MODELLING SURFACE FLOWS FOR MACROSCOPIC PHENOMENA BY CELLULAR AUTOMATA: AN APPLICATION TO DEBRIS FLOWS

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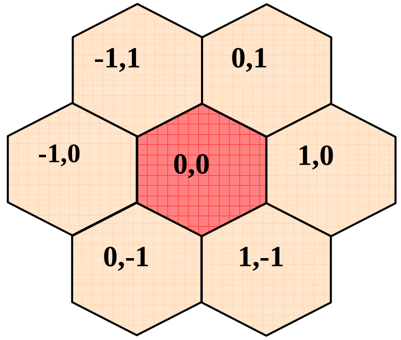
SCIDDICA: *S*imulation *through* *C*omputational *I*nnovative *methods for the* *D*etection *of* *D*ebris *flow path using* *I*nteractive *C*ellular *A*utomata (release S3-hex)

SCIDDICA = $\langle$R, X, Q, P, $\sigma\rangle$

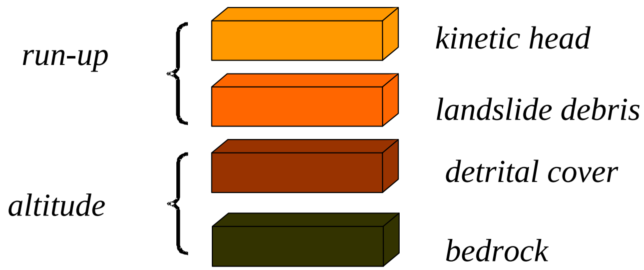
• **R** = $\{(x, y) \mid x, y \in \boldsymbol{N}, 0 \le x \le l_x, 0 \le y \le l_y\}$ is the set of points with integer co-ordinates in the finite region, where the phenomenon evolves. ***N*** is the set of natural numbers.

• **X** = {(0,0), (0,1), (0,1), (1,0), (-1,0), (-1,1), (1,-1)} is the set, which identifies the geometrical pattern of the cells, which influence the cell state change.



• The finite set **Q** of states of the ea: $\mathbf{Q} = \mathbf{Q_a} \times \mathbf{Q_{th}} \times \mathbf{Q_r} \times \mathbf{Q_d} \times \mathbf{Q_o}^6 \times \mathbf{Q_i}^6$

Q_a	altitude of the cell (related to bedrock and depth of detrital cover)
Q_{th}	thickness of landslide debris
Q_r	run-up height (it is a function of the kinetic energy of the landslide and expresses the height that can be overcome by the flowing debris)
Q_d	depth of detrital cover that can be eroded and hence transformed into landslide debris
Q_o (Q_i)	debris outflow (inflow)



SCIDDICA (release S3-hex)

• **P** is the set of *global parameters* of SCIDDICA **$P = \{p_c, p_t, p_{adh}, p_t, p_r, p_{rl}, p_{mt}, p_{pef}\}$**

p_c	apothem of the hexagonal cell	1.5 m
p_t	temporal correspondence of a step of SCIDDICA	0.25 s (?)
p_{adh}	adhesion	0.001 m
p_f	elevation threshold for movement (related to friction angle)	0.1 m
p_r	relaxation rate of debris landslide outflows	1
p_{rl}	run-up loss	0.6 m
p_{mt}	activation threshold for mobilisation	2 m^2
p_{pef}	factor of progressive erosion	0.04

• **σ: $Q^7 \rightarrow Q$** is the deterministic transition function of the *CA*

elementary process in order	***input***	***variations/determinations***	***updating***
soil mobilisation	$Q_{th} \times Q_d \times Q_r$	$\Delta(Q_a, Q_{th}, Q_d, Q_r)$	Q_a, Q_{th}, Q_d, Q_r
outflow of debris	$(Q_a \times Q_{th})^7 \times Q_r$	Q_o^6	Q_o^6, Q_i^6
debris mixing	$Q_{th} \times Q_i^6 \times Q_o^6 \times Q_r^7$	Q_{th}, Q_r	Q_{th}, Q_r
energy loss	$Q_{th} \times Q_r$	Q_r	Q_r

SCIDDICA (release S3-hex) **transition function σ (1)**

Internal transformation MOBILISATION $\sigma_M: Q_{th} \times Q_d \times Q_r \rightarrow Q_a \times Q_{th} \times Q_d \times Q_r$

The erosion of the detrital mantle is allowed, in proportion to the energy of the moving mass in the cell.

