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STÉPHANE COSTA (*), DANIEL DELAHAYE (*), PAULINE LETORTU (*),
JOHNNY DOUVINET (**), OLIVIER CANTAT (*) & ROBERT DAVIDSON (*)

SPATIAL COEXISTENCE AND TEMPORAL LOGOUT BETWEEN MAINLAND AND MARINE HAZARDS IN UPPER NORMANDY (NW FRANCE)

ABSTRACT: COSTA S., DELAHAYE D., LETORTU P., DOUVINET J., CANTAT O. & DAVIDSON R., *Spatial coexistence and temporal logout between mainland and marine hazards in Upper Normandy (NW France)*. (IT ISSN 0391-9838, 2013).

This paper focuses on the spatial coexistence between different hazards (strong west winds, beach sedimentary crisis and flash floods) in outlets of small catchments in a sedimentary basin. This study was carried out in the department of Upper Normandy located in north-western France. To anticipate possible future hazards and damages without depending on meteorological triggers (neither intense rainfall nor synoptic conditions), we combine previous knowledge accumulated on local phenomena to highlight the pre-conditioning factors and identify those areas characterised by the highest susceptibility to risk due to the accumulation of numerous hazards. This approach enables both space and time distribution patterns of natural hazards to be revealed. In space, the risk susceptibility strongly depends on morphology. Populations located at the outlet of large wet valleys, at the final outlets of small basins at a short distance from the plateaus and on the coastal fringe appear to be the most endangered. Even if hazards never occur at the same time, these areas can be affected by different hazards during one year (summer flash floods, floods, winter storm surges). This study identifies 14 sensitive areas along hollow shapes of the study area. Finally, our methodological investigations question the creation of a warning system combining mainland and marine hazards in these 14 outlets.

KEY WORDS: Natural hazards, Spatial interactions, Parisian Basin, France.

INTRODUCTION

Both the mainland and coastal parts of Upper Normandy (France) present a strong sensitivity to hydrological risks (fig. 1). Three reasons can explain this characteristic. Firstly, there is a close relationship between their morphology (hollow shape) and human occupation. In fact, urbanisation is preferentially located in the valleys and «*valleuses*» (*i.e.*, dry valleys), which can be flooded but are the only link between the sea and inland. Secondly, this department is characterised by a sharp interface between land and sea. For example, cliffs frame the valleys over 50 m and the slopes of the valleys and their thalwegs are often steep. Thirdly, there is a strong spatial proximity between vulnerabilities and hazards (*i.e.*, flash floods/coastal flooding) that occur over a very short time-duration (short time interval between the preparation of the phenomena leading to damage and the occurrence of risk). It should be recalled that these hazards (coastal flooding and mainland flooding, including flash floods) are among the most fatal phenomena in France (Costa, 1997; Delahaye, 2002; Douvinet & Delahaye, 2010). To improve knowledge on this topic, we combined various scientific data collected during previous field-experiments and research (Delahaye, 2002; Costa & *alii*, 2004; Douvinet, 2008; Letortu, 2010). This paper presents the different features of the hazards that are concentrated in the hollow shapes of the study area. By studying past phenomena, their spatial distribution can be better understood and some solutions for the management of hydrological risks can be provided.

STUDY AREA

The department (*i.e.*, administrative sub-division in France) of Upper Normandy corresponds geologically to the north-western termination of the Parisian Basin. The plateau of Upper Normandy and its cliffs are formed by Cretaceous (Cenomanian to Campanian) chalk and are more or less resistant to weathering. Residual formations

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(*) *Université de Caen Basse-Normandie, Umr-Cnrs Letg 6554 Géophen, Caen, France.* E-mail: stephane.costa@unicaen.fr

(**) *Université d'Avignon, Umr-Cnrs Espace 7300, Avignon, France.*

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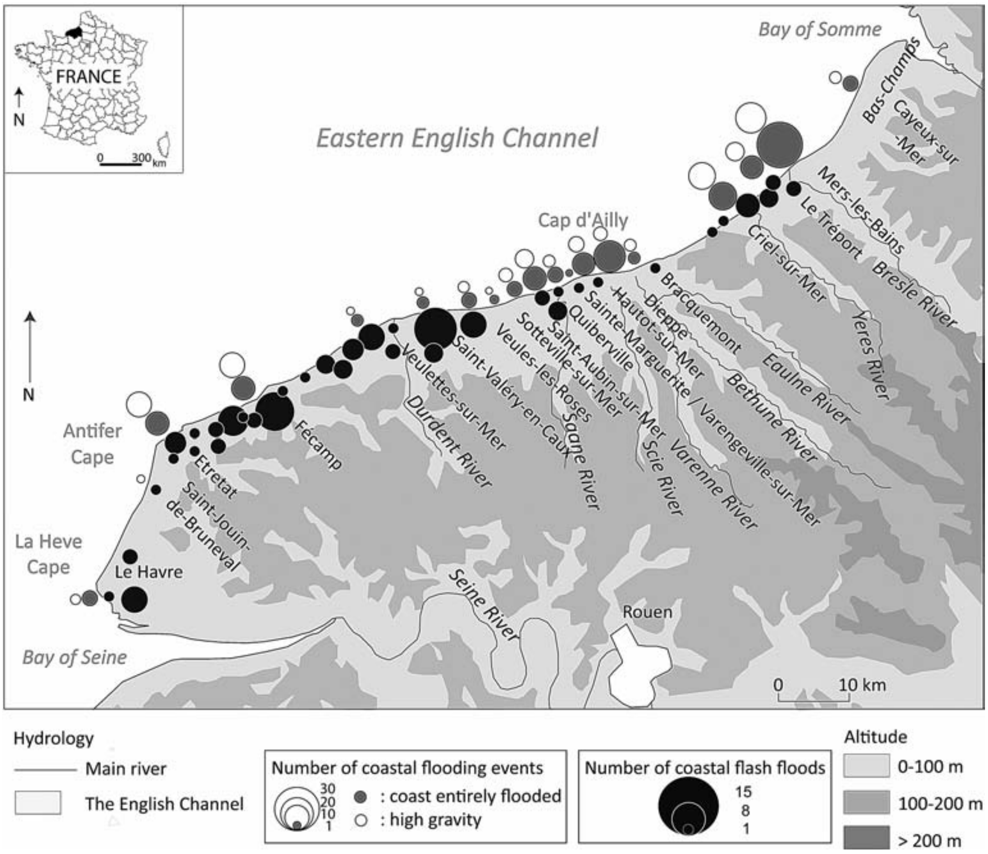


