Criteria for the choice of flood routing methods for natural channels with overbank flow

by

Roger MOUSSA

Laboratoire d'étude des Interactions Sol - Agrosystème - Hydrosystème
UMR LISAH ENSA-INRA-IRD, Montpellier

Context : Flood events

In the world

More than 50 % of the damages caused by natural disasters are due to floods : on average 20 000 deaths/year.

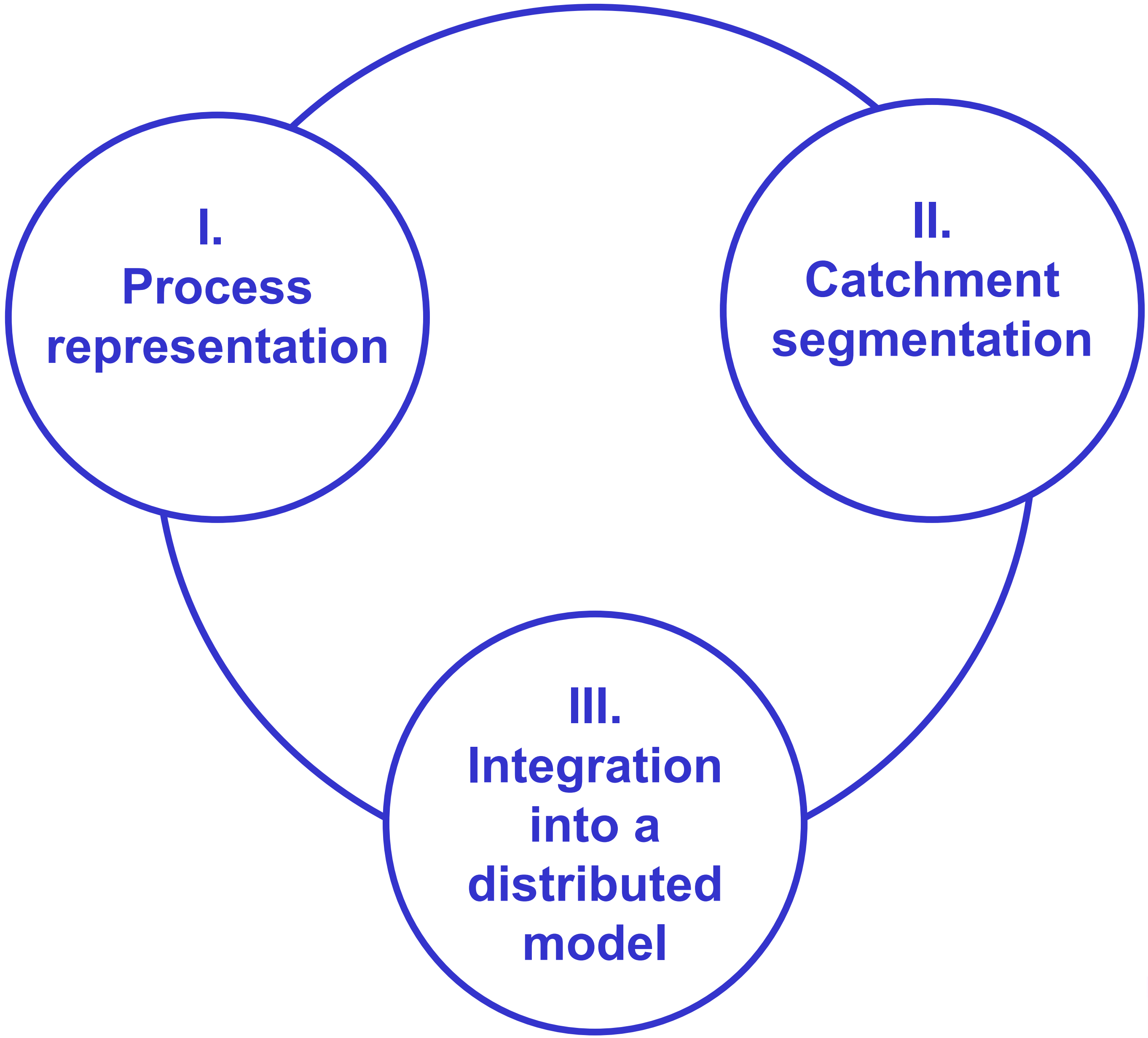
In France

Over a 160 000 km long river network, an area of 22 000 km² is recognised as very prone to flooding: 7 600 villages and 2 000 000 residents are concerned.

Objectives

Develop a spatially distributed hydrological modelling tool to simulate flood events on natural and farmed catchments.

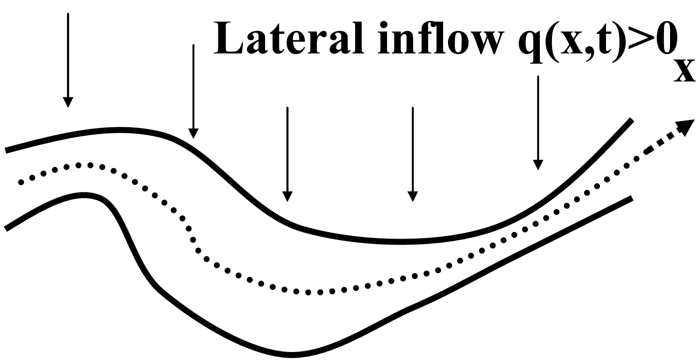
Spatially distributed hydrological modelling of flood events on natural and farmed catchments



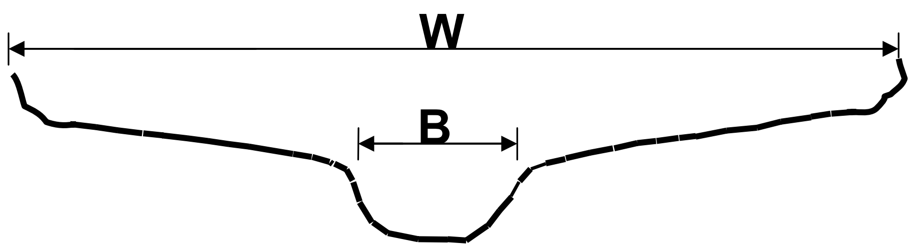
I. Flood routing

Context

Flood routing in natural channels is governed by the Barré de Saint-Venant (1871) equations.



Longitudinal section



Lateral section

Saint-Venant system

Equation of mass conservation

$$\frac{\partial y}{\partial t} + y\frac{\partial V}{\partial x} + V\frac{\partial y}{\partial x} = 0$$

Terms I II III

Equation of energy conservation

$$\frac{\partial V}{\partial t} + V\frac{\partial V}{\partial x} + g\frac{\partial y}{\partial x} + g\left(S_f - S\right) = 0$$

