Soil Detachment Efficiency Coefficient Functions for an Unpaved Road in Southern Brazil

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Abstract

Soil detachment is a key parameter to describe the hydrosedimentological cycle in rural and urban watersheds. Few studies explore the applicability of equations for calculating soil detachment efficiency, especially in specific environments such as unpaved roads in *Pinus taeda L.* reforestation areas. The aim of this study was to compare the methodologies for estimation of soil detachment efficiency coefficient, available in the openLISEM hydrological model (Rauws and Govers 1988; Morgan et al. 1998; and Morgan 2001), for a section of an unpaved rural road in a *Pinus taeda* forest in Southern Brazil, over six contrasting rainfall events monitored in 2013. The results of the simulations were compared with monitored series of discharge and sediment production. The Morgan et al. (1998) function resulted in the lowest soil detachment rate, while the Rauws and Govers (1988) function presented better adjusted accumulated values, which are highly affected by the site properties and initial calibration. These results can help in calculating the coefficient of soil detachment by runoff in regions with similar climates.

1 Introduction

Soil detachment is an important parameter of the hydrosedimentological cycle, and its estimation is based on the simulation of the erosion by water drop and runoff [1], where the rate of sediment production caused by runoff depends mainly on its ability to disaggregate the soil, determined by soil properties, such as cohesion and hydraulic conductivity [2]. All methods used to calculate the soil detachment are based on the balance between erosion and deposition. The soil detachment efficiency coefficient generated in these calculations is mainly a result of soil cohesion, which provides specific values of erosion or deposition for the soil types of the basin [3–4].

Rauws and Govers [5] estimated the soil detachment efficiency coefficient through linear regression of soil cohesion versus critical shear velocity for different soil textures. Later, based on the studies of Rauws e Govers [5], Morgan et al. [6] and Morgan [7] proposed equations for the simulation of soil detachment for different soil textures, originally developed for the European Soil Erosion Model (EUROSEM) and Morgan-Morgan-Finney (MMF) model.

The equation Morgan et al. 1998 is solely based on soil cohesion, easily measured in the field. According to the authors there was no methodology for calculating the detachment efficiency coefficient for all soil types. Moreover, initial soil moisture and soil structure affect the relationship between soil cohesion and sediment detachment. However, these parameters are difficult to measure and yet not considered in the calculations [6].

The methodology proposed in Morgan 2001 in a review of the semi-empirical MMF model for forecasting erosion, represents a simplification of the work developed by Rauws and Govers [5]. According to Morgan [7], the soil detachment coefficient was not designed for all soil textures in its initial formulation, and the MMF model would tend to overestimate erosion values in specific conditions. In the revised version of the equation, the detachment coefficient highly depended on the soil texture, varying between 0.17 (clay soil) to 1 (sand soil).

All three equations developed to calculate the soil detachment coefficient by runoff suit different environments, with distinct soil properties and climatic conditions. Thus, the need to find the equation that provides the best results for compacted environments and runoff concentration, such as the unpaved road, has a key role in the understanding of the alteration of the natural conditions of the affected slopes, where the anthropization promotes changes in the soil properties and in the water flow conditions [8–9].

The unpaved roads accounts for most part of the erosion in forest environments, mainly due to the exposed soil and intermittent compaction by vehicle traffic, resulting in decreased infiltration rate and increased runoff [8–10]. In addition, the splash effect contributes to the formation of surface crust, which alters soil properties and, consequently, increases erosion [11–12]. Despite of the relevance of soil detachment for the understanding of the hydrogeomorphological dynamics in an unpaved road and its environmental impact, a comparative study of the different methodologies applied to the calculation of the soil detachment coefficient by runoff was not yet verified.

Hydrosedimentological processes in a watershed are a complex phenomenon and can be finely analyzed by hydrological models that simulates water discharge and erosion over precipitation events, key processes to be considered for the quantification of sediment accumulation in rural and urban catchments [13]. One of the most used and complete models that simulates runoff and soil erosion is the openLISEM, open-source version of Limburg Soil Erosion Model [1, 13–14]. The openLISEM is a reliable physically-based spatial hydrological model were the soil and watershed input parameters are defined by a raster file format, obtained through Geographical Information System (GIS). The model simulates runoff and soil erosion during rainfall events based on interception, water flux in the soil surface, potential erosion, and sediment deposition and transport [15]. Among the most important features, the model provides different methods to calculate soil detachment coefficient.

The simulation would make it possible to understand the mechanisms that characterize the occurrence of erosive processes and allow the calibration of the model in similar environments of low infiltration and high compaction [16]. Despite that, the openLISEM model has not been well explored in unpaved roads. Due to the number of climate and soil data needed for the application of the model, and its non-linear response to the input parameters, the model highly depends on the calibration, mainly under conditions that require specific combinations of parameters [17–18]. The model's application location will determine the calibration conditions, by adjusting a set of input parameters that uniquely define the behavior of the model's responses. The applicability of the openLISEM model is quite diverse, including from large watersheds to small stretches of unpaved roads, being possible to accurately describe the erosive mechanisms of small areas [1].

Accordingly, here we examine the differences between the most used soil detachment equations of the openLISEM model for an unpaved road in a Pinus taeda L. forest in Southern Brazil. Our goal is contribute to the modeling of erosion in unpaved roads, mainly with regard to soil detachment by runoff.