FIG. 1 - Urbanised valley of Upper Normandy affected by storm floods between 1949 and 2010 (from Letortu, 2012) and flash floods between 1960 and 2000 (from Delahaye, 2002). Source: Number of coastal flooding events from Les Informations Dieppoises, Ouest-France, Liberté de Normandie, commune and department files, CETE of Rouen files, scientific papers, Costa (1997), and MEDDE - Ministère de l'Ecologie, du Développement Durable et de l'Énergie files from 1949 to 2010).

with flint and Quaternary loess are also deposited upon this karstified chalk. These plateaus are cut by valleys, whose orientation is driven by the major tectonic deformations (NW-SE direction). The Pays de Caux is specifically a homogeneous plateau with an elevation ranging from 140 m to 3 m. Nearest the English Channel (*i.e.*, La Manche), steep cliffs can reach an elevation of 120 m (Étretat). The eastern termination of the Pays de Caux corresponds to the Pays de Bray syncline, cut off by a double cuesta where Jurassic rocks outcrop. This plateau is delineated by the Seine River to the south. The upper Cretaceous chalk associated with sandstone (Cenomanian) or flint in various proportions (Turonian, Coniacian, Santonian, Campanian) represents a thickness of 300 m. Flint clay generated by climatic variations during the Cenozoic period appears locally and the onset of glaciation cycles during the Quaternary period has induced differential erosion.

The first period of incision by hydrographical networks over the Tertiary formations began during the Early Pleistocene, concomitant with the start of a gentle surrounding of the plateau estimated at 0.05 mm/a (Lautridou & *alii*, 1999). The incision lasted during the Pleistocene and occurred synchronously with significant loess supply, thus leading to the formation of soils. The incision of slopes and valleys has evolved over the last million years following climatic variations and interactions in time between freeze and thaw periods, especially on the slopes exposed to the north. Finally, the biggest loessic accumulation appeared during the Late Pleistocene with an elevation ranging from 7 m to 8 m (Lautridou & Coulthard, 1995).

The landscape currently consists of successive sub-horizontal to slightly undulating plateaus that are incised by «dry valleys» inherited from the Quaternary periglacial periods (Lahousse & *alii*, 2003; Larue, 2005). This inherited network presents a multi-scalar form with valleys highly susceptible to react during intense rainfall. Elementary catchments constitute the smallest element of this network, with an area less than 1 km^2. However, when the plateaus are sufficiently developed between two permanent rivers, catchments can cover larger areas (ten km^2) with a Strahler indexation of 4 (fig. 2).

The dominant soils (luvisols) are highly exposed to erosion due to low levels of organic matter (<2%) and clay (<15%) but high silt contents (>70%). Soil sensitivity has been well demonstrated in several previous works (Auzet & *alii*, 1995; Souchère, 1995; Le Bissonnais & *alii*, 2002): 67% of the 189 catchments (fig. 1B) present a high sensitivity to erosion during summer and 58% during spring. Surface degradation under raindrop impact induces a strong reduction in infiltration capacity and a progressive disappearance of soil roughness, which together provide significant concentrated runoff waters (Delahaye, 2002). For this reason, soil erosion has first been studied in this region in the context of land-use dynamics, agricultural practices and long-duration rains.

