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To cite this version:

Dominique D. King, Yves Le Bissonnais, Olivier Cerdan, Christine King, Guy Richard, et al.. Origin and specificity of the STREAM model. 5. European Congress on Regional Geoscientific Cartography and Information Systems, Jun 2006, Barcelone, Spain. 6 p. hal-02822962

ORIGIN AND SPECIFICITY OF THE STREAM MODEL (Sealing and Transfer by Runoff and Erosion related to Agricultural Management)

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KEY WORDS: soil erosion, soil surface characteristics, modelling, remote sensing, optic satellite data, SAR data, GIS.

INTRODUCTION

The European Commission recognised when they launched their thematic strategy for soil protection in 2002 (CEC 2002) that erosion was the primary threat to soil resources. This phenomenon has long been well known and has been the object of much scientific research (De Ploey, 1989 ; Oldeman *et al*., 1991). Current studies focus on how to quantify the impact of anthropogenic and climate changes that might cause an increase in soil loss and to develop tools to evaluate soil protection measures (landscaping, spatial distribution of cropping systems, technical itinerary). Numerical modelling of runoff and erosion is an excellent means of responding to these challenges.

We encounter numerous problems when attempting to model erosion: the complexity of the processes involved (rainsplash, sheetwash, rilling and gullying, deposition, etc.) and their occurrence at vastly different scales (from aggregates to entire drainage basins), the wide range of determining factors and their spatial variability (soil properties, rainfall intensity, tillage practices, etc (Papy & Boiffin,1989). Furthermore, farming practices are multifactorial and depend not only on soil-climate conditions, but also on economic, social and even political components (Boardman, 1990 ; Auzet *et al*., 1993 ; Souchere *et al*., 2002).

One of the oldest erosion equations, and certainly the most widely-used, is the USLE, or Universal Soil Loss Equation (Wischmeier & Smith, 1978). It is a conceptual model expressed as a combination of causes. It has been refined over the years and has been adapted to conditions in different parts of the world (i.e Williams *et al*., 1983). The advent of numerical methods during the 1980s led to the development of mechanistic models based on physical principles and enabled researchers to take into account more efficiently the processes involved and their interactions (Beven & Kirkby, 1979). These models proliferated in the 80s and were the object of numerous publications in subsequent years (Knisek, 1980 ; Morgan *et al*., 1982 ; Woolhiser *et al*., 1990 ; Laflen *et al*., 1991 ; De Roo *et al*., 1996).

The STREAM model (*Sealing and Transfer by Runoff and Erosion related to Agricultural Management*) was created in the end of 1990s following a critical analysis of various modelling approaches (Cerdan *et al*., 2001) (fig.1). USLE-based models could not account for the erosion observed in Northern Europe—relatively flat topography, oceanic climate, loamy soil (Fullen & Reed, 1987; De Ploey, 1989 ; Auzet *et al*., 1990). Mechanistic models are poorly suited due to the large number of parameters involved, many of which are often unavailable at such a vast scale (De Roo, 1993). The decision to develop a new model within the framework of an international concerted action was born of the conjunction of three phenomena: 1) the demonstration of the importance of surface degradation of soil structure as a determining factor in soil erosion, 2) the development of digital technology (GIS—Geographic Information Systems) enabling both the description of a model's fluxes and the quantitative spatialization of input variables (King *et al*., 1998), and 3) the availability of new remote sensing data in the operational phase for gathering images over large surface areas. These three points are discuss briefly here.

(1) SURFACE DEGRADATION OF SOIL STRUCTURE

Most soil erosion models describe hydrological processes and soil particle removal and transport processes. The equations are based mainly on the laws of water transfer in soil and on the surface. The velocity of surface runoff determines the quantity of particles removed and transported in relation to the soil's structural properties (Govers, 1985). These are described in the models mainly by their geometry (roughness, which enables retention of rain) and by soil water content (which limits infiltration) (Engman, 1986). The surface mechanisms studied are mainly those linked to the splash effect (Bradford *et al.*,1987) and to the particle movement implied by this mechanism and the slope (Quinn *et al.*, 1995; Salles *et al.*, 2000).

The soil surface characteristics, however, are not sufficiently taken into account in these models. Indeed, French studies in the 1980s clearly demonstrated the determining role of crusting on the decrease in infiltration and the formation of runoff (Valentin & Bresson, 1992; Le Bissonnais et Singer, 1992). They also showed that these soil surface characteristics were themselves determined by interaction between the nature of soils and the action of rainfall. Conditions preceding the rainfall events that triggered runoff were studied — in particular, the farming practices that produced the structural state of the soil (degree of fragmentation during tillage, degree of compaction by farm machinery) (Govers *et al.*, 1994 ; Souchere *et al.*, 1998; Martin, 1999 ; Richard *et al.*, 2001) and the weather on days prior to the rainfall event (Le Bissonnais & Singer, 1992; Kirkby & Cox, 1995).