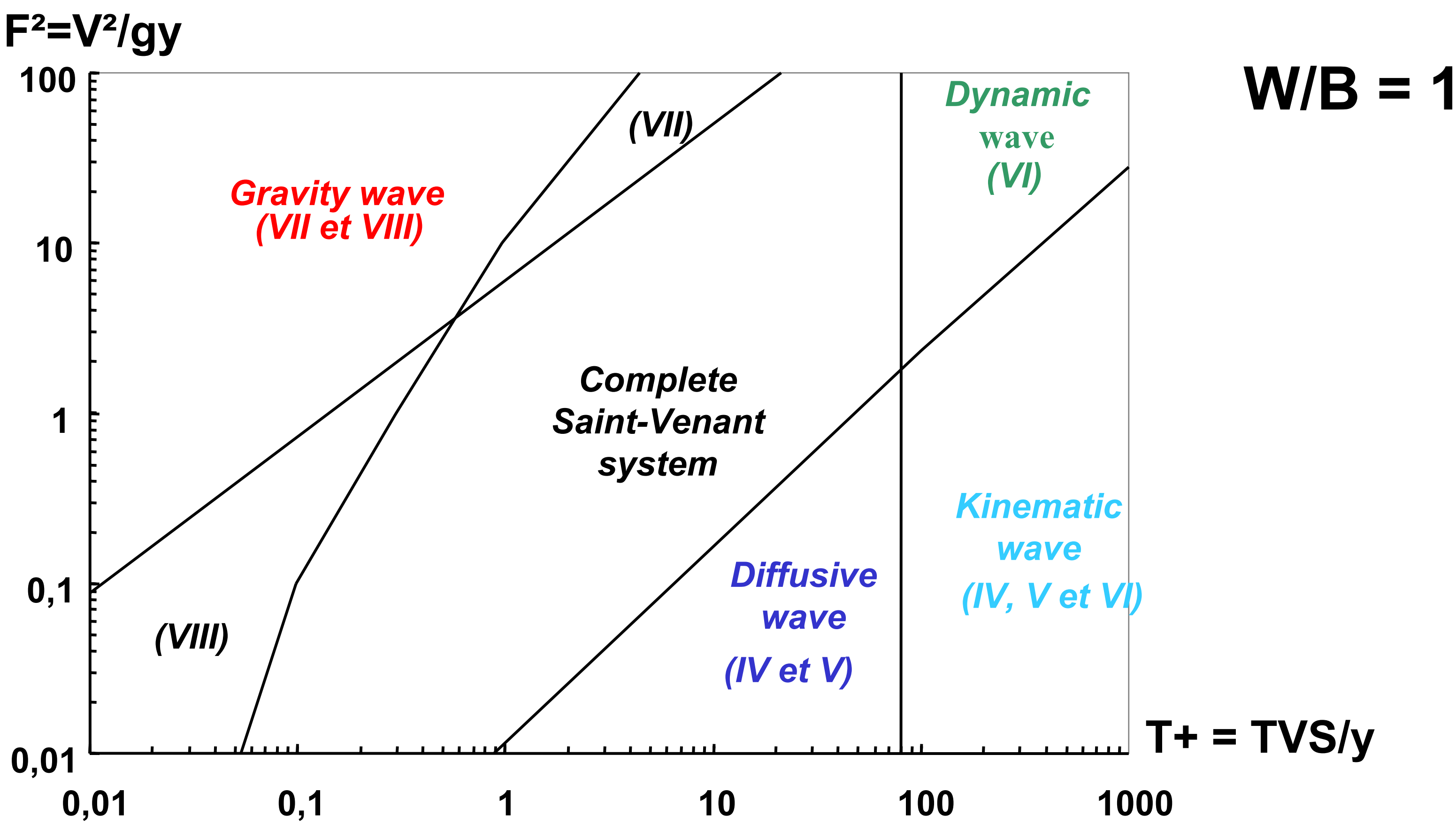
Terms IV V VI VII VIII

I.1. Approximation zones of the Saint-Venant system

(Moussa and Bocquillon, 1996, J. Hydrol.)

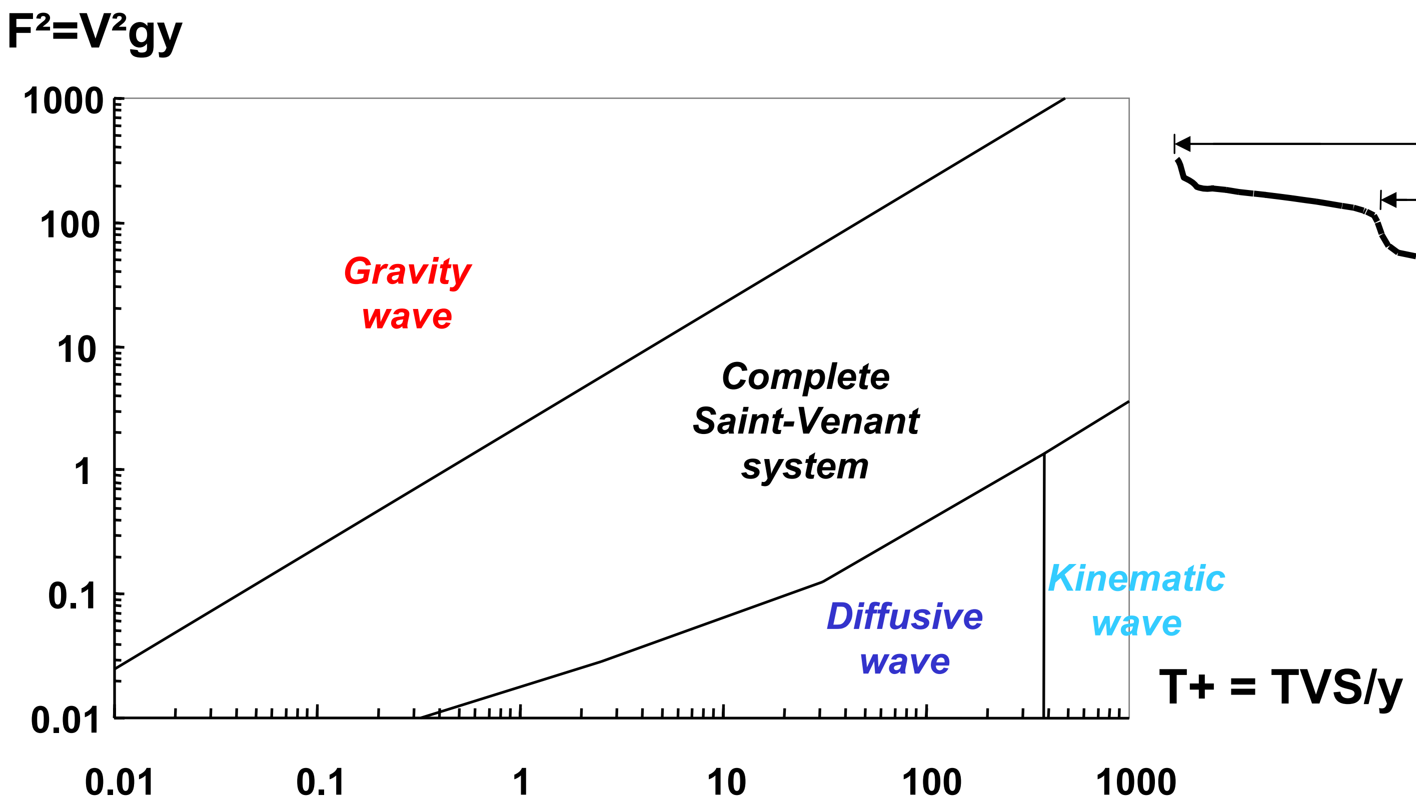
Propagation of a sinusoidal function :

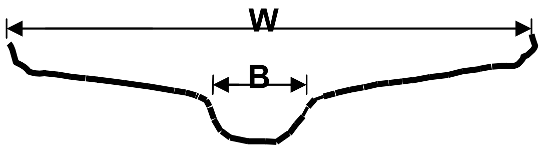
- **Froude number (F^2)**
- **a characteristic time of the hydrograph**



Approximation zones of the Saint-Venant system with overbank flow : example W/B = 20

(Moussa and Bocquillon, 2000, Hydrol. Earth System Sc.)





In some hydrological models, the flood routing model can be used outside its application domain.

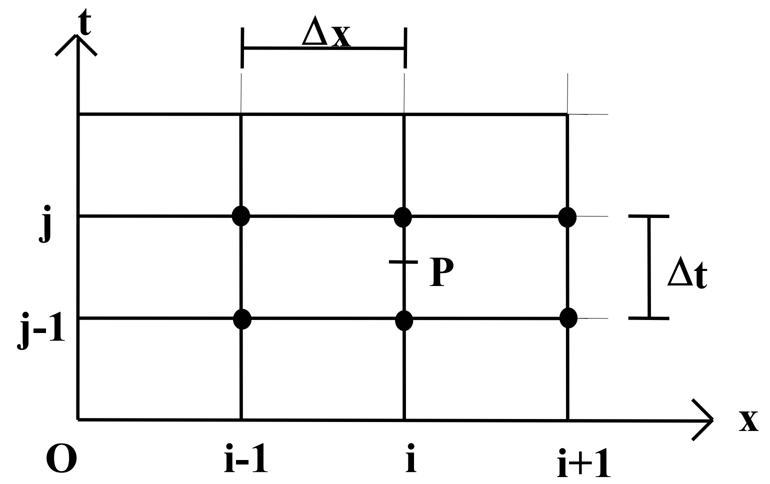
ex : kinematic wave in KINEROS, TOPOG, TOPMODEL, LISEM, QPBRRM.