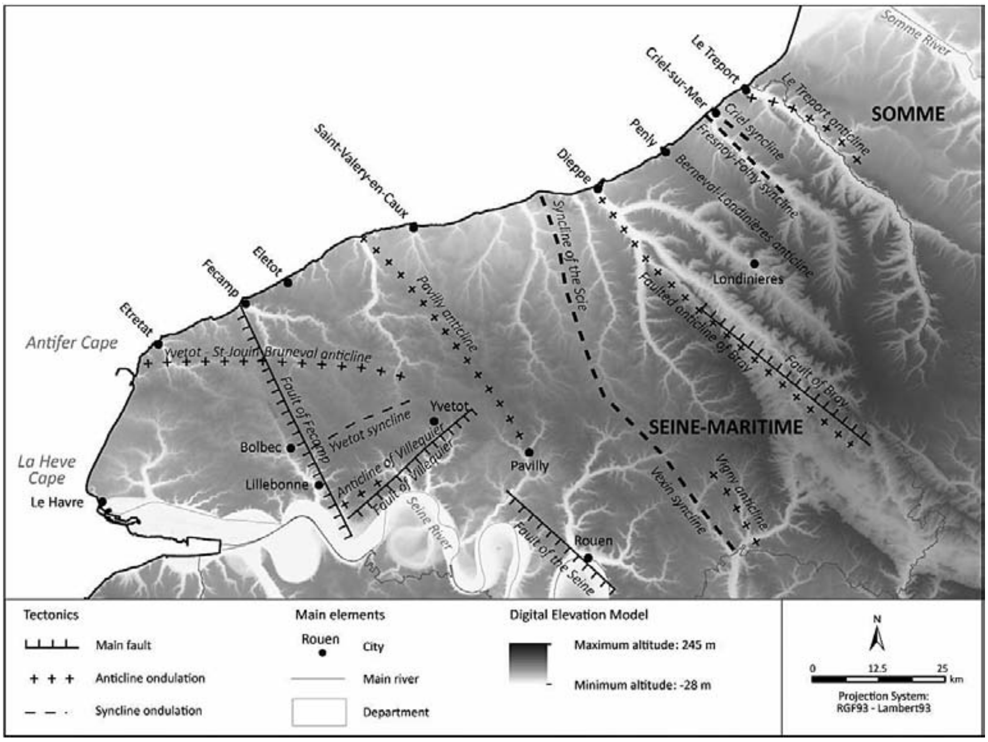


FIG. 2 - Location map, hydrography and morphostructural characteristics of the studied area. Source: BD Carthage® and GEOFLA®, IGN 2011, and Mégnien (1980).

The climate of Upper Normandy is oceanic and characterised by mild temperatures and normal humidity levels. Winter temperatures are positive (an average of +5 °C in January) along coastal parts and slight differences are observed with those recorded in Rouen (+4 °C). Summer is also temperate, with an average of +17 °C in July both within and behind coastal areas. Rainfall is equally distributed over the year, but this homogeneity hides large disparities in space and time. For example, there is a rainfall gradient between the western parts (1100 mm/a in Bolbec) and the drier south (only 650 mm/a in Rouen) while coastal parts are also dry. Heavy rains can also hide more intense rains, observed during the spring or summer periods. On average, 35 days with rainfall up to 10 mm are recorded but daily rainfalls of up to 30 mm are also frequent (fig. 3).

Along the coast (120 km-long from Cap d'Antifer to Le Tréport with chalk cliffs averaging approximately 70 m in height), chalk cliffs are interrupted by drained or dry valleys, which are the only links between the sea and inland. This is why coastal communities and areas of economic activity are preferentially located in these valleys, although they are liable to flood (marine and mainland floods). Several sectors are prone to flooding due to morphostructural and climatic factors (facing the westerly fluxes associated with mid-latitude low-pressure systems). Furthermore, significant urbanisation occurs at elevations often lower than the high-water level of spring tides. Together, these patterns make the Upper-Normandy coast particularly exposed to natural hazards, namely coastal flooding. Although this hazard has always threatened the study area, it is currently of concern to policymakers and populations because of the increasing repetition of these phenomena over the last forty years. At the foot of the coastal cliffs, a shore platform is cut into the chalk substrate and the seaward slope is gentle (1° maximum at Antifer). This wide shore platform (150-300 m) is covered on its landward margin by a thin gravel beach. In fact, the numerous dry and drained valleys perpendicular to the shoreline are protected by a gravel beach that is often thick (due to the presence of jetties and groynes) and 30 m to 100 m wide. Behind the urbanised valleys, the gravel beaches are blocked by a seawall parallel to the coastline, whose purpose is also to protect the lower coast (fig. 2).

The strongest and most frequent waves (Hs) develop to the west, causing a dominant longshore drift of beach gravels from southwest to northeast. Any notable wave height is still below 1 m during 70% of the time, 2 m for 95% of the time, and exceeds 3 m 0.3% of the time, *i.e.* 25 h/a. The wave period varies between 2 s and 19 s, but the average is *ca.* 5-7 s. For stronger waves, the period is *ca.* 7-10 s. In the English Channel, the tide is semi-diurnal. The tidal range is *ca.* 8.5 m in Dieppe for an average spring tide, defining a megatidal environment. For an exceptional spring tide, the tidal range increases from Le Havre (8.1 m) to Le Tréport where it exceeds 10 m (SHOM, 1999).

