Mekong River Commission
Regional Workshop on Discharge and Sediment Monitoring, and Geomorphological Tools for the Lower-Mekong Basin
21-22 October 2008
Mekong River Secretariat in Vientiane

Measuring and modelling sediment yield at the small catchment scale

Ongoing works from the MSEC project

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IWMI-IRD
Agriculture Land Research Center

Brief presentation of the MSEC project

Management of **S**oil **E**rosion **C**onsortium

- **An international project established in 1997**

➔ Soil, Water and Nutrient Management (SWNM) initiative (4 CGIAR consortia)

- <u>Five SEA countries</u>: Laos, Vietnam, Thailand, Indonesian and the Philippines

Produce and disseminate knowledge on the interactions b/w socio-economic and biophysical processes

- 5 books
- 21 book chapters
- 17 international publications
- 13 national journal articles
- more than 80 conference papers/proceedings
- more than 20 internal technical reports
- 7 CD, web pages…

2) Capacity building

Discharge measurements in large rivers and streams

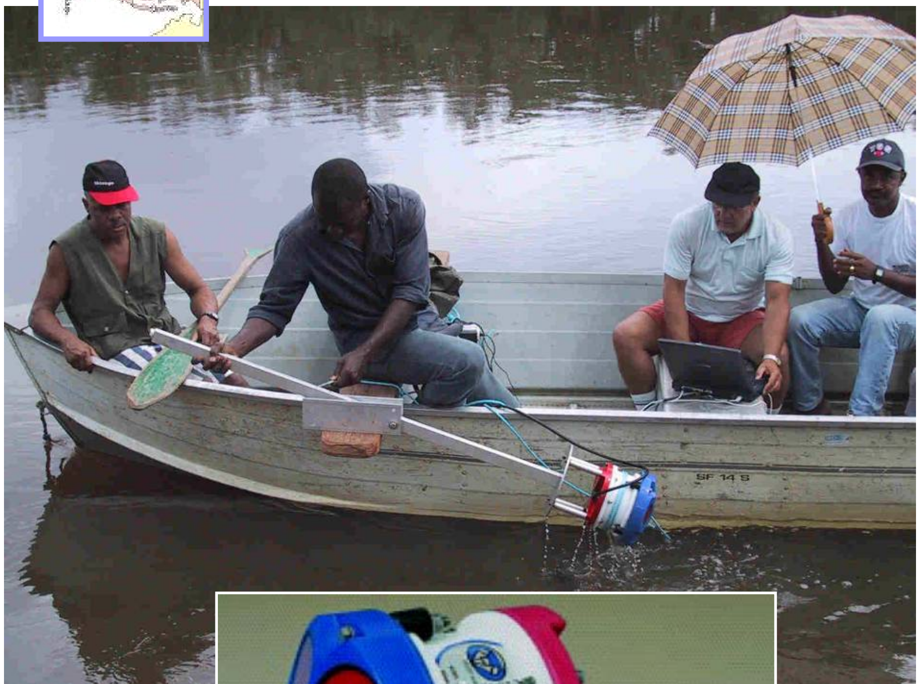
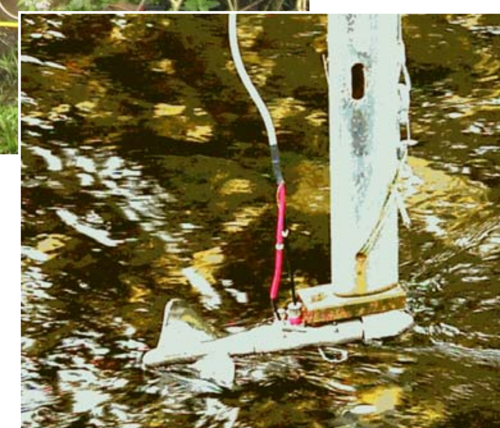
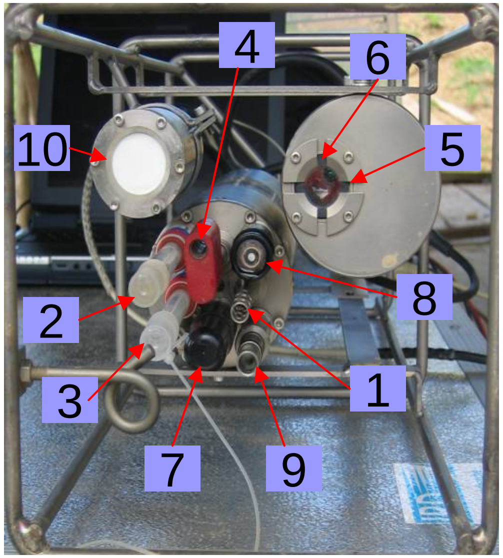


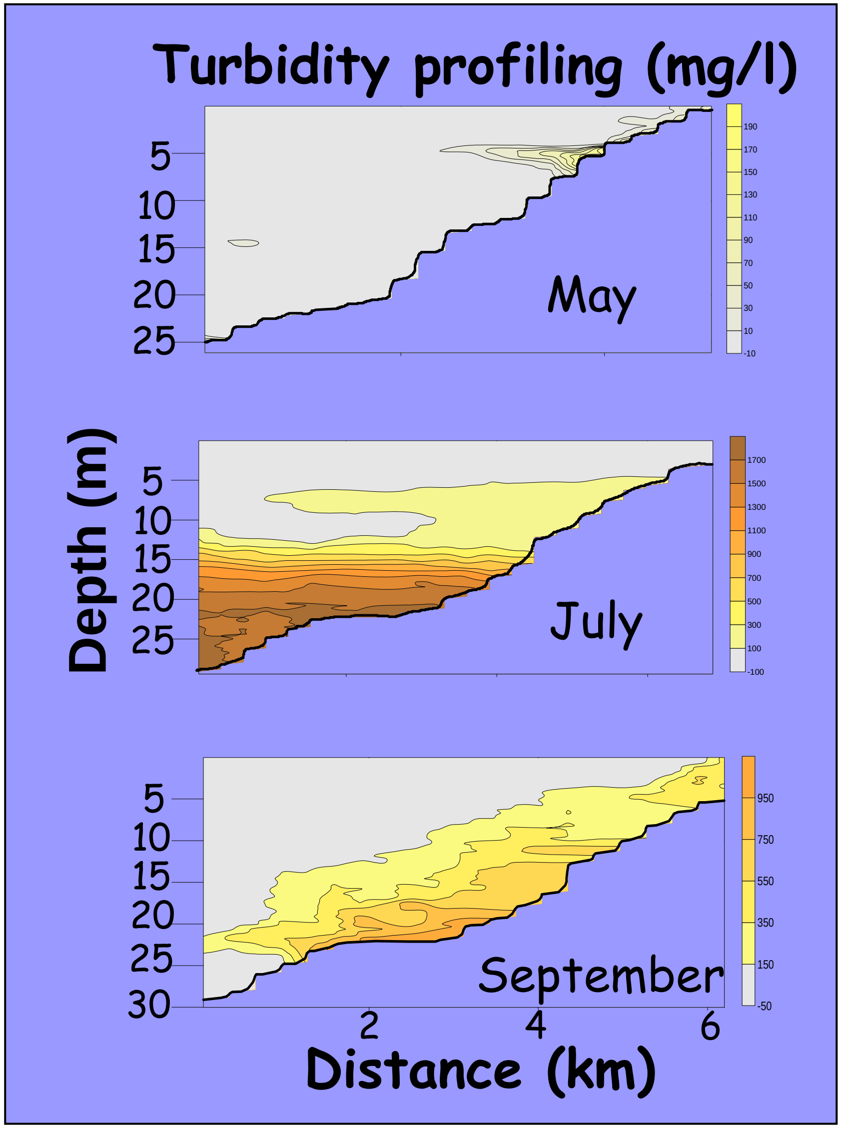
Photo IRD US-OBHI



ADCP WORKHORSE RIO GRANDE 1200 kHz (SEBA, RDI-Instrument)
Mode 12 (High Resolution, Shallow water profiling in rivers and streams)

In situ measurement of environmental parameters in the water column





- temperature
- pH
- redox potential
- water electrical conductivity
- chlorophyll-a concentration
- light backscatter
- turbidity
- dissolved-oxygen concentration
- dissolved H_2S concentration
- dissolved CH_4 concentration

Understanding sediment generation within catchments

A difficult challenge…

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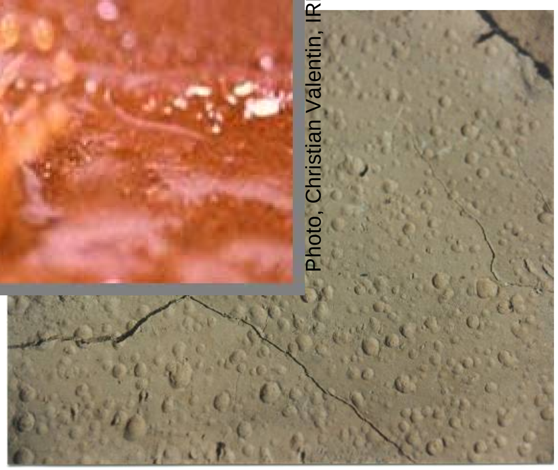
Many interactive factors and processes varying in time and space

Photo, Christian Valentin, IRD



Photo, Olivier Ribolzi, IRD

- External factors: rainfall intensity and depth…
- Internal factors: vegetation cover, soil characteristics (slope gradient, roughness, composition), farming practices…
- **Various scale-dependent processes**: splash erosion, rill erosion, gully erosion, tillage erosion, land slide…

What are the main processes that govern sediment generation fragmented lands?

