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Hydrological and Erosion modeling of a small Sahelian catchment (Tougou) using the Kineros2 model

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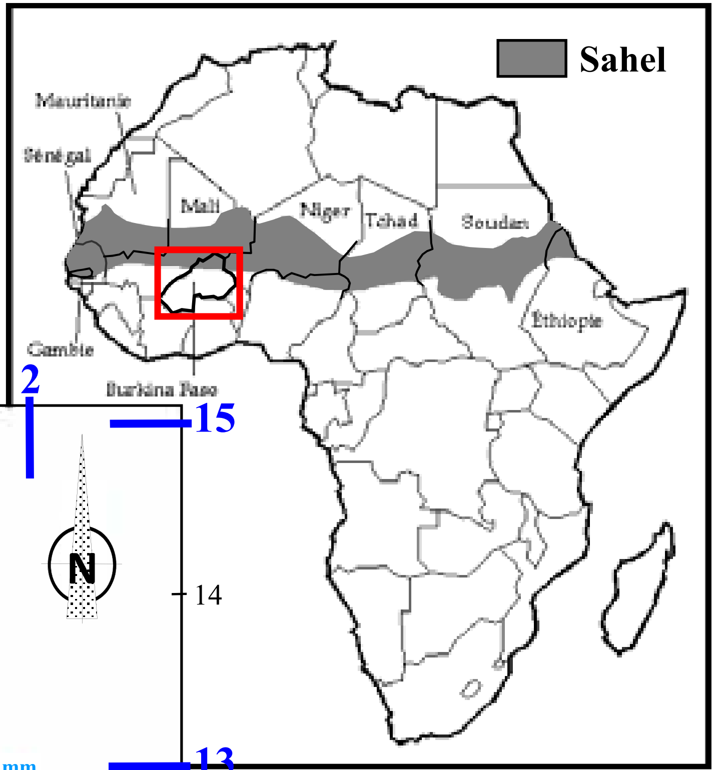
Outline

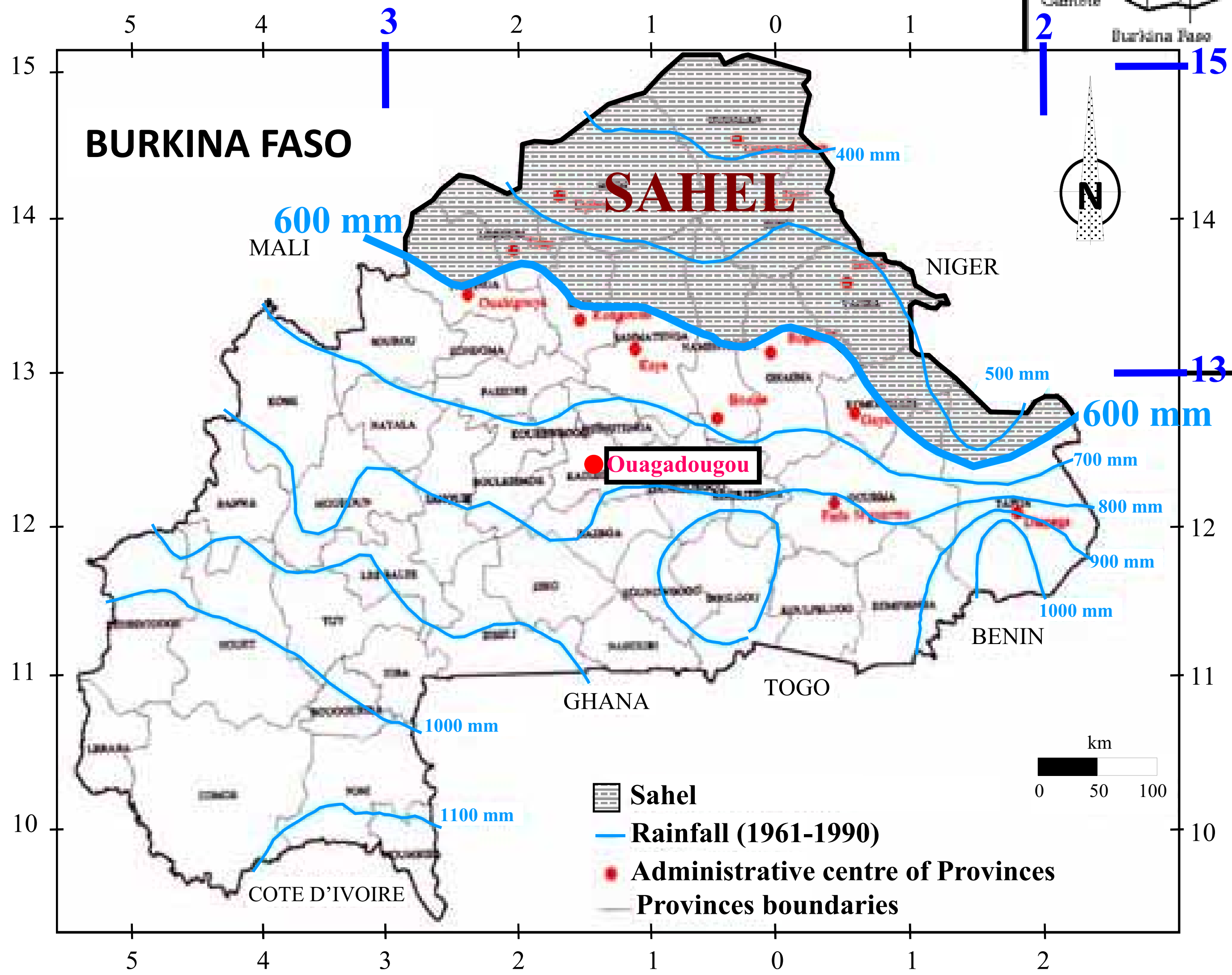
1. Introduction - issues
2. Objectives
3. Study catchment
4. Materials and methods
5. Results and discussion
6. Lessons learnt and perspectives

1. Introduction - issues

The Sahelian zone of Burkina Faso:

- ➡ Rainfall between 300 and 600 mm/year
- ➡ Area of 61 000 km²





Environmental issues

Constraints

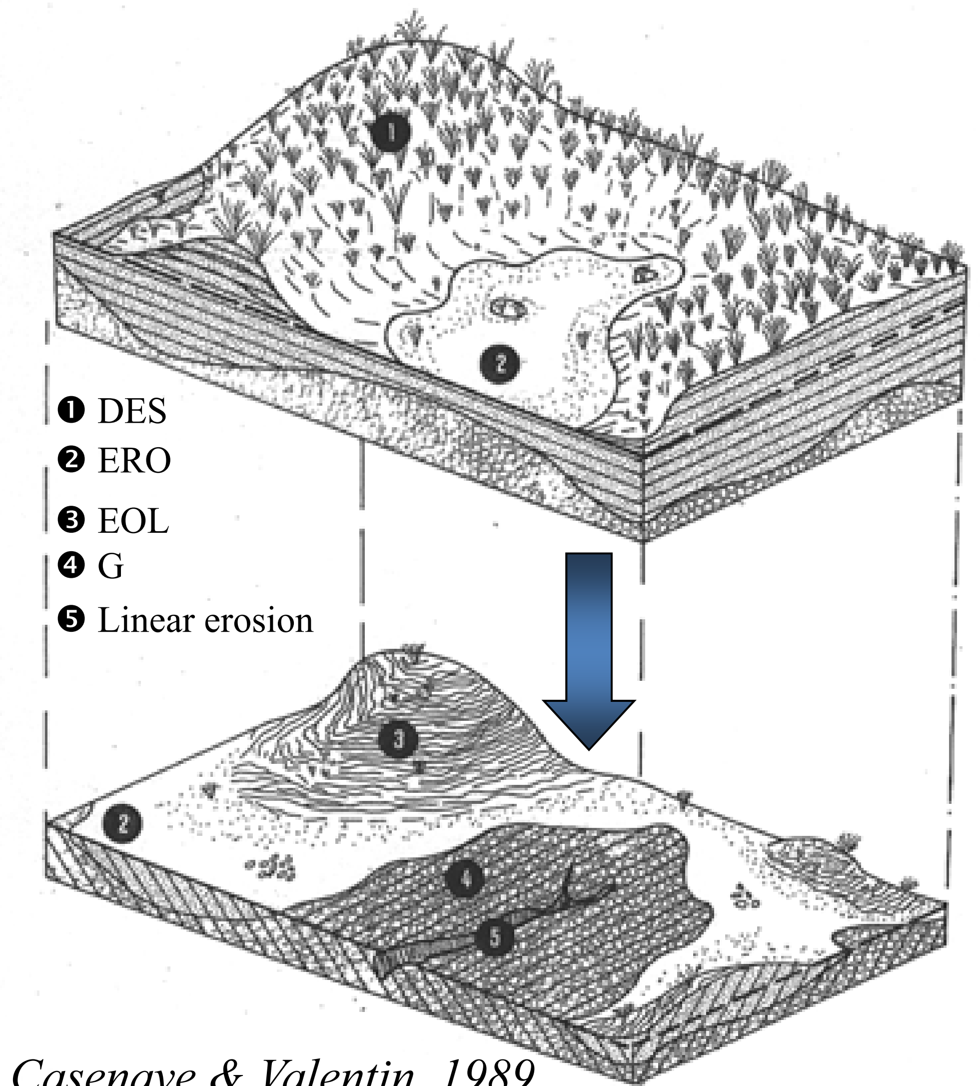
Human
- Increase of the population
- Deforestation (domestic uses)
- Increase of cultivated lands
- Unsuitable farming techniques

Animals
- Overgrazing
- Extensive and Transhumant livestock farming

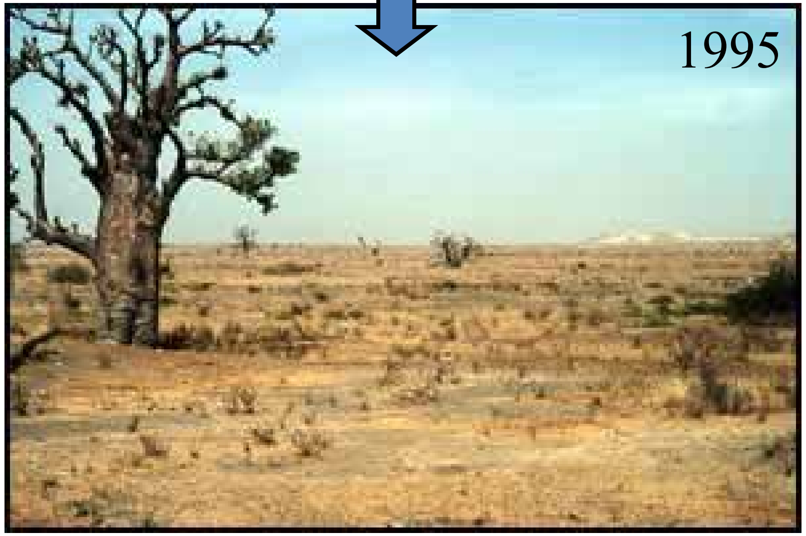
Climate
- Significant decrease of rainfall since 1970
- Aggressiveness of rains and winds

- Soil erosion
- Soil crusting
- Loss of biodiversity
- **Change of hydrological processes**

Evolution of Sahelian soil surface characteristics under climate and human pressures



Casenave & Valentin, 1989



Source : *EROS Data Center International Program, U.S. Geological Survey*

Some illustrations of the Sahelian environmental degradation

Soil erosion and loss of fertility

Dam silting

Soil surface crusting

Surface water quality degradation and eutrophication

Change of hydrological norms

Conflicting uses of water

2. Objectives

- Better understand the hydrological cycle at local scale and under a changing climate.

- Better assess the different components of the water cycle (runoff, infiltration, evaporation, etc…) of the Tougou catchment related to land-use/land-cover changes

- Better assess environmental degradation (soil erosion, dam silting, surface water quality degradation, etc..) related to the hydrological cycle modification.