SPECIFIC FLASH FLOOD FEATURES

In the last two decades, flash floods have posed serious risk conditions in the small valleys located in Upper Normandy (Douvinet, 2008; Delahaye & *alii*, 2010; Douvinet & Delahaye, 2010; Douvinet & *alii*, 2013). They are gener-

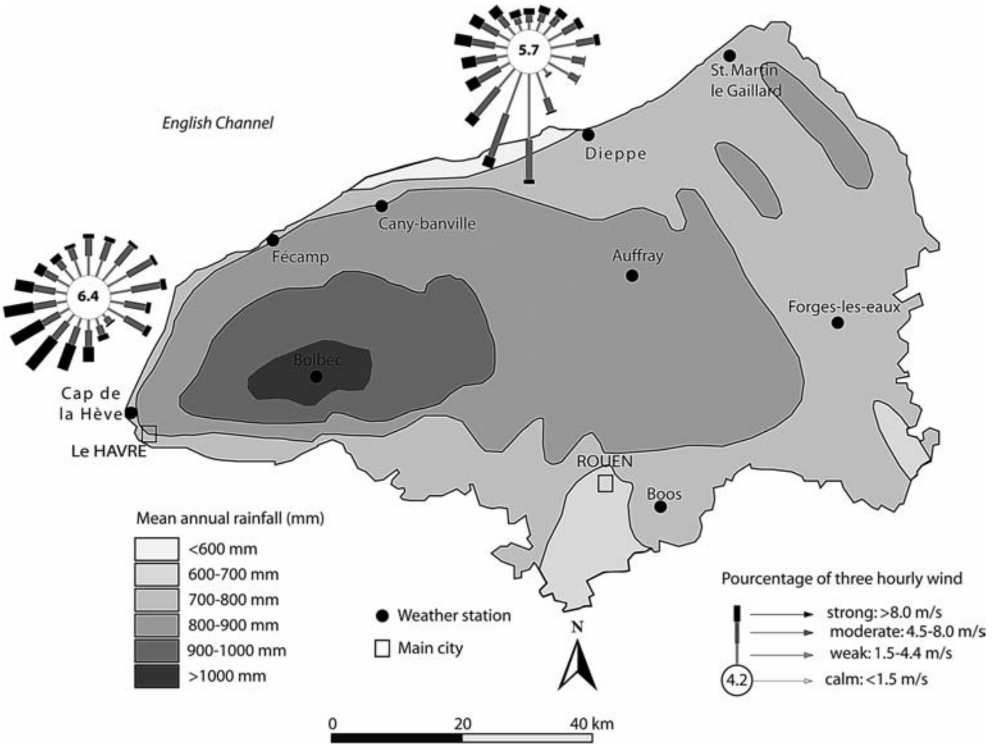


FIG. 3 - Distribution and height of yearly rains and winds observed in Upper Normandy. Source: Météo-France, Time periods: 1981-1990 for La Hève and Dieppe. Nota: for the readability of the map, wind roses are not exactly positioned at the location of stations but are representative of studied sectors. DIREN: Mean annual rainfall.

ated during and shortly after high rainfall intensities during the spring or summer periods, and are characterised by a sudden onset and a rapid rising time (fig. 1). These floods present similar features to those occurring in European sedimentary areas (Boardman & *alii*, 2003; Evard & *alii*, 2007): these phenomena reveal significant runoff production that strongly depends on spatial interactions between the morphology and nature of the land cover and rainfall intensities. High specific peak discharges (up to 1 m^3.s^{-1}.km^{-2}) and high specific shear stress (15-525 W/m^2) explain why we call them flash floods (Douvinet & Delahaye, 2010), even though the damage, the violence of onset and the rain intensity are different from those characterising the flash floods in the Mediterranean mountains (Montz & Grunfest, 2002; Gaume & *alii*, 2009). Such phenomena have been observed since the 1970s but damage increased over the 1990-2000 period (Delahaye & *alii*, 1999). Since the 2000s, the number of floods seems to have decreased due to the construction of dams and dykes and other structural measures (grass strips, bunds). The flash floods therefore occur following a similar pattern: an overall contribution of the catchments produces (i) high runoff, ranging from an average of 17% (overall rainfall event) to 100% (extreme, intense rains for a few minutes), and (ii) abundant sediment yield (ranging from 1% of the flood flow to less than 10% in rare field-experiments). Muddy flows quickly appear in the upstream part of the dry valleys and a surge generally rushes down the main valley just a few minutes after the rainfall peak. Numerous parcels located in the downstream part of the plateaus then present rill erosional forms. Flows endanger the population when they are sufficiently concentrated in space (*i.e.*, when the water height exceeds 1 m or when the flow velocity is up to 1 m/s) or when the total amount of water supplied in the downstream part of the catchments threatens urbanised areas.

Each of these patterns may be related to a distinct hydro-meteorological event: floods during the spring or summer periods (from May 1st to September 10th) and winter floods, respectively (fig. 4):

– The spring and summer events are generated by thunderstorms with intense rains (*i.e.* between 50 to 100 mm in a few hours). The process is different from winter floods because previous rains do not play a key role, except during the events observed in May as this period relates the winter to the spring process. Sub-torrential flows quickly occur because rainfall intensity exceeds infiltration capacity, so that runoff constitutes the only source of flows. All the field-experiments prove that land cover and mainly the relationships between runoff production and infiltration areas are of prime importance in the occurrence of flash floods. Affected catchments are characterised by small areas (<40 km^2) and the highest slope gradients of the study region (up to 15% in shallow slopes). Catchments ranging from 10 to 20 km^2 in area generate the most sudden onsets as they cumulate high surface flow concentrations and the main valley concentrated runoff coming from upstream (Douvinet & *alii*, 2013). In this case, the time of concentration is the more important trigger, rather than the cumulative amounts of water. Secondly, morphology and local topography is the dominant controlling factor as explained by the synthetic functioning scheme proposed in previous studies (Delahaye, 2002; Lahousse & *alii*, 2003; Douvinet, 2008). Affected catchments always present a

