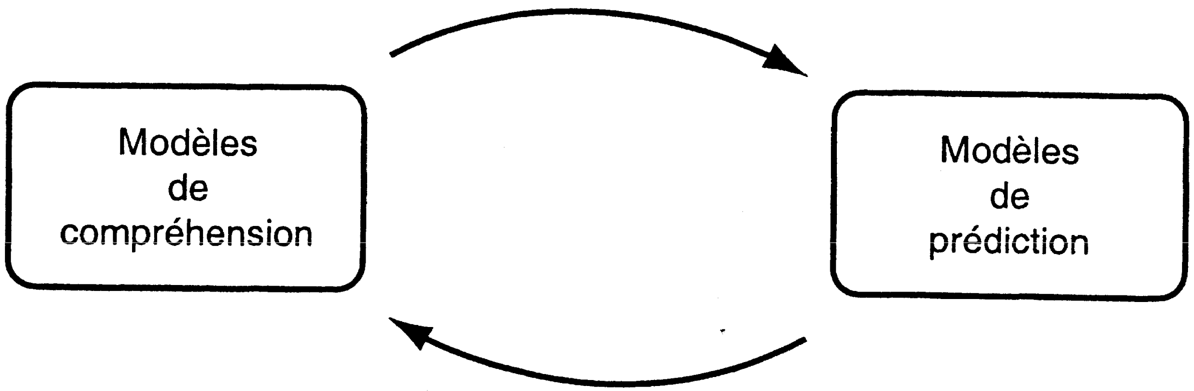


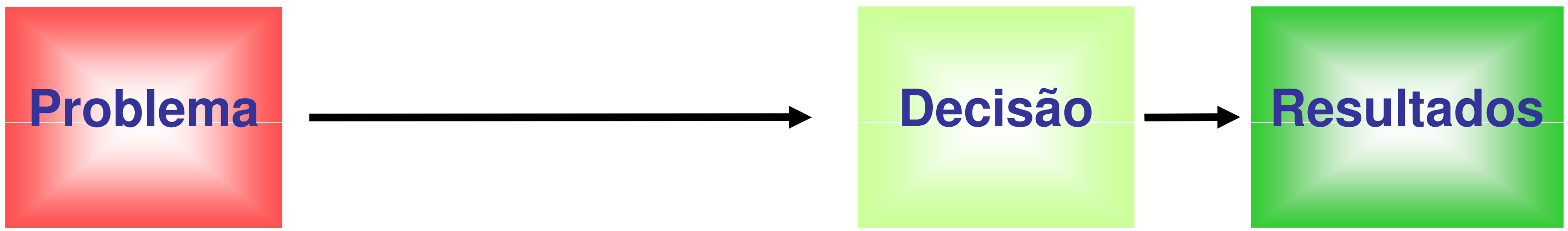
FIG. 1.5 – *Les deux grandes familles de modèles.*

O que é um Modelo?

Modelo *s.* Uma descrição esquemática de um sistema, teoria ou fenómeno que contabiliza as suas propriedades conhecidas ou inferidas, e pode ser utilizada para estudos mais aprofundados das suas características.

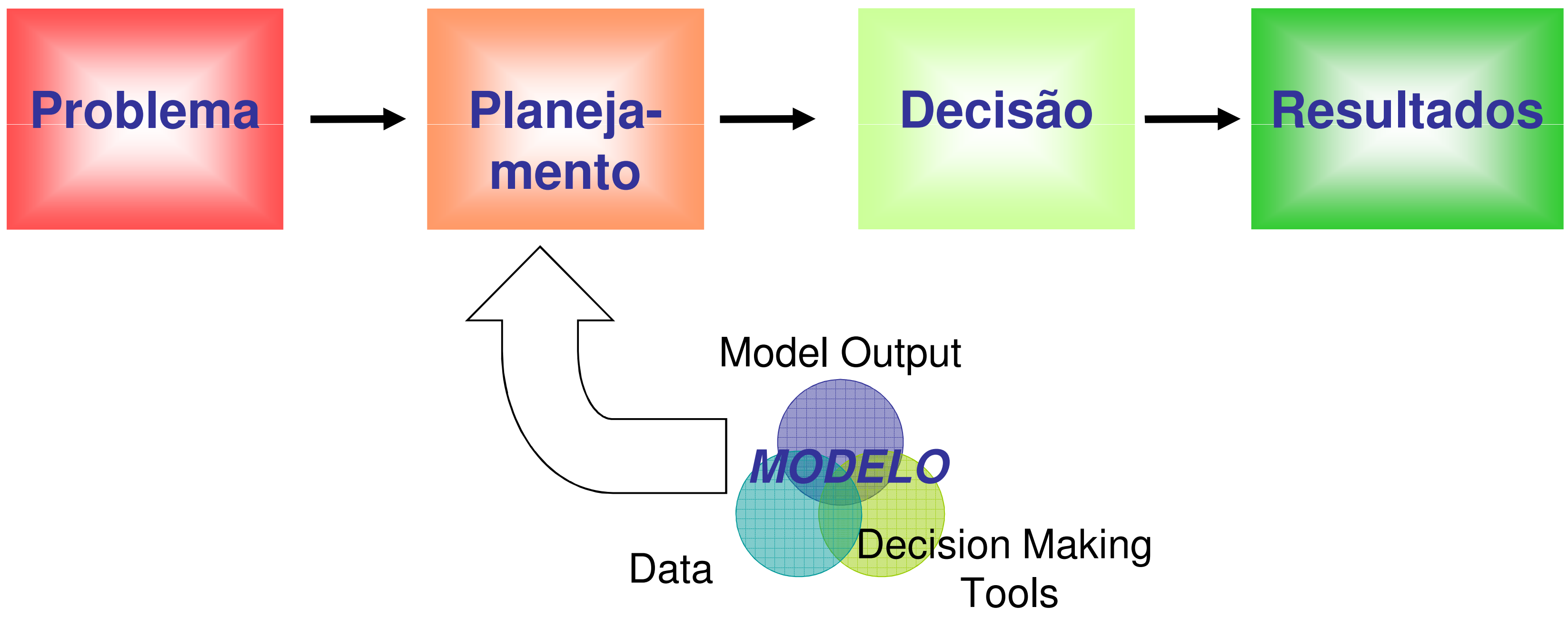
-The American Heritage® Dictionary of the English Language: Fourth Edition. 2000.

Porque usamos modelos?



Porque usamos modelos?

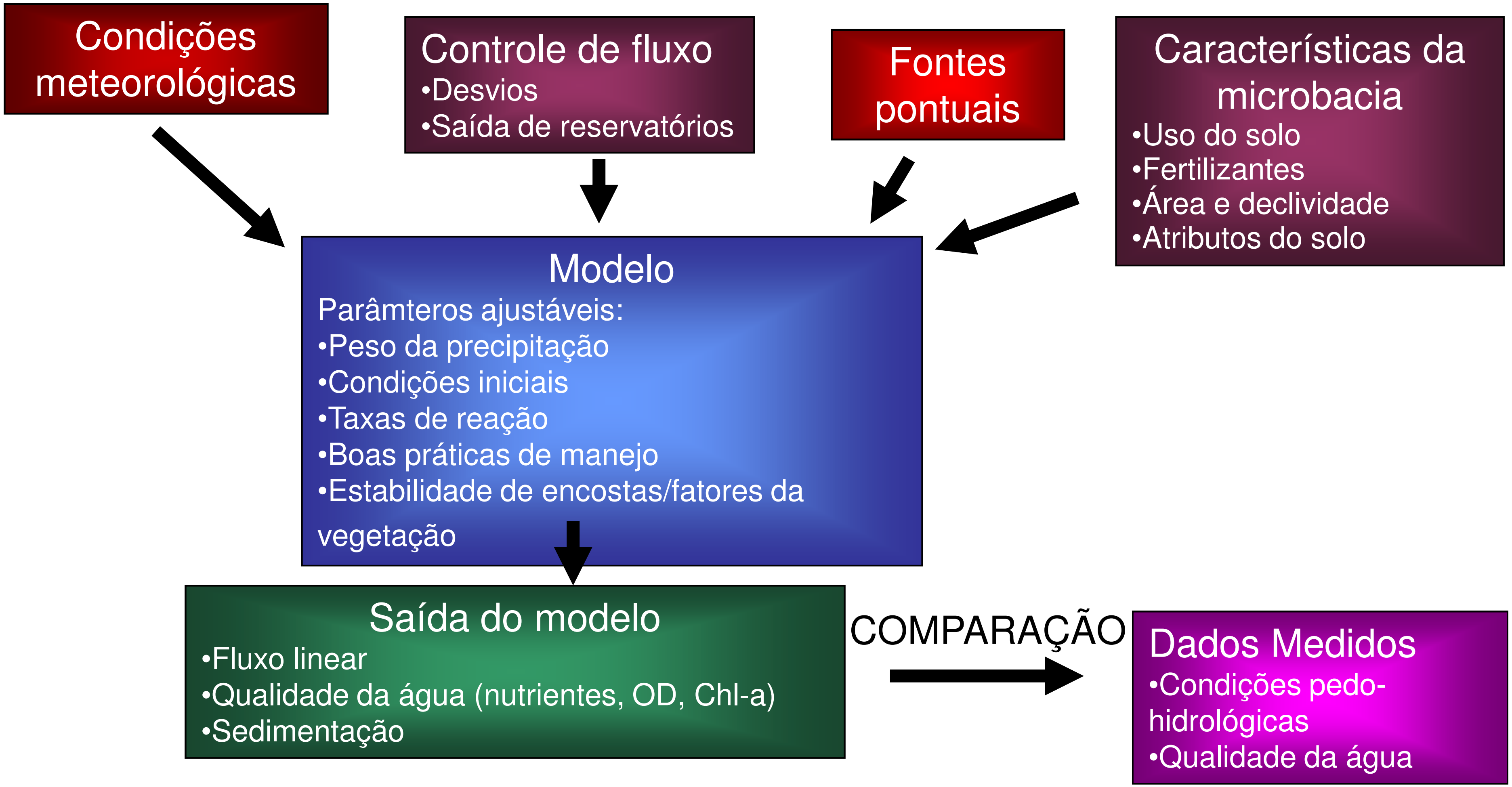
- Modelo ajuda a responder “E se?”



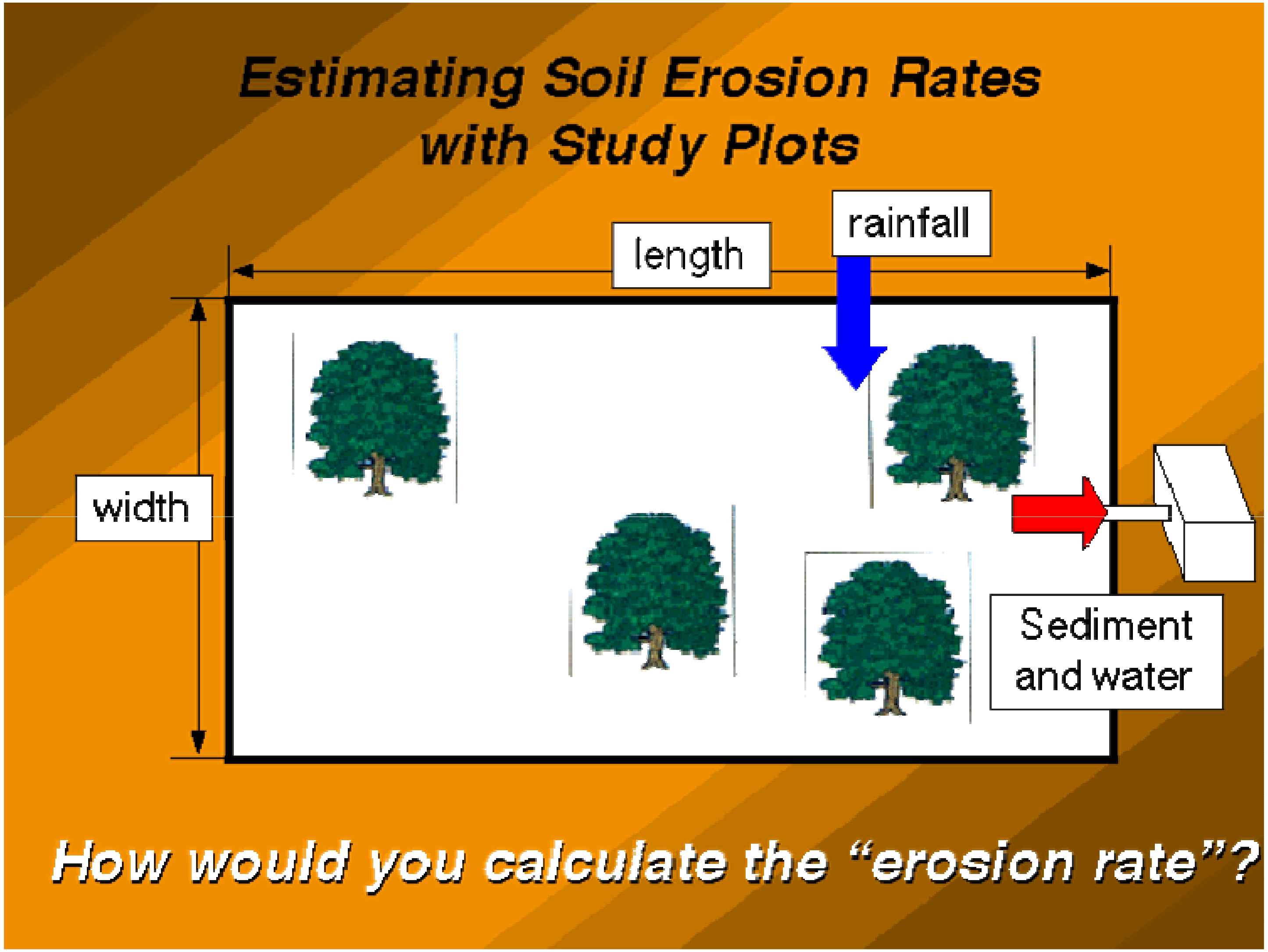
Tipos de Modelos de Erosão

- Avaliação dos Balanços de Massa
  - Cálculos simplificados, planilhas de cálculo
  - Baixo custo, fácil de implementar, partem de suposições simplificadas
- Ferramentas baseadas em SIGs
  - Relacionar modelos de balanço de massa simples a bases de SIG
  - Produzir mapas ressaltando regiões das microbacias de alta sensibilidade
- Modelos Matemáticos
  - Ferramentas complexas utilizando equações diferenciais para descrever processos físicos
  - Rigoroso, baseado em processos físicos, fornecem simulações dinâmicas de um sistema

O que é um modelo de erosão?

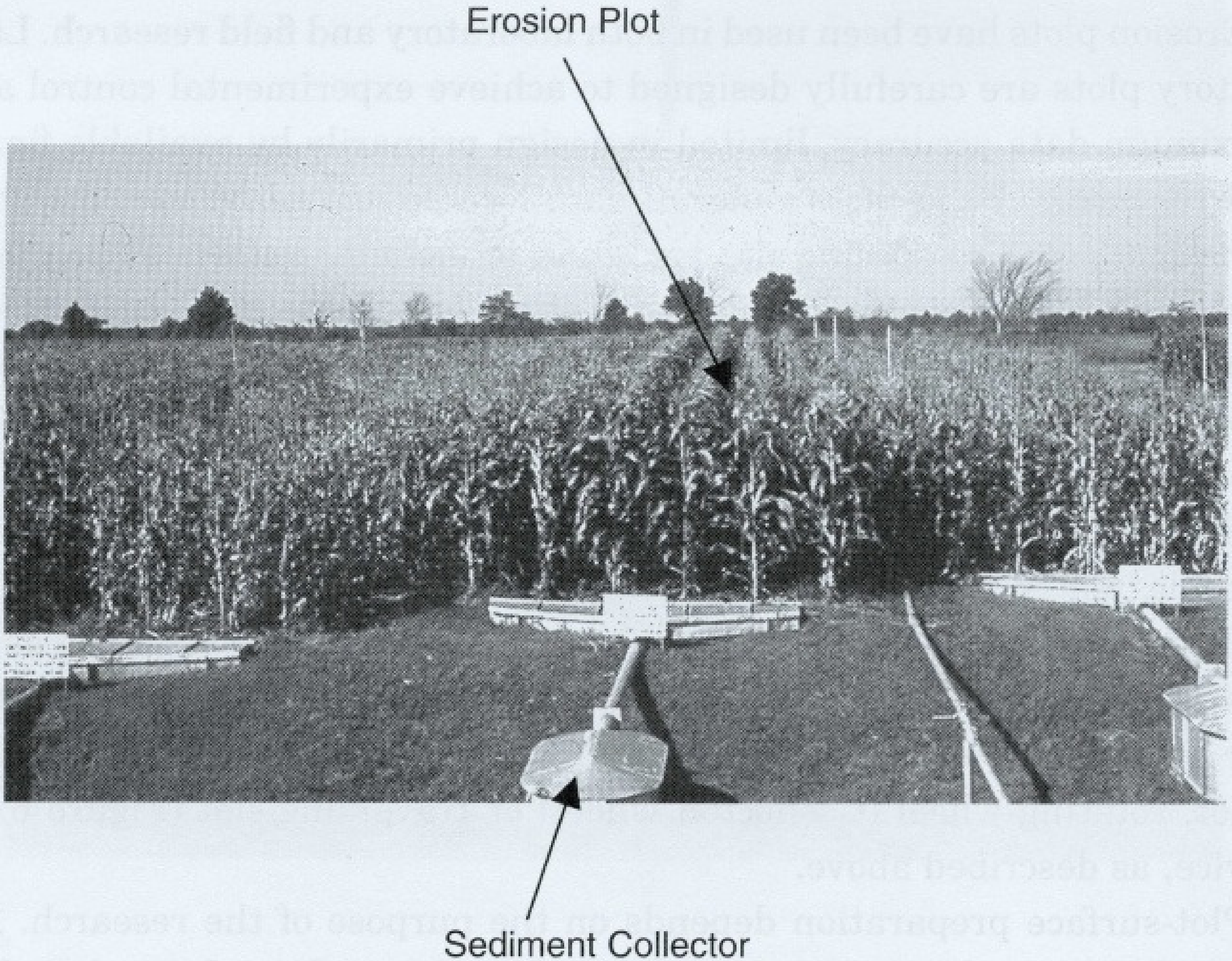


Quantificando a Erosão do Solo


Estimating Soil Erosion Rates
with Study Plots
length
rainfall
width
Sediment
and water
How would you calculate the "erosion rate"?