Houay Pano catchment almost entirely covered by fallow (2001)

Houay Pano catchment after slashing and burning (2007)

<u>Shifting cultivation lands</u>: pluriannuelle rotational cycles

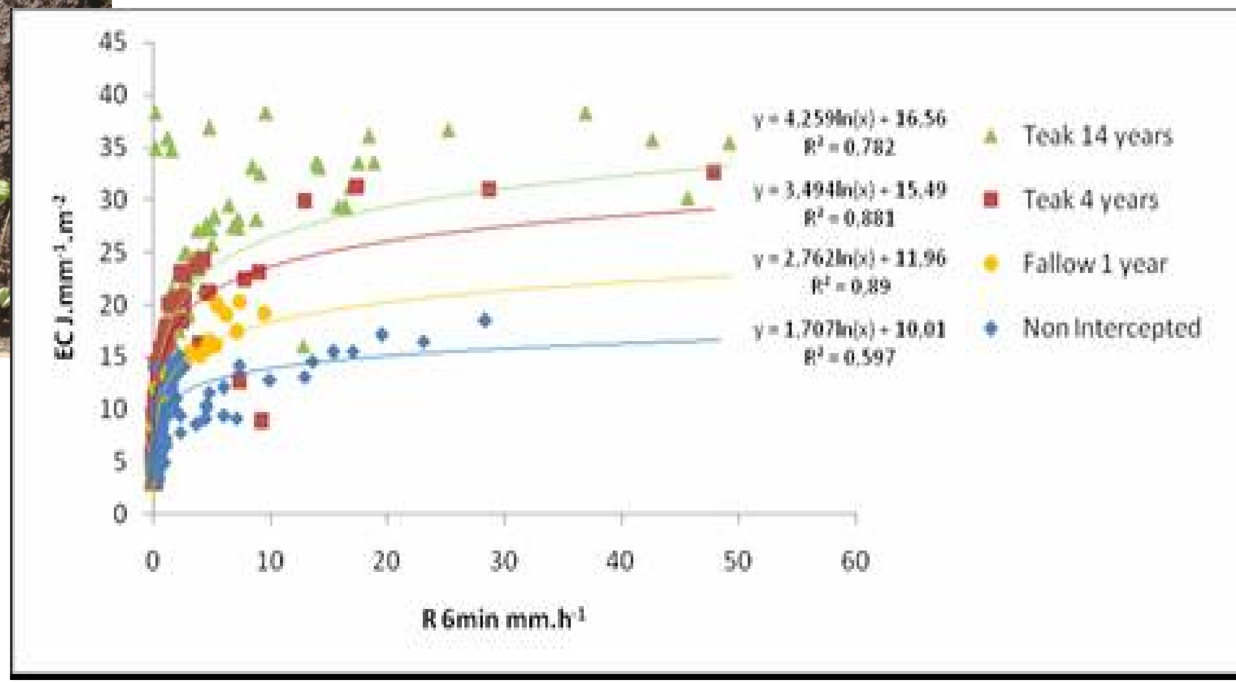
➔ Variations with time

At the sample-plot scale

“Splash” erosion *vs* Canopy cover

Photo, Christian Valentin, IRD

Soil detachment features under a canopy of old teaks

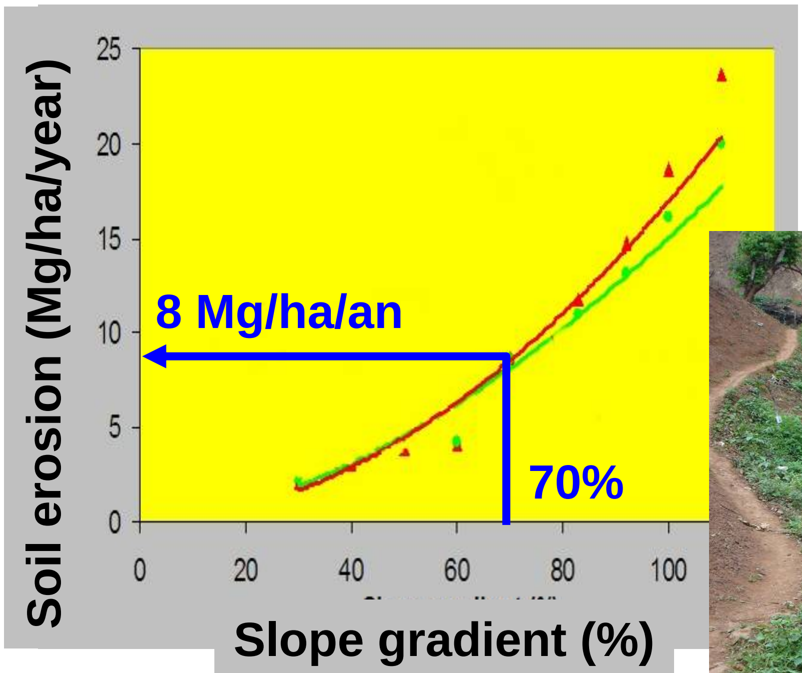


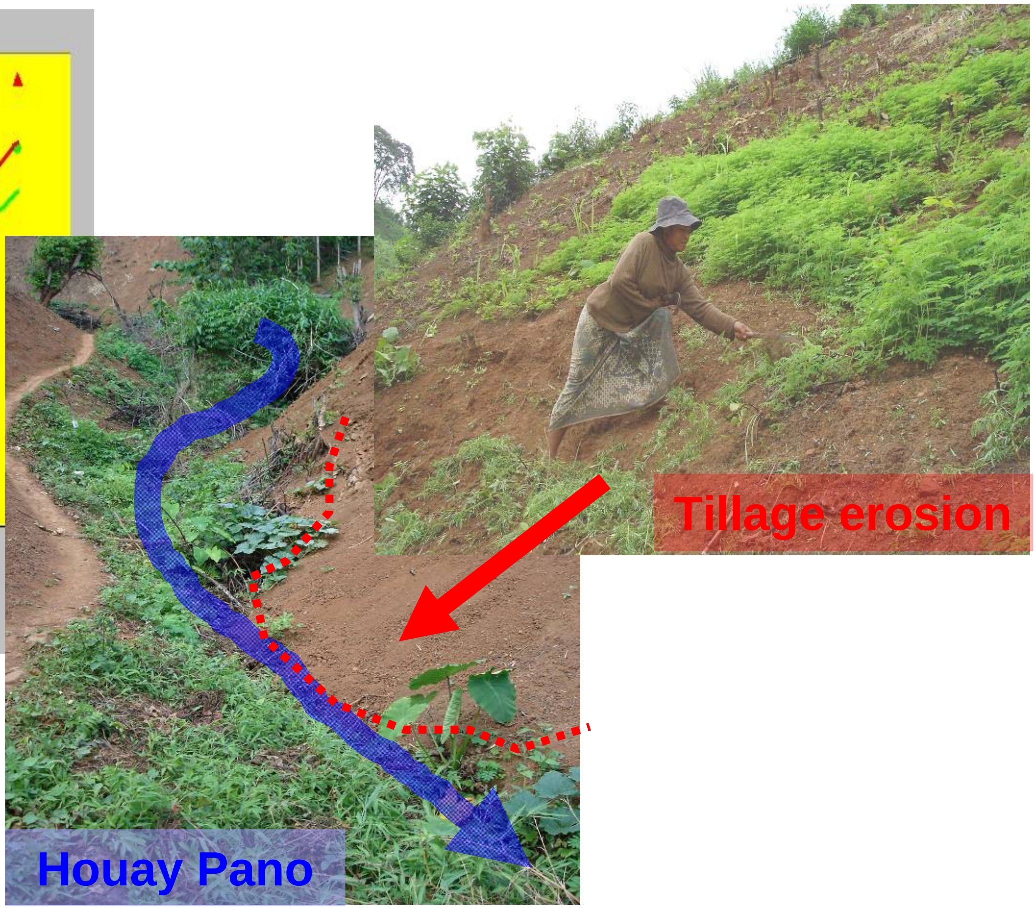
Kinetic energy of rain drops impacting the soil surface under various canopy covers of the Houay Pano catchment.

Modified from Robert (2008), MSEC

Tillage erosion vs Riparian vegetation clearance

(modified from Dupin et al., 2002)





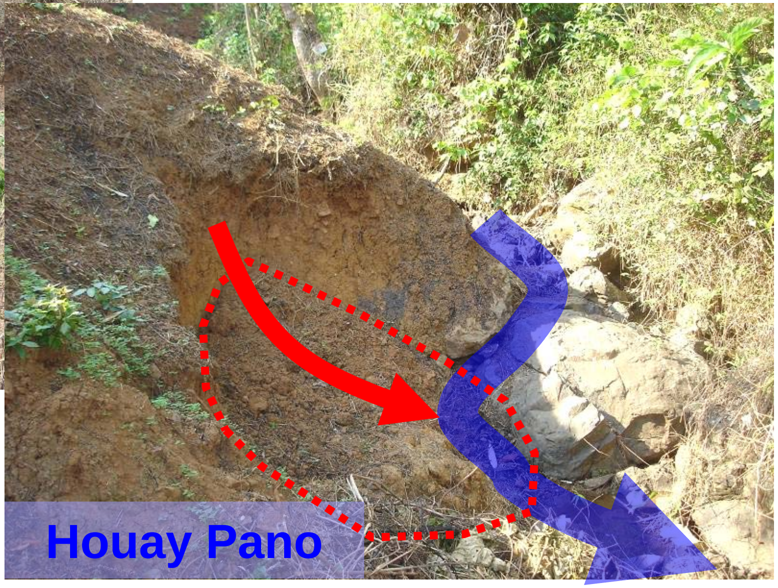
Dupin B., Phanthavong K., Chanthavongsa A., Valentin C., 2002. Assessment of tillage erosion rates on steep slopes in the northern Lao PDR. The Lao Journal of Agriculture and Forestry. 4:52-59.

