Part 6:

Flood Hazards, GIS Applications and Flood Risk Management

49. FLOODING VULNERABILITY OF A TOWN IN THE TANARO BASIN: THE CASE OF CEVA (PIEDMONT - NORTHWEST ITALY)

F. Luino

Italian National Research Council (CNR) - Istituto di Ricerca per la Protezione Idrogeologica (IRPI) – Sezione di Torino, Strada delle Cacce 73, 10135 Torino, Italy.

ABSTRACT

Historical investigations covering the last 200 years (1801-2001) have shown that the Tanaro River (northwestern Italy) has been affected 136 times by flood events in different parts of its basin, with a recurrence interval of once every 18 months. During the first week of November 1994, following extremely heavy rainfall, a flood hit several areas of Piedmont and the Tanaro Valley in particular. The discharge of the Tanaro River was characterized by unprecedented peaks. Large inundations caused damage totaling over Euro 10 billion, with 38 urbanized areas along the valley bottoms flooded, 44 casualties and 2,000 left homeless.

Many surveys were carried out during the subsequent weeks in the most damaged urbanized areas to identify the flooded areas, to measure the water levels and to gain a better understanding of the flood dynamics. The geomorphological data were then integrated with an analysis of aerial photographs taken some days after the event. Using historical information, past floods were investigated, taking into consideration changes in the river beds and expansion of the urbanized areas that have taken place over the last 150 years.

This paper summarizes the results from a study about Ceva, a small town located in the Tanaro Basin, at the confluence of the Tanaro River and the Cevetta Stream. The town suffered many floodings in the past. A historical reconstruction of the urban development covering last two centuries demonstrates how Ceva expanded by occupying the areas of natural water expansion, showing little regard for the old inundations of Tanaro and Cevetta. For this reason, during the November 1994 flood, the damage was vastly greater than the preceding floods.

1 INTRODUCTION

The November 1994 alluvial event can be considered on a secular scale for the Tanaro River (southern Piedmont). To find a comparable case, it is necessary go back to the event of May 26-27, 1879. The first week of November 1994 was characterized by a persistent large depression over the Piedmont region that generated heavy rainfalls on the whole Tanaro basin (8500 km²). Intense precipitation began on the afternoon of November 2nd, and continued into the night of November 5th (Figure 1). In the first period, the rains were concentrated on the southernmost sectors of the upper Po basin, near the Ligurian border, and then moved northwards to the Langhe and Monferrato Hills, before reaching the foothills of the Alps. The Tanaro Valley was the basin most affected by the rainfalls of

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November 4-5th. Forty-two long-term series pluviometric rain gauges of the Tanaro basin recorded values above the previous maximums: in 4 cases for 1 day and in 5 cases for 2 successive days (Luino, 1999). All the Tanaro tributaries reached their maximum levels simultaneously, with unprecedentedly high hydrometric levels and discharges recorded in nearly each case. Along the tributaries and the Tanaro River many small towns suffered damage, as did some quarters of large cities (Alba, Asti and Alessandria) that were entirely flooded. These areas were mostly built during the 1950s--1960s, and since then have undergone further intensive and unorganized urban development, without correct land-use planning.

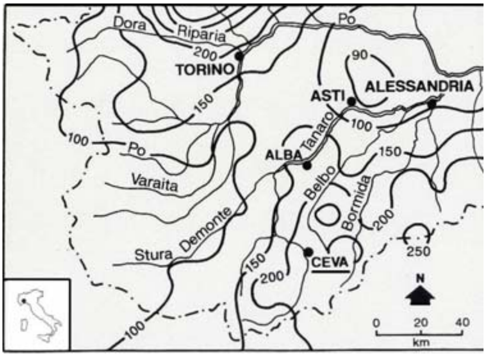


Figure 1 – Map of the Tanaro basin showing isohyetals (mm) of the November 5-6th 1994 event. The main tributaries of the Tanaro, Ceva and other important towns of the southern Piedmont are also indicated.

Figure 2 – "Gran Carta degli Stati Sardi in Terraferma" mapped in 1818-19. In spite of the scale at 1:50.000, the village is clearly visible: the core of the village is "packed" between Tanaro River and Cevetta Stream. In the south there is only a large agricultural area.

2 METHODOLOGY

In the weeks following the 1994 event in the Tanaro Valley, a systematic study of the flood-related effects was carried out to better understand the flooding dynamics. The inundated zones of the towns and the depth reached by the waterfloods were surveyed. The areas were also mapped in detail using snap-shots taken soon after the event.

The collection of other descriptive material including photographs and amateur movies and eyewitness accounts aided greatly in the comprehension of flood dynamics.

The historical investigation was carried out by analysis of the extensive cartographical and archival records kept at the IRPI of Turin since its foundation in 1970. After the 1994 event, the documents were integrated with unpublished records collected from the archives and libraries of the municipalities affected by floods. The study of historic maps revealed the various changes in the land layout that have taken place. The earliest reliable maps ("Gran Carta degli Stati Sardi in Terraferma", 1820-30), the later maps of the "Istituto Geografico Militare" (1875-1964), and the most recent technical maps (CTR, 1991) were used to trace the different phases of the urban development each town underwent and to reconstruct the history of the natural and man-made river changes. In this way, the historic inundations of each town were correlated to the their period of occurrence.

3 OLD INUNDATIONS

An in-depth study was made of the small town of Ceva (390 m a.s.l.), located in the southeastern part of Piedmont, at the confluence of the Tanaro River (391,5 km²) and the Cevetta stream (71,2 km²). Old documents, maps and technical reports were looked up in the municipal archive. Many documents classified in the category “Public works” contain information about past floods and references to the inundated areas, casualties, and the amount of damages they caused. Deep research in the archives of various Authorities working in land management were conducted. Books and newspapers were also consulted. This historical research demonstrated that Ceva (5700 inhabitants) has had a very long history of inundations since the 14th century.

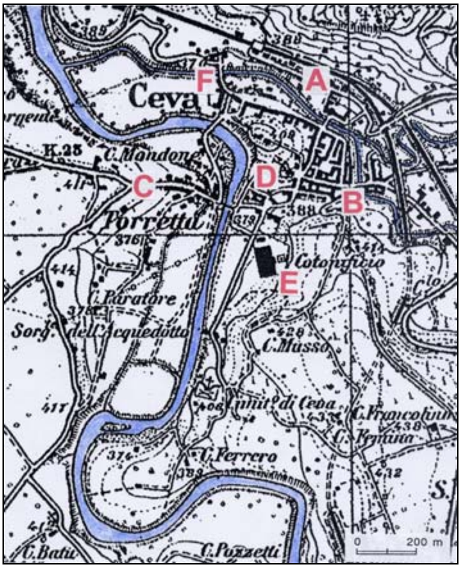
The earliest reports date back to October 7, 1331 when the village was inundated by the Tanaro River. The fury of the waters destroyed 4 of the 12 arches of the main bridge, a great part of the village was completely flooded and many people drowned. On July 6, 1584, a tornado hit the town between 5 and 9 p.m. Rainfall provoked a flood in the Cevetta basin. Many trees, shrubs and boulders jammed against a bridge, forming a dam that created a lake upstream. When the bridge collapsed, a large wave suddenly fell on the San Giovanni quarter, destroying a third of the houses and killing 156 people. Pieces of furniture and other remnants were found near Alessandria (165 km downstream).

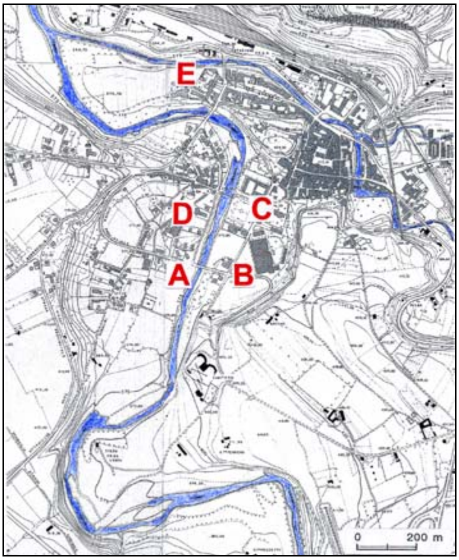
On January 14, 1610, another terrible inundation hit the town. According to Casalis, a famous 19th century Italian historian, a very large flood of the Tanaro River destroyed four forts, a bridge and 100 houses and claimed over 4000 victims. But according to another historian, this assertion was exaggerated: probably only 300 inhabitants died.

