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THE INTEGRATION OF FUNCTIONAL SPACE IN FLUVIAL GEOMORPHOLOGY, AS A TOOL FOR MITIGATING FLOOD RISK. APPLICATION TO THE LEFT-BANK TRIBUTARIES OF THE AUDE RIVER, MEDITERRANEAN FRANCE

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ABSTRACT

In November 1999, a flash flood (1:30 year's return interval) severely damaged several areas of South France. Along the north tributaries (rank 4, Strahler) of the Aude River, the current system of flood-risk management proved to be rather inefficient during this flood. After the 1999 flood event, several plans were formulated to improve water flow and floodplain drainage. Two contrasting examples are illustrated. Along the Argent-Double tributary, the proposal chosen by the competent decision-making authorities (SIAHBAD, the community water association) consisted in restoring the capacity of the floodplain, occupied by extensive vineyards and local settlements. This does not account for mitigating the effects of larger floods, nor does it consider the vulnerability of the population living near the river. This option even leads to increase the human vulnerability locally in the floodplain. We proposed another option, based on the concept of stream-way or freedom space, which enabled us to quantify the optimal width for the channel to divagate and avulse in its floodplain, and the utilisation of the riparian trees as natural sediment traps, locally reinforced by low-cost structures. The two examples illustrate the two different concepts of river management: on the one hand, heavy (and costly) flood control structures in relation to the protection of local assets; on the other hand "environmentally friendly", low-cost structures, which should be encouraged where the rivers are still natural and free-flowing.

Key words: Extreme flood, Hydro-morphological impact, Water management, Stream-way concept, Semi-quantitative hydraulic model, Mediterranean France

1. INTRODUCTION

The management of river hydro-systems based on sustainable development implies that the hydraulic and engineering works carried out in the floodplain are of good quality, and that flood risk has been minimized (Werrity, 2006). During autumn 1999, extensive flooding affected southern France and raised public, political and scientific awareness of the large-scale consequences of low frequency, high magnitude events. It also highlighted the urgency of improving our knowledge on the significant measures to be taken to mitigate these events, and the need for a sustainable solution to flooding. The objectives of this paper are to define the flood hazards along the left-bank tributaries of the Aude catchment, namely the Argent-Double, Rivassel, Clamoux and Orbiel rivers, to show which measures have been considered to reduce the impact of the large floods to date, and to suggest which solutions would be better to apply in order to significantly reduce flood risk.

2. GENERAL CHARACTERISTICS OF THE CATCHMENTS

The Aude tributaries are small rivers (30-250 km^2), characterised by a meandering channel and by a torrential, Mediterranean regime; they flow from the north (mountain) to the south (piedmont; Fig. 1). In the Montagne Noire (schists), the rivers are deeply entrenched (>200 m), with a longitudinal slope (0.2-0.015 m/m) favouring a flashy response during flood events. On the piedmont, the rivers are 10-to-40-m deep entrenched into the Eocene (Bechtold and Basile, 2001; Gaume *et al*., 2004; Verdeil, 1999) molassic bedrock or Quaternary alluvium. In the floodplains, various types of stakes are facing flood hazard: in fact, some rural market towns extend into the river floodplain. In the floodplain, agricultural practices are characterized by the predominance of vineyards and some localised fruit-tree orchards.

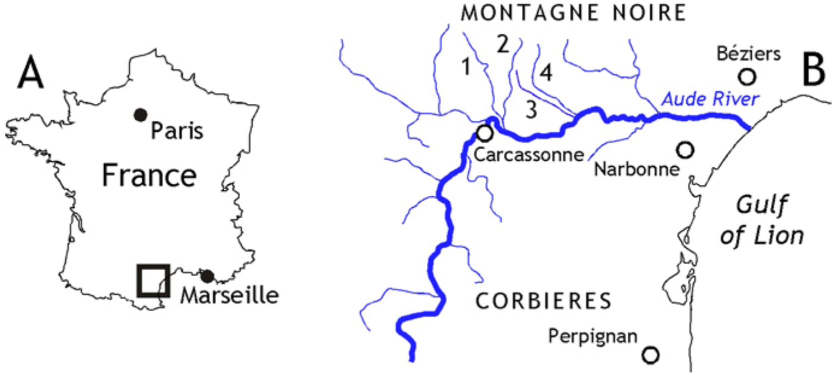

Figure 1 – Location of the studied area (A) and hydrography of the Aude catchment (B). 1=Orbiel River; 2=Clamoux River; 3=Rivassel River; 4=Argent-Double River.

