THE 2007 FLOOD IN THE EBRO BASIN (SPAIN): HYDROMETEOROLOGICAL PROCESSES AND RISK MANAGEMENT PERSPECTIVES

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1. INTRODUCTION, OBJECTIVES AND AREA OF STUDY

In spite of the fact that river floods are extreme episodes needed for the appropriate functioning of rivers and their associated ecosystems, the riparian societies do not coexist well with the floods. On the contrary, they suffer more damage every time as they have more interests in the areas subject to flooding. In developed countries and plain rivers, as in the case studied, enough planning mechanisms and security systems are available so that a flood does not become a drama, but a beneficial event for the river and the citizens' education instead. This paper is within the framework of the research line on fluvial systems in the territory of the river Ebro basin. One of this work's axes is constituted by the environmental and risk problems of the middle Ebro River and the search for mitigation and land management solutions. A good example of this due to its magnitude and mainly to its management was the March and April, 2007 flood recorded in the middle Ebro River. Up to now, the scientific study of this flood process has not been as important as the process itself.

The objectives of this paper are the determination of the relationship between the series of precipitations in the high and middle reaches of the Ebro catchment and the formation and development of the flood, the detailed assessment analysis of the March-April, 2007 flood in the middle Ebro, the identification and evaluation of the overflow that took place in the middle Ebro reach and the comparison of this flood's effects with the previous effects of February, 2003.

Being 930 km long the Ebro is the largest Mediterranean river of the Iberian Peninsula, its catchment ranked sixth in surface of the whole Mediterranean basin thanks to its 85000 km^2 and third if those catchments contributing water to the Black Sea are excluded. Its environmental and territorial importance, its riches as an ecosystem and its role in the configuration of a first class socioeconomic and cultural axis are outstanding. The area of study of this paper focuses in the middle Ebro River, in particular in the free meandering sector,

as it has the most remarkable flood processes, as well as population centres with a special risk situation. Along its entire middle reach it develops a 346,5-kilometer-long meandering channel (Figure 1) with a very low slope, being one of the most valuable examples of dynamic channel in Europe. The mean width of its extensive floodplain is 3,2 km, reaching a maximum width of 6 km. The mean sinuosity index is 1,505 and the mean channel slope is remarkably low: 0.67 m/km. This reach of the river has experienced very active dynamics, with continuous changes in its course, migrations and meander cut-offs. Although this high geoecological value dynamics has practically disappeared since the eighties of the 20th century, the erosion processes maintain a certain activity in some points. The river keeps on moving materials, maintaining the dynamicity in some gravel bars. The middle Ebro River has a pluvionival hydrologic regime, with a maximum in February and a low water season in summer, as Figure 2 shows. The middle Ebro interannual irregularity is remarkable, with coefficient values between 6 and 7, large floods coexisting with important low water seasons. Since 1950 the peak discharges of the extraordinary middle Ebro floods are shown in Table 1. All the extraordinary floods of the last century have taken place between November and March. The January, 1961 flood is the most important of the 20th century, with a return period of 84 years in the Zaragoza gauging station.

The methodology used for the study of this situation is the classic one, differing between its atmospheric aspects and the hydrological response of the river network. Nevertheless, the high interrelation of both elements means that the references between both of them are very frequent. For the study of the atmospheric phase the analysis outcomes of weather numerical models have been used, as well as various fields at different levels and satellite images. The spatial distribution of the precipitations has been studied by means of spatial interpolations using GIS of the daily data of the climatology network, represented here as accumulations for each of the stages in which the episode has been divided. The episode's hydrological evolution can be studied very much in detail thanks to the good gauging station network of the Ebro Basin Authority and the data availability of the Automatic Hydrological Information System (SAIH). In this case neither satellite nor aerial photography images have been used to assess the flooded surface due to the large cloud cover during the moments of maximum flooding.

2. THE MARCH-APRIL, 2007 EBRO FLOOD: METEOROLOGICAL ASPECTS

From the meteorological point of view, the episode was very long, from the 18th of March up to the 10th of April , along which three stages could be observed: a first stage corresponding to the typical winter flood situation, an intermediate transitional stage and a third one corresponding to the equinox flood situation.