On October 4, 1744, a flood of the Cevetta Stream partially destroyed the well-built city walls; the waterfloods killed 12 people and many animals.

4 URBAN DEVELOPMENT AND INUNDATIONS IN THE XIX AND XX CENTURIES

The earliest map taken into account is the "Gran Carta degli Stati Sardi in Terraferma" (1819): in this map (Figure 2) the village is centred around the castle and the cathedral, that are located about 30 m higher than the surrounding area: the village is concentrated between Cevetta and Tanaro riverbeds and only a few houses are exposed to the floodings of the watercourses. The two banks are connected by the Cattalana bridge, already at that time made by the spans that exist today. In the southern zone, the large depression included between the village and the wide Tanaro bend is completely lacking in buildings.





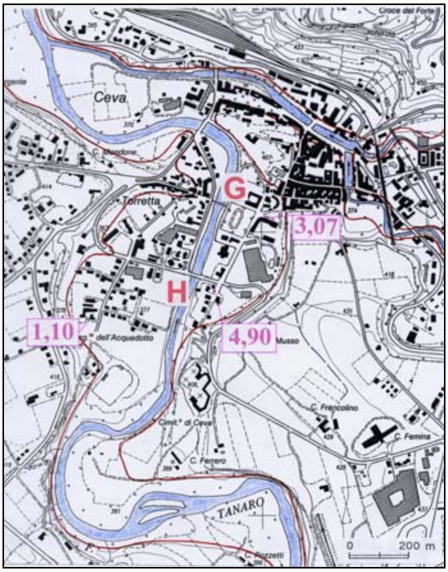


Figure 3. (top left) – Third edition of the Istituto Geografico Militare map, dated 1930. It shows how the urban centre grew in all directions and particularly to the North of the old centre, along the Cevetta Torrent, to the West (C), and to the South (E). All these areas were heavily damaged by the 1886 and 1926 events. **Figure 4.** (top right) – After the second World War there was a large urbanization. The 1971 map shows the urban expansion with the new buildings along the Tanaro riverbed (A-B-C-D), the same buildings that were heavily flooded in the November 1994 event. **Figure 5.** (bottom left) – November 5, 1994 map: the red line shows the largest extent of the Tanaro flooding. The water heights above the ground level, taken from the marks on the buildings (asterisks), are indicated in meters.

After more than one century, the 1930 map (Figure 3) shows great substantial modifications. In particular we can note the presence of the railway with the railway station (black lines) on the right Cevetta bank. In the same area there are two new bridges on the Cevetta and some new buildings on the right Cevetta bank (A), in the suburb of the old center (B), but above all on the left of the Tanaro (C, "Porretta" quarter) and on the south with a new area consisting of barrack (D), kindergarten (D), the spinning and water mills, schools, restaurant and a large industrial shed ("Cotonificio", E). Records show that on 1843 and 1885 the Tanaro inundated the area of the barrack, while on 1857 and 1876 the Cevetta flooded the A zone and some buildings in zone B ("Borgo Doria" quarter). But the heaviest inundation of XIX century occurred on November 10-11th, 1886. The Tanaro rose fast: waterfloods ran over the barracks square, the kindergarten, the spinning mill and the water mill, uprooting many trees, demolishing walls and carrying out everything. In the kindergarten a depth of 1-1.5 m was measured.

On May 16th, 1926 Ceva was heavily damaged by a contemporaneous inundation of the Tanaro and Cevetta. The Tanaro flooded the barrack square, while the Cevetta knocked down a parapet and invaded the streets along the riverbed, damaging a bridge and many houses. Sixteen years later, on October 28, 1942, the Cevetta flooded in a short time the urbanized areas located along the riverbed, reaching 2 m in depth. The Cameroni bridge (F) was undermined and blew up to allow a fast flow of the waters.

The next map considered dates from 1971 (Figure 4). In 41 years the town grew appreciably, in particular in the sixtees, increasing the urbanized area from 0.27 km² to 0.88 km² (+326%). In spite of many ruinous floods the most built up areas lie along the two riverbeds. In the southern part it is possible to note a new bridge (A). On the right bank, several buildings, a new school (B) and sports grounds (C) were built, while on the left, several houses and industries developed (D). On the left bank of the Cevetta, particularly close to Cameroni bridge, many houses (E) were built as well, although the zone was a well-known flood-prone area.

5 THE 1994 EVENT

The present urban condition is represented in the map of the 1994 event (Figure 5). This flood was the heaviest of the last two centuries. The Tanaro peak discharge evaluated by the slope-area method was about 1,300 m³/s, with a unit discharge of 2.8 m³/s km². Tanaro waterfloods spread in a wide area and the water levels in the town were the highest ever recorded. The Cevetta discharge was about 300 m³/s, a value probably already recorded in the 1942 event. The first peak of this torrent occurred around 10 a.m. on November 5th. Meanwhile, the level of the Tanaro was rising. At 6 p.m. the first peak occurred, followed by at least four other flood waves, until 10 p.m. In the centre of Ceva there are five bridges: two cross the Tanaro River and three span the Cevetta Stream, four of these proved to be too small. The bridge crossing the Tanaro along Provincial Road 225 (H) played a determinant role in the flood. Uprooted trees obstructed the flow, causing overflow of the structure and its outflanking. This led to upstream diversion of a huge amount of water and the subsequent flooding of the newest buildings located near the bridge to a depth of 4,90 m.

Damage was extremely heavy: 500 houses (30 of which were partly destroyed), 4 industries, 3 schools, the sports grounds were flooded, and the steel platform (G) was swept away. Total damage was estimated to be about 43 millions of Euros, comprising 13 for private houses, 18 for commercial activities and 12 for public structures. If a similar flooding had occurred in 1887, only 80 buildings would have been flooded, or only 15% of those inundated in November 1994. If the same flood had occurred in 1930, only 80 buildings would have been flooded, 15% of those damaged in November 1994.

6 CONCLUSIONS

Ceva is a classical example of an Italian town involved in inundation in the last decades. In spite of many severe alluvial events that occurred in the past, provoking many casualties (proved by documents and maps) the town has expanded, in particular after the Second World War, just in the areas particularly hit by waterfloods. The southern zone of Ceva, around the bridge of the Provincial Road, is characterized by a large flat valley bottom, where the Tanaro waters were used to spread during the inundations. For this reason, after the devastating flood that occurred on the Po Delta ("Polesine") in November 1951, this area was just called "Polesine" from its inhabitants. The zone was not urbanized, except for a couple of farms, until the sixties. In the following years a large urbanization began: many villas, detached houses, workshops, stores and two schools were built. During the 1994 event this area was inundated from 1,10 to 4,90 m in depth. A correct land-use planning to reduce the risk in heavily populated areas, has to take into account the information coming from historical research, the morphological evidences (like for instance palaeochannels), the presence of new man-made structures and infrastructures, with a precise evaluation of their interactions with the river's dynamics.

Following these rules a review of town planning procedures will be possible, introducing at the same time a compulsory insurance able to direct correctly the urban development of areas already heavily populated. These actions, together with a flow of information to inhabitants and local communities, could influence positively the present welfare system referring to the State in case of natural disasters.

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50. THE CATASTROPHIC FLOOD EVENT OF THE 18TH OF OCTOBER, 1973, IN THE RAMBLA OF ALBUÑOL (LA RABITA, GRANADA, SPAIN)

E.Romero Cordón[(1)], E. Alvarez Vigil[(1)], L. Garrido Perez[(1)], F. De Las Heras Martín[(1)], J.J.Duran Valsero[(2)] & R. Madrid García[(3)]

(1) Subdelegación del Gobierno en Granada. Gran Vía 50. 18071 Granada. Spain. Email: procivil@granada.map.es
(2) Instituto Geológico y Minero de España.
(3) Servicio de Protección de la Naturaleza de la Guardia Civil.

ABSTRACT

The catastrophic flooding on the 18th of October, 1973, in the dry stream (rambla) of Albuñol caused the loss of 46 lives, the destruction of 91 houses and serious damages to 141. A layer of mud (2 to 3 metres thick) covered the streets of La Rabita (the village most damaged). The roads and the bridges of comunication between the town and the rest of the province were destroyed along with 250 hectares of cultivated land. The damages were estimated at 300 millions of pesetas.
A heavy rainstorm (600 mm) produced the rapid development of a high density flow in the dry stream, with an elevated volume of sediments (1/3 of the discharge), that was the responsible factor of the high discharge reachedduring the flood (2580 m^3/s).
The object of this study is not only the identification of the episode and the analysis of the disaster's social impact, but also to analyse the different techniques to study the flooding in this type of fluvial system. The historic reconstruction of the event includes an analysis of the social impact and restoration works of the affected area. In addition the hydrologic analyses of the flooding that was based on the study of the greatest floods in small basins has been carried out. Finally, a morphodynamic and sedimentologic reconstruction was undertaken. The sedimentological study of deposits corresponding to the flash flood shows that the dynamic nature of these alluvial channels has important implications for floodplain management policy. The potencial for dramatic changes in geomorphic and hydrologic characteristics of alluvial channels must be considered in establishing procedures for flood hazard evaluation.

