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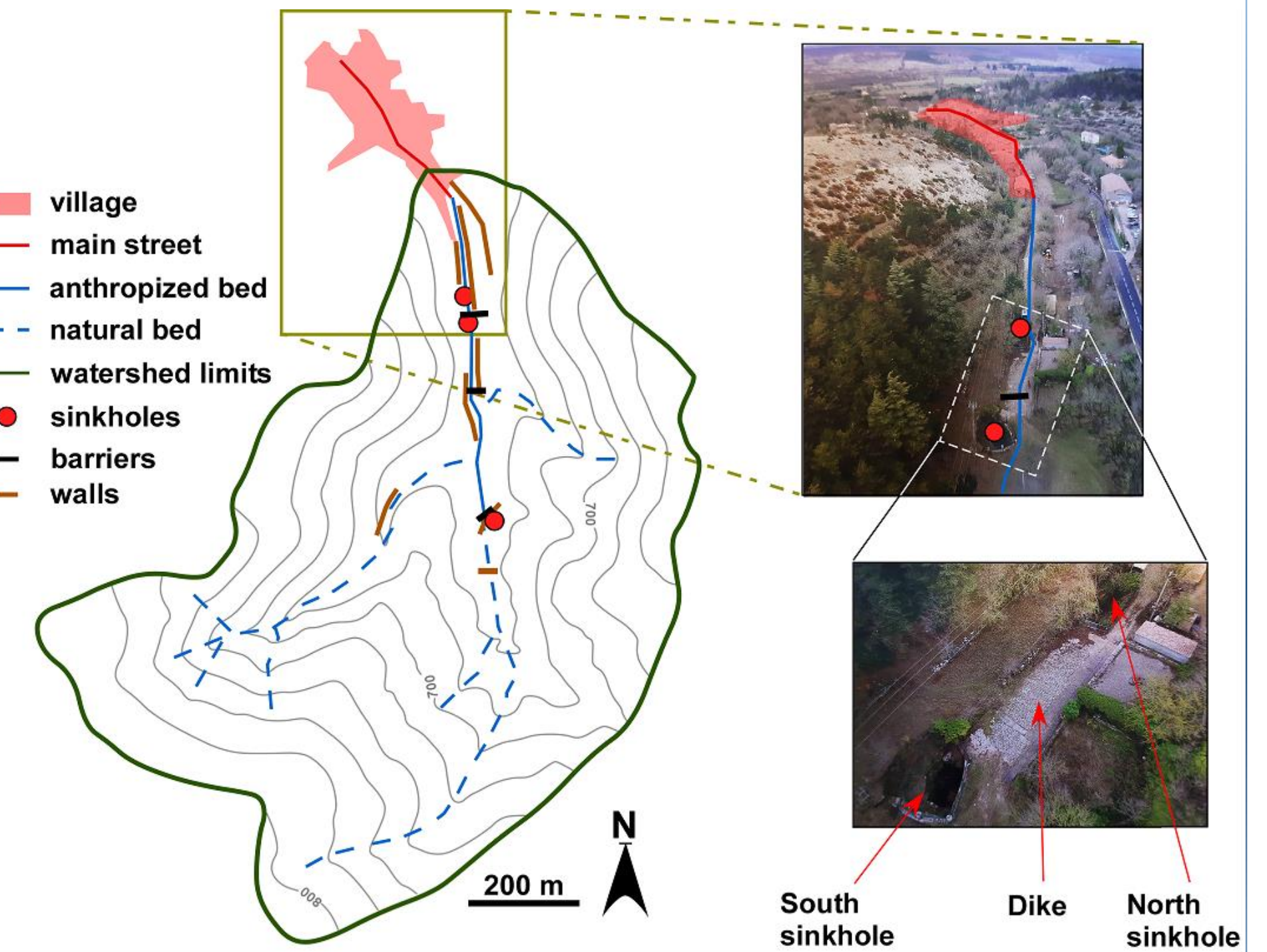
Spatial modeling of flash flooding in a small karst basin: Example of St-Pierre-la-Vacquerie (Causse du Larzac, France)

Context of the study area



La Vacquerie is a village located on a Plateau in Southern France (Larzac Plateau), at the outlet of a small watershed (~1km²) between ~630 and 800m altitude.

