<table>
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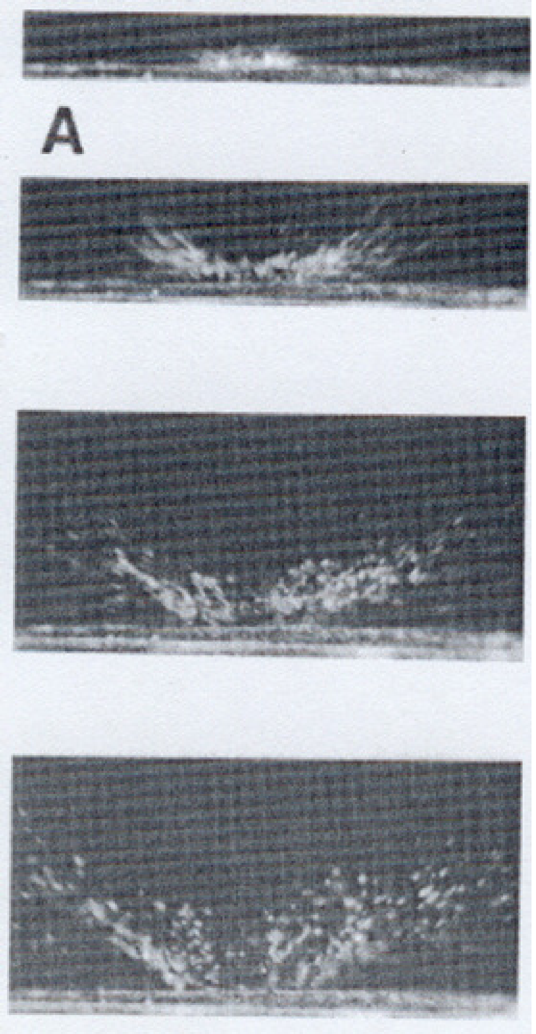
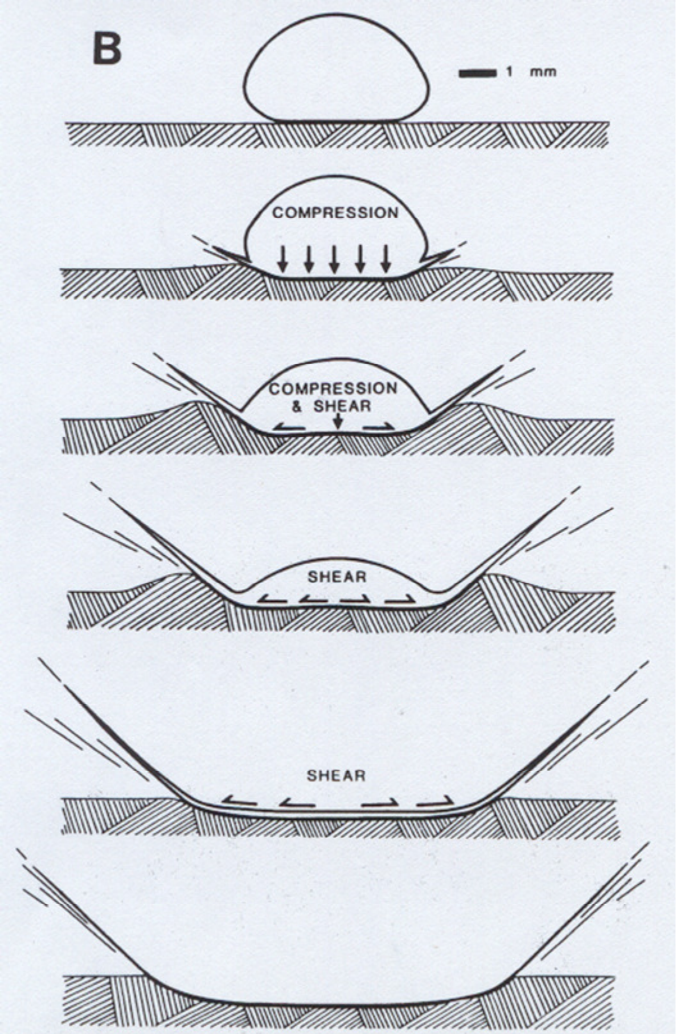
<td> </td>
<td> </td>
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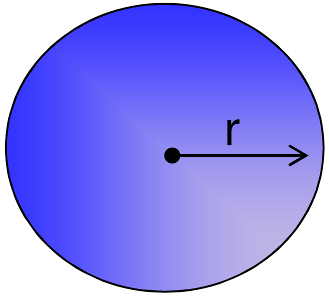
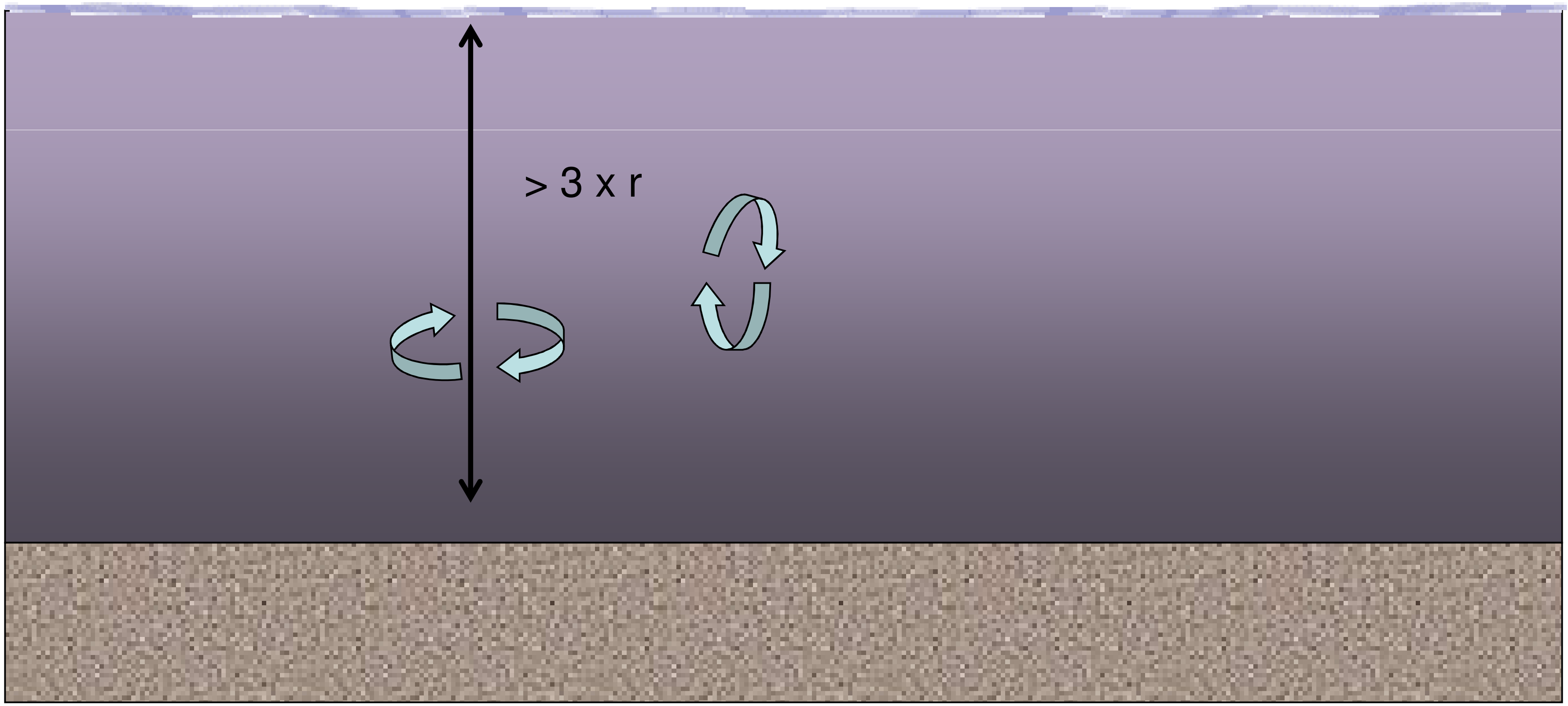
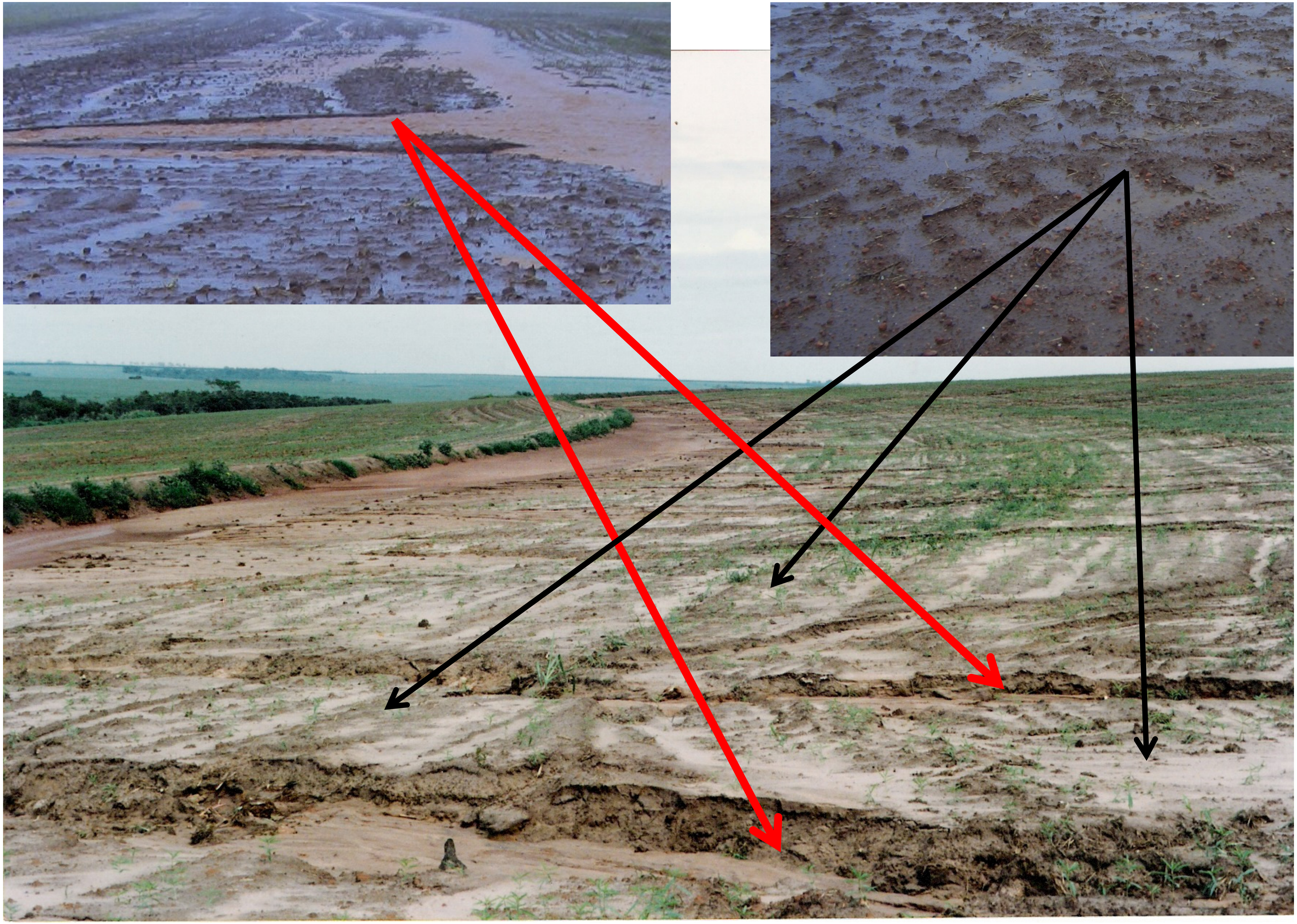
<tr>
<td colspan="2">low shear strength $\tau = 2.6$ kPa</td>
</tr>
</table>