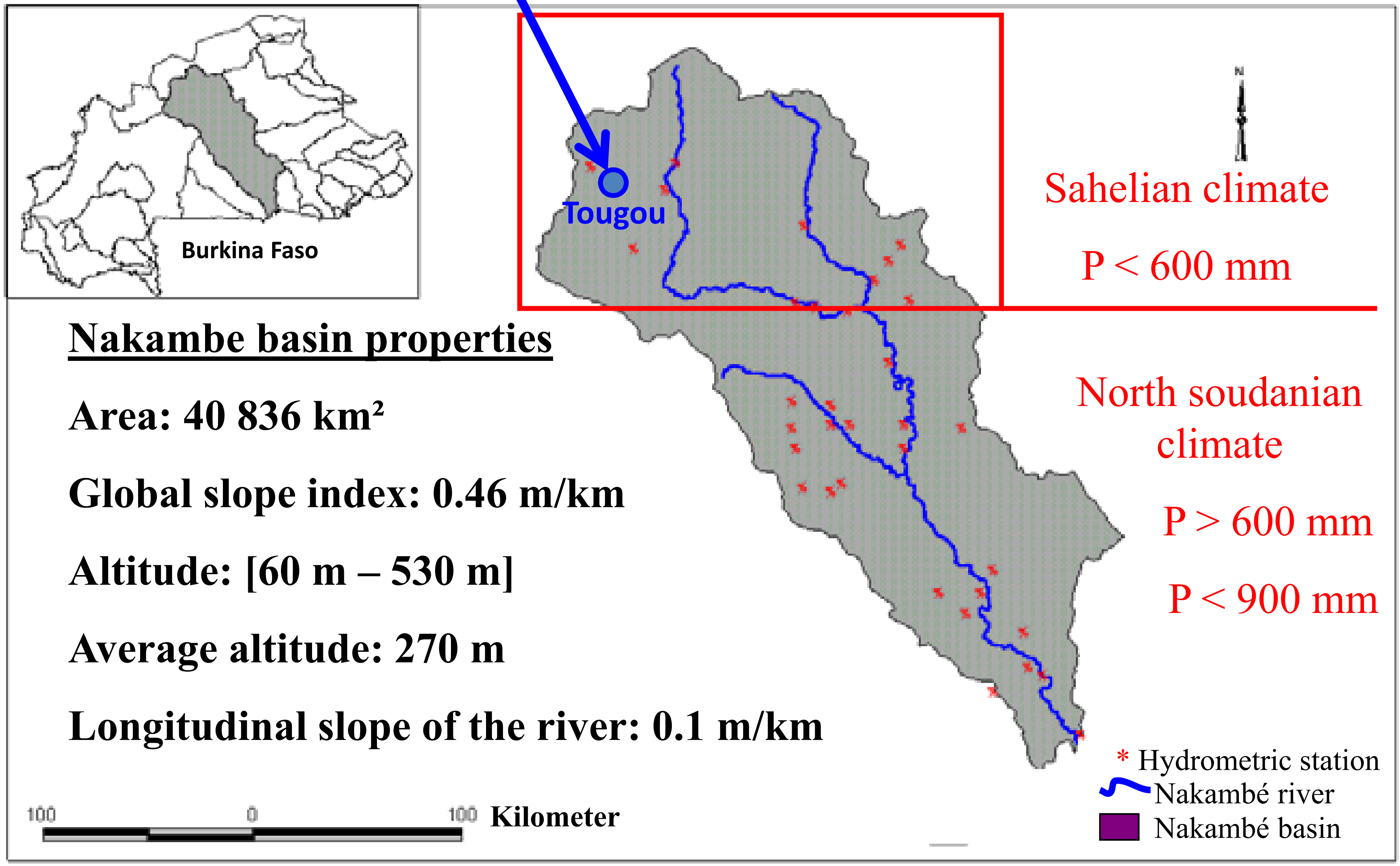
- Set up a hydrological modelling at small scale integrating environmental changes in the Sahel.

3. Study catchment

The Tougou catchment (37 km²)

Local intensive observation site

Pilot basin



Nakambe basin properties

Area: 40 836 km²

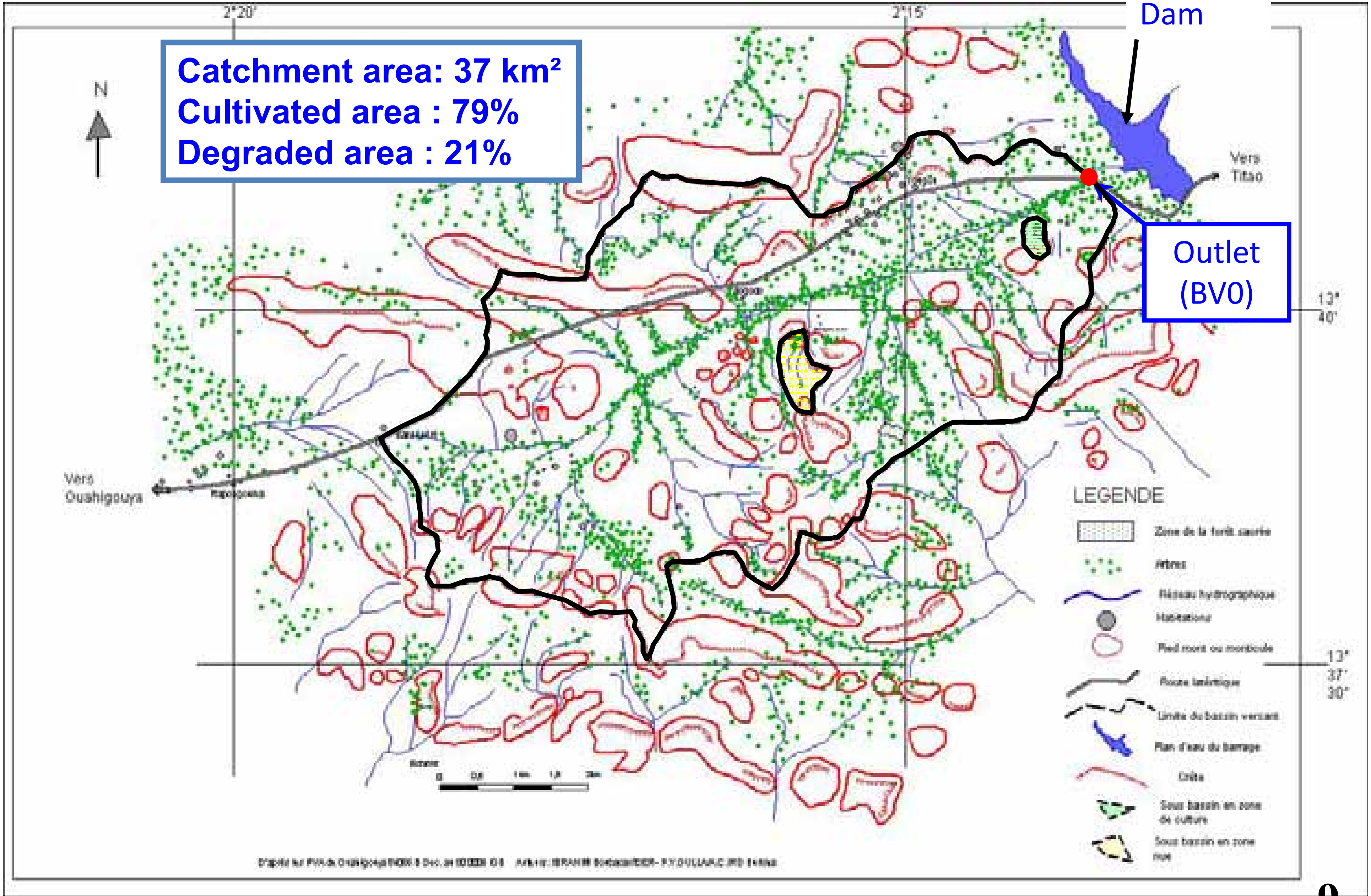
Global slope index: 0.46 m/km

Altitude: [60 m – 530 m]