From micro-catchment to hillslope scale

Concentrated erosion along flow paths are of great importance

- Sediments transferred downstream through concentrated flow path (gullies or rills) can **bypass the filtering effect of the riparian vegetation** and reached the main stream.

Bank slides genesis *vs* natural riparian vegetation removal



Lebreton, M., 2007 – Rôles de l'occupation des sols sur la stabilité des berges dans un bassin versant des régions montagneuses du nord du Laos. Mémoire de fin d'étude de l'INSA, département « génie civil et urbanisme » (Rennes, France). Participation à l'acquisition et aux traitements des données, aide à la rédaction (Co-direction : Olivier Ribolzi et Alain Pierret).

Sediment yield measurements in the lower-Mekong uplands

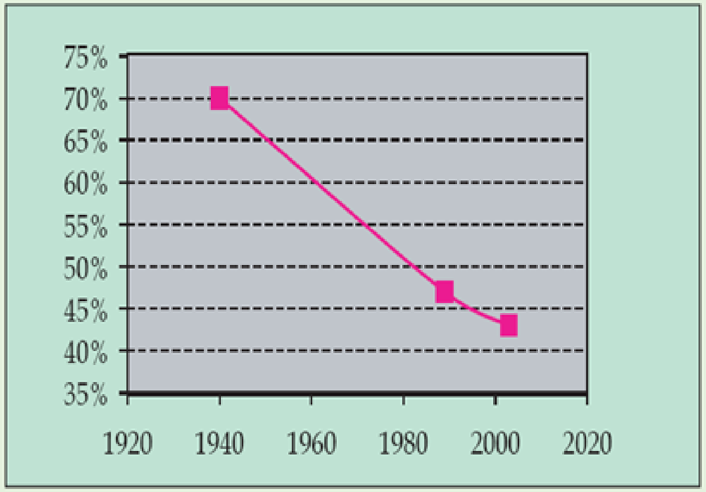
Illustrations from MSEC-Laos

Illustrations from MSEC-Laos

- Upland areas of the Lower-Mekong including many protected areas are responsible for sustaining a steady supply of good clean water for :
  - downstream agriculture
  - hydropower generation
  - public consumption

International Centre for Environmental Management (2003)

Does the undergoing land use changes in the Lao P.D.R. threat these Environmental Services ?

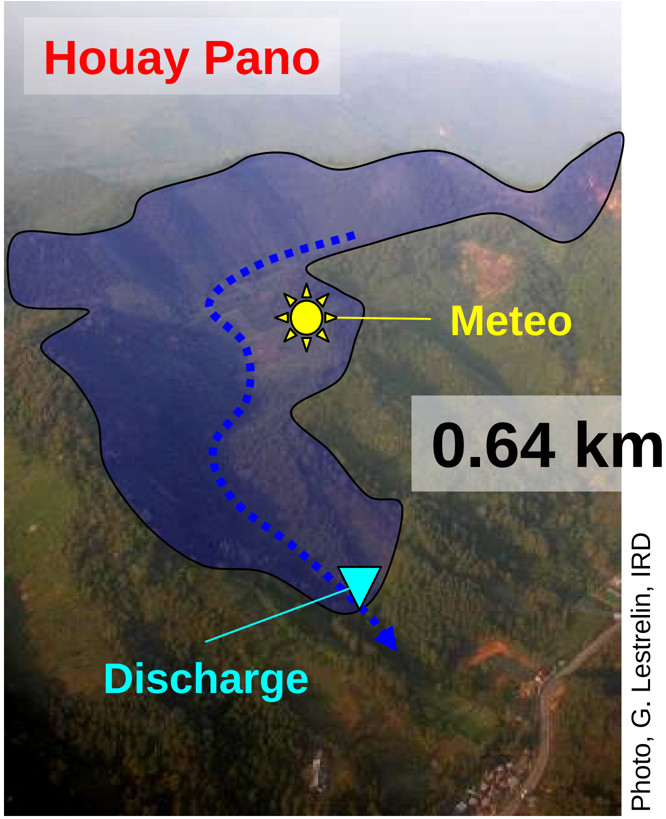


Source: UNEP/ADB, 2004

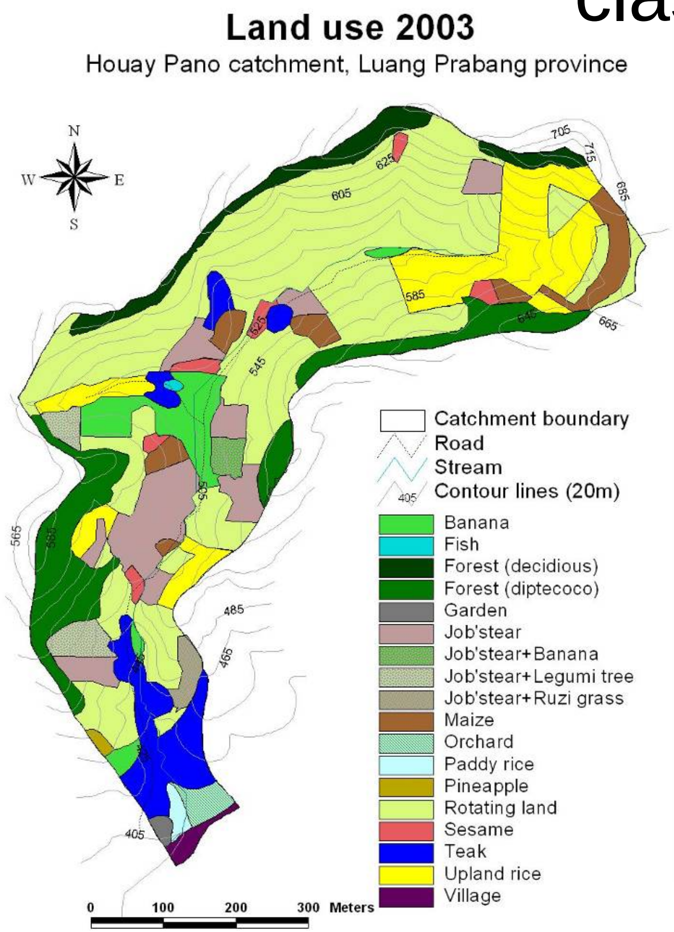
- Rapid deforestation due to the expansion of the commodity crop sector (i.e. Rubber, agrofuels, etc...)
- Increasingly intensive use of upland fields by poor farmers due to low investment allocated (70 % of the GoL's investment allocated to irrigation…)

(Douangsavanh & Bouahom 2006)

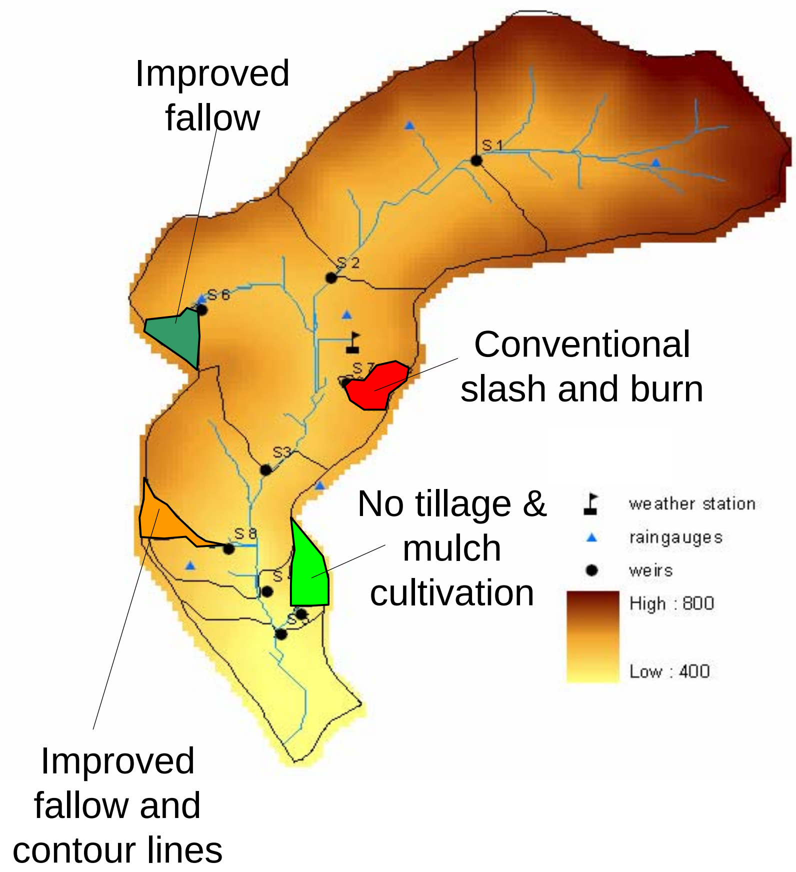
Experimental catchment in Northern Lao PDR



