

GSA Data Repository 2015233

Supplemental Information

Prior Measurements of Hydrologic Properties and Response

The proximity of the 2010 Fourmile Canyon Fire to the town of Boulder and the number of residences along Fourmile Creek prompted a multi-year hillslope-scale study of hydrologic response at the research area near Sugarloaf (Fig. 1). These data provide a baseline for comparison to hydrologic response during the 2013 floods and characterization of soils needed to estimate local soil-water storage. Volumetric soil-water content has been measured continuously (aside from isolated times of sensor malfunction) since September 2010. Table DR1 presents measurements of gravel fraction (diameter > 2 mm) by mass in the top 10 cm of soil from north-versus south-facing slopes in the research area collected by Moody and Nyman (2013).

Rainfall Spatial Variability During the September 2013 Storms

There was considerable spatial and temporal variability in rainfall during the September 2013 storms in the Colorado Front Range (e.g. Gochis et al., 2014). The time series of cumulative rainfall during the September storms for the five closest rain gages operated by the Urban Drainage and Flood Control District (www.udfcd.org) is shown in Figure DR1. Rainfall generally increases to the north and east of the experimental soil-water content plots at the field site shown in Fig. DR1, as shown by the rain gage totals for the Gold Hill and Logan Mill gages compared to the Sugarloaf, Swiss Peaks, and Twin Sisters gages. This trend is shown in more detail in Gochis et al. (2014) and Coe et al.

(2014); the total precipitation contours trend SE-NW in the area of the soil-water content plots with the Sugarloaf, Swiss Peaks, and Twin Sisters gages aligning closest to the total precipitation contour nearest to the field area. Note that there is little difference between the measured cumulative precipitation between the Sugarloaf, Swiss Peaks, and Twin Sisters gages (Fig. S1). This suggests that the Sugarloaf gage is adequate for analysis of rainfall totals and rates for the analysis presented here. The Urban Drainage and Flood Control District rain gage network is not sufficient to address whether rainfall intensity or total was aspect dependent, a possibility suggested but not tested by Coe et al. (2014).

Influence of Gravel Fraction on Saturated Soil-Water Content

The saturated soil-water content values in Table 1 are based on 4-cm diameter core measurements that exclude large stones that were observed during instrument pit installation and in soil pits. The example calculation below approximates the influence of large stones on porosity as an estimate of saturated soil-water content and estimates how differences between north- and south-facing aspects in mass fractions of large stones would affect saturated soil-water content and saturation development.

For a sample soil volume, the mass of large stones, M_{stone} , and the mass of matrix materials consisting of fine gravel, sand, silt, and clay, M_{matrix} , together make up the total mass, M . The mass fraction of the stone, F_{stone} , and matrix, F_{matrix} , constituents can be represented as:

$$F_{stone} = M_{stone} / M \quad (1)$$

$$F_{matrix} = M_{matrix} / M = 1 - F_{stone} \quad (2)$$

The composite dry bulk density, ρ_b , including large stones and soil matrix is:

$$\rho_b = \frac{1}{(F_{stone} / \rho_{stone} + F_{matrix} / \rho_{matrix})} \quad (3)$$

where ρ_{stone} is the stone dry bulk density and ρ_{matrix} is the matrix dry bulk density. The composite porosity of the stone and matrix, η , is the volume-weighted sum of the porosity contributions of the stones, η_{stone} , and the matrix, η_{matrix} :

$$\eta = \eta_{stone} F_{stone} (\rho_b / \rho_{stone}) + \eta_{matrix} F_{matrix} (\rho_b / \rho_{matrix}) \quad (4)$$

The available stone porosity for water storage at the storm timescale of minutes to hours is one of the important considerations that affect the resulting estimate of η . The other physical property values in equations (1-4) also need to be estimated accurately. Table S2 shows values for η based on a range of F_{stone} values. For the calculations in Table S2, measured ρ_{matrix} was approximately 1.45 g cm^{-3} from the 4-cm diameter cores. Measured ρ_{stone} for the Boulder Creek Grandiorite bedrock in this area varies from 2.67 g cm^{-3} for unweathered bedrock to 1.98 g cm^{-3} for rock weathered into grus (Isherwood and Street, 1976). The weathered rock value of 1.98 g cm^{-3} is used as ρ_{stone} in our calculations. The η_{matrix} was calculated from ρ_{matrix} (assuming solid density of 2.65 g cm^{-3}) using:

$$\left[1 - (\rho_{matrix} / \rho_{solid})\right] = 0.45 \quad (5)$$

The η_{stone} was calculated using equation (5) using the ρ_{stone} value (assuming solid density of 2.65 g cm⁻³) from Parizek and Girty (2014) for Sugarloaf Mountain, which is adjacent to this research area; the η_{stone} value was 0.098. The η_{matrix} value in Table S2 approximates η without hydrologically-accessible stone porosity at the storm timescale. It is clear from Table S2 that η declines considerably with increasing stone content. In the context of the north- and south-facing slopes described herein, the difference in F_{Stone} was 6% larger for south-facing slopes (percentage by mass of gravel in Table S1). Approximating F_{Stone} using percentage by mass of gravel in Table S1 results in an F_{Stone} of approximately 0.4, resulting in η on the south-facing slope of 0.335 and on the north-facing slope of 0.350 (Table S2). This is a difference of $[(0.350-0.335)/0.350] \times 100\% = 4.3\%$, or about 5% smaller η on the south-facing slope. An approximately 5% difference in porosity and saturated soil-water content may be inconsequential for typical storms but very important in extreme rainfall events. Further information on correcting ρ_b and η for stone content can be found in Andraski (1991), Grossman and Reinsch (2002), and Flint and Flint (2002).

Supplemental References

- Andraski, B.J., 1991, Balloon and core sampling for determining bulk density of alluvial desert soil: *Soil Science Society of America Journal*, v. 55, p. 1188-1190.
- Isherwood, D., and Street, A., 1976, Biotite-induced gneissification of the Boulder Creek Granodiorite, Boulder County, Colorado: *Geological Society of America Bulletin*, v. 87, p. 366-370.
- Flint, L.E. , and Flint, A.L., 2002, Porosity, *in* Dane, J.H., and Topp, G.C., eds., *Methods of Soil Analysis, Part 4, Physical Methods*: Soil Science Society of America, Madison, Wisconsin, p. 241-254.
- Grossman, R.B., and Reinsch, T.G., 2002, Bulk density and linear extensibility, *in* Dane, J.H., and Topp, G.C., eds., *Methods of Soil Analysis, Part 4, Physical Methods*: Soil Science Society of America, Madison, Wisconsin, p. 201-228
- Parizek, J.R., and Girty, G.H., 2014, Assessing volumetric strains and mass balance

relationships resulting from biotite-controlled weathering: Implications for the isovolumetric weathering of the Boulder Creek Granodiorite, Boulder County, Colorado, USA: *Catena*, v. 120, p. 29-45.

Supplemental Figure captions

Figure DR1. A) Map of the 5 closest tipping bucket rain gages to the field site in the Sugarloaf research area (Figure 1). The rain gage network is maintained by the Urban Drainage and Flood Control District. The distances from the gages to the experimental plots at the field site are 1.5 km for the Sugarloaf gage, 2.4 km for the Swiss Peaks gage, 2.7 km for the Gold Hill gage, 2.2 km for the Logan Mill gage, and 5.2 km for the Twin Sisters gage. (B) Total rainfall in mm from 9-17 Sept. 2013 at the 5 closest rain gages (shown in Part A).

Table DR1. Percentage by mass of gravel (particles > 2 mm diameter) in soil samples from 0-10cm depth from north- and south-facing hillslopes within the Fourmile Creek watershed from data collected by Moody and Nyman (2013). A two-tailed, two sample t-test without assuming equal variance showed significant difference in > 2mm size

North-facing slope (N=12)	South-facing slope (N=12)	
% > 2 mm	% >2 mm	
39.0	44.5	
30.0	48.2	
27.5	39.4	
23.5	46.2	
23.6	40.0	
47.5	30.0	
35.2	30.5	
17.8	38.6	
46.9	35.1	
42.4	40.7	
34.7	40.7	
32.6	38.6	
33.4	39.4	Mean
9.5	5.6	Standard deviation

fractions at the 7.5% significance level (threshold $p = 0.075$).

Table DR2. Estimates of porosity with increasing large stone fraction ($\gg 2$ mm diameter). Note that η_{matrix} approximates if available stone porosity is approximately zero on the storm timescale of minutes to hours.

F_{stone} (kg/kg)	F_{matrix} (kg/kg)	P_b (kg/cm ³)	η_{stone} (cm ³ /cm ³)	η_{matrix} (cm ³ /cm ³)	η (cm ³ /cm ³)
0	1	1.450	0	0.450	.0450
0.05	0.95	1.470	0.004	0.433	0.437
0.1	0.9	1.490	0.007	0.416	0.424
0.15	0.85	1.511	0.011	0.399	0.410
0.2	0.8	1.532	0.015	0.380	0.396
0.25	0.75	1.554	0.019	0.362	0.381
0.3	0.7	1.577	0.023	0.343	0.366
0.35	0.65	1.600	0.028	0.323	0.350
0.4	0.6	1.624	0.032	0.302	0.335
0.45	0.55	1.649	0.037	0.281	0.318
0.50	0.5	1.674	0.041	0.260	0.301

Figure DR1