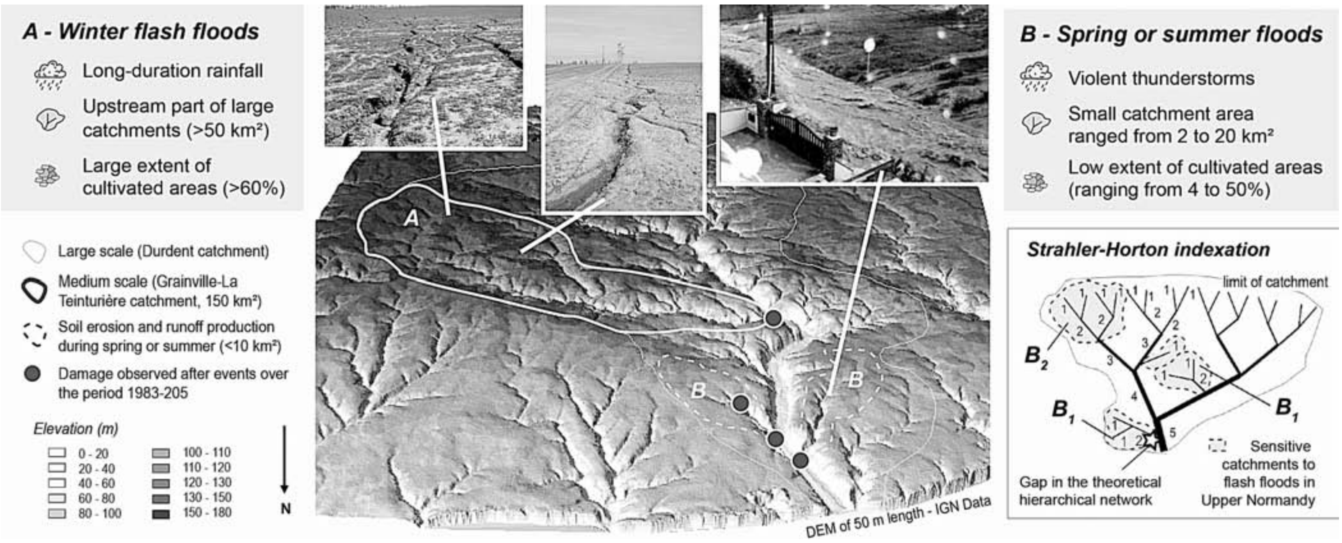


FIG. 4 - Simplified diagram of spatial interaction between winter or spring and summer events, explaining why flash floods occur in dry valleys in northern France.

gap in the Strahler-Horton indexation. Catchments have values ranging from 2 to 4 but they are connected to orders of up to 7 (wet valleys). This anomaly in the theoretical Strahler-Horton indexation is explained by the longitudinal profile (marked) and the slopes (exceeding 10% in the main dry valley bottom). This gap makes up for the relief differences between plateaus and wet valleys. As a consequence, by collecting water and runoff amounts, the main valley can generate most of the damage if urbanised areas are located at the outlet of these small basins.

– Winter floods are due to heavy but gentle rains. Such events require large cultivated areas within catchments (over an area of more than 1 km^2) that produce high runoff amounts. Floods generally appear in the downstream parts of catchments in which a large number of elementary catchments and plateaus are characterised by low slope gradients. In these catchments, floods are of high frequency, and runoff can occur at least once per year. High cumulative amounts of rain explain why local runoffs change into severe flash floods (Papy & Douyer, 1991; Auzet & *alii*, 1995; Le Bissonnais & *alii*, 2002).

The controlling factors are different for spring and summer events, and for winter events, thus both types of flash flood coexist in space. First, winter phenomena are not sensitive to slope gradients, as their occurrence is explained by the nature of soils (especially the percentage of silts) and agricultural practices. Large catchments with gentle slopes, a high percentage of cultivated areas and an advanced rill network are thus the most sensitive areas to generate winter floods. Small basins with few cultivated areas do not generate winter floods because they cannot gather enough water. To activate the small catchments, rainfall intensity has to exceed infiltration capacity, giving a strong controlling effect to the local morphology, especially high slope gradients and steep longitudinal profiles. Following this assumption, all the municipalities located near the coastal fringe of Upper Normandy are sensitive to flash floods, and especially during spring periods. These areas are indeed located at the outlets of small dry rivers or in the lower part of wet valleys, and they are also systematically connected to adjacent catchments with higher slopes. All the municipalities were affected over the 1980-2010 period (*e.g.*, Étretat, Fécamp, Veules-les-Roses, and Saint-Valéry-en-Caux). The catchments have been morphologically shaped by the flash floods but human settlements have never decreased over the last thirty years. Consequently, properties are exposed to stream flows and the damage can be substantial: the 1997 flash flood event at the outlet of the Saint-Martin-de-Boscherville catchment cost more than 14 M¤. Furthermore, the spatial proximity between hazard and vulnerability strongly endangers the population.