I.2. Numerical resolution of the diffusive wave model

In general :

- resolution using finite differences schemes

- problems of numerical stability and convergence



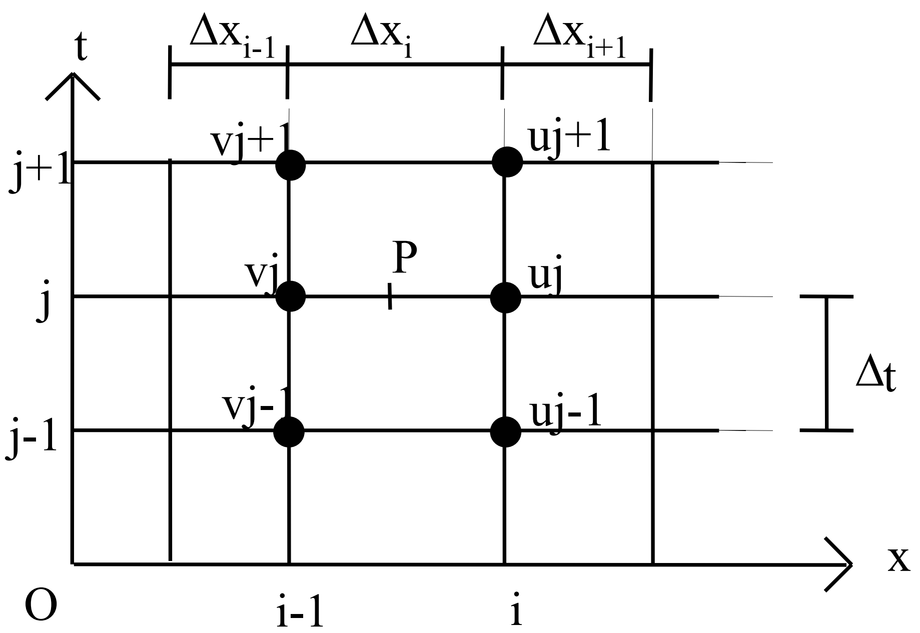
Case where celerity and diffusivity can be considered constant :

Hayami (1951) analytical solution.

I.2. Development of new numerical scheme to resolve the diffusive wave equation in flood routing applications over treelike channels

- a scheme that enables the use of variable spatial steps *(Moussa and Bocquillon, 1996, Hydrol. Pro.).*

- a scheme based on the fractional step method that enables to separate convection and diffusion *(Moussa and Bocquillon, 2001, J. Hydrol. Eng.).*



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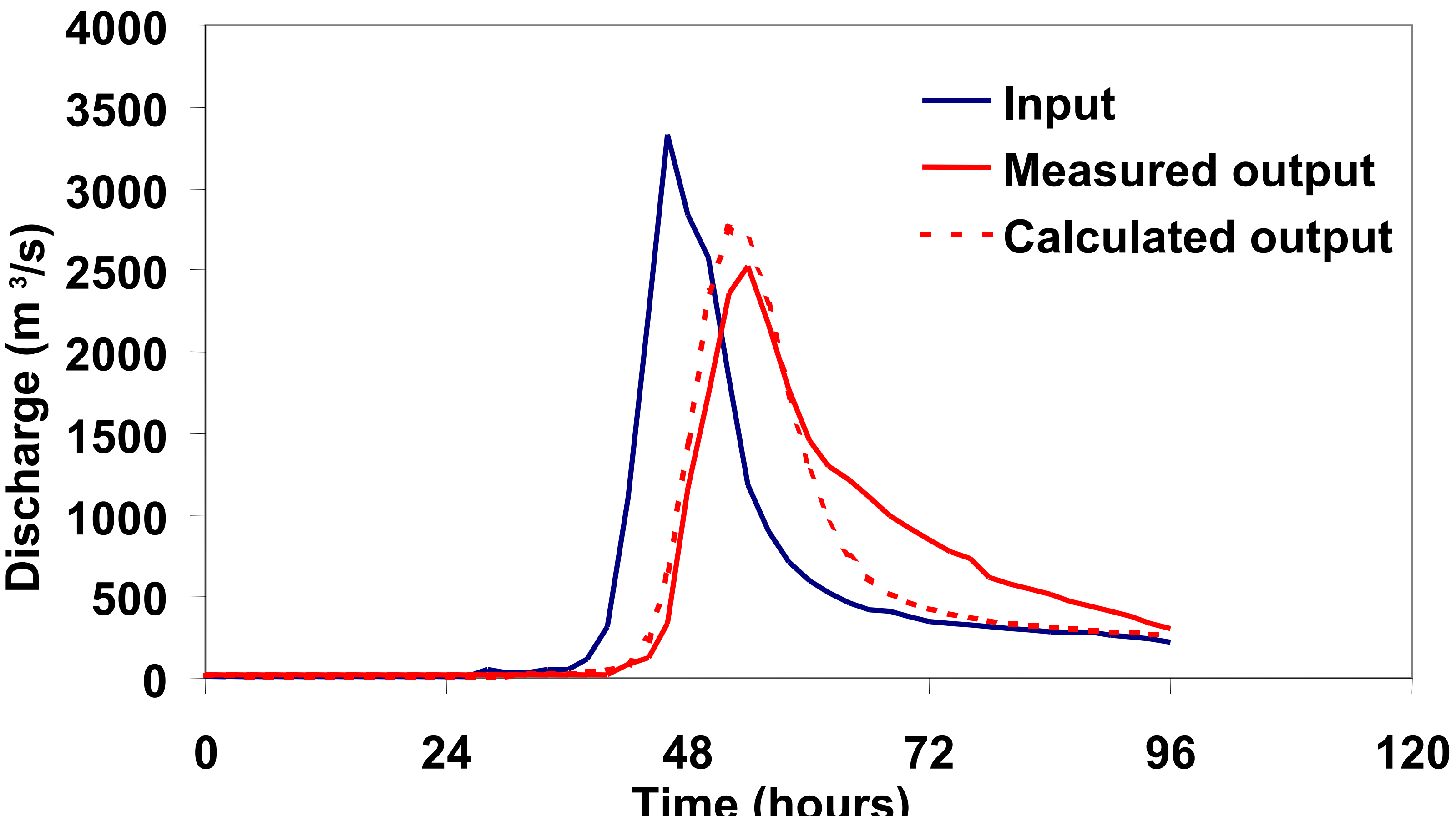
Application : flood prevision on the Loire river
(between Grangent and Feurs : distance 43 km)