That is expressed by $Q_{th} * Q_r > p_{mt}$.

The depth of eroded material, at each step, depends on the parameter p_{pef} . It is the minimum value between *1)* the depth of available detrital cover Q_d and *2)* the product $p_{pef} \times Q_{th} \times Q_r$

Local interaction: DEBRIS OUTFLOWS $\sigma_{DO}: (Q_{th} \times Q_a)^7 \times Q_r \rightarrow Q_o^6$

A preliminary test is executed in order to account the friction effects, that prevent debris outflows, when the height difference between the two cells is insufficient; the condition is expressed by the formula $(q[0]+p[0]-q[i])<p_f$.

Minimisation algorithm application

q_d = quantity, that may be distributed, in the central cell = $Q_r - p_{adh}$

q_0 = inamovable quantity in the central cell = $Q_a + p_{adh}$

q_i = quantity in the cell i $1 \leq i \leq 6 = Q_a + Q_{th}$

SCIDDICA (release S3-hex) transition function σ (2)

Local interaction: DEBRIS MIXING $\sigma_{DM}: Q_{th} \times Q_i^6 \times Q_o^6 \times Q_r^7 \rightarrow Q_{th} \times Q_r$

Debris mixing involves the determination for the central cell:

a) the remaining debris thickness (**rem_th**): $rem\_th = Q_{th}[0] - \Sigma_j Q_o[j] \quad 1 \leq j \leq 6$

b) new debris thickness (**new_th**): $new\_th = rem\_th + \Sigma_j Q_i[j] \quad 1 \leq j \leq 6$

c) The run-up determination is calculated as the average weight of Q_r, by considering both the remaining debris in the central cell and the inflows:

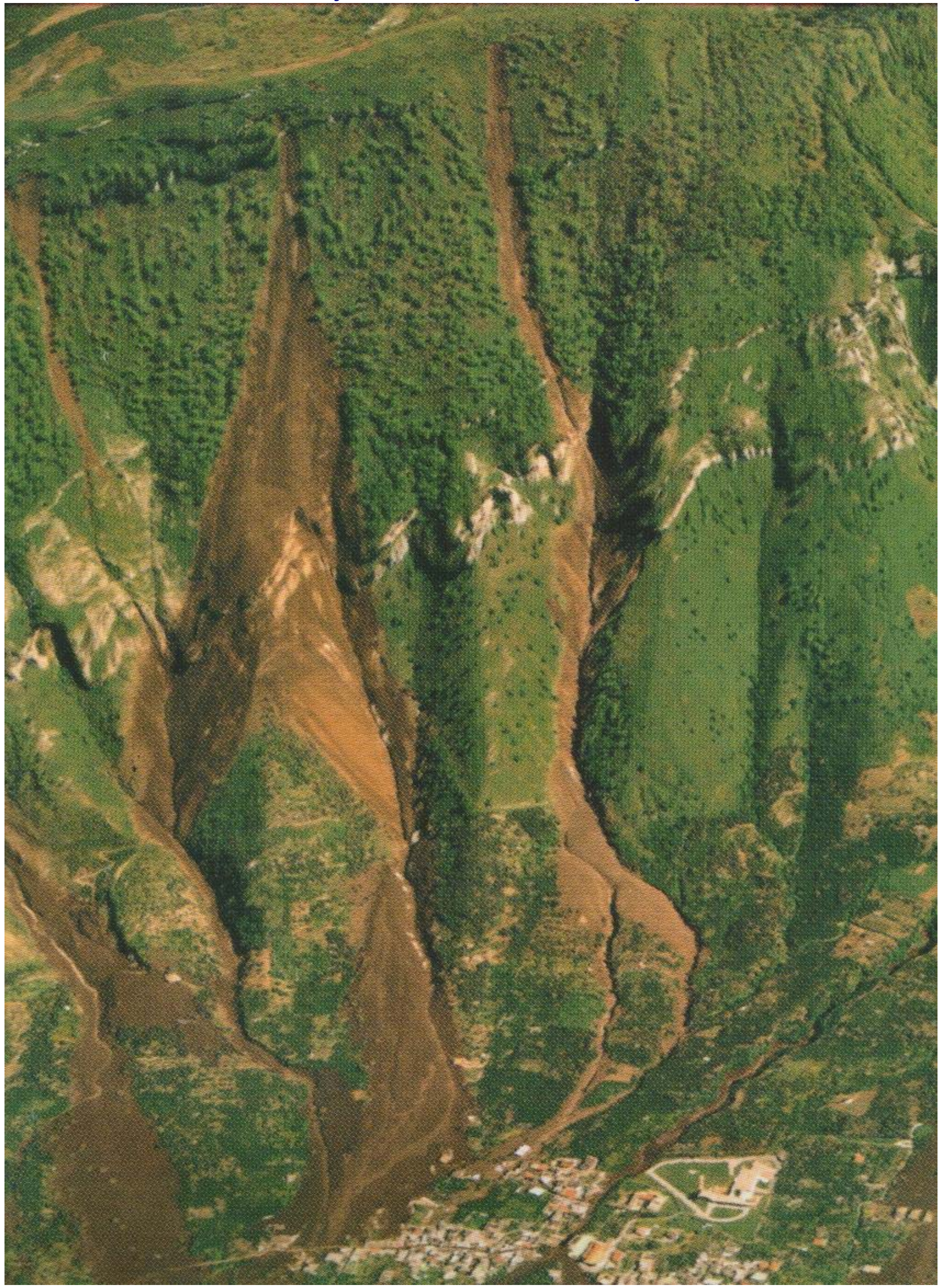
$$\left(\left(Q_{th}[0] - \sum_{j=1}^{6} Q_o[j]\right) \times Q_r[0] + \sum_{j=1}^{6} \left(Q_i[j] \times Q_r[j]\right) \right) \Big/ \left(Q_{th}[0] + \sum_{j=1}^{6} \left(Q_i[j] - Q_o[j]\right) \right)$$