1 INTRODUCTION

Spain is periodically devastated by catastrophes. The measures taken to solve this natural risk are territory management policy by risk maps and the solutions of the emergencies once the catastrophe has happened. The flood of the 18th of October of 1973, in the dry stream (rambla) of Albuñol, constitutes a basic example of catastrophic flooding – a catastrophe of a low frequency and high magnitude event exceeding the balance of the fluvial system (*Schumm*, 1973) in a Mediterranean dry streams.

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2 THE HISTORIC RECONSTRUCTION OF THE EVENT

The rain started in the morning of the 18th October of 1973 after six months of drought. In total 600 mm fell, according to the *Comisaria de Aguas del Sur de España* records. At about nine o'clock in the evening (the river had half a metre of water) the rate of rain increased suddenly and the lights of the village went off. At midnight the river, about fifty metres wide and seven metres deep, overflowed. The majority of the habitants took shelter in the castle tower, the graveyard and nearby hills to the village, but the villagers that lived in two blocks of flats near the river and those living in the fishing district (*Rambla de la Mochila*) were left isolated. The rainfall became heavily torrential causing the formation of two massive waves over the river. The first wave went through the village at about half past three in the morning, razing crops, cars, houses, etc. The second wave pulled out a building, near the river, from its foundations and swept it to the sea with twenty seven people inside. At dawn the water had disappeared. The flood caused the following damages:

- The loss of 46 lives in the villages of *Albuñol, La Rabita, El Pozuelo* and in some isolated houses.
- Destruction of 91 houses and serious damages to 141.
- The streets of the villages *La Rabita, Albuñol* and *El Pozuelo* were left covered with a layer of mud (2 to 4 metres thick). Several cars were left buried.
- The water supply and drainage network were seriously damaged. Roads were destroyed (the C-333 and N-340), 30 km of country lanes ruined, 250 ha of cultivated land were devastated and covered by a layer of debris 2 to 3 m thick.
- Several industries were completely destroyed (Distillery, Gravel pit, etc).
- Creation of a delta over the sea about 200 metres long.

ADMINISTRATION	TYPE OF DAMAGES	EVALUATION
National Institute of Land Reform and Development	Devastated land recovery (3.265 has.)	173.638.000
	Recovery of irrigation systems	58.000.000
	30 Km of paths destroyed	12.000.000
Public Works	Conditioning of the road Granada – La Rabita	7.083.000
	New road between La Rabita and Albuñol	100.000.000
	Bridge construction	35.000.000
Confederacion Hydrografica del Sur	Channelling of the Albuñol rambla	450.000.000
	Recovery of irrigation systems	16.000.000
Delegacion de Vivienda	House construction and access conditioning	34.400.000
	Building repairs	3.177.000
	Repairs in the La Rabita Church	3.165.000
	School	30.000.000
Delegacion de Industria	Restitution of the electrical layout	4.536.000
	Industries	15.870.000
Delegacion de Education and Science	Child maintenance until school conditioning	14.180.000
Council	Structures	1.600.000
TOTAL COST		958.649.000

Table 1. Evaluated damages (in pesetas) caused by the flood event

3 HISTORICAL RECONSTRUCTION

3.1 Damage evaluation

The evaluation of the catastrophic damages elaborated by the Gobierno Civil of Granada (1974) shows the resultant social impact. Table 1 shows the evaluation of the damages made by each participant public organisations.

3.2 Aid organisation during the first days after the catastrophe

Work carried out during the first days of the emergency (Table 2) show the actions needed to be taken in case of similar emergencies and the organisations who are responsible for implementing it.

ACTIONS	ORGANISATION
Search and rescue of people	Guardia Civil, Army
Wounded evacuation to Motril Hospital (10 of a total of 25 seriously ill)	Helicópteros ejército S.A.R.
Accommodation and social assistance	Delegación Provincial de Acción Social y Sección Femenina
Victims evacuation to Motril and Adra	Cofradía de pescadores (por barco)
Medical assistance	Delegación de Salud,
Wreckage clearance and cleaning of village (94 houses destroy)	Guardia Civil, Bomberos, volunteers OJE, damnificados
Search and identification of mortal victims (46)	Guardia Civil, Grupo de submarinistas del Ejercito
Distribution of clothes and first aid equipment	Sección Femenina
Food distribution and organisation of a sufferers dining room	Guardia Civil, Sección Femenina
Incineration of dead animals	Guardia Civil, volunteers
Provisional electrical installation	Army
Repairs of the water supply network	Motril City Council

Table 2. Work carried out in the first days after the catastrophe

4 CONDITIONING FACTORS: INTRINSIC BASIN CHARACTERISTICS, HYDROLOGICAL AND GEOMORPHOLOGICAL ANALYSES

The importance of the great volume of material in suspension (see Table 3) as the leading factor of the high river flow reached is conditioned by:

- Basin topography with dominant slopes between 20 and 40 %.
- Poor development of soils with a tendency to slide off a rocky subsoil.
- The use of crops incompatible with the retention of the ground.
- The Flow Basin of the *Albuñol* rambla lies over metapelitic rocks overlaying carbonated materials, which outcrop at the base of the Aldayar and Agijón ramblas. The intense crushing suffered by the materials increase their facility to be altered, therefore they are an important source of solid material for the floods.

MORPHOMETRIC CHARACTERISTICS		HYDRAULIC PARAMETERS	
Basin area	116 km2	Maximum flow	2580 m3/s
Relief rate (Rr)	0.088	Liquid flow	1518 m3/s
Weigh slope	423 m/km	Solid flow	1062 m3/s
Average slope	30-40%	Drained total volume	17 Hm3
Elongation relation (Re)	0.51	Specific flow	13.4 m3/s/km2
Index of circularity (Cc)	0.45	Escorrentia coefficient	0.62
Index of compaction (Ic)	1.39	Stream flow velocity	3.44 m/s
Solids concentration	41%	Period of return	> 500 years
Index of torrentially	50	Calculated flow for 600 mm precipitation	2831 m3/s
Drainage density	10 km/km2<		
Concentration time (Tc)	4		

Table 3. Morphometric characteristcs of the basin and hydraulic parameters of the flood

5 MORPHODYNAMIC AND SEDIMENTOLOGICAL RECONSTRUCTION

5.1 Production zone

The production zone is identified by a predominance of erosive landforms (scars of sliding, landslides and important development of grooves) that occur in the basin. As depositional landforms the solifluction mudflows and the accumulation of fell boulders are frequent.

During the flood in the gauges excavated in limestone (2 to 3 m wide) the water raised tens of metres favouring rock falls that once combined with water multiplied the erosive power.

5.2 Transference zone

The BRAIDED PLAIN covered most of the river valley. The morphological adjustment of the braided channel to the flood, is changed into a channel surface increment that constitutes the braided plain. This erosive adjustment is produced as a consequence of the great magnitude of river flow and the high energy that had to be dissipated throughout the base of a relatively narrow valley.

The FLOODPLAIN takes up sheltered areas from the principal river flow, producing small terraces in the braided plain margins. The overflow deposit originated by the flood over those terraces was a layer of well graded sand and gravel with silt (10 to 30 cm thick). On the surface boulders, of 2-4 m diameter, can be seen that have been pulled up from the walls that protect the crops, and transported tens of metres. Linked to the boulders crescent mark structures can be seen.

ALLUVIAL FANS form where streams confined by narrow valleys emerge onto a plain or mayor trunk valley. The development of a small fan in the Barranco de la Mochila opening should be noted, located to the northwest of the La Rabita village, which buried a great amount of houses before going into the sea were it originated a fan delta.

The ACCUMULATION ZONE is formed by a delta which is the result of the amalgamation of a series of lobes whose growth, during the flood, advanced 200 m into the sea (Figure 1) with a thickness of 4 m in the apical zone.