As many others in the Mediterranean basin, the catchments are naturally prone to extreme river-floods and hydrological variability (Fort *et al*., 2001; Arnaud-Fassetta *et al*., 2002; Plet *et al*., 2002). Since June 1963, the hydraulic management of the Argent-Double catchment has been governed by the SIAHBAD (Intercommunity River Trust). Recently, a new agency was created, the SMMAR (Mixed Trust for the Management of Aquatic Environments and Rivers, that includes all river trusts of Aude's tributaries), spanning over administrative districts limits to include the entire territory subject to flood risk (i.e., the Aude catchment and its tributaries).

2. WHAT IS A CATASTROPHIC FLOOD EVENT ON THE LEFT-BANK TRIBUTARIES OF THE AUDE CATCHMENT?

In order to define and characterize the flood hazard in the Argent-Double catchment, one can rely on the experience and knowledge gained after the recent floods, and more specifically after the 12-13 November 1999 event (35 fatalities). Field investigations carried out just after the event (Fort *et al*., 2001; Arnaud-Fassetta *et al*., 2002) allowed us to evaluate the hydrodynamic functioning (e.g., hydraulic values) and to set up a systemic model (including triggering and aggravating factors, and hydro-geomorphic impacts) upon which strategies for rehabilitation of the hydro system can rely (Fig. 2).

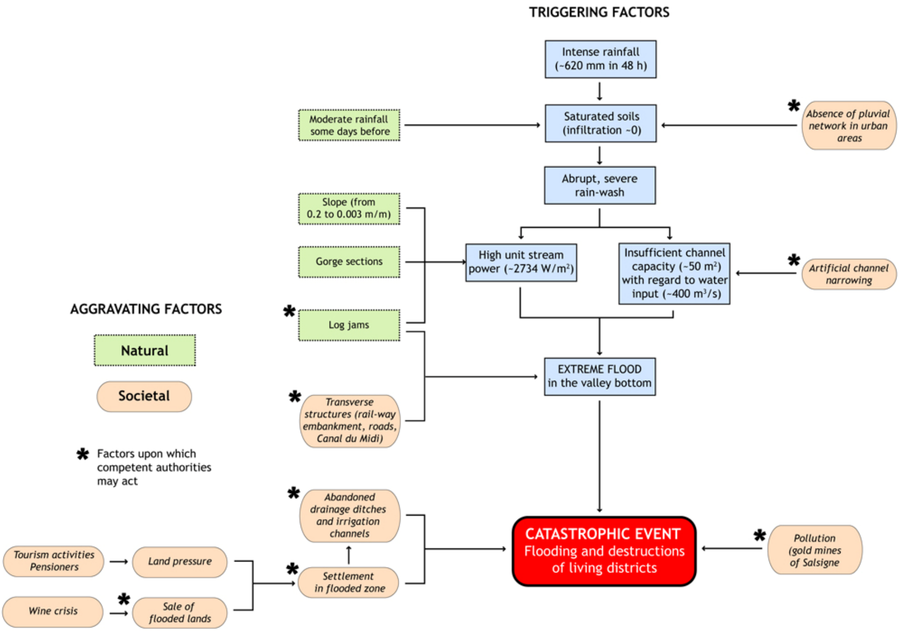

Figure 2 – Systemic approach of flood risk, left-bank tributaries of the Aude River.