8 sub-catchments are equipped with classical hydrological stations



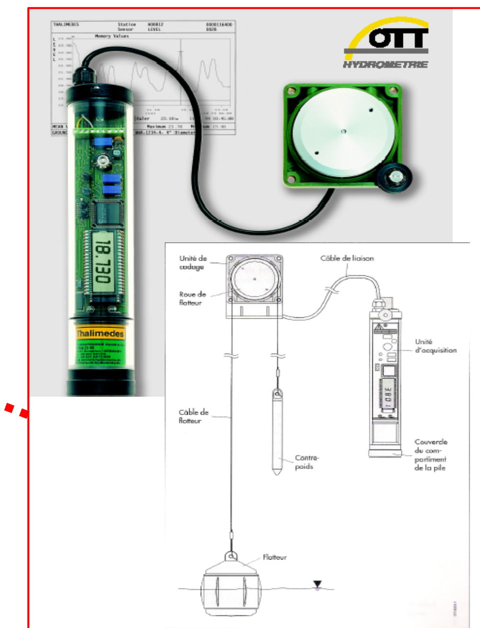
Yearly land use maps



- 4 nested catchments along a permanent stream
- 4 hillslope catchments with ephemeral flow

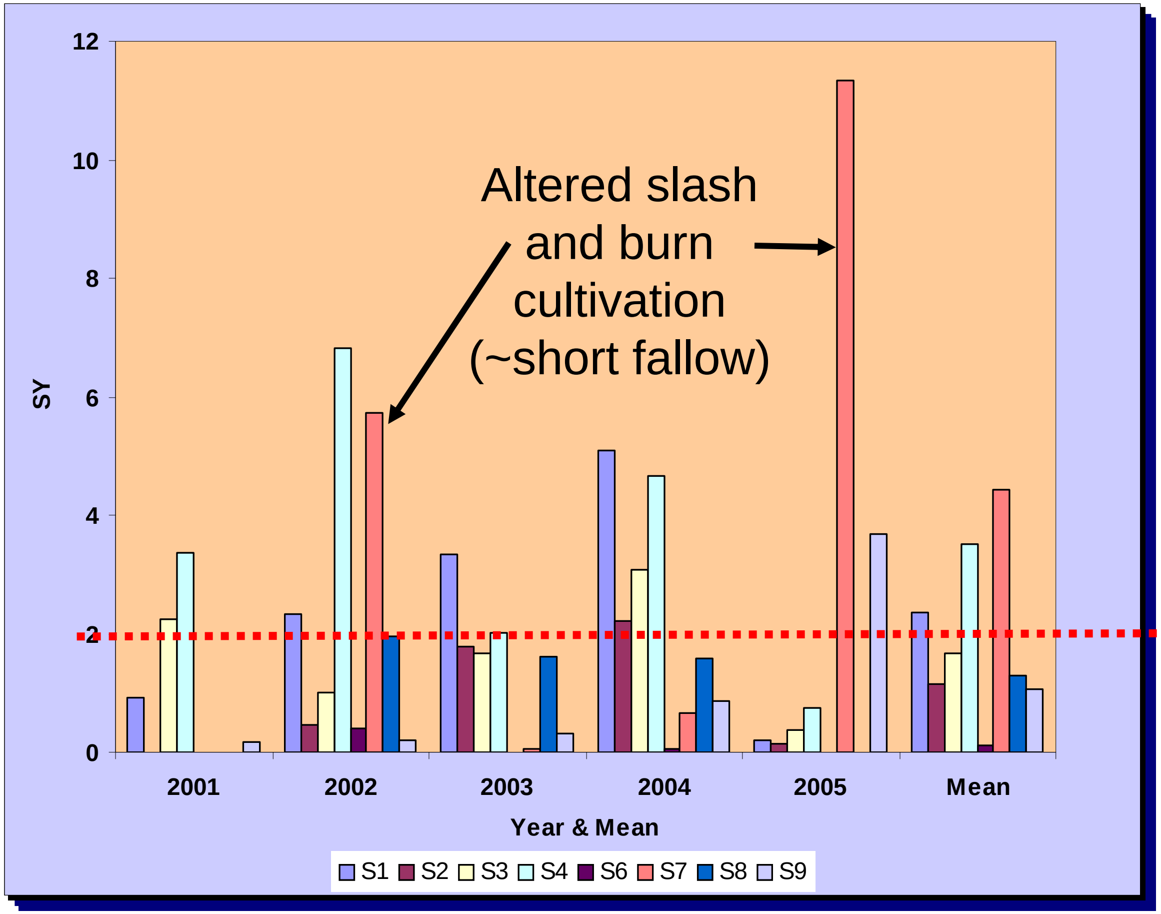
Typical **MSEC** hydrological station

Automatic INDIAN sampler



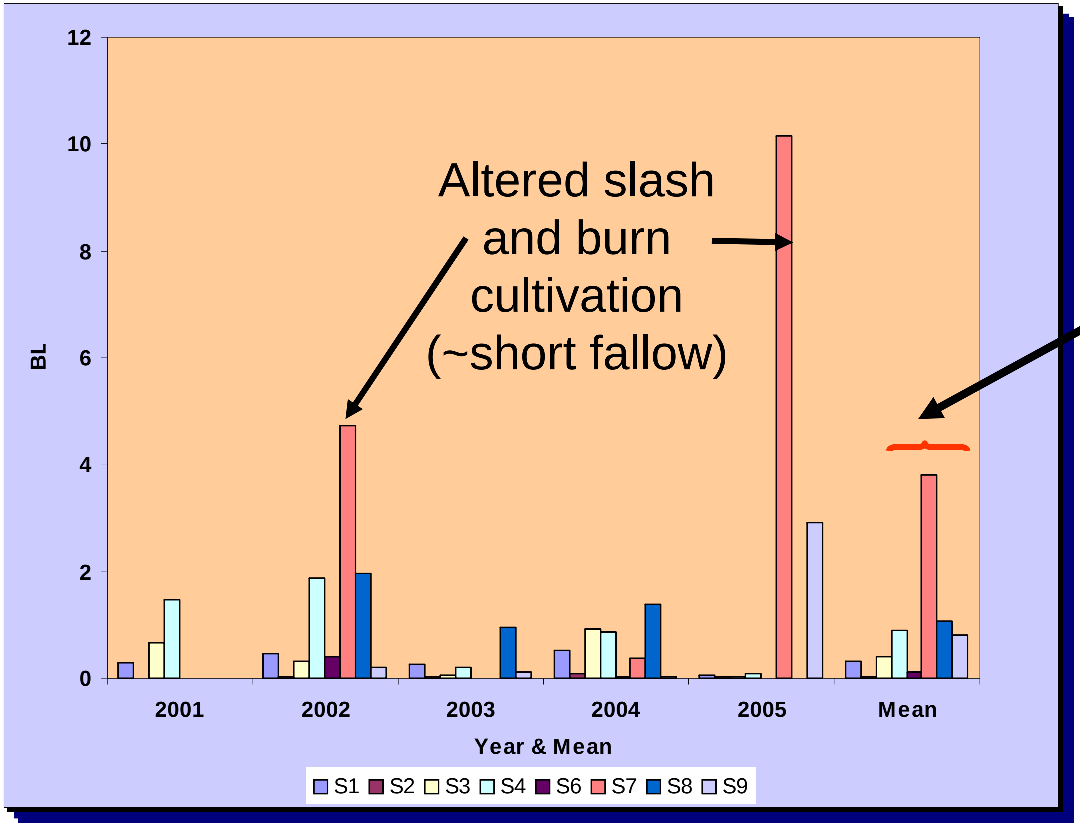
Shaft Encoder with Data Logger THALIMEDES

Total sediment loads (Mg ha^{-1} yr^{-1}) **2001-2005**



- Sediment yields exceed 'tolerable losses' (2 Mg ha-1 yr-1) for most catchments except for those under improved fallow and no tillage conditions