Internal transformation ENERGY LOSS $\sigma_{EL}: Q_r \times Q_{th} \rightarrow Q_r$

Energy loss , at each step, is computed in terms of run up loss and depends on the parameter $\mathbf{p_{rl}}$. It is the minimum value between *1)* the difference $\mathbf{Q_r - p_{rl}}$ and *2)* debris thickness $\mathbf{Q_{th}}$

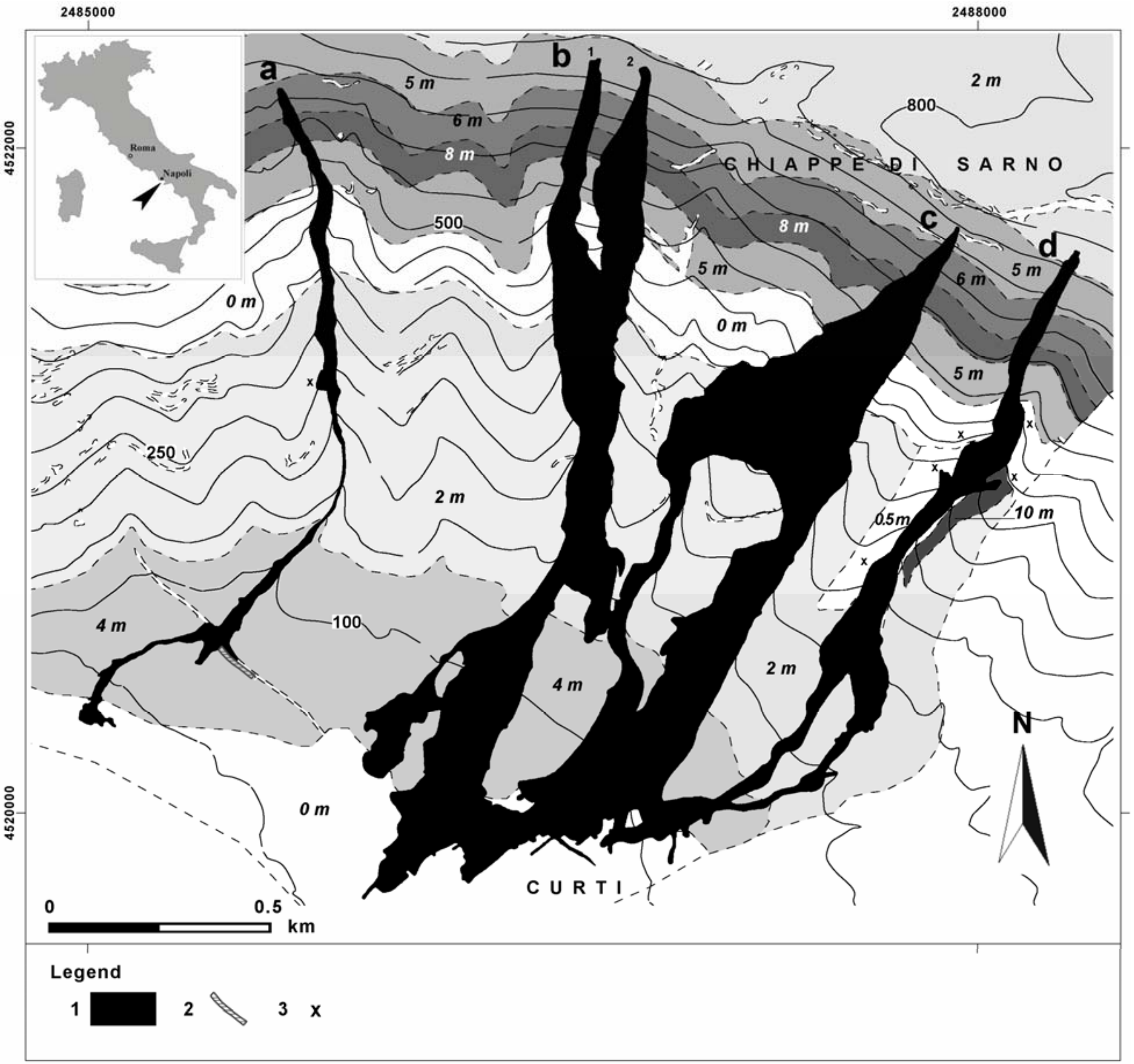
THE SARNO LANDSLIDES

On 5-6 May 1998, numerous rapid-extremely rapid debris flows were triggered by exceptional rainfalls in Campania, mostly on the slopes of Pizzo d'Alvano. Hundreds of small debris slides originated in the volcaniclastic mantle, and transformed into fast-moving debris flows. These