The 1999 event had many fluvial morphological impacts. During two days (November 12-13), the Montagne Noire and its piedmont received more than 400 mm of rain, resulting in the flooding of the left bank tributaries of the Aude River. In the mountains underlain by schists, the talwegs were the most affected by localized debris flows, whereas the slopes remained relatively stable. In the piedmont, terrace scarps cut into the molassic bedrock were subjected to deep gullying (vineyards). Streams such as the Argent-Double occupied almost their entire floodplain (Fig. 3). As a consequence, many meanders were cut off, resulting in local incision of the main channel and/or in the accumulation of gravels, at the loss of substantial amounts of material along the river sides. These changes (metamorphosis), often amplified upstream of the confluences, reflect the normal, irregular behaviour of these rivers over the past few centuries, as shown by the superposition of the flood deposits constituting their alluvial plain.

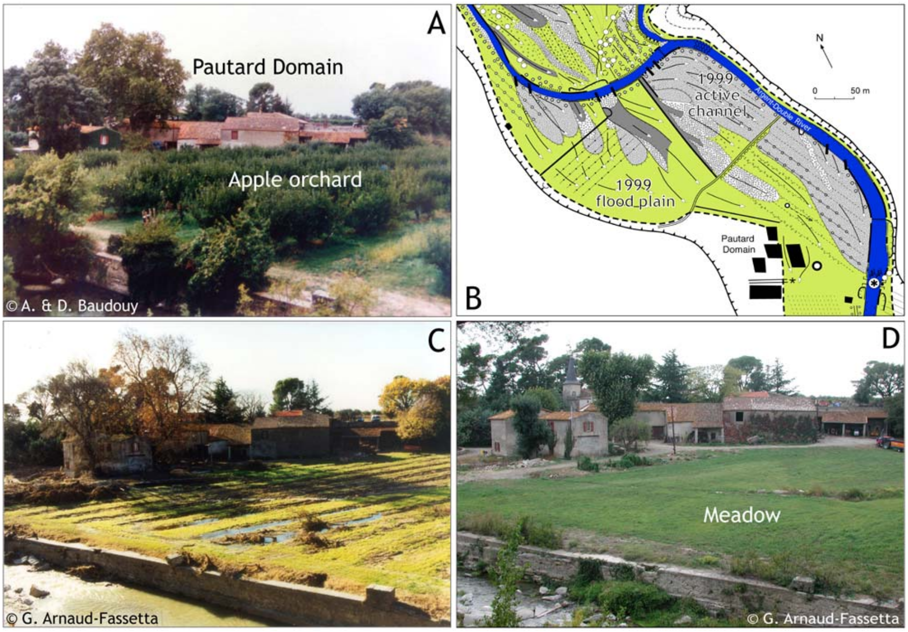

Figure 3 – Evolution of the Argent-Double floodplain (Pautard Domain) between 1998 and 2002. A: Apple orchard in the flood plain (July 1998). B and C: Hydro-morphological impacts in the floodplain of the rivers Argent-Double and Souc after the flood of November 1999. D: Meadow in the flood plain (September 2002).

The lack of maintenance of the flood protection structures by the local population and/or by the river trusts and the absence of coherence in the type and emplacement/succession of these structures has weakened the entire system, which thus could not resist the 1999 flood. Eventually, the bridges and walls have aggravated the impacts of the flood, by expanding the inundated areas and reinforcing the flood power by reflection against the walls (Fig. 4).