2 Methods

2.1 Site description. The study area was an unpaved road section in Rio Negrinho city (Santa Catarina state), Southern Brazil (Fig. 1). The region has climate type humid subtropical with temperate summer (Cfb) with an average temperature in the warmest month below 22ºC and average annual precipitation around 1500 mm, totaling between 138 and 164 days of rain over the year [19–20]. The area is mainly represented by inceptisols [21] originated from the sedimentary deposits of Itararé e Guatá formations (shales and claystones) of the glacial and periglacial periods between the Superior Carboniferous and the Middle Permian [22], and is located between the First plateau and the Canoinhas plateau, at 960 m altitude.

The land use in the region is mainly represented by Pinus taeda L. forests, where the unpaved roads inside the forest are used only for maintenance and logging. A portion of an unpaved road of 41.5 m length, 3% of slope and 0.167 ha was selected for the study. The road is in the watershed, with no outflow contribution from the lateral areas of Pinus plantation.

2.2 Monitoring and Measurement. The water flow rate was monitored by a tipper flow meter and a turbidimeter, and the series of sediment production were obtained in the laboratory. The precipitation was measured by a pluviometer WaterLog H-340 with temporal resolution of 1 minute [24]. The monitoring was performed during the precipitation events of February, 2013, humid season in the region when are normally observed variable rain intensities (Table 1).

Table 1
Precipitation events monitored in February, 2013

Event	**1**	**2**	**3**	**4**	**5**	**6**
Date	Feb 3	Feb 7	Feb 8	Feb 10	Feb 12	Feb 14
Precipitation (mm)	13.0	8.6	15.5	2.0	6.6	6.9
Event duration (min)	150	800	200	150	180	40
I_{1min}[a]	30	15	76	15	15	61

[a] I_{1min} is the maximum precipitation intensity in *i* minutes.

The saturated hydraulic conductivity (*Ksat*) was measured using a tension infiltrometer, model 09.09 (Eijkelkamp Agrisearch Equipment, Giesbeek, Netherlands). The soil cohesion (*coh*) was measured by a Vane Tester (Eijkelkamp Agrisearch Equipment Field Inspection Vane Tester). The soil granulometry (*d50* and *d90*) was measured by a laser diffractor (Microtac MRB, Inc). The determination of *Ksat*, *coh*, *d50* and *d90* was performed according to described in Schultz [24].

2.3 Model’s input parameters and calibration. The simulation of the precipitation events was performed using the openLISEM 5.97 model, based on the elevation map of the road terrain parcel. The elevation map of the road terrain was obtained through the Digital Terrain Model (DTM) elaborated with a total station and introduced in the PCRaster, software for manipulation raster maps.

The road section features and model standard input parameters were established according to previous measurements and estimates based on the literature [23–24] (Table 2).

Table 2
Calibrated input parameter values for openLISEM model

Parameter	Code	Unit	Measured	Calibrated
Manning coefficient	*n*	dimensionless	-	0.16
Random roughness	*rr*	mm	-	0.01
Saturated hydraulic conductivity	*Ksat*	mm h^{-1}	0.09-68	0.15
Suction at the wetting front	Ψ_{soil}	mmH_2O	-	11.1
Aggregate stability	*aggrstab*	dimensionless	-	200
Soil cohesion	*coh*	kPa	30	30
Mean aggregate diameter – 50% of the aggregates	*d50*	µm	30	30
Mean aggregate diameter – 90% of the aggregates	*d90*	µm	260	260
Initial soil moisture content	θ_i	dimensionless	-	0-0.31
Porosity	θ_s	dimensionless	-	0.37
Soil depth	z	mm	-	1000

Simulations were performed for each precipitation event using the soil detachment efficiency coefficient equations based on Rauws and Govers [5] Morgan et al. [6] and Morgan [7] available in the openLISEM 5.97 package. The use of different detachment equations in this study is also possible due the silty clay properties of the soil of the study area.

The Rauws and Govers [5] model, named Rauws and Govers 1988, estimated the detachment coefficient according to the Eq. 1 [15]. The model is based on the relation between the minimum shear velocity and the critical shear velocity for the formation of furrows and ravines.

$$y = \frac{u_{gmin}}{u_{gerit}} = \frac{1}{0.89 + 0.56 * coh}$$

1

where: *y* is the efficiency coefficient (dimensionless); u_{gmin} is the minimum critical shear velocity (cm s^{-1}); u_{gerit} is the shear velocity that initiates the formation of river furrows (cm s^{-1}); *coh* is the cohesion of a saturated soil (kPa).

The output of the Eq. 1 is used in the Eq. 2 to verify the detachment rate, which is affected by the soil cohesion [15].

$$DF = y * w * v_s * (TC - C)$$

2

where: *DF* is the rate of soil particle detachment by flow (kg m^{-3}); *y* is the efficiency coefficient; *w* is the flow height (m); v_s is the velocity of the particles sedimentation (m s^{-1}); *TC* is the transport capacity (kg m^{-3}); *C* is the particle concentration in the water flow (kg m^{-3}).

The equation proposed by Morgan et al. [6], named Morgan et al. 1998, estimates the detachment coefficient according to the Eq. 3.

$$y = 0.79 * e^{-0.85coh}$$

3

where: *y* is the detachment efficiency coefficient; *coh* is the soil cohesion (kPa).

The equation described by Morgan [7], called Morgan 2001, estimated the efficiency coefficient according to the Eq. 4.

$$y = \frac{1}{2 * coh}$$

4

where: *y* is the detachment efficiency coefficient; *coh* is the soil cohesion (kPa).

The *y* coefficient obtained in the Eq. 4 is used in the Eq. 5 to calculate the soil particle detachment by flow [7].

$$H = y * Q^{1.5} sinS\left(1 - GC\right) * 10^{-3}$$

5

where: *Q* is the water flow; *S* is the slope; *GC* is the soil cover fraction.