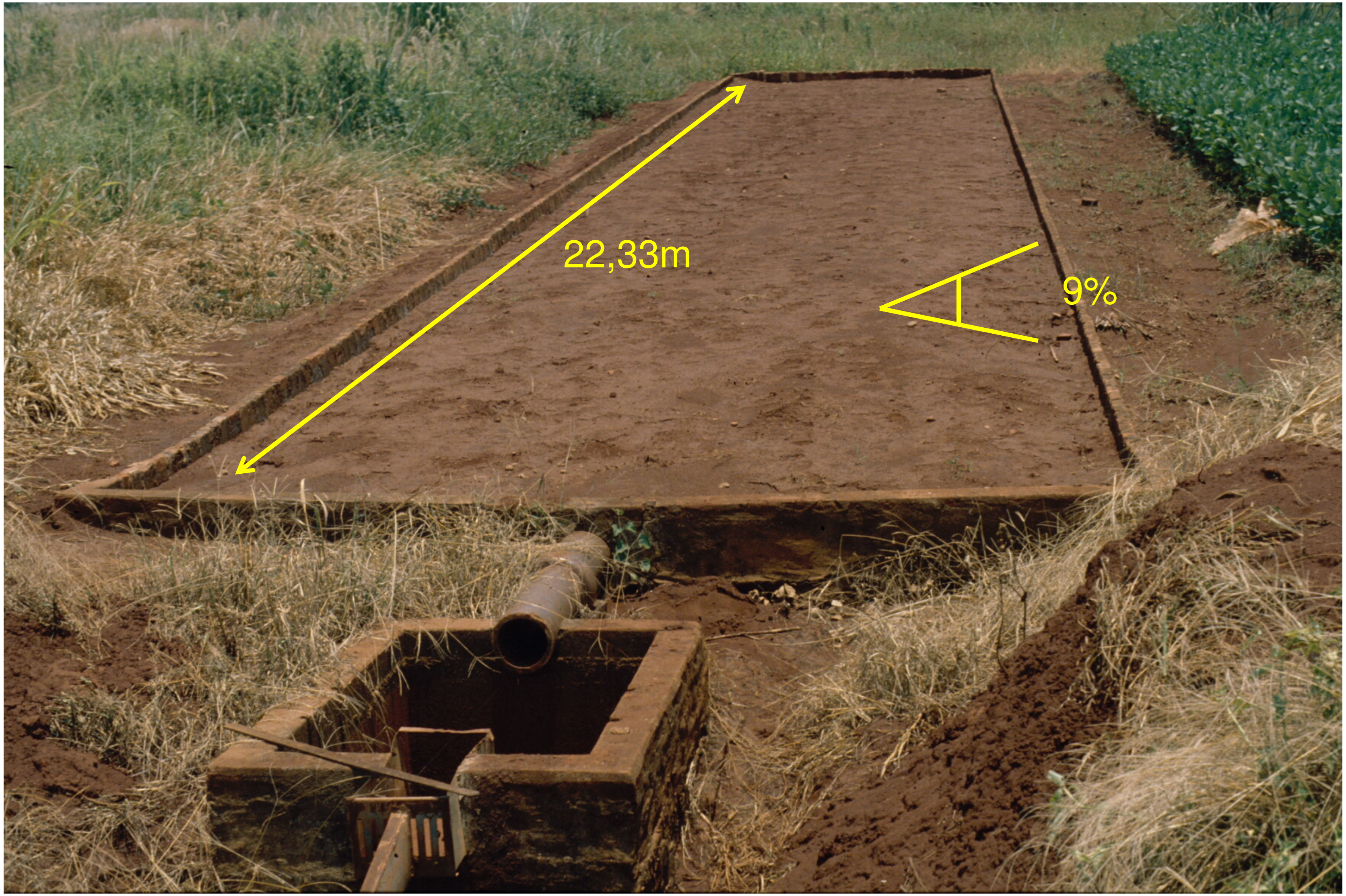



Erosion Plot
Sediment Collector

Canteiro coletor USLE

- Comprimento 22,33m
- Declividade 9%
- Largura 4m.

Canteiro coletor USLE (valor padrão)



USLE
Equação Universal de Perda de Solo

- Wischmeier, W.H. and D.D. Smith. 1978. Predicting rainfall erosion losses. USDA Agriculture Handbook 537, U.S. Department of Agriculture.

- Modelo Empírico:
  - Análise de observações
  - Procura caracterizar respostas destas informações

- Baseado:
  - Padrões de chuva, tipo de solo, topografia, sistema de cultivo e práticas conservacionistas.

- Prediz:
  - <u>Taxas anuais de perda do solo de longo prazo</u>

- Subrotinas em modelos como:
  - SWRRB (Williams, 1975), EPIC (Williams et al., 1980), ANSWERS (Beasly et al., 1980), AGNPS (Young et al., 1989)

A equação:

$$A = R \times K \times LS \times C \times P$$

– A = perda do solo anual (tons/ha ano)
– R = índice de erosividade
– K = erodibilidade do solo
– L = comprimento de rampa
– S = declividade
– C= fator de cultivo/preparo
– P = fator práticas conservacionistas

R (índice de erosividade)

- Índice de erosão (EI) para um evento:
  - Produto da energia cinética das gotas de chuva e a intensidade máxima em 30 minutos.
- Fator R = Σ EI num ano/100

A = **R** x K x LS x C x P

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Rainfall erosivity map for Brazil

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

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).

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

A = **R** x K x LS x C x P

K (erodibilidade do solo)

- Susceptibilidade de um solo ao processo erosivo pela água e enxurrada
- Depende de:
  – Textura, estrutura, conteúdo de matéria orgânica, e permeabilidade.

A =R x **K** x LS x C x P

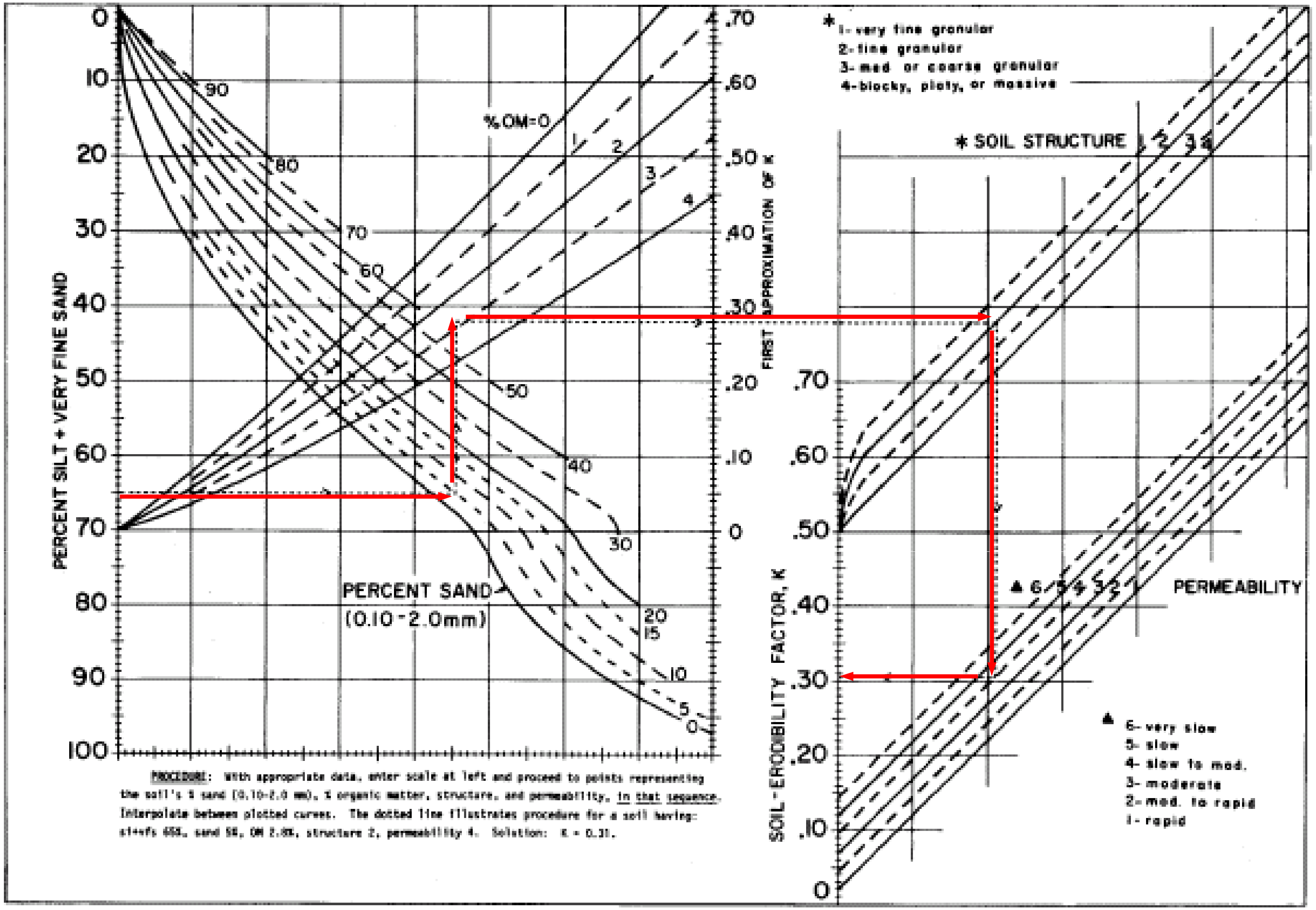
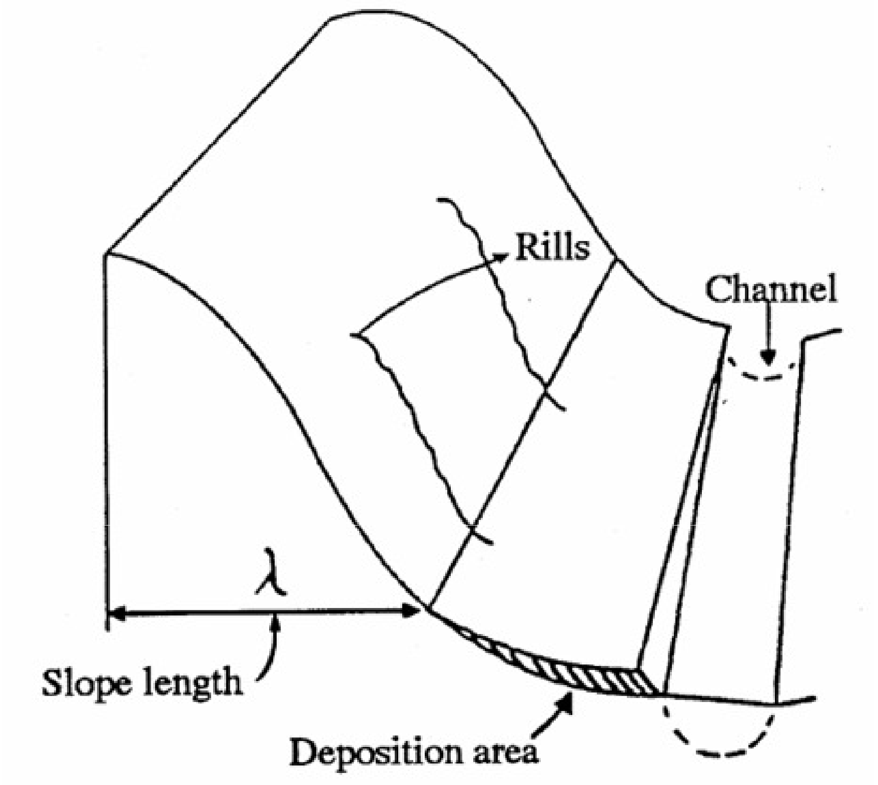


FIGURE 3.—The soil-erodibility nomograph. Where the silt fraction does not exceed 70 percent, the equation is $100\ K = 2.1\ M^{1.14}\ (10^{-4})\ (12 - a) + 3.25\ (b - 2) + 2.5\ (c - 3)$ where $M =$ (percent si + vfs) (100 − percent c), $a =$ percent organic matter, $b =$ structure code, and $c =$ profile permeability class.

Nomograma da Erodibilidade do Solo

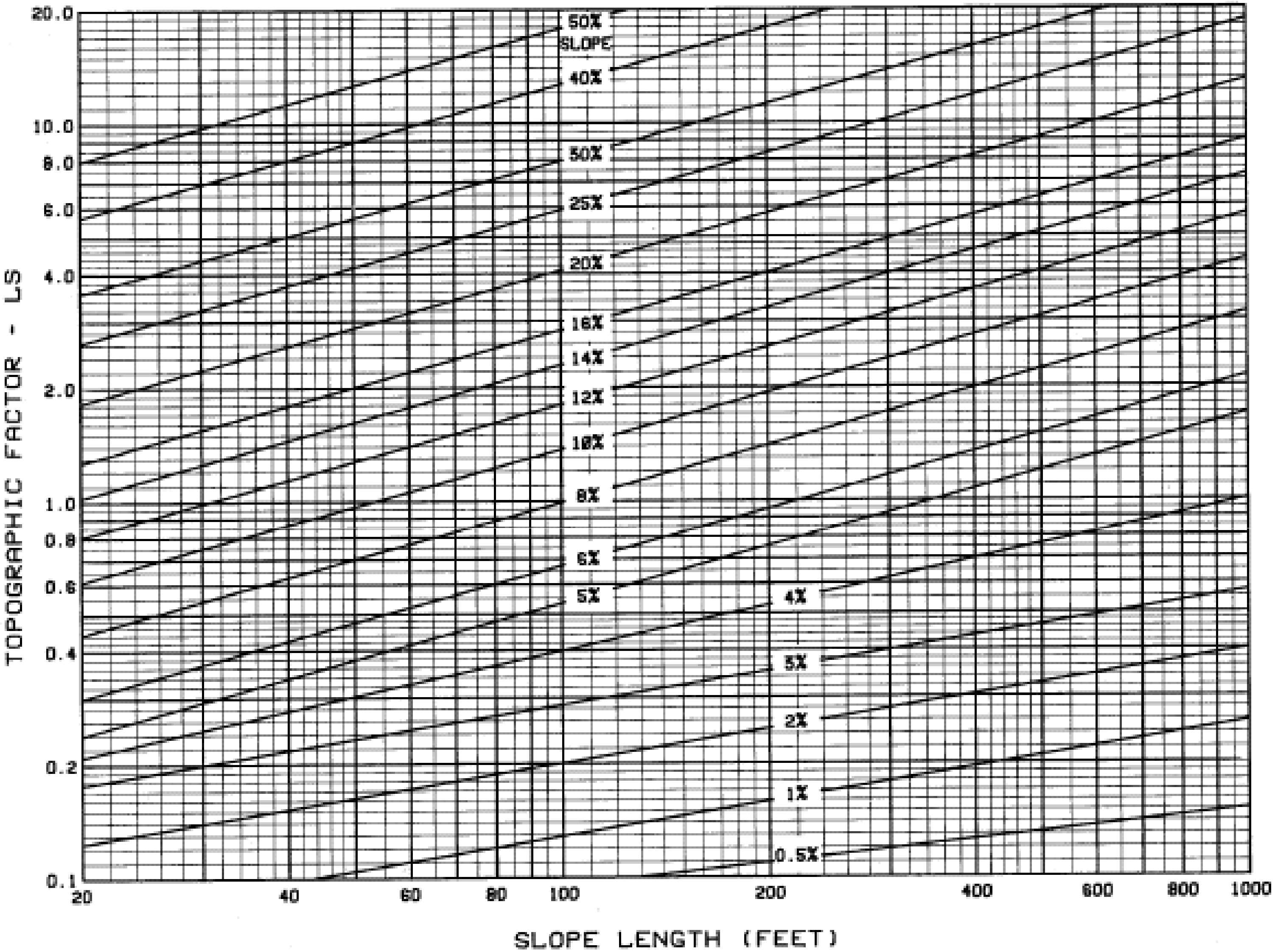
A =R x **K** x LS x C x P

LS (comprimento de rampa e declividade)



- Razão da perda do solo sob certas condições de topografia em relação a um local com um comprimento de rampa e declividade padrões.