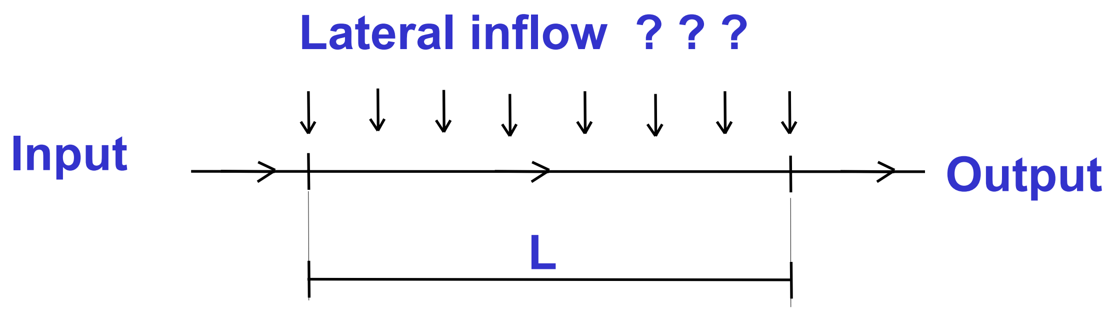
Loire : Event of 20 - 23 September 1980



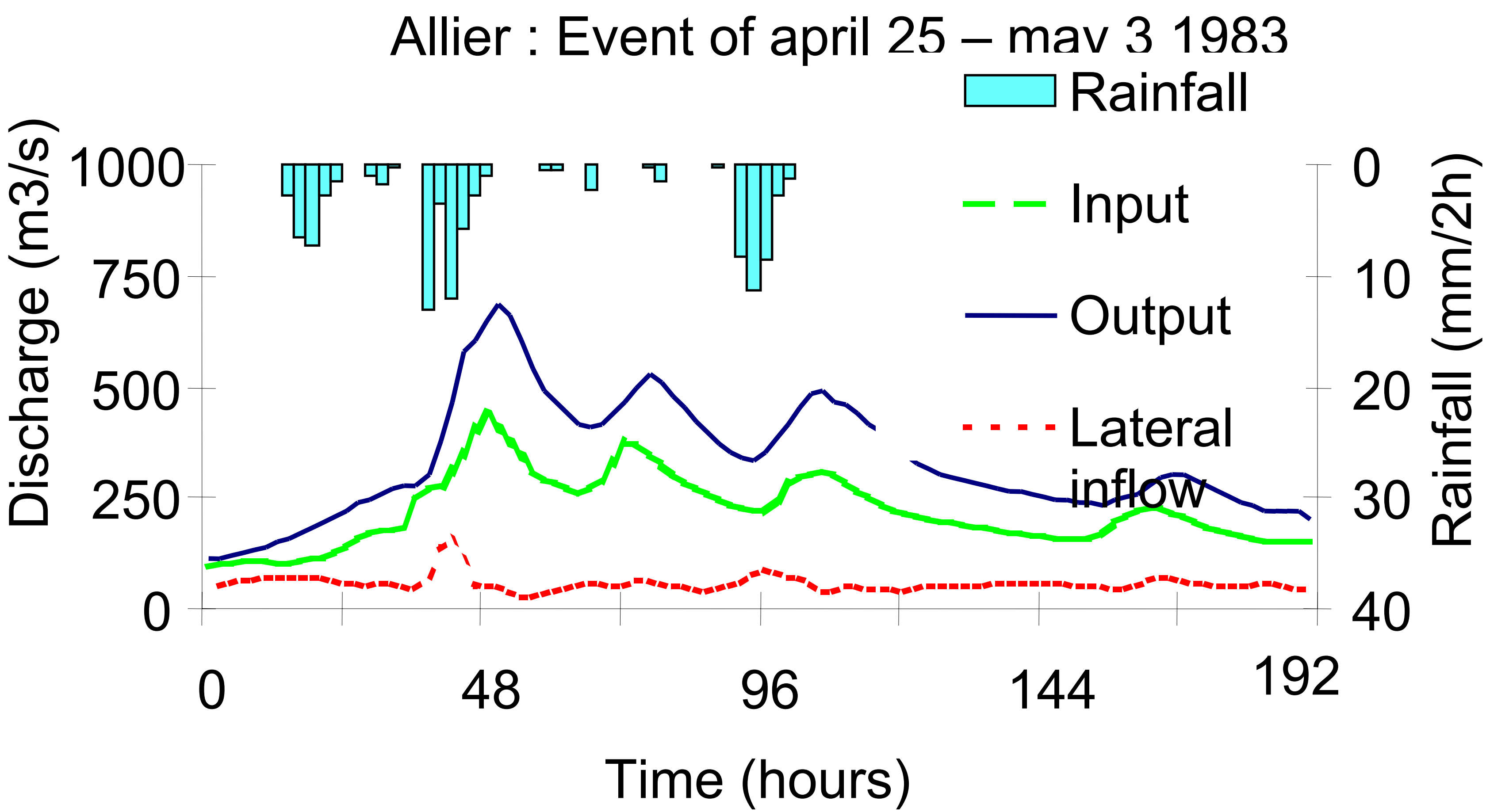
I.3. Development of a new scheme for the analytic resolution of the diffusive wave equation *(Moussa, 1996, Hydrol. Pro.)*

- Taking into account uniformly distributed lateral inputs or outputs.

- Identification of the lateral inflow by input/ouput deconvolution.

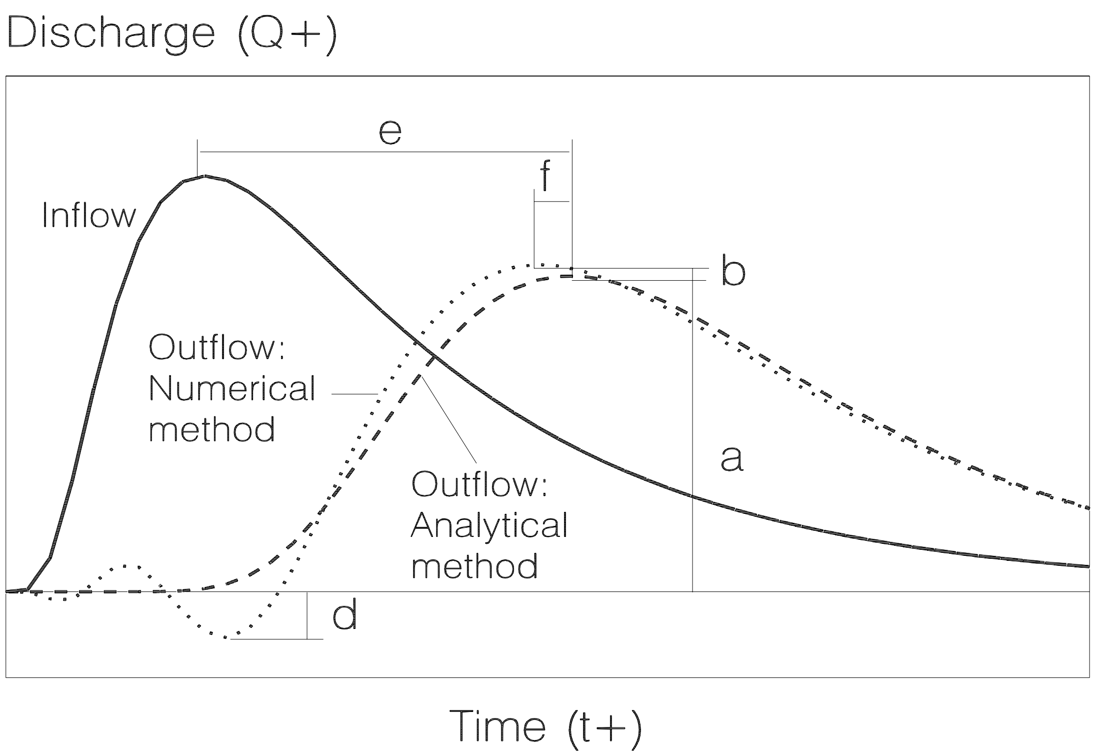


Example of application on the Allier river between Prades (1350 km² catchment) and Vieille Brioude (2269 km² catchment) distant of 42 km.
(data source : EPALA)



I.4. Development of a method to estimate numerical errors

(Moussa and Bocquillon, 1996, J. Hydrol.)



Three types of error :

eQ = b/a
eT = f/e
eOsc = d/a

The analysis enables the choice of the spatial increment Δx and the time step Δt that minimise the errors.

Applications

France

- Roujan (1 km²)
- Gardon d'Anduze (542 km²)
- Allier (2269 km²)
- Loire (4978 km²)
- Moselle (9400 km²)

