and direction are measured at the six weather stations. The three low-elevation sites (M1, F1,and G1) are sheltered by topography and vegetation, while the ridge-top sites (E2, M2,and G2) are wind-exposed. F1 is extremely wind sheltered by both topography and vegetation with a mean wind speed of 0.7 m s^{-1}, while M2 is the most wind-exposed with a mean wind speed of 2.4 m s^{-1}. The prevailing wind direction during precipitation is from the west (274°). The maximum wind speed recorded during six water years of the dataset was 14.3 m s^{-1}. We did not attempt to gap-fill missing or bad data from the wind direction time series, as correlations between wind measurement stations are low. However, there is sufficient wind direction data to obtain average wind directions during water years and individual storms. An example of monthly mean wind speed and the monthly range of wind speed values from weather station E2 is shown in Fig. 3e.

4.4 Incoming solar radiation

Incoming solar radiation is measured at the six weather stations. Solar radiation measurements from weather stations F1 and M1 are vegetation-affected in the mornings and evenings. The average solar loading at the F1 site was 12.9 MJ day^{-1} m^{-2}, while at site E2 it was 16.1 MJ day^{-1} m^{-2}. An example of monthly solar loadings from weather station E2 is shown in Fig. 3c.

5 Snow and streamflow data

5.1 Snow data

Snow depth is continuously measured at the six weather stations. Because these automated snow depth measurements are inherently noisy, the data are processed using multiple smoothing windows. This practice allows for the cleaning of instrument noise, while maintaining sharp accumulation and melt events. We did not attempt to fill large time periods with excessively noisy data in the cleaned snow depth data file, and have denoted them as missing data (Fig. 3b, WY2011). Excessively noisy data were identified as time periods that contained more erroneous measurements than reasonable measurements. Raw snow depth data are provided. In addition to automated snow depth measurements, manual measurements of snow water equivalent (SWE) were made two to three times each year at snow courses near the six weather stations using a federal-type snow tube. Snow courses were visited 16 times during the 6-year dataset, and were not measured in WY2009. These snow water equivalent values are reported in the final data file, and depths and densities are reported in the raw data file. Although significant resources were expended collecting SWE data, we recognize that this is a limited model validation dataset. The combination of continuous snow depth and SWE measurements should be sufficient to evaluate distributed snow model results. An example of the cleaned snow depth from weather station E2 is shown in Fig. 3b.