A =R x K x **<u>LS</u>** x C x P



Fator Topográfico LS

A = R x K x **LS** x C x P

C (fator de cultivo/preparo)

- Razão da perda do solo por um uso do solo sob condições específicas em relação à áreas em pousio ou preparo contínuo.

Crop	Fator
Milho grãos	0.40
Milho silagem, Feijão & Canola	0.50
Cereais	0.35
Cultivos hortícolas	0.50
Frutíferas	0.10
Feno e Pastagens	0.02

Preparo	Fator
Aração de outouno	1.00
Aração de primavera	0.90
Preparo com mulch	0.60
Preparo em nível	0.35
Preparo em talhões	0.25
Plantio Direto	0.25

A = R x K x LS x **C** x P

P (práticas conservacionistas)

- Razão da perda do solo de uma prática conservacionista em relação a um preparo morro abaixo.

Prática	**Fator P**
Morro Abaixo	1.00
Plantio cruzado	0.75
Plantio em nível	0.50
Plantio em faixas, cruzado	0.37
Plantio em faixas, em nível	0.25

A = R x K x LS x C x **P**

WEPP
Water Erosion Prediction Project

- Foster, G.R. and L.J. Lane (compilers). 1987. User Requirements. USDA-Water Erosion Prediction Project. NSERL Report #1, USDA-ARS National Soil Erosion Research Laboratory, West Lafayette, IN.

Water Erosion Prediction Project (WEPP)

- Desenvolvido em 1987
- Modelo baseado em processos físicos que simula todo o processo de erosão
- Pode predizer a distribuição espacial e temporal da perda e deposição líquida do solo

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 ($kg/(m^2 s)$)

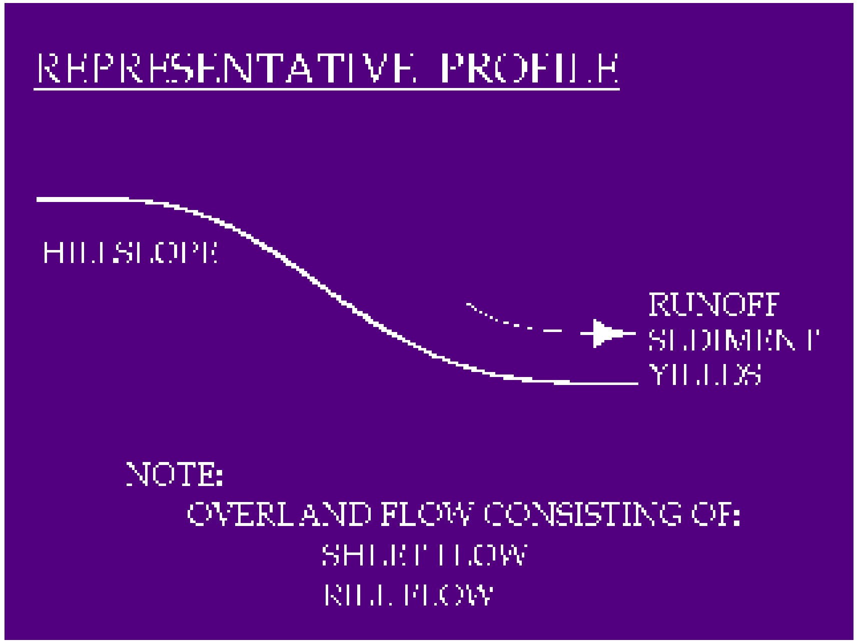
WEPP

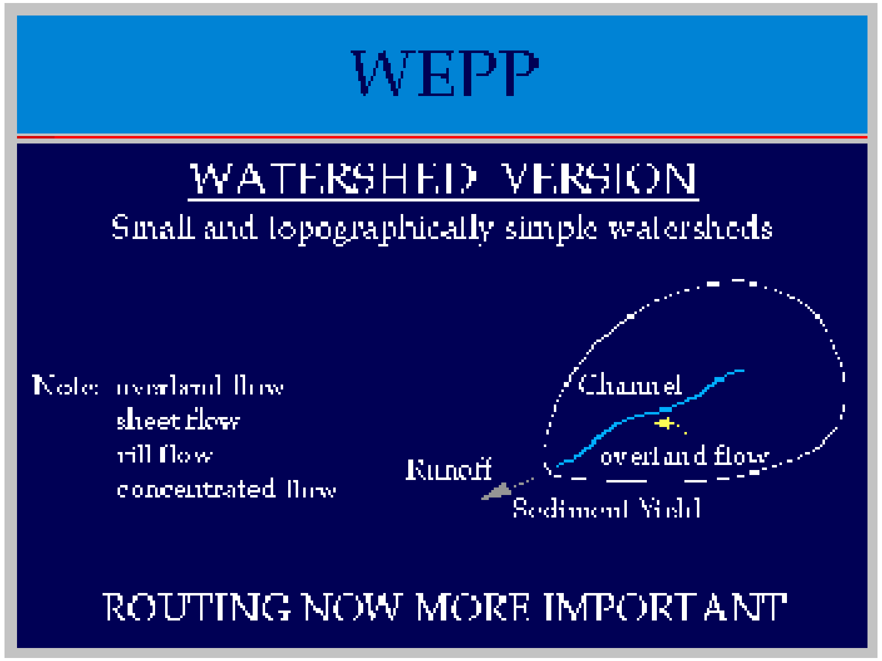
$$dG/dx = Dr + Di$$

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 ($kg/(m^2\ s)$)

Aplicações do modelo WEPP

- Vertente
  - Substituição direta da USLE
  - Pode predizer a perda e deposição do solo numa vertente
- Microbacia hidrográfica
  - Desprendimento, transporte e deposição de sedimentos em sistemas fluviais e na vertente





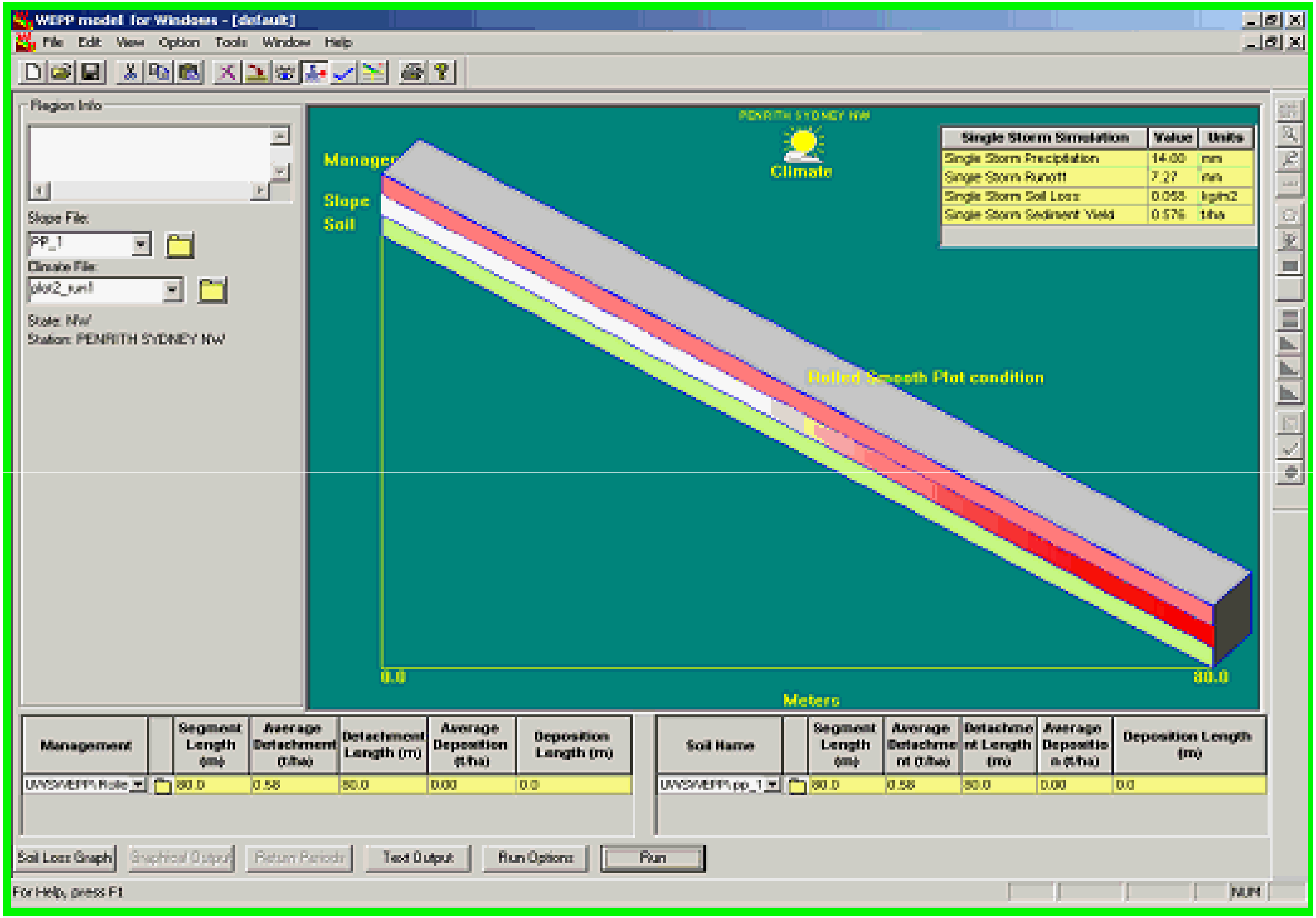

WEPP model for Windows - [default]
File Edit View Option Tools Window Help
Region Info
Slope File:
PP_1
Climate File:
plot2_run1
State: NW
Station: PENRITH SYDNEY NW
PENRITH SYDNEY NW
Climate
Management
Slope
Soil
Single Storm Simulation | Value | Units
Single Storm Precipitation | 14.00 | mm
Single Storm Runoff | 7.27 | mm
Single Storm Soil Loss | 0.058 | kg/m2
Single Storm Sediment Yield | 0.576 | t/ha
Rolled Smooth Plot condition
0.0
80.0
Meters
Management | Segment Length (m) | Average Detachment (t/ha) | Detachment Length (m) | Average Deposition (t/ha) | Deposition Length (m)
80.0 | 0.58 | 80.0 | 0.00 | 0.0
Soil Name | Segment Length (m) | Average Detachment (t/ha) | Detachment Length (m) | Average Deposition (t/ha) | Deposition Length (m)
80.0 | 0.58 | 80.0 | 0.00 | 0.0
Soil Loss Graph
Graphical Output
Return Periods
Text Output
Run Options
Run
For Help, press F1
NUM

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.

Modelagem de erosão:

Der Tropenlandwirt, Beiträge zur tropischen Landwirtschaft und Veterinärmedizin,
101. Jahrgang, Oktober 2000, S. 107 - 118.

Comparison of Three Water Erosion Prediction Methods (^{137}Cs, WEPP, USLE) in South-East Brazilian Sugarcane Production

G. Sparovek* [1], O.O.S. Bacchi*, E. Schnug**, S.B.L. Ranieri* and I.C. De Maria***

Key words: Erosion prediction, ^{137}Cs, WEPP, USLE, sugarcane, Brazil.

PERGAMON

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Erosion database interface (EDI): a computer program for georeferenced application of erosion prediction models

Simone Beatriz Lima Ranieri[a], Quirijn de Jong van Lier[a,*], Gerd Sparovek[a], Dennis C. Flanagan[b]

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[b] USDA-Agricultural Research Service, National Soil Erosion Research Laboratory, 1196 Building Soil, West Lafayette, IN 47907-1196, USA

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Computers & Geosciences 31 (2005) 1270–1276

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Short note

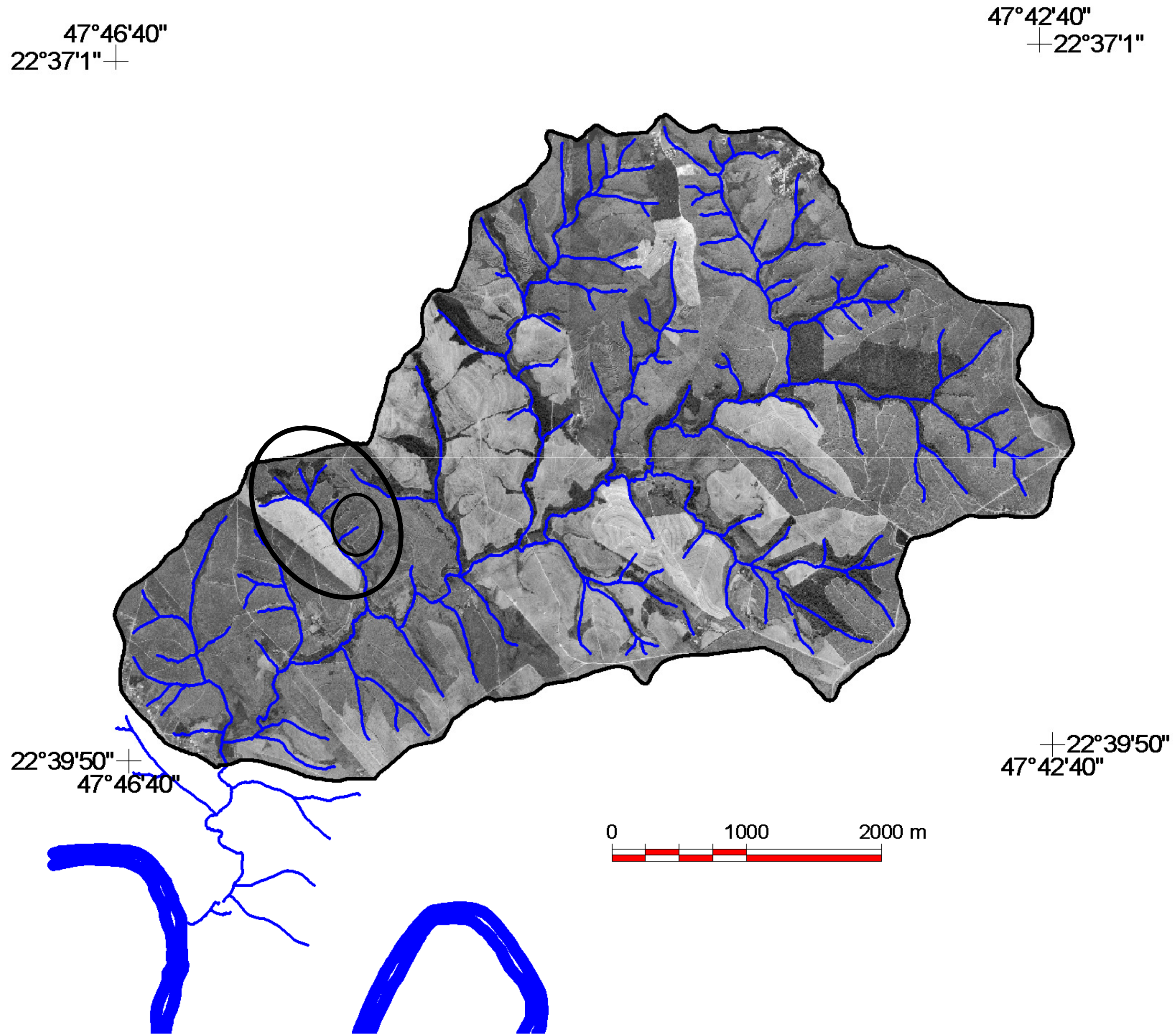
Runoff mapping using WEPP erosion model and GIS tools

Quirijn de Jong van Lier[a,*], Gerd Sparovek[a], Dennis C. Flanagan[b], Elke M. Bloem[c], Ewald Schnug[c]

[a] University of São Paulo, CP 9, 13418-900, Piracicaba (SP), Brazil
[b] USDA-Agricultural Research Service, National Soil Erosion Research Laboratory, 275 S. Russell Street, West Lafayette, IN 47907, USA
[c] Institute of Plant Nutrition and Soil Science, Federal Agricultural Research Center (FAL), Bundesallee 50. D-38116, Braunschweig, Germany

Received 15 September 2003; received in revised form 22 March 2005; accepted 22 March 2005