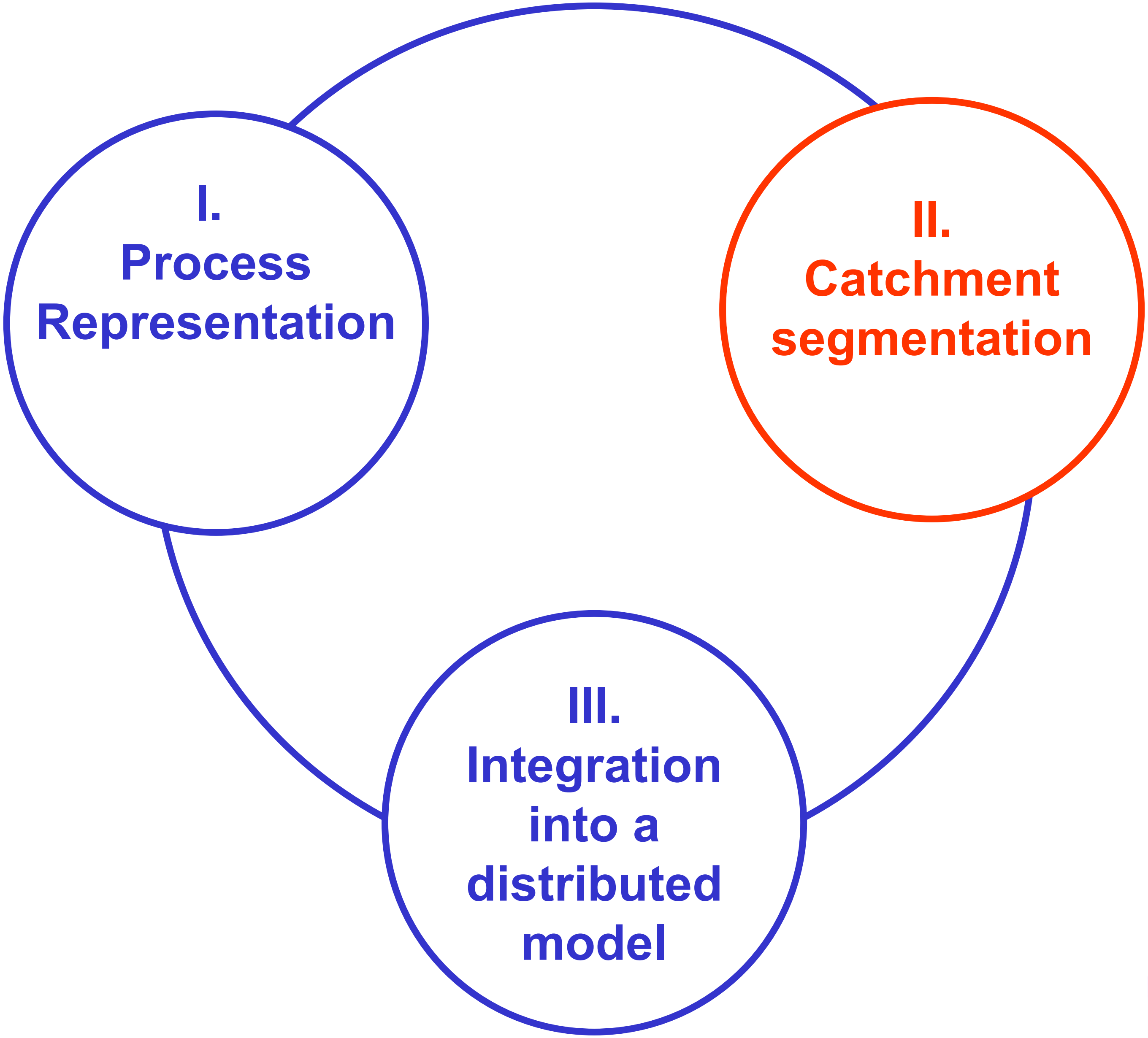
Canada

The diffusive wave equation resolution scheme is integrated in the Hydrotel model and has been used on several Canadian catchments (de 100 à 10000 km²) *(Fortin et al., 1995, RSE; 2001a, 2001b, JHE).*

Argentina

Salado (1500 km²) *(MSc. Del Valle Morresi, 2001).*

Spatially distributed hydrological modelling of flood events on natural and farmed catchments



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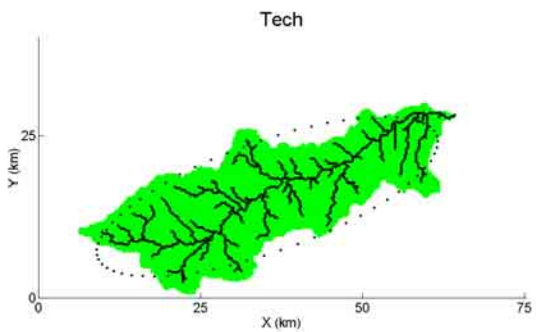
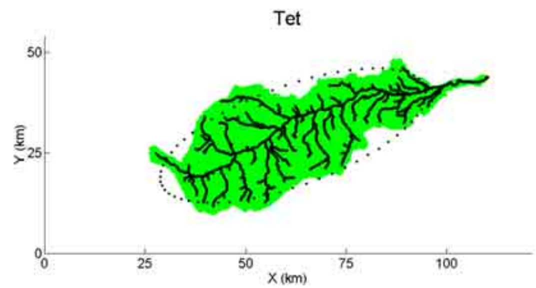
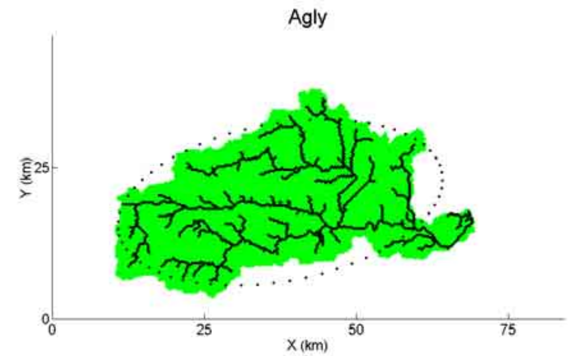
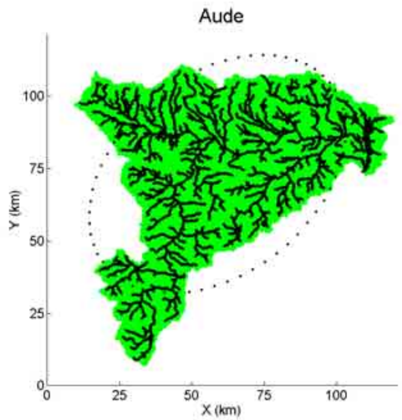
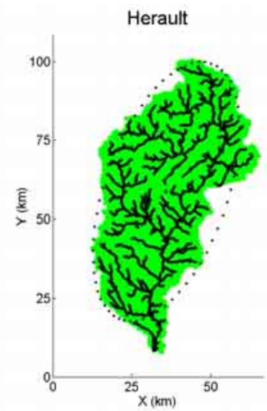
The study site : Tech, Têt, Agly, Aude, Orb, Hérault and Vidourle catchments (738 to 5346 km²)

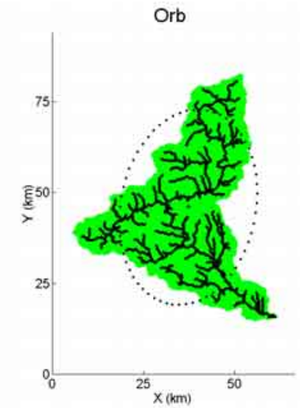


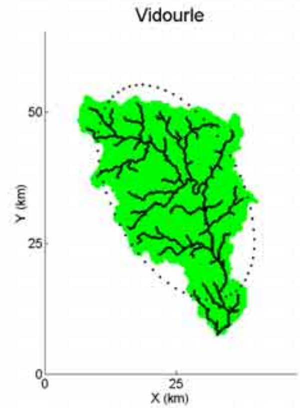












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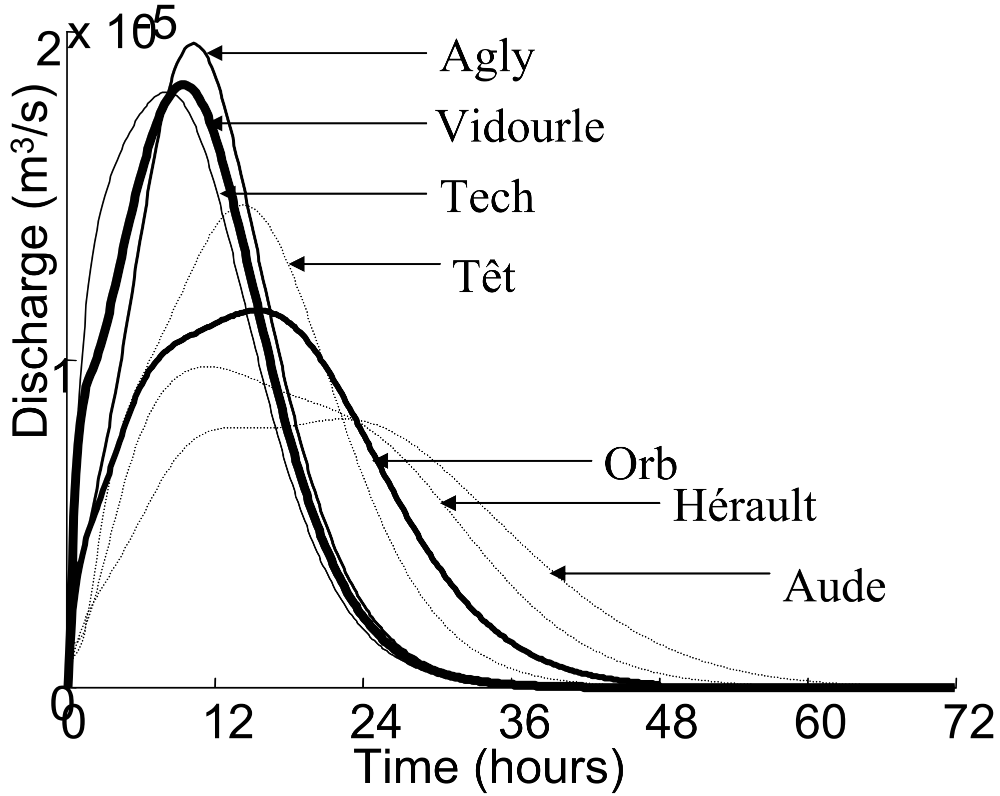
II.1. Identification of a Geomorphological Unit Hydrograph

(Moussa, 2003, Hydrol. Pro.)