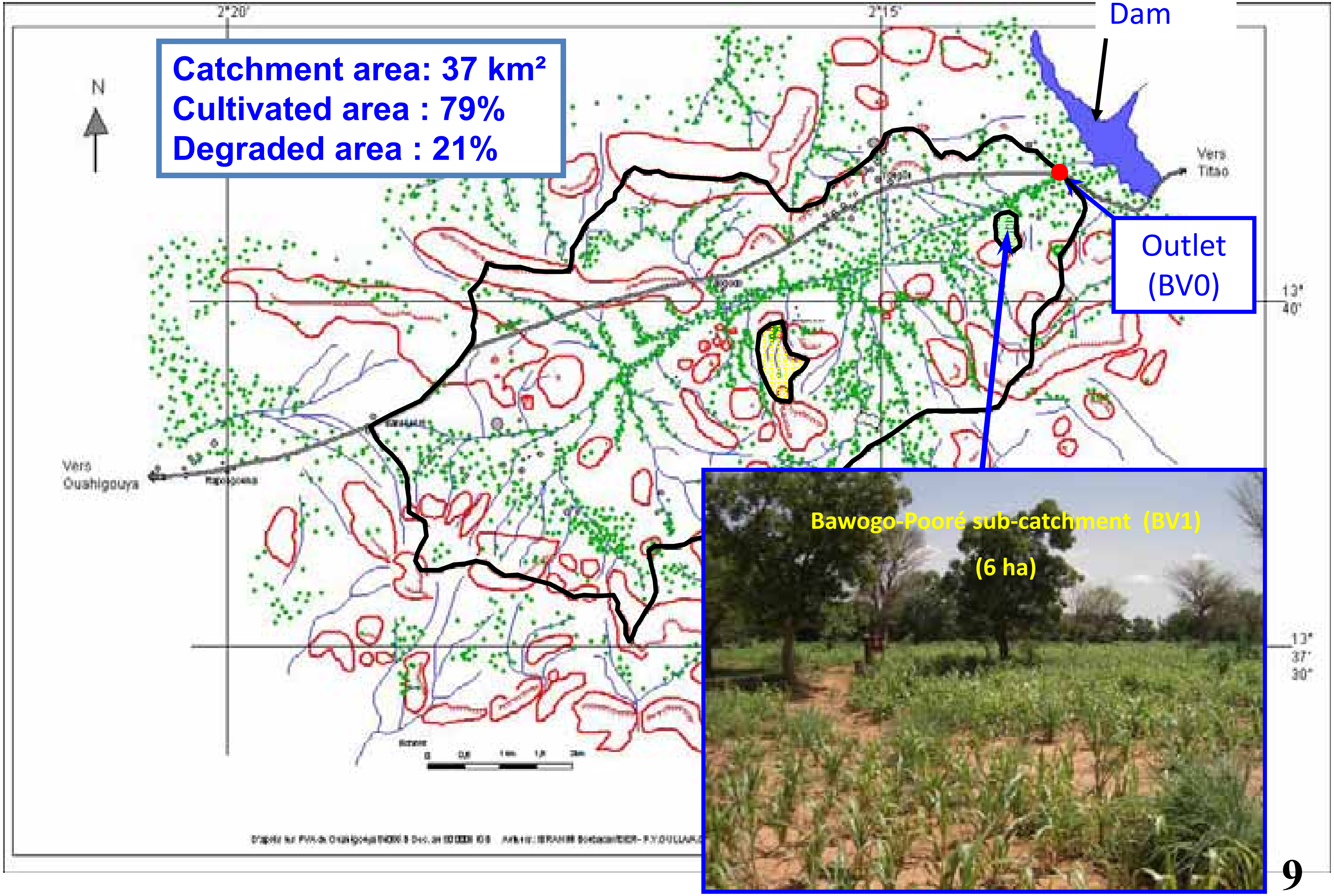
Average altitude: 270 m

Longitudinal slope of the river: 0.1 m/km

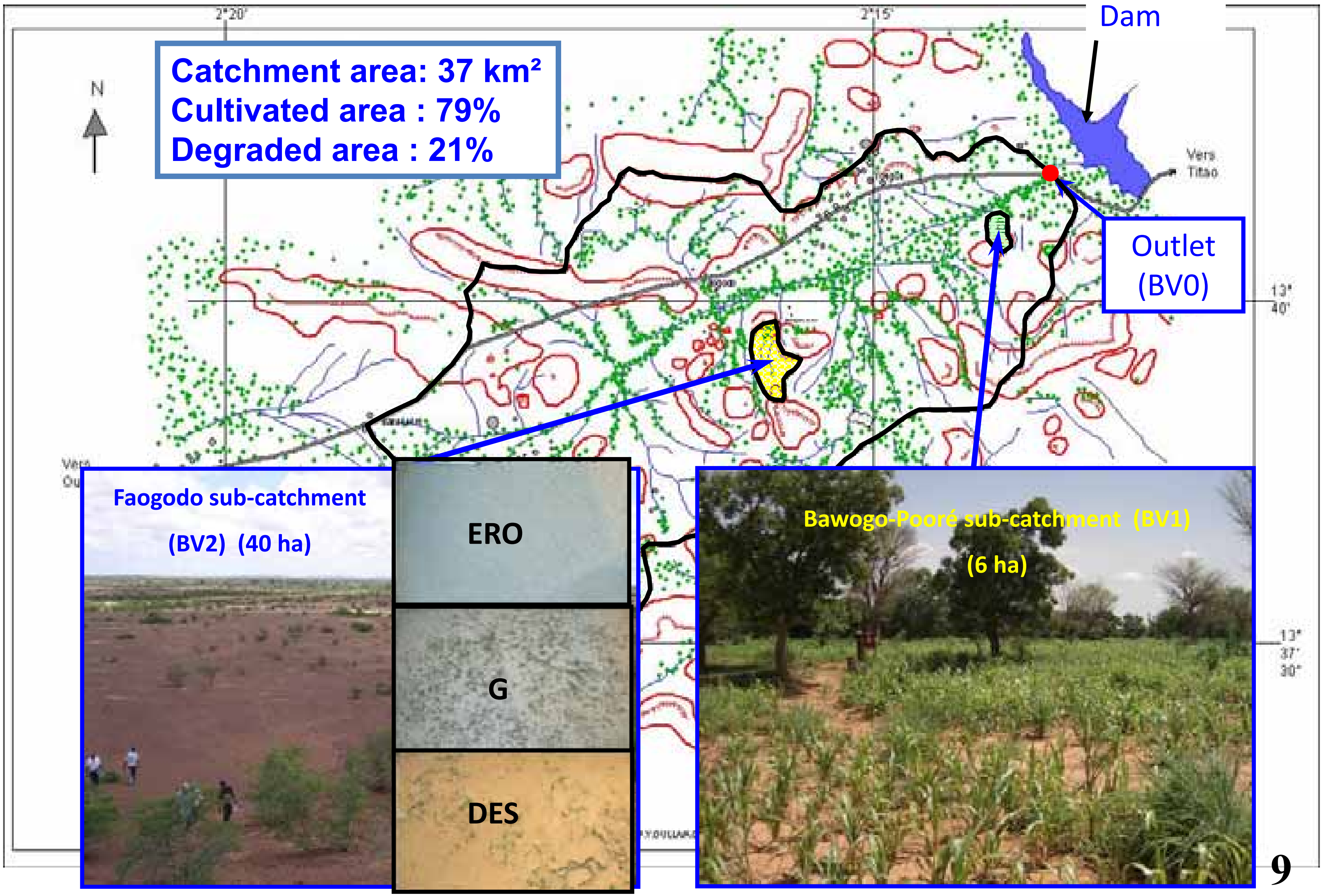
Land uses of the Tougou catchment



Land uses of the Tougou catchment

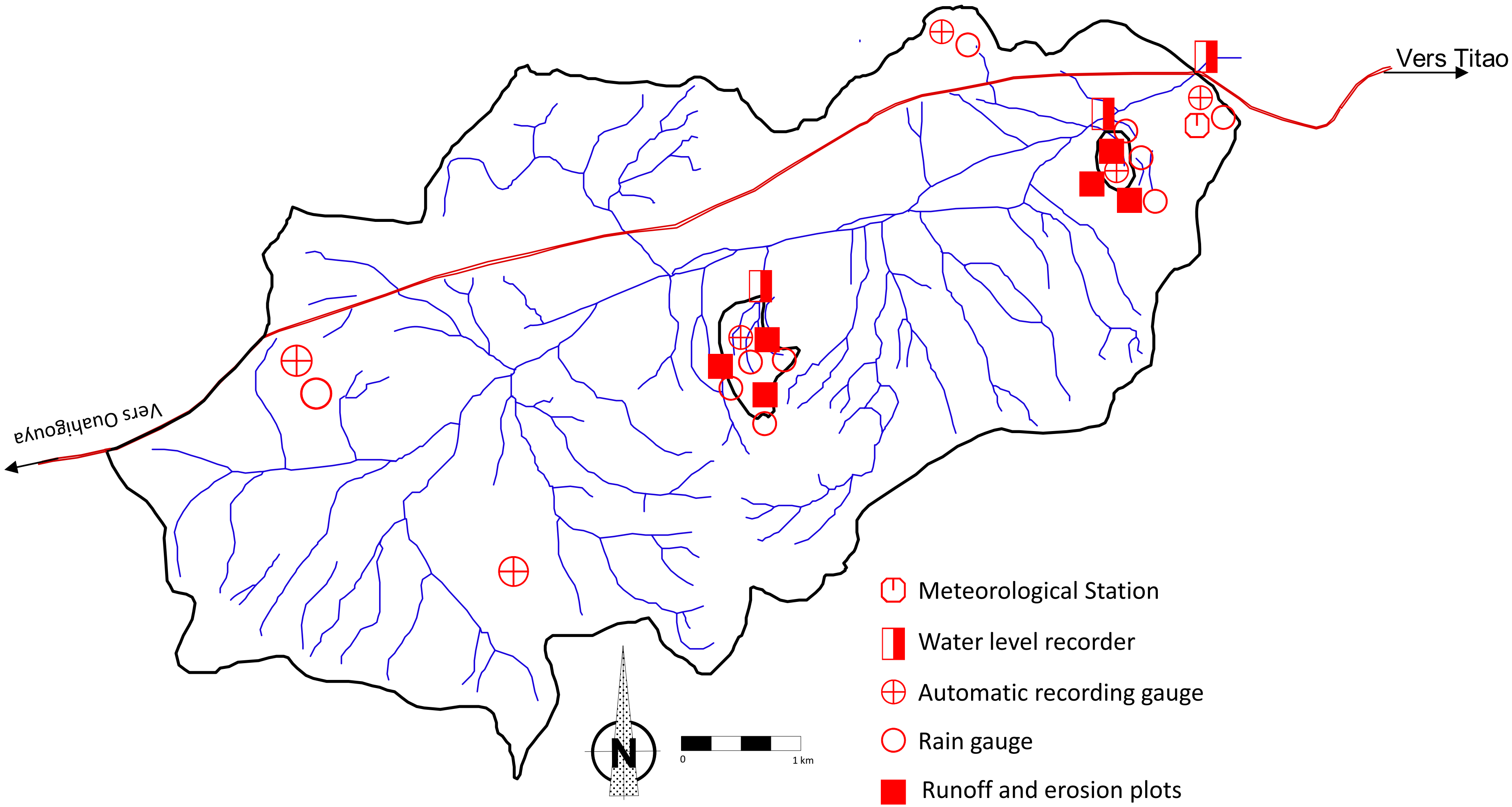


Land uses of the Tougou catchment



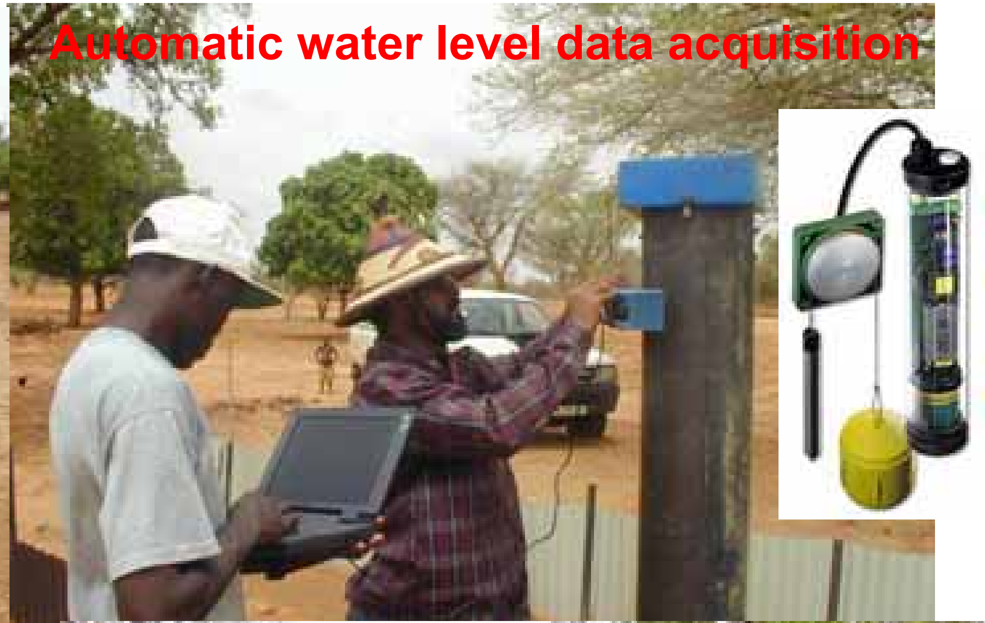
4. Materials and methods

Monitoring equipments (since 2004)

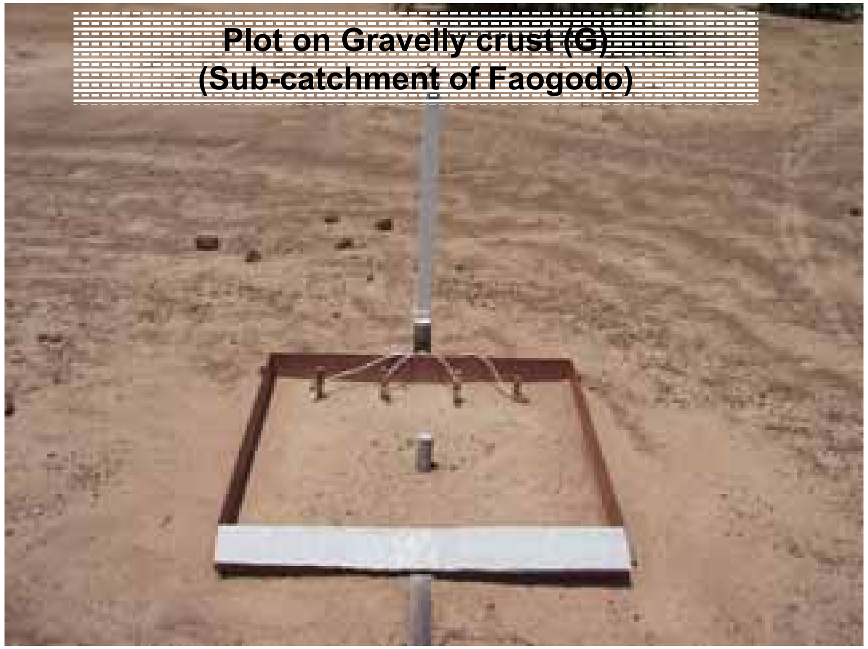


➢ Meteorological equipments

➢ Hydrological equipments



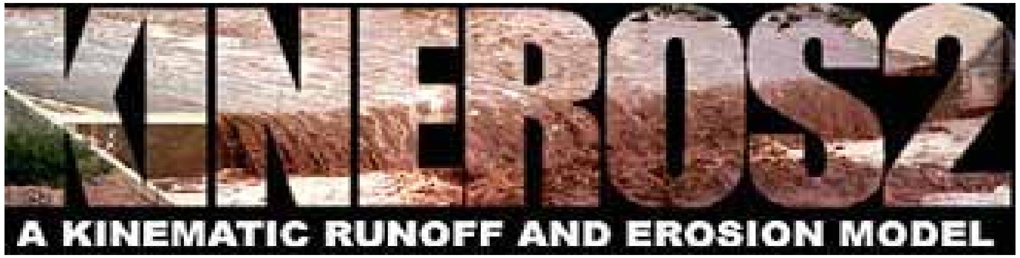
➢ Erosion plots



➤ Measurements

➢ Soil physics

Modeling



The KINEROS2 model:

(KINEmatic Runoff and EROsion) (Smith et *al.*, 1995)*

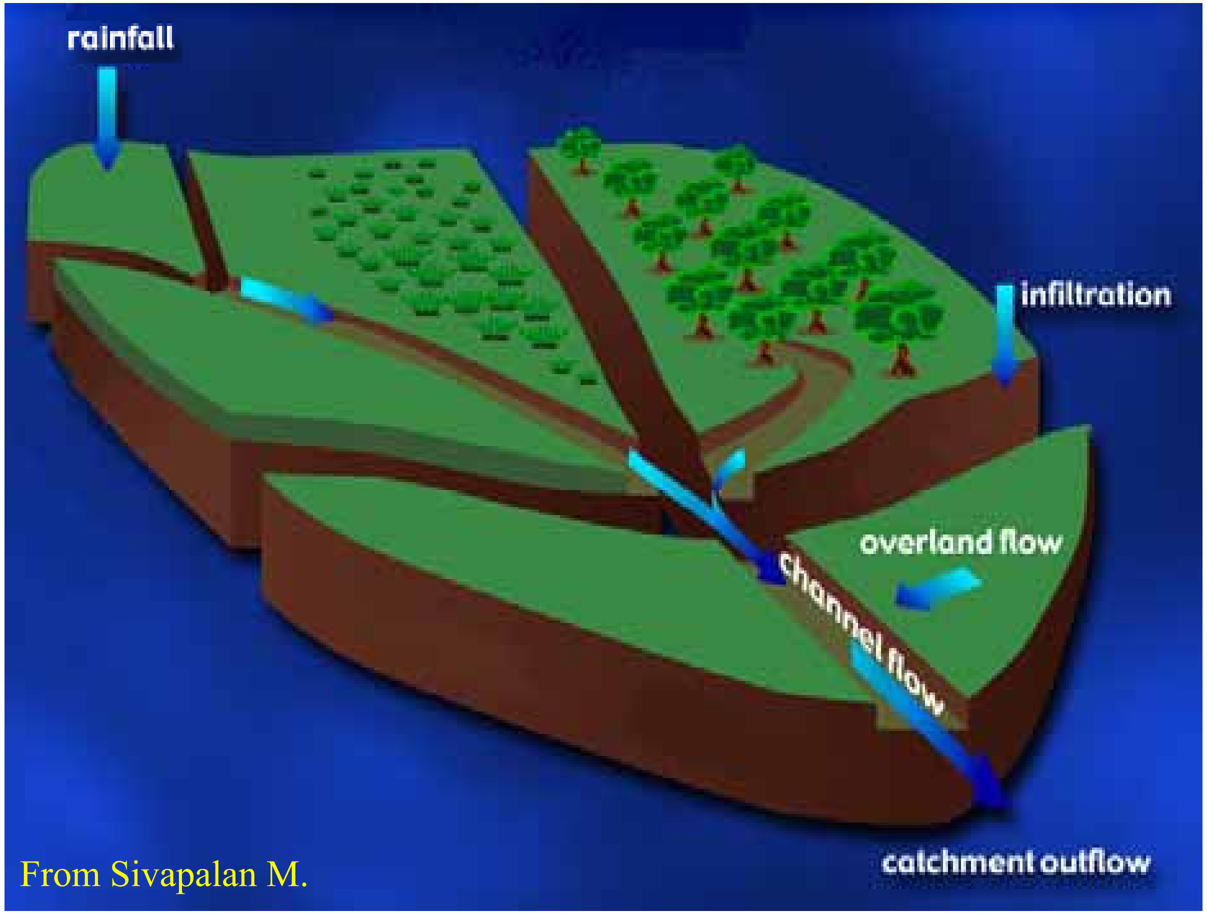
⇨ **A physically-based model**

⇨ **An event-based model**

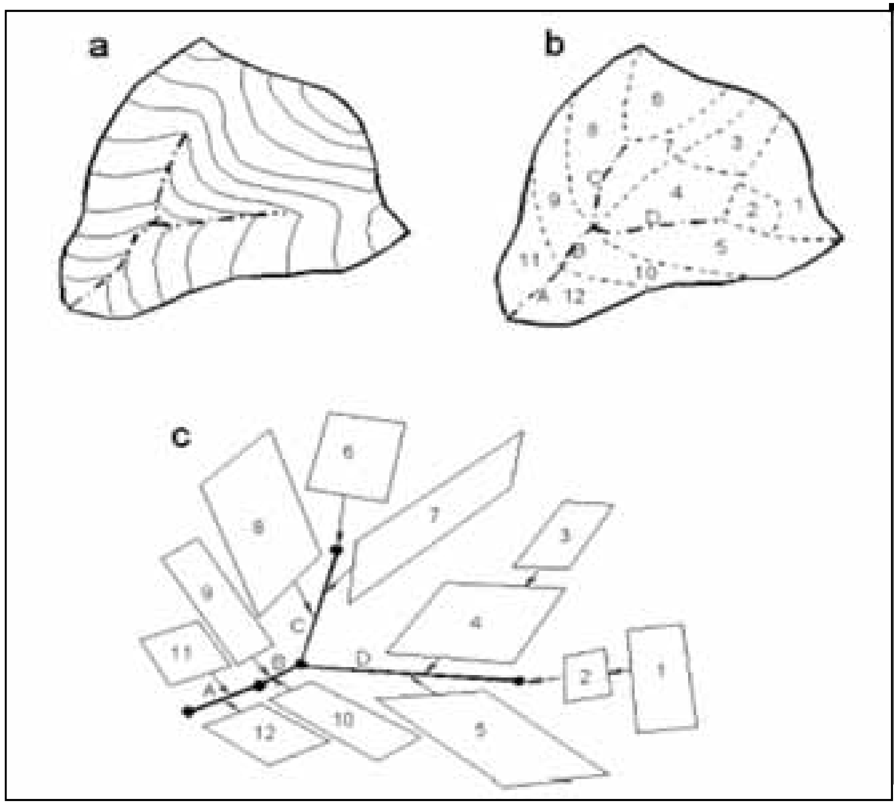
⇨ **A spatial distributed model**

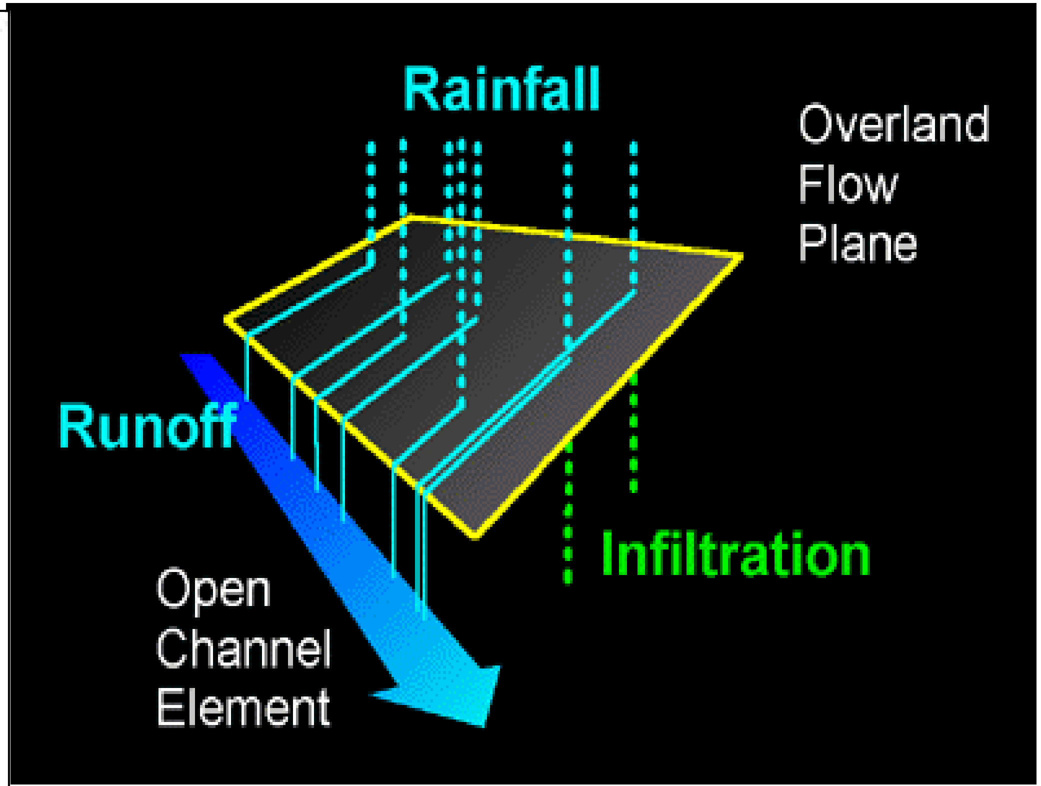
⇨ **Hydrological processes**
- **Overland flow and infiltration**
- **Channel flow and Infiltration**

⇨ **Erosion processes**
- **Splash erosion**
- **Overland and channel erosion**
- **Overland and channel deposition**



**Smith, R. E., Goodrich, D. C. & Quinton, J. N. (1995). Dynamic, distributed simulation of watershed erosion: the KINEROS2 and EUROSEM models. J. Soil Water Conserv. 50(5), 517–520.*





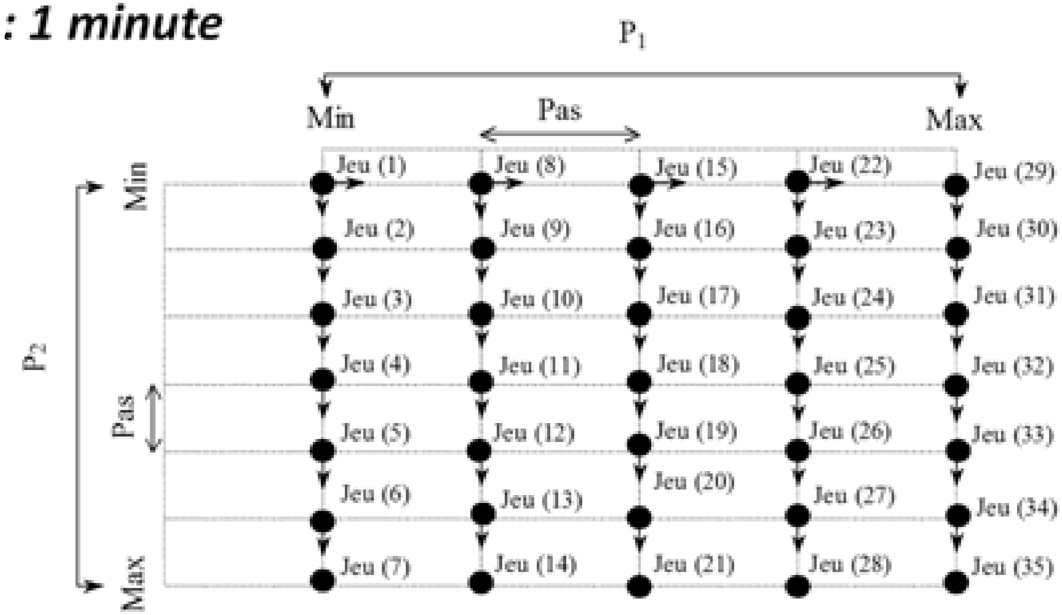
- In KINEROS2 the catchment is treated as a cascading network of surface, channel and pond elements. Channels receive flow from adjacent surfaces or upslope channels. Rectangular surfaces may be cascaded or arranged in parallel to represent complex topography or erosion features.
- Each element is characterized by assigning parameter values that control runoff generation and erosion processes.
- The flow modeling in KINEROS2 requires a temporal record of rainfall rate at one or more locations.