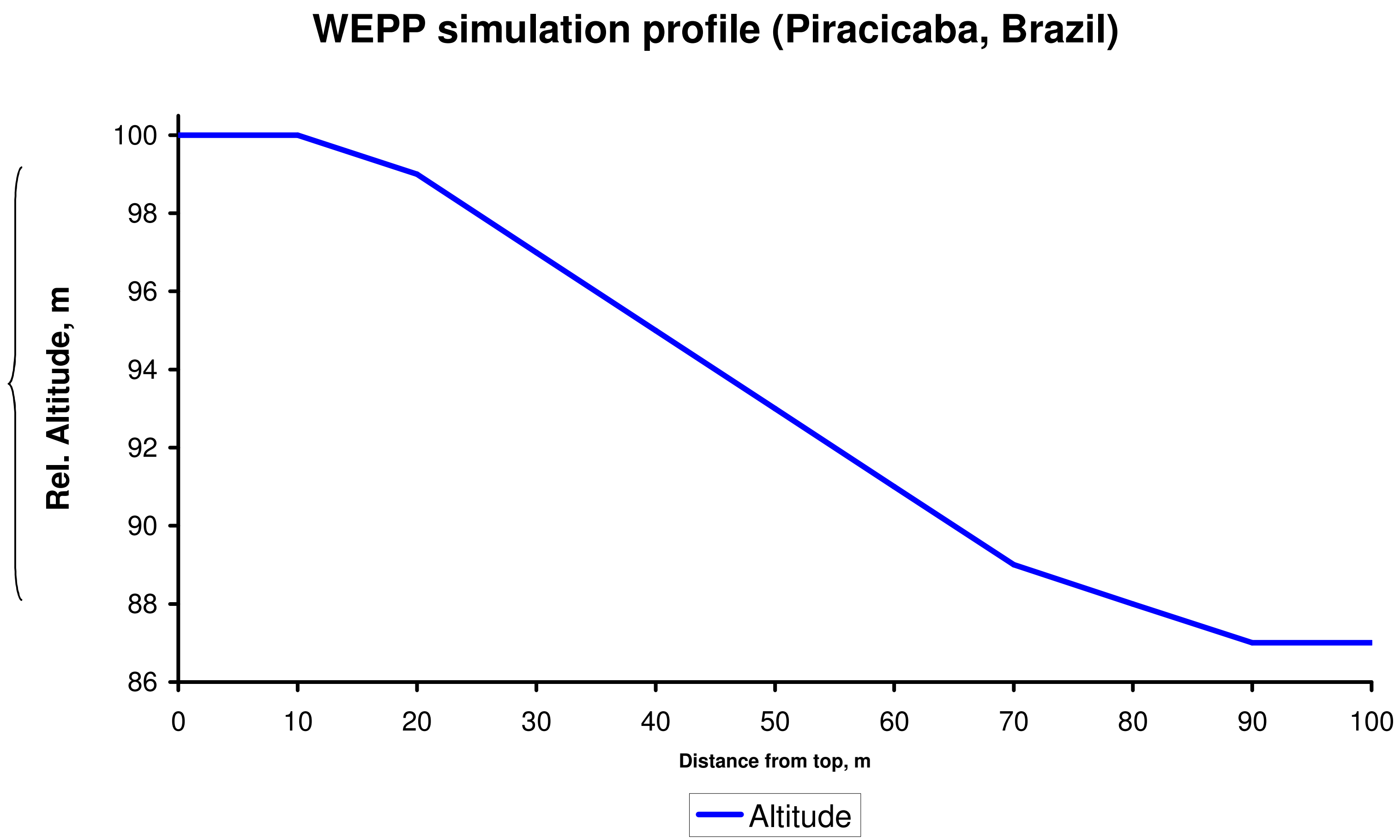
MBH- Ceveiro

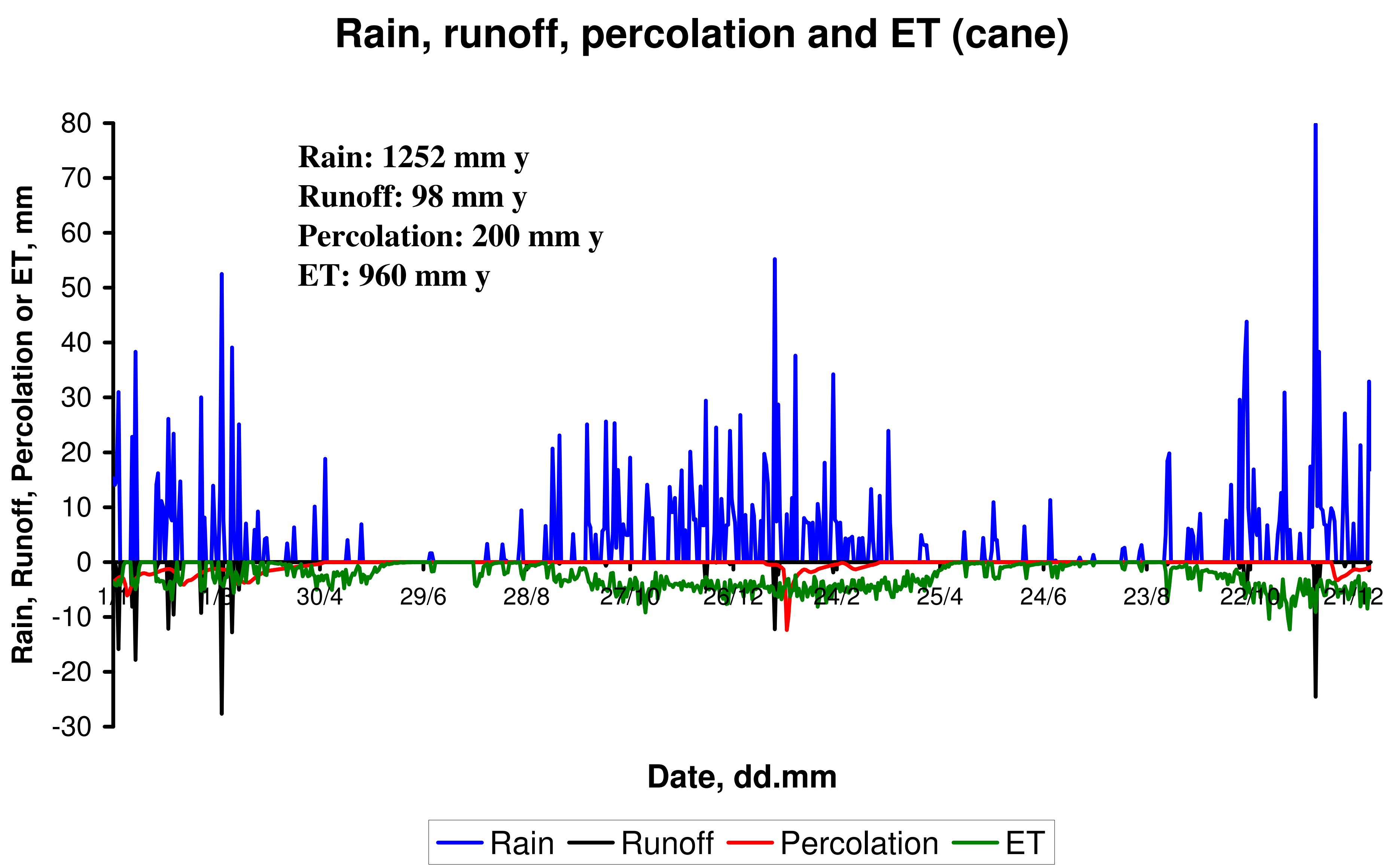

47°46'40"
22°37'1"
47°42'40"
22°37'1"
22°39'50"
47°46'40"
22°39'50"
47°42'40"
0
1000
2000 m

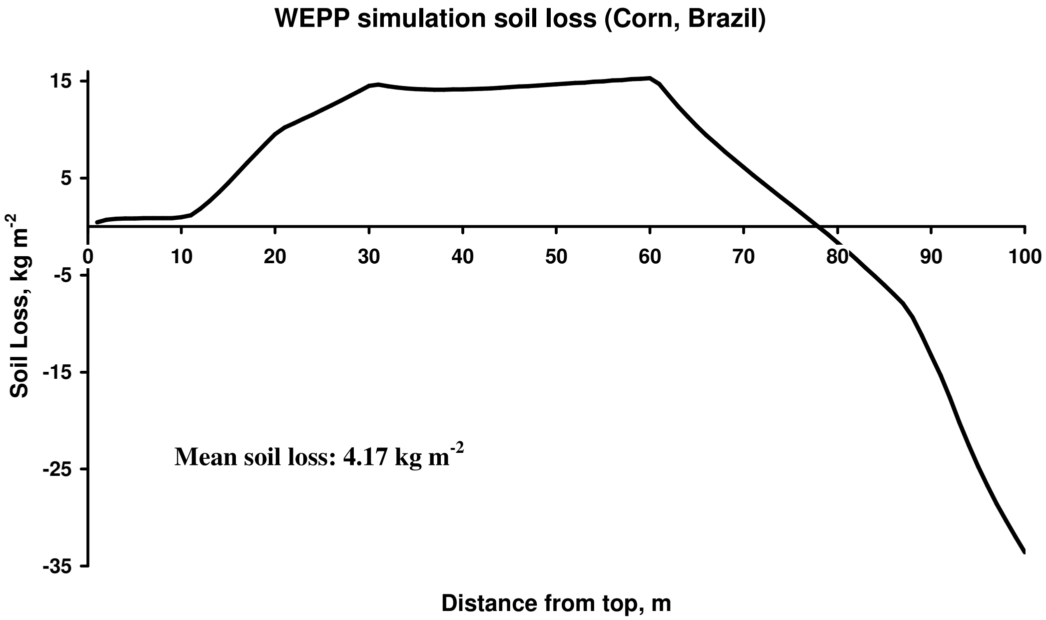
Modelos:

• ^{137}Cs

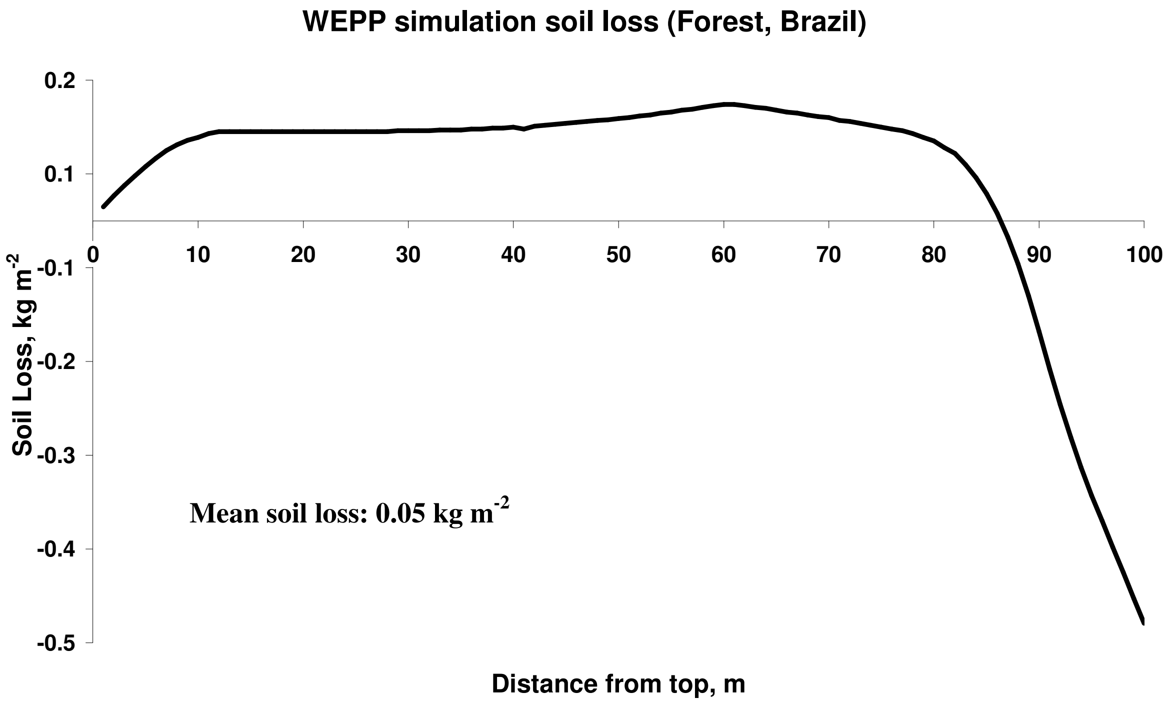
• USLE
• Wepp




Rain, runoff, percolation and ET (cane)
Rain: 1252 mm y
Runoff: 98 mm y
Percolation: 200 mm y
ET: 960 mm y
Rain, Runoff, Percolation or ET, mm
80
70
60
50
40
30
20
10
0
-10
-20
-30
1/1
1/3
30/4
29/6
28/8
27/10
26/12
24/2
25/4
24/6
23/8
22/10
21/12
Date, dd.mm
Rain
Runoff
Percolation
ET

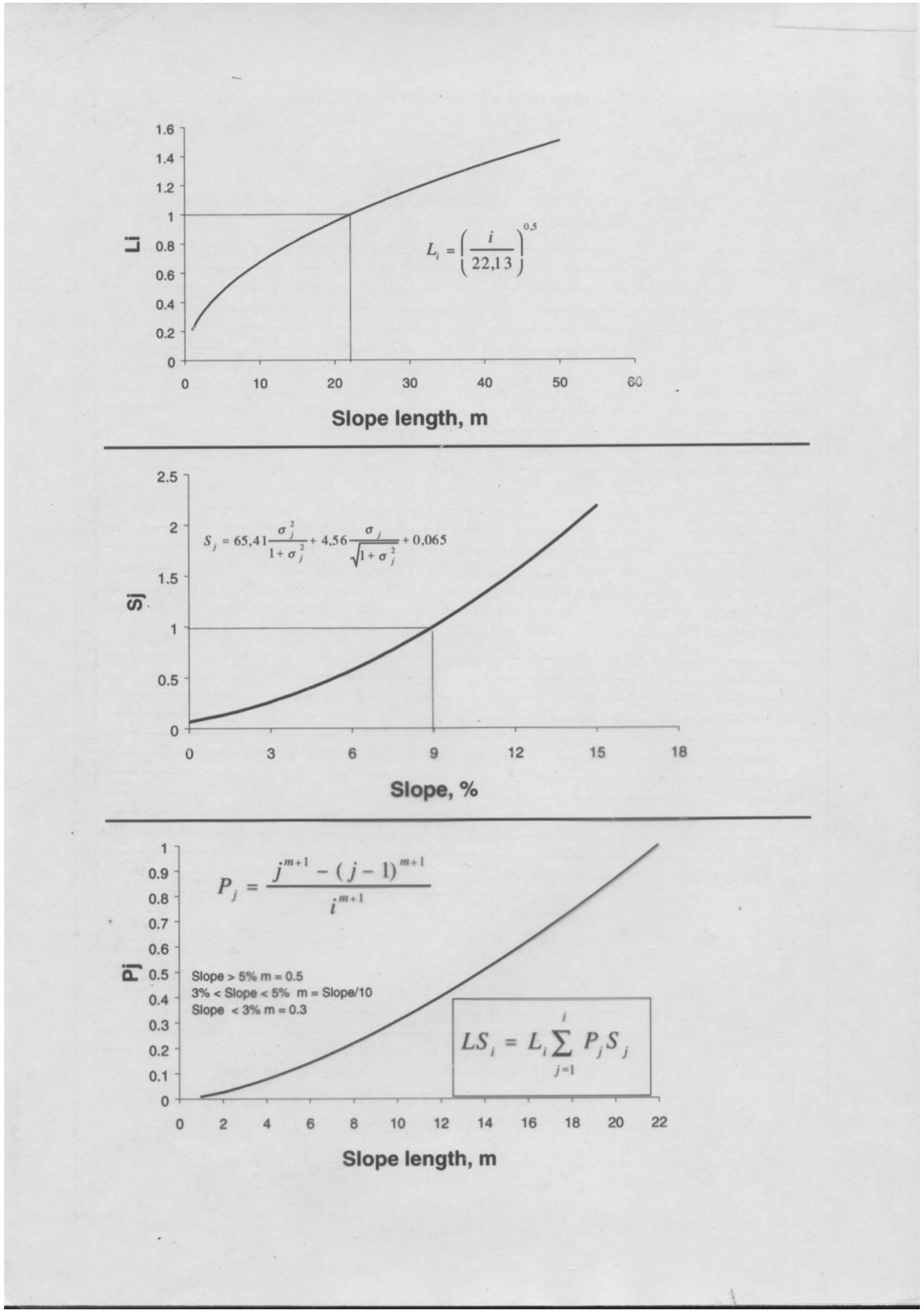


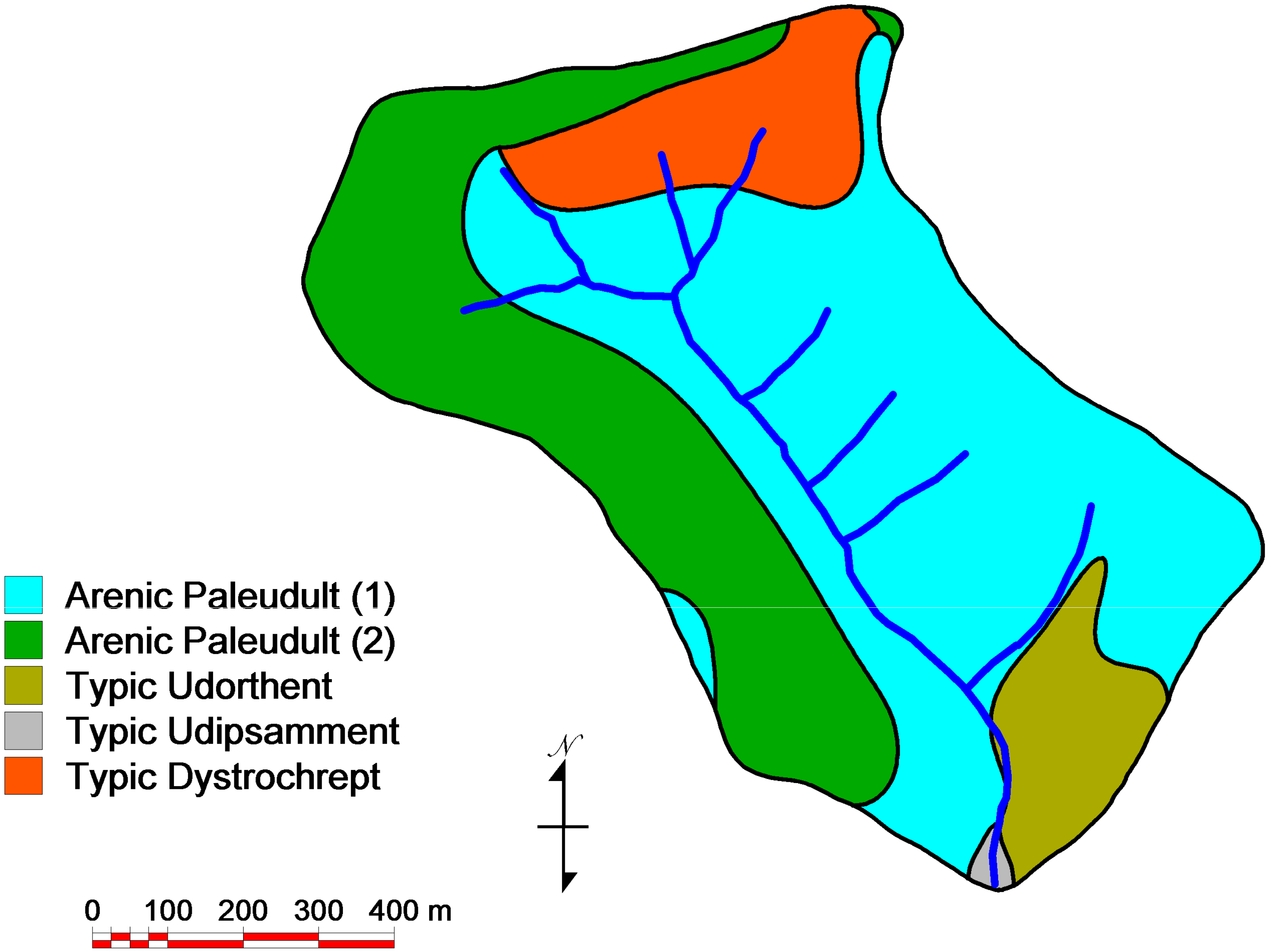
WEPP simulation soil loss (Corn, Brazil)
15
5
-5
-15
-25
-35
0
10
20
30
40
50
60
70
80
90
100
Soil Loss, kg m-2
Mean soil loss: 4.17 kg m-2
Distance from top, m