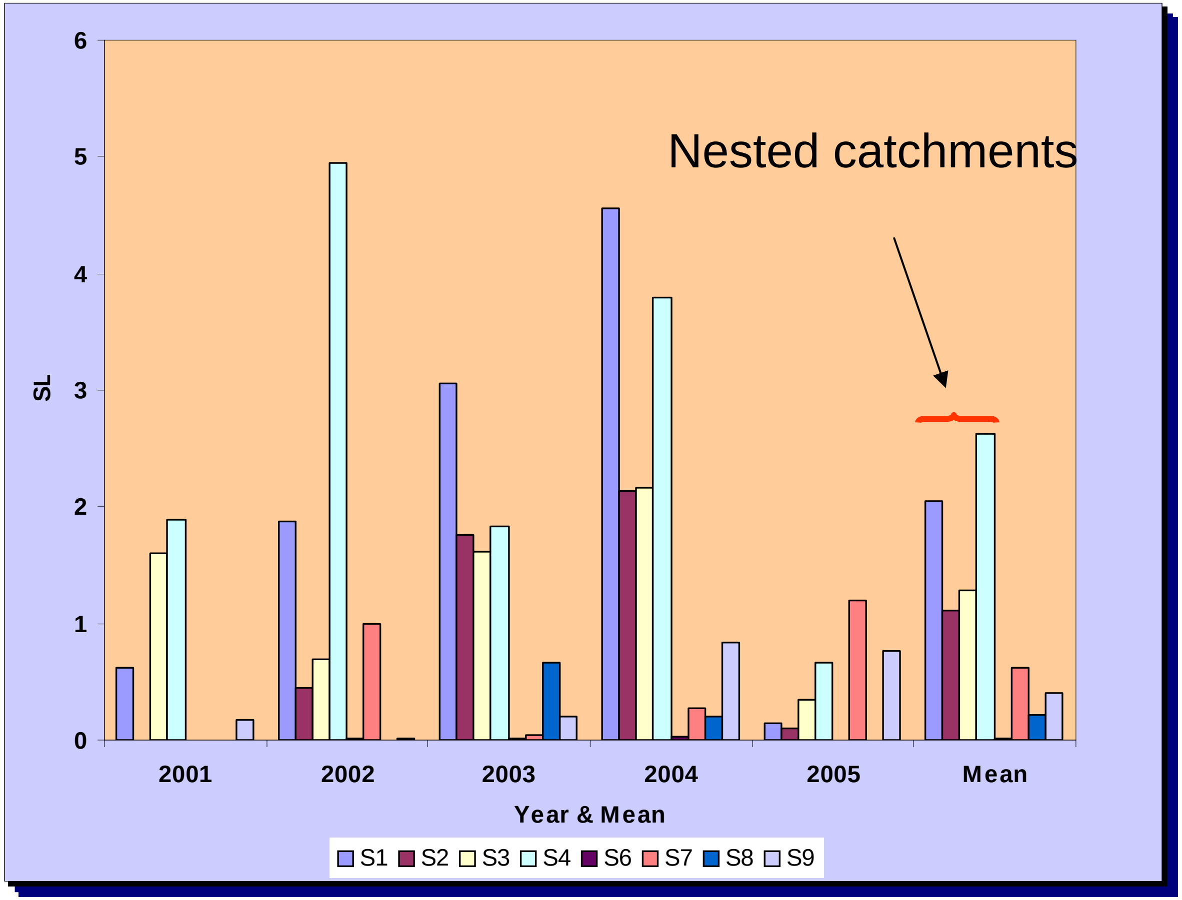
Bed load (Mg ha-1 yr-1) **2001-2005**



- Higher bed load from the hillslope catchments (with ephemeral flow)

Oloth et al. (2006)

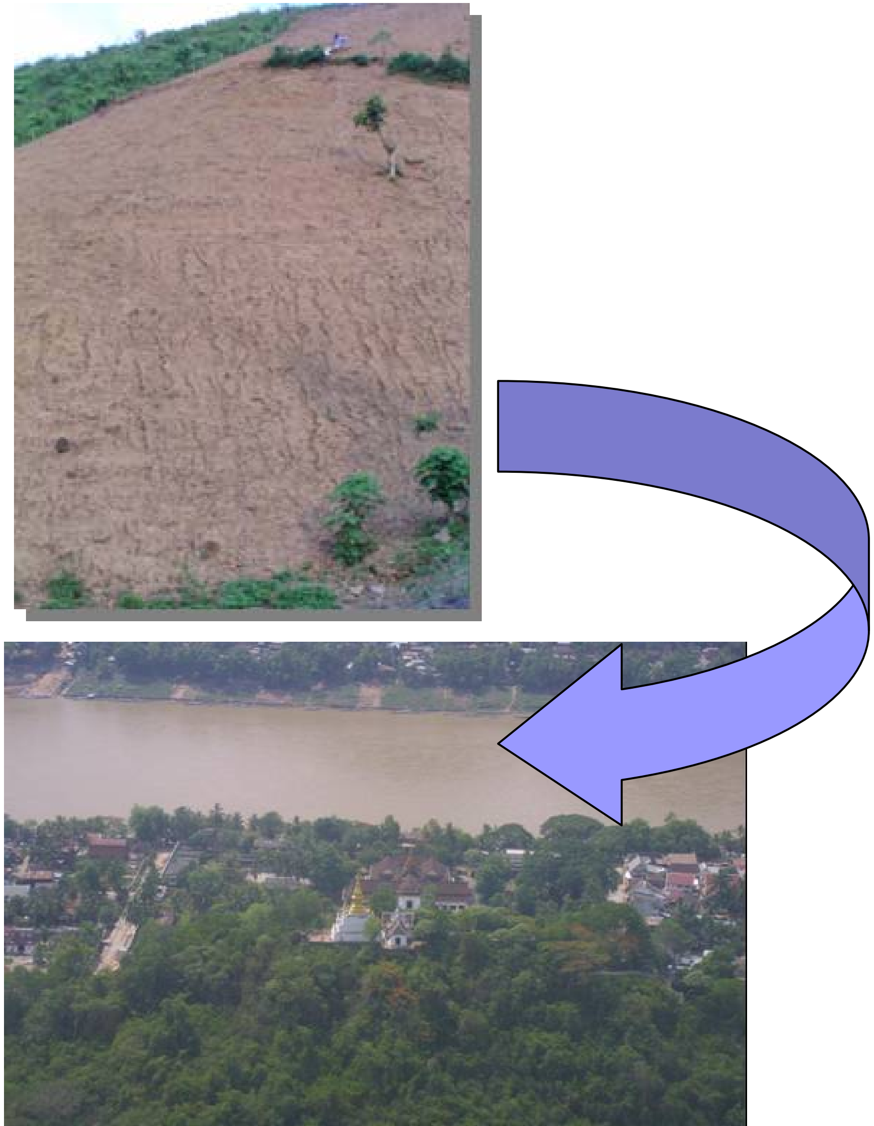
Suspended load (Mg ha^{-1} yr^{-1}) **2001-2005**



- Higher suspended load from the nested catchments (along the permanent stream)

Oloth et al. (2006)

Off-site effects



- 53 Mg bed load sediments trapped each year in average in the main weir would have normally been trapped in downstream irrigation canals.
- More important are the 156 Mg exported annually from the catchment, in the form of suspended sediments that could potentially migrate down to the Mekong.

Modelling sediment generation within small catchments

1) Statistical modeling approach

Objective

- Study the relation between several variables (annual runoff, suspended sediment load, bed load) and selected environmental factors (soil characteristics, land cover types…) using correlation matrix and stepwise linear regression analysis.

Main factors influencing runoff and soil losses

Explained variables	Linear regression equation	R^2 (n=36)
Runoff coefficient	**log(Rc)= 2.117- 0.033 Slp – 0.007 Impfw**	**0.83**
Suspended load	**log(SL)= 0.473- 0.028 Slp + 0.014 Tac – 0.027 Ttree**	**0.64**
Bed load	**Bd= 0.575 + 0.132 Jt – 0.014 Fw**	**0.77**
Sediment yield	**log(SY)= -0.345 + 0.016 Tac – 0.019 Impfw**	**0.49**

FACTORS ACCELERATING WATER AND SOIL LOSSES

+Ttac: Annual crops (upland rice, Job's tear, maize, sesame) (%)

+ Jt: Job's tear (*Coix lacryma-jobi* L.) (%)

FACTORS LIMITING WATER AND SOIL LOSSES

-Slp: mean stream slope (%)

-Ttree: Secondary forest and teak plantations (%)

- Fw: Fallow (%)

- Impfw: Improved fallow (%)

➔ Annual crops are the major cause of soil losses from the upland catchments.

2) Dynamic modeling for linear erosion initiation and development

Objective

- Our main objective was to estimate the impact of expected land-use and climate changes on linear erosion.

In brief

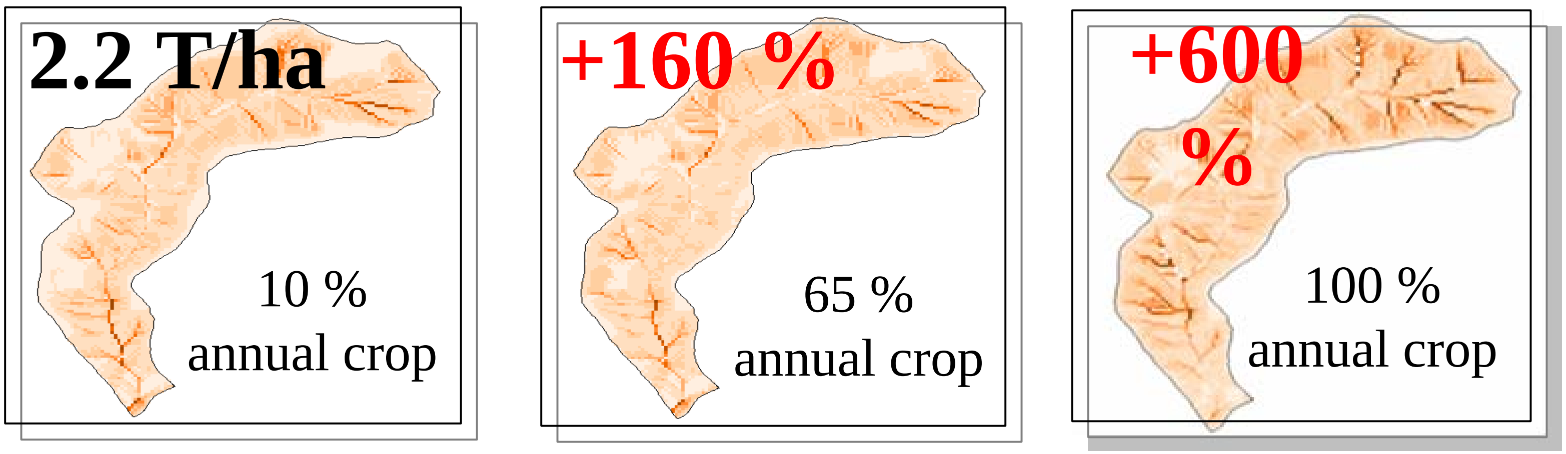
Distributed physically-based model

- Field observations of the formation and the development of linear erosion features were compared to flow velocity estimations from **LISEM** (De Roo, et al., 1996), a surface water routing algorithm developed at Utrecht University.