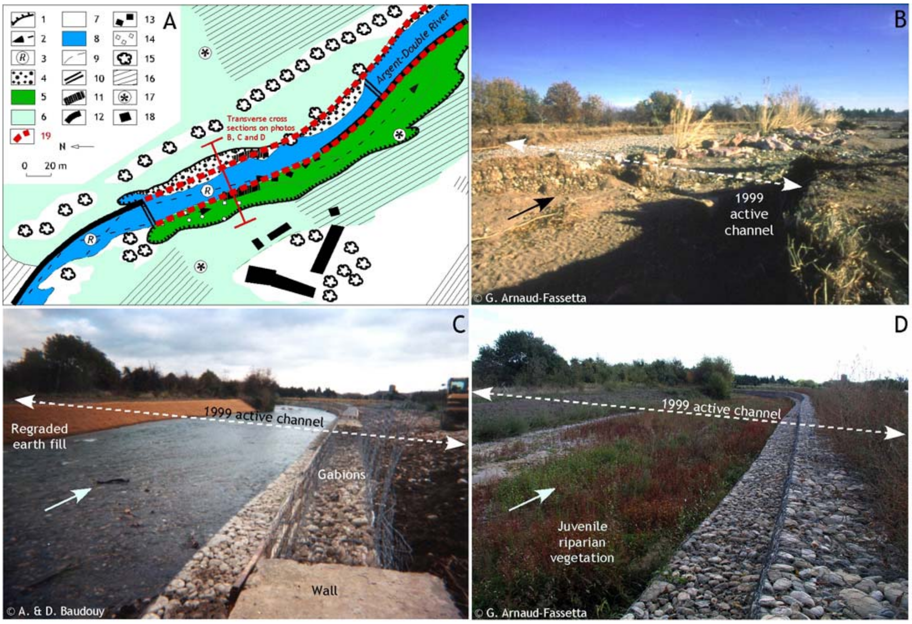

Figure 4 – Channel evolution of the Argent-Double River between 1999 and 2003. A and B: Impacts of hydraulic structures on the morphogenesis of the Argent-Double bed, upstream Peyriac-Minervois, during the 12-13 November 1999 flood (1: incision outlining the flooded channel; 2: direction of flood flows; 3: reflexion of the flood flows caused by the presence of the concrete wall; 4: gravel bar; 5: sand aggradation; 6: floodplain; 7: exondated zone; 8: low-stage channel; 9: limits of the channel after the flood; 10: concrete threshold; 11: gabion (not destroyed); 12: concrete wall (not destroyed); 13: wall destroyed or toppled over; 14: destroyed rocks; 15: riparian vegetation or hedgerows; 16: uprooted or buried vineyard; 17: uprooted vineyards or vineyards covered by debris; 18: houses; 19: channelisation 2002; December 1999). C: Channelisation works of September 2002. D: Vegetation development reduces the channel capacity and increases the roughness during low-magnitude floods (September 2003).

We analyzed the consequences of the flood with a diachronic approach that highlighted major flood geomorphic impacts and their spatial effects: breach opening along river banks, avulsion, meander cut-off, and braiding. It appeared that the rivers behaviour was well predictable, evidencing the same zones of disturbance and “weak points” such as meanders and confluences which are the most sensitive zones where any control measure could be repeatedly affected during floods.

3. TWO DIFFERENT CONCEPTIONS OF RIVER MANAGEMENT

3.1 Inefficient, expensive actions taken to reduce the impact of great floods

After the 1999 flood event, several plans were formulated to improve water flow and floodplain drainage. Among various proposals, the one chosen by the competent decision-making authority (SIAHBAD, the community water association, or river trust) consisted in restoring the channel capacity at low flow only. This does not account for mitigating the effects of larger floods, nor does it consider the vulnerability of the population living nearby the river (Fig. 4 C and D and Fig. 5).