The data series of discharge (Q_{sim}) and sediment production (Qs_{sim}) simulated by the openLISEM were compared to the monitored discharge (Q_{obs}) and sediment production (Qs_{obs}), using the Nash–Sutcliffe (*NSE*) model efficiency coefficients [25]. *NSE* values vary from -∞ to 1, where 1 means perfect adjustment (Eq. 6).

$$NSE = 1 - \left[\frac{\sum \left(P_{sim} - P_{obs}\right)^2}{\sum \left(P_{obs} - \overline{P}_{obs}\right)^2}\right]$$

6

where: P_{sim} is the simulated parameter; P_{obs} is the observed parameter; $\overline{P}_{obs}$ is the average of the observed parameter. *NSE* values vary from -∞ to 1, where 1 means perfect adjustment.

Considering *NSE* = 1 as the optimal result, the combination of parameters that produced discharge and sediment production series with a coefficient closer to 1 was the scenario considered the best match for reality.

2.4 Statistical analysis. Total discharge (Q), sediment production (Q_s), splash erosion (E_s), runoff erosion (E_r), deposition (D) and the soil detachment efficiency coefficient were compared between simulations using n-way ANOVA and the multiple comparison test of the Multcompare procedure using MATLAB R2015b (MathWorks, Natick, MA) considering the Tukey test (α = 0.01 of significance) to compare between the soil detachment efficiency coefficient functions.

3 Results

Q was similar between soil detachment efficiency coefficient equations, while Qs was significant different for the unpaved road parcel for most part of the precipitation events (Table 3). The best results were observed when using the equation proposed in Morgan 2001. For the first event, Morgan et al. 1998 equation resulted in the highest *NSE* values.

The equation proposed by Morgan et al. 1998 resulted in positive *NSE* coefficient for the sediment production in the first rain event (Table 3), minimizing the observed values, which were significative lower. However, the Morgan et al. 1998 equation provided the best *NSE* coefficients in sediment production in the events 1, 2 and 3, comparing to the Rauws and Govers 1988 equation. Despite the results presented by Rauws and Govers 1988 equation, the *NSE* coefficients should not be considered alone. The *NSE* coefficient can be affected by the features of the data series that does not represent the best adjustment between the simulated and observed values, but provides a better equilibrium between the data series. The Morgan 2001 equation better represented the sediment production over time, while Rauws and Govers 1988 equation provided better adjusted accumulated results.

Table 3
NSE coefficients for total discharge (Q) and sediment production (Q_s), for different soil detachment efficiency coefficient equations

Event	Rauws and Govers 1988		Morgan et al. 1998		Morgan 2001	
	$Q_{obs}{}^{a}$ x $Q_{sim}{}^{b}$	$Qs_{obs}{}^{c}$ x $Qs_{sim}{}^{d}$	$Q_{obs}{}^{a}$ x $Q_{sim}{}^{b}$	$Qs_{obs}{}^{c}$ x $Qs_{sim}{}^{d}$	$Q_{obs}{}^{a}$ x $Q_{sim}{}^{b}$	$Qs_{obs}{}^{c}$ x $Qs_{sim}{}^{d}$
1	0.33	0.63**	0.33	0.73**	0.33	0.25**
2	-0.58	-3.81**	-0.58	-0.07**	-0.58	0.51**
3	0.69	-0.57**	0.69	-0.07**	0.69	0.38**
4	0.52	-0.23	0.52	-0.23	0.52	-0.23
5	-15.32	-0.87	-15.32	-0.87	-15.32	-0.87
6	-0.30	-0.28**	-0.30	-0.42**	-0.30	0.66**

[a] Q_{obs} is the observed discharge; [b] Q_{sim} is the simulated discharge; [c] Q_{Sobs} is the observed sediment production; [d] Q_{Ssim} is the simulated sediment production. **Significative difference between soil detachment efficiency coefficient equations (P < 0.01).

Morgan et al. 1998 equation resulted in lower runoff erosion, while Rauws and Govers 1998 equation presented the highest runoff erosion values, which were significant closer to the observed values. The Morgan et al. 1998 and Morgan 2001 subestimated the runoff erosion over the events (Table 4).

Table 4
Sediment production (Q_s), splash erosion (E_s), runoff erosion (E_r) and deposition (D) simulated by the openLISEM using different soil detachment efficiency coefficient equations

Parameter	Event					
	1	2	3	4	5	6
Rauws and Govers 1988						
Q_s (kg ha^{-1})	109.40**	5.71**	143.87**	0.00	0.00	85.17**
E_s (kg)	3.57	3.64	4.30	0.98	2.92	1.54
E_r (kg)	6.53**	0.13	9.26**	0.00	0.00	6.39**
D (kg)	7.75**	3.65	10.46**	0.98	2.92	6.10**
Morgan et al. 1998						
Q_s (kg ha^{-1})	0.18**	0.00**	0.70**	0.00	0.00	0.71**
E_s (kg)	3.57	3.64	4.30	0.98	2.92	1.54
E_r (kg)	0.00**	0.00	0.00**	0.00	0.00	0.00**
D (kg)	3.57**	3.64	4.28**	0.98	2.92	1.53**
Morgan 2001						
Q_s (kg ha^{-1})	32.84**	1.72**	44.14**	0.00	0.00	26.31**
E_s (kg)	3.57	3.64	4.30	0.98	2.92	1.54
E_r (kg)	2.00**	0.04	2.87**	0.00	0.00	1.98**
D (kg)	4.86**	3.64	6.21**	0.98	2.92	2.96**

**Significative difference between soil detachment efficiency coefficient equations (P < 0.01).

The splash erosion simulations were not affected by the method of calculation of the soil detachment efficiency. However, we observed significant modifications in the sediment production, runoff erosion and deposition between the soil detachment efficiency coefficient equations (Table 4), which can be also observed by the variability of the *NSE* values between simulated and observed sediment production (Table 3).