Two types of deposits can be distinguished:

1) Sheet flow deposits: produced as a consequence of the flow expansion and a fast diminution of the water sheet. They constitute the principal deposit type in the construction of the different deltaic lobes. The development of those is, at the same time, in relation with the pass of the flow through La Rabita bridge and with the various destruction phases.

2) Overflow deposits: formed when the wall that was protecting La Rabita failed and the fine materials that were in suspension were deposited.

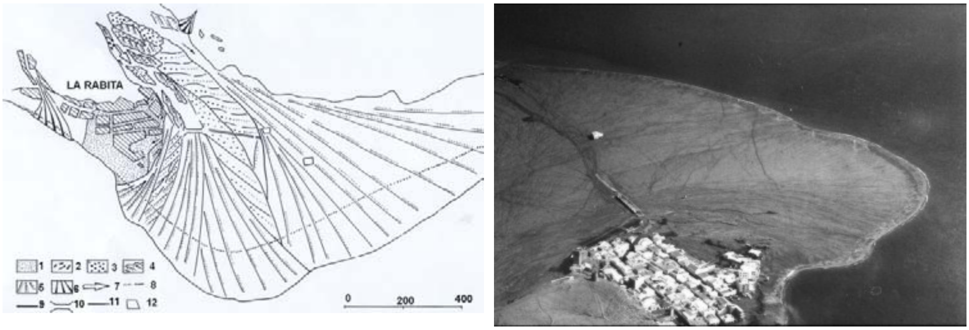

Figure 1. Distribution of erosive and depositional landforms caused by the 1973 flood at the Albuñol delta.

6 CONCLUSIONS

From the study of the 1973 catastrophic flood in La Rabita it can be deduced that the ramblas working system takes a drastic occupation of the valley bed, therefore it is important to take it into account for the territorial ordination of those areas looking for the maintenance of natural conditions.

The areas with high rates of erosion as well as those with a high sedimentation rate (alluvial fans), should be considered as areas with a significant risk, not only for low magnitude floods but also for greater floods.

The risk mapping should be carried out from an analysis estimation of the probable discharge, and bearing in mind the hydraulics and hydrologic characteristics together with the record of deposits.

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51. IMPORTANCE OF THE WATER TABLE RAISING IN THE FLOODS OF ZAFARRAYA POLJE (SOUTH SPAIN)

J. Gisbert[1], M.L. Calvache[2], M. López-Chicano[2] & W. Martín-Rosales[2]

(1) Department of Hydrogeology and Analytical Chemistry, University of Almería, Sacramento road, 04120-Almería – Spain. e-mail: jgisbert@ual.es
(2) Department of Geodynamics, University of Granada, 18071, Spain.

ABSTRACT

The Zafarraya polje undergoes periodical flooding, of which the last episode (1996-1997) is analysed in detail in this paper. On the basis of the retention curves of the two lakes that formed in the north-western and south-western sectors, we calculated the total infiltration capacity of the polje to have a maximum value of 3-3.5 m^3/s. Thus we infer that when the flow of the Arroyo de la Madre exceeds this value, there will be a risk of flooding in the polje. We also propose a model for the 1996 flood that can be extended to other similar occurrences in this and other poljes where we can establish the role played by groundwater and surface water during this flood. In response to the heavy precipitation, the flow of the Arroyo de la Madre rose abruptly, exceeding the infiltration capacity of the main swallow holes on the polje, causing first the northern lake and then the southern lake to form with only surface water supply. The water table of the karst aquifer rose sharply, reaching a situation of equilibrium between the level in the lakes and the water table in this sector that prevented infiltration through the swallow holes. In the case of the southern lake, there were even cases of swallow holes that began to operate as estavelles. During this phase of maximum flooding one single lake was present, which was divided into two once more when the water table of the karst aquifer in the polje sector began to fall and surface supply also began to decrease.

1 INTRODUCTION

Geologically speaking a polje is a large, karstic, closed depression with a flat bottom, often slightly tilted towards the drainage point and surrounded by steep walls and prone to intermittent flooding (*Prohic et al., 1998*). Poljes tend to be areas used for settlement and economic development. This study concerns the Zafarraya polje, in the province of Granada in southern Spain (Figure 1). Three main towns are located on this polje (Zafarraya, Ventas de Zafarraya and El Almendral,) with over 2000 ha of arable land that provide a high income per capita for the inhabitants of the region.

The Zafarraya polje is a tectonic, karstic depression situated in the limestone massif of Sierra Gorda, in the central sector of the Betic Cordillera and, more precisely, in the Subbetic Zone of the External Zones or South Iberian Palaeomargin (Figure 1). This massif consists of intensely fractured Early Jurassic limestones and dolostones over 1000 m thick (*Pistre et al., 1999*). The high permeability of the intensely karstified, carbonate rocks allows high infiltration of surface water. Thus, only Madre and Cazadores can be

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considered legitimate seasonal streams, the other tributaries being dry valleys. These two streams not only have larger drainage areas, but also flow locally over impermeable rocks allowing high surface runoff. Simultaneous measurements at different points show that this stream loses large amounts of flow (60%) through infiltration in the alluvial deposits of the eastern sector of the polje (*López-Chicano et al., 2002*).

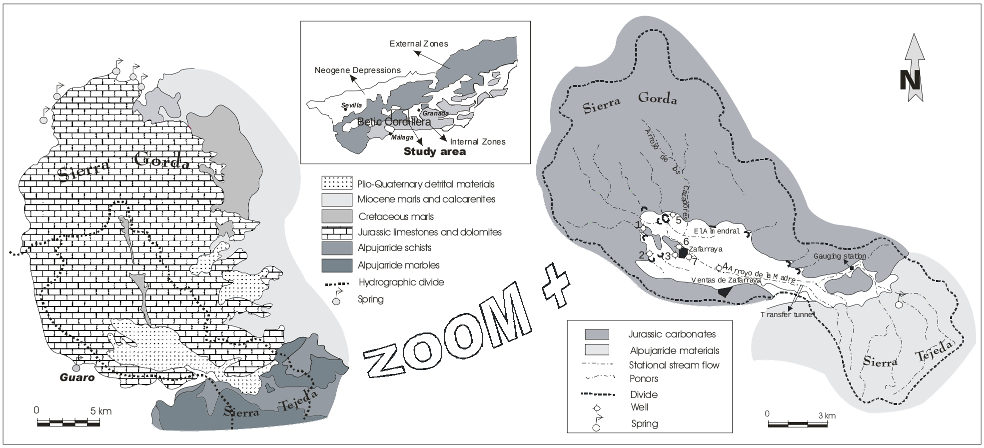

Figure 1. Geological and hydrological setting of the study area and Zafarraya polje. Location of control points in the polje.

The main aim of this study is to describe the flooding in a karstic polje. We therefore undertook a quantitative characterisation of the hydrological process in the Zafarraya polje on the basis of the data available from the last flood in 1996, and determined volumes of flood water as well as drainage rates of the polje. Finally, we examined the influence of both surface water and groundwater on the dynamics of the flooding process.

2 HYDROLOGICAL AND HYDROGEOLOGICAL OPERATION

Two independent hydrogeological units can be distinguished. The first is the detrital Quaternary filling of the Zafarraya polje, constituting an unconfined intergranular aquifer, and the second is an unconfined karst aquifer made up of the Jurassic limestones and dolostones of Sierra Gorda (Figure 1). The main recharge of the aquifer comes, therefore, from direct infiltration of rain (96.4 %), with a mean annual rainfall of 840 mm, whereas indirect recharge from stream flow (Arroyo de la Madre) is only 3.6%. Almost 95% of the drainage of this aquifer occurs through twenty or so springs on the northern margin (Figure 1) at an altitude of approximately 500 m a.s.l. The rest of the natural discharge of the hydrological system takes place through a number of overflow type springs at Guaro on the southern margin at an altitude of approximately 700 m a.s.l., which are only operative when the water table reaches high levels in the rainy season.

Figure 2C shows the rise of more than 150 m at points 1, 2 and 3 at the end of 1995. This was, in fact, an extreme situation as it occurred during a shift from a very dry period to a very wet one and the change in level was therefore very high. About 75 to 100 m can be taken as normal variations between dry and wet seasons. The water table of the alluvial aquifer (line 4 of Figure 2C) is near the surface and seasonal variations are much less pronounced (less than 10 m) than those of the karst aquifer. The two aquifers have different water tables (Figure 2A-2B) and so we can speak of two independent systems. However, there is normally supply from the detrital to the karst aquifer across the contact zones between permeable detrital rocks and the limestones of the Sierra Gorda aquifer, depending on a higher hydraulic head in the detrital aquifer. This flow can invert, with discharge from the karst aquifer to the detrital if the hydraulic head is higher in the former, which is what tends to occur during large floods (Figure 2C).