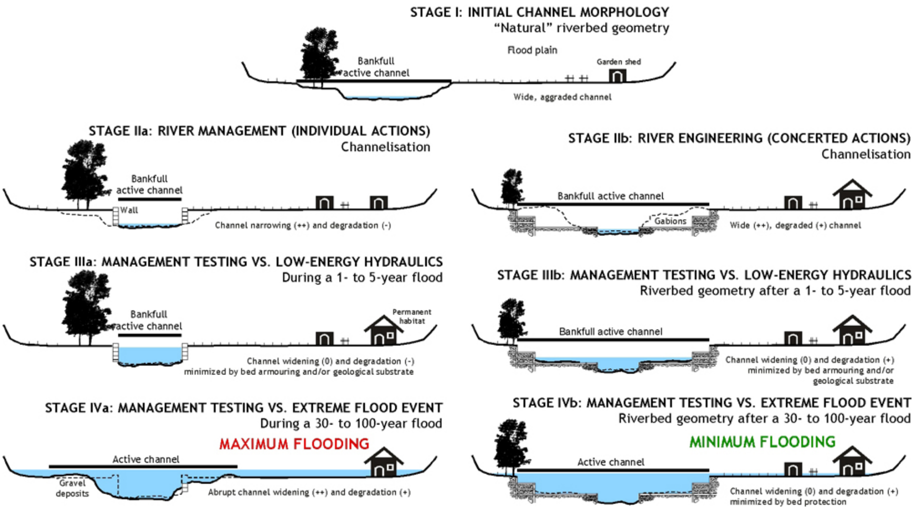

Figure 5 – Two conceptions (inefficient, expensive, left; ecologically friendly, right) of floodplain dynamics and channel restoration, left bank of the Aude's tributaries.

Various, "classical" options were chosen by local authorities. In the channel, the dimensions of the channel geometry were maintained (Caunes, Peyriac, Rieux) and the channel courses were restored with insufficient discharge capacity. Moreover, maintenance was done only along reaches visible from the road and villages centres (Rieux) because the regeneration of riparian forest is very rapid and its control requires expensive works.

In the floodplain, the active channels were recalibrated into a single channel, with a capacity adapted to low magnitude floods only. The flood deposits were retrieved or levelled, whereas they could be used as hydrological benchmarks to delineate the functional flooding area. In the villages, nothing was planned to reduce urban runoff whereas new housing estates were given permits to develop (Fig. 5, left).