The model running options:

- ☑ ***Nash-Sutcliffe criteria for model performance evaluation***

$$Nash(Q) = 1 - \frac{\sum_{i=1}^{N}\left(Q(i)obs - Q(i)sim\right)^2}{\sum_{i=1}^{N}\left(Q(i)obs - Qmoy\right)^2}$$

- ☑ ***Calibration hydrological parameters: Manning roughness coefficient (n), Saturated hydraulic conductivity (Ks), Mean capillary drive (G)***
- ☑ ***Calibration erosion parameters: Splash coefficient (c_f), soil cohesion coefficient (c_g)***
- ☑ ***Time step for simulation : 1 minute***
- ☑ ***Automatic optimization algorithm***



5. Results and discussion

Soil physical properties

	Site	Soil type	Tillage type	Crop type	Ksat (mm/h)	Ksat (Casenave and Valentin, 1992)	Bulk density Da (g/cm^3)	Porosity (%)
Cultivated soils (BV1)	S_1	Loam	Light tillage + weeding + mounding	Millet, sorghum and cowpea	21–25		1.40–1.46	45–47
	S_2	Sandy	Means tillage + weeding + mounding	Millet, sorghum and cowpea	27–33	15–35	1.36–1.44	46–49
	S_3	Sandy gravelly	Light tillage	Millet, sorghum and groundnut	16–19		1.46–1.48	44–45
Bare soils (BV2)	S_4	Dry clay	No tillage	No crop	2–2.5	2–4	1.58–1.61	39–40
	S_5	Gravelly			3–3.5	3–5	1.88–1.94	27–29
	S_6	Sand			12–15	10–20	1.66–1.70	36–37

Number of infiltration tests by site: 12; number of porosity tests by site: 9.

From Mounirou LA, et al. Measuring runoff by plots at different scales: Understanding and analysing the sources of variation. C. R. Geoscience (2012), http://dx.doi.org/10.1016/j.crte.2012.08.004

Annual rainfall, runoff and erosion

➢ Plot scale

	Plot	2004			2005			2006		
		Rainfall (mm)	Runoff (%)	Erosion (t/ha)	Rainfall (mm)	Runoff (%)	Erosion (t/ha)	Rainfall (mm)	Runoff (%)	Erosion (t/ha)
Cultivated soils	PZC1	392	16%	5	449	46%	17	726	44%	14
	PZC2		2%	9		21%	18		23%	10
	PZC3		6%	6		21%	24		28%	18
Bare soils	PZN1		64%	42		79%	44		79%	64
	PZN2		83%	57		105%	62		91%	57
	PZN3		11%	30		29%	76		61%	103

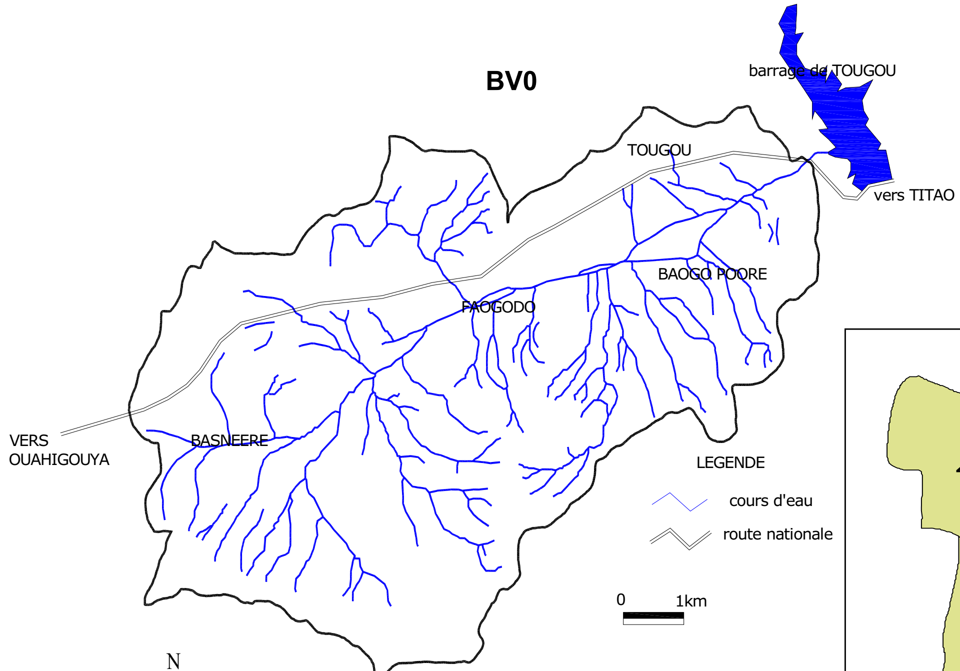
Crusted and bare soils showed higher runoff and seemed to be more sensitive to water erosion.

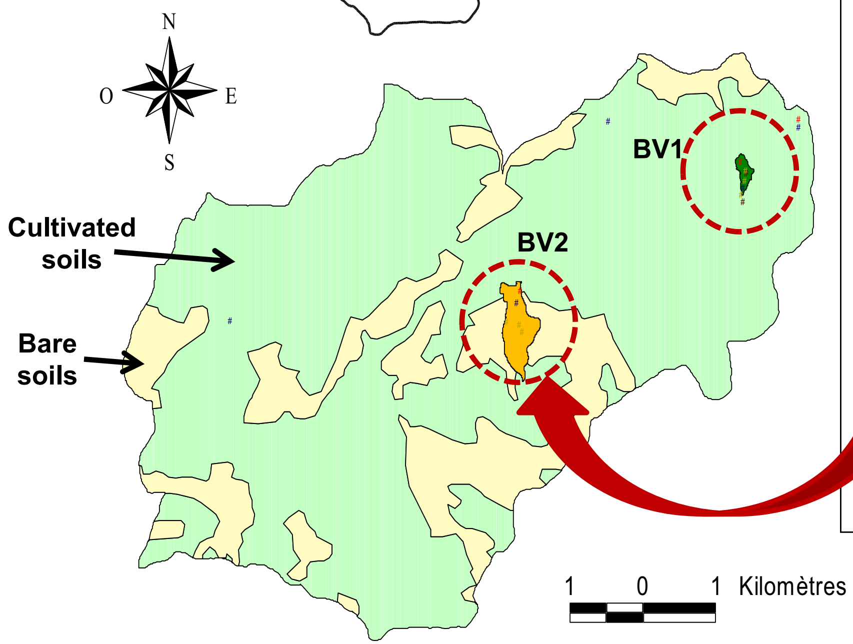
➢ Catchment scale (BV0)

Year	Rainfall (mm)	Runoff (%)	Erosion (t/ha)
2004	392	11%	0,5
2005	449	20%	4
2006	726	23%	7

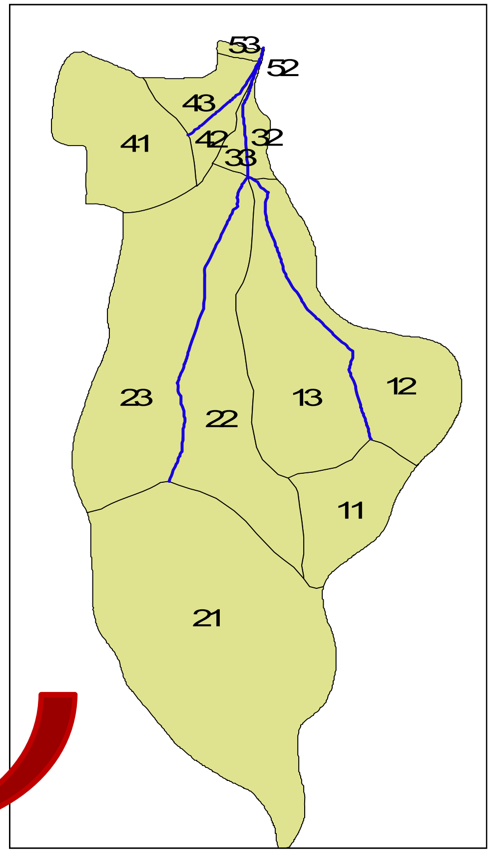
About 80% of total annual soil losses are caused by less than 40% of rainfall-runoff events.

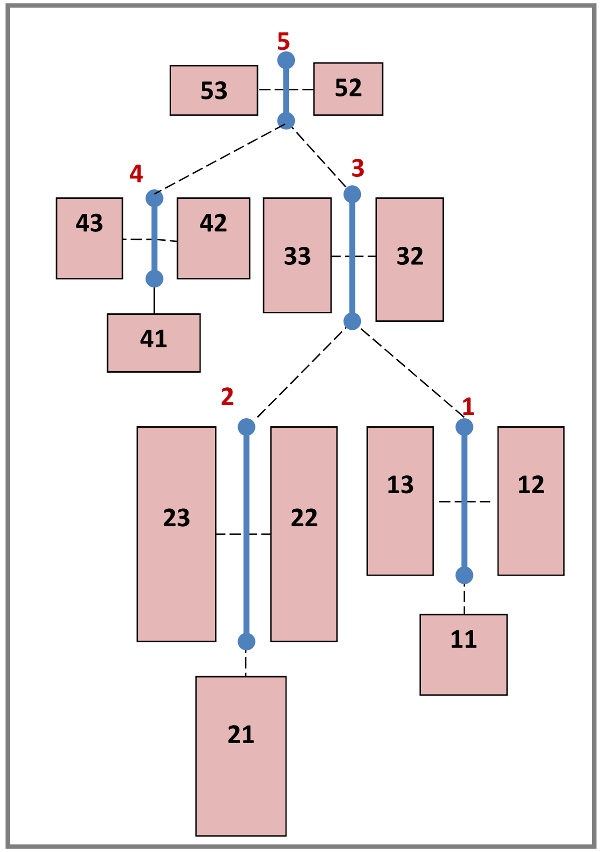
Hydrological and erosion modeling





Implementation of the model first on the sub-catchment BV2 (bare soils)