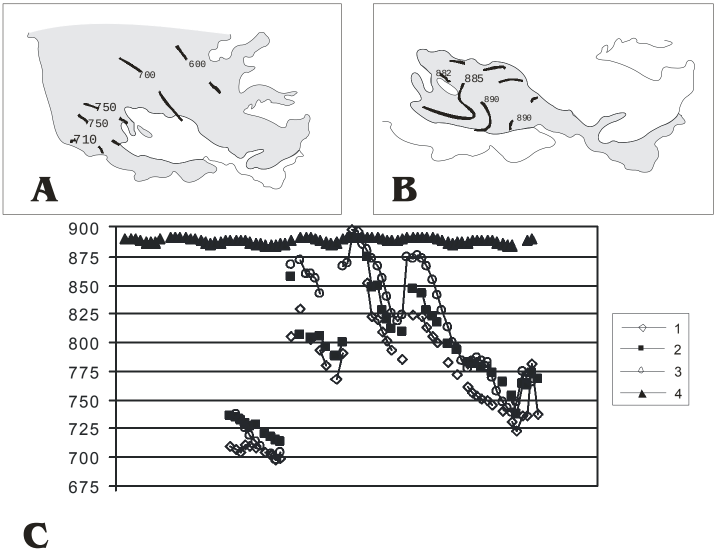

Figure 2. (A) Water table map of the Sierra Gorda karst aquifer adjacent to the polje, November 1989. (B) Water table map of alluvial aquifer, July 1982. (C) Water table evolution at three wells in the karst aquifer (1, 2 and 3) and one well in the alluvial aquifer (4).

Figure 2C shows the rise of more than 150 m at points 1, 2 and 3 at the end of 1995. This was, in fact, an extreme situation as it occurred during a shift from a very dry period to a very wet one and the change in level was therefore very high. About 75 to 100 m can be taken as normal variations between dry and wet seasons. The water table of the alluvial aquifer (line 4 of Figure 2C) is near the surface and seasonal variations are much less pronounced (less than 10 m) than those of the karst aquifer. The two aquifers have different water tables (Figure 2A-2B) and so we can speak of two independent systems. However, there is normally supply from the detrital to the karst aquifer across the contact zones between permeable detrital rocks and the limestones of the Sierra Gorda aquifer, depending on a higher hydraulic head in the detrital aquifer. This flow can invert, with discharge from the karst aquifer to the detrital if the hydraulic head is higher in the former, which is what tends to occur during large floods (Figure 2C).

3 1996 FLOODING OF THE POLJE

Although the 1996 flood was not the worst in recent times, it did however have a catastrophic effect on the area, calculated at around 3.5 million euros, a considerable loss for a rural economy with few inhabitants. After a prolonged drought of some five years, 1995-96 was the first hydrological year with heavy precipitation (1620 mm, when the annual mean is 950 mm), which caused a rise of up to 175 m in the water table of the Sierra Gorda karst aquifer (Figure 2C), only 11 m below the lowest swallow holes (887 m a.s.l.). In 1996-97 precipitation was not so intense as the previous year, but as the water table was already quite high and since there was no water deficit in the unsaturated zone, the reaction was flooding of the polje in the form of two independent lakes at first in the western sector, which later joined to become one single lake.

The initial data on which the flood process was studied were as follows: (a) Discharge in the Arroyo de la Madre measured at a gauging station in the eastern sector of the polje (Figure 2), where mean daily flow values were recorded. (b) Analysis of evolution of water levels of the two lakes (retention volumes), measured using a theodolite giving centimetre precision. (c) Water table at well 3, also levelled, using the continuous record provided by a limnigraph of the Confederación Hidrográfica del Sur, also levelled with centimetre precision.

Calculation of the swallow capacity of the ponors in the Zafarraya polje is a rather complicated matter as it involves numerous factors (*Bonacci, 1987*) which, moreover, are not constant but vary with time. Infiltration capacity was calculated on the basis of the variation of retained water volume in the two lakes during emptying (based on the fall in water level in both lakes) plus the water entering the lakes every day (*Bonacci, 1987*). A minimum value was taken for the latter as we only took into account the measured flow of the Arroyo de la Madre and not the other smaller flows, such as Arroyo de los Cazadores or possible groundwater supplies. Calculation was carried out for the two lakes together, as it was not known how the flow from Arroyo de la Madre was distributed between them. Specifically, we applied the following equation: $I = Q - \Delta V$, where I is infiltration rate in the two lakes, Q is Arroyo de la Madre discharge and ΔV is variation in retention volume of the two lakes based on two consecutive daily measurements. Figure 3 shows that total infiltration varies in the first stage, although, the mean value remains quite constant at 3 – 3.5 m^3/s. After March 3rd the value drops. The most important fact to emerge from this is that when the Arroyo de la Madre's flow approaches 3.5 m^3/s, flooding is likely.

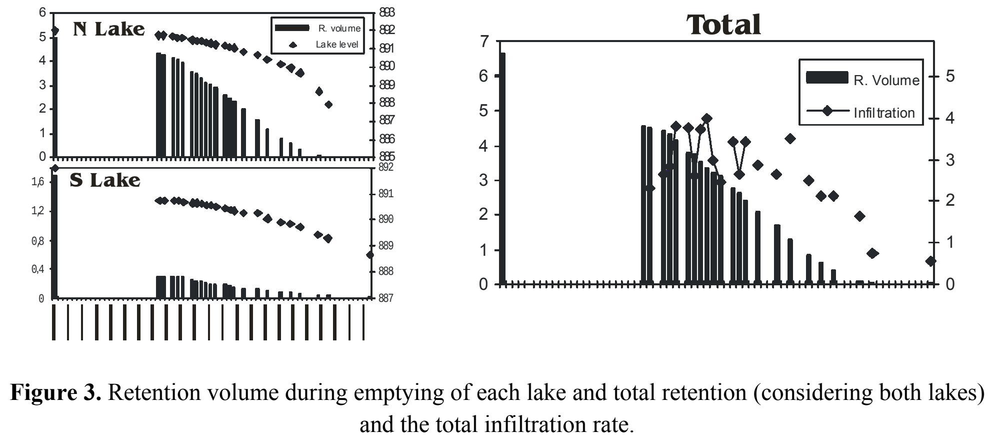

Figure 3. Retention volume during emptying of each lake and total retention (considering both lakes) and the total infiltration rate.

4 FLOOD DYNAMICS

In order to determine the role played by surface water and groundwater in the floods on the Zafarraya polje, we must examine the relation between the water table of the karst aquifer and the water level in the lakes. We propose a model for formation of the two lakes and their controlling factors that would be as follows (*López-Chicano et al., 2002*):

The Arroyo de la Madre discharge rose abruptly (> 3.5 m^3/s) as a result of abundant precipitation in a short period, exceeding the infiltration capacity of the main ponors located in the north-western sector of the polje (Phase 1, Figure 4.1). The northern lake was first to form and the water table of the karst aquifer began to rise quickly, although it did not reach the level of the ponors. This phase would correspond to what happened on the Zafarraya polje between the 18th and 19th of December 1996, when high peaks were recorded in the Arroyo de la Madre discharge and there was a rapid rise in the water table at point 3.

During phase 2 the northern lake grew rapidly and its level continued to rise until, at a point near the town of Zafarraya, it overflowed the dividing line between the northern and southern sectors, with transfer from the northern lake towards the south-western sector of the polje. This caused rapid growth of the southern lake, which was smaller than the northern one, since the surface water supply here was much smaller than in the north-western sector (Figure 4.2). The Arroyo de la Madre flow continued to be high. Given the lack of data for the karst aquifer (the limnigraph installed in piezometer 3 became blocked due to the rapid rise in level), in order to determine the possible influence of groundwater on the flooding of the polje during this phase, we have only been able to estimate the total water supplied by the Arroyo de la Madre from December 18th 1996 (when flow began to be significant) until January 5th 1997 (when the first measurement of water level in the lakes was made). The total supply of surface water for this interval was 5,6 hm^3, which is slightly less than the maximum amount of water stored in the two lakes (6,7 hm^3). By this calculation we can infer that, although we have no evidence of groundwater supply, in this second phase, we can say that infiltration into the ponors and the polje in general must have been negligible, as an equilibrium had been reached between the level in the northern lake and the water table of the karst aquifer in this sector. The maximum level (892 m a.s.l.) was reached, when a single lake formed that remained as such with very high levels for 5 days (Phase 3, Figure 4).