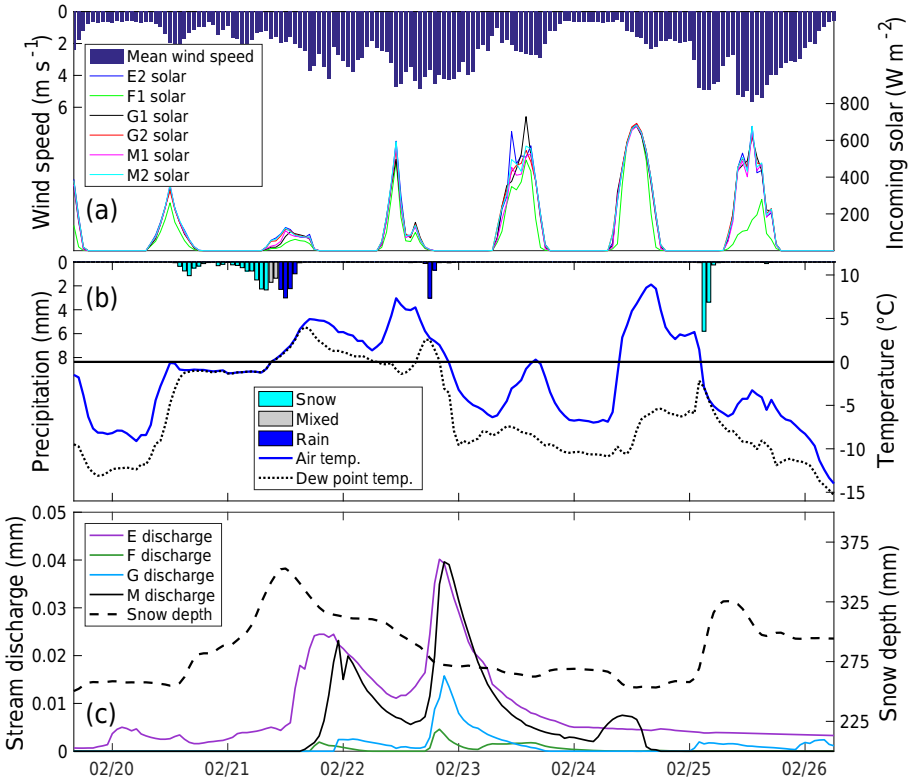

Figure 6. Example weather and response data from a February storm at the South Mountain Experimental Catchments showing **(a)** mean precipitation mass and phase with air and dew point temperatures, **(b)** mean wind speed and incoming solar radiation, and **(c)** streamflow and snow depth response data.

5.2 Streamflow

Stream stage is measured with Druck pressure transducers in stilling wells at four drop-box V-notch weirs. Stage is converted to discharge with well-established rating curves (Bonta and Pierson, 2003). The streams that drain the South Mountain Experimental Catchments are intermittent and initiate in response to rain on snow or snowmelt events (Fig. 3a and b). Streamflow ceases in late spring to mid-summer. Mean water year discharge from all catchments across years was 115 mm (Fig. 2). Catchment M, which has the smallest contributing area, has the lowest mean annual discharge at 90 mm. Catchment F has the highest mean annual stream discharge at 145 mm. The lowest stream yields occurred in WY2013 and the highest stream yields occurred in WY2011. Runoff ratios are approximated for the four South Mountain Experimental Catchments by assuming that the mean of precipitation measured by gauges within each catchment represents the precipitation that fell in that catchment. Average catchment runoff ratios varied from 0.07 for M to 0.22 for F. An example of the streamflow data included in this dataset from weir E is shown in Fig. 3b.

6 Example data

We present data from a mid-February storm in 2012 as an example of the dynamic weather that is described in this paper (Fig. 6). At the start of this storm, the air was cold and saturated, resulting in snowfall and an accumulation of about 9.5 cm of snow depth (Fig. 6b and c). Wind was relatively calm and cloud cover led to low incoming solar radiation at all weather stations (Fig. 6a). Snow depth increased until midday on 21 February, when air and dew point temperatures rose above freezing and caused precipitation to change from snow to mixed precipitation, and then to rain (Fig. 6b and c). Snowmelt and rain led to streamflow initiation from catchments F, G, and M, and an increase in flow at weir E (Fig. 6c). An additional rain-on-snow event occurred from 22 February, at 17:00 to 19:00 LT, leading to increased streamflow at all weirs. Clear skies and warming temperatures caused increased flow from the smallest, catchment M, on 24 February. A small snow event occurred in the early morning of 25 February, which led to an increase in snow depth.

7 Data availability

All data presented in this paper are available from the National Agricultural Library website (doi:10.15482/USDA.ADC/1254010). Included is a readme file that contains a detailed description of data file contents, including header information and contact information for additional details. Additional weather and hydrologic response data for the South Mountain Experimental Catchments are available at ftp://ftp.nwrc.ars.usda.gov/publicdatabase/.

8 Summary

Data presented in this paper support ongoing research in a mountain environment that is relevant to both native ecosystems and the local economy in the Great Basin region of the northwestern US. This region has experienced extensive woodland encroachment into sagebrush-dominated landscapes, which has become a critical issue regarding the regional economy and ecosystem health. This publication provides details on background data from catchments that are now juniper-dominated. A treatment schedule to remove juniper is now being implemented so comparative studies can be conducted. Catchment M was burned in the fall of 2015 and catchment G is scheduled to burn in the spring of 2017. Catchments F and E are also to be treated. The data are unique because they capture the complicated weather–snow–streamflow dynamics representative of a large portion of the juniper-impacted western US. In addition, the data provided represent model forcing variables that are commonly required to conduct modeling studies of the hydrologic and environmental systems in the region. Spatial data are derived from a lidar dataset and represent the topography and vegetation of the South Mountain Experimental Catchments at 1 m resolution. In all, six water years of gap-filled and serially complete hourly weather, snow depth, and streamflow data are presented from six weather stations and four weirs, which adequately capture the environmental gradients present in the study area.

Competing interests. There are no conflicts of interest.

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