➢ Selection of rainfall-runoff events for calibration and validation

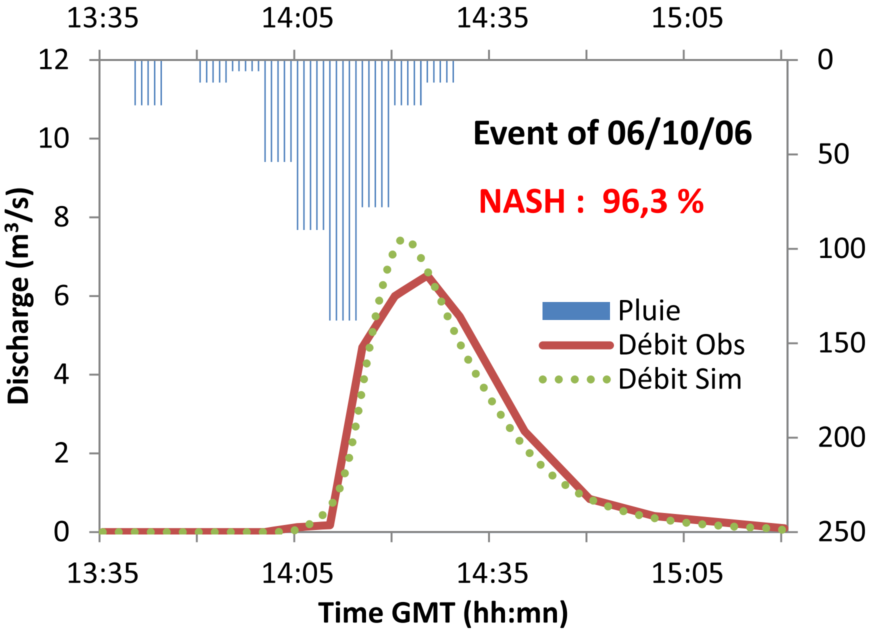
	Hydrology			Erosion		
	Date	Rainfall (mm)	Q_{max} (m3/s)	Date	Q_{max} (m3/s)	Erosion (Kg)
CALIBRATION	06/10/2006	37	6,52	19/07/2006	2,35	46007.2
	04/08/2006	59	4,134	15/09/2006	1,962	46071.5
	22/08/2006	53,5	4,000	18/09/2006	0,550	31596.6
	19/07/2006	31,5	2,35	06/10/2006	6,52	17493.7
	15/09/2006	13	1,962	27/10/2006	0,960	5695.7
VALIDATION	12/09/2006	14	1,087	11/08/2006	0,478	7620.7
	27/10/2006	12,5	0,960	12/09/2006	1,087	1150.3
	18/09/2006	8,5	0,550	22/08/2006	4,000	1794.4
	11/08/2006	8,5	0,478	04/08/2006	4,134	2060.6

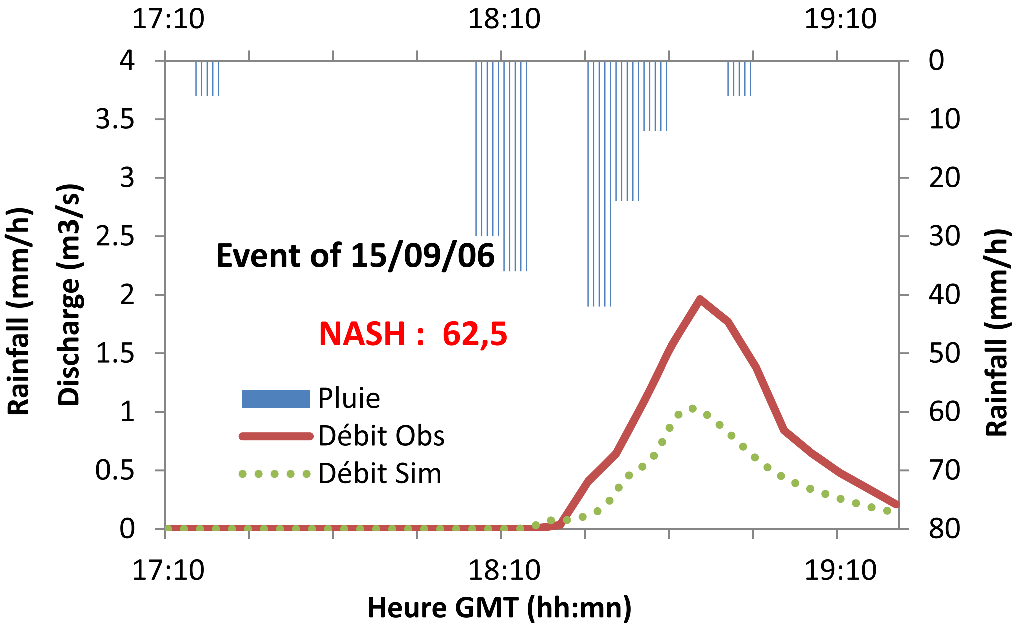
➢ Model parametrization

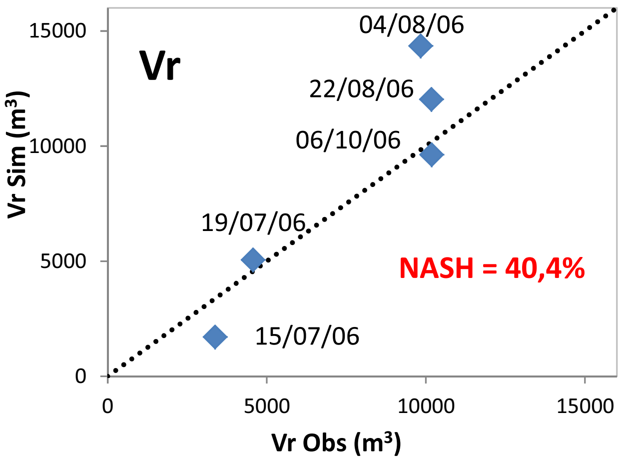
Parameters	Symbol	Values		Unit	References
		Plane	channel		
Saturated hydraulic conductivity	Ks	3,3	0	mm/h	Mesure de terrain
Mean capillary drive	G	77	-	mm	(Rawls et al., 2000)
Poral distribution index	λ	0,35	-	-	(Rawls et al., 2000 ; Karambiri, 2003)
Total porosity	ϕ	0,44	-	m^3/m^3	Mesure de terrain
Manning roughness coefficient	n	0,022	0,025	-	(Woolhiser, 1975 ; Lancastre, 2008)
soil cohesion coefficient	Cg	0,02	0,02	-	(Foster et Smith, 1984)
Splash coefficient	Cf	198,3	0	-	(Foster et al, 1983)

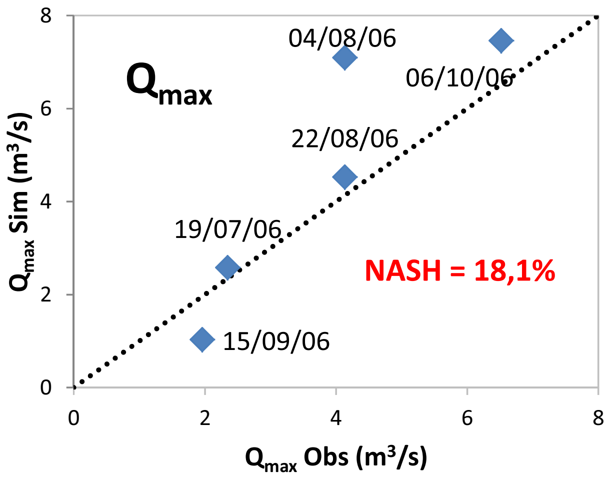
➢ Hydrological calibration

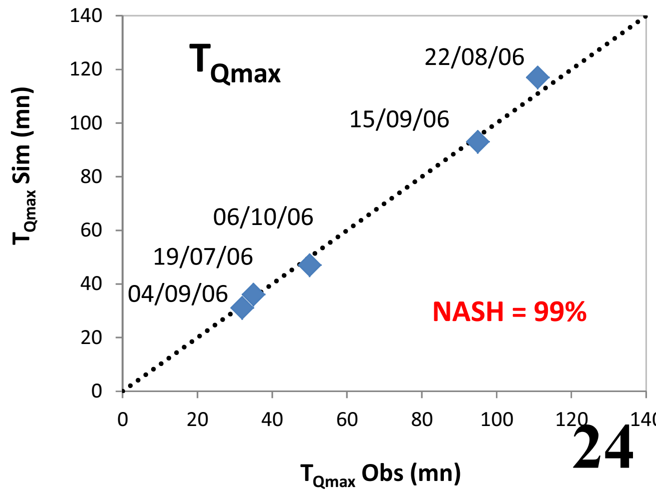
Nash = 83,14% in average for hydrograph simulations