3.2 Other inexpensive, ecologically friendly solutions to reduce the flood risk?

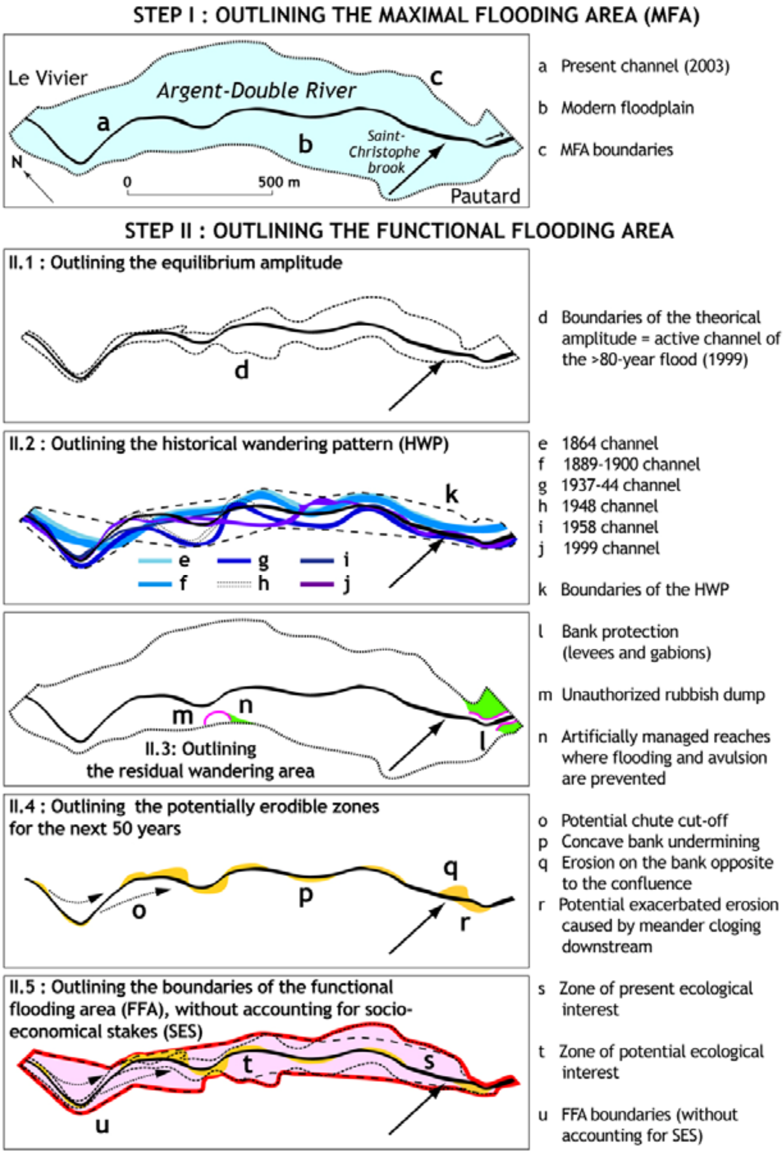

Figure 6 – The concept of “functional flooding area” [Malavoi *et al.*, 1998] applied to the Argent-Double River downstream to Caunes-Minervois.

A sustainable floodplain management generally requires a plan at the catchment scale, which accounts for the continuity of the upstream and downstream parts of the hydrosystem. In our inventory, we noted some common, recurrent weak points: discontinuities in the protection structures, with no consideration of the hydrosystem functioning and management before and after the 1999 event.

The concept of "stream-way" or "freedom space" (Malavoi *et al.*, 1998; Piégay *et al*., 2005) serves to maintain a "functional flooding area", hence to restore a sufficient channel capacity. Outlining the functional space requires six steps (Fig. 6). This reach segmentation allowed us assessing what are the instable reaches and what are those susceptible to be affected by important changes in bed geometry. We quantified the optimal width for the channel to divagate and avulse in its floodplain (Fig. 5, right). Tested upstream of Peyriac-Minervois, this method showed that present stream-way width varies from 22 to 186 m (mean 124 m).

A recent management trend is oriented towards naturalness within a "living river" perspective. The native riparian vegetation is allowed to remain dominant, thus enhancing habitat diversity and acting as a sediment trap, especially along abandoned channels (Fig. 7).

Figure 7 – Example of management for naturalness along the Clamoux River. The breach opened during the flood of November 1999 was artificially increased to force the river temporally to cut-off the meander during the next floods.

In little populated areas, the flood channels are kept naturally open, allowing flood channel divagations. Several reaches were thus identified as natural, potential zones of expansion and dissipation of floods (so-called ZPEDOC; Fig. 8).

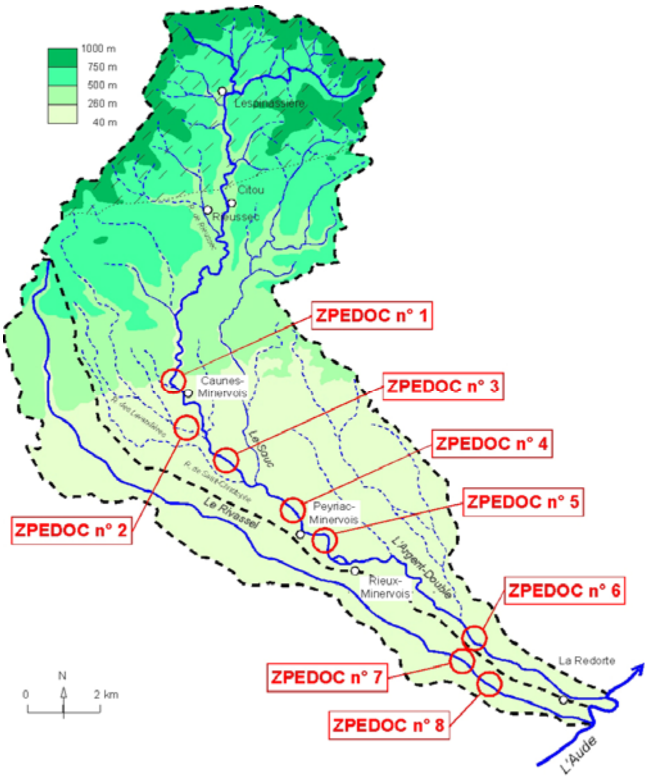

Figure 8 – Zones of expansion and dissipation of floods (“ZPEDOC”) along the river corridors of Argent-Double and Rivassel (after Arnaud-Fassetta *et al.*, 2004).

