D40 STORM ALEX – LESSONS LEARNT FROM THE DEBRIS FLOODS THAT OCCURRED ON OCTOBER 2ND 2020 IN THE FRENCH MARITIME ALPS

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INTRODUCTION

The passage of storm Alex along the Atlantic coast on October 2nd 2020 triggered an exceptional Mediterranean episode in the Alpes-Maritimes (southern and eastern department in France, close to Italy – Figure 1), resulting in very high rainfalls (> 500 mm in 24 hours at several stations), with absolute records observed in the Tinée, Vésubie and Roya catchments (Météo France, 2020). The rainfalls recorded over 12 hours in the Roya and Vésubie catchments, as well as in the lower Tinée, are associated with return periods between 500 and 1000 years (ONF-RTM et al., 2022a, 2022b).

On these torrents and mountain rivers with steep gradients, such rainfalls generated floods of exceptional intensity, characterized by dramatic levels of erosion and volumes of sediment transported. Hundreds of buildings, dozens of kilometers of roads and numerous bridges were destroyed or severely damaged. Dozens of hectares of riparian vegetation were scoured and recruited by the flows. Riverbeds were transformed from relatively narrow and generally paved streams to continuous braided rivers on the Vésubie and discontinuous ones on the Roya (Figure 1).

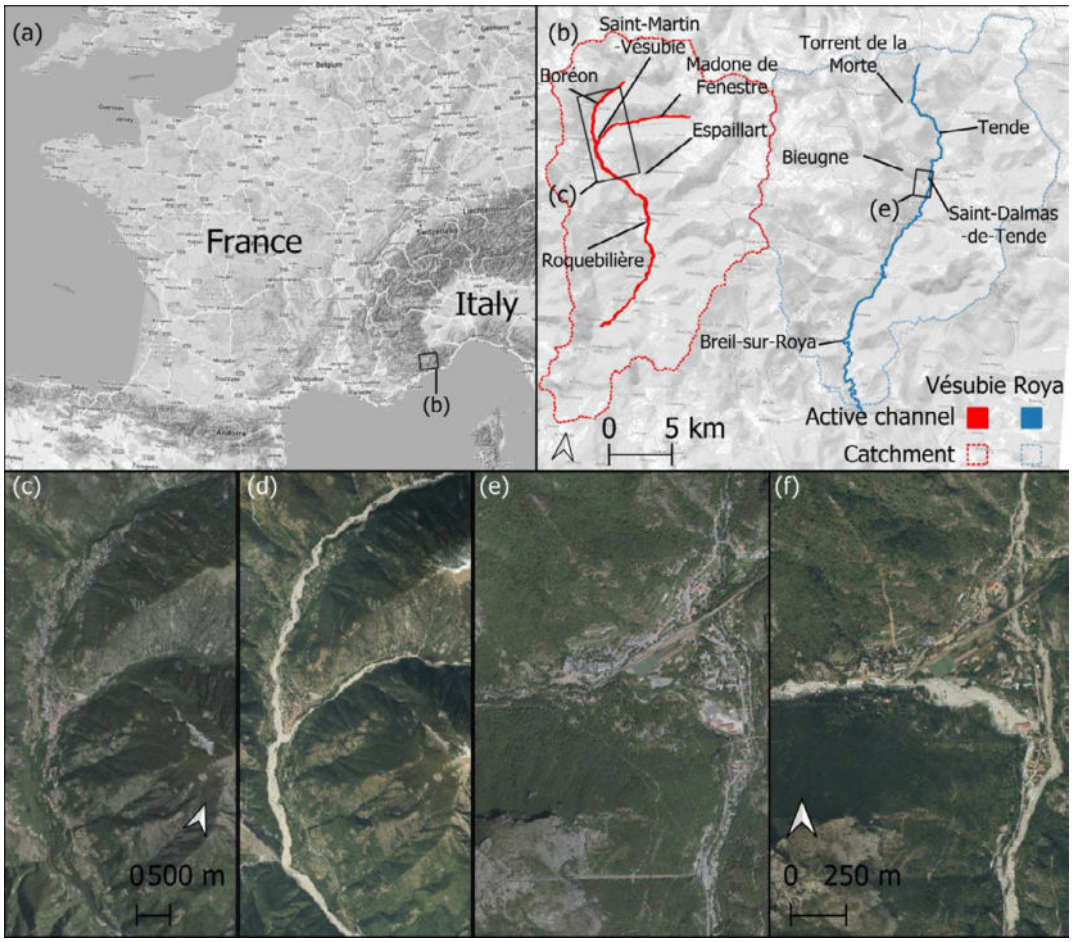

Figure 1 : (a) Location of the study area, (b) Catchment areas mainly investigated, (c) Aerial view of Saint-Martin-Vésubie municipality before and (d) after the flood, (e) aerial view of the Tende community before and (f) after the flood (Sources: IGN BD Ortho and IGN post-Alex emergency survey).