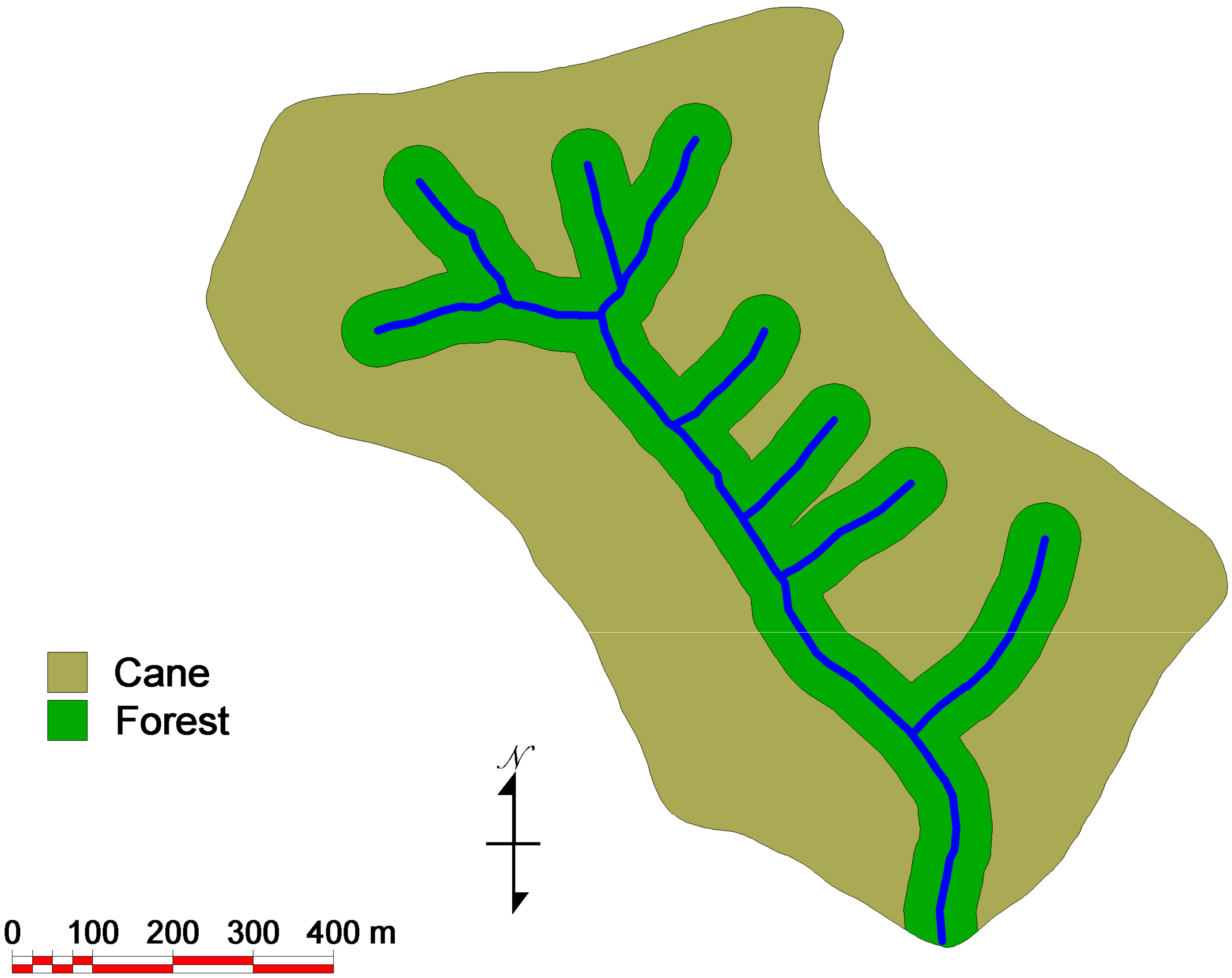


WEPP simulation soil loss (Forest, Brazil)
0.2
0.1
-0.1
-0.2
-0.3
-0.4
-0.5
0
10
20
30
40
50
60
70
80
90
100
Soil Loss, kg m-2
Mean soil loss: 0.05 kg m-2
Distance from top, m

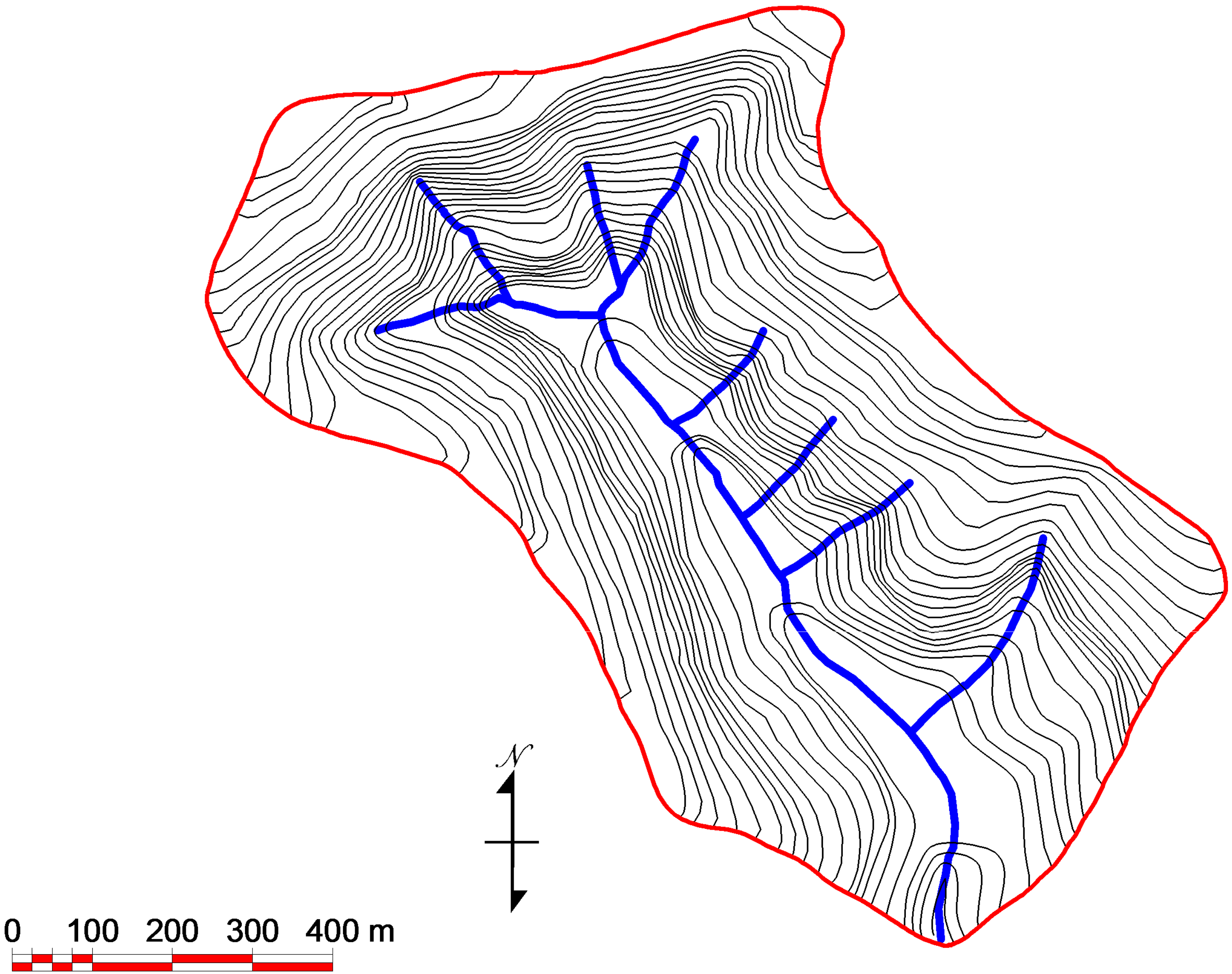
$A = EI_{30}\ K\ LS\ C\ P$

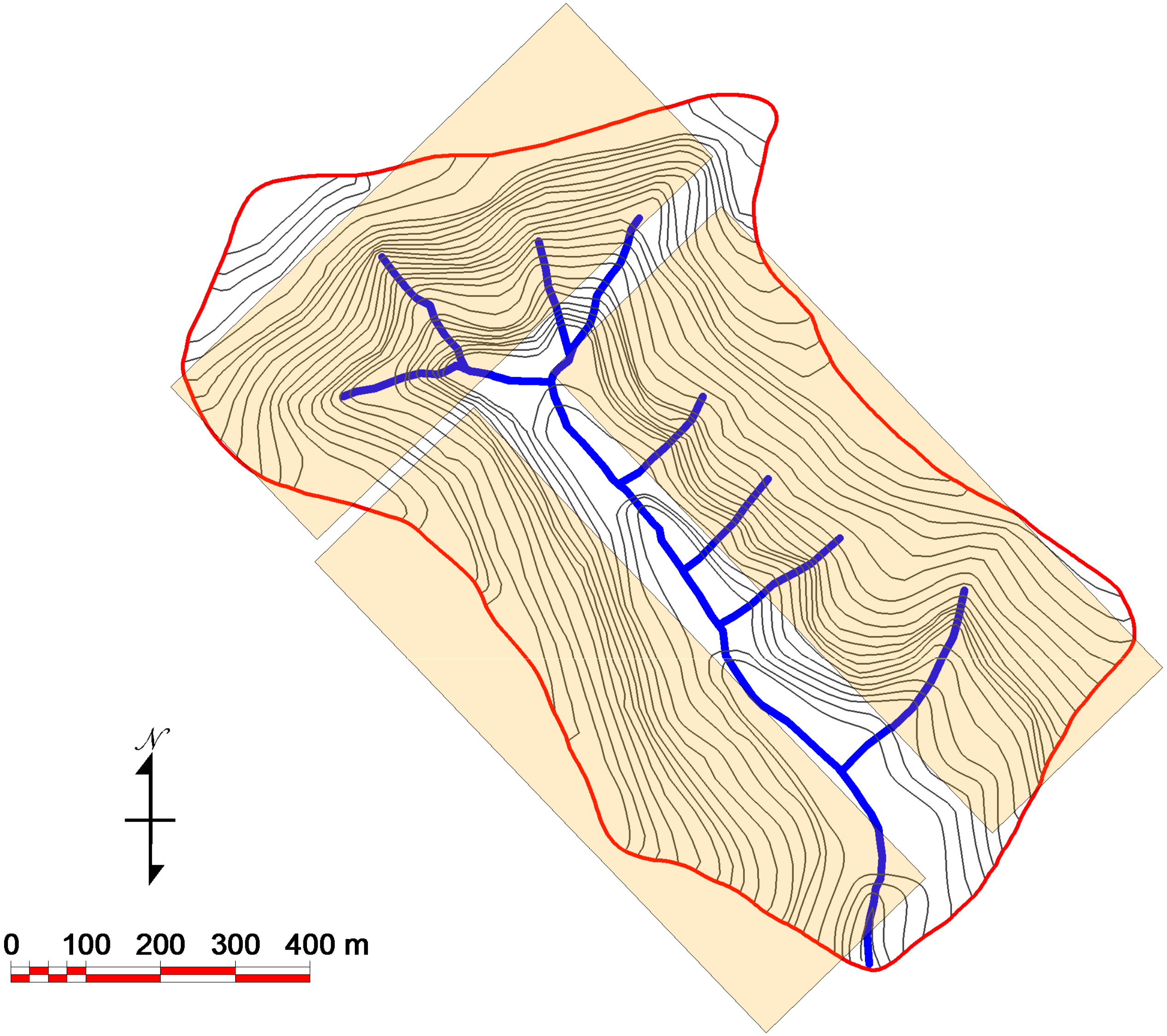

Li
Slope length, m
$L_i = \left(\frac{i}{22,13}\right)^{0,5}$
Sj
Slope, %
$S_j = 65,41\frac{\sigma_j^2}{1+\sigma_j^2} + 4,56\frac{\sigma_j}{\sqrt{1+\sigma_j^2}} + 0,065$
Pj
Slope length, m
$P_j = \frac{j^{m+1} - (j-1)^{m+1}}{i^{m+1}}$
Slope > 5% m = 0.5
3% < Slope < 5% m = Slope/10
Slope < 3% m = 0.3
$LS_i = L_i \sum_{j=1}^{i} P_j S_j$


Arenic Paleudult (1)
Arenic Paleudult (2)
Typic Udorthent
Typic Udipsamment
Typic Dystrochrept
N
0 100 200 300 400 m