Capacidade de transporte







Erosividade da Chuva

Quantidade de Chuva

-Dados de chuva em totais ou médias mensais ou anuais pouco significam em relação à erosão.

- Dados de chuva totais diários, limitados a observações a cada 24hs, pouco significado em relação à erosão.

Distribuição da chuva

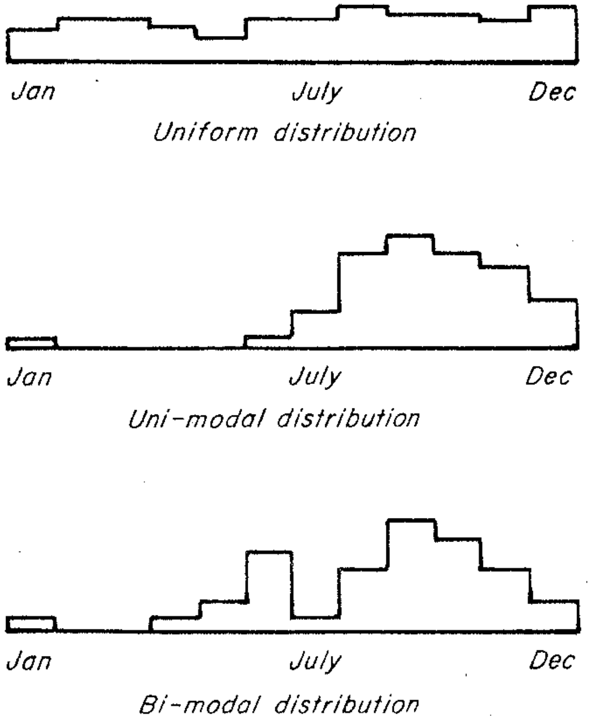


FIGURE 3.1 *Patterns of distribution of annual rainfall*

Intensidade da Chuva:

- fator mais importante

- quanto maior a intensidade da chuva maior a perda por erosão

  exemplo: para uma chuva total de 21mm, uma intensidade de 7,9mm/h produziu uma perda de terra 100 vezes maior que uma de 1mm/h