The first stage was characterized by a trough at high levels with a N-S axis over the center-East of France that deepened towards the South between the 18th and 21st of March (Figure 4). At surface, the ridge that prevailed over the Iberian Peninsula moved back towards the West and gave way to an intense northern circulation, with successive frontal systems that produced many precipitations in the upper sector of the basin, mainly as snow, accumulating more than 200 mm in the headwaters of the Arga and Ebro rivers (Figure 5).

The second stage was characterized by jet stream disturbances –cold fronts associated to northern depressions- and their interactions with an isolated depression situated more to the South that was approaching the area of study (Figure 6). In the basin, the most significant characteristic of this second episode was the precipitation associated to an occlusion, which produced moderate precipitations – of around 30-50 mm- in a band in the meridian direction along the central zone (Figure 7). However, from the hydrological point of view, what was most significant was, undoubtedly, the result of the polar flow interruption and the warm advection that entailed the snow melt during the previous days in relatively low levels.

The third stage started on the 30th, when a new depression that had formed during the previous hours over the British Isles moved to the South following the high altitude path marked by the descending branch of the ridge that was becoming consolidated over the central axis of the Atlantic (Figure 8). Thus, the influence of the fronts and the systems associated to the depression increased on the basin and the intensity of the precipitations, which were widespread in the basin during the following three days, also increased. The depression, which was very deep, induced Southwest flow over the basin, with warm advection and produced precipitation accumulations of around 60 mm / 24 h in the headwaters of the Western and Central Pyrenean courses, as well as in the upper courses of the Prepyrenean tributaries (Figure 9). The precipitations of these three days were added to the runoffs generated by the snow-melt, reinforced by the warm advection and the precipitations themselves, to produce the third and most important peak discharge of the middle Ebro episode.

3. THE MARCH-APRIL, 2007 EBRO FLOOD: HYDROLOGICAL ASPECTS

The hydrologic progression of the flood is defined by the presence of three peaks that come after one another rapidly, the main one being the last one, with a total correspondence with the three stages of the atmospheric situation defined before (Figure 10). The flood was preceded by a less important one that left the soil ready to favour the runoff. From the rain falling in the basin headwaters on the 18th, the discharges of both the Ebro and the Aragon rivers started an increase on the 19th that became accentuated during the 20th and the 21st in Castejón and the 21st and the 22nd in Zaragoza that increased the discharges above 450 m^3/s, level more or less maintained up to the 24th. Very early that day in Castejón and at the crack of the following dawn in Zaragoza a quick discharge increase is observed that caused the first upward curves of this complex flood episode. Both in Castejón as in Zaragoza three peaks are perfectly noticed, separated by sudden and very significant drops of the circulating flow. The first of them was on the 25th of March in Castejón, some hours after the Arga, Irati and Ega rivers had their discharges increased. Also in Mendavia the Ebro discharge was high at those moments, exceeding 900 m^3/s. In Zaragoza the maximum discharge of this peak was reached during the evening of the 27th, with 1383.24 m^3/s.

When in Zaragoza the first peak was becoming evident, in the Arga River a rapid recession had already been produced that quickly evolved into a new upward curve that would lead to the second peak of the flood episode, of a secondary nature too. The second peak in Mendavia meant 955.4 m^3/s measured on the afternoon of the 28th of March, in Castejón it meant 2362.17 m^3/s recorded first thing in the morning of the 29th, being very clear in the contributions made to the Ebro by the Arga, Aragón and Irati rivers, the peaks of which

where reached on the 28th of March. In Zaragoza, after the discharge marked a much less important decrease than that of Castejón, the upward curve that led to the second peak of the flood episode started to take shape at the end of the above-mentioned 28th, reaching the crest, of 1885 m^3/s, the night of the 30th of March, 46 hours after it were recorded at Castejón.