STORM-SURGE AND STORM-FLOOD HAZARDSOWER COAST

Each year, a high toll is paid by French coastal areas during meteorological and marine peaks. Due to the concentration of activities and population on the coastal fringe, the forecasting and prevention of natural hazards are fundamental economic issues. Because of cumulative factors (exposure to strong west winds, sedimentary crisis on beaches, low elevation of valley bottoms), the lower coastal areas of Upper Normandy are of interest in the analysis of risk due to coastal flooding (Caspar, 1988; Caspar & Poullain, 1996; Costa, 1997; Galli & Hontarrède, 2001; Costa & *alii*, 2004; Pirazzoli & *alii*, 2006; Caspar & *alii*, 2010). Societal vulnerability, which has always affected the study area, is becoming of growing concern to policy makers and to the population due to the increasing repetition of these phenomena over the last forty years.

Coastal flooding in the eastern English Channel (tide regime) is the result of a combination of low atmospheric pressure and strong winds perpendicular to the coast during spring high tides. This flooding can occur by overtopping, overwash, or breaching of coastal defence infrastructures (Besson, 1991; Reeve & Burgess, 1993; Garry & *alii*, 1997; Perherin & Roche, 2010). For the Upper-Normandy shoreline, most coastal flooding events occur by overtopping and the beating of waves against the seawall, leading to the flooding of lower valleys. From an inventory of past events (Costa, 1997; Costa & *alii*, 2004; Letortu & *alii*, 2012), the aim of this work is to define the meteorological, marine, and geomorphological conditions leading to overtopping, and to discuss the possible changes in both the frequency and intensity of these hazards.

Meteorological and marine conditions leading to damage:

The adopted method is based on an inventory of all the events that have generated coastal flooding during the last sixty years (Letortu & *alii*, 2012). This record, derived from the local and regional press, was examined with great attention to mitigate the effects of «journalistic resonance» that can lead to an overestimation of the frequency and intensity of these phenomena or, conversely, their trivialisation. From this inventory, it was possible to determine the tide heights and wind forces which resulted in, and will result in, risk due to coastal flooding. This predictive approach, initiated in 1986 by the prefecture of Upper Normandy in partnership with Météo-France, is a simple method that is the basis of the coastal flooding warning system of the prefecture. For example, for the site of Fécamp, during a forecast tide height of 8.5 m (coefficient of 90 at Fécamp, appearing about 80 d/a), a wind of 38 knots from the western sector can generate overtopping (fig. 5). This type of approach can identify the periods of the year when the tides are at dangerous levels. If Météo-France forecasts a gale from the west quadrant at the same time, the population has to be particularly vigilant. Nevertheless, for similar meteorological and marine conditions, severe coastal flooding events or no flooding are alternately observed. This indicates that one or several other factors contribute to the process of coastal flooding.

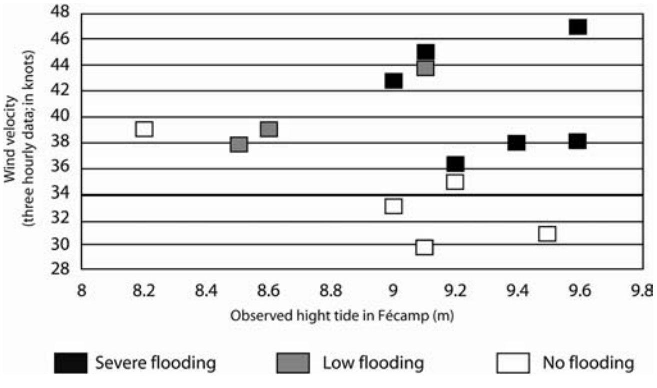


FIG. 5 - Tidal level and critical west-wind velocity for which sea flooding is possible at Fécamp (from Costa & *alii*, 2004).

Analysis of meteorological conditions on a synoptic scale during coastal flooding

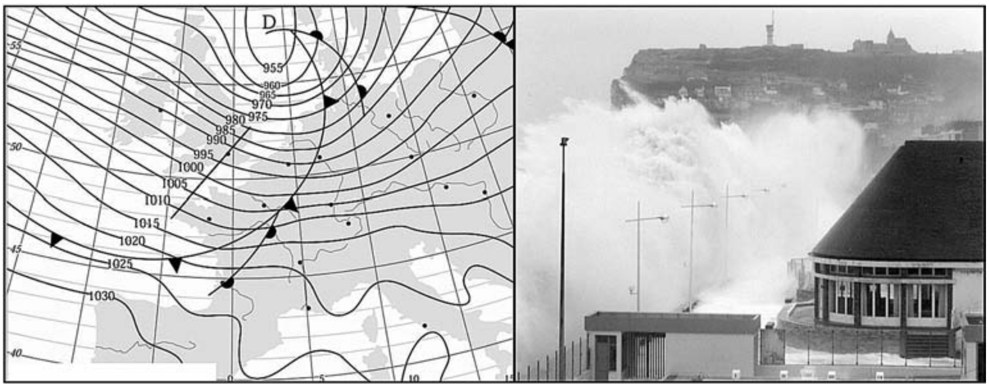
Due to the limited reliability of some recorded wind time series, a coastal flooding inventory was also used to determine, in both the English Channel and part of the North Sea, the main meteorological aspect of these events leading to damage. This analysis was conducted from more reliable documents for this type of approach, namely daily synoptic charts with the surface pressure [BQR (*Bulletin quotidien de renseignement*) and BQE (*Bulletin quotidien d'étude*)]. Thus, two major types of atmospheric circulation leading to flooding were defined.