The heat maps indicated different behavior of discharge and sediment production for the different soil detachment equations (Figs. 2 and 3). The equation Rauws and Govers 1988 generated the most expressive results, with higher peaks in relation to the equation Morgan et al. 1998 (Fig. 2). On the other hand, the sediment production series generated with the Morgan 2001 equation underestimated the monitored series, presenting the lowest values of the tested equations (Fig. 3).

The comparison between the results of the three soil detachment efficiency coefficient equations for the range of possible soil cohesion values can be seen in Fig. 4.

The soil detachment efficiency coefficient was significant different between equations, considering the range of 1 to 200 KPa, which corroborates the indications of the openLISEM model regarding the specific soil physical conditions in which each equation was designed.

4 Discussion

In similar work in a rural watershed in Southern Brazil, Morgan et al. 1998 equation provided the best sediment production results in the openLISEM 5.2 model [4], opposite to the observed in the present work, probably due to properties of the analyzed area and the differences in the calibration.

According to Morgan [7], the MMF model is suitable for simulations of lower erosion rate events, however, under specific conditions it might subestimate the soil erosion, as observed in the present work. According to Mondal et al. [26], the MMF model showed the best adjustments, with the lowest soil loss values. However, according to the authors, showed the most discrepant soil loss values, when compared to USLE and RUSLE models.

Despite the clear recommendation in the openLISEM model for the use of the Morgan 2001 and Morgan et al. 1998 equations for a wider variety of soils, and the Rauws and Govers 1988 equation for silty soils, the simulations present too broad results.

The soil compaction and drainage concentration promoted by the roads [10], which seriously compromise the cohesion and energy of the soil detachment by the water, can alter the relation between the soil properties and the erosion generated by the drainage [27]. It can affect the empirical equations that relate soil cohesion to detachment, making the modeling of erosive phenomenon a complex task in altered environments.

Soil cohesion is not the only factor that determines soil detachment by runoff [28], which can also be seen in Eq. 2. Parameters such as flow height and particle transport capacity by the flow are directly related to detachment, although the empirical equations proposed by Rauws e Govers 1988, Morgan et al. 1998 e Morgan 2001 do not present considerations regarding the initial moisture content or the flow characteristics, key factors in the study of soil detachment [28].

Rauws and Govers [5] indicated that the erosive behavior of clayey soils can be significant different from that considered in the elaboration of the equation obtained by linear regression between soil cohesion and critical values of effective shear velocity, which is used in Eq. 1 of the present work. This can explain some of the poor results of the simulations of the openLISEM model. However, more complex factors can also affect the performance of the simulations, such as the effect of the precipitation on the runoff erosion and soil detachment. According to Rauws and Govers [5], the power effect of the precipitation significantly increases erosion, especially at low flow velocities (< 3 cm s^{-1}).

5 Conclusion

The Morgan 2001 soil detachment efficiency equation provided the highest efficiency coefficients for the simulated sediment production, while the Rauws and Govers 1988 equation resulted on the best accumulated values, better adjusted to the observed values. The choose by the soil detachment efficiency coefficient equation hold significant importance in the performance of the simulation by the openLISEM model, which is mainly affected by the conditions of the analyzed area and the initial calibration of the openLISEM model. On unpaved roads, the empirical relationships between soil cohesion and soil detachment may be different, due to compaction conditions and runoff concentration.

Declarations

Conflicts of Interests

On behalf of all authors, the corresponding author states that there is no conflict of interest.

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Author Contribution

L.J.: Conceptualization, Formal analysis; Methodology; Roles/Writing – original draft; and Writing – review & editing.G.B.S.: Conceptualization, Formal analysis; Methodology; Roles/Writing – original draft; and Writing – review & editing.D.J.: Roles/Writing – original draft; and Writing – review & editing.I.S.: Conceptualization; Formal analysis; Methodology; Roles/Writing – original draft; and Writing – review & editing.All authors read and approved the final manuscript.

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Data Availability

The datasets generated during and/or analyzed during this study are available from the corresponding author on request.