Precipitation decreased and, in response, depletion began in the Arroyo de la Madre flow and the single lake split once more into two separate parts (Phase 4). During this phase there was groundwater flow to the southern lake, since the level of the northern lake was higher than that of the southern one and there was hydraulic connection between the two across this sector of the karst aquifer, which meant that the ponors of the south-western sector of the polje would have inverted, acting as outlets for the water or estavelles (*Ford & Williams, 1989*). The level of the southern lake fell very slowly, indicating that there must have been some slight infiltration in some part of the lake (probably on the southern side), while groundwater continued to enter on the northern edge (Figure 4.4). In this phase, supply to the southern lake would have been almost only groundwater, whereas to the northern lake it would probably only have been surface water. This situation would have lasted from the 11th January to 13th February 1997. During phase 5 the water table of karst aquifer fell below that of both lakes, cutting off groundwater supply to the southern lake, as shown by an increase in the rate of water level fall. The levels continued to drop more quickly in the northern lake, which indicates that the infiltration capacity was higher in the northern lake, as was to be expected in view of the more developed swallow holes in this zone, so that on February 26th the level in the northern lake began to be lower than that in the southern one. This meant that the northern lake disappeared first, despite its receiving the entirety of the supply from the Arroyo de la Madre, while the southern lake remained about twenty five days longer (Figure 4.5). This phase would correspond to the events between February 13th and the disappearance of the last lake towards the end of March 1997.

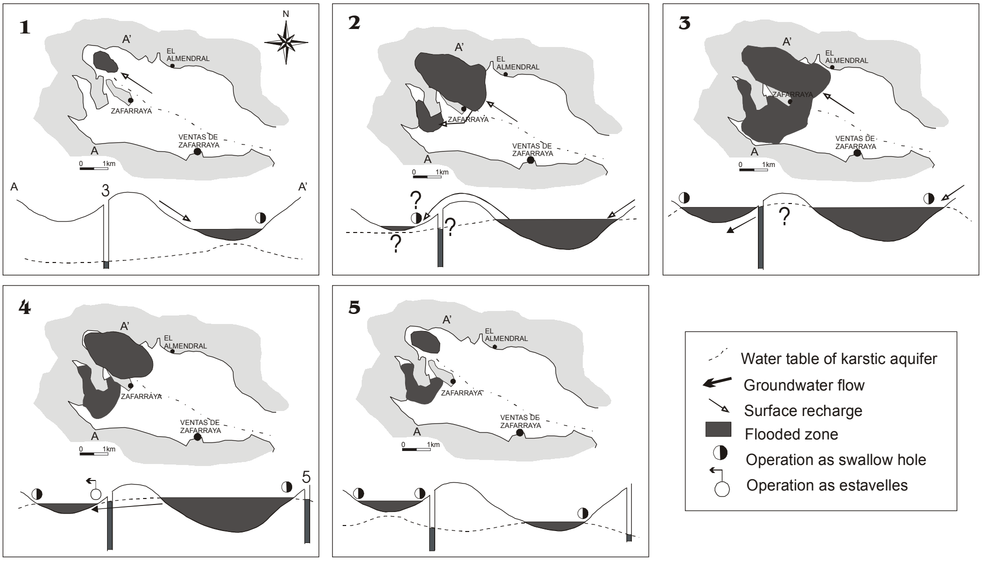

Figure 4. Model of the 1996 flood.

5 CONCLUSIONS

Maximum infiltration capacity of the Zafarraya polje is approximately 3-3.5 m^3/s: when flow of the Arroyo de la Madre exceeds this figure there will be risk of flooding in the polje. The infiltration capacity of the Zafarraya polje is not constant. The factor that brought about the main flooding was the high flow of the Arroyo de la Madre, but what made the flooding more extensive and prolonged was the intersection of the water table of the karst aquifer with the height of the main sinkholes in the polje. Groundwater was therefore mainly responsible for the flood, although surface water provided an important supply that increased the volume of water retained in the lakes. Surface water causes small instances of flooding, as long as the evacuation capacity of the sinkholes is insufficient, but it never causes flooding of the dimensions caused by ground water.

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52. EFFECTS OF HISTORICAL URBAN DEVELOPMENT ON FLOOD HAZARD: THE CLAMORES RIVER WATERSHED AND THE TOWN OF SEGOVIA (CENTRAL SPAIN)

J.M. Bodoque[1], A. Díez[2], J.F. Martín-Duque[1], M.A. Sanz[1] & G. de Marcelo[3]

(1) Dpto. Geodinámica, Universidad Complutense de Madrid, 28040 Madrid. e-mail: jbodoque@geo.ucm.es
(2) Dpto. de Ingeniería Geológica y Minera, Universidad de Castilla-La Mancha, 45071 Toledo
(3) Palacio de Riofrío, Patrimonio Nacional, 40420 Navas de Riofrío (Segovia)

ABSTRACT

The hydrologic behaviour of the Clamores urban watershed (Segovia, Spain) has been characterized for the last three hundred years, with the objective of evaluating the hydrologic impacts of the increasing of the impervious area within its watershed, due to the urban growth of Segovia. The methodology used is divided into four stages. In the first one, the rainfall- runoff process is simulated; that was yielded for recent storms with a total precipitation higher than 30 millimetres. The obtained hydrographs, as a result of implementing the hydrologic model, were calibrated by using, for each studied storm, the measured discharge in the water treatment plant of Segovia. Next, all the existing information related to the historical floods that have happened in Segovia during the studied period, as well as the historical evolution of land uses, was compiled. In the third stage, the hydraulic model of one of the considered floods, more specifically, the flood that took place on June 23rd, 1733, was accomplished. After that, the hydrologic model was run again, in order to estimate the total precipitation and the temporal distribution of this event. Finally, the hydrologic response of the urban watershed to a similar magnitude storm, that may occur in the near future, was determined. Therefore, the hydrologic model was implemented for the present-day situation, in accordance to the current land use, and likewise for the future situation, when the planned development of Segovia will occur.

1 INTRODUCTION

The conversion of rural land into urban land generates numerous adverse effects on the water quality and on the integrity of the surrounding terrestrial and aquatic ecosystems (*Novotny & Olem,* 1994). Moreover, natural flow paths in the watershed are likely to be replaced or supplemented by paved gutters, storm sewers, and other elements of artificial drainage. The most significant of these effects is the alteration of the hydrological cycle, so that several parts of it undergo major changes. Not only do flood flow, baseflow and groundwater components change, but also the contributing areas in the watershed are modified. There is a group of primary, interrelated, but separable effects on the hydrology of an area. The most common effects are: (1) a reduction in the infiltration and a decreasing in the travel time; (2) changes in peak-flow characteristics; (3) changes in total runoff (*Leopold,* 1968). As the watershed gradually develops, and consequently turns more

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impervious, it also becomes hydrologically more active, changing the stream's flow components as well as the origin of the discharge. Additionally, urbanization tends to increase both the flood volume and the flood peak. Thus, flood flows have now become more frequent in developed areas due to the progressive transformation of watersheds from rural to urban land uses. Another significant effect of urbanization on the hydrology of a watershed is the change in the recurrence interval of a given discharge (*Novotny et al.*, 2000).

In this context, the aim of this work is to assess the effects that the urban development of Segovia, Spain, has had in the modifying of the flood hazard.

2 STUDY AREA

Segovia is located in Central Spain, eighty-four kilometres north-west of Madrid. Segovia straddles an area where three main physiographic units of the Iberian Peninsula join – the northern Guadarrama piedmont (granitic-gneissic), the limestone terrains of the border of the piedmont, and the southern part of the Cenozoic Douro Basin (*Martín-Duque et al.*, 2002).