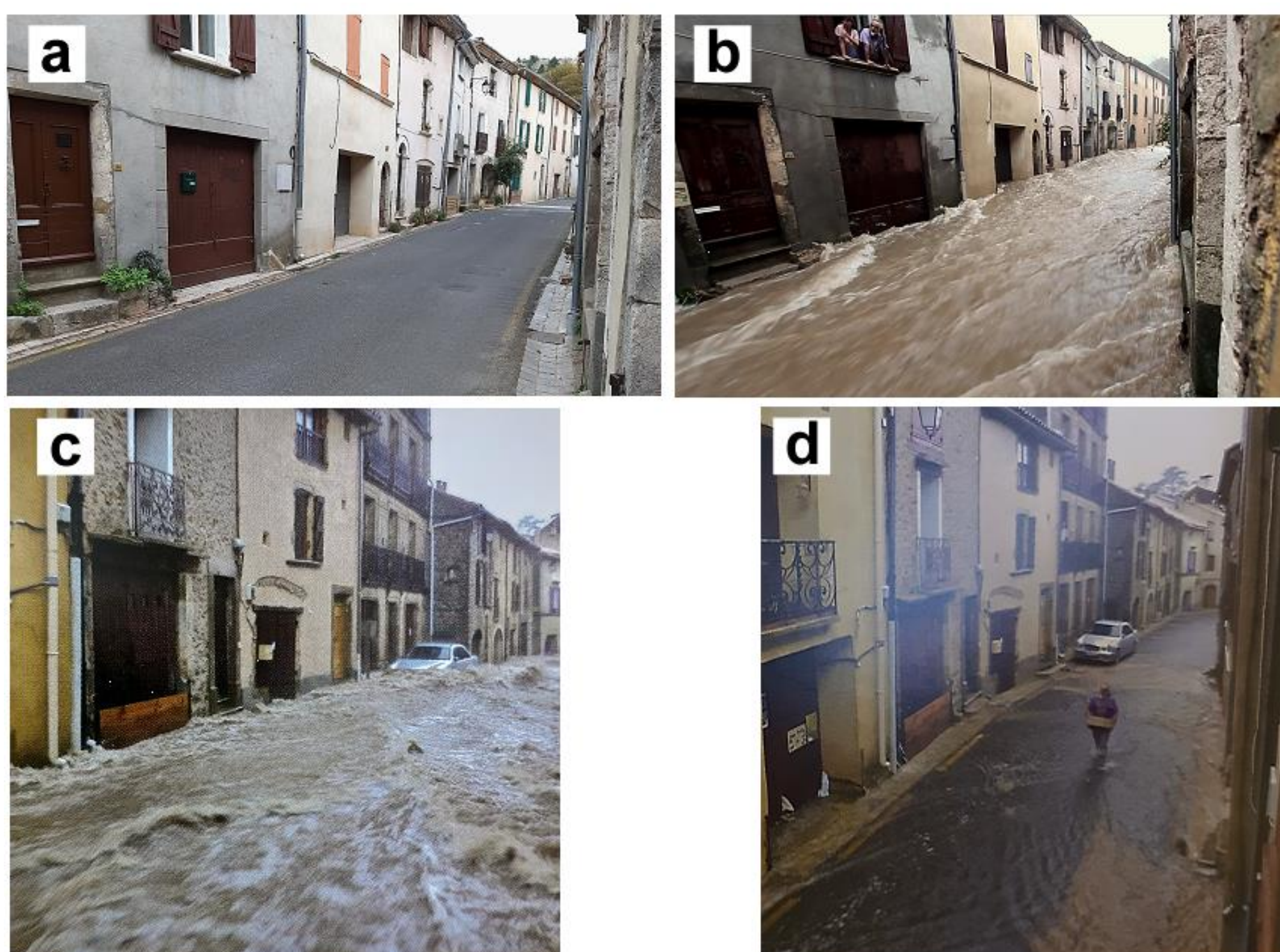
- GEOLOGY**
- Bajocian dolomites and Oxfordian fractured limestones.
 - Several sinkholes connected to a common karst network associated to a spring in the Herault river canyon (at ~100m altitude).
 - Large thickness of unsaturated karst network at the altitude of the watershed.
- HYDROLOGY**
- Mediterranean 'Cevenol' storms, short but very intense rain events.
 - The main street of the village can be assimilated to a Venturi canal, funneling all runoffs of the watershed.
 - Over years, villagers have constructed structures (walls, dike) to lead runoffs to the sinkholes to protect the village from floods.