latter generally eroded the entire depth of volcanic detrital cover, greatly increasing their initial volume. Landslides hit the urbanised areas, at the base of the slopes, killing 161 people and leaving more than 1,000 others homeless.



THE SARNO LANDSLIDES

A map of the disaster has been realised, at 1:5,000 scale: the geologic-geomorphologic context has been critically analysed, and the required information for simulation purposes acquired (e.g. pre-event conditions of slopes and detrital cover).



SCIDDICA(S3-hex) **application to the Sarno landslides** (Curti case)

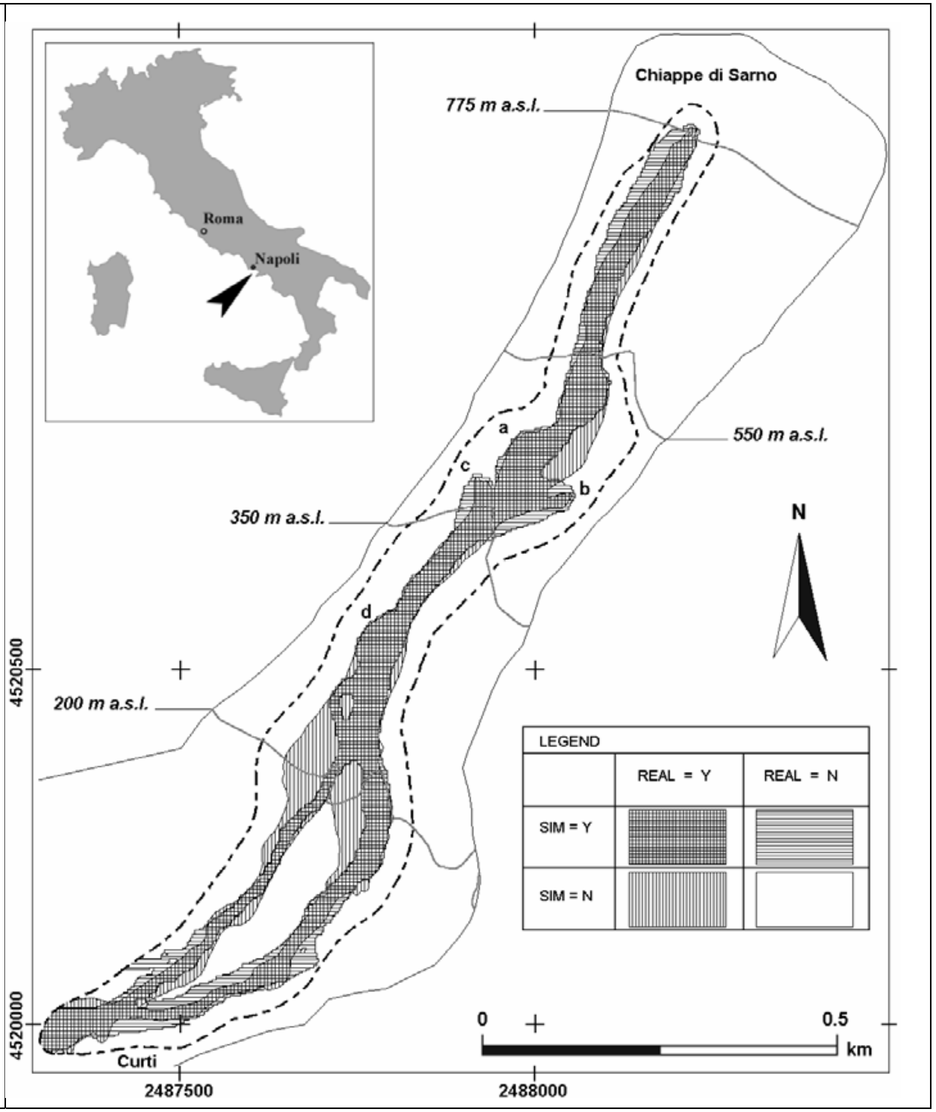
Simulation data: Real area (R) = m^2 96902