This first analysis showed that changes in the surface state appeared to be a key element and should be incorporated into the models. This data could be entered directly as one of the model's input parameters, thus simplifying parameterization (Le Bissonnais *et al*, 1998). It seemed that the surface state was a variable that would be easier to acquire directly than calculate using a model combining characteristics that are themselves difficult to measure, that is to say, the quantity and intensity of rainfall, the structural stability of soils and farming practices.

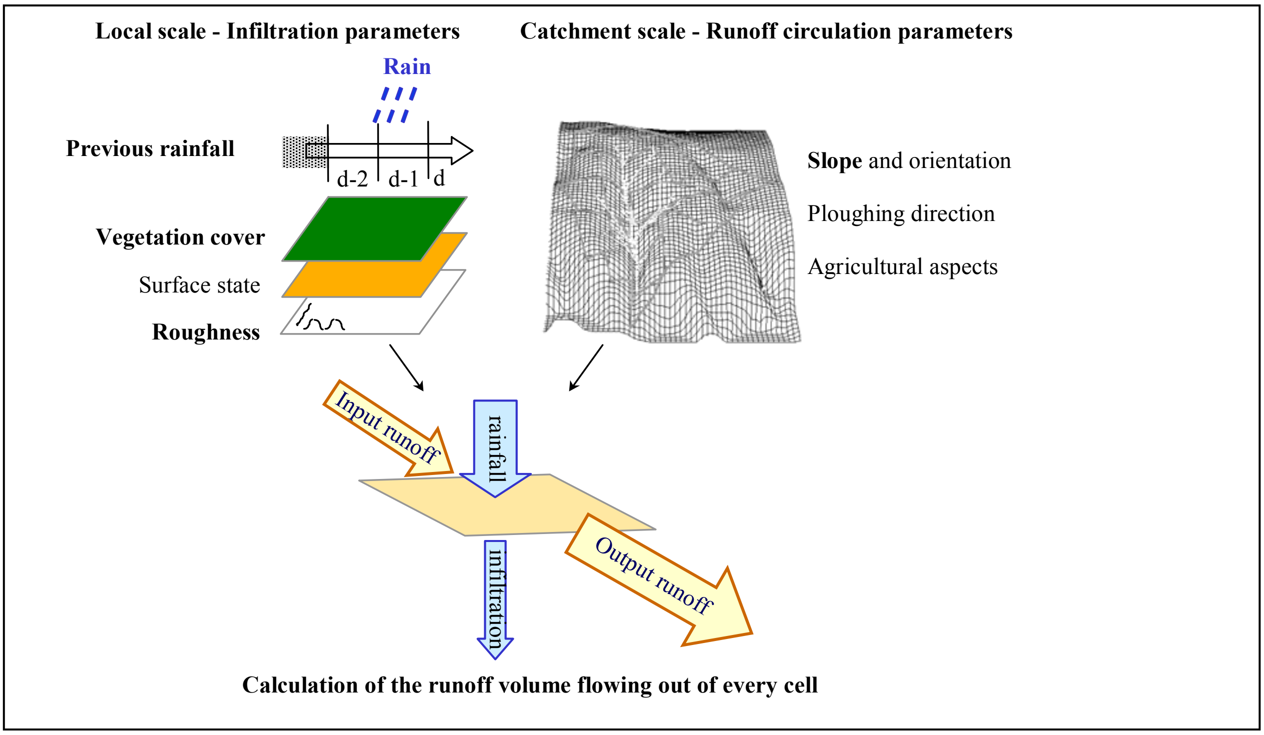

Figure 1 – Input data for the STREAM model: the parameters in bold are retained in the version of STREAM assimilating remote sensing data (STREAM-TED).

(2) DEVELOPMENT OF DIGITAL SPATIALIZATION TECHNIQUES

Geographic Information Systems (GIS) unite all of the methods that enable digital acquisition, spatialization, management and restitution of geographic data (Burrough, 1986), and have progressively replaced manual mapping. Up until the early 1980s, map information was mostly qualitative. The appearance of GIS and geographic databases opened up new possibilities for cross-referencing spatialized data. The appearance of the first Digital Elevation Models (DEM) enabled researchers to calculate slope gradients and orientations and generate theoretical runoff models from which numerous hydrological characteristics in the field could be deduced (Beven *et al*, 1984). The first studies involved combining the various factors causing soil erosion and mapping erosion risk (King & Le Bissonnais, 1992) and were essentially a formalization of experience gained in the field (Le Bissonnais & Singer, 1993; Le Bissonnais *et al*, 1998). Very rapidly, however, we were faced with the question of including models of water and matter transport in soil using methods developed for GIS (De Roo, 1998 ; Cerdan *et al.* , 2002 ; Souchere *et al.*, 2003).

A description of fluxes entailed a spatialized description of the parameters, other than slope, that control these fluxes. At this stage, we noticed that the more parameters a model had, the more trouble it had dealing with their variability. It was therefore necessary to identify and rank the parameters involved in the runoff and erosion processes in an attempt to arrive at relatively stable results. It is of interest to note that while DEM have enabled us to rapidly generate quantitative and detailed images of slopes, they have obscured the fact that the direction of runoff also depends on other factors such as surface roughness (Engman, 1986; Govers *et al.*, 2000) or manmade structures (ditches, dead furrows, etc.) (Souchere *et al.*, 1998).