▲ Delimitation of the watershed associated to an outlet located in the main street of La Vacquerie. Rivers are non-perennial, flows occur only during rain events. Karst sinkholes over the area allow for fast infiltrations. Anthropic structures have been built to lead runoffs to the sinkholes.

▲ Topographic map and localization of the study area on the Larzac Plateau (La Vacquerie) and the spring of its underground karst network (St Guilhem) supplying the Herault river.

Mediterranean meteorological extreme events



a: Photography of the main street of La Vacquerie-et-Saint-Martin-de-Castries, view towards the S-E
b: Around 1pm the 23th of August 2015, view towards the S-E (upstream)
c: Around 1pm the 23th of August 2015, view towards the N-W (downstream)
d: At 1:50pm the 23th of August 2015, view towards the N-W (downstream)

August 23rd 2015 storm event in La Vacquerie-et-Saint-Martin-de-Castries (based on the visual descriptions by Dr. Marc Leblanc)

Chronology

- 11 to 12am: Around 5cm of water in the street. Gutters begin to overflow.
- 12am to 1pm: Water depth in the street rises from 15cm to 50cm in 15min. Six videos from the flood are taken around 1pm. Downstream of the village water depth and velocity decreases as it reaches the Larzac Plateau.
- 1:20pm: Water level in the street starts decreasing.
- 1:45pm: Around 20cm of water in the street.
- Around 2pm: End of the flood in the village. A water volume is still present upstream from the dike, it is slowly absorbed by the South sinkhole.
- 4:20pm: Absorption of the remaining water into the South sinkhole is finished.

Post-flood observations based on visual indices

- The Vacquerie loss and its retention walls have been submerged.
- The North sinkhole has been submerged and water level has reached 1,10m above surface next to it.
- The South sinkhole has been submerged and water level has reached 1,20m above surface next to it. The frontal protective bars is full of vegetal debris. Large debris have been found in the sinkhole.
- The dike has been submerged and water level has reached 30cm above surface at its highest point.
- A flooded areas of 100m length has been formed upstream to the dike.
- The street between the dike and the village (built in cement) has been destroyed by the flows.

A numerical model simulating runoffs over the watershed is built in 2D in the physic-based hydraulic software HEC-RAS.