The first, accounting for roughly one third of the observed cases, corresponds to a movement from west to east of a young, low pressure accompanied by NW winds immediately behind the barometric minimum (fig. 6). The second major type of atmospheric circulation, which has provoked severe storm flooding events, corresponds to the penetration of an Atlantic low pressure (higher latitude low pressure) in the North Sea, moving to the Netherlands or Scandinavia. Finally, the fundamental meteorological characteristic of these events leading to damage corresponds to a high northwest pressure gradient (measured from «Pointe du Raz» (France) to Cromer (UK) higher than or equal to 20 hPa (or 4 isobaric intervals).

The systematic analysis of daily synoptic charts performed from 1894 to 2003 shows no significant trend over the last 110 years (fig. 7). However, some multi-year oscillations, more or less acyclic, are clearly individualised (the period 1970-1990 is remarkable for this; Costa, 1997), corresponding more to climate variability than to any other variation or temporal trend. The significant repetition of severe coastal flooding between 1970 and 1990 is obviously linked to these peak situations that other studies have also highlighted (Lambert, 1996; Hofstede, 1997; Alexandersson & *alii*, 1998; Héquette & Vasseur, 1998; Schmith & *alii*, 1998; Wasa Group, 1998; Jones & *alii*, 1999; Alexandersson & *alii*, 2000; Pirazzoli & *alii*, 2004). However, since the early 2000s and until today, these synoptic situations potentially generating damage have decreased significantly (Wang & *alii*, 2011; Ulbrich & *alii*, 2009; Garnier, 2012; Letortu & *alii*, 2012; Schoenenwald, 2013).

The meteorological analysis of past coastal flooding events (since 1967) has highlighted that nearly 70% of the cases observed occurred at or shortly after the passage of an atmospheric cold front (fig. 8; Costa & *alii*, 2004; Caspar & *alii*, 2007). In fact, when an atmospheric cold front approaches, several phenomena appear prone to overtopping. Firstly, the pressure drops dramatically, reaching its minimum at the front, and the wind force increases. Just after the front occurs, the pressure begins to increase, and the wind (i) undergoes a significant rotation, turning to the west or to the northwest, (ii) remains strong and (iii) is characterised by the occurrence of very strong gusts. This situation results, on the one hand, from the creation of a storm surge at the cold front due to the barometric minimum and, on the other hand, from the emphasis of the water flow perpendicular to the coast induced by

FIG. 6 - Example of an atmospheric situation generating significant storm floods: NW pressure gradient of 30 hPa, 6 isobaric intervals intersecting the line segment connecting the Pointe du Raz and Cromer (1990/2/26, situation at 12:00 GMT, and storm flooding at Fécamp). Photo credit: S. Costa, Fécamp in February 1990.



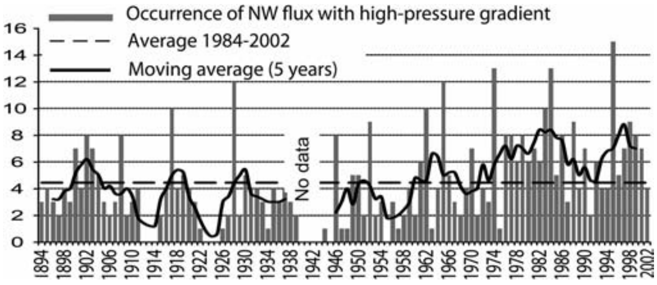


FIG. 7 - Annual evolution of atmospheric situation (in frequencies) with a high northwest pressure gradient (≥20 hPa) between 1894 and 2002 (from Costa, 1997; Costa & *alii*, 2004).

strengthening and the fact that the wind has turned to the west. Wind speed and (momentarily) wave height increase while, more importantly, the sudden change in wind direction is favourable to the formation of a crossed swell. This leads to beach lowering and the projection of large volumes of water above the seawall.

To summarise, it appears that coastal flooding events result from a combination of interacting factors, which depend on the position of the main low-pressure centres, the trajectory and displacement speed of low pressure, disturbances of the sediment budget of beaches, and the proximity of the cold front during high tide. Although the low coastal areas of Upper Normandy have suffered extensive damage, the perfect combination of factors (maximum height of the storm surge, wind at spring high tide, and passage of a cold front) has not been observed since 1960 (Pirazzoli & *alii*, 2006, 2007). Nevertheless, this combination is statistically possible. For example, the severe flooding of 1990/2/11-12 was associated with a storm-surge height of 70 cm, while 2 hours before the high tide, the

