Incorrect rock fragment correction factor computation in WEPP

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I had some difficulty in parameterizing and calibrating the SPUR2000 model for soil hydrologic properties at Walnut Gulch Experimental Watershed, particularly for soil horizons with abundant rock fragments (diameter ≥ 2mm). Investigation of this problem led to the discovery of an error in SPUR2000 code, which was originally taken from WEPP and corrects soil hydrologic properties for rock fragment content. This error is also found in the WEPP documentation available online (Alberts et al., 1995) and in recent WEPP source code. Details are given below, along with the correct form of the correction factor.

The problem

A correction for the volume of coarse (≥ 2mm) fragments in a soil is given in chapter 7 of the WEPP documentation (Alberts et al., 1995, p. 7.8). The correction factor (F_{cf}) is shown as follows (citation made to Brakensiek et al. (1986)):

$F_{cf} = 1 - V_{cf}$ (eq. 7.8.3)

where
V_{cf} = volume fraction of coarse fragments and is obtained from:

$$V_{cf} = \frac{M_{cf}\frac{\rho_t}{1000}}{2.65\left[1 - M_{cf}\right]} \quad \text{(eq. 7.8.4)}$$

where
M_{cf} = mass fraction of coarse fragments
ρ_t = soil bulk density (for fraction < 2mm diameter) at time *t*

This correction factor gives erroneous results; a computed example is shown in Table 1 and Figure 1 below. Note that as $M_{cf} \rightarrow 1$, $V_{cf} \rightarrow \infty$ and $F_{cf} \rightarrow -\infty$. It can be readily seen that, for very rocky soils common in southwestern semi arid grasslands, use of the (multiplicative) correction factor results in inappropriately low to negative values for "corrected" soil hydrologic properties. Error checking in SPUR and WEPP code sets a lower limit for these values, but better still is to correctly calculate the correction factor.

The correct correction factor

Brakensiek et al. (1986) wrote that the volume fraction R_v of rock fragments in a soil (equal to V_{cf}, above) can be expressed as:

$$R_v = \frac{\alpha(R_w)}{[1 - R_w(1-\alpha)]}$$ where

α = (bulk density fine-earth fraction) / (bulk density rock fragments)
R_w = rock fragment content by weight (as decimal) = M_{cf} above

Using the notation of eq. 7.8.4 above, this can be rewritten as:

$$V_{cf} = \frac{M_{cf}\frac{\rho_t}{2650}}{\left[1 - \frac{\rho_t}{2650}\left(1 - M_{cf}\right)\right]} = \frac{M_{cf}\rho_t}{\left[M_{cf}\rho_t + 2650\left(1 - M_{cf}\right)\right]}$$

where 2650 kg/m^3 is the modal bulk density of rock over a variety of compositions (Carmichael, 1989).

Values for the correct correction factor are presented in the example in Table 1 and graphically in Figure 1, below.

WEPP code

In the WEPP source code I have (v.2004.6), the soil rock fragment content by mass has been truncated at 50% in subroutine INPUT, presumably in response to errors resulting from the incorrect formulation described above. The calculation for volumetric rock content V_{cf} in subroutine SCON appears in the same (incorrect) form as eq. 7.8.4 above. Note that V_{cf} computed using the incorrect formula will still be about 50% too large for rock mass fraction of 0.5, resulting in overcorrection of soil hydrologic properties.

References

Alberts, E.E., M.A. Nearing, M.A. Weltz, L.M. Risse, F.B. Pierson, X.C. Zhang, J.M. Laflen and J.R. Simanton. 1995. Chapter 7: Soil component. In: (Flanagan, D.C., and M.A. Nearing, eds.). *USDA-Water Erosion Prediction Project Hillslope Profile and Watershed Model Documentation.* NSERL Report No. 10. W. Lafayette, IN: USDA-ARS National Soil Erosion Research Laboratory.

Brakensiek, D.L., W.J. Rawls, and G.R. Stephenson. 1986. Determining the saturated hydraulic conductivity of a soil containing rock fragments. Soil Sci. Soc. Am. J., 50: 834-835.