1 Inputs:

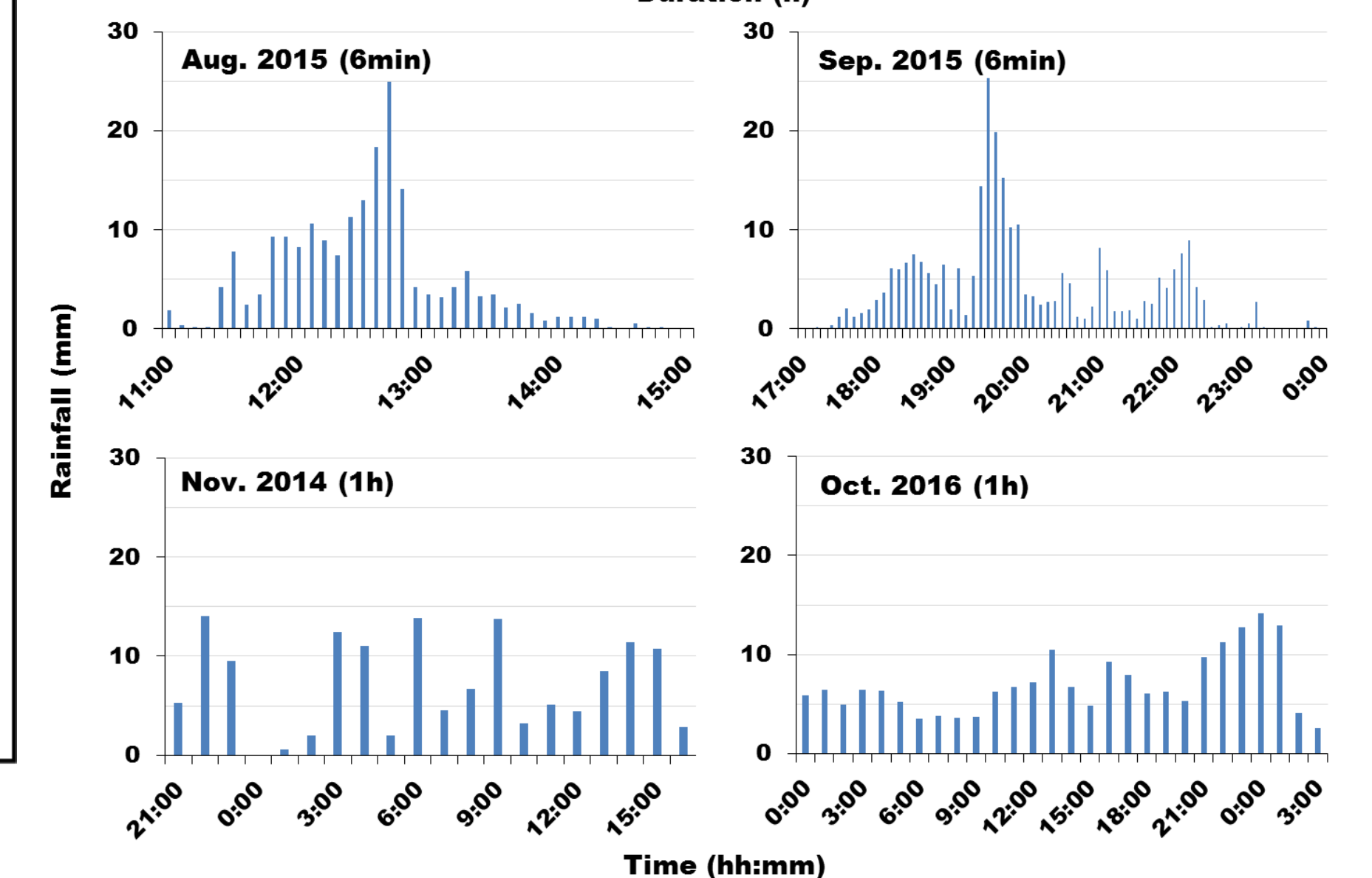
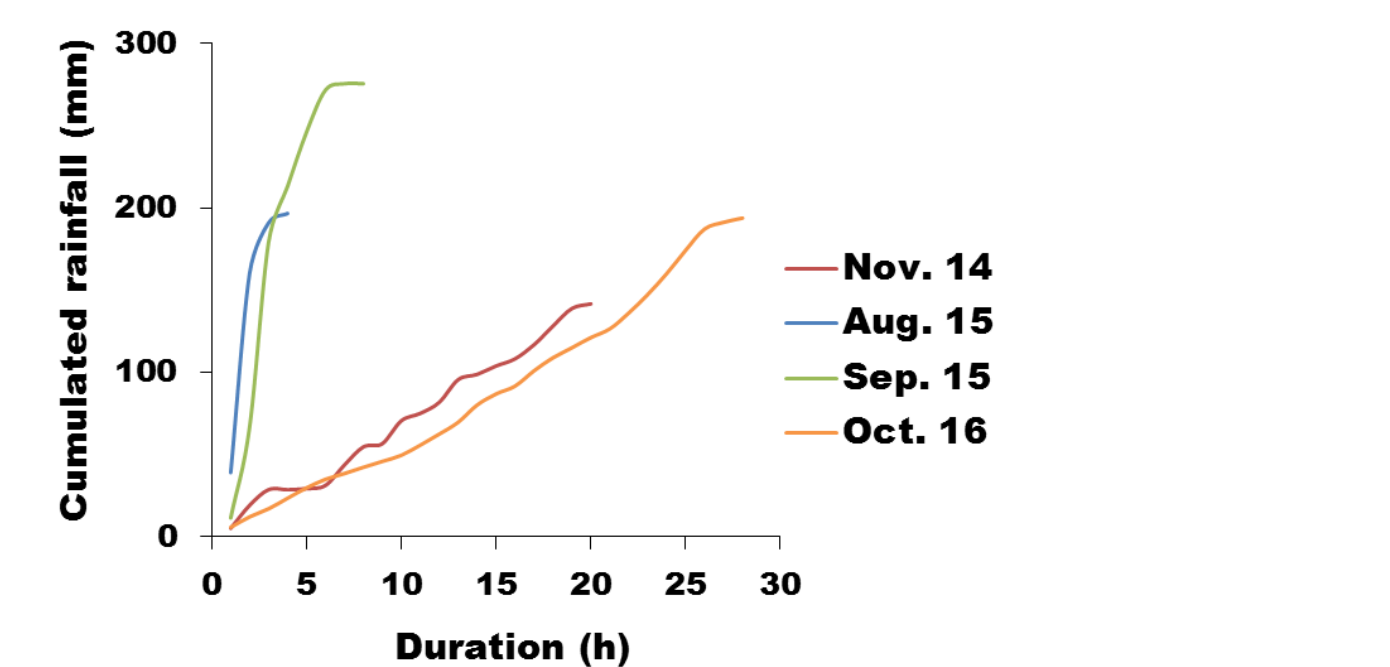
- A DEM of the area for the topography.
- Soils occupation map and drone aerial views for roughness and infiltration spatialization.
- On-site Beerkan measurements for infiltration rates.
- Tacheometry in the river beds.