References

1. De Roo, A. P. J., Wesseling, C. G., & Ritsema, C. J. (1996). LISEM: a single-event physically based hydrological and soil erosion model for drainage basins. I: theory, input and output. *Hydrological Processes*, *10*, 1107–1117. https://doi.org/10.1002/(SICI)1099-1085(199608)10:8%3c1107::AID-HYP415%3e3.0.CO;2-4
2. Nearing, M. A., Bradford, J. M., & Parker, S. C. (1991). Soil detachment by shallow flow at low slopes. *Soil Science Society of America Journal*, *55*, 339–344.
3. Smith, R. E., Goodrich, D., & Quinton, J. N. (1995). Dynamic, distributed simulation of watershed erosion: the KINEROS2 and EUROSEM Models. *Journal of Soil and Water Conservation*, *50*, 517–520.
4. Schlesner, A. A. (2017). Modelagem da produção de sedimentos em bacia hidrográfica rural sob diferentes equações de eficiência de desagregação do modelo erosivo LISEM. Dissertation, Universidade Federal de Santa Maria. https://repositorio.ufsm.br/bitstream/handle/1/16037/DIS_PPGCS_2017_SCHLESNER_ALEXANDRE.pdf?sequence=1&isAllowed=y
5. Rauws, G., & Govers, G. (1988). Hydraulic and soil mechanical aspects of rill generation on agricultural soils. *Journal Of Soil Science*, *39*, 111–124. https://doi.org/10.1111/j.1365-2389.1988.tb01199.x
6. Morgan, R. P. C., Quinton, J. N., Smith, R. E., Govers, G., Poesen, J. W. A., Auerswald, K., Chisci, G., Torri, D., & Styczen, M. E. (1998). The European Soil Erosion Model (Eurosem): a dynamic approach for predicting sediment transport from fields and small catchments. *Earth Surface Processes and Landforms*, *23*, 527–544.
7. Morgan, R. P. C. (2001). A simple approach to soil loss prediction: a revised Morgan-Morgan-Finney model. *Catena*, *44*, 305–322.
8. Neary, D. G., & Hornbeck, J. W. (1994). Impacts of harvesting and associated practices on off-site environmental quality. In D. G. Neary (Ed.), *Impacts of forest harvesting on long-term site productivity* (pp. 81–119). Chapman and Hall. https://www.springer.com/earth+sciences+and+geography/earth+system+sciences/journal/40808
9. Garcia, A. R., Machado, C. C., Silva, E., de Souza, A. P., & Pereira, R. S. (2003). Volume de enxurrada e perda de solo em estradas florestais em condições de chuva natural. *Rev Árvore*, *27*, 535–542. http://www.scielo.br/pdf/rarv/v27n4/a14v27n4.pdf
10. Reid, L. M., & Dunne, T. (1984). Sediment production from forest road surfaces. *Water Resources Research*, *20*(11), 1753–1761.
11. Ellison, W. D. (1945). Some Effects of Raindrops and Surface-Flow on Soil Erosion and Infiltration. *Transactions of American Geophysical Union*, v.26, n.3, pp. 415–429, Dez.

12. McIntyre, D. S. (1958). Soil Splash and The Formation of Surface Crusts by Raindrop Impact. *Soil Science*, *85*, 261–266.
13. Baartman, J., Jetten, V. G., Ritsema, C. J., & De Vente, J. (2012). Exploring effects of rainfall intensity and duration on soil erosion at the catchment scale using openLISEM: Prado catchment, SE Spain. *Hydrological Processes*, *26*, 1034–1049. https://doi.org/10.1002/hyp.8196
14. Takken, I., Beuselinck, L., Nachtergaele, J., Govers, G., Poesen, J., & Degraer, G. (1999). Spatial evaluation of a physically-based distributed erosion model (LISEM). *Catena*, *37*, 431–447. https://doi.org/10.1016/S0341-8162(99)00031-4
15. De Roo, A., Jetten, V., Wesseling, C., & Ritsema, C. (1998). LISEM: a physically-based hydrologic and soil erosion catchment model. In: Boardman, J., Favis-Mortlock, D. (Eds.) *Modelling Soil Erosion by Water*. NATO ASI Series (Series I: Global Environmental Change) 55:429–440.
16. Lelis, T. A., Calijuri, M. L., Santiago, A. F., Lima, D. C., & Rocha, E. O. (2012). Análise de sensibilidade e calibração do modelo SWAT em bacia hidrográfica da Região Sudeste do Brasil. *Revista Brasileira de Ciência do Solo*, *36*, 623–634.
17. Jetten, V., De Roo, A. D., & Guérif, J. (1998). Sensitivity of the model LISEM to variables related to agriculture. In J. Boardman, & D. Favis-Mortlock (Eds.), *Modelling soil erosion by water* (pp. 339–349). NATO Scientific Affairs Division.
18. Christofoletti, A. (1999). *Modelagem de sistemas ambientais*. Edgard Blücher.
19. Thomé, V. M. R., Zampieri, S., Braga, H. J., Pandolfo, C., Silva Júnior, V. P., Bacic, I., Laus Neto, J., Soldateli, D., Gebler, E., Ore, J. D., Echeverria, L., Mattos, M., & Suski, P. P. (1999). *Zoneamento Agroecológico e Socioeconômico de Santa Catarina*. Epagri, Florianópolis 1000, pp 236 http://ciram.epagri.sc.gov.br/images/documentos/ZonAgroecoMapas.pdf
20. Santos, I. (2009). Monitoramento e modelagem de processos hidrogeomorfológicos: Mecanismos de geração de escoamento e conectividade hidrológica. Dissertation, Programa de Pós-Graduação em Geografia, Universidade Federal de Santa Catarina. http://repositorio.ufsc.br/xmlui/handle/123456789/92207
21. EMBRAPA SOLOS (2020). *Solos do Estado de Santa Catarina*. Embrapa: Boletim de Pesquisa e Desenvolvimento n. 46, 2004. Escala 1:250.000. Disponível em: <http://ciram.epagri.sc.gov.br/index.php?option=com_content&view=article&id=1172&Itemid=543> Acesso em: 01 Set.
22. CPRM. (2014). *Serviço Geológico do Brasil*. Mapa geológico do estado de Santa Catarina. *Porto Alegre Escala*, *1*, 500000. http://rigeo.cprm.gov.br/xmlui/handle/doc/17996?show=full
23. Jerszurki, L., Schultz, G. B., Jerszurki, D., & Santos, I. (2022). Sensitivity analysis of the OpenLISEM model: calibration for an unpaved road in Southern Brazil. *Modeling Earth Systems and Environment*, *8*, 3089–3102. https://doi.org/10.1007/s40808-021-01288-0
24. Schultz, G. B. (2013). Avaliação do processo de produção de sedimentos em um trecho de estrada não pavimentada. Dissertation, Universidade Federal do Paraná. http://hdl.handle.net/1884/36540
25. Nash, J. E., & Sutcliffe, J. V. (1970). River flow forecasting through conceptual models part I—a discussion of principles. *Journal Of Hydrology*, *3*, 282–290. http://www.sciencedirect.com/science/article/pii/0022169470902556

26. Mondal, A., Khare, D., & Kundu, S. (2018). A comparative study of soil erosion modelling by MMF, USLE and RUSLE. *Geocarto International*, *33*(1), 89–103.
27. Cao, L., Zhang, K., & Zhang, W. (2009). Detachment of road surface soil by flowing water. *Catena*, *76*, 155–162.
28. Owoputi, L. O., & Stolte, W. J. (1995). Soil Detachment in the Physically Based Soil Erosion Process: A Review. *Transactions of the ASAE*, *38*, 1099–1110.