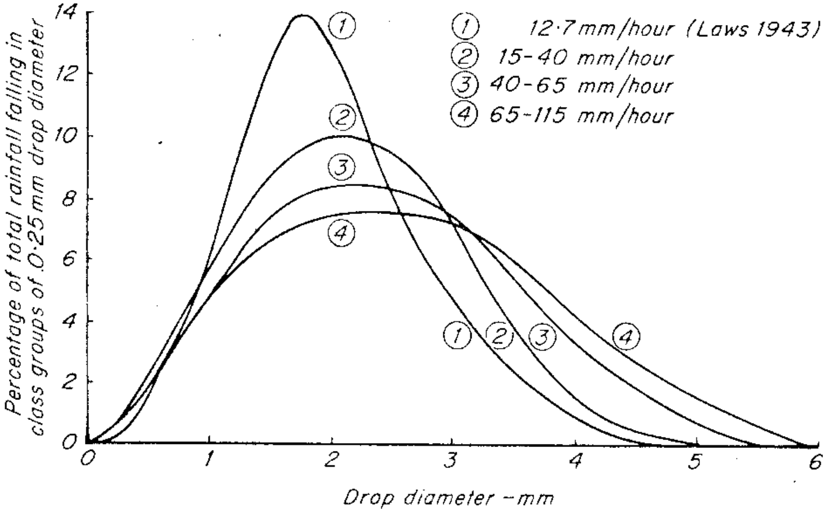


FIGURE 3.4 *Drop size distribution at low and medium intensities*

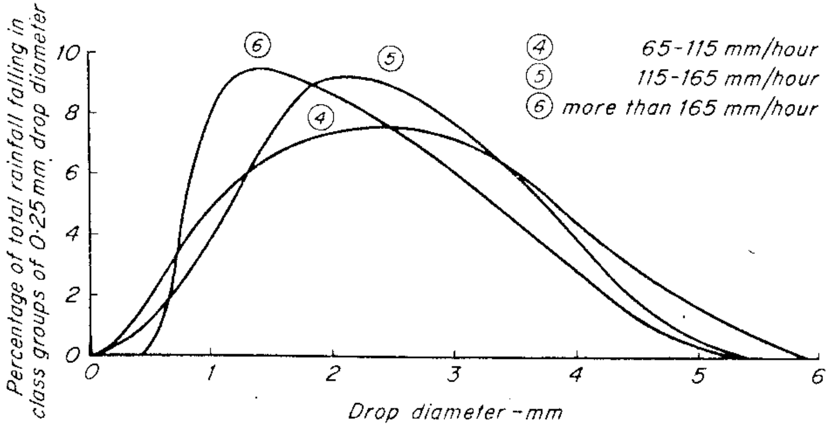


FIGURE 3.5 *Drop size distribution at high intensities*

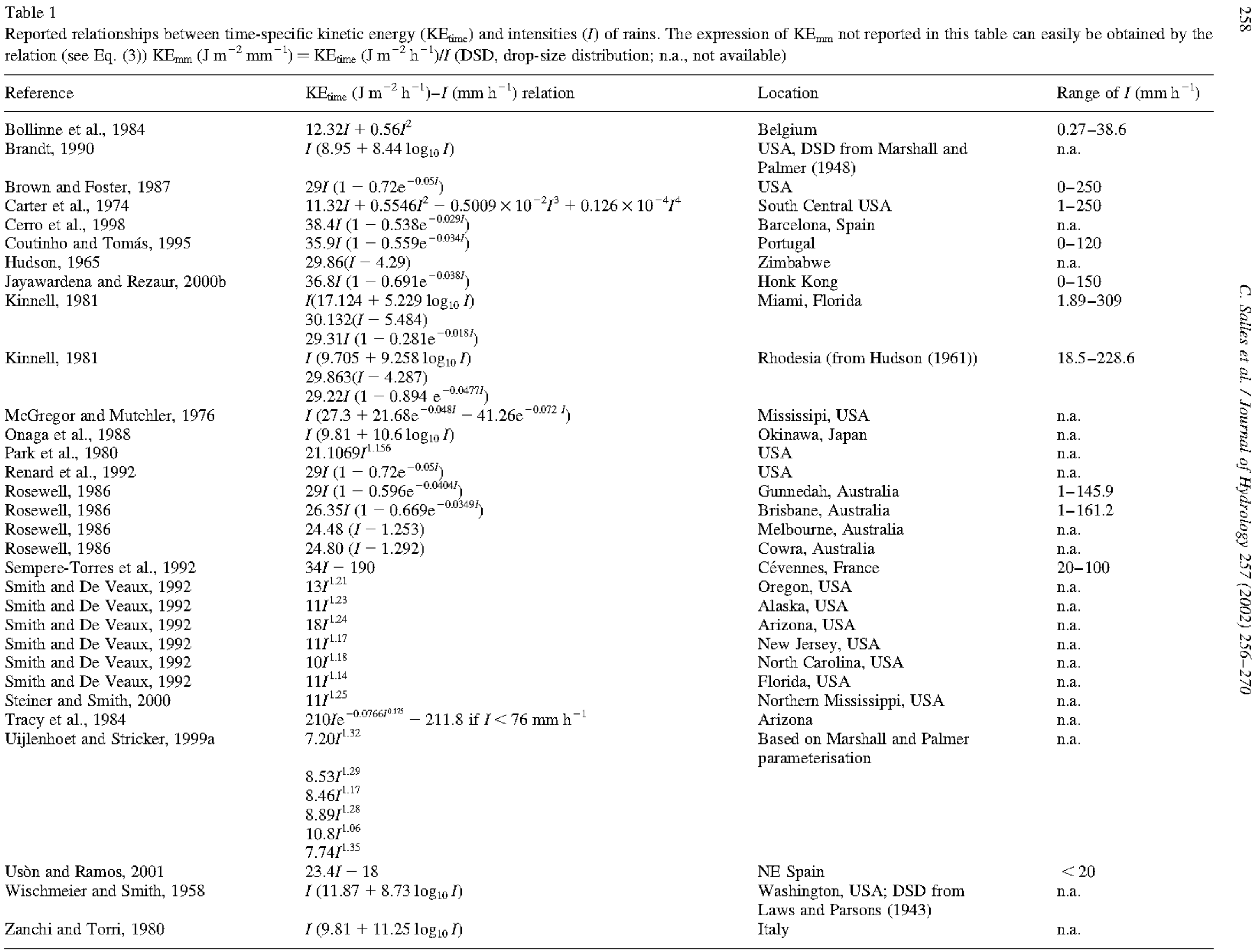


Table 1

Reported relationships between time-specific kinetic energy (KE_{time}) and intensities (I) of rains. The expression of KE_{mm} not reported in this table can easily be obtained by the relation (see Eq. (3)) KE_{mm} ($J\,m^{-2}\,mm^{-1}$) = KE_{time} ($J\,m^{-2}\,h^{-1}$)/I (DSD, drop-size distribution; n.a., not available)

Reference	KE_{time} ($J\,m^{-2}\,h^{-1}$)–I ($mm\,h^{-1}$) relation	Location	Range of I ($mm\,h^{-1}$)
Bollinne et al., 1984	$12.32I + 0.56I^2$	Belgium	0.27–38.6
Brandt, 1990	$I\,(8.95 + 8.44\log_{10} I)$	USA, DSD from Marshall and Palmer (1948)	n.a.
Brown and Foster, 1987	$29I\,(1 - 0.72e^{-0.05I})$	USA	0–250
Carter et al., 1974	$11.32I + 0.5546I^2 - 0.5009 \times 10^{-2}I^3 + 0.126 \times 10^{-4}I^4$	South Central USA	1–250
Cerro et al., 1998	$38.4I\,(1 - 0.538e^{-0.029I})$	Barcelona, Spain	n.a.
Coutinho and Tomás, 1995	$35.9I\,(1 - 0.559e^{-0.034I})$	Portugal	0–120
Hudson, 1965	$29.86(I - 4.29)$	Zimbabwe	n.a.
Jayawardena and Rezaur, 2000b	$36.8I\,(1 - 0.691e^{-0.038I})$	Honk Kong	0–150
Kinnell, 1981	$I(17.124 + 5.229\log_{10} I)$ $30.132(I - 5.484)$ $29.31I\,(1 - 0.281e^{-0.018I})$	Miami, Florida	1.89–309
Kinnell, 1981	$I\,(9.705 + 9.258\log_{10} I)$ $29.863(I - 4.287)$ $29.22I\,(1 - 0.894\,e^{-0.0477I})$	Rhodesia (from Hudson (1961))	18.5–228.6
McGregor and Mutchler, 1976	$I\,(27.3 + 21.68e^{-0.048I} - 41.26e^{-0.072\,I})$	Mississipi, USA	n.a.
Onaga et al., 1988	$I\,(9.81 + 10.6\log_{10} I)$	Okinawa, Japan	n.a.
Park et al., 1980	$21.1069I^{1.156}$	USA	n.a.
Renard et al., 1992	$29I\,(1 - 0.72e^{-0.05I})$	USA	n.a.
Rosewell, 1986	$29I\,(1 - 0.596e^{-0.0404I})$	Gunnedah, Australia	1–145.9
Rosewell, 1986	$26.35I\,(1 - 0.669e^{-0.0349I})$	Brisbane, Australia	1–161.2
Rosewell, 1986	$24.48\,(I - 1.253)$	Melbourne, Australia	n.a.
Rosewell, 1986	$24.80\,(I - 1.292)$	Cowra, Australia	n.a.
Sempere-Torres et al., 1992	$34I - 190$	Cévennes, France	20–100
Smith and De Veaux, 1992	$13I^{1.21}$	Oregon, USA	n.a.
Smith and De Veaux, 1992	$11I^{1.23}$	Alaska, USA	n.a.
Smith and De Veaux, 1992	$18I^{1.24}$	Arizona, USA	n.a.
Smith and De Veaux, 1992	$11I^{1.17}$	New Jersey, USA	n.a.
Smith and De Veaux, 1992	$10I^{1.18}$	North Carolina, USA	n.a.
Smith and De Veaux, 1992	$11I^{1.14}$	Florida, USA	n.a.
Steiner and Smith, 2000	$11I^{1.25}$	Northern Mississippi, USA	n.a.
Tracy et al., 1984	$210Ie^{-0.0766I^{0.175}} - 211.8$ if $I < 76\,mm\,h^{-1}$	Arizona	n.a.
Uijlenhoet and Stricker, 1999a	$7.20I^{1.32}$ $8.53I^{1.29}$ $8.46I^{1.17}$ $8.89I^{1.28}$ $10.8I^{1.06}$ $7.74I^{1.35}$	Based on Marshall and Palmer parameterisation	n.a.
Usòn and Ramos, 2001	$23.4I - 18$	NE Spain	< 20
Wischmeier and Smith, 1958	$I\,(11.87 + 8.73\log_{10} I)$	Washington, USA; DSD from Laws and Parsons (1943)	n.a.
Zanchi and Torri, 1980	$I\,(9.81 + 11.25\log_{10} I)$	Italy	n.a.

Salles et al., 2001

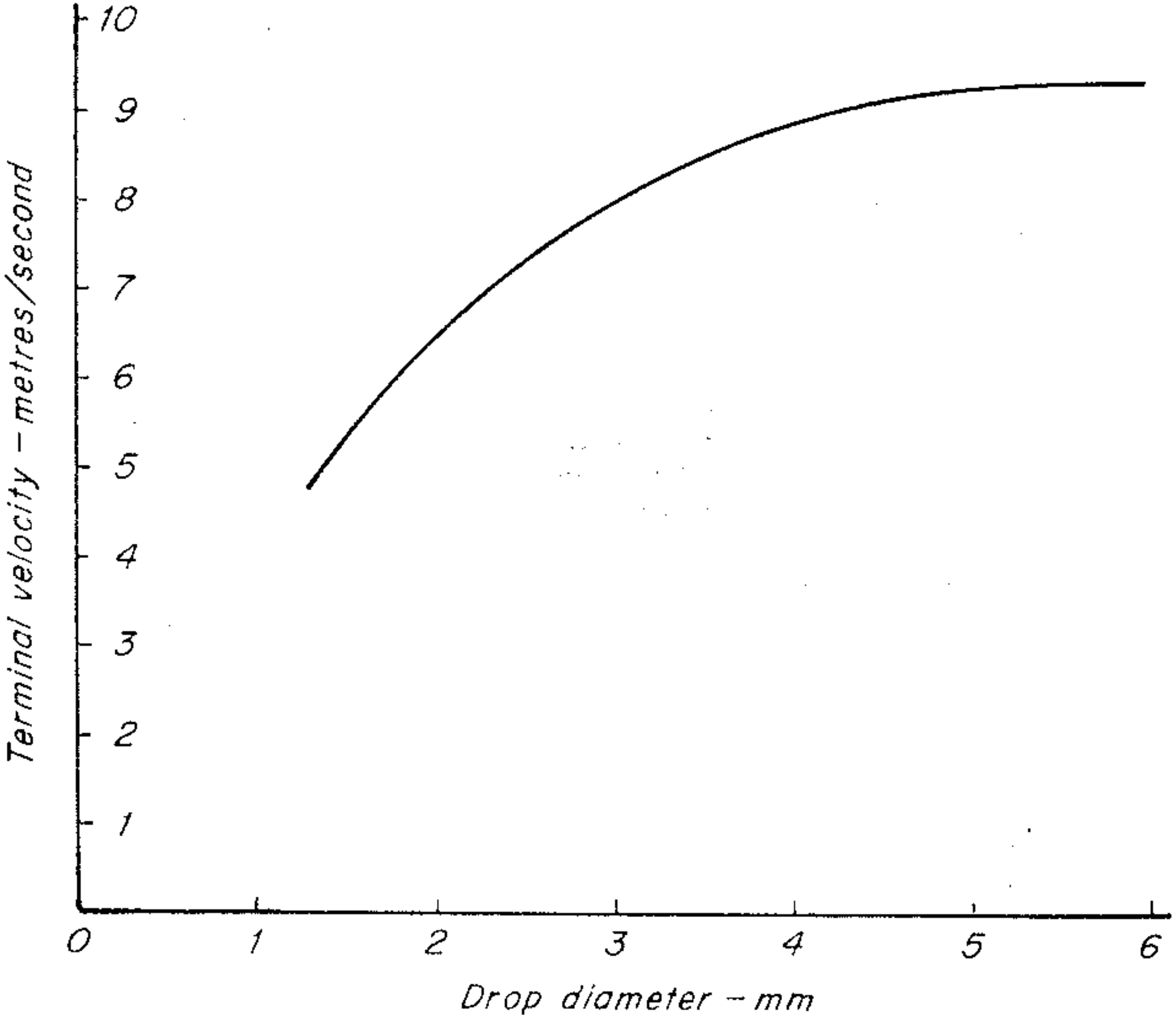


FIGURE 3.8 *The terminal velocity of raindrops* (data from LAWS 1941)