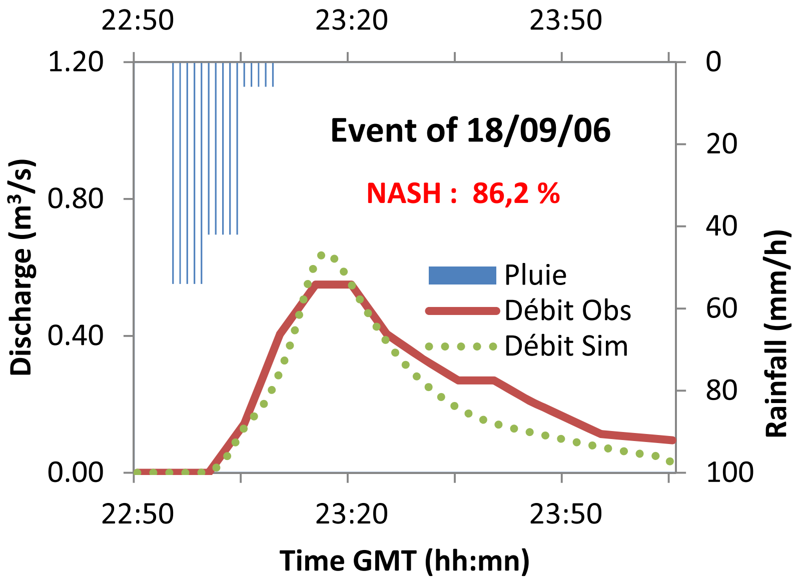


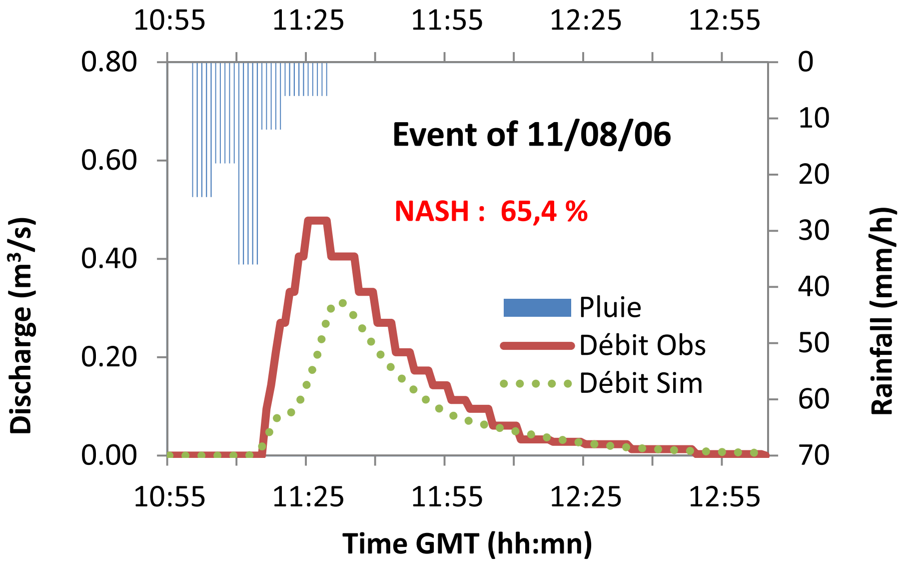




➢ Hydrological validation

Nash = 73,8% in average for hydrograph simulations

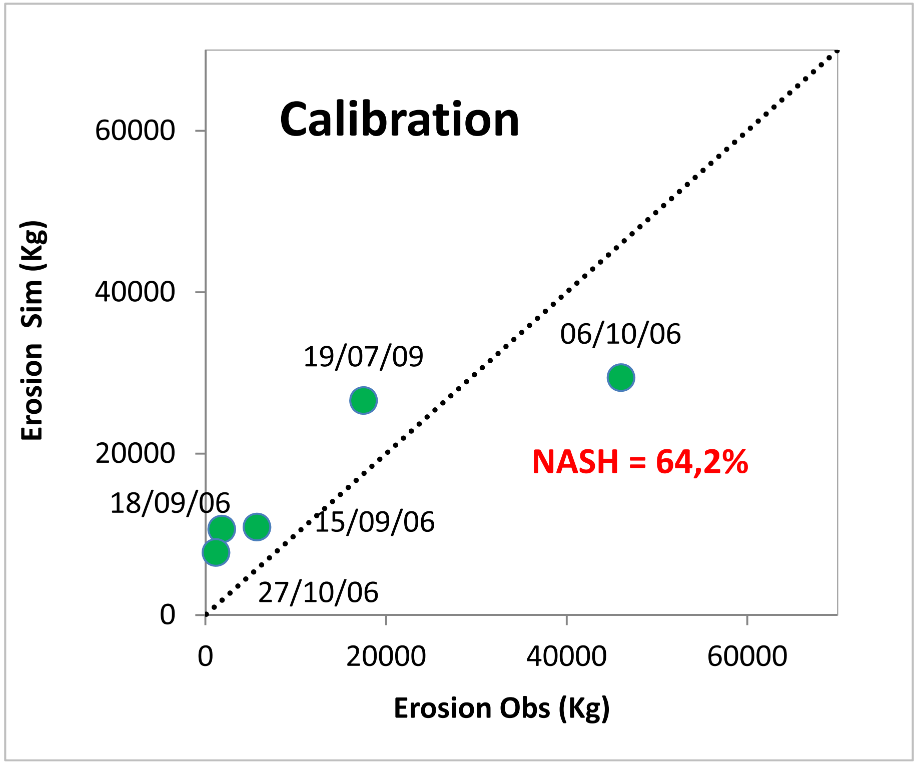


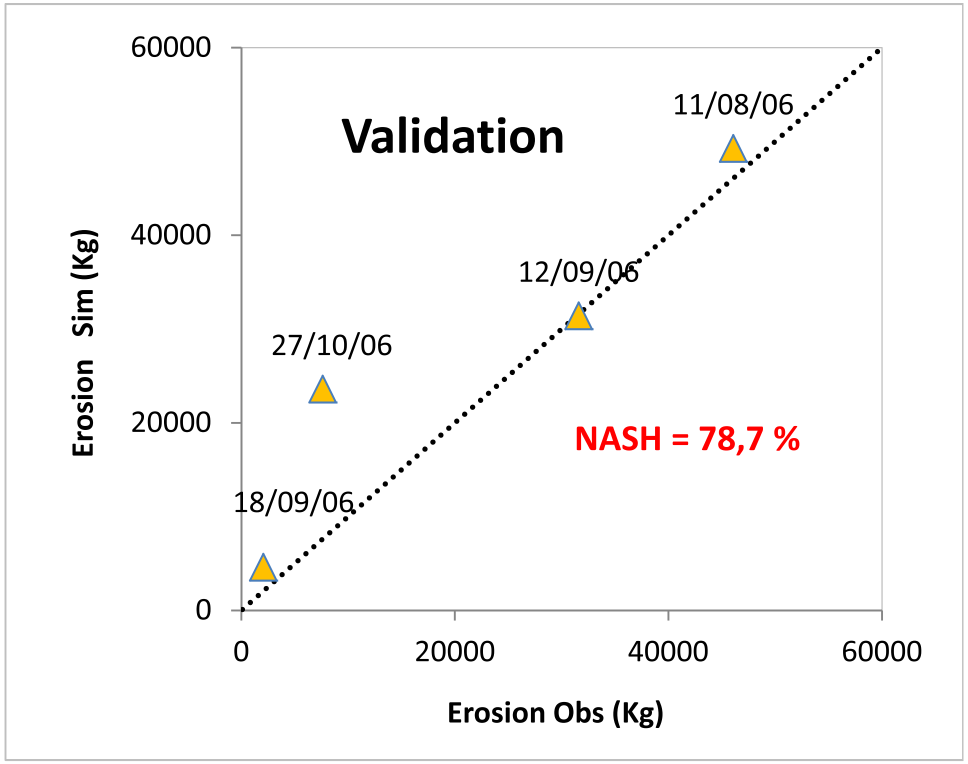


➢ Hydrological parameters

	Saturated hydraulic conductivity (Ks)	Manning roughness coefficient (n)	Mean capillary drive (G)
Initial parameters	3.3	0.022	77
Optimum parameters	**5.775**	**0.0119**	**87.01**

➢ Erosion calibration and validation

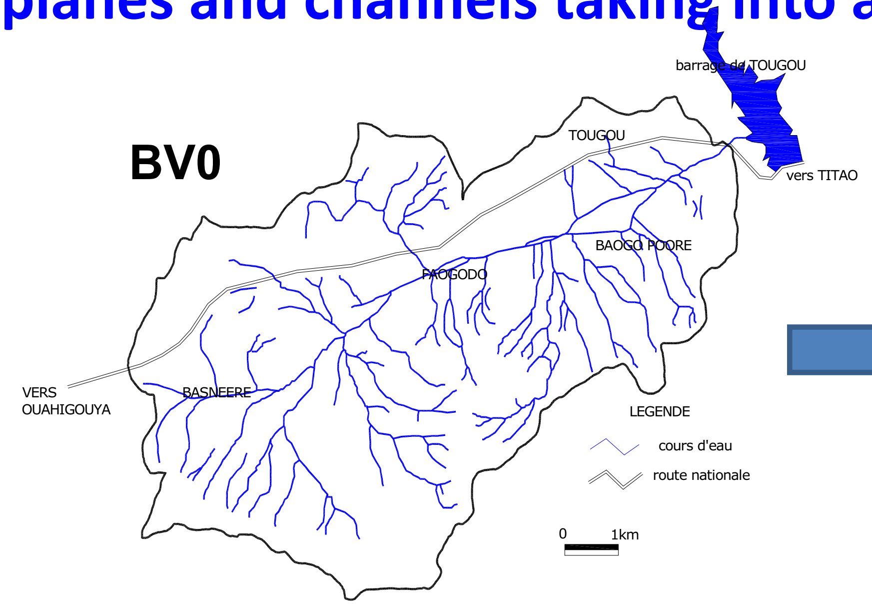


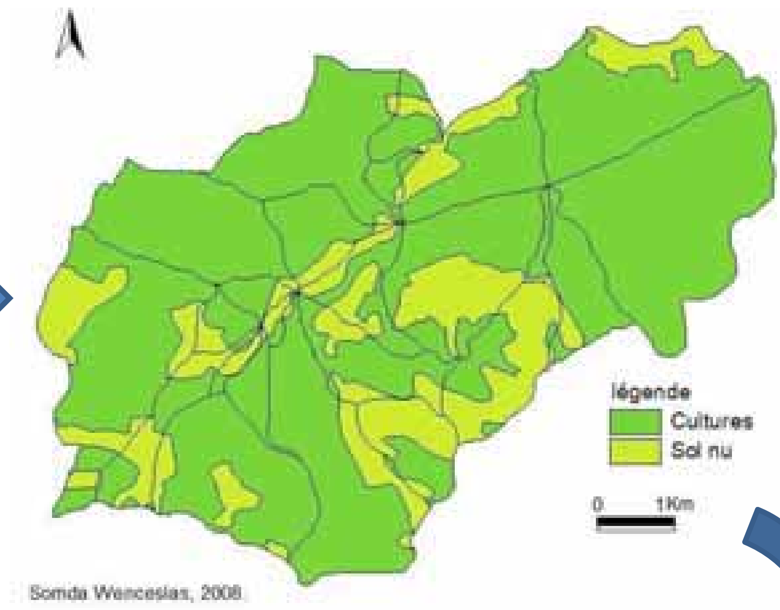


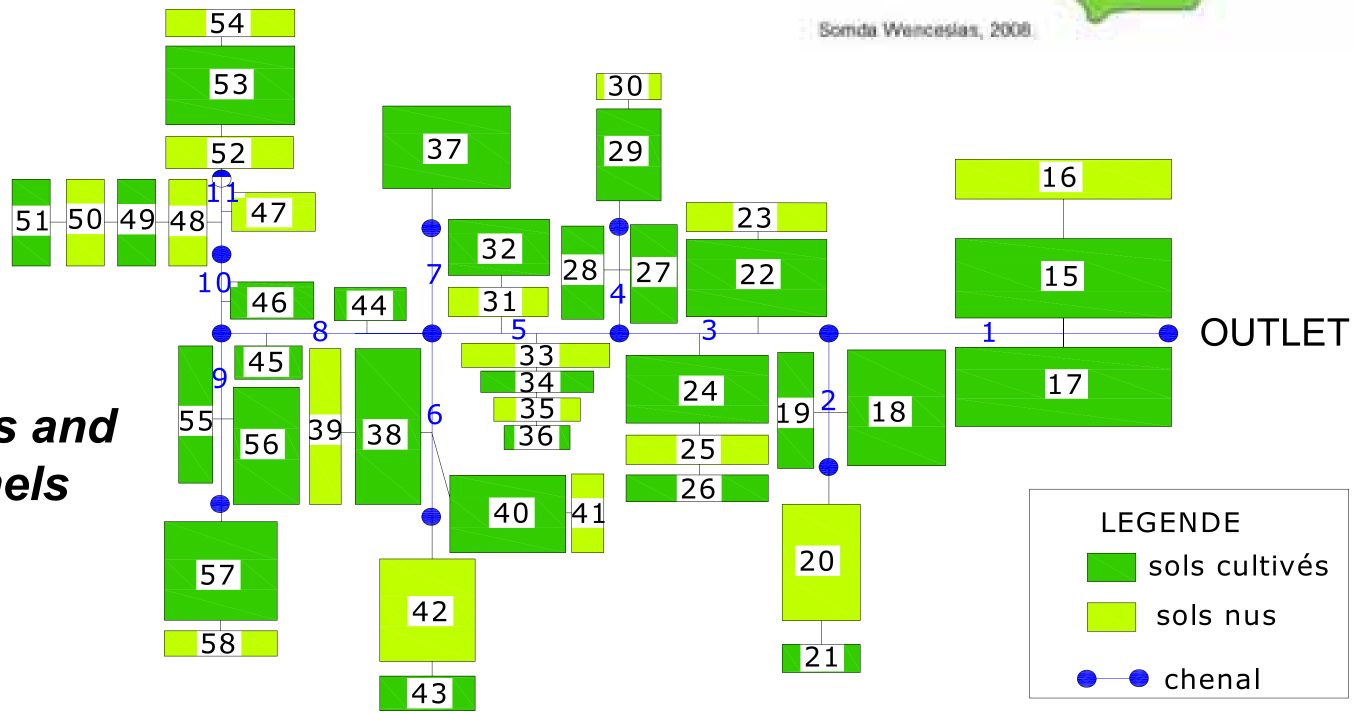
➢ Erosion parameters

	Splash coefficient (cf)	Soil cohesion coefficient (cg)
Initial parameters	198,3	0,02
Optimum parameters	**2111**	**39.5**

➢ Representation of the Tougou catchment (BV0) by a cascade of planes and channels taking into account the soil surface characteristics