In the aftermath of the flood, it became necessary to characterize the hydrological and morphological phenomena to understand the event, and to draw lessons from it for the benefit of risk prevention and reconstruction. The back analysis commissioned by the local State authority was organized into two groups: a hydrological group led by CEREMA, which led to consensus work to establish the flood peak flows (CEREMA, 2021), and a geomorphological group led by ONF-RTM (French torrent and avalanche control service: Service de Restauration

des Terrains de Montagne de l'Office National des Forêts) supported by INRAE and several researchers from other institutions.

The mobilization of this second group enabled a considerable amount of data and observations to be gathered quickly after the event. The various contributors then organized themselves to deliver, 18 months after the event, a detailed analysis of the course of events, the processes and effects of flooding and the associated damage (ONF-RTM et al., 2022b, 2022a). The aim of this contribution is therefore to illustrate the exceptional nature of storm Alex in terms of morphological changes, and to share the way in which the back analysis was provided, both in terms of documenting the event (an operation designed to draw lessons for the medium and long term), and in terms of supporting the stakeholders in the months and years following the event (short term). This contribution provide a broad perspective on the back analysis and is complementary to some scientific contributions focusing on detailed questions (Carrega and Michelot, 2021 on hydro-meteorology; Chmiel et al., 2022 on seismic measurement of bedload sediment transport; Rey et al., 2022 on damage to infrastructure).

METHODS

Compiling and sharing data was one of the first challenges to achieve in the aftermath of the event. The geographical scale and intensity of the event meant that the usual methods of data collection and organization had to be adapted to cover the whole affected area as quickly as possible, using the human resources available.

The immediate mobilization of the State enabled the IGN (French geographical survey) to launch an acquisition of orthophotos and LiDAR data only three days after the event, from 5th October 2020. The acquisition of this data for the three valleys affected was crucial for two reasons:

1. To optimise the organization of the field missions, carried out between October 13th and November 20th 2020 by the ONF-RTM teams, with the support of the local authorities and the scientific community. Photographs taken by CEREMA during helicopter flights between October 3rd and 9th 2020 also helped guiding the organization of the missions and consolidate field observations;
2. To target field surveys by prioritizing floodmarks and damage to elements-at-risk. Quantitative data on erosion and deposition (e.g. length of bank erosion, heights of talus slope eroded, widths of channels and slopes of failed banks) were obtained by comparing pre- and post-flood digital terrain models (DTMs). The use of a mobile data collection application on smart phone with specially designed data entry forms optimized the surveys and their subsequent use.

RESULTS AND DISCUSSION

The analyses carried out as part of the back analysis in the Roya and Vésubie valleys illustrated the exceptionally high intensity of the Storm Alex flood:

- Major morphological changes: The longitudinal profiles of the Vésubie (Figure 2a-c) and the Roya were extracted from topographic data (LiDAR IGN post-Alex, LiDAR 2018 on the Vésubie), as well as from the IGN database BD TOPO® 2019. The longitudinal profile analysis before and after the Alex flood revealed a generalized aggradation of the riverbeds. The bed level of the Roya River rose by an average of 3 m in the Tende and Breil-sur-Roya crossings. On the Vésubie River, the changes in elevation are just as spectacular, with some reaches of the Boréon and Madone de Fenestre that experienced aggradation reaching 10-12m. The rising in the bed level of the Roya and Vésubie rivers was associated with a considerable widening of the active channel, leading to an actual fluvial metamorphosis (compare for example Figure 1c & d). Diachronic analysis based on aerial photographs shows an average widening rate at valley scale of 4 for the Vésubie and 2 for the Roya (Melun et al., 2022). The post-Alex active channel occupies more than 75% of the entire valley floor, and even exceed its former limit in some reaches where the hillslopes were deeply eroded and the valley floor area significantly widened.
- Exceptional bedload sediment transport: A comparison of the two DTMs from the 2018 and 2020 LiDAR surveys available on the Vésubie enabled to assess the volumes of material transported (Piton and Liébault, 2023). The results show exceptional volumes of mobilised material. Forty active tributaries to the main hydrologic network experienced a cumulated erosion of 2.4 million m3 of which 0.9 million m3 stayed in these sub-catchments and 1.6 million m3 were delivered to the main streams. In the Vésubie river and its two main branches (Madone de Fenestre and Boréon), 4.4 million m3 of material were eroded and 3.9 million m3 were deposited. The hillslope tributaries and two main upper branches were thus net suppliers of sediment while the Vésubie main channel stored a large share of the supply.