This second analysis showed the importance when choosing model parameters not only of the role that they play in reality but also the accessibility and precision over a large spatial field of the parameter data. This naturally led us to consider parameter data acquisition and spatialization methods.

(3) ACQUISITION OF NEW SPATIALIZED DATA BY REMOTE SENSING

Satellite techniques provide a easy means of obtaining precise and thorough information. Since the late 1970s, remote sensing has furnished images enabling us to acquire data on land use (Cihlar *et al.*, 1987; Bocco & Valenzuela, 1991). This opened up the possibility of including in numerous models the role of vegetation in protecting soil from degradation and erosion (by reducing the energy of raindrops, retaining water, slowing runoff, etc.) (Keech, 1990). Remote sensing techniques seemed to provide more limited results, however, when it came to directly determining soil characteristics (Huete 1989, Hill *et al.*, 1992 ; Arrouays *et al.* , 1996 ; Mathieu *et al.*, 1996). Not only did the presence of vegetation rarely enable researchers to access bare soil, but also, the wavelengths, most often in the visible and near infrared range at that time, furnished only information on the spectral response of the soil surface (De Jong & Riezeboss, 1994; Jacob *et al.,* 2002). These techniques therefore seemed to be poorly suited to estimating the spatial variability of soils and even less to mapping their hydrodynamic properties, if we except the 2D contribution of images for extracting as interpretative or automated methods the ways of water (linear incisions, rills, furrows, natural or artificial drains, slope..) (Blanchard *et al.,* 1999).

As we have seen in the two previous analyses, however, soil surface properties are the key parameters for infiltration and therefore runoff (Govers *et al.*, 2000). The remote sensing data therefore needed to be re-examined from another angle. In addition, new techniques were being developed with the launching of radar satellites (Autret *et al.*, 1989 ; Beaudoin *et al.* 1990). These, thanks notably to sensitivity to dielectric properties, delivered two essential elements of information concerning erosion phenomena: soil moisture and roughness (Remond *et al.*, 1999 ; Baghdadi *et al.*, 2002). Those information can be successfully assimilated by STREAM (King *et al.*, 2005b).

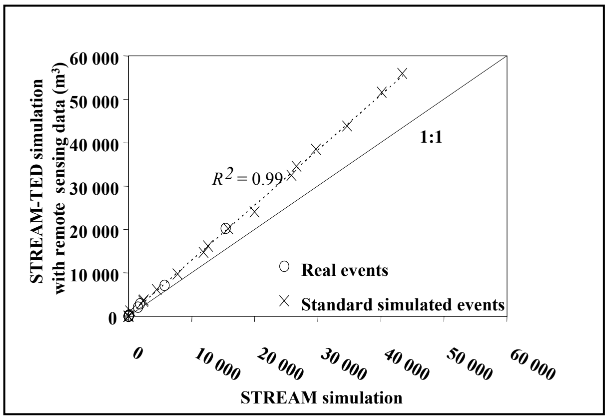

Figure 2 – Prediction of the runoff at the outlet by STREAM-TED as a function of the STREAM simulation.

This third analysis, together with the two previous analyses, offered direct acquisition and spatialization tools for parameters describing soil surface states and roughness. The convergence of these three analyses therefore led us to emphasize the determinant role of these parameters in the development of the STREAM model. The processes of formation and evolution of surface states and roughness are poorly understood and are themselves very responsive to the random character of interactions between various soil types and both climate conditions and human activities (farming practices). It was therefore preferable to input soil surface characteristics and roughness directly as control parameters in the STREAM model rather than attempt to reconstruct their evolution using a model that is uncertain and overloaded with variables that are hard to spatialize (fig.2) (King *et al.*, 2005a; 2005b).

CONCLUSION

The driving force behind the creation of the STREAM model was therefore the concurrence of 1) the introduction of recently acquired knowledge (i.e. the role of soil surface states and roughness on infiltration and the direction of fluxes, respectively) and 2) the contribution of new digital data acquisition and processing technologies (i.e. DEM, remote sensing, GIS). Our aim is to develop an operational system in interaction with the actors in areas affected by erosion soil. We have therefore favoured, in addition to remote sensing and based on the work of the French school, qualitative parameters easily accessible in the field and calibrated using experimental approaches under controlled conditions These experimental approaches were necessary in order to verify our hypotheses and precisely calibrate the model.

COLLABORATION

This article was made possible due to the support of the BRGM Research Programme (01METR05), the FLOODGEN European programme (CEE-CEO ENV4CT 96 0368), and the french programme ANR-ECCO- PNRH (RIDES). Specific thanks to Joël Daroussin and Alain Couturier (INRA) for help in using the Kaleidos software (INRA's internal software and Normandy's Regional Association for the Study and Improvement of Soil (AREAS).

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