- The water routing algorithm was calibrated using the water and the sediment hydrographs observed at the watershed outlet.

De Roo, A.P.J., Wesseling, C.G. and Ritsema, C.J. 1996. **LISEM**: a single event physically based hydrologic and soil erosion model for drainage basins. I: theory, input and output. hydrological processes 10 (8): 1107–1117.

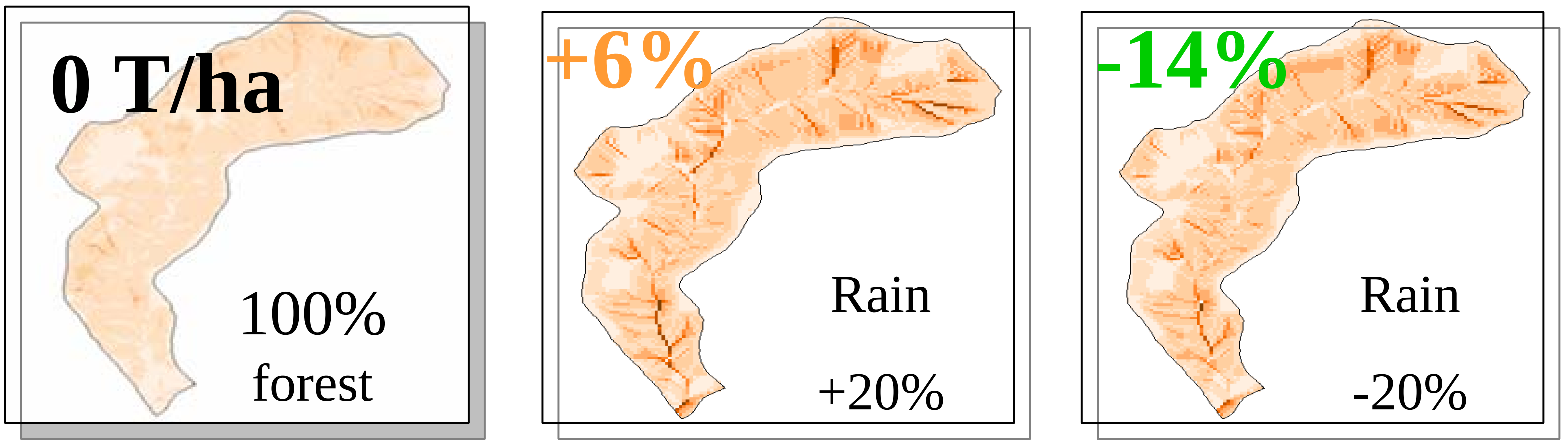
Scenario testing: Impact of land use changes on linear erosion



- Using this simulation tool, an increase of the percentage of land under cultivation from 10% to 100% resulted in 600% increase in linear erosion.

Modified from Chaplot et al. (2005), CATENA

Scenario testing: Impact of climate changes on linear erosion



- The tested scenarios of climate changes had less impact on linear erosion. A 20% increase of the annual rainfall depth generates an increase of only 6% of sediment load.

Modified from Chaplot et al. (2005), CATENA

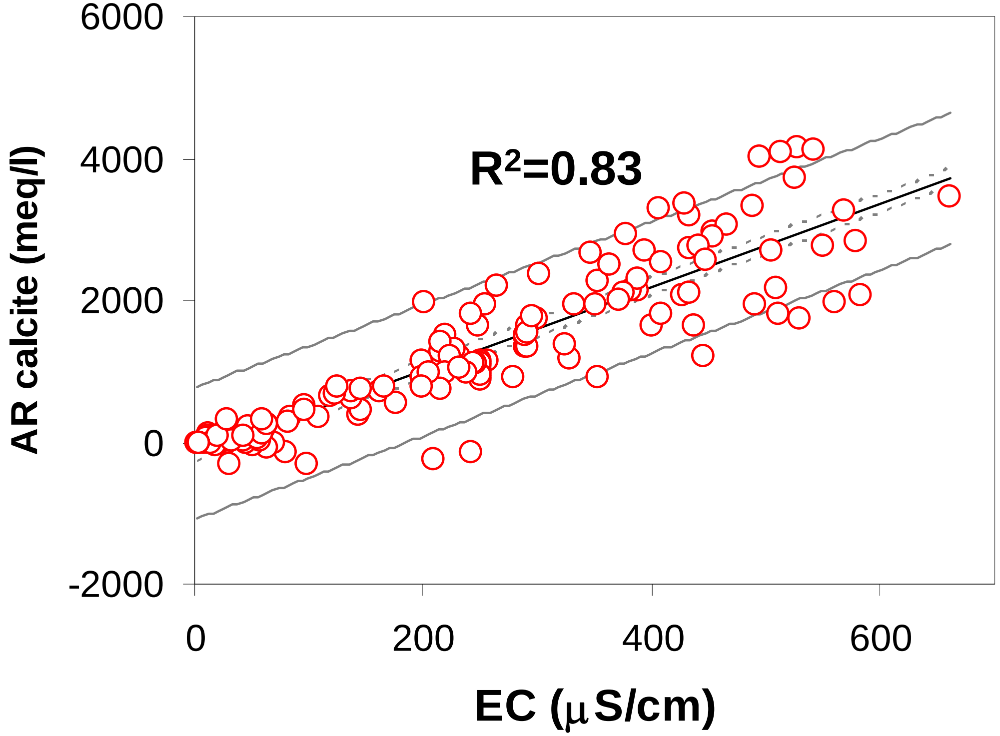
3) Preliminary results from a tracer-based mixing model approach

International Water Management Institute

Institut de recherche pour le développement

Main objectives

- Understanding flood and sediment generation processes at the small catchment scale.
- Quantifying overland flow and groundwater contributions to floods.

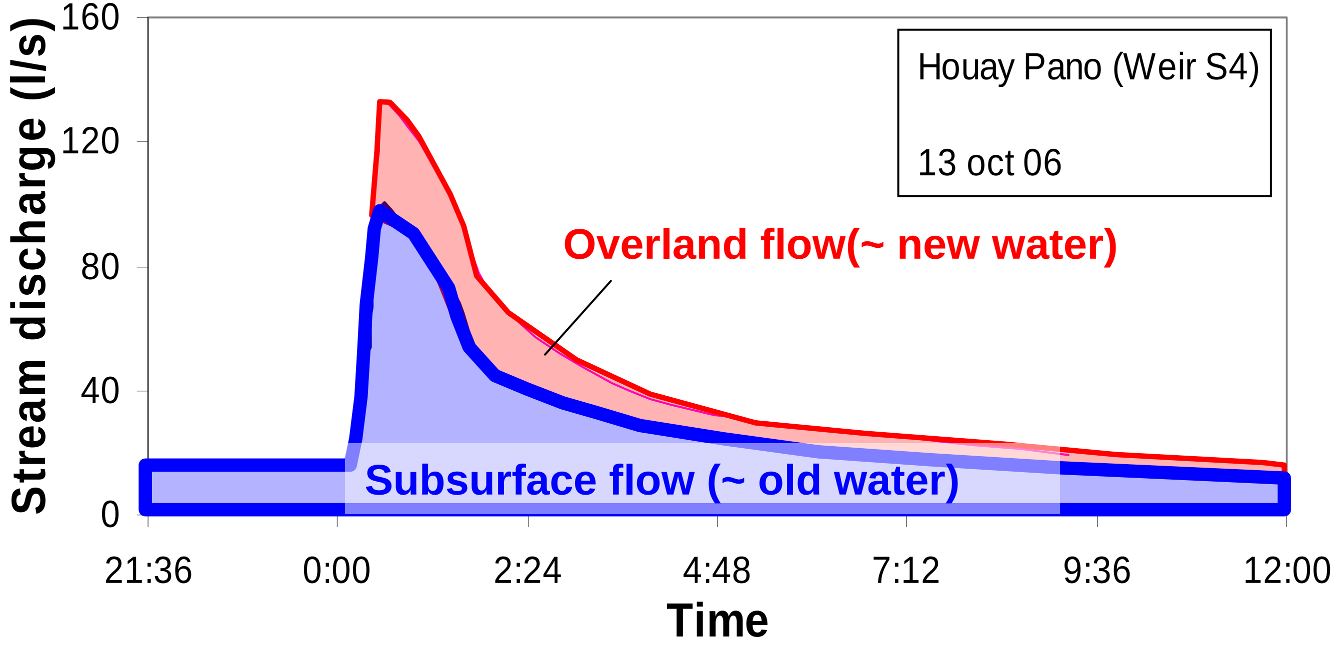


- Electrical conductivity (EC) of waters (i.e. rain, overland flow and groundwater, stream) within our study area was very well correlated to residual alkalinity, a reference conservative parameter (Ribolzi et al., 1996).

➔ Use EC for tracer-based hydrograph separations in two components: **overland flow** (~precipitated rainwater) and **subsurface flow** (~pre-stored ground and soil water)

Ribolzi, O., Vallès, V., Bariac, T., 1996 - Comparison of hydrograph deconvolutions using residual alkalinity, chloride and oxygen 18 as hydrochemical tracers. Water Resources Research, 32 (4): 1051-1059.