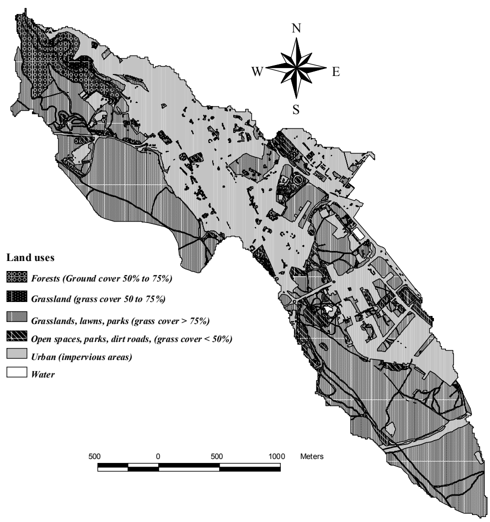

Figure 1. Existing land uses in the Clamores watershed

The Segovia region is drained by two rivers: the Eresma, on the north side of the old town, and the Clamores, that crosses the town from the south to the north. The watershed of the latter is where this study focuses. At the present day, because of the gradual urban growth of the town, the Clamores river behaves as a collector of residual waters. The channelling and covering of the Clamores river was carried out in different stages between

1893 and 1948. Only in the headwaters of the catchment, along a reach of one kilometre, the river flows in its natural channel.

The Clamores river is a tributary of the Eresma, that likewise is an affluent of the Douro river. It has an approximate length of five kilometres, whereas its average slope is 0.030 m/m. The area of its draining watershed is 5.2 km^2. Land uses through the watershed are: 40.3 % urban (impervious areas); 46.7 % open spaces (grassland, lawns, parks), with a grass cover higher than 75 %; 6.8 % open spaces, parks, dirt roads, with a grass cover less than 50%; 6.2 % woods, with a ground cover higher than 50 % and less than 75 %) (Figure 1).

3 METHODOLOGY AND RESULTS

The methodology developed in this work had four interrelated stages:

- modelling of the rainfall-runoff process;
- compilation of all the existent historical information;
- hydraulic-hydrologic modelling of the 1733 event;
- implementing the hydrological model for the present-day situation.

3.1 Modelling of the rainfall-runoff process for the current situation of the Clamores

By using hydro-meteorological methods, the rainfall-runoff process as a result of storms with a total precipitation higher than 30 millimetres has been modelled. The aim was to know the hydrological response of the Clamores watershed at the present time.

The drainage pattern of the study area, as well as the lumped hydrologic parameters, were obtained by using HEC-GeoHMS, the geospatial hydrologic modelling extension of ArcView GIS. In order to simulate surface runoff processes from precipitation, the Flood Hydrograph Package (HEC-1, HEC-HMS) was used (Figure 2). HEC-HMS consists of three components: basin model, meteorological model, and control specifications.

For the basin model, the SCS Curve Number Loss Model (*Soil Conservation Service*, 1986) has been used to evaluate loss rates, and direct runoff has been modelled by means of the Clark Unit-Hydrograph Model. Baseflow was not considered in the model.

In relation to the meteorological model, the User Hyetograph method was implemented by using the precipitation data provided by the rainfall gauge of Segovia. Regarding control specifications, a fifteen minutes time interval was selected.

Finally, the simulated hydrographs were calibrated by using the observed discharge in the waste water treatment plant of Segovia (WWTP), as a consequence of the same storms studied in the modelling of the rainfall-runoff process. In order to calibrate the model, an automated procedure was carried out, by using an objective function that measures the degree of variation between computed and observed hydrographs.

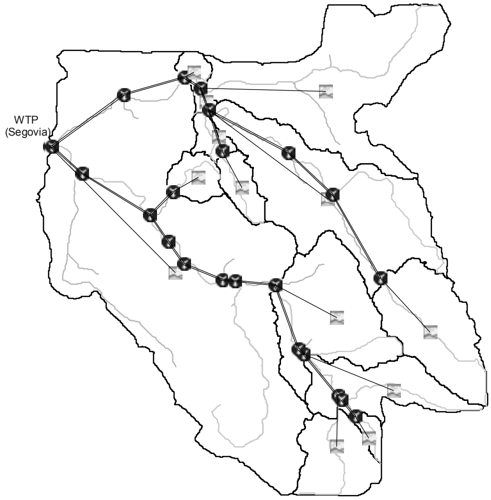

Figure 2. Schematic diagram of the HMS basin model of Segovia and its surroundings. (WWTP, waste water treatment plant)

3.2 Compilation of the historical information

The historical information about the land uses, the process of channelling and covering of the Clamores river and the historical floods, was obtained from different sources. The historical variation of land uses in Segovia was assessed through: (1) for the present-day situation, the digital urban cartography at 1/500 scale; (2) for the past situation, the urban cartography made by the city council of Segovia in 1902, and a set of aerial photographs taken in 1948, on a 1/2000 scale, were also used.

Concerning the channelling and covering of the Clamores river, all the existing rehabilitation projects of the Municipal Record Office of Segovia were consulted.

Finally, a group of historical flood chronicles were obtained at the Record Office of San Quirce Academy of History and Art. Moreover, present-day flood data were obtained by consulting the local newspaper library. Of all the considered historical floods, only the one that took place on June 23rd, 1733, was characterized.

3.3 Hydrologic-Hydraulic modelling of the 1733 flood

To carry out the hydraulic modelling of the 1733 flood, the natural channel of the Clamores river had to be rebuilt. This was made with reliability in one of the two considered reaches, specifically downstream of the Valdevilla bridge. In the other one, located in the vicinity of the Santa Eulalia church, the original geometry of the channel was obtained by considering the current slope of the main flow line of the urban watershed, as well as the known heights in some points of the natural streambed.

The 1733 event's hydraulic modelling in the two studied control reaches was made by using a Geographic Information System (GIS). The necessary geometry data for implementing the hydraulic model were obtained by means of a Digital Elevation Model (DEM) generated from a Triangular Interpolation Net (*Díez*, 2002). By using its PreRAS menu, the HEC-GeoRas extension for ArcView allowed us to obtain: geometry data of the cross section cutlines, longitudinal profiles, and main channel banks. The resulting file was imported as geometry data in the HEC-RAS software to perform a Steady Flow analysis. At the Valdevilla bridge, a peak flow of 40 cms was measured. In the vicinity of the Santa Eulalia church, in contrast, a much higher peak flow (of 135 cms) was measured. However this value could be misleading, because of the existing uncertainties in the estimated channel geometry.

The HEC-RAS-obtained water sheet heights were interpolated in the HEC-GeoRAS's PostRAS menu, with the aim of obtaining a Digital Terrain Model of the water table. Finally, the flooded area as a consequence of the 1733 event was determined by using the HEC-GeoRAS's PostRAS menu (*Flood Plain Delineation*) (Figure 3 a & b).

After that, the hydrological model was run again by assuming the most adverse one-hour hyetograph, with the objective of estimating the 1733 event's total precipitation. The obtained figure was 295 millimetres.

a) b)

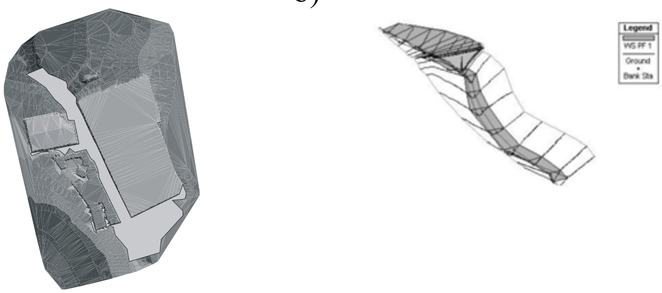

Figure 3. a) TIN with the effects of the flood in the surroundings of the Santa Eulalia church; b) perspective plot of the Valdevilla bridge during the 1733 flood

3.4 Hydrological model for the present-day situation

The hydrologic response of the urban watershed was determined considering a similar storm that would occur at the present time. Thus, the hydrologic model for the present-day situation was implemented in accordance to the current land uses and likewise for the future situation, when the new planned developments of the city takes place.

The results are that if a storm of these characteristics would take place nowadays, the peak discharge would be 35% higher than that one generated as a result of the 1733 event, whereas for the future situation, no significant change in the watershed's hydrological response is observed.

4 Discussion and conclusions

As a main outcome, this work shows how the decreasing permeability of the Clamores watershed, as a consequence of the urban development of Segovia, has modified its hydrological response.

However, the obtained results have some uncertainties, that can be summed up in two main aspects. Firstly, it has been assumed that the whole runoff that is generated as a result of a storm flows along the collector until the water treatment plant. Secondly, conventional hydrological models, often used in watersheds with a low to moderate rate of anthropogenic modification, have been implemented in an urban watershed, where the drainage has been completely modified by human action. Currently, we are working on the resolution of these uncertainties.

Likewise, a distributed hydrological model is being developed for the Clamores urban watershed. By doing that, a more detailed modelling of hydrologic processes than that obtained with lumped parameter methods, will be achieved.