Figures

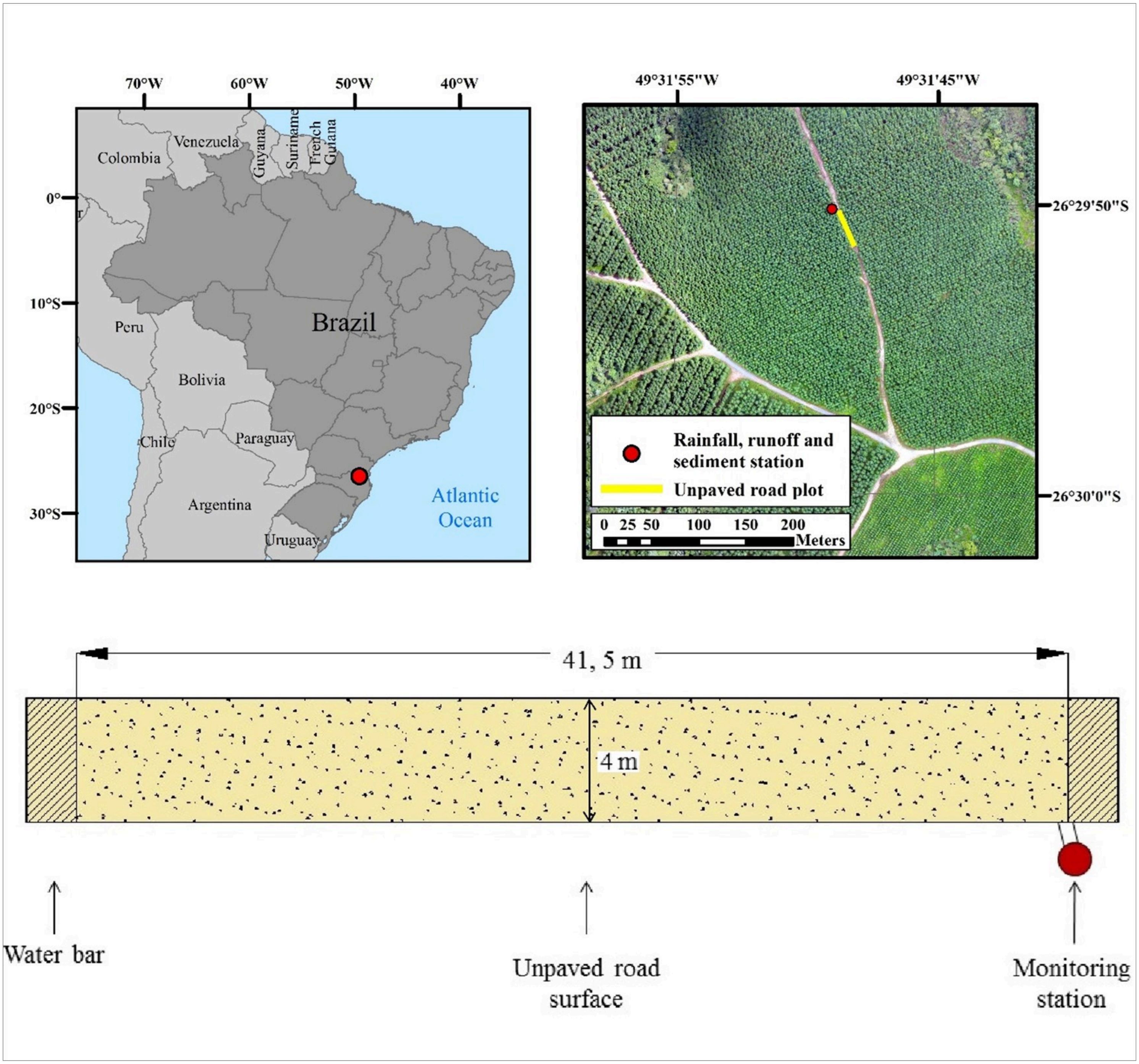

Figure 1

Localization of the study area [23]