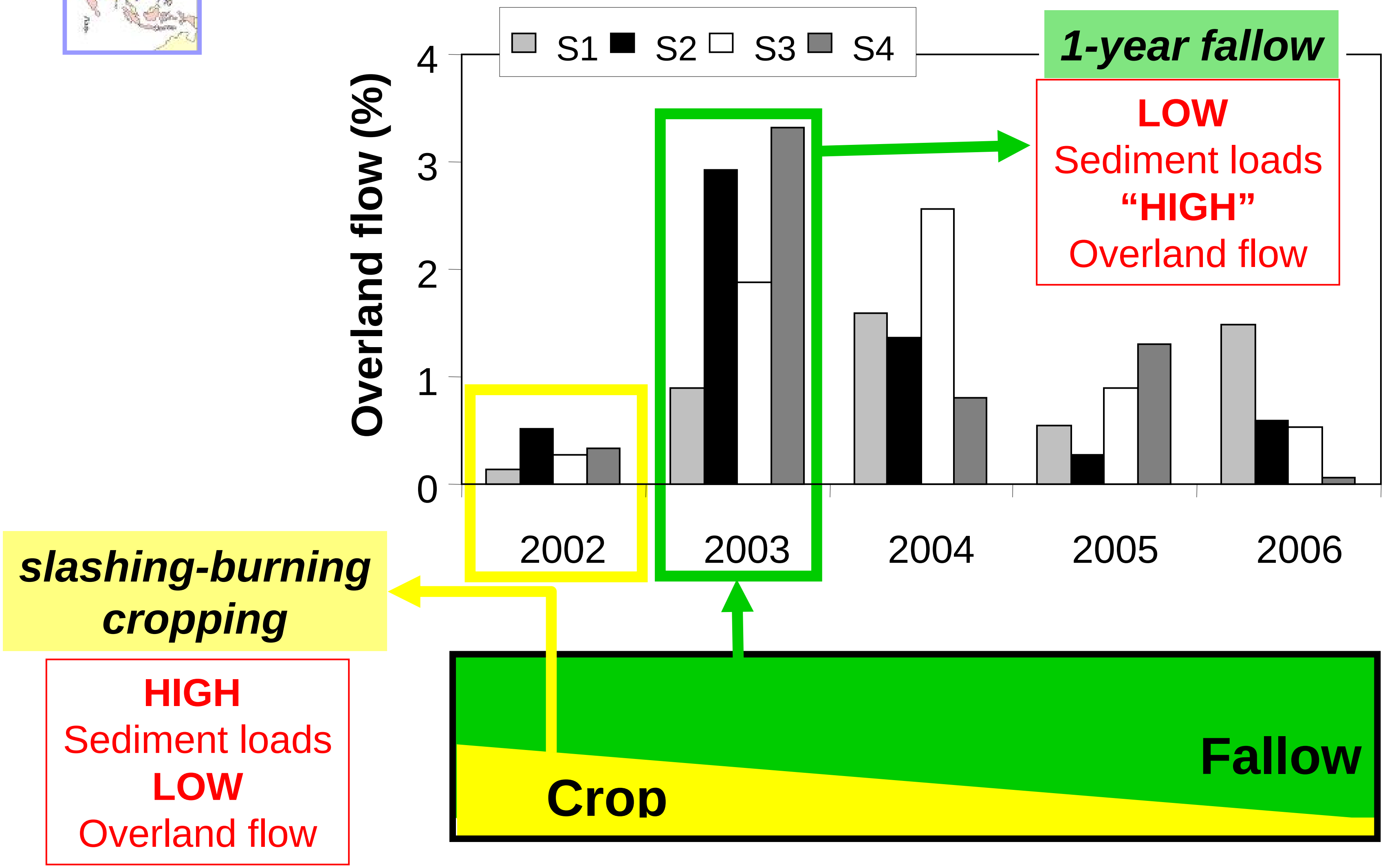
EC-based hydrograph separation



- For the study period (2002-2006), the mean contribution of overland flow was only **11 ± 9 %**
- Subsurface pre-event water was the main contributor with a stormflow contribution of **89 ± 9%**

Ribolzi, O., Thiébaux, J.P., Sengtaheuanghoung, O., Bourdon, B., Chaplot, V., de Rouw, A., Huon, S., Mouche, E., Pierret, A., Briquet, J.P., Marchant, P. Robain, H., Soulileuth, B., Valentin, C. - Effect of fallow regrowth on stream water yield in a headwater catchment submitted to shifting cultivation, Northern Lao PDR. The Lao Journal of Agriculture and Forestry (ongoing).
Ribolzi, O., Vallès, V., Bariac, T., 1996 - Comparison of hydrograph deconvolutions using residual alkalinity, chloride and oxygen 18 as hydrochemical tracers. Water Resources Research, 32 (4): 1051-1059.

Annual overland flow contribution



Ribolzi, O., Thiébaux, J.P., Sengtaheuanghoung, O., Bourdon, B., Chaplot, V., de Rouw, A., Huon, S., Mouche, E., Pierret, A., Briquet, J.P., Marchant, P. Robain, H., Soulileuth, B., Valentin, C. - Effect of fallow regrowth on stream water yield in a headwater catchment submitted to shifting cultivation, Northern Lao PDR. The Lao Journal of Agriculture and Forestry (ongoing).

Conclusions

Stream-groundwaters interactions is a key point for the understanding of sediment generation from the uplands:

- Groundwater has extremely low sediment concentrations and might be described as "**hungry water**", following the terminology of Mathias Kondolf, and hence contribute to sediment generation (i.e. gully erosion and stream bank falling along seepage faces…).

- Groundwater contribution during floods is responsible for a massive **dilution effect** of sediment-rich overland flow waters from the hillslopes.

➔ groundwater inflows must be addressed in modelling sediment loads

4) Darcy multi-domain approach for integrated surface/subsurface in a 3D distributed hydrologic model

➔ Potential to upscale

ONDINE project

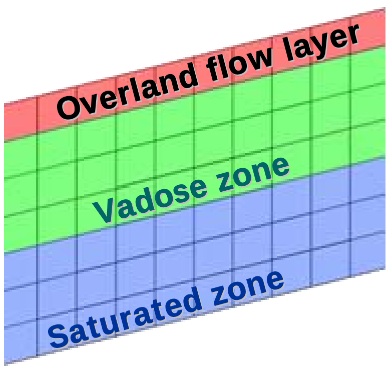
Impact **O**f la**ND** use changes on flood generat**I**o**N** Study combining num**E**rical and real catchments

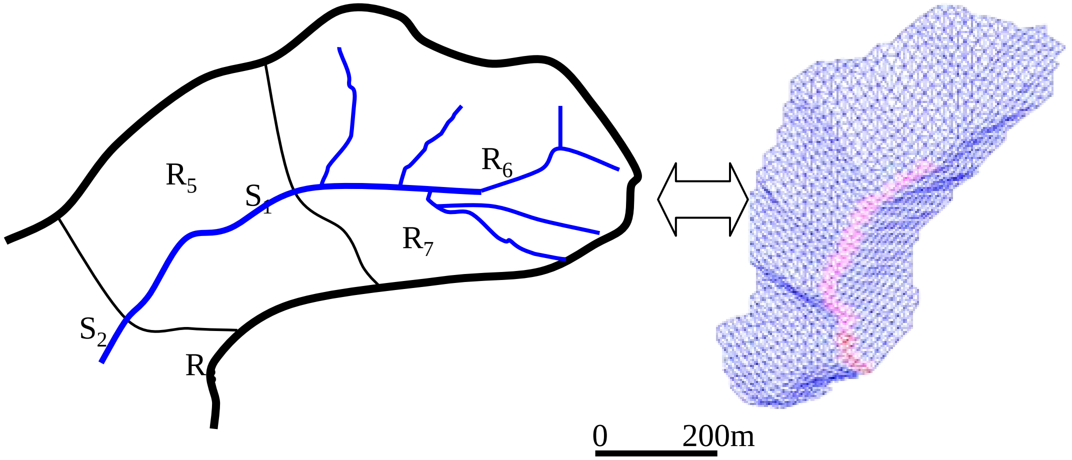
- Main objective: understanding and modelling the partitions and mixing processes of groundwater and overland flows from 1-m^2 to the small catchment scale.

Ambroise B, 1999 – La dynamique du cycle de l’eau dans un bassin versant – Processus, facteurs, modèles. EGA, Bucarest.