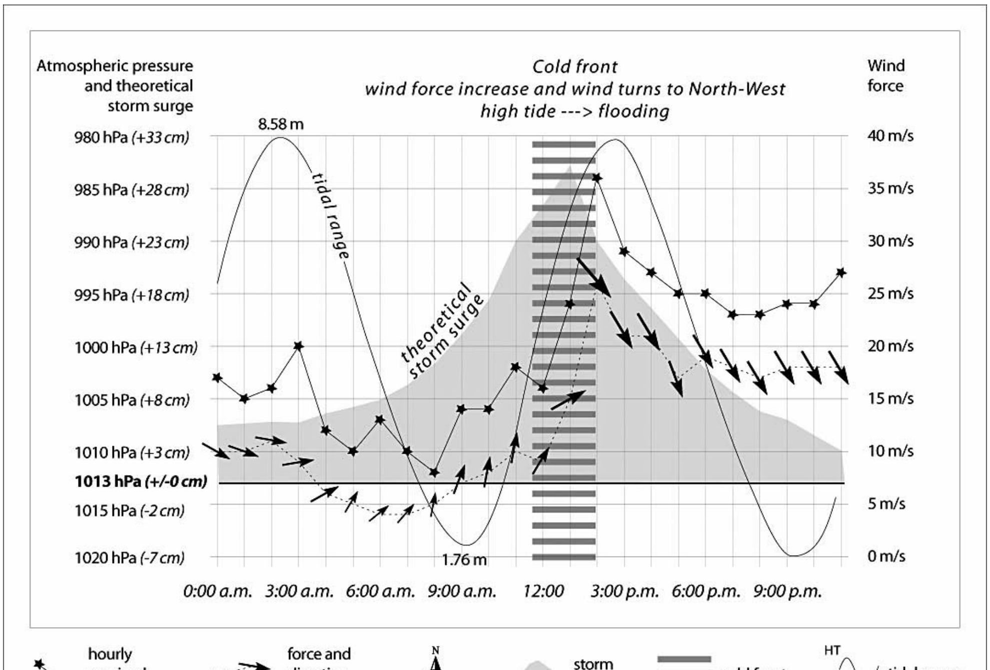


FIG. 8 - Coupling of meteo-marine elements (atmospheric pressure, storm surge, wind speed and direction, cold front, tidal) during the storm flooding of December 17, 2004 in Dieppe (data from Météo-France and SHOM).

peak of the storm surge reached 1.1 m. For this severe flooding, what would be the extent of the damage with a water level higher than 40 cm?

DISCUSSION AND CONCLUDING REMARKS

(i) A significant proportion of the habitation is concentrated in the valleys of the Upper Normandy plateau. These valleys are both the only points of access to the sea and the natural north/south axes of circulation, connecting the coast to the Seine valley. With 1,250,000 inhabitants, Seine Maritime, including its coastline (Dieppe: 33,000 inhab.; Fécamp: 19,500 inhab.; Saint-Valery-en-Caux: inhab.; Le Tréport: 5300 inhab.) is a populated French department (14th place). These figures do not take into account the influx of tourists. Industrial activity is also concentrated in these small valleys in contrast to the plateau devoted to agriculture.

(ii) Obviously, coastal towns are particularly susceptible to mudflows and especially those related to thunderstorms. They are located at the mouths of small coastal rivers in the lowest areas of the region. They are always in contact with small lateral basins with steep slopes linking the plateau to the lower valley. Thus, all these municipalities are endangered and most have already been affected (Étretat, Fécamp, Veules-les-Roses, Saint-Valery-en-Caux). Morphologically, these sites are very adapted to the formation of mudflows during spring (steep slope between the plateau and the lower valley, lateral small valleys) and they represent a significant vulnerability with numerous properties on the flow path.

(iii) Coastal towns are also sensitive to the risk of coastal flooding (storm) because of their low altitude and the concentration of people and activities. These phenomena are generally distinct but may be concomitant. Sometimes heavy rainfalls (cumulative or instantaneous) are blocked at the outlet of the river because of the maintenance of a spring high tide (for one to two hours) by a storm surge due to low pressure. The latter often leads to heavy rains. Thus, the geomorphological characteristics of the valleys (steep slopes covered with unconsolidated, erodible soil, low slope gradient of the longitudinal profile, low altitude in comparison with the current mean sea level) may combine to make these hollow shapes particularly prone to mainland and marine hydrological risks.

(iv) In both cases (flooding and mudflows), there is a spatial proximity between the hazard and vulnerability. For example, in the first case, the waves just need to overtop the dyke to reach the houses while in the second case, turbid flows have a short distance to go between the lateral small valleys and the urbanised areas of the valley. This closeness partly explains the danger of these processes that are sudden and hard to forecast. The spatial interaction between the two phenomena is also special because the same properties are exposed to the two different hazards. These coastal towns, located at the interface between land and sea, are also at the interface of hydrological risks. These phenomena have reciprocal routes (upstream and downstream), which complicates their management. For the first, access to the sea should be closed to prevent it from intruding while for the second the estuary should be wide open to allow the flood to escape.

(v) For all these reasons, these areas are subject to significant risks, which are difficult to manage, and in morphological and climatic contexts that do not seem to be the most sensitive. In the context of contemporary global warming, part of the scientific community of modellers forecast for this region an accentuation of the frequency and intensity of storms, winter precipitation, summer storms, and a rise in sea level. This situation could be particularly favourable to an increase in hydrological hazards leading to damage. Meanwhile, the attractiveness of the Normandy coast and its proximal territories (valleys) will intensify its vulnerability.

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