2 Sinkholes integrations:

- Assimilated to constant outgoing flux.
- A 20m³/s rate calibrated on the Aug. 15 event observations: videos in the main street (velocity), post-event water marks (highest levels).

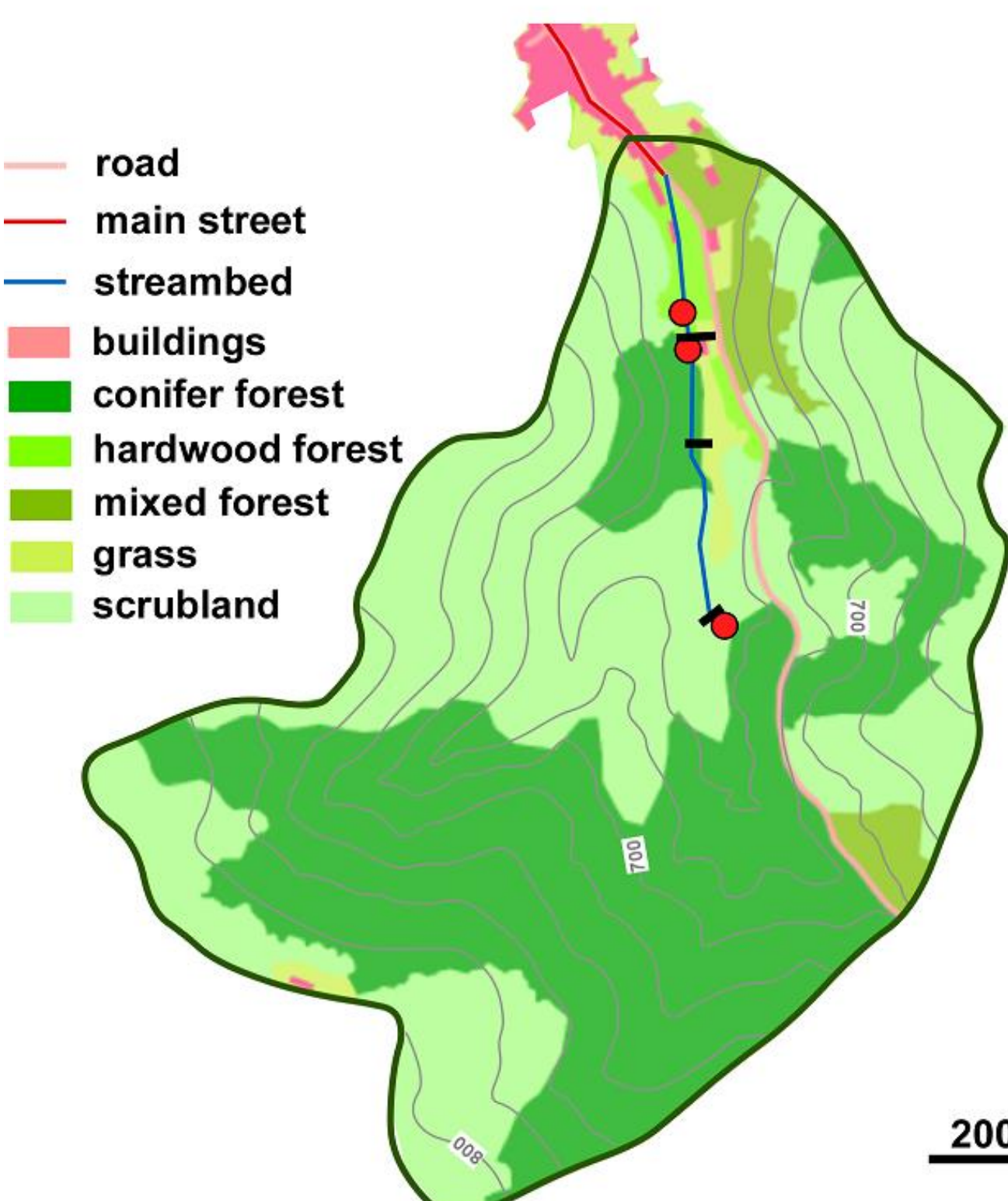
3 Results:

- Validated on the three other rain events on soft information (village flooded or not).
- When rain intensity exceeds a given threshold (110mm/h), the absorption capacity of the sinkhole is surpassed and village is flooded.
- Show the important role of absorption of the sinkhole (water level in the village divided by two during the Aug. 15 storm event).



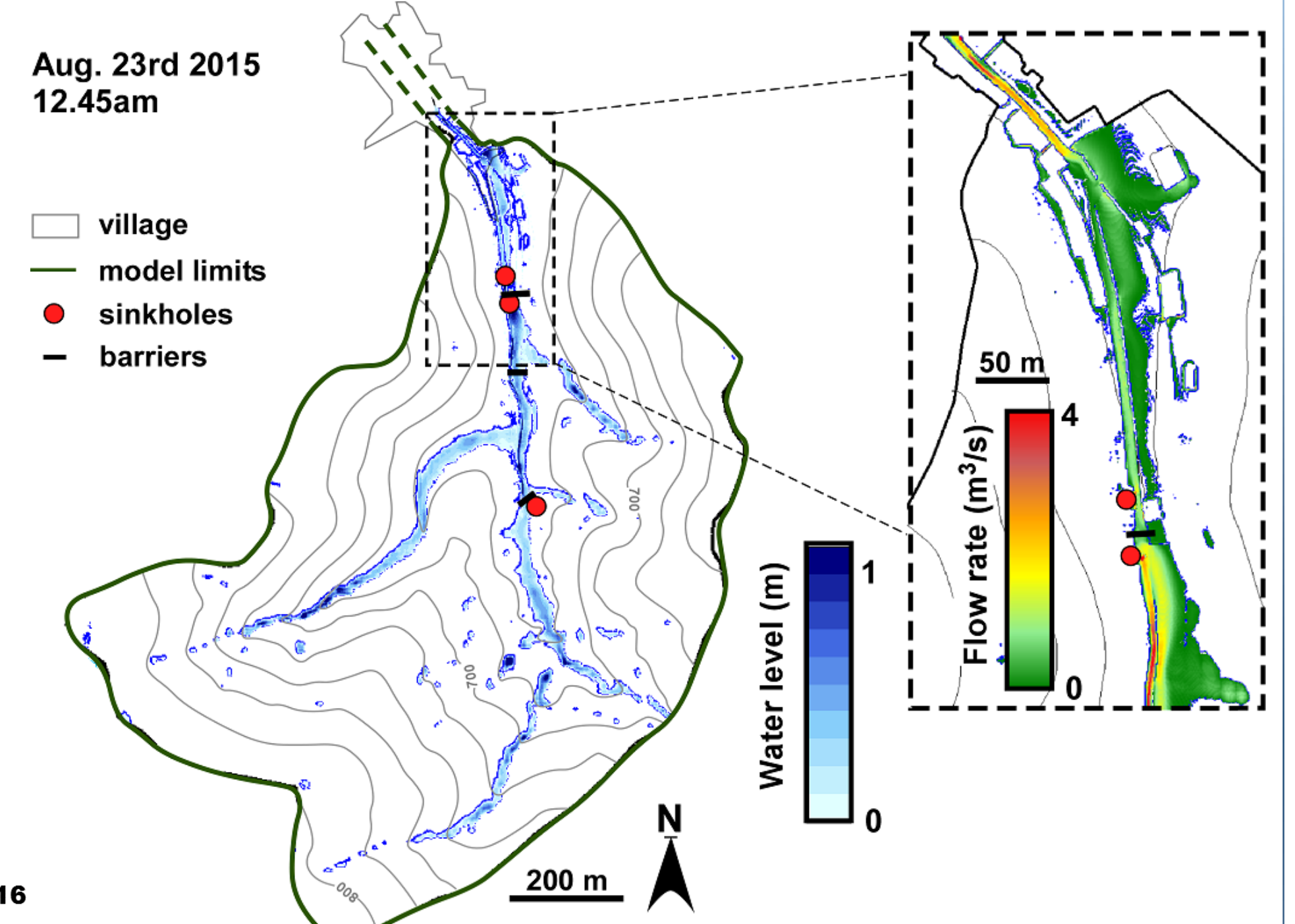
▲ Hyetograms of the 4 historical events associated to equivalent cumulated rainfalls tested in the numerical model.