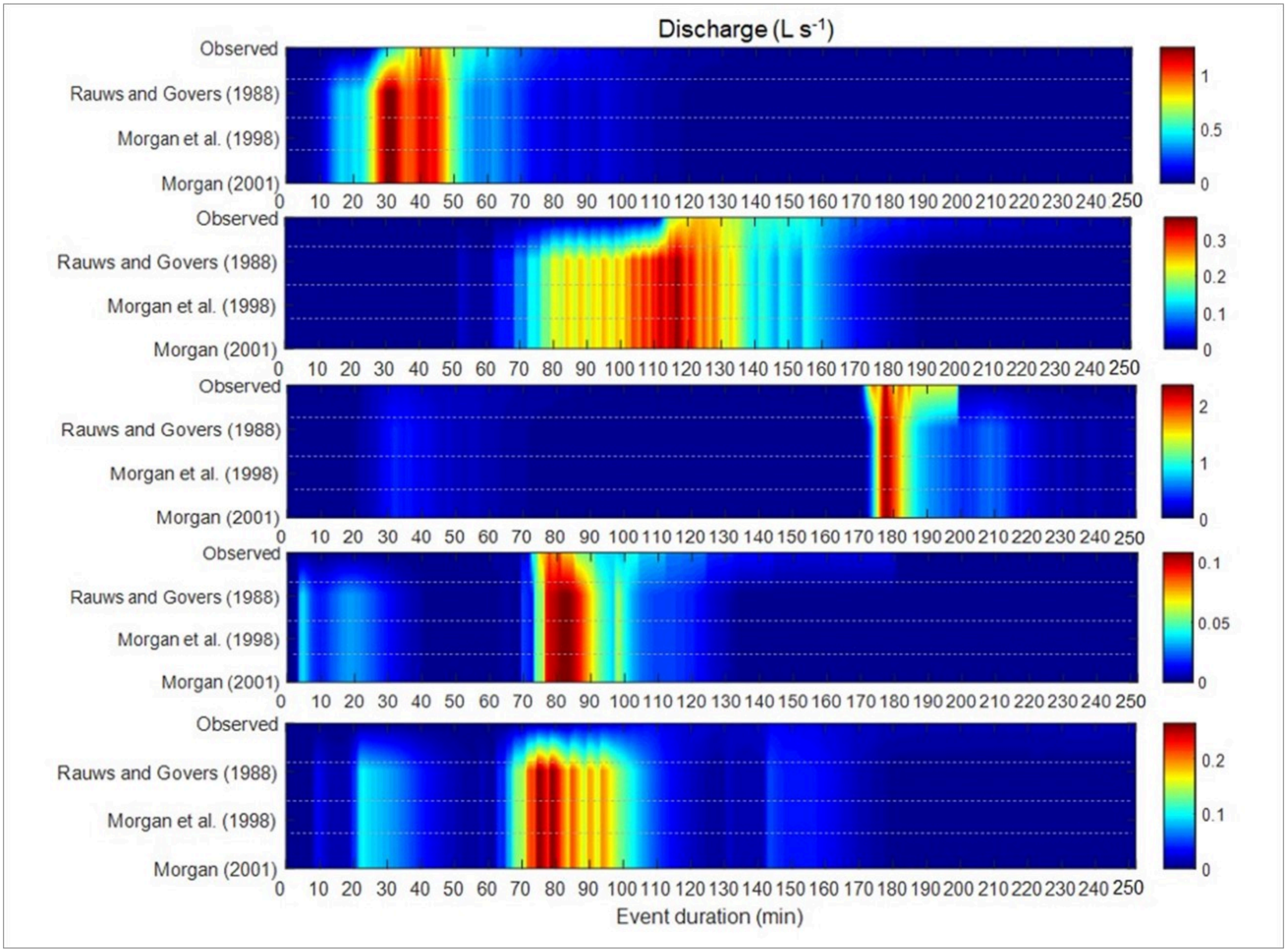

Figure 2

Total discharge simulated by the openLISEM using different soil detachment efficiency coefficient equations, over precipitation events