Comparison of the Unit hydrograph transfer function of seven Mediterranean basins.



This transfer function takes into account :

- **the channel network structure.**
- **the spatial variability of rainfall.**

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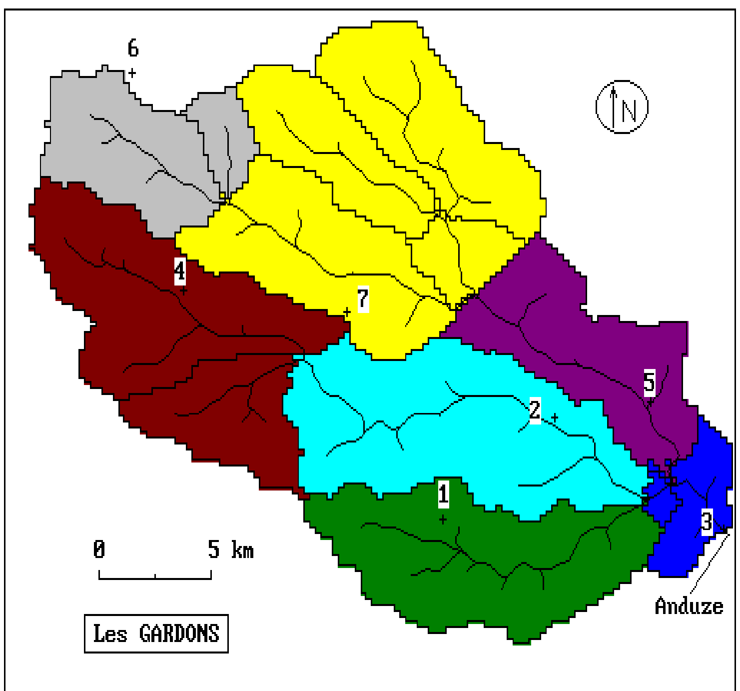
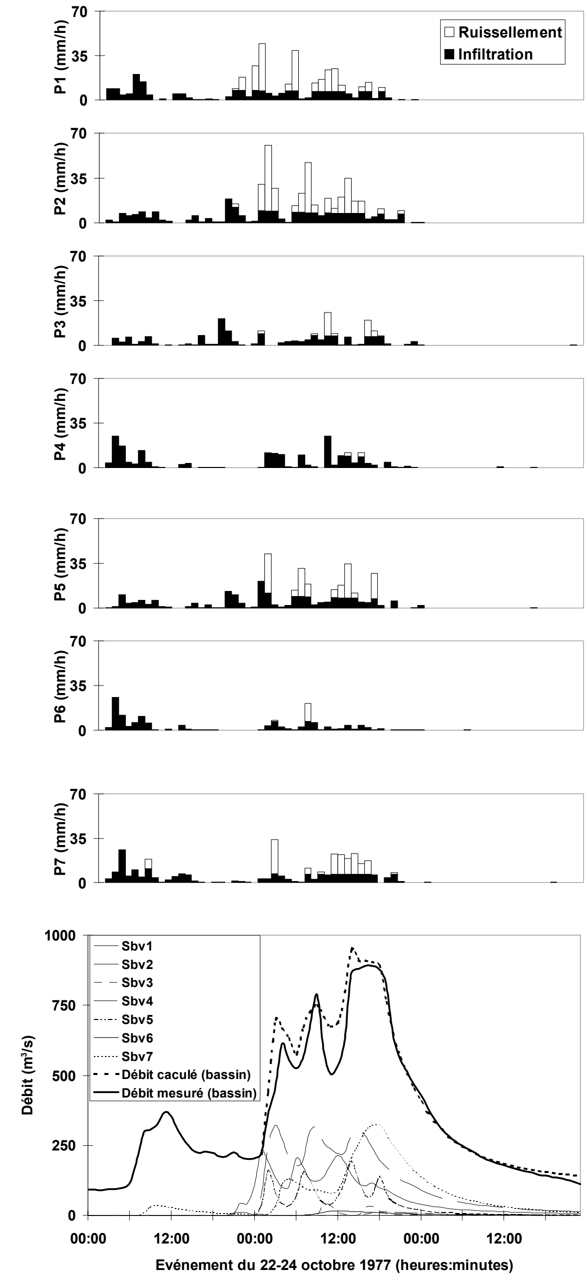
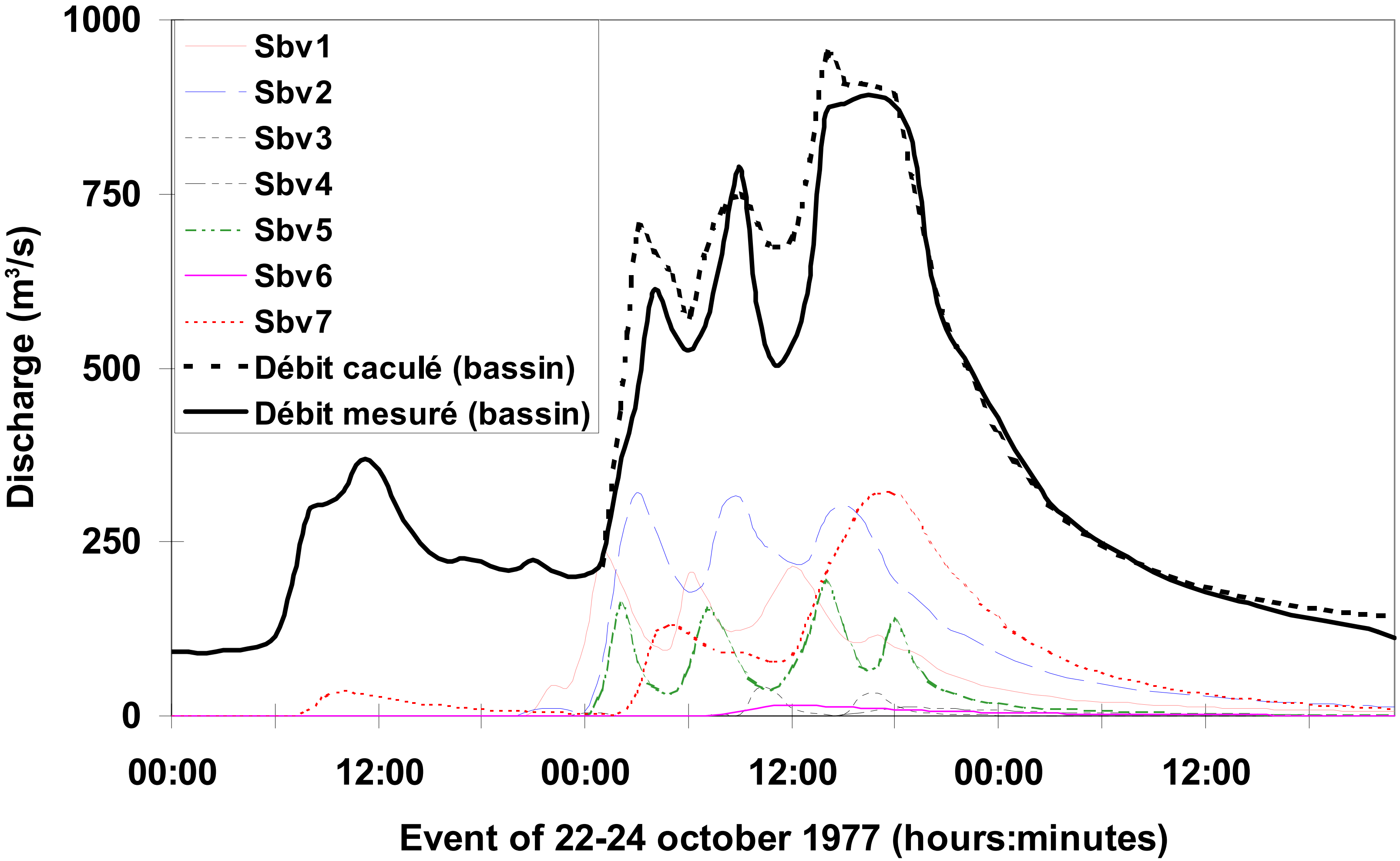
II.2. Identification of the contribution of each sub-catchment.
Example : The Gardon d'Anduze (545 km²)