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53. MAPPING THE VULNERABILITY OF CULTURAL HERITAGE TO THE FLOOD HAZARD IN THE FLUVIÀ RIVER BASIN (CATALONIA)

L. Ribera Masgrau[1], A. Ribas Palom[2] & D. Saurí Pujol[3]

(1) Departament de Geografia, Història i Història de l'Art, Universitat de Girona, Spain – anna.ribas@udg.es
(2) Departament de Geografia, Història i Història de l'Art, Universitat de Girona, Spain - lluis.ribera@udg.es
(3) Departament de Geografia, Universitat Autònoma de Barcelona, Spain - david.sauri@uab.es

ABSTRACT

The paper attempts to undertake a vulnerability analysis to flooding of the elements of cultural heritage present in the Fluvià River basin and some of its tributaries in Girona (Spain). Elements of the cultural heritage include architectural, archeological, industrial and artistic artifacts located within the flood-prone areas of this river. We have catalogued a total of 389 elements of such characteristics, ranging from houses, factories and religious monuments to archeological sites, hydraulic works and fountains. Information on each element has been incorporated within a Geographical Information System associated to a database that includes all relevant variables for the estimation of vulnerability.
Purposely, our approach to the estimation of the vulnerability to flooding does not assume that vulnerability is simply a function of physical exposure. Hence the need of developing alternative methodologies that take into account both physical exposure (i.e. the location of the element within the return periods of 10, 100, or 500 years) and what we define as "intrinsic vulnerability" or the characteristics of the element itself that may make this element more prone to degradation, independently of its exposure to flooding. Among these characteristics, we have considered the state of conservation of the element; the existence or not of investments addressed to improve this state; the type of property and the legal protection. Our working hypothesis is that damages from flooding can be very different depending on the intrinsic vulnerability of each element. Thus, elements may not be vulnerable to flooding even when they may be located in areas highly exposed to this risk. Conversely, elements that do not appear as highly exposed may be more vulnerable because of their intrinsic characteristics.

1 INTRODUCTION

The cartography of environmental hazards is often limited to the mapping of the physical phenomena causing the risk and seldom takes into account the multiple dimensions of vulnerability other than physical exposure (i.e. the relative location of population, economic activities, infrastructures, etc. regarding the spatial extent of the physical agent). Taking as an example the cultural heritage of the Fluvià River we propose a more comprehensive view of vulnerability based on the characteristics of these elements of the cultural heritage exposed to the flood risk or what we call "intrinsic vulnerability".

V.R.Thorndycraft, G. Benito, M. Barriendos and M.C. Llasat (2003). Palaeofloods, Historical Floods and Climatic Variability: Applications in Flood Risk Assessment (Proceedings of the PHEFRA Workshop, Barcelona, 16-19th October, 2002).

Our central argument is that elements may be very exposed to flooding but because of some of their characteristics (investments in conservation, for instance) may not be vulnerable and vice-versa.

Therefore, the paper attempts to develop a vulnerability analysis to flooding of the elements of the cultural heritage present in the Fluvià River of Girona (Spain) and some of its tributaries. Elements of the cultural heritage include architectural, archaeological, industrial and artistic artefacts located within the flood-prone areas of this river. We have catalogued a total of 389 elements of such characteristics, ranging from houses, factories and religious monuments to archaeological sites, hydraulic works and fountains. The characteristics of each element have been incorporated in to a Geographical Information System associated to a database that includes all relevant variables for the estimation of vulnerability.

As stated before, our approach to the estimation of the vulnerability to flooding does not assume that vulnerability is simply a function of physical exposure. Hence the need for developing alternative methodologies that take into account both physical exposure (i.e. the location of the element in flood prone areas defined in our case for several return periods) and what we define as "intrinsic vulnerability", or the characteristics of the element itself that may make this element more subject to degradation, independently of its exposure to flooding. Among these characteristics, we have considered the state of conservation of the element; the existence or not of investments addressed to improve this state; the type of ownership, and the existing legal status (protection or non protection under law). Our working hypothesis is that damages from flooding can be very different depending on the intrinsic vulnerability of each element. Thus, elements may not be vulnerable to flooding even when they may be located in areas highly exposed to this risk. Conversely, elements that do not appear as highly exposed may be more vulnerable because of their intrinsic characteristics.

Figure 1. Some of the cultural elements studied: Textile mill of "can Porxes" (left), in the Bianya valley, and the romanesque bridge of Besalú.

2 DATA AND METHODS

We combine physical exposure data with a number of characteristics of each heritage element to produce a vulnerability map for the Fluvià river basin. We have defined cultural heritage as all architectural, archaeological, industrial, and artistic elements located within the flood-prone areas of the Fluvià river. We have identified 398 elements distributed in 21 categories.

Physical vulnerability, understood as physical exposure to the hazard, has been calculated according to the location of each element in one of the three flood areas mapped and that correspond respectively to the return periods of 10, 100 and 500 years. We have only considered those heritage assets present in the flood zones. All elements included within the area defined by the 10-year return period have been classified as of "high vulnerability" since they tend to be affected relatively frequently by floods; elements located in the area between the 10 and the 100-year return periods have been defined as of "medium vulnerability", whereas those located between the 100 and the 500-year return periods would have a low vulnerability since this in an area that only exceptionally experiences floods.

The calculation of what we have defined as "intrinsic vulnerability" of the heritage components (that is a vulnerability which is independent of the relative location within the flood-prone areas) is more difficult since we do not have a clear explanatory variable and have to resort to qualitative assessments. The index of intrinsic vulnerability is composed by four factors that capture different salient characteristics of each element and are as follows:

1) State of conservation of the element. It describes the physical state of the heritage element and assumes that vulnerability is inversely proportional to the state of conservation. In other words, the better the conservation the lower the vulnerability and vice-versa.

2) Physical protection. It describes the presence of actions addressed to the conservation of the element including restoration (for buildings, infrastructures, etc.) or consolidation (archaeological sites). It also includes buildings that have a restricted access. As in the previous case, vulnerability will be inversely proportional to protection. The higher the protection, the lower the vulnerability and vice-versa.

3) Ownership status. The ownership of the heritage asset is a crucial factor when planning for protection. Concerning cultural heritage in Spain there are three types of ownership: private ownership; ownership by civic entities (including the Catholic Church), and public ownership. Our hypothesis here (contrasted with experts in the field of cultural heritage) is that the element will benefit from a more effective protection if it is under public rather than private ownership since more resources are likely to be available. Hence we assume that vulnerability will be directly related with private ownership and inversely related with public ownership.

4) Legal Protection. If an element is protected under law we can assume in principle that its conservation will also be better. Again, vulnerability will be inversely related to legal protection of the element.

Each of these qualitative estimations have received a quantitative counterpart or a value of 0, 1 or 2 according to the characteristics of each element (in the case of legal protection only 0 and 1 depending on whether this protection exists or not). The four values thus obtained are then added to obtain a final number that reflects the level of intrinsic vulnerability for each of the elements inventoried. According to the final value obtained intrinsic vulnerability is then defined as high, medium or low.

Final vulnerability is obtained from relating intrinsic vulnerability to physical vulnerability. The combination of both vulnerabilities is represented in the vulnerability matrix that locates the element in one of each theoretically possible positions within the matrix. In order to simplify the cartographical expression of the value of each element we have reduced the nine possibilities to five: very high, high, medium, low and very low.

3 ANALYSIS AND RESULTS

Along the Fluvià floodplain we can observe a clear dominance of the low physical vulnerability group with 223 elements (57.30 percent of the total). Elements in this case are mainly architectural, most of them houses; the rest are infrastructures still in use and to a much lesser extent abandoned elements. Generally speaking, these elements present a good state of conservation, have been subject to restoration, are legally protected and are of private ownership. Elements with high physical vulnerability (150) constitute 38.6 percent of the total whereas 16 elements with medium physical vulnerability or 4.16 percent of the total complete the picture.

		Intrinsic vulnerability		
		HIGH	MEDIUM	LOW
Physical vulnerability	HIGH	Very high	High	Medium
	MEDIUM	High	Medium	Low
	LOW	Medium	Low	Very low

Table 1. Final vulnerability matrix.

With regard to intrinsic vulnerability, 230 elements belong to the class of "medium vulnerability" These are basically architectural elements, infrastructures in use or houses. The state of conservation is generally good and they have been the object of some restoration tasks. 82 elements have a high intrinsic vulnerability and 32 elements have a low intrinsic vulnerability. Data for intrinsic vulnerability is missing in the remaining cases.