Numerical modeling



▲ Soils occupation map. Each biome is associated to a measured infiltration rate and estimated roughness and impervious coefficient in the model.

▼ Simulated water levels and flow rates over the watershed at the peak of the Aug. 2015 event. One sees the effect of the dike and the sinkhole reducing the flow rate at the entrance of the village.

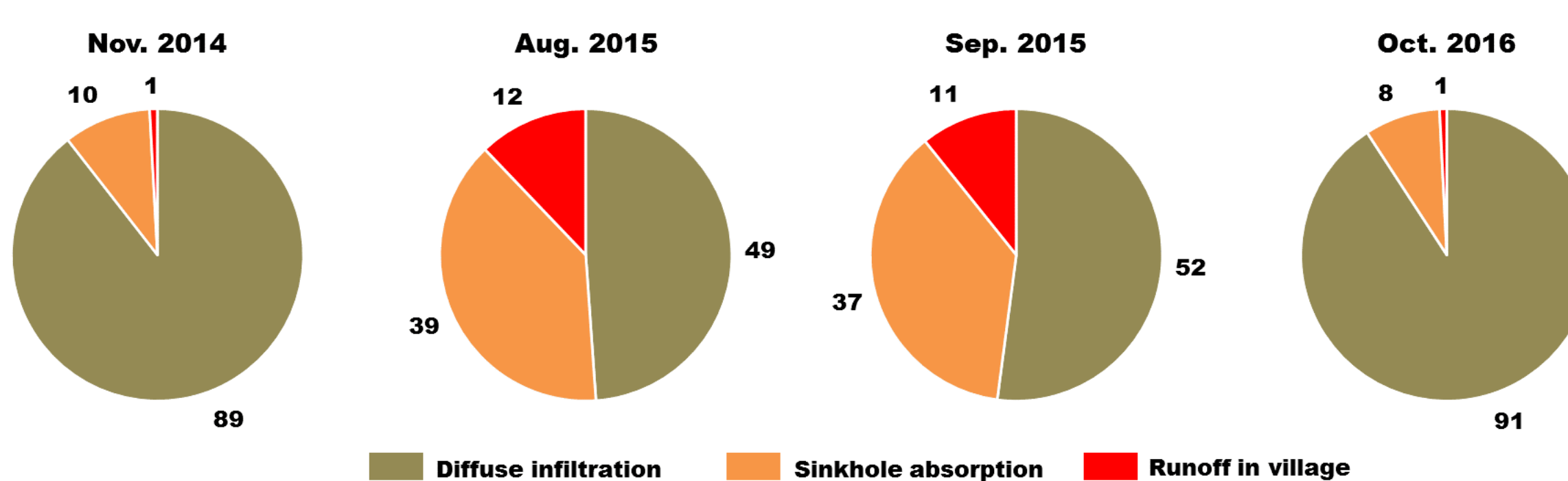


Highlights

- Specific configuration of the La Vacquerie watershed allows for a quantified hydrologic study in a karst environment
- Spatial physic-based modeling permits to link hydrologic and hydraulic data
- Sinkholes play an important role by reducing runoffs during high intensity rain events

Limits

- No retro-actions of the groundwater level on the runoffs are considered (important unsaturated karst network thickness)
- Soils become instantly saturated: infiltration rates are constant (limited soils thickness)
- Simplified physics of absorption in sinkholes



▲ Simulated water budgets for the different rainfall events. Runoffs over the watershed are limited by diffuse infiltrations in soils during long, moderate intensity events (Nov. 14 & Oct. 16) while absorptions in sinkholes play a more important role during short, high intensity events (Aug. & Sept. 15).