In brief

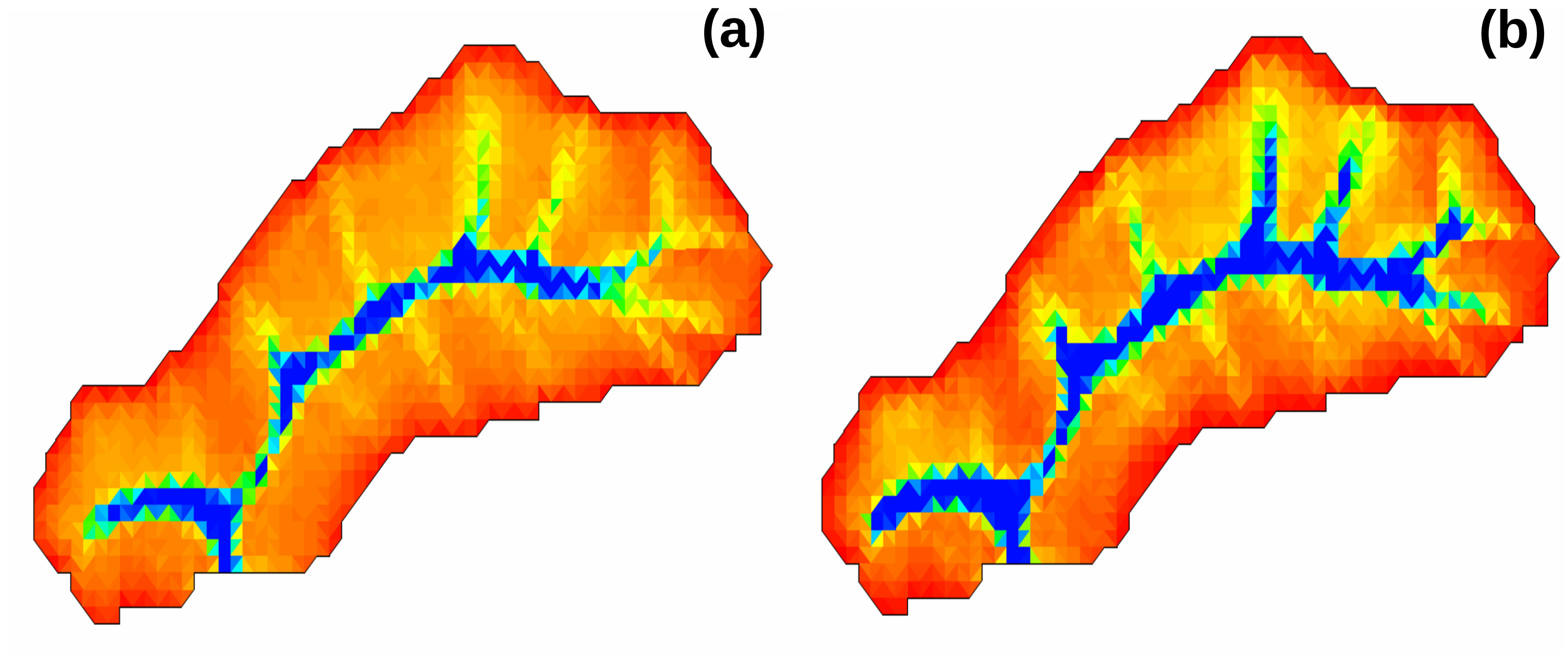
- Fully coupled surface/subsurface 3D model in which the **diffusive wave approximation** is used to simulate runoff (Weill et al., in press).
- The water dynamic in three physical domains: i.e. soil surface (overland flow “layer”), vadose zone and saturated zone, is described through a **single Darcy nonlinear equation** with domain-dependent parameters.
- This multi-domain equation is solved with Mixed Hybrid Finite Element Formulation. The time discretisation is implicit and the nonlinear equations are solved with a sequential iterative Picard scheme.





Weill S. Mouche E., Patin J. - A generalized Richard’s Equation for Surface/Subsurface Modelling. J. of Hydrology (in press)

Soil surface saturation maps: (a) during the dry season (1st March) and during the rainy season (1st August).



- Extension of groundwater contributing area along the main flow path during the wet season

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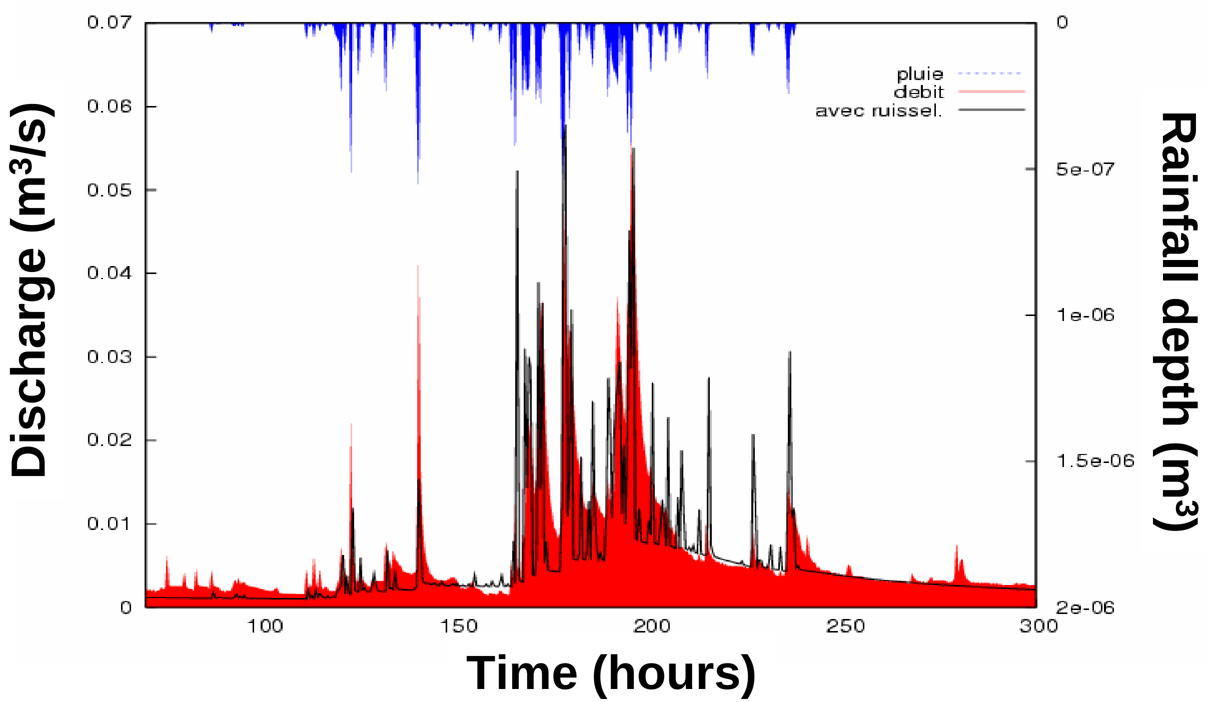
Staub M. 2007, Amélioration de la compréhension des phénomènes hydrologiques dans un bassin versant du Sud Est asiatique sous régime de mousson. Rapport de fin d'études, ENGEES, promotion Allier.

Measured and simulated discharge at the outlet of the Houay Pano catchment



- First simulation runs show a good agreement between observed and simulated discharge

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Staub M. 2007, Amélioration de la compréhension des phénomènes hydrologiques dans un bassin versant du Sud Est asiatique sous régime de mousson. Rapport de fin d'études, ENGEES, promotion Allier.

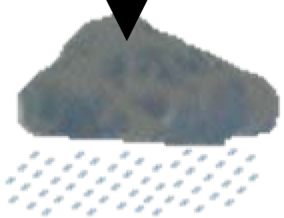
Conclusion and perspectives

Conclusions

- Environmental services, as production of clean water, from uplands should be better acknowledged and rewarded.
- Long term catchment studies are invaluable tools
  - To monitor the impacts of land use changes upon soil losses and water quality
  - To test innovative conservation practices.
- Scale considerations are of fundamental importance when assessing the impact of land use (and climate) changes as they indicate whether a land use upstream may affect a water downstream.
- Modelling runoff and sediment generation from upland areas is a difficult task. They depend on many interactive factors and processes often varying in time and space.

Support the MRC modelling platform to **validate** the current SVATS approach at the Mekong scale

GIEC climate forecasting (➔ year 2100)



Mixed
Land use and climate change
scenarios

Up scaling approach

Cast3M numerical platform
(www.Cast3M.fr)
3D distributed modelling
surface and groundwater flows

GRID size

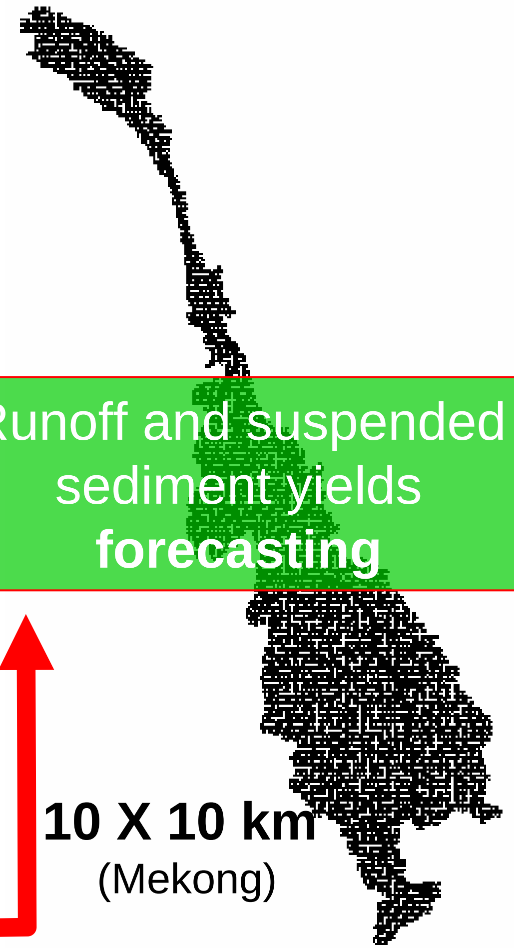
10 X 10 m
(e.g. Houay pano)

100 X 100 m
(e.g. Houay Xong)

1 X 1 km
(main tributaries)

10 X 10 km
(Mekong)

Runoff and suspended sediment yields **forecasting**



Mekong 1/12° (5 arc-minutes) resolution stream network.

Costa-Cabral, M.C., Richey, J.E., Goteti, G., Lettenmaier, D.P., Feldkotter, Anond Snidvongs, C., 2008 – Landscape structure and use, climate, and water movement in the Mekong River basin. Hydrol. Process. 22, 1731–1746, DOI: 10.1002/hyp.6740.

MSEC

Thanks for your attention !

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