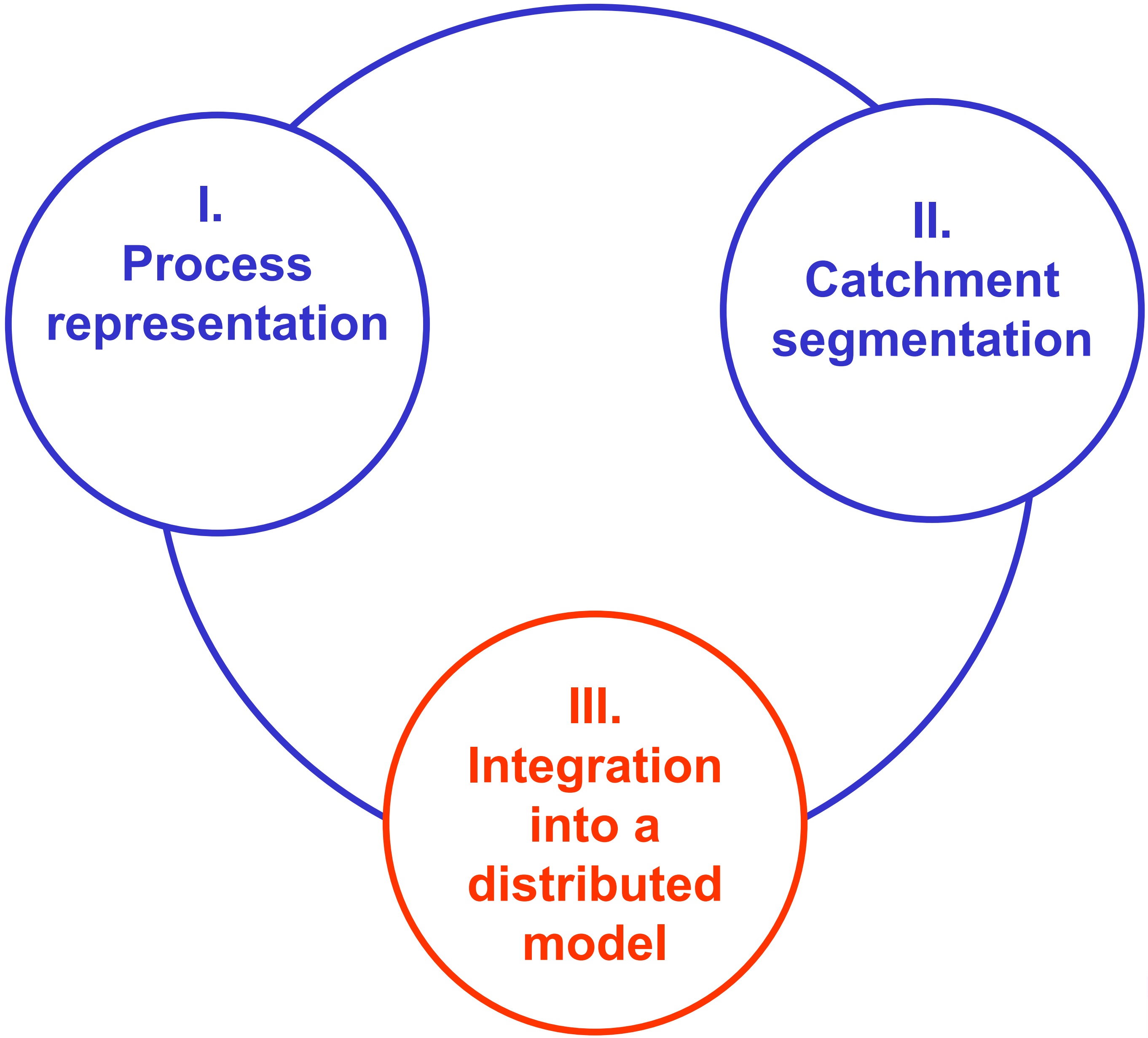
(Moussa, 1997, Hydrol. Pro.)






1000
750
500
250
0
Discharge (m³/s)
Sbv1
Sbv2
Sbv3
Sbv4
Sbv5
Sbv6
Sbv7
Débit caculé (bassin)
Débit mesuré (bassin)
00:00
12:00
00:00
12:00
00:00
12:00
Event of 22-24 october 1977 (hours:minutes)

Spatially distributed hydrological modelling of flood events on natural and farmed basins



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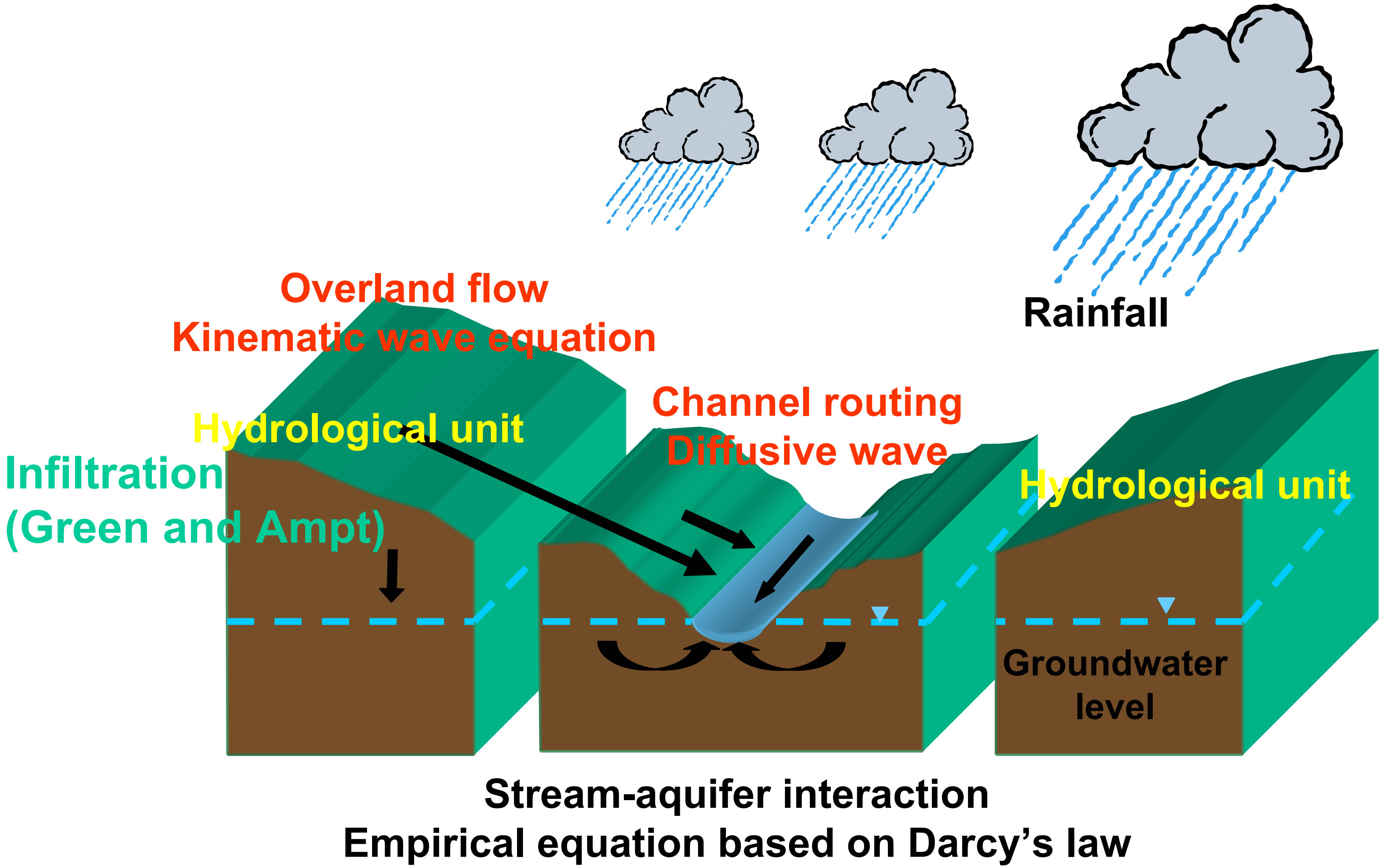
The MHYDAS spatially distributed hydrological model (Modelling HYDrological AgroSystems)