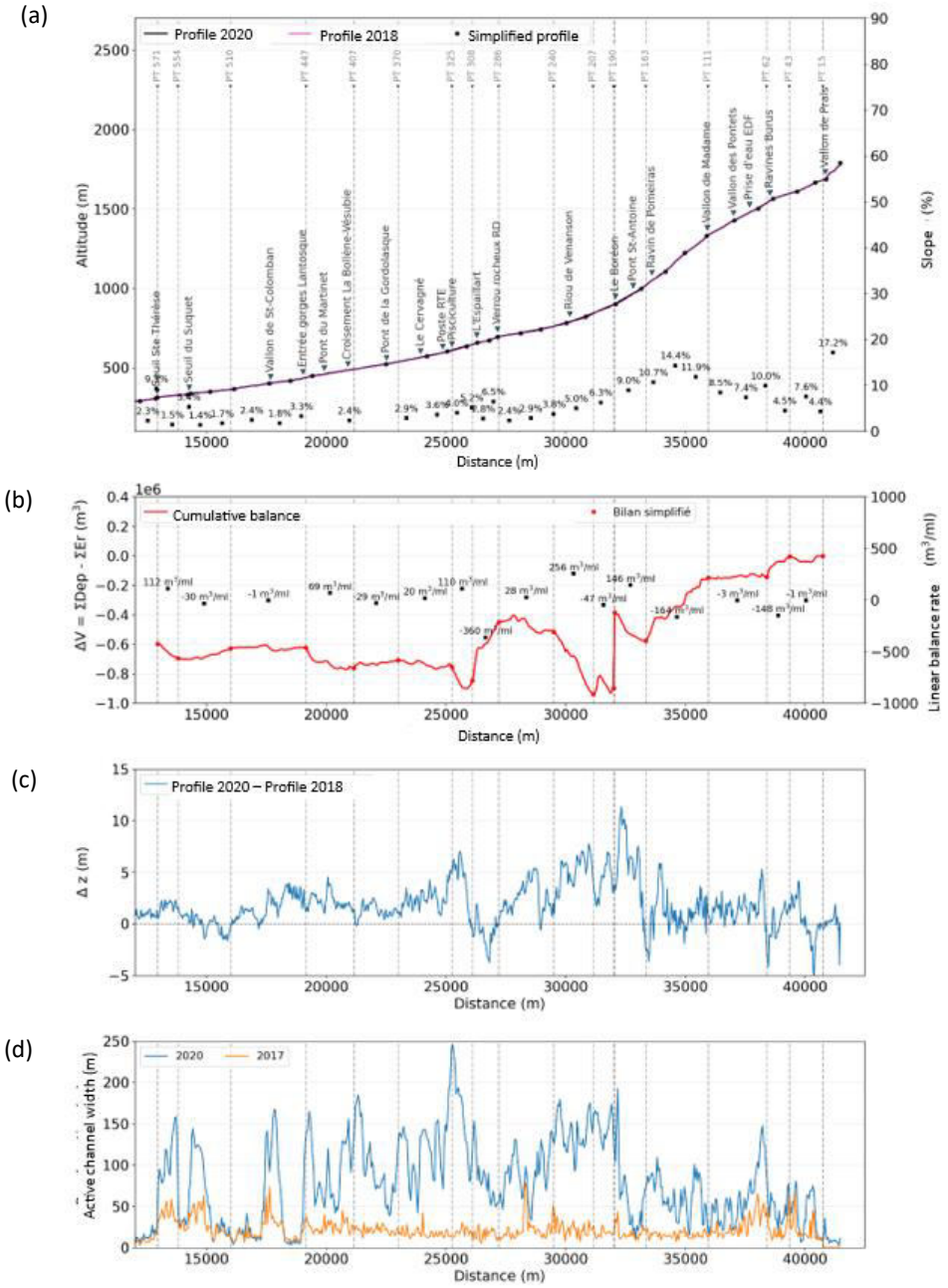

Figure 2 : Examples of analyses carried out on the Vésubie: (a) Pre- and post-flood longitudinal profiles with longitudinal slope (Sources: LiDAR 2018, MNCA; LiDAR 05/10/2020, IGN); (b) Cumulative differential topography sediment budget along the longitudinal profile resulting from the difference between the pre- and post-flood DTMs; (c) Elevation change in the bed level resulting from the difference in elevation between the pre- and post-flood longitudinal profiles; (d) Comparison of the width of the pre-(orange) and post-(blue) flood active channel width along with the longitudinal profile.

- Large contribution from large wood: the flows scoured and recruited large quantities of large wood (woody debris) from the riparian zones of active rivers, as can be seen from the numerous bridges blocked by logjams and the beaches along the coast covered in driftwood in the immediate aftermath of the flood. A specific analysis was carried out to quantify the quantity of forest recruited, of large wood transferred and deposited during the flood at catchment scale. On the Vésubie side, it is estimated that between 24,000 and 45,000 m3 of large wood was exported to the Var and then to the Mediterranean Sea. On the Roya side, a volume of about 14,000 m3 (uncertainty range: 7,000 - 29,500 m³) was exported to Italy and to the sea (assessment by Piton and Liébault, 2023).
- Considerable damage exacerbated by the debris flood process: the material toll following flood Alex is high, with extensive damage to infrastructure and buildings. The back analysis provided an opportunity to analyse the links between the nature of the damage, its extent and the intensity of the torrential phenomena. Over the two valleys, more than 400 buildings were affected, including 171 that were totally destroyed, 52 that were threatened with ruin and 203 with various types of damage. The results also show that the buildings were damaged in different ways: by flooding/submergence (by liquid water with a low sediment content), by filling with bedload transport (Figure 3 right), or by scouring of the foundations, (Figure 3 left). The main cause of structural damage to buildings is scouring of the foundations, with the rate of damage increasing sharply when the foundations become locally and then generally undermined.