Energia Cinética da Gota de Chuva

É muito importante conhecer a força com que a chuva impacta contra o solo.
A energia cinética é uma função da massa e da velocidade:

$$Ec = \frac{1}{2}mv^2$$

Energia cinética da chuva e da enxurrada:

	Chuva	Enxurrada
Massa	Suponha uma massa de queda da chuva = R	Suponha 25% de enxurrada, e a massa da enxurrada = R/4
Velocidade	Suponha uma velocidade de 8m/s	Suponha a velocidade de escorrimento na superfície de 1m/s
Energia Cinética	1/2 x R x $(8)^2$ = 32R	1/2 x R/4 x $(1)^2$= R/8

Desta forma a chuva tem <u>256 vezes</u> mais energia cinética que a enxurrada

Duração da chuva:

- complemento da intensidade

- a combinação dos dois determina a chuva total

- importante para determinar o limite no qual o solo para de infiltrar a água e começa a enxurrada.

Frequência de chuva:

-fator importante que influi nas perdas de terra por erosão.

Se intervalos são curtos ⇒ o teor de umidade do solo é alta ⇒ enxurradas mais volumosas (inclusive com chuvas de menor intensidade)

Se intervalos maiores ⇒ o solo esta seco ⇒boa infiltração inicial ⇒ pouca enxurrada com chuvas de baixa intensidade.

Períodos de estiagem ⇒ diminuição da proteção vegetal por falta de umidade ⇒ maiores riscos de erosão nas primeiras chuvas

Impacto da Gota de Chuva

Contribuição da gota de chuva no processo erosivo:

-desprendem partículas de solo no local que sofre impacto;

-transportam, por salpicamento, as partículas desprendidas;

- imprimem energia, em forma de turbulência, à água superficial.

Table 9.1. Comparison of the main model characteristics

Erosion model	Event based	Empirical equation for simulating erosion	Interface to Arc/Info	Simulation of transport, deposition, etc.	Required input data	Maximum number of grid cells	User friendliness
USLE	No	Yes	No	No	+	n.i.	Yes
RUSLE/MUSLE	Yes	Yes	No	No	+	n.i.	Yes
EPIC	No	Yes	No	No	+++	n.i.	No
AGNPS	Yes	Yes	Yes	Yes	++	1 900	Yes
CREAMS	No	Yes	No	Yes	++	n.i.	No
GLEAMS	No	Yes	No	Yes	++	n.i.	No
ANSWERS	Yes	No	No	Yes	++	1 700	Yes
EROSION-2D/3D	Yes	No	Yes	Yes	++	50 000	Yes
KINEROS	Yes	N.I.	No	Yes	+++	n.i.	No
OPUS	Yes	No	No	Yes	+++	n.i.	No
SPUR I/II	Yes	Yes	No	No	+++	n.i.	No
WEPP	Yes	No	Yes	Yes	+++	n.i.	No
EUROSEM	Yes	No	Yes	Yes	+++	n.i.	No

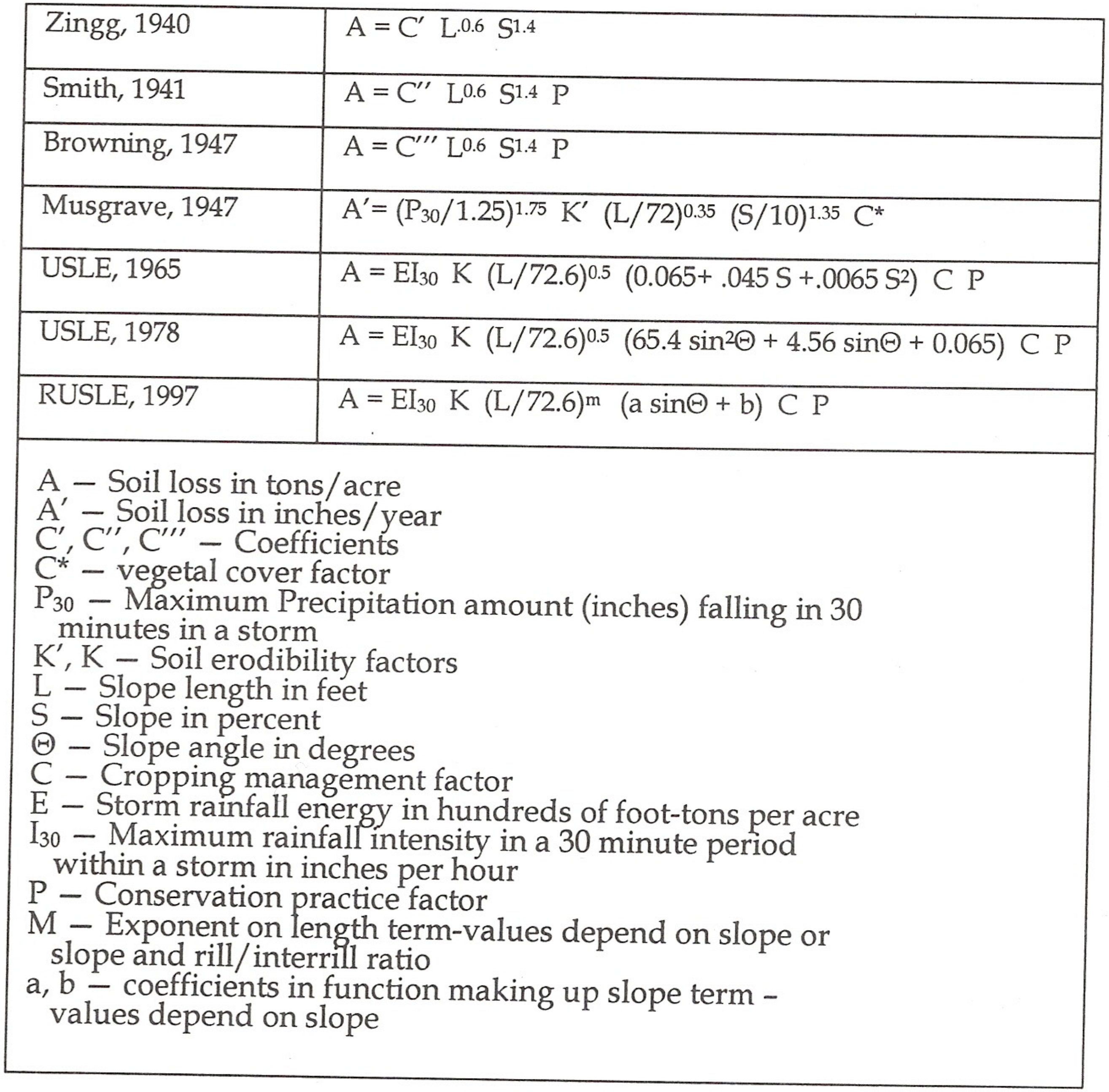
n.i. No information;
+ Few;
++ Moderate;
+++ Many.

Modelos estatísticos:

Energia cinética
Intensidade máxima

↓

Conversão estatística utilizando funções do volume e da intensidade de precipitação



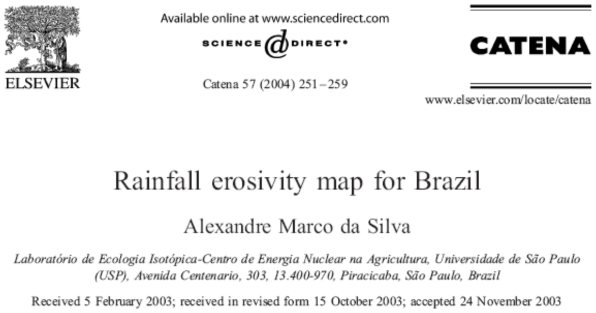
Zingg, 1940	$A = C' \; L^{0.6} \; S^{1.4}$
Smith, 1941	$A = C'' \; L^{0.6} \; S^{1.4} \; P$
Browning, 1947	$A = C''' \; L^{0.6} \; S^{1.4} \; P$
Musgrave, 1947	$A' = (P_{30}/1.25)^{1.75} \; K' \; (L/72)^{0.35} \; (S/10)^{1.35} \; C^*$
USLE, 1965	$A = EI_{30} \; K \; (L/72.6)^{0.5} \; (0.065 + .045\,S + .0065\,S^2) \; C \; P$
USLE, 1978	$A = EI_{30} \; K \; (L/72.6)^{0.5} \; (65.4 \sin^2\Theta + 4.56 \sin\Theta + 0.065) \; C \; P$
RUSLE, 1997	$A = EI_{30} \; K \; (L/72.6)^{m} \; (a \sin\Theta + b) \; C \; P$