5. CONCLUSIONS

Our investigations led to evaluate the relevance of the present land-use and of the methods utilised by environmental managers to mitigate flood risk. We conclude stressing on the need for a concerted management of the river at the entire catchment scale and for a multi-disciplinary approach (engineering, hydraulics, and hydro-morphology), without which no serious protection against a real risk of flooding can be ensured to the local population.

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REFERENCES

Arnaud-Fassetta G., Beltrando G., Fort M., Plet A., André G., Clément D., Dagan M., Méring C., Quisserne D. and Rycx Y. (2002) – La catastrophe hydrologique de novembre 1999 dans le bassin-versant de l'Argent-Double (Aude, France): de l'aléa pluviométrique à la gestion des risques pluviaux et fluviaux. Géomorphologie: relief, processus, environnement, 1, 17-34.

Arnaud-Fassetta G., Fort M., Plet A. and Si Moussa S. (2004) – Les bassins versants de l'Argent-Double et du Rivassel (Aude): cartographie haute résolution (1/10 000ème) de l'aléa de crue des 12-13 novembre 1999, fonctionnement et dysfonctionnements hydrauliques observés, propositions d'aménagement de la plaine alluviale. Rapport d'expertise pour le compte du Syndicat Mixte des Milieux Aquatiques et des Rivières/Conseil Général de l'Aude, 74 pp.

Bechtold P. and Bazile E. (2001) – The 12-13 November 1999 flash flood in southern France. Atmospheric Research, 56, 171-189.

Fort M., Arnaud-Fassetta G., Beltrando G., Plet A., André G. and Mering C. (2001) – Impacts hydromorphologiques des fortes précipitations des 12-13 novembre 1999 sur la retombée méridionale de la Montagne Noire : l'exemple de l'Argent-Double (Aude). In: Médi-Terra (2001, Eds.) - Au chevet d'une catastrophe. Les inondations des 12 et 13 novembre 1999 dans le Sud de la France, Presses Universitaires de Perpignan, Perpignan, pp. 41-52.

Gaume E., Livet M., Desbordes M. and Villeneuve J.-P. (2004) – Hydrological analysis of the river Aude, France, flash flood on 12 and 13 November 1999. Journal of Hydrology, 286, 135-154.

Malavoi J.R., Bravard J-P., Piégay H., Héroin E. and Ramez P. (1998) – Détermination de l'espace de liberté des cours d'eau. Guide Technique n°2, Bassin Rhône Méditerranée Corse, DIREN Rhône-Alpes, 40 pp.

Meschinet de Richemond N., Scarwell H.J., Fort M., Arnaud-Fassetta G., Laganier R., Ogé F. and Plet A. (2006) – Restituer le territoire au risque. In: Laganier R. (2006, Eds.) - Territoires, inondation et figures du risque. La prévention au prisme de l'évaluation, L'Harmattan, Paris, 177-215.

Piégay H., Darby S.E., Mosselman E. and Surian N. (2005) – A review of techniques available for delimiting the erodible river corridor: a sustainable approach for managing bank erosion. River Research and Applications, 21, 773-789.

Plet A., Arnaud-Fassetta, G., Beltrando, G. and Fort, M. (2002) – Contraintes hydrologiques et gestion des territoires dans le Minervois. Retour d'expérience après la crue de novembre 1999. Proceedings of the colloquium "Hydrosystèmes, paysages, territories", 6-8 September 2001, Lille, Commission des Hydrosystèmes Continentaux of the Comité National Français de Géographie, CD-rom.

Verdeil P. (1999) – Les crues de l'Aude au cours des temps. Spele Aude, 8, 34-45.

Werritty A. (2006) – Sustainable flood management: oxymoron or new paradigm? Area, 38 (1), 16-23.