(Moussa et al., 2002, Hydrol. Pro.)



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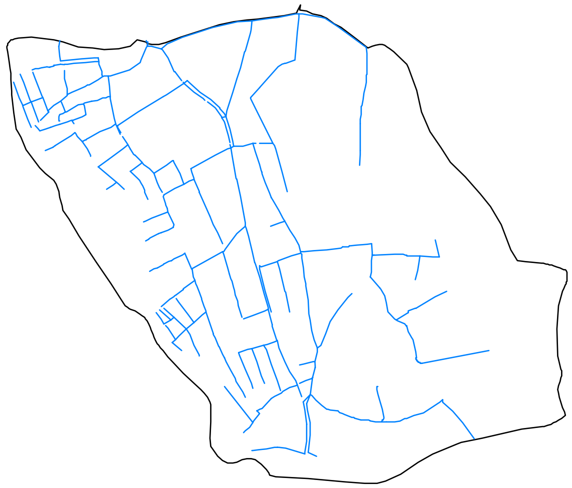
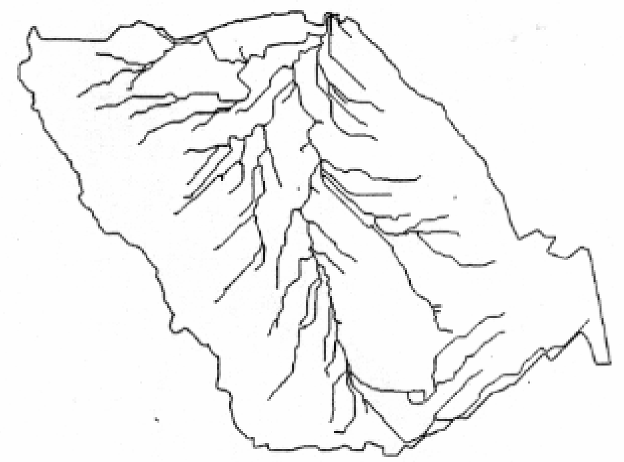
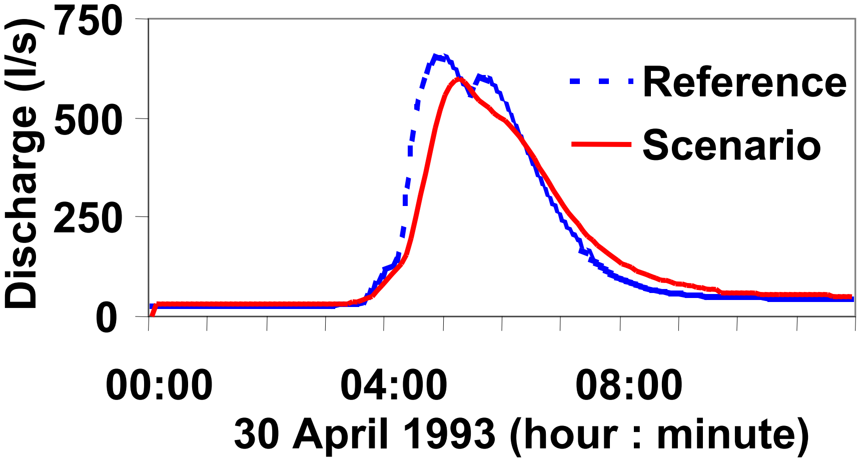
Testing the channel network management impact

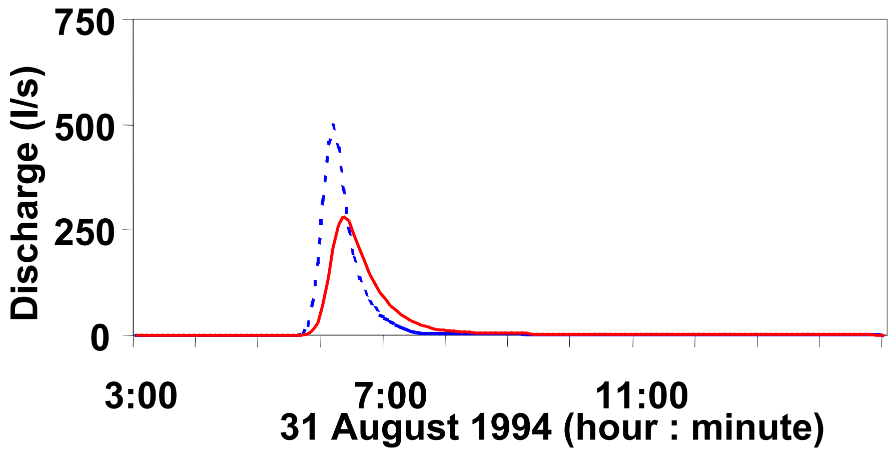
Actual ditch network



Hypothetical scenario







Conclusions

Development of a spatially distributed hydrological modelling approach (MHYDAS) that is well adapted to natural and farmed catchments based on :

- **The analysis of the Saint-Venant equations for flood routing with overbank flow, and the choice of the numerical method that minimises errors.**

- **Catchment segmentation into hydrological units and calculation of a transfer function based on catchment geomorphology.**

- **Multiscale calibration and validation.**

- **Human management impact analysis.**

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References

Moussa R, Bocquillon C. 1994. TraPhyC-BV : A hydrologic information system. *Environmental Software* **9**(4) : 217-226.

Moussa R, Bocquillon C. 1996. Algorithms for solving the diffusive wave flood routing equation. *Hydrological Processes* **10**(1) : 105-124.

Moussa R. 1996. Analytical Hayami solution for the diffusive wave flood routing problem with lateral inflow. *Hydrological Processes* **10**(9) : 1209-1227.

Moussa R, Bocquillon C. 1996. Criteria for the choice of flood-routing methods in natural channels. *Journal of Hydrology* **186**(1-4) : 1-30.

Moussa R, Bocquillon C. 1996. Fractal analyses of tree-like channel networks from digital elevation model data. *Journal of Hydrology* **187**(1-2) : 157-172.

Moussa R. 1997. Geomorphological transfer function calculated from digital elevation models for distributed hydrological modelling. *Hydrological Processes* **11**(5) : 429-449.

Moussa R. 1997. Is the drainage network a fractal Sierpinski space? *Water Resources Research* **33** (10) : 2399-2408.

Moussa R, Bocquillon C. 2000. Approximation zones of the Saint-Venant equations for flood routing with overbank flow. *Hydrology and Earth System Sciences* **4**(2) : 251-261.

Moussa R, Bocquillon C. 2001. Fractional-step method solution of diffusive wave equation. *Journal of Hydrologic Engineering* **6**(1) : 11-19.

Moussa R, Voltz M, Andrieux P. 2002. Effects of the spatial organization of agricultural management on the hydrological behaviour of a farmed catchment during flood events. *Hydrological Processes* **16** : 393-412.Moussa R. 2003. On morphometric properties of basins, scale effects and hydrologic response. *Hydrological Processes* **17**(1) : 33-58.