A — Soil loss in tons/acre
A′ — Soil loss in inches/year
C′, C″, C‴ — Coefficients
C* — vegetal cover factor
P_{30} — Maximum Precipitation amount (inches) falling in 30 minutes in a storm
K′, K — Soil erodibility factors
L — Slope length in feet
S — Slope in percent
Θ — Slope angle in degrees
C — Cropping management factor
E — Storm rainfall energy in hundreds of foot-tons per acre
I_{30} — Maximum rainfall intensity in a 30 minute period within a storm in inches per hour
P — Conservation practice factor
M — Exponent on length term-values depend on slope or slope and rill/interrill ratio
a, b — coefficients in function making up slope term - values depend on slope

USLE

A = RKLSCP

A = Long term average annual soil loss
R = Rainfall erosivity
K = Soil erodibility
L and S = Slope factors
C = Crop factor
P = Management factor



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Rainfall erosivity map for Brazil

Alexandre Marco da Silva

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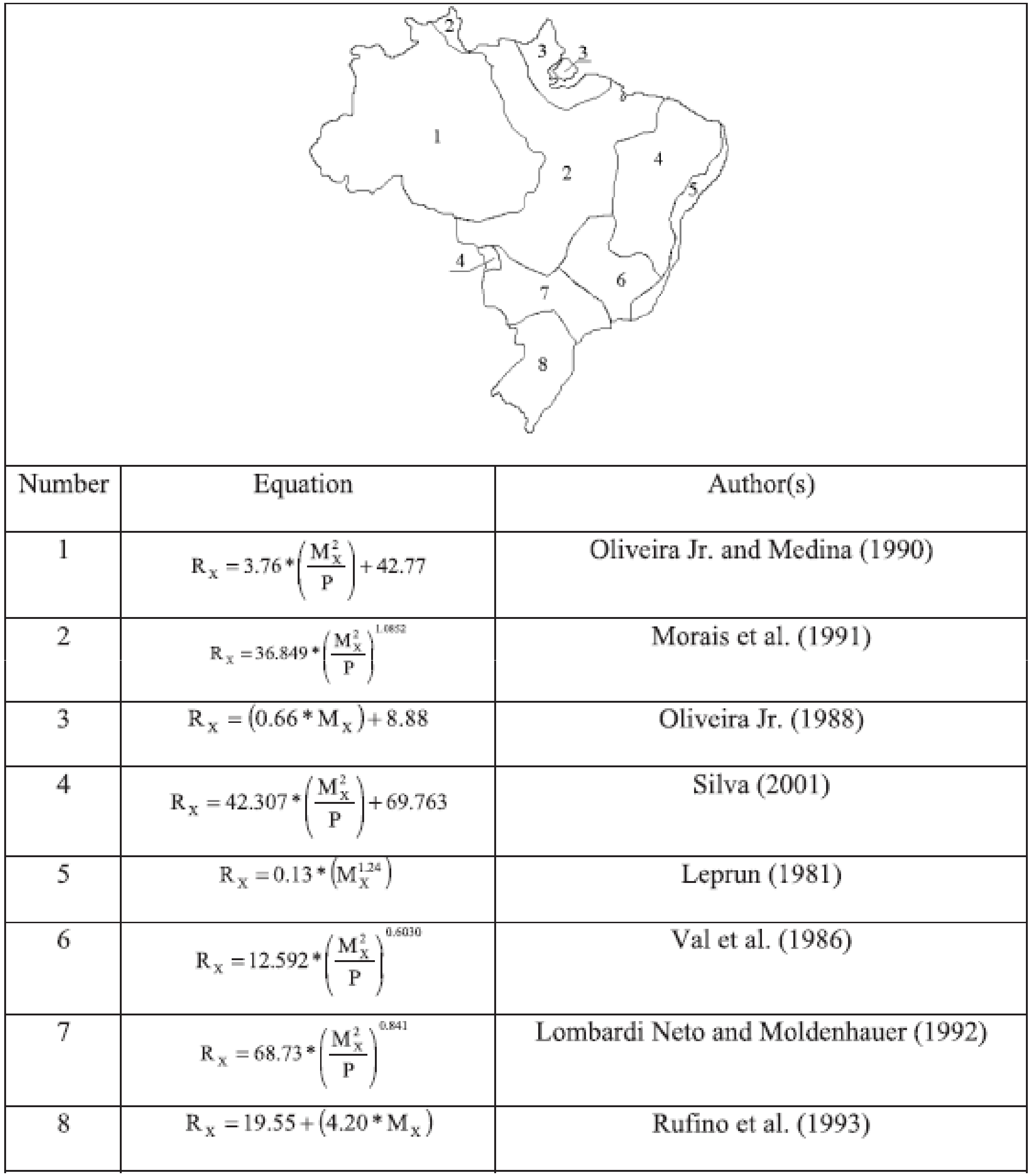
Received 5 February 2003; received in revised form 15 October 2003; accepted 24 November 2003

x = índice mensal
M = Precipitação média mensal
P = Precipitação média anual



Number	Equation	Author(s)
1	$R_x = 3.76 * \left(\frac{M_x^2}{P}\right) + 42.77$	Oliveira Jr. and Medina (1990)
2	$R_x = 36.849 * \left(\frac{M_x^2}{P}\right)^{1.0852}$	Morais et al. (1991)
3	$R_x = (0.66 * M_x) + 8.88$	Oliveira Jr. (1988)
4	$R_x = 42.307 * \left(\frac{M_x^2}{P}\right) + 69.763$	Silva (2001)
5	$R_x = 0.13 * (M_x^{1.24})$	Leprun (1981)
6	$R_x = 12.592 * \left(\frac{M_x^2}{P}\right)^{0.6030}$	Val et al. (1986)
7	$R_x = 68.73 * \left(\frac{M_x^2}{P}\right)^{0.841}$	Lombardi Neto and Moldenhauer (1992)
8	$R_x = 19.55 + (4.20 * M_x)$	Rufino et al. (1993)

Fig. 1. Equations used to determine the monthly/annual values of the erosivity according to the area of the territory and their respective authors. Eqs. number (1), (2), (4), (6), and (7) were based from the Fournier's model. Eqs. (3) and (8) are linear models and Eq. (5) is an exponential model. R_x is R factor (MJ mm ha^{-1} h^{-1} year^{-1}) for month x, M_x is average monthly precipitation depth (mm), and P is average annual precipitation (mm) (Silva, 2001).

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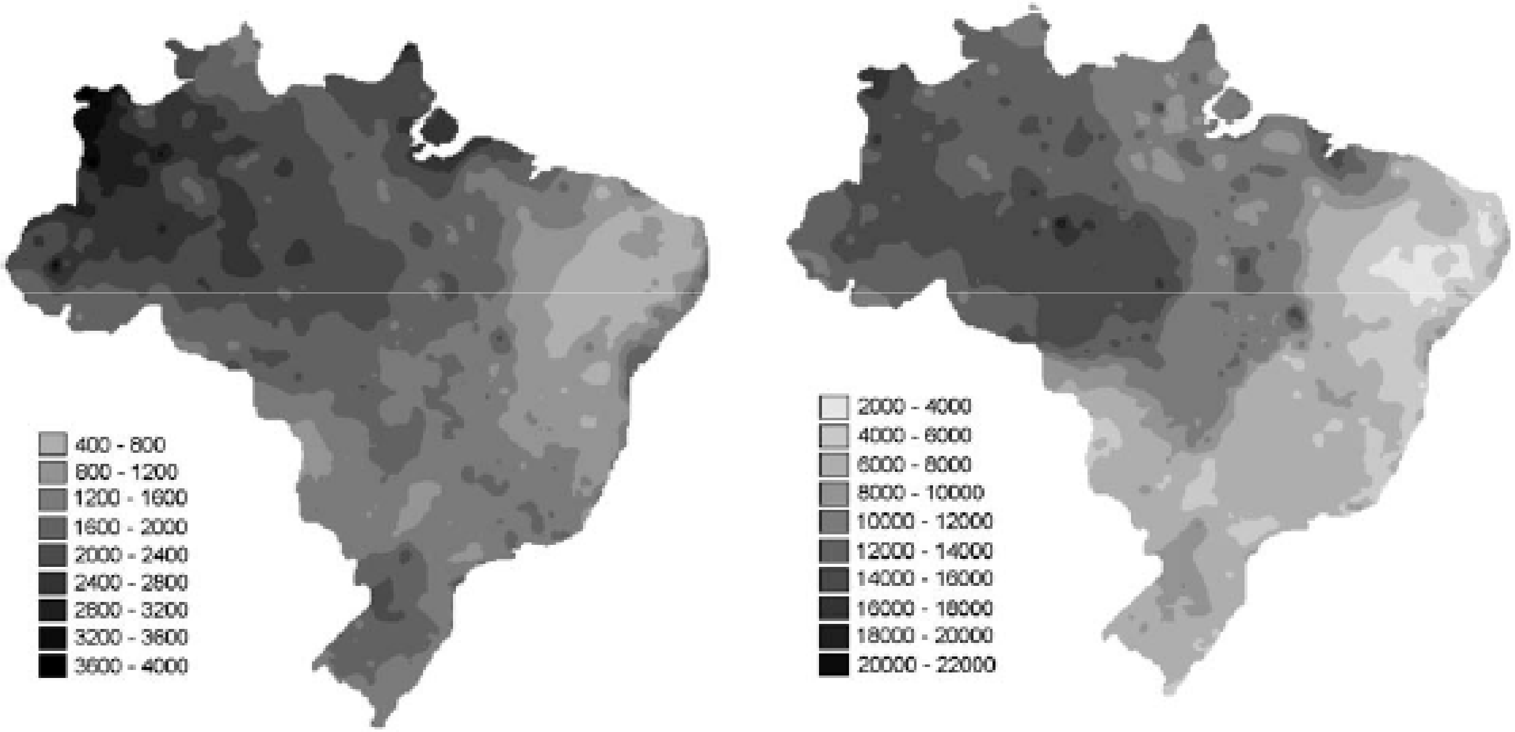

Fig. 2. Comparison of the annual pluviometric (left, in mm $year^{-1}$) and the annual erosivity maps (in MJ mm ha^{-1} h^{-1} $year^{-1}$).

