Study of hydrological processes for better models and flood estimations

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Introduction

• **Actual hydrological context**
  - Increase of preoccupation for climate change
  - Floods prevention

• **Needs**
  - Efficient models
    • Good reproduction of processes and hydrological responses

  Evaluation and prevention of the extreme event consequences

• **Objectives**
  - Improve the comprehension of the hydrological behavior

  Realistic conceptualization of hydrological model
Study area

- The Haute-Mentue watershed (12 km²)
  - Climate
    - Humid and temperate with continental characteristics
    - P = 1250 mm AET= 600 mm
  - Hydrology
    - Seasonal cycle
      (max. discharge in winter)
    - Annual average runoff = 680 mm
  - Geology
    - Molasse
      - Sedimentary deposits (carbonated)
    - Moraine
      - Very low permeability (clay)
  - Pedology
    - Acid soil
    - Soil average depth = 1 m

- Bois-Vuaco sub-basin (24 ha)
  - Soil occupation
    - 100 % forested
Environmental tracing

- Identification of hydrological responses at the catchment scale

- Haute-Mentue three-component mixing model
  - Tracers
    - Silica
      - Contact with the mineral matrix
    - Calcium
      - Contact with the carbonated substratum
  - Components
    - Direct precipitation (DP)
    - Acid soil water (SW)
    - Groundwater (GW)

![Diagram showing relationships between components and tracers with a graph plotting Ca²⁺ and SiO₂ concentrations in different water types.](attachment:image.png)
Hydrograph decompositions

- Spatial and temporal variability
  - Systematic decomposition of main floods observed between 1997-99 in 4 sub-basins

- Hydrological responses
  - Spatial variation
    - Combination of processes which depends on geology and morphology
    - Dominance of process varies in time with wet conditions
  - Similar temporal trend
    - Dry conditions
      - Direct precipitation - groundwater
    - Wet conditions
      - Increase of soil water contribution
Hillslope measurements

• Motivation
  – Environmental tracing
    • Study of hydrological processes at the catchment scale
  • Limitation
    – Mechanisms cannot be identified
    – Equifinality problem
      » Water following different pathways can present the same tracer concentration or a mechanism can involve different kinds of water

Hillslope measurements

• Explanation in process terms of the important contribution of subsurface flows
• Strong influence of wet conditions

Time Domain Reflectometry
Time Domain Reflectometry

- **Principle**
  - Determination of soil moisture
  - Measure of the propagation velocity of an electromagnetic wave in the soil

- **Configuration**
  - 9 multiplexers
  - 64 probes (500 m²)
    - 2 vertically wires of 30 cm
  - Hourly measurements during 8 months
Results of the Time Domain Reflectometry experiment

- **Spatial variability**
  - Wet season
    - Strong variability
  - Example
    - 8 probes
      - 1-8 meters apart
  - Two patterns
    - Big amplitude and rapid drainage
    - Small amplitude and slow drainage

![Graph](image)
Association of TDR and environmental tracing

- Same measurements period
  - Similar dynamic
    - Maximum at the same time
- Confirmation
  - Soil water is a potential component
  - Soil is almost saturated
    - Mobile water
- Subsurface flows
  - Not homogeneous within hillslope
  - Lateral rather than vertical
    - Saturated soil
    - Shallow "impermeable" layer
  - Hypothesis of preferential flows
    - Macropores
      - Observations in the field
      - Identification during a rainfall simulator experiment
Rainfall simulator

- **Motivation**
  - Study of soil infiltration capacity
  - Explanation of the important soil water contribution

- **Principle**
  - Application of rainfalls
    - Intensity 40 - 120 mm/h
  - Collection of the surface runoff
  - Five locations

- **TDR measurements**
  - Record of soil water content during the experiment

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Results of the rainfall simulator experiment

• Example
  - Two plots 20 m apart
  - Same intensity 60 mm/h and duration 30 min
• Plot 1
  - Important surface flow
  - Very slow drainage
• Plot 2
  - No surface flow
  - Macropore (d = 1-2 cm)
    - Flow = 75 mm/h
    - Max flow = 103 mm/h
  - Quick drainage

• Comparison with large TDR experiment
  - Hypothesis: spatial variability

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Dye tracing

• Motivation
  - Test the hypothesis of macropore flows
  - Does the structure of the macropore network allow the flow of soil water through all the hillslope?

• Procedure
  - Injection of 2 tracers (sulforhodamin G and uranin) at respectively 2 depths (40 and 120 cm)
  - Determination of tracer concentrations by using a field fluorimeter
  - Environmental tracing experiment in parallel
    - Comparison of results

• Configuration

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Results of the dye tracing experiment

- **Rapid reaction**
  - High tracer velocity
    - Sulforhodamin = 5610 mm/h
    - Uranin = 1670 mm/h
    - Saturated hydraulic conductivity
      - 36 - 108 mm/h
    - No diffuse flow

- **Comparison with the hydrograph separation**
  - Sulforhodamin - soil water component
    - Similar reaction
  - Conclusion
    - Contribution of soil water
      - Water contained in hillslopes next to the stream
    - Preferential flows
      - Macropores
        » Chemical signature?

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Conceptual model

- Proposition of a conceptual model
  - As a general hypothesis
  - Based on the present results and the physical properties of the catchment

- Dry conditions
  - Groundwater flows

- Start of precipitation
  - Mixture of precipitation and groundwater
    - Precipitation on saturated areas
    - Groundwater ridging
    - Preferential flows
  - Increase of the soil water content
  - Rapid elevation of the groundwater
    - Velocity of kinematic waves

- Saturation of the soil
  - Activation of macropore flows
    - Mixture of precipitation and soil water
Conclusions

• Main contribution
  – Association of different types of measurements
  – Environmental tracing
    • Information at the catchment scale
    • No identification of mechanism
  – Punctual measurements
    • Limited spatial vision of processes
  – Combination of information from different scales
  – Better processes identification

• Perspectives
  – Consideration of the environmental tracing information in hydrological models
    • Calibration phase
    • Adaptation of the structure
      – Reproduction of hydrological and chemical responses
  – Better conceptualization of processes in models
    – Improvement of streamflow simulations?
      » Number of parameters
  – More realistic previsions
    » Better evaluation of the impact of climate change