Cane
Forest
N
0
100
200
300
400 m


N
0
100
200
300
400 m


N
0 100 200 300 400 m

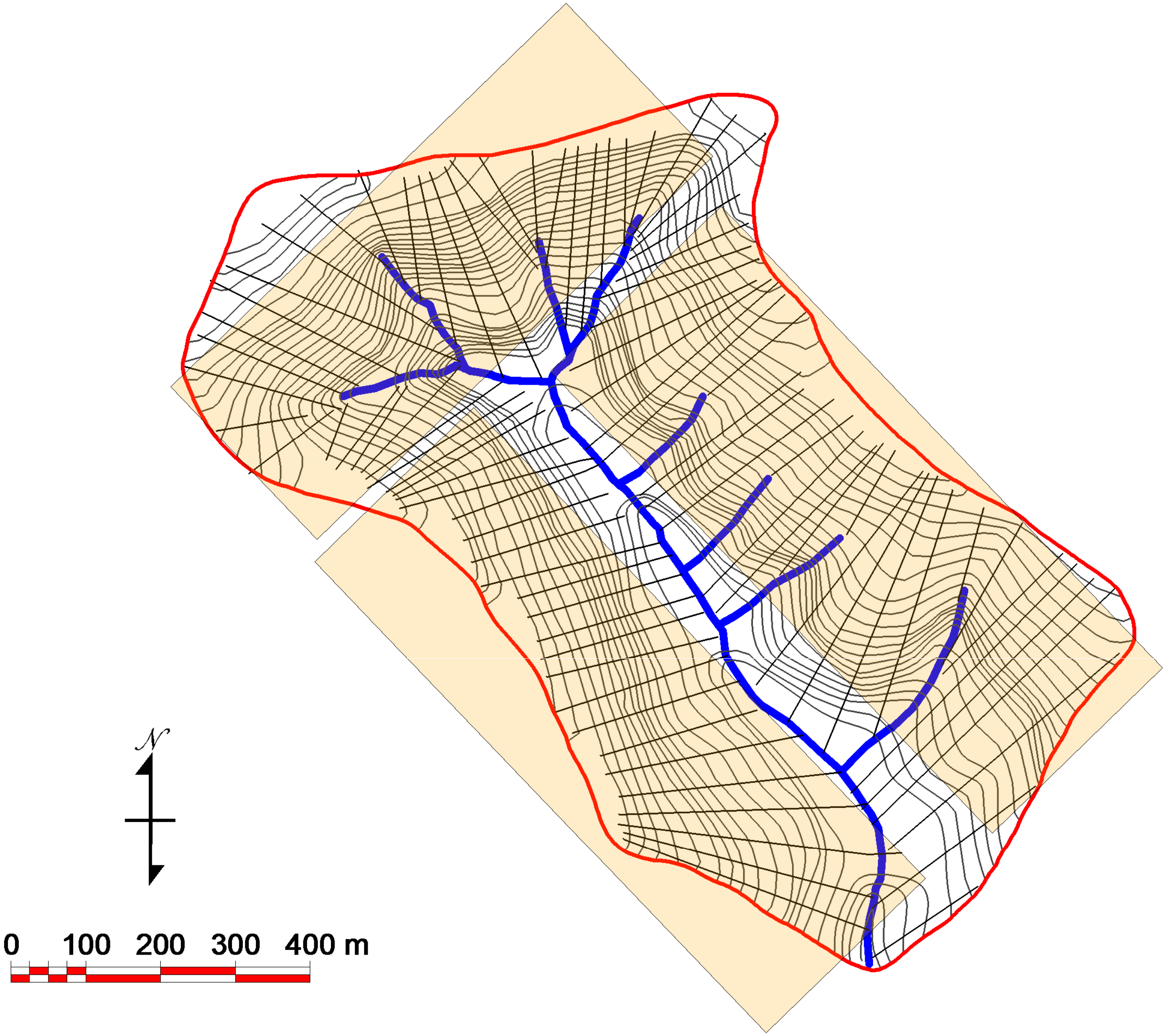
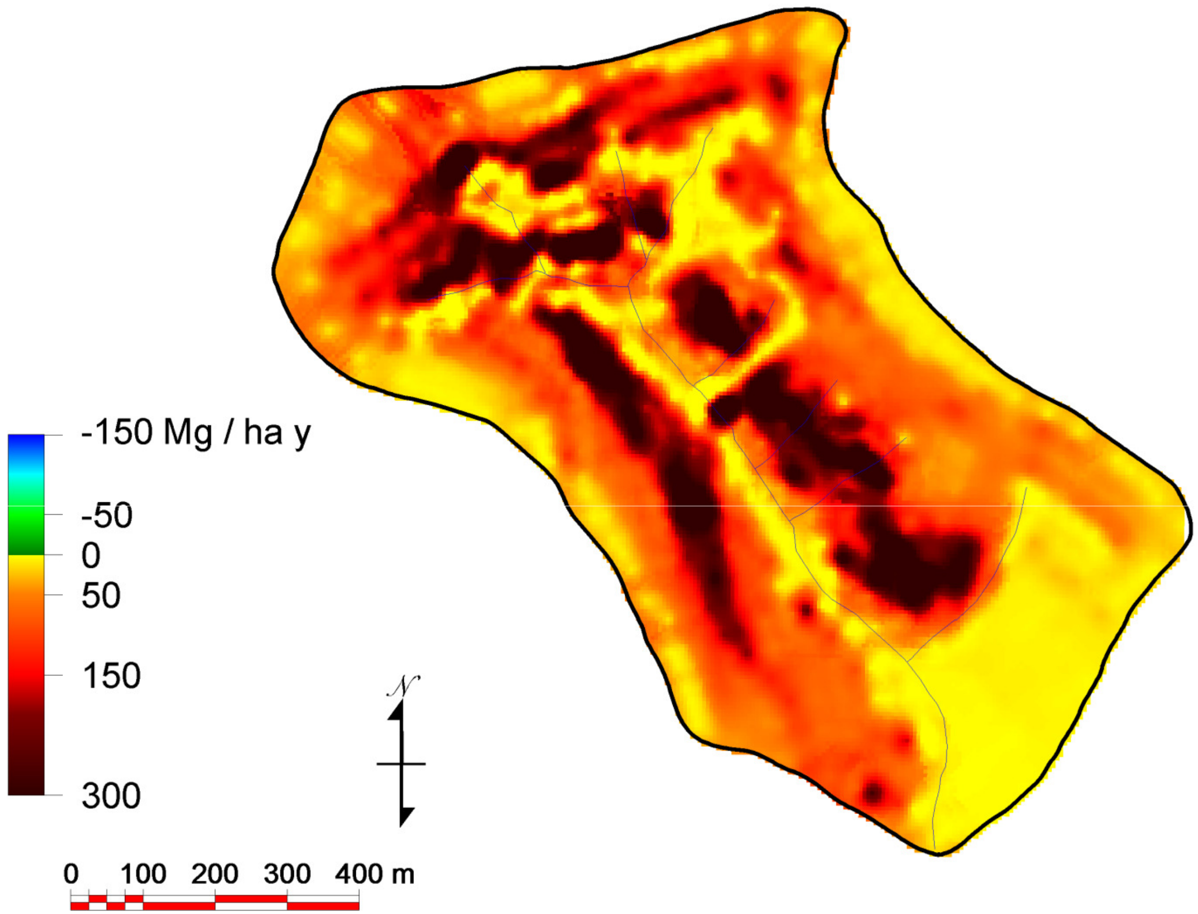
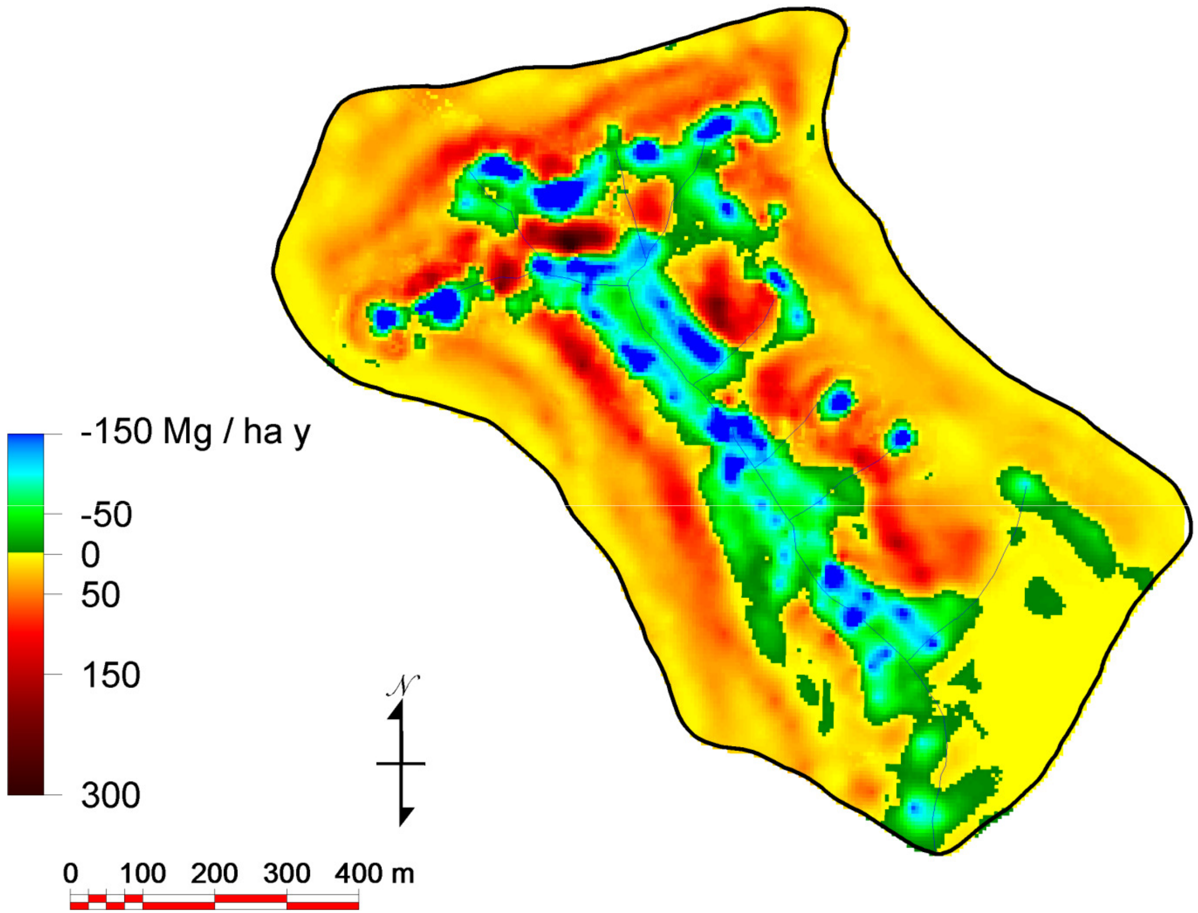

N
0 100 200 300 400 m

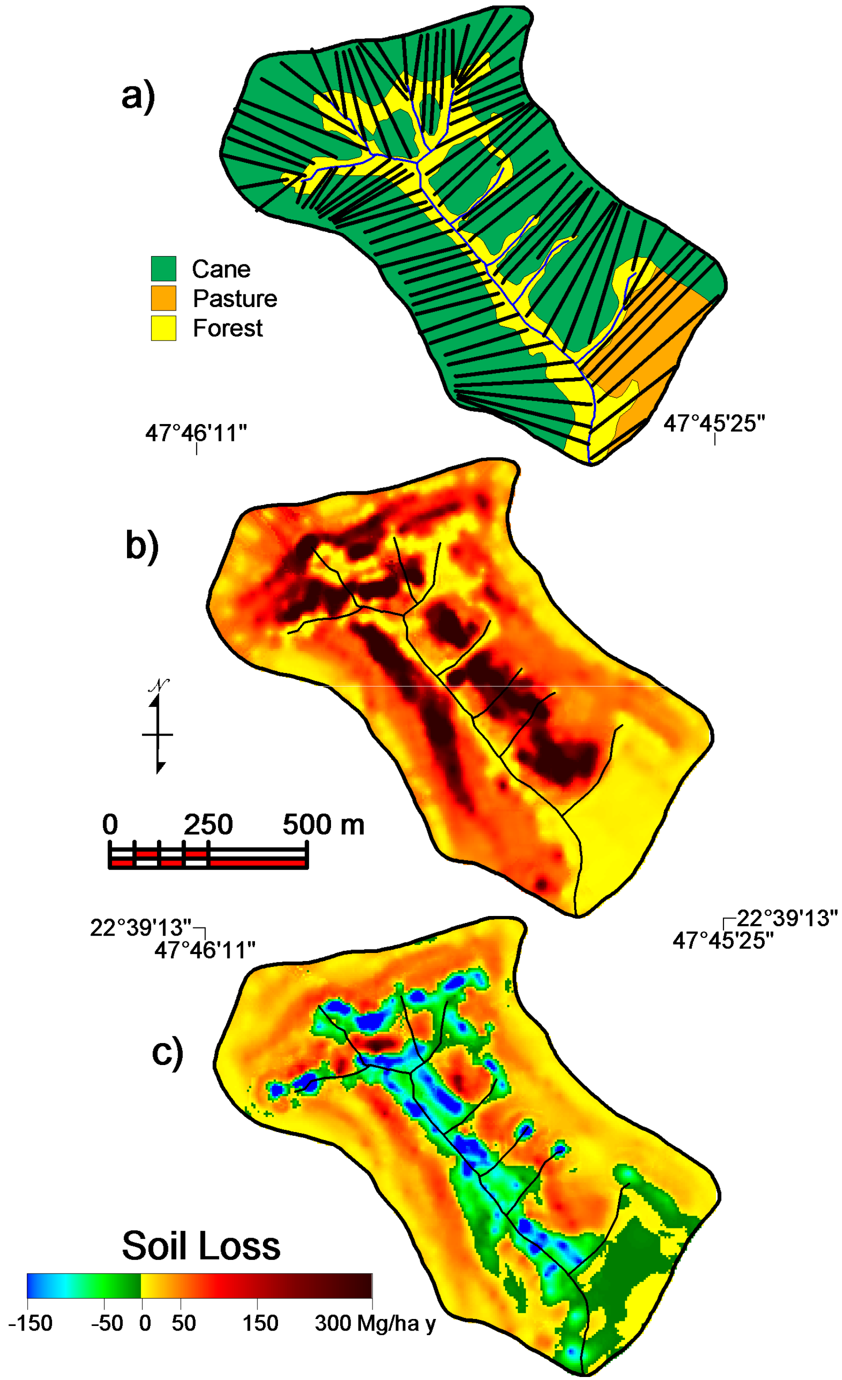
Table 1
Example of input text format database file used for erosion calculations by EDI for WEPP and USLE in Ceveiro watershed for hillslopes 1 and 2 from a total of 84 hillslopes

X[a]	Y[b]	Z[c]	Soil[d]	Land use[e]	Hillslope[f]
215972.14	7492357.91	500	5	1	1
215990.84	7492351.37	498	5	1	1
216012.30	7492343.87	496	5	1	1
216036.98	7492335.24	494	5	1	1
216064.13	7492325.75	492	5	1	1
216093.04	7492315.65	490	5	1	1
216109.58	7492309.86	488	5	1	1
216125.73	7492304.22	486	5	1	1
216145.52	7492297.30	484	3	1	1
216168.09	7492289.41	482	3	1	1
216188.68	7492282.21	480	3	1	1
216196.28	7492279.56	478	3	1	1
216204.46	7492276.70	476	3	1	1
216218.54	7492271.77	474	3	1	1
216236.58	7492265.47	472	3	1	1
216253.16	7492259.67	470	3	1	1
216263.90	7492255.92	468	3	1	1
216274.53	7492252.20	466	3	1	1
216288.76	7492247.23	464	23	1	1
215972.28	7492367.25	500	5	1	2
215992.31	7492362.44	498	5	1	2
216010.06	7492358.18	496	5	1	2
216033.34	7492352.59	494	5	1	2
216061.82	7492345.76	492	5	1	2
216091.39	7492338.66	490	5	1	2
216108.31	7492334.60	488	5	1	2
216123.42	7492330.97	486	5	1	2
216143.98	7492326.04	484	5	1	2
216169.89	7492319.82	482	3	1	2
216191.85	7492314.55	480	3	1	2
216204.36	7492311.55	478	3	1	2
216215.97	7492308.76	476	3	1	2
216229.35	7492305.55	474	3	1	2
216249.48	7492300.72	472	3	1	2
216268.06	7492296.26	470	3	1	2
216279.50	7492293.51	468	3	1	2
216291.42	7492290.65	466	3	1	2

[a] Easting in Universal Transverse Mercator (UTM) coordinates (zone 23S, ellipsoid IUGG 1967, datum South American 1969 Brazil).
[b] Northing in UTM coordinates.
[c] Altitude (BSL) in metric units extracted from the digital contour line map from the Ceveiro watershed.
[d] Soil type, where 3—Arenic Paleudult; 5—Typic Dystrochrept and 23—Typic Udorthent.
[e] Land use, where 1—sugarcane.
[f] Hillslope number.