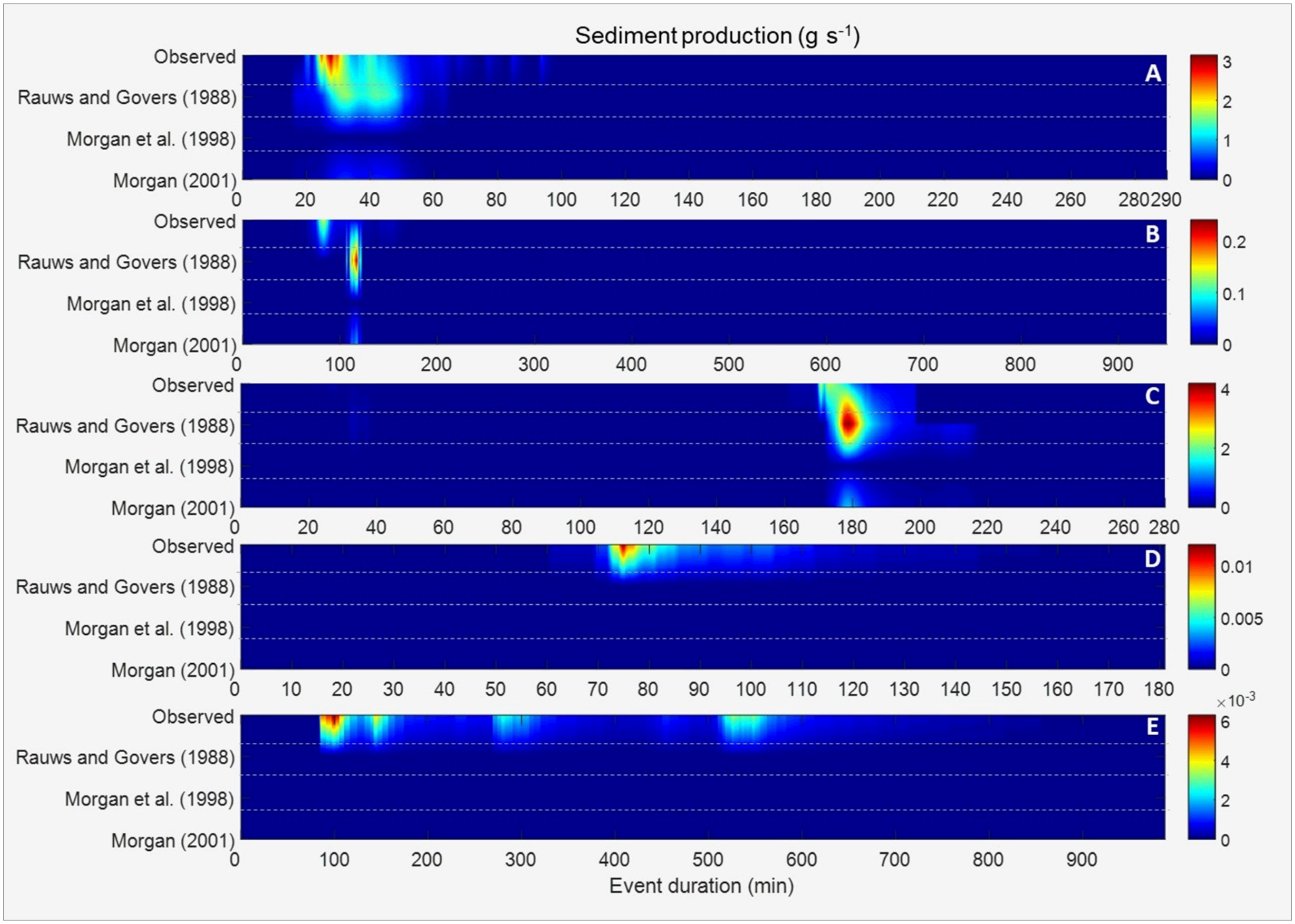

Figure 3

Sediment production simulated by the openLISEM using different soil detachment efficiency coefficient equations, over precipitation events

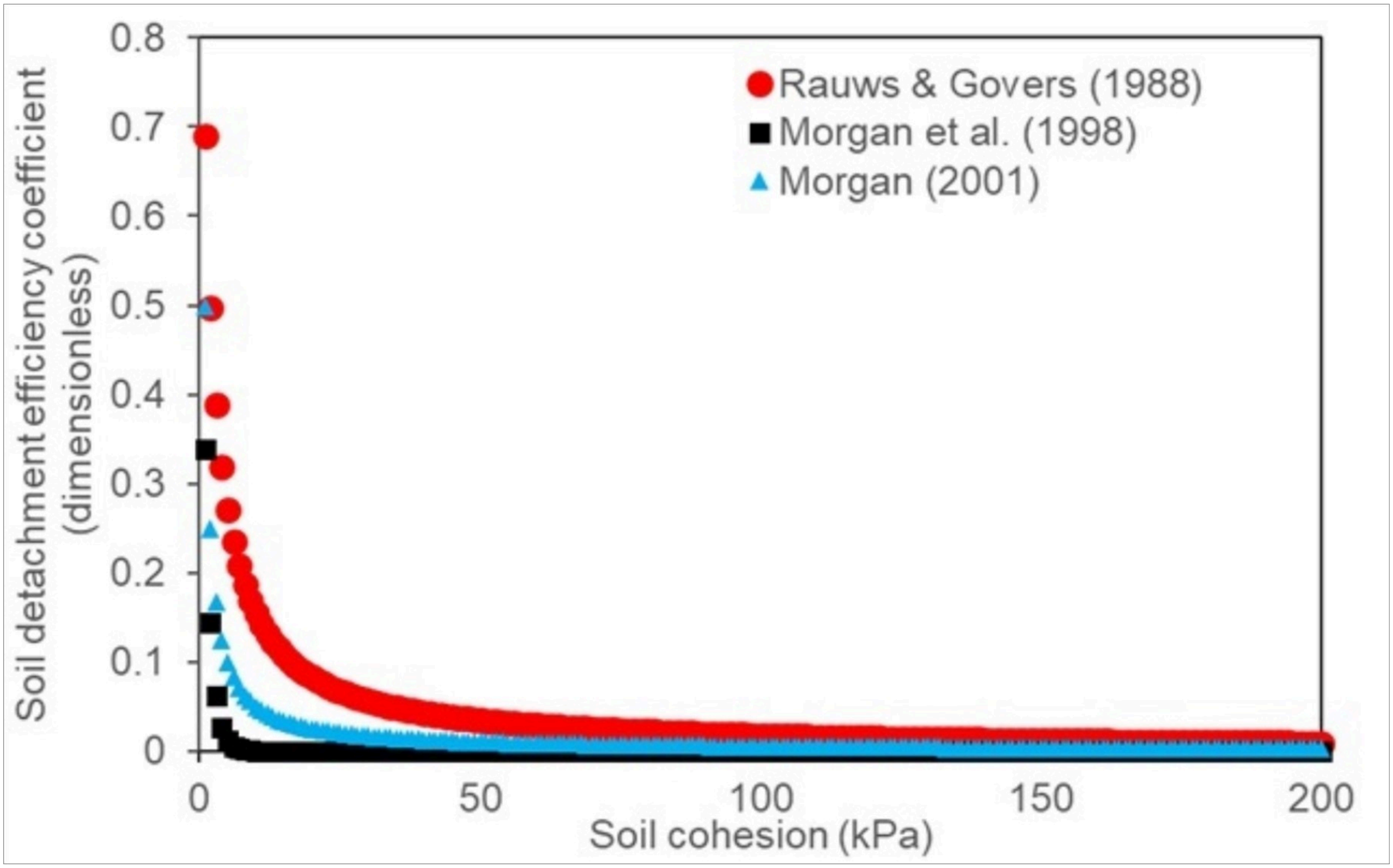

Figure 4

Soil detachment efficiency coefficient simulated by the openLISEM using different soil detachment efficiency coefficient equations as a function soil cohesion