Figure 3 : Post-event photos of the field: (left) St Dalmas de Tende, damage caused by scouring of foundations (Source: ONF-RTM); (right) St Martin Vésubie, damage caused by massive deposition (Source: ONF-RTM).

CONCLUSIONS

This contribution first emphasizes the need, the importance and the relevance of a back analysis after an extreme event and how it was organized into two complementary groups: hydrological and morphological. In a context where peak flow estimates are subject to considerable uncertainty and where hydrology alone cannot explain the magnitude and damage of the event, the morphological group revealed the exceptional nature of the event. The analyses focused on morphological changes, transport of sediments and large wood, the impact on buildings and structures crossing the river, and a comparison with existing risk warning and information documents on the potential extent of flood-prone areas (not shown in this paper). They all lead to the conclusion that the floods that occurred on October 2nd 2020 in the Vésubie and Roya valleys are without precedent for several centuries.

From a methodological point of view, it is worth highlighting the contribution of new technologies (LiDAR surveys, aerial photographs, mobile data collection application) for optimizing the organization of field missions as well as for studying sediment transport and morphodynamics. Another significant advance was the organization of field surveys of morphological indices of flooding and of damage to key areas using robust indicators inspired by existing studies, which should enable the data produced to be used in subsequent studies.

Finally, this back analysis proved to be an essential tool to support the State and local authorities during the reconstruction phase, with the aim of controlling land use planning and reducing vulnerability to future severe weather events. Firstly, this work produced detailed maps to keep track of the main areas affected in the two basins. In addition, it was also an opportunity to define fundamental principles of river management and training aimed at reducing the vulnerability of redevelopment and of the assets at stake, to better prepare at-risk areas for possible future events. Finally, it provides a database that will be used for scientific research in a wide range of fields (hydrology, geomorphology, hydraulics, risks).

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