Carmichaels, R.S. 1989. *Practical Handbook of Physical Properties of Rocks and Minerals*. Boca Raton, FL: CRC Press. 741 p.

Table 1. Example comparison of WEPP and original Brakensiek et al. (1986) rock fragment correction. Soil bulk density ρ_t = 1425 kg/m^3. M_{cf} = mass fraction of coarse fragments; M_{ff} = mass fraction of fine soil (< 2mm); V_{cf} = volume fraction of coarse fragments; F_{cf} = correction factor for coarse fragments.

M_{cf}	M_{ff}	V_{cf} (WEPP)	V_{cf} (Brak)	F_{cf} (WEPP)	F_{cf} (Brak)
0.0	1.0	0.0	0.0	1.0	1.0
0.1	0.9	0.06	0.06	0.94	0.94
0.2	0.8	0.13	0.12	0.87	0.88
0.3	0.7	0.23	0.19	0.77	0.81
0.4	0.6	0.36	0.26	0.64	0.74
0.5	0.5	0.54	0.35	0.46	0.65
0.6	0.4	0.81	0.45	0.19	0.55
0.65	0.35	1.00	0.50	0.00	0.50
0.7	0.3	1.25	0.56	-0.25	0.44
0.75	0.25	1.61	0.62	-0.61	0.38
0.8	0.2	2.15	0.68	-1.15	0.32
0.9	0.1	4.84	0.83	-3.84	0.17
1.0	0.0	[undefined]	1.00	[undefined]	0.00

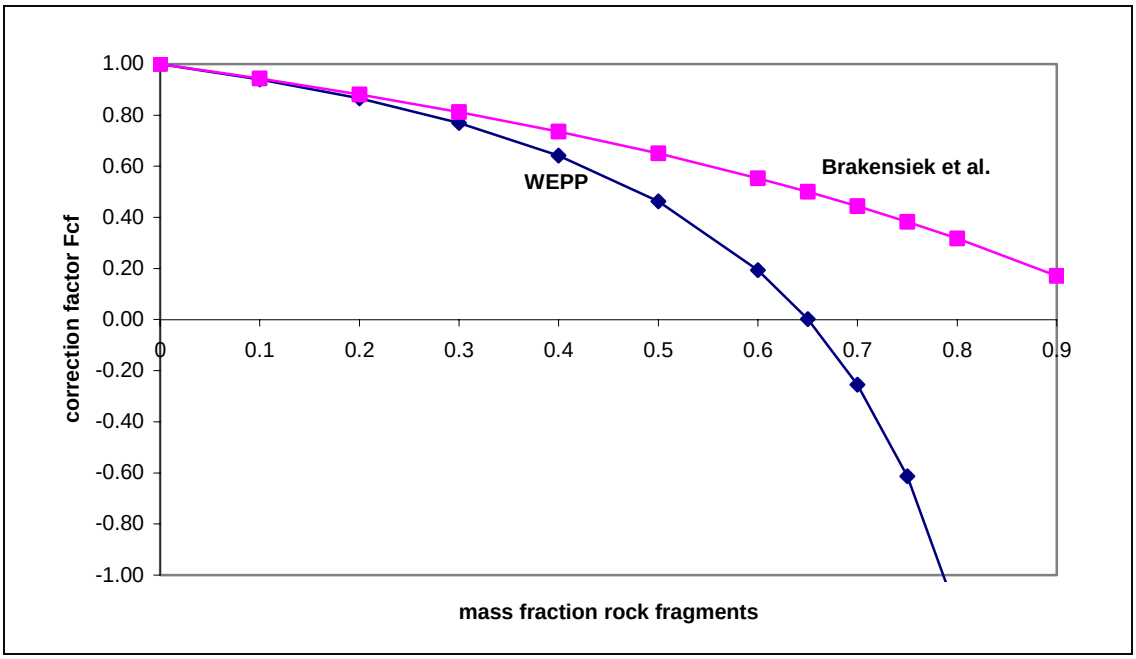

Figure 1. Graphical comparison of WEPP and original Brakensiek et al. (1986) corrections for rock fragment content; data from Table 1.