Simulation area (S) = m^2 91093

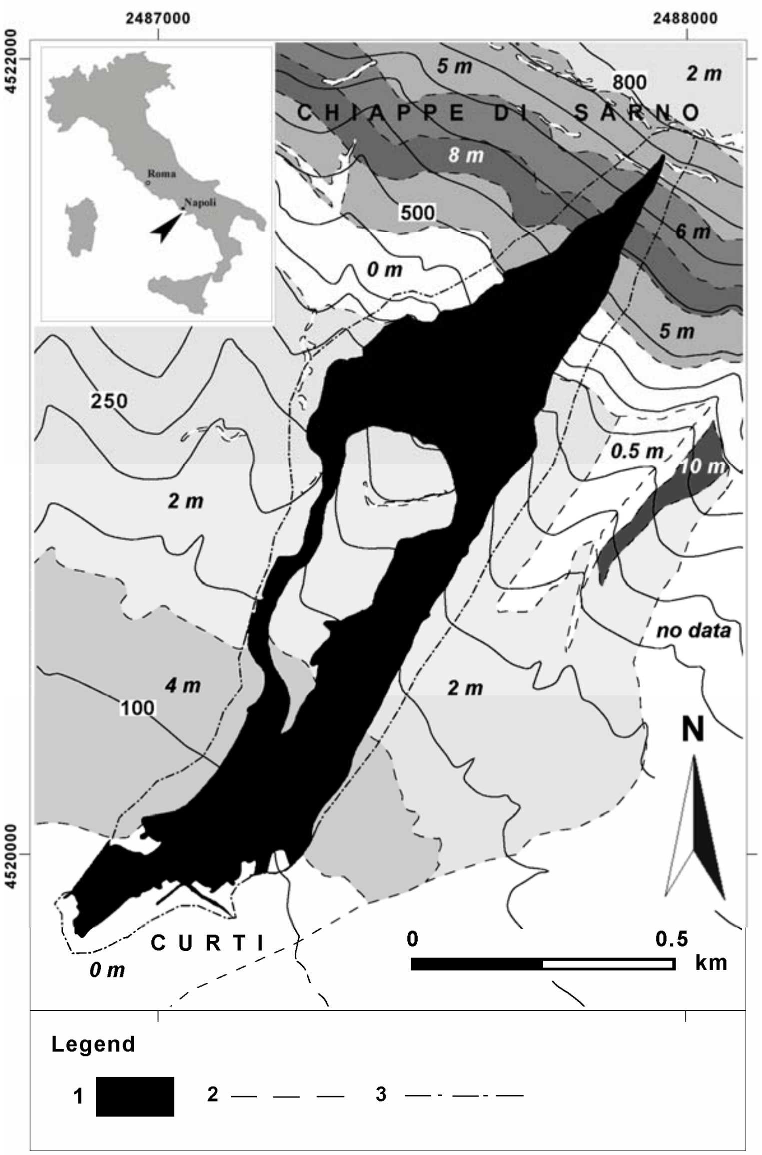
$R \cap S = m^2 70927$ - $R \cup S = m^2 117017$