44 planes and 11 channels

- **Selection of rainfall-runoff events for calibration and validation**

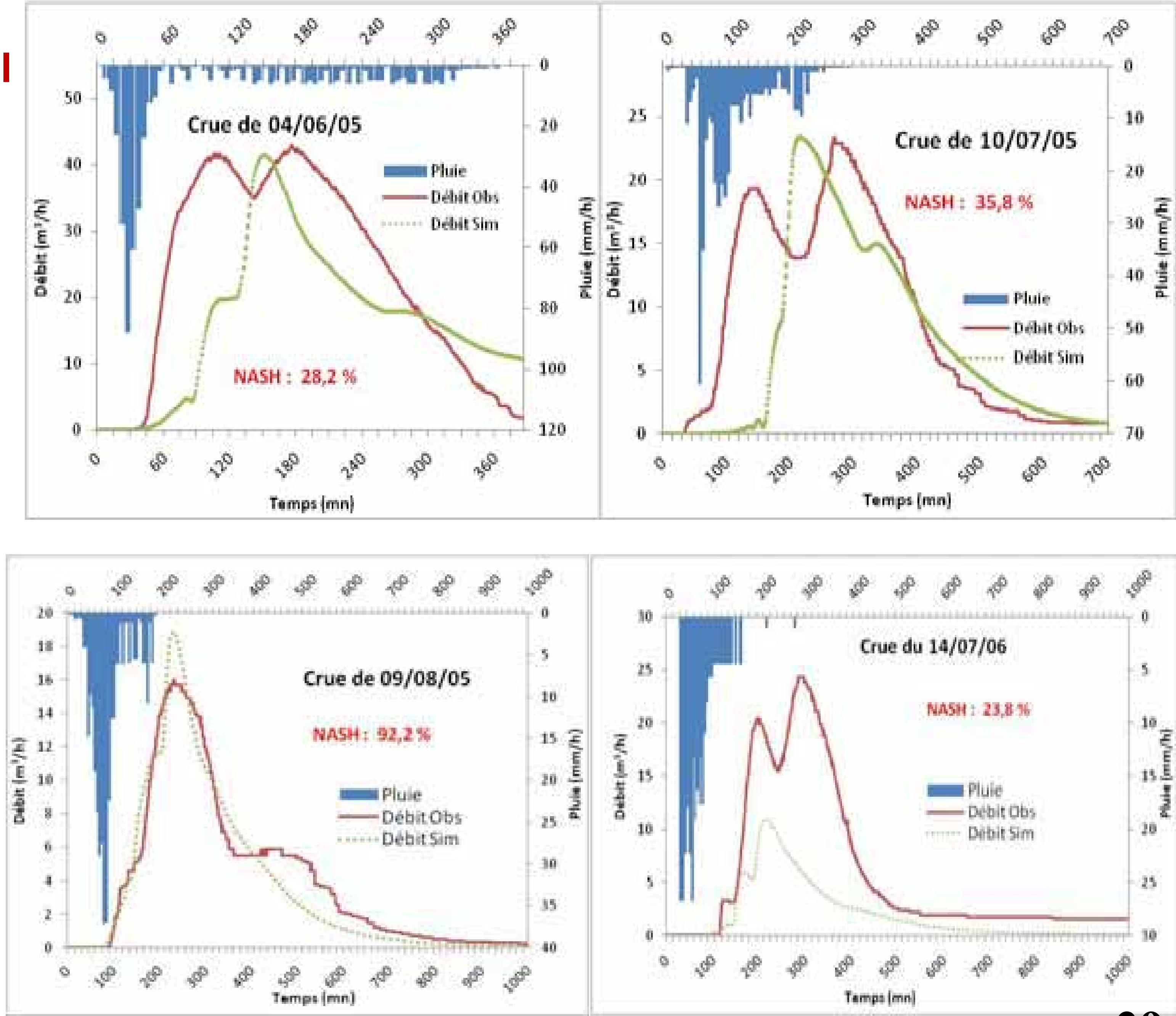
	Date	Max discharge (m3/s)
CALIBRATION	04 June 2005	42.9
	14 July 2006	24.4
	10 July 2005	23.3
	09 August 2005	16.1
	19 July 2006	15.5
VALIDATION	16 August 2004	11.2
	30 June 2005	14.9
	21 July 2005	3.7
	29 July 2005	1.9
	04 August 2005	10.5

- **Model parametrization**

	Cultivated soils	channels
Total porosity	0,370	_
Saturated hydraulic conductivity (Ks in mm/h)	23,4 / **19.6**	0
Manning roughness coefficient (n)	0,1 / **0.03**	0,05
Mean capillary drive (G in cm)	26 / **21.84**	_
Poral distribution index (λ)	0,32	_

- **Hydrological simulations**

The bi-modal behavour of the catchment was never reproduced by the model !



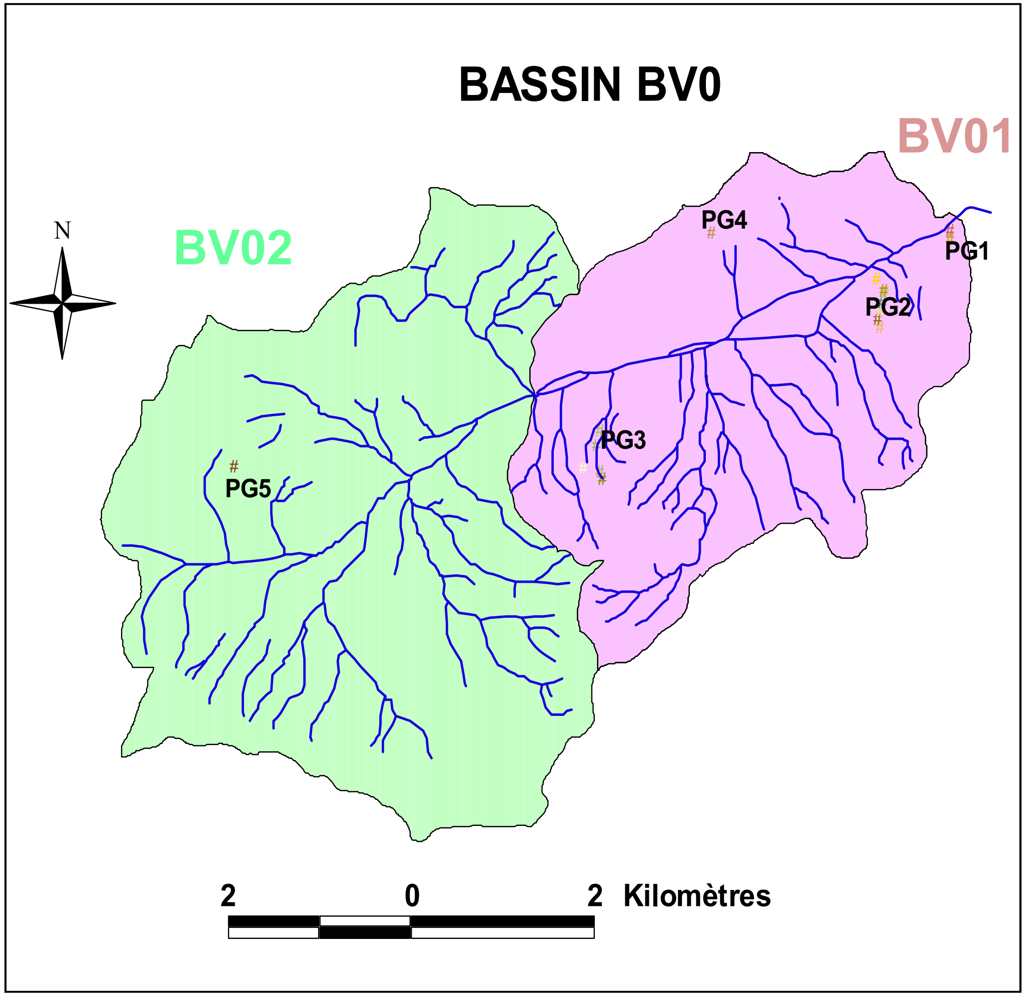
Remarks:

☞ Simulations do not show the bi-modal shape of observed hydrographs

☞ Simulated runoff volumes are underestimated

☞ A sensitivity analysis showed a strong influence of the roughness coefficient (n) on the hydrographs shapes, whereas the saturated hydraulic conductivity and the mean capillarity drive influence the runoff volume and the maximum discharge

Hypothesis of 2 connected catchments

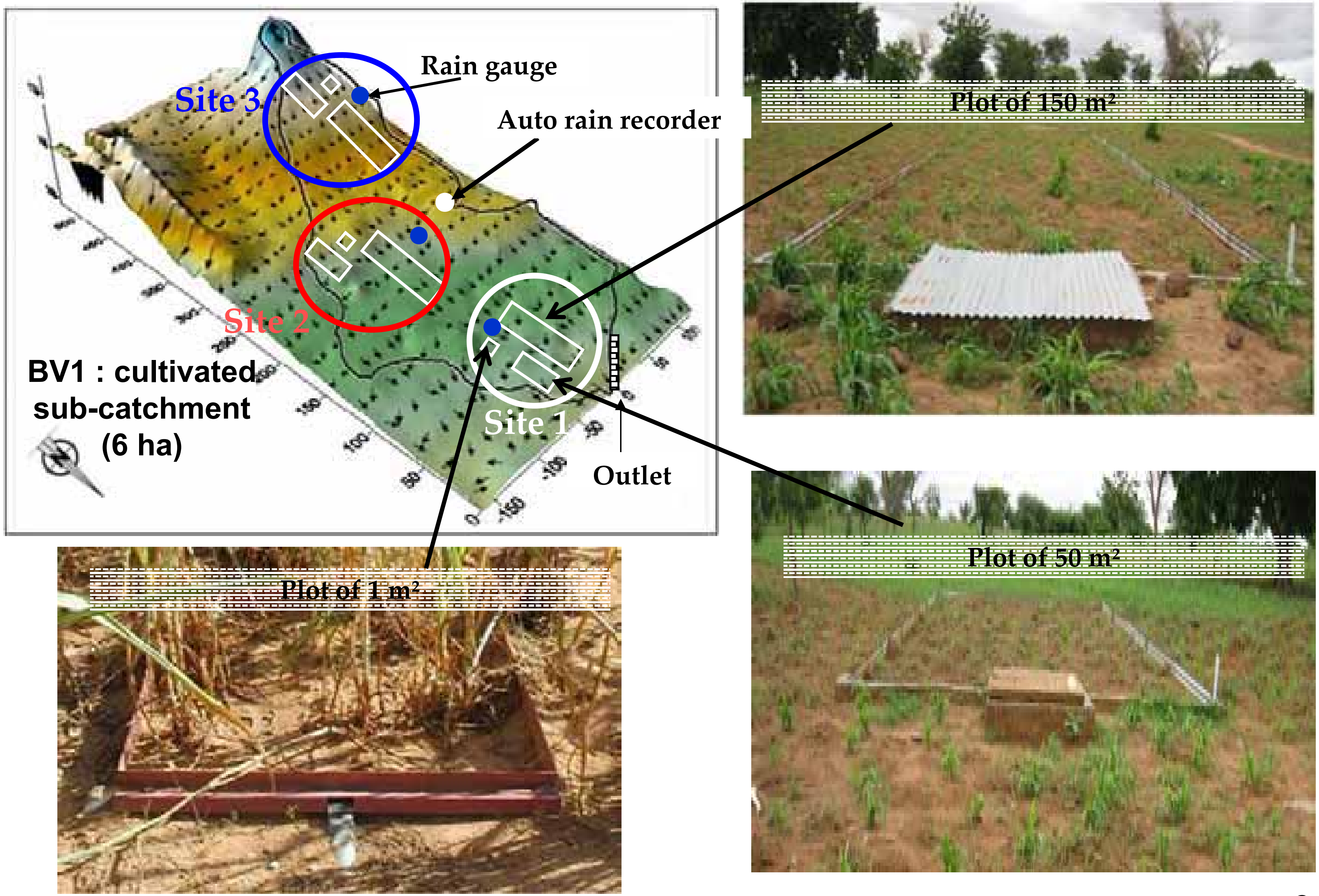


6. Lessons learnt and perspective

- ➢ Traditional hydrological and erosion modeling (using apparent parameters for the basin) showed limitations in this area of the Sahel because of the strong seasonal changes of land uses/cover ☞ ***There is a need to move toward seasonal or event-based parameterization***

- ➢ Gaps in hydrological and erosion processes analyzing and understanding from plot to catchment scale
☞ ***Document more scaling effect on runoff and erosion.***

Scale effect analysis experiments



See Mounirou LA, et al. Measuring runoff by plots at different scales: Understanding and analysing the sources of variation. C. R. Geoscience (2012), http://dx.doi.org/10.1016/j.crte.2012.08.004

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