-150 Mg / ha y
-50
0
50
150
300
N
0
100
200
300
400 m

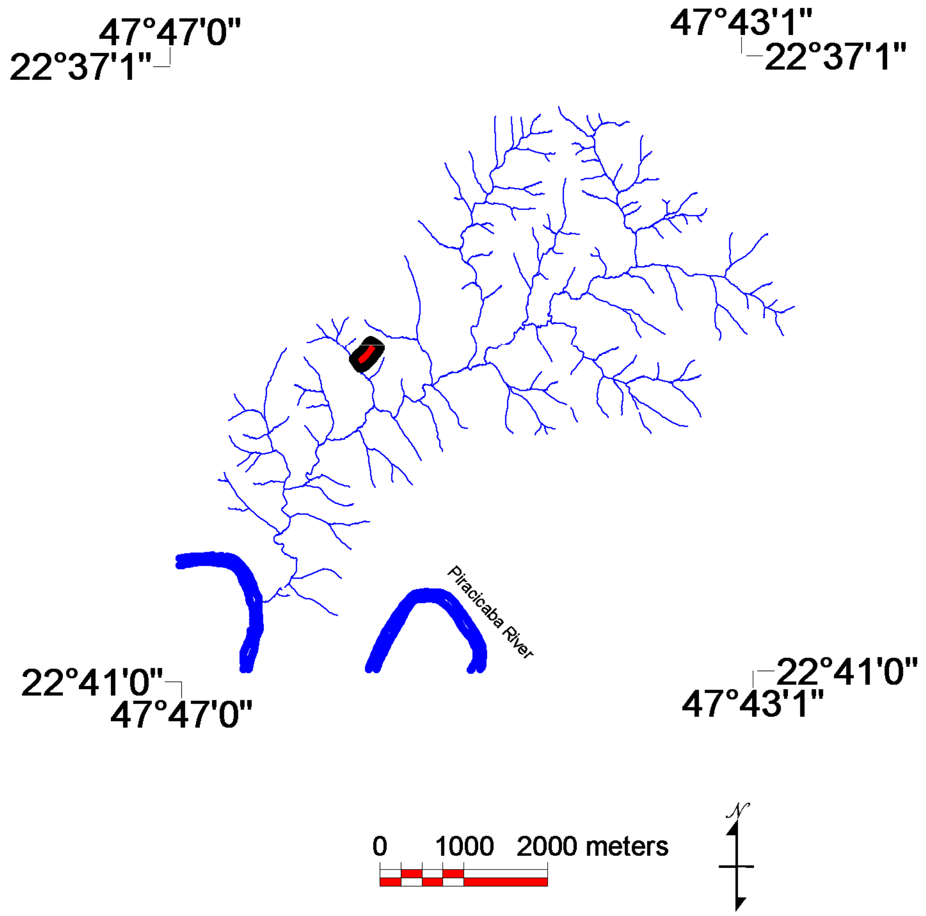

-150 Mg / ha y
-50
0
50
150
300
N
0
100
200
300
400 m

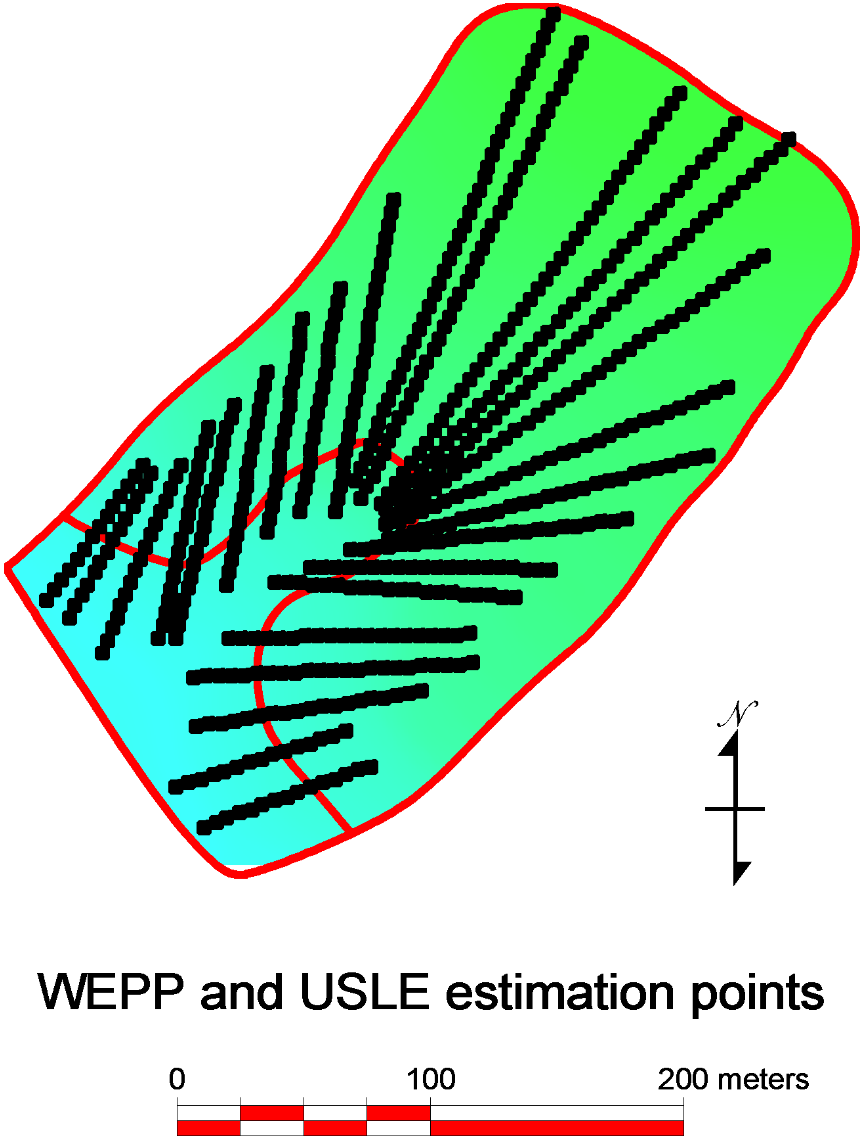


a)
Cane
Pasture
Forest
47°46'11"
47°45'25"
b)
0
250
500 m
22°39'13"
47°46'11"
22°39'13"
47°45'25"
c)
Soil Loss
-150
-50
0
50
150
300 Mg/ha y

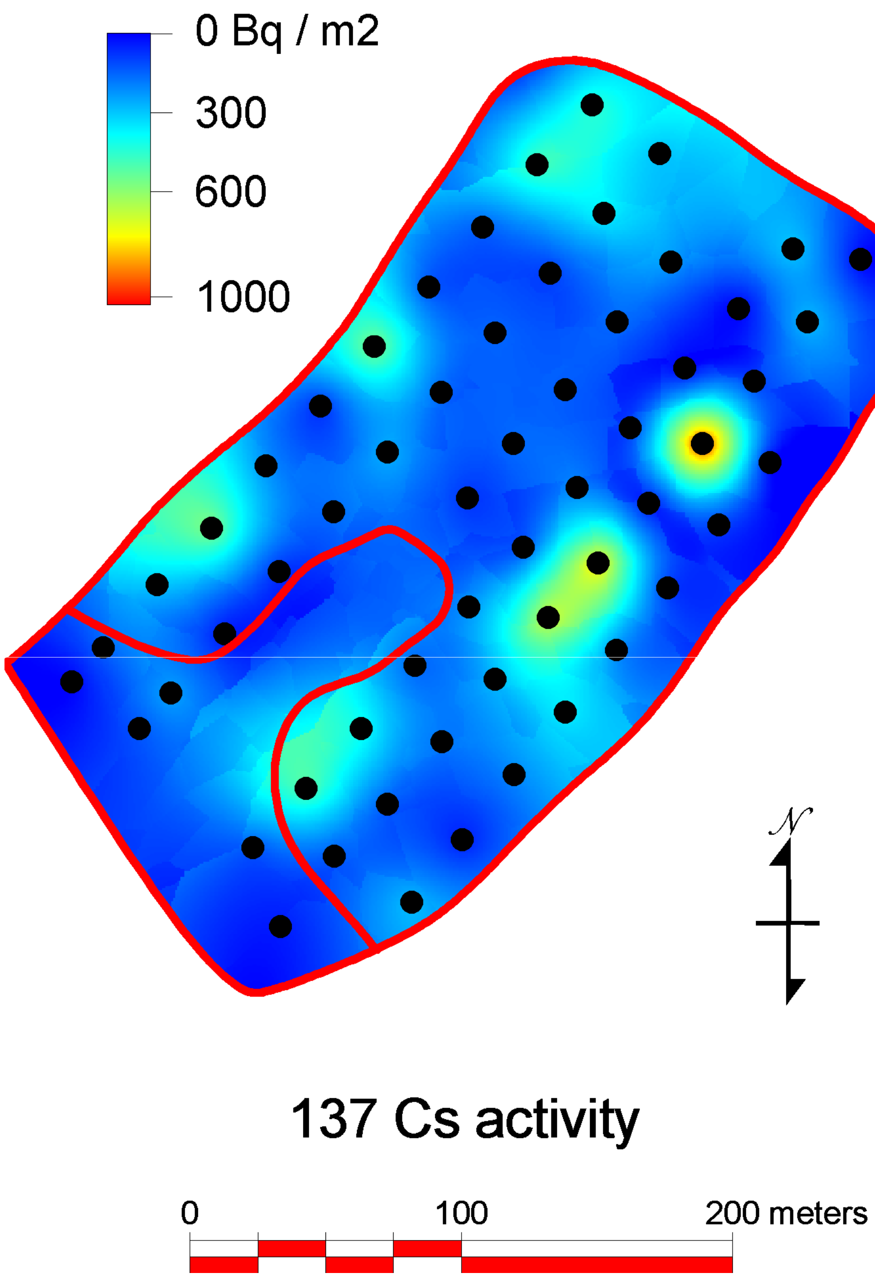
Ceveiro Watersehd

Area: 6 ha
Soil: Arenic Paleudult
Climate: Cwa
Rainfall: 1,200 mm y

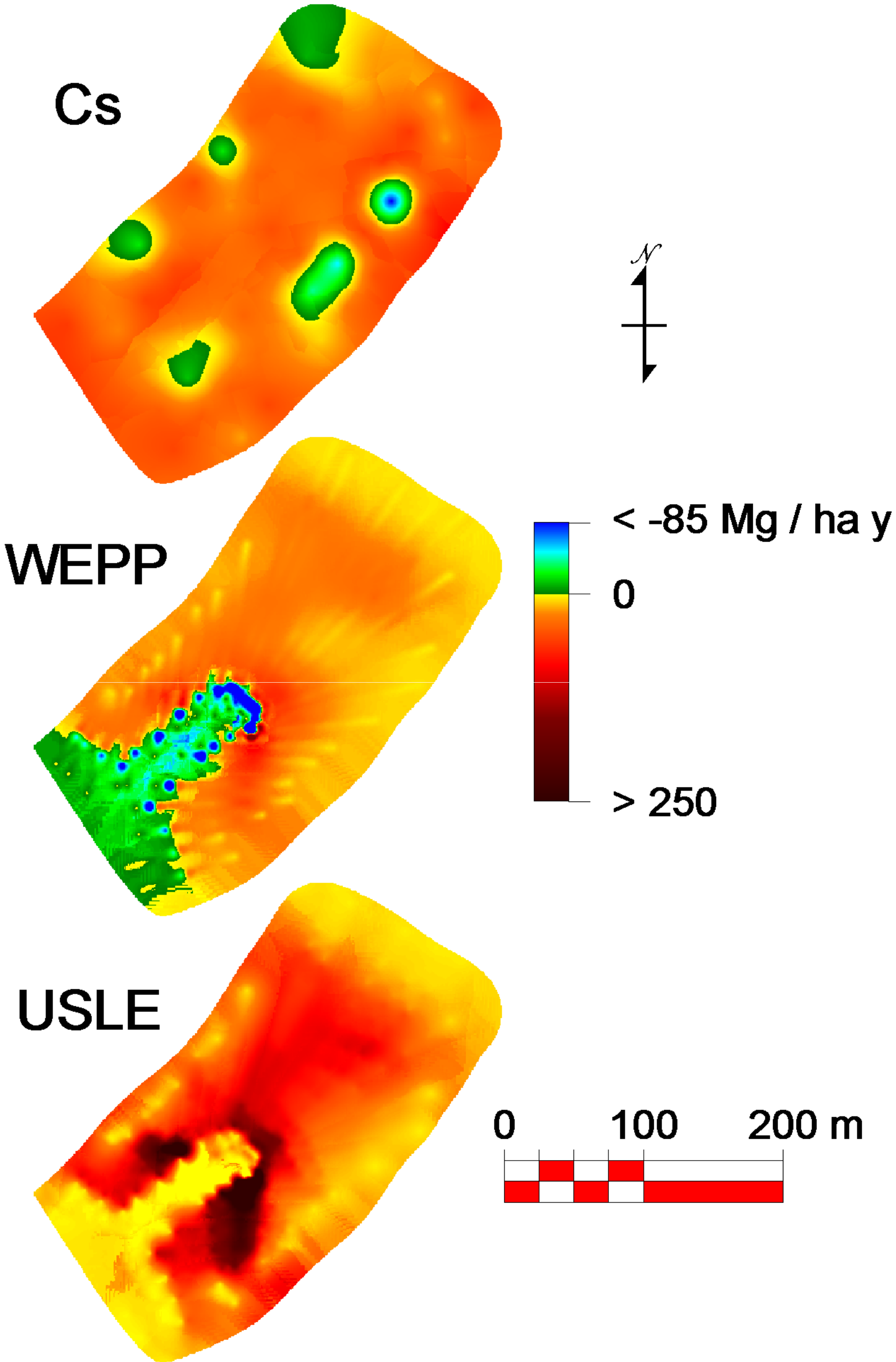




WEPP and USLE estimation points



137 Cs activity


Cs
WEPP
USLE
< -85 Mg / ha y
0
> 250
0
100
200 m

WEPP output results are contained in several files, among those the files with extension .wtr. These files are optionally created and contain detailed information about accumulated runoff estimates at the lower end of each OFE for each day (d) of each one of the n years (y) of the simulation ($Qac_{ofe,d,y}$, mm d^{-1} or 10^{-3} m^3 runoff water per m^2 of contributing area per day). The .wtr files are read by EDI, and daily runoff values are extracted and transformed into annual means for each OFE ($\bar{Q}ac_{ofe}$, mm y^{-1}).

$$\bar{Q}ac_{ofe} = \frac{\sum_{y=1}^{n}\sum_{d=1}^{365} Qac_{ofe,d,y}}{n}. \tag{1}$$

To estimate runoff values within each OFE, the accumulated runoff volume from the top of the hillslope to the bottom of each OFE (Vac_{ofe}, m^3 yr^{-1}) is computed as

$$Vac_{ofe} = \bar{Q}ac_{ofe} Lac_{ofe} W \times 10^{-3}, \tag{2}$$

where Lac_{ofe} (m) is the distance between the top of the hillslope and the bottom of the OFE and W (m) is the width of the OFEs. Assuming mass conservation, the volume of runoff produced by each OFE (V_{ofe}, m^3 y^{-1}) can be calculated as

$$V_{ofe} = Vac_{ofe} - Vac_{ofe-1} \tag{3}$$

and from V_{ofe} the average runoff for the OFE ($Qavg_{ofe}$, mm y^{-1}) can be computed as

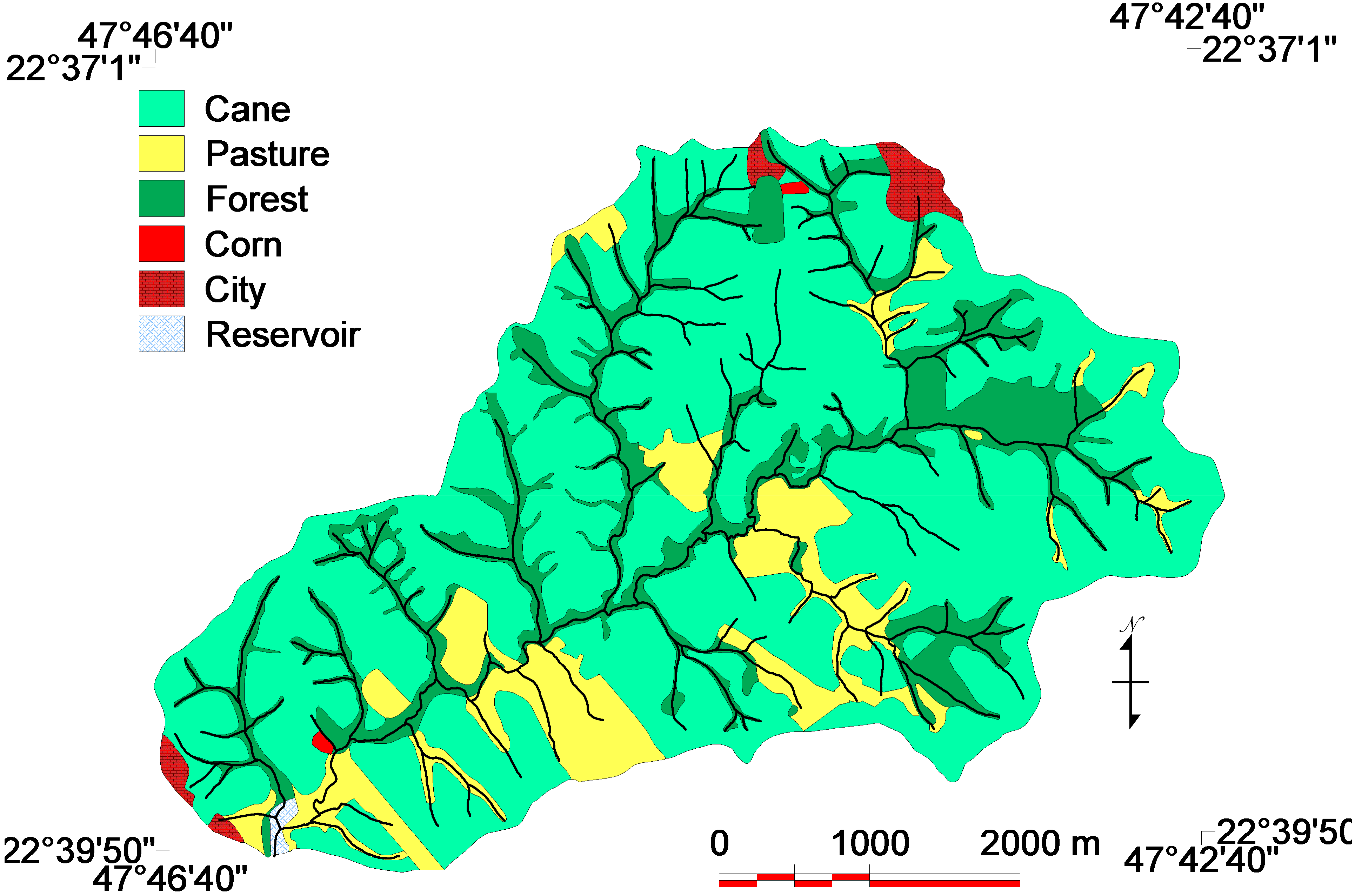
$$Qavg_{ofe} = \frac{V_{ofe}}{L_{ofe} W} \times 10^3, \tag{4}$$