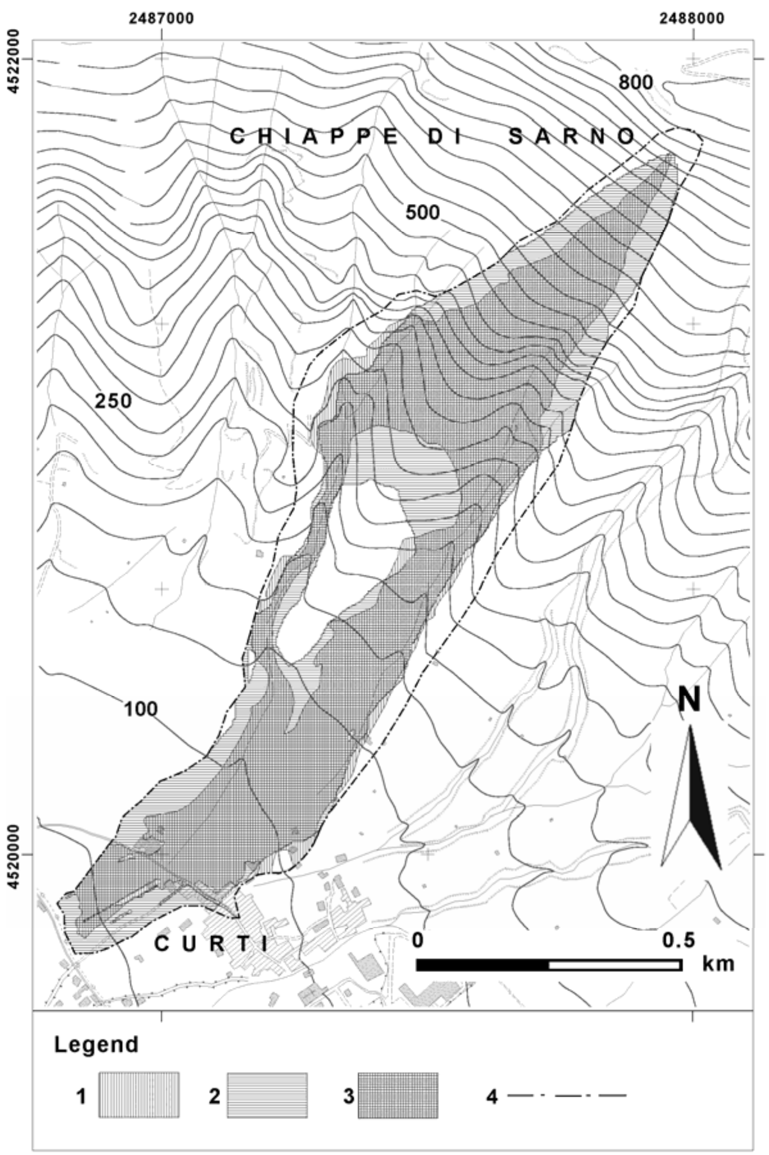
$(R \cap S)/R = 0.73$ - $(R \cap S)/S = 0.78$