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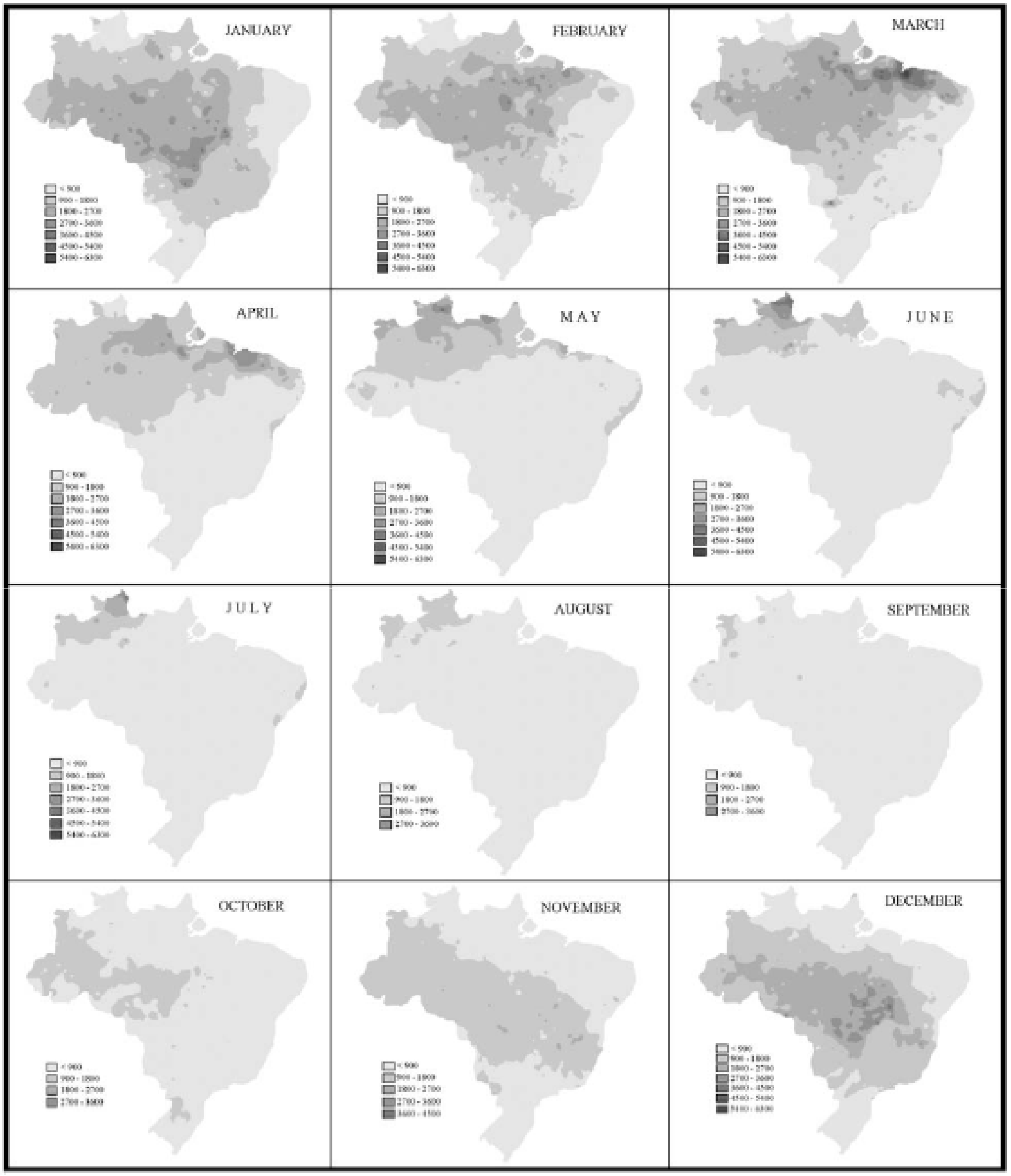


Fig. 5. Geography of the erosivity along the Brazilian territory (monthly average).

Process Based Models: Mass balance differential equation

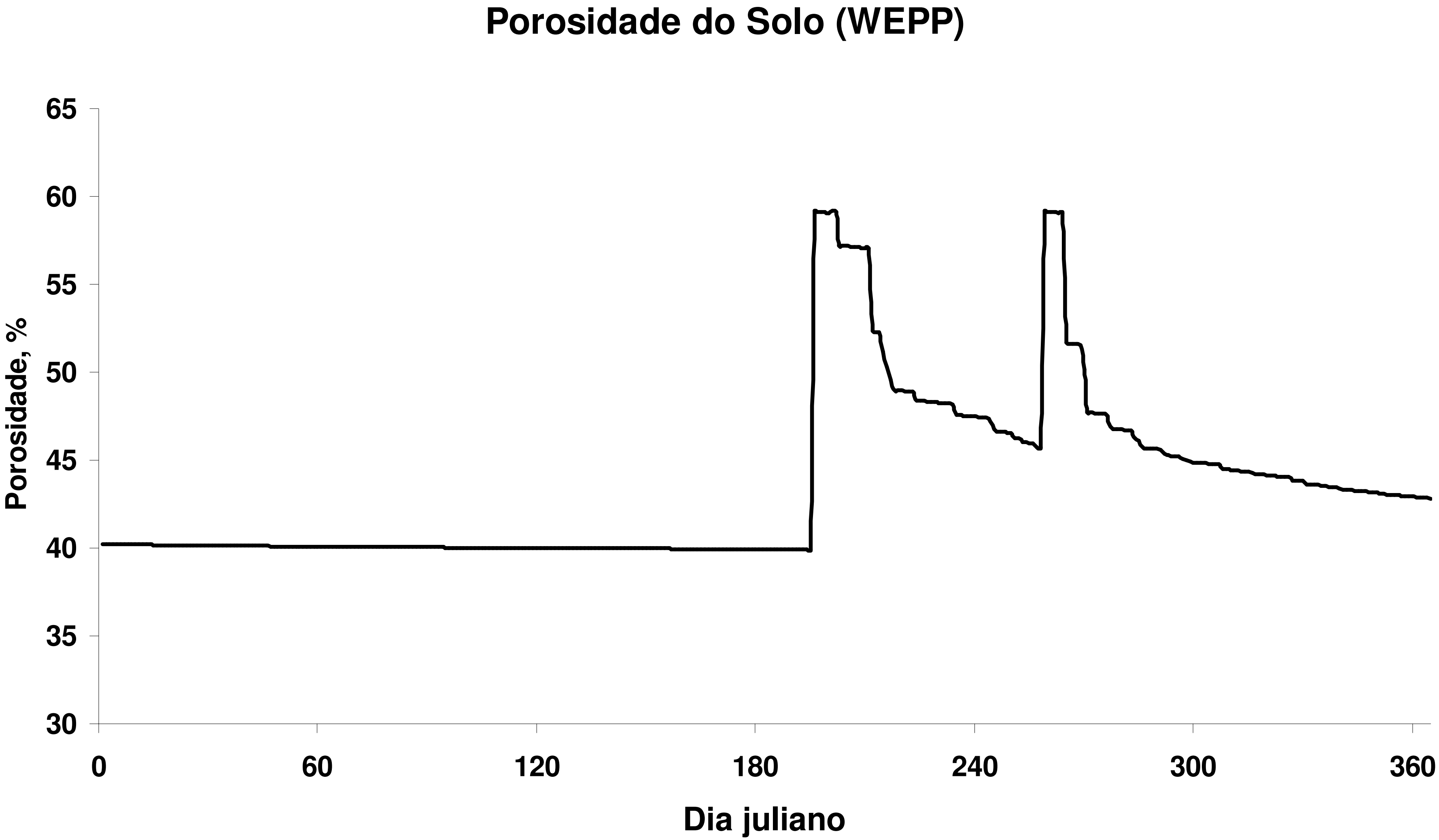
$$\delta(cq)/\delta x + \delta(ch)/\delta t + S = 0$$