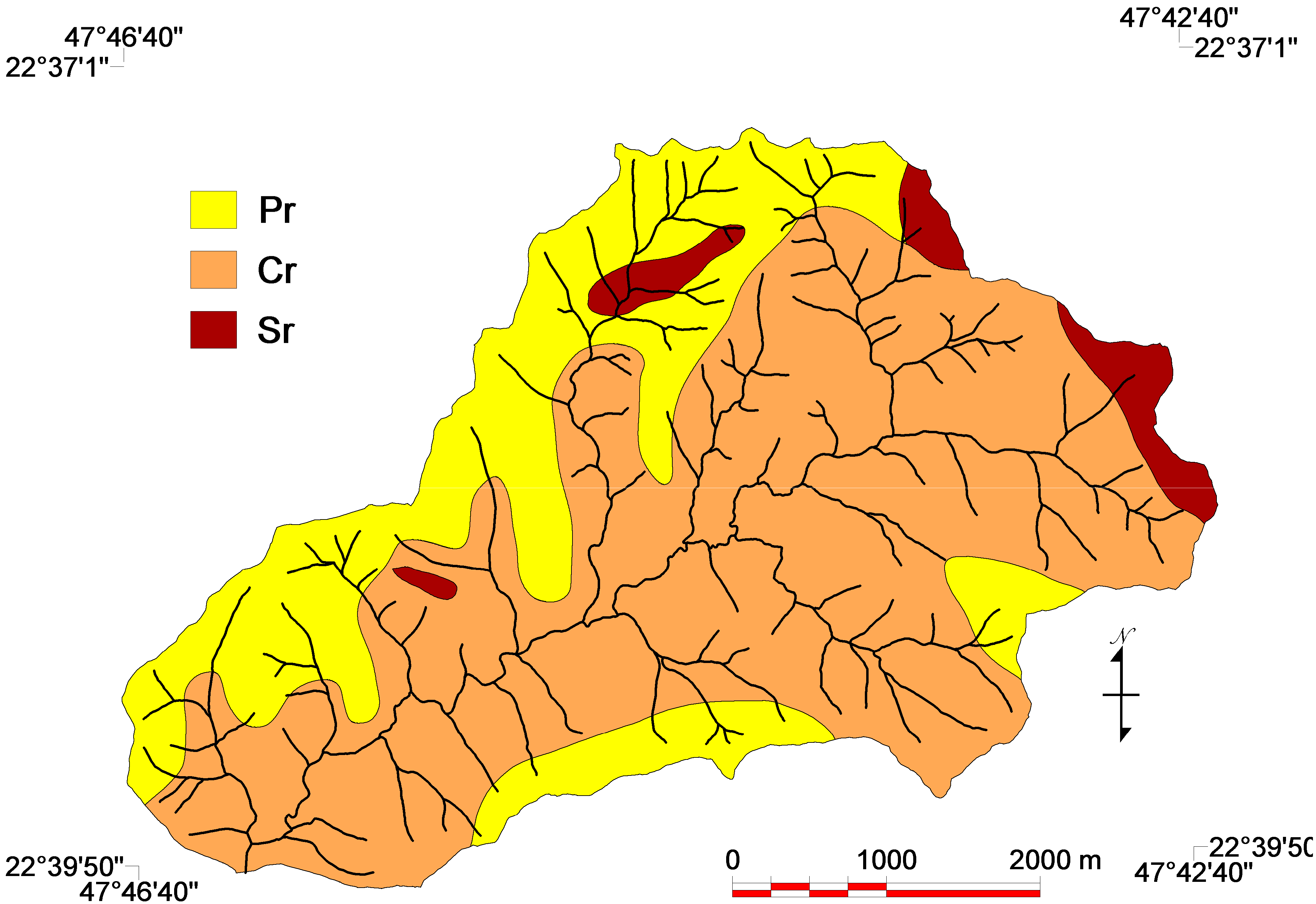
where L_{ofe} (m) is the length of the OFE. As an OFE is defined as a portion of a hillslope with equal soil and management, infiltration rate and runoff production may be assumed constant along one OFE. Therefore it may be assumed that

$$\begin{aligned} Qavg_{ofe} &= \frac{Qtop_{ofe} + Qbot_{ofe}}{2} \\ &= \frac{Qbot_{ofe-1} + Qbot_{ofe}}{2} \Rightarrow Qbot_{ofe} \\ &= 2Qavg_{ofe} - Qbot_{ofe-1}, \end{aligned} \tag{5}$$

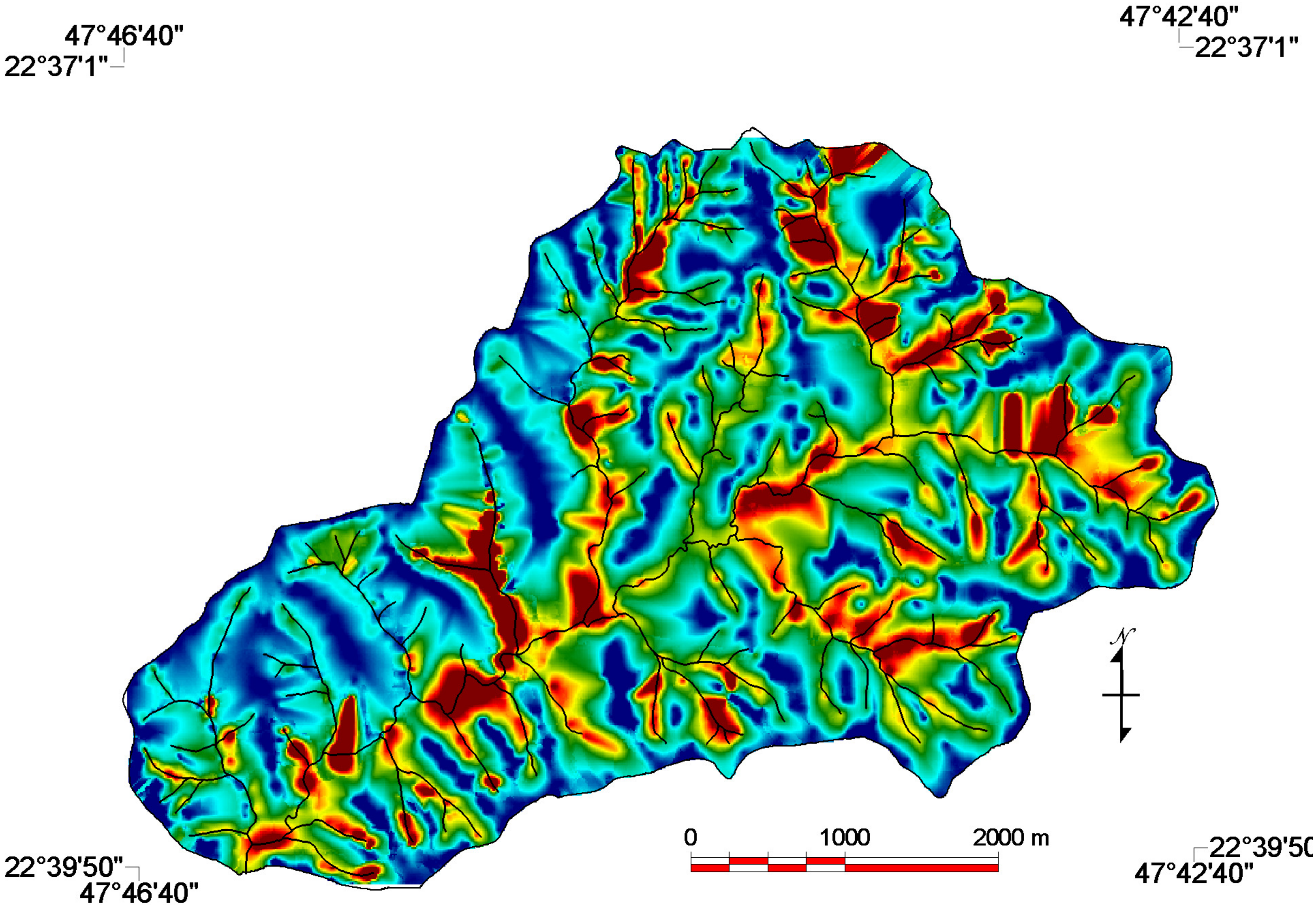
where $Qtop_{ofe}$ (mm yr^{-1}) and $Qbot_{ofe}$ (mm yr^{-1}) are the runoff values at the top and the bottom of each OFE, respectively. If it is assumed that runoff at the top of each hillslope equals zero (i.e., $Qtop_1 = Qbot_0 = 0$), this approach allows estimation of $Qbot_{ofe}$ for each OFE by interpolating linearly between OFE bottom values. The runoff within each OFE can also be computed. After this, the coordinates not considered by WEPP processing are restored by EDI, and a file containing coordinates and runoff estimates in text format is created.

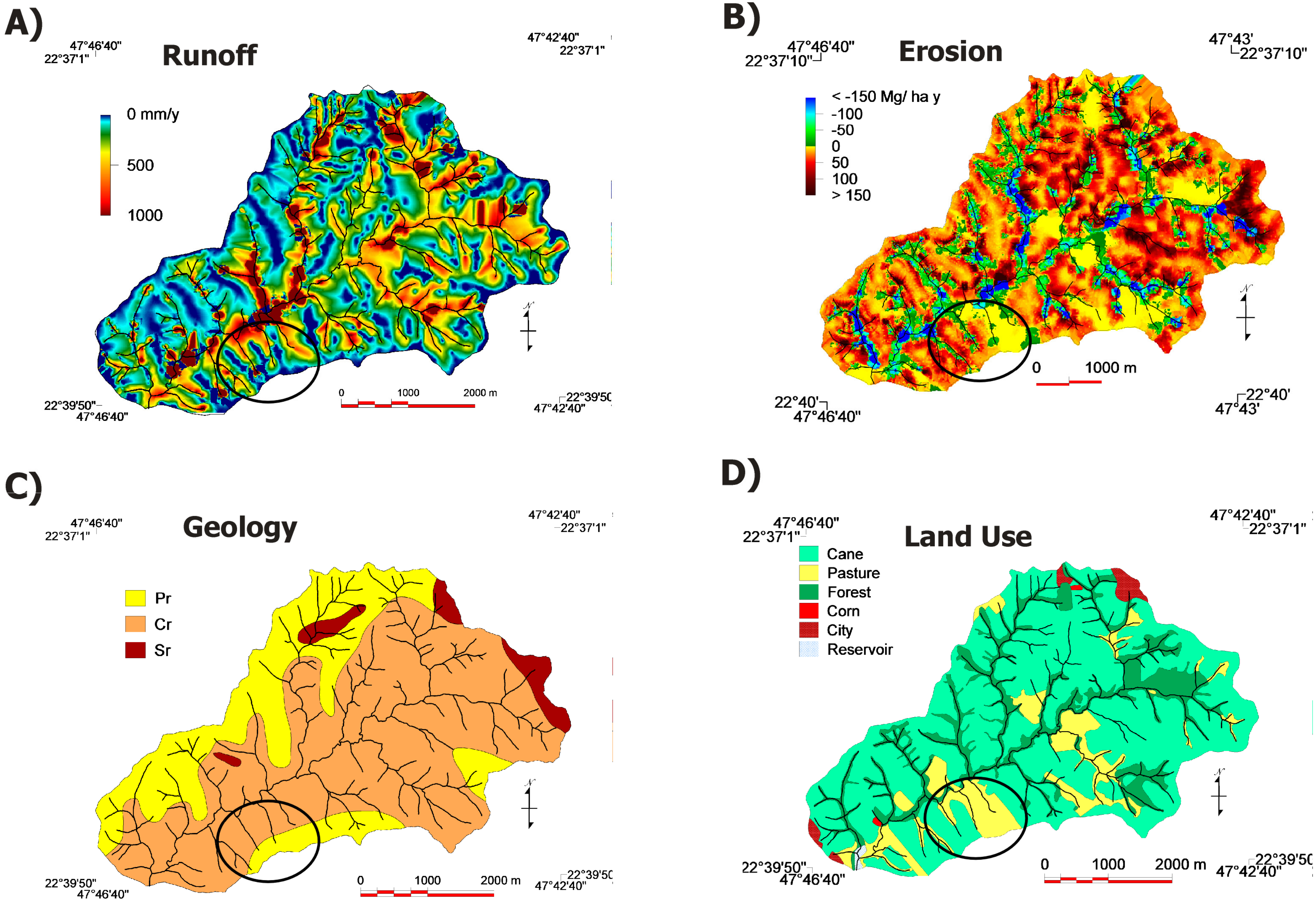
Order	X	Y	Soil Loss	Runoff
1	218623.1	7495027.6	0.23	17.492
2	218635.2	7495044.9	0.3	18.818
3	218558	7495297.7	0.51	21.247
4	218605	7495182.1	0.79	23.84
5	217093.8	7494673.1	0.87	24.974
6	215438.6	7492096.5	0.91	26.288
7	215386.1	7492204	0.91	26.356
8	218514.1	7495278.6	0.71	27.538
9	218612.8	7495043.8	0.67	27.743
10	215342.7	7492603.4	1.98	32.247
11	217410.8	7494984.7	1.27	34.976
12	217025	7494528.7	2.82	35.833
13	215332.3	7492605.9	2.43	37.158
14	217566.4	7495122.6	1.34	37.971
15	218536.2	7494999	1.48	38.893
16	215366.3	7492602.6	2.47	39.092
17	215363.5	7493013.2	2.83	39.238
18	217018.1	7494509.3	2.95	40.162
19	217024.7	7494524.6	3.14	40.885
20	215353.5	7492601.7	1.92	41.606
21	215375.6	7493012.4	3.24	41.735
22	215380.6	7492605.5	3.15	42.471
23	215973.5	7492327.9	2.92	42.821


47°46'40"
22°37'1"
47°42'40"
22°37'1"
Cane
Pasture
Forest
Corn
City
Reservoir
N
22°39'50"
47°46'40"
0
1000
2000 m
22°39'50
47°42'40"



47°46'40"
22°37'1"
47°42'40"
22°37'1"
Pr
Cr
Sr
N
0
1000
2000 m
22°39'50"
47°46'40"
22°39'50
47°42'40"


47°46'40"
22°37'1"
47°42'40"
22°37'1"
N
0
1000
2000 m
22°39'50"
47°46'40"
22°39'50
47°42'40"


A)
Runoff
47°46'40"
22°37'1"
47°42'40"
22°37'1"
0 mm/y
500
1000
0
1000
2000 m
22°39'50"
47°46'40"
22°39'50
47°42'40"
B)
Erosion
47°46'40"
22°37'10"
47°43'
22°37'10"
< -150 Mg/ ha y
-100
-50
0
50
100
> 150
0
1000 m
22°40'
47°46'40"
22°40'
47°43'
C)
Geology
47°46'40"
22°37'1"
47°42'40"
22°37'1"
Pr
Cr
Sr
0
1000
2000 m
22°39'50"
47°46'40"
22°39'50
47°42'40"
D)
Land Use
47°46'40"
22°37'1"
47°42'40"
22°37'1"
Cane
Pasture
Forest
Corn
City
Reservoir
0
1000
2000 m
22°39'50"
47°46'40"
22°39'50
47°42'40"

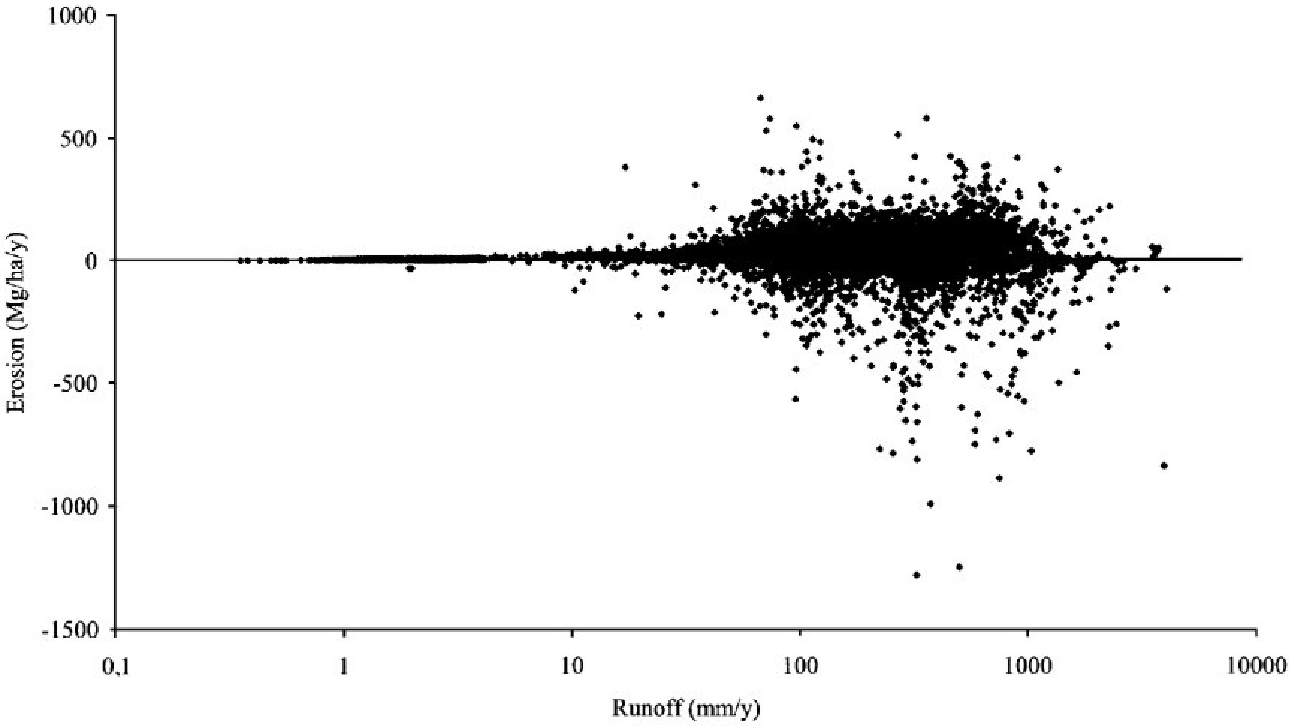


Fig. 3. WEPP 100-year simulation mean soil erosion estimates plotted against runoff estimates for Ceveiro watershed (negative erosion values indicate deposition in WEPP).