Again the outline was repeated, so that when the second flood peak was evident in Zaragoza, upstream this gauging station a new downward curve had been completed and even the flood was drawing its depletion curve, although in Castejón the latter was only starting. On the 2nd of April there is a new twist in the flood evolution, as the discharges increased very abruptly, mainly those of the Arga and the Aragón rivers, but also the Irati and even the Gállego rivers and a bit less the Ega River. As a result, also the Ebro discharge increased rapidly in Castejón, although no increase was recorded at Mendavia, where the said depletion curve continued developing. This clearly shows that the waters that fed the main peak of this Ebro flood in Castejón and Zaragoza came essentially from the Arga-Aragón system. With all this, in Castejón the Ebro reached a maximum peak for the whole flood episode of 2825.60 m^3/s at noon on the 3rd of April. In Zaragoza, the peak decrease of the 30th of March was interrupted along the 2nd of April, a new increase starting slowly at the beginning and much quicker from the second half of the 3rd of April on. The main flood peak was recorded in Zaragoza between 11:30 p.m. and 11:45 p.m. of the 5th of April, with 2282.44 m^3/s, which means a very considerable lamination respect to the value reached in Castejón. The time lag between the peaks of these two Ebro gauging stations was practically 60 hours, almost double the usual time, as a result of the intervention in the floodplain allowing, by means of breaking some of the defences, the flood lamination and the loss of speed of its flood wave. Why the three peaks of the March-April flood episode in Zaragoza were so soft deserves special mention. It was due to both the natural and the induced lamination carried out in the vast floodplain existing between the Castejón and Zaragoza gauging stations by the Ebro Basin Authority.

4. DISCUSSION AND CONCLUSIONS

The analysis of this hydrometeorological event has shown the enormous monitoring options currently existing, both for the meteorological component, with data and pictures, and for the hydrological one, with real time gauging station records. This allows to establish and analyse in detail the cause-effect relationship between both components. Although these processes do not use to awaken so much public and scientific interest as those of the *flash-flood* type, the detailed study of a flood in an extensive basin with a vast floodplain also contributes data relevant for the knowledge of the natural dynamics of the system, useful for the land management.

With a return period of between 4 and 5 years in the middle Ebro, the March-April, 2007 flood was not relevant due to its volume but to its long duration and hydrometeorological complexity, that make this flood a good example to show the functioning of this type of processes in extensive river basins.

The atmospheric situation that produced the flood presented high space-time variability, so that processes like snowfall in different basin scopes, the various responses of these processes to warm advections, to the subsequent snowmelt and to the precipitations' change

from solid to liquid, gave especially interesting features to this flood process. These are shown especially in the three stages of the meteorological situation that gave rise to the three discharge peaks, the last one of them turning out to be the main one, when all the factors above noted acted sinergically.

The flooded surface in the middle Ebro only reached half the one recorded in the 2003 flood, although it meant that more defences were broken, as it was mainly the surface flow that acted instead of the relevance of the water table, as opposed to what happened in 2003. Nevertheless, the surface flooded in 2007 is still important even being an ordinary flood, which confirms the relevance of the middle Ebro as high-risk territory.

This flood's evolution has shown the correct combined management on the part of the basin and meteorological organizations, by means of prediction and monitoring tools. Once this management ability is demonstrated and the goodness of lamination in the floodplain itself is verified, it seems the right moment to take measures such as the withdrawal of defences, there where protection exclusively affects goods and not persons, and the creation of relief flows, always bearing in mind the River Mobility Area (Territorio de Movilidad Fluvial) perspective that enables the rivers to keep their dynamics and ecological diversity. This River Mobility Area, wide and continuous enough as to guarantee the conservation and improvement of the river and its banks, the management of the areas subject to flooding, the risk minimization and the plurifunctionality and sustainable development in the area subject to flooding, was approached as main objective in the Ebro Environmental Plan, involving the removal of bank defences and the withdrawal of dykes. The convenience of checking the current defence system and the need to define that River Mobility Area have become evident in the small June, 2008 flood, in which again dykes upstream Zaragoza had to be broken in order to reduce the discharge peak and thus protect the International Exhibition site just a few days before its opening.