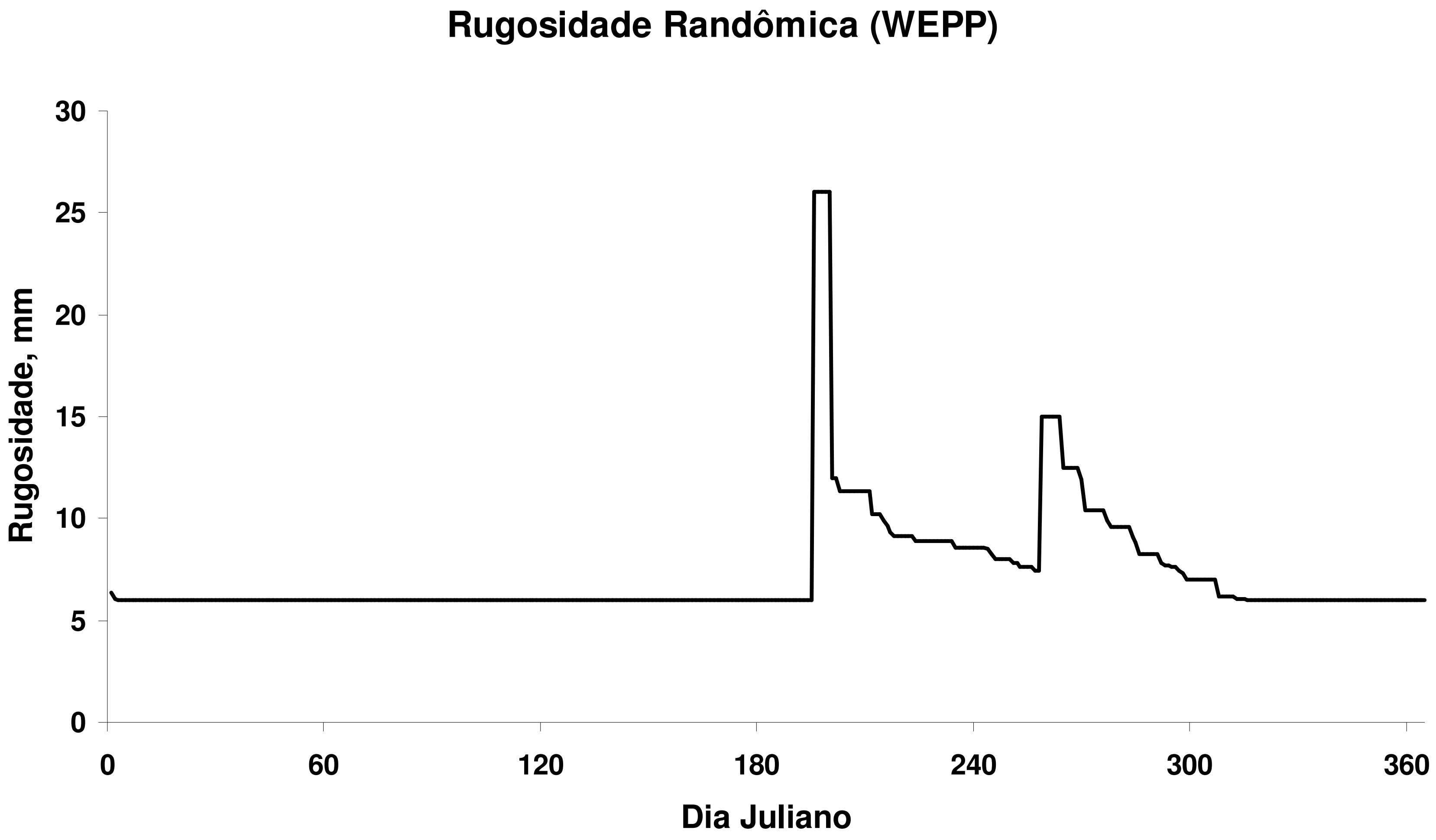
c = Sediment concentration (kg/m^3)
q = Runoff discharge (m^2/s)
x = Distance in the direction of flow (m)
h = Depth of flow (m)
t = Time (s)
S = Source/sink term (kg/(m^{2}s))

WEPP

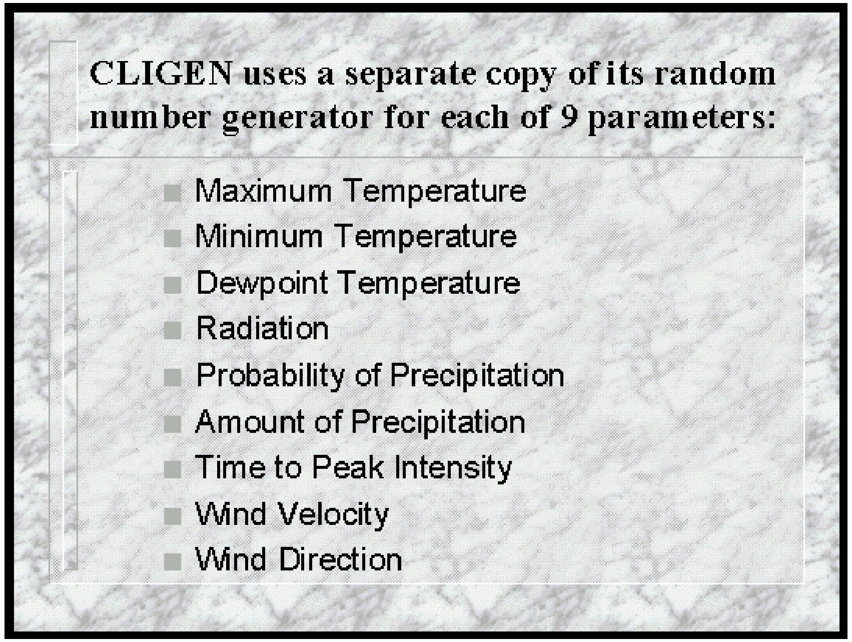
$$dG/dx = Dr + Di$$

G = Sediment load per unit width in the flow (kg/(m s)) = cq
Dr = net rill erosion rate per unit area of rill bottom (kg/(m^2 s)) (+ or -)
Di = Interrill sediment delivery to rill (kg/(m^2 s))


Porosidade do Solo (WEPP)
Porosidade, %
65
60
55
50
45
40
35
30
0
60
120
180
240
300
360
Dia juliano


Rugosidade Randômica (WEPP)

Gerador de Clima: Cligen (WEPP e RUSLE)



CLIGEN uses a separate copy of its random number generator for each of 9 parameters:

- Maximum Temperature
- Minimum Temperature
- Dewpoint Temperature
- Radiation
- Probability of Precipitation
- Amount of Precipitation
- Time to Peak Intensity
- Wind Velocity
- Wind Direction

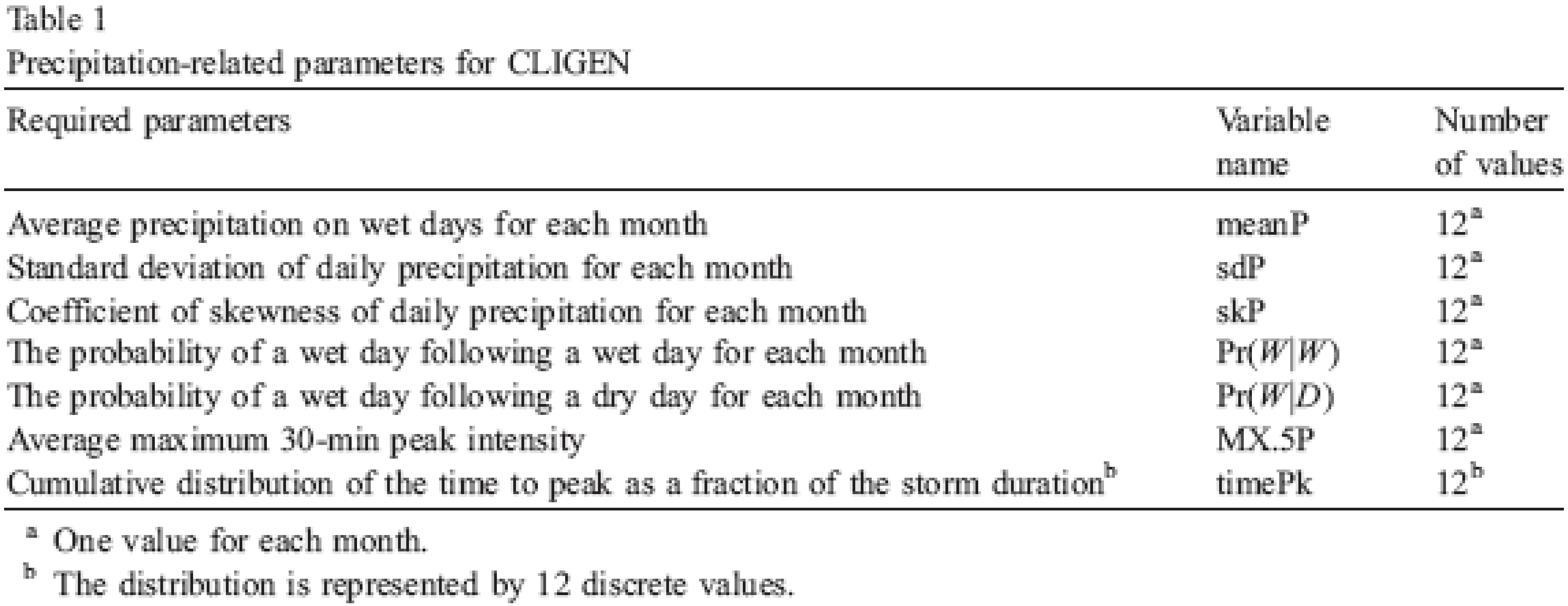


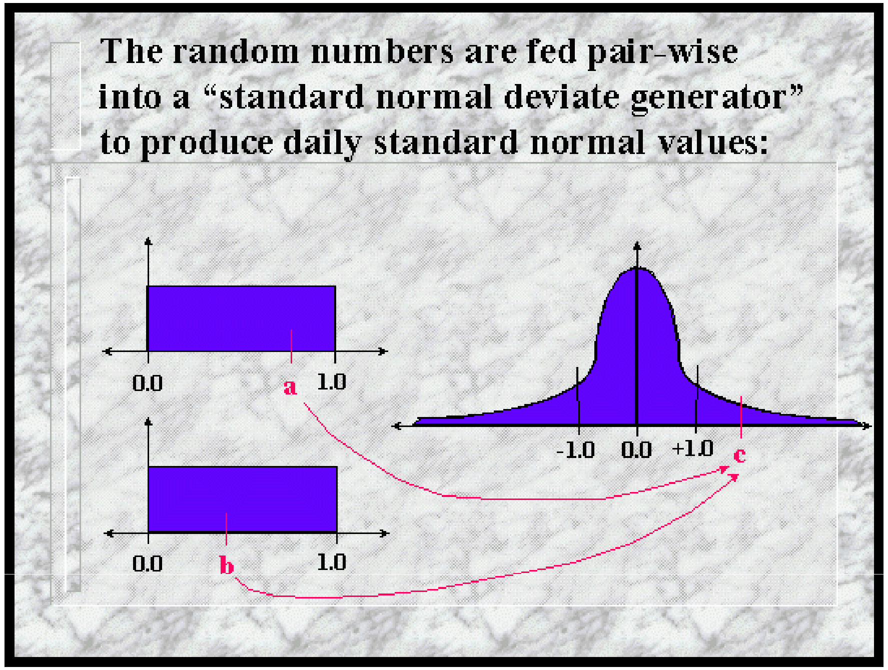
Table 1
Precipitation-related parameters for CLIGEN