$$\sqrt{((R \cap S)/(R \cup S))} = 0.78$$

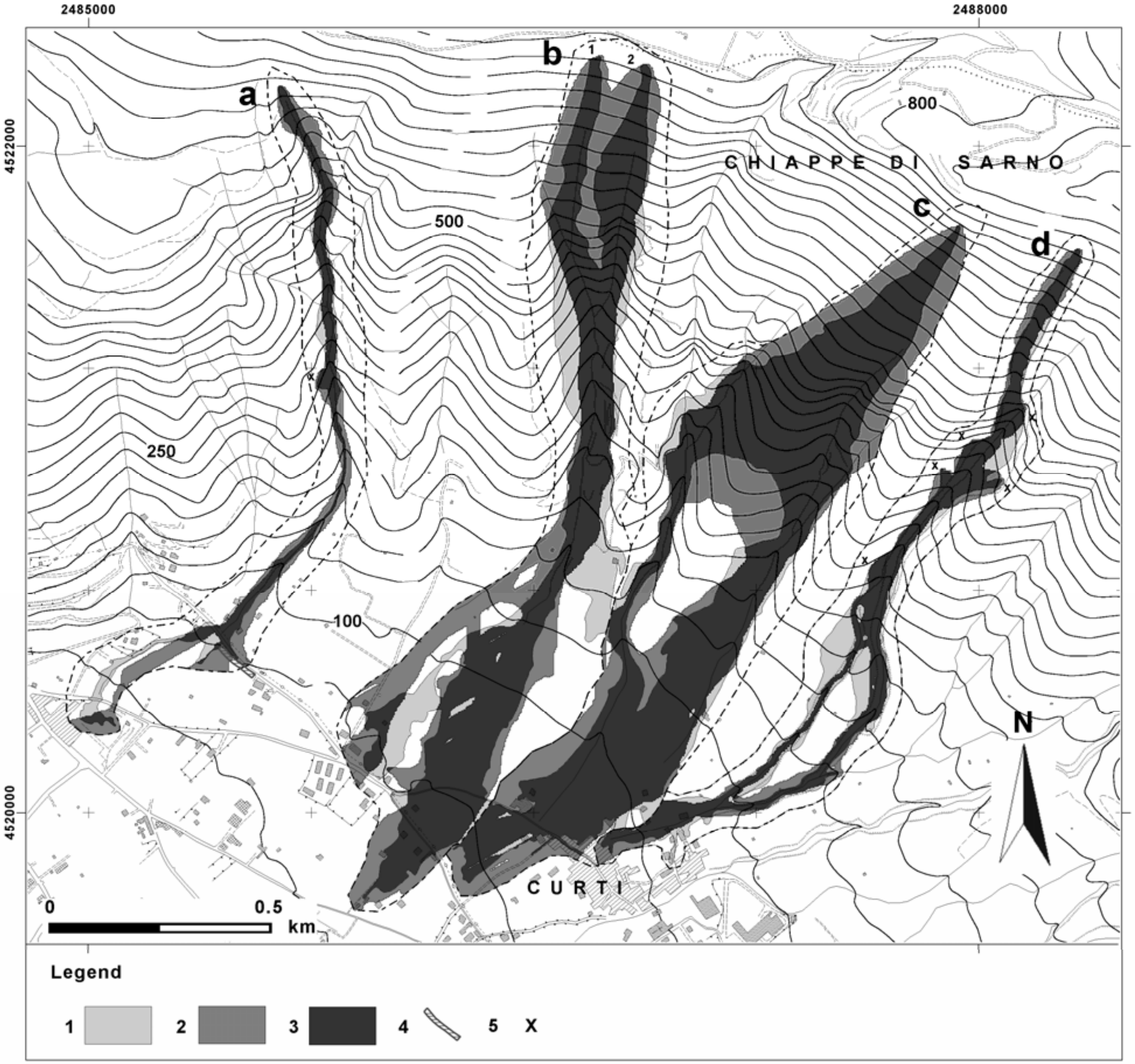


SCIDDICA(S3-hex) **application to the Sarno landslides** (Chiappe di Sarno case)

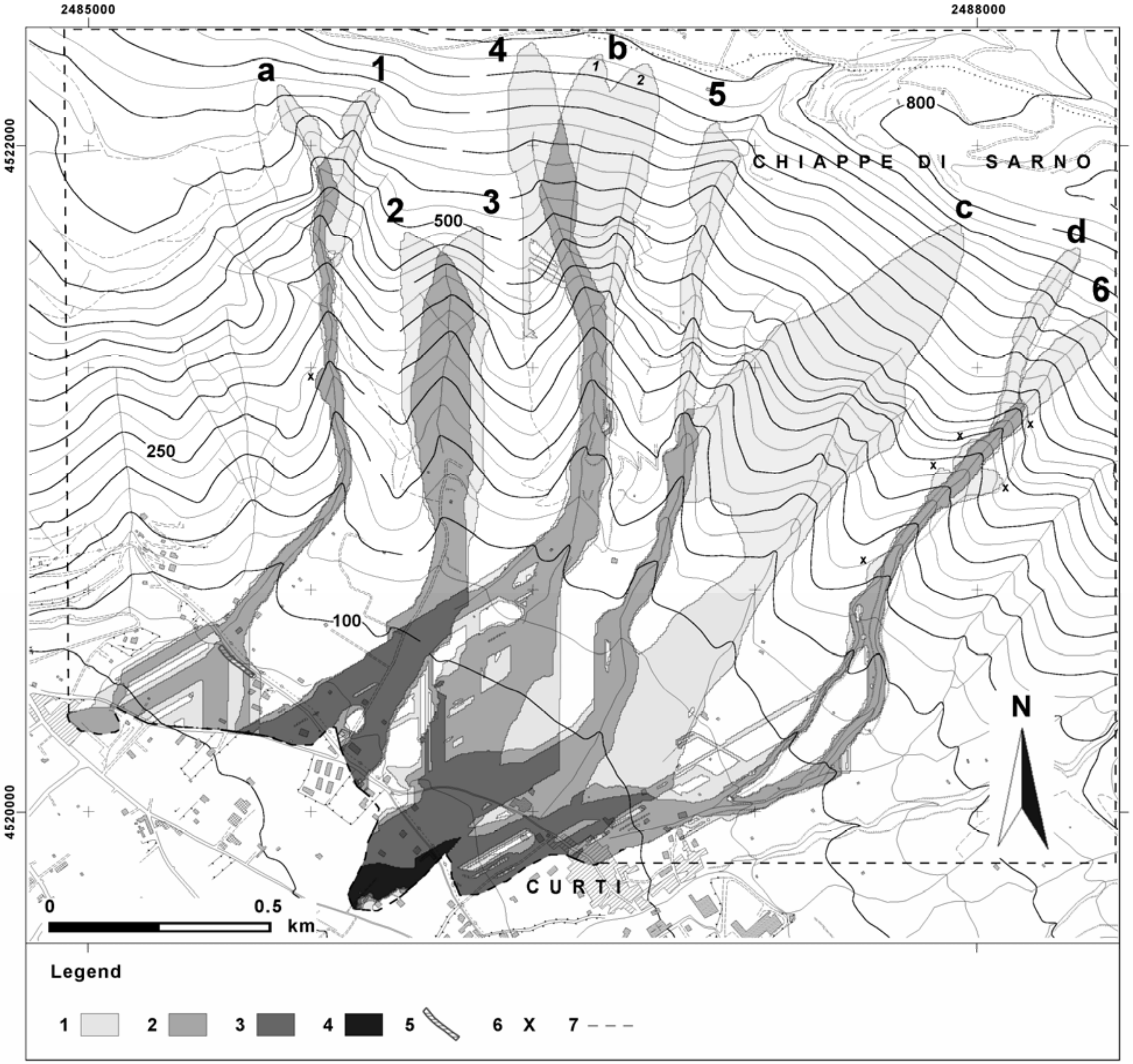




SCIDDICA(S3-hex) application to the Sarno landslides



SCIDDICA(S3-hex) debris-flow susceptibility assessment



COMMENTS AND CONCLUSIONS

- Cellular Automata may represent an alternative approach to differential equations in modelling complex systems, whose evolution is strongly dependent on local interactions of their constituent parts.

- The empirical method, here introduced, was successfully applied by the research group "Empedocles" to other macroscopic complex phenomena, such as soil contamination and bioremediation, forest fires, soil erosion by rain; new application fields are considered: pyroclastic flows, marine environment evolution.

- This empirical method permits to start with simple models, whose refinement can be performed in an incremental way, introducing other internal transformations and local interactions. This allows a careful monitoring of the model building phase by comparison between real phenomena and simulations.

- This empirical method involves, for each internal transformation or local interaction, the introduction of problem-specific parameters, whose determination may be performed by applying optimization methods to minimize the difference between model results and experimental data. Genetic algorithms were effective for applications with several parameters.

- It is important to define the limits to the application of the model to similar phenomena: e.g., SCIARA was validated for the Etnean lava flows in 1986/7 eruption and 1991/2 eruption. SCIARA application during the eruption in the 2001 Summer for the hazard analysis was possible, because Etnean lavas features don't change significantly in the time. Cases, where the features change, involve a validation considering an interval of possible values of parameters, corresponding to different typologies of cases.

- This point is crucial; investigantions showed that there are different confidence intervals for phenomena of the same type.

- A last consideration can be added: the decomposition of the complex macroscopic phenomenon in internal transformations and local interactions seems to have encouraged interdisciplinary cooperations and exchange of information, at least in the cases treated here.