Required parameters	Variable name	Number of values
Average precipitation on wet days for each month	meanP	12[a]
Standard deviation of daily precipitation for each month	sdP	12[a]
Coefficient of skewness of daily precipitation for each month	skP	12[a]
The probability of a wet day following a wet day for each month	$Pr(W\|W)$	12[a]
The probability of a wet day following a dry day for each month	$Pr(W\|D)$	12[a]
Average maximum 30-min peak intensity	MX.5P	12[a]
Cumulative distribution of the time to peak as a fraction of the storm duration[b]	timePk	12[b]

[a] One value for each month.

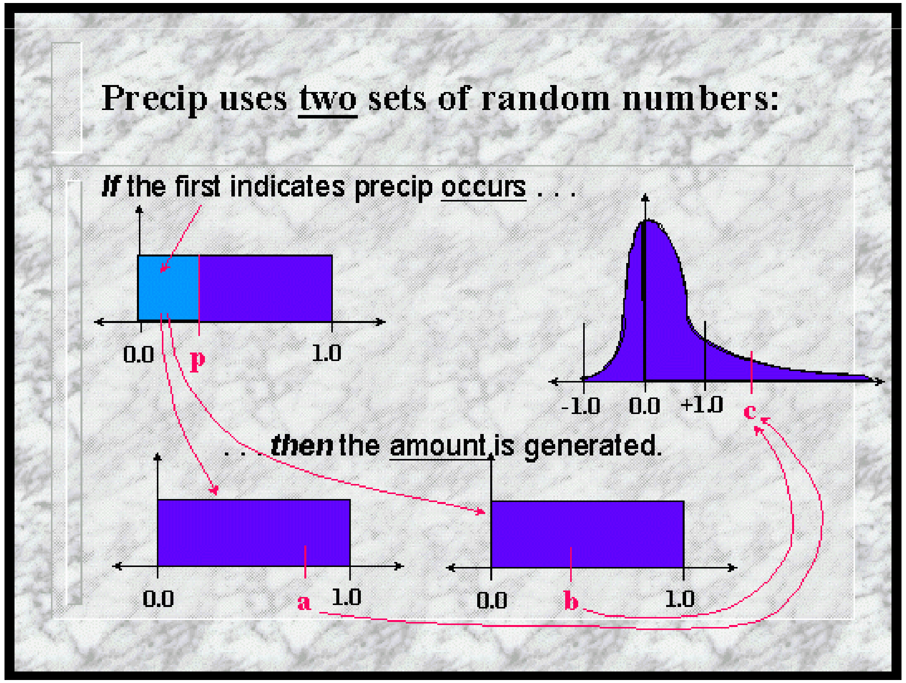
[b] The distribution is represented by 12 discrete values.

Normal: Temperatura, vento...



The random numbers are fed pair-wise into a “standard normal deviate generator” to produce daily standard normal values:

Pearson: Precipitação



Precip uses two sets of random numbers:

If the first indicates precip occurs . . .

. . . *then* the amount is generated.

Arquivo de parâmetros do Cligen

PIRACICA SP 129271 0
LATT= -22.71 LONG= -47.64 YEARS= 80. TYPE= 3
ELEVATION = 1791. TP5 = 1.74 TP6= 2.75

MEANP	0.65	0.57	0.45	0.26	0.27	0.18	0.15	0.18	0.31	0.41	0.46	0.58
SDEVP	0.49	0.52	0.45	0.32	0.30	0.24	0.24	0.17	0.25	0.37	0.42	0.47
SQEWP	2.75	3.62	3.18	4.63	5.25	5.21	5.21	6.15	3.69	3.39	3.24	2.96
P(W/W)	0.36	0.32	0.22	0.10	0.10	0.08	0.06	0.07	0.13	0.17	0.22	0.33
P(W/D)	0.13	0.17	0.15	0.12	0.12	0.08	0.07	0.08	0.12	0.16	0.16	0.16
TMAXAV	86.76	87.58	86.74	83.01	78.76	76.98	77.94	81.05	82.09	84.69	85.71	85.68
TMINAV	66.24	66.29	64.40	59.86	54.10	50.41	49.57	52.29	56.43	60.55	63.01	65.21
SDTMAX	2.18	2.65	1.84	2.59	3.33	2.43	2.41	2.52	3.62	2.63	2.86	2.11
SDTMIN	1.78	1.82	1.69	3.15	3.56	2.84	2.81	2.30	1.91	1.91	2.23	1.80
SOLRAD	494.	487.	443.	404.	323.	305.	330.	380.	407.	477.	498.	482.
SDSOL	131.0	117.0	115.0	107.0	90.0	70.0	64.0	66.0	103.0	123.0	137.0	124.0
MX5P	1.42	1.89	1.67	1.85	1.17	1.17	0.55	0.75	0.90	1.20	1.39	1.31
DEWPT	68.67	69.17	67.87	63.27	59.05	56.30	54.39	55.72	58.57	63.01	65.14	67.78
TimePk	0.290	0.426	0.536	0.621	0.701	0.761	0.813	0.863	0.910	0.942	0.974	1.000
MEAN	5.53	5.17	5.01	5.01	4.59	4.84	5.45	5.68	6.36	6.75	6.75	5.99
STDDEV	1.74	1.80	1.52	1.52	1.48	1.43	1.66	1.85	1.81	2.09	2.45	2.34
SKEW	0.80	1.21	1.30	1.30	1.87	0.95	0.52	1.19	1.81	1.75	1.87	0.93

Entrada de dados pelo WEPP

da	**mo**	**year**	**prcp**	**dur**	**tp**	**ip**	**tmax**	**tmin**	**rad**	**w-vl**	**w-dir**	**tdew**
			(mm)	(h)			(C)	(C)	(l/d)	(m/s)(Deg)	(C)	
1	**1**	**1**	**22.6**	**2.42**	**0.04**	**5.81**	**30.0**	**18.9**	**214.**	**5.5**	**234.**	**22.3**
2	**1**	**1**	**13.3**	**1.64**	**0.26**	**6.93**	**29.0**	**18.2**	**374.**	**5.9**	**188.**	**20.7**
3	**1**	**1**	**41.9**	**1.57**	**0.77**	**7.01**	**29.4**	**18.3**	**578.**	**5.0**	**86.**	**18.0**
4	**1**	**1**	**0.0**	**0.00**	**0.00**	**0.00**	**32.1**	**18.1**	**464.**	**5.9**	**264.**	**18.1**
5	**1**	**1**	**87.5**	**4.97**	**0.28**	**9.70**	**30.3**	**20.0**	**353.**	**5.4**	**179.**	**21.2**
6	**1**	**1**	**11.8**	**1.91**	**0.05**	**6.32**	**31.7**	**21.3**	**327.**	**6.1**	**183.**	**21.4**
7	**1**	**1**	**0.0**	**0.00**	**0.00**	**0.00**	**29.5**	**20.4**	**410.**	**4.8**	**45.**	**20.0**
8	**1**	**1**	**0.0**	**0.00**	**0.00**	**0.00**	**31.5**	**19.8**	**591.**	**3.8**	**97.**	**20.2**
9	**1**	**1**	**8.3**	**3.99**	**0.61**	**8.28**	**30.4**	**20.0**	**563.**	**6.4**	**357.**	**20.8**
10	**1**	**1**	**10.2**	**3.68**	**0.23**	**7.55**	**30.9**	**18.6**	**526.**	**4.2**	**305.**	**21.2**
11	**1**	**1**	**0.0**	**0.00**	**0.00**	**0.00**	**30.9**	**18.3**	**631.**	**0.0**	**0.**	**17.0**
12	**1**	**1**	**0.0**	**0.00**	**0.00**	**0.00**	**29.8**	**18.5**	**725.**	**4.0**	**324.**	**21.2**
13	**1**	**1**	**0.0**	**0.00**	**0.00**	**0.00**	**29.3**	**19.8**	**474.**	**7.1**	**273.**	**22.4**

Large Storm effects:

Edwards and Owness (1991):

“With more than 4,000 rainfall events during the study period (28 years), the five biggest erosion-producing events on each watershed (of 229) accounted for 66% of the total erosion”

Strom Rank	Cummulative % of 25 year
1	25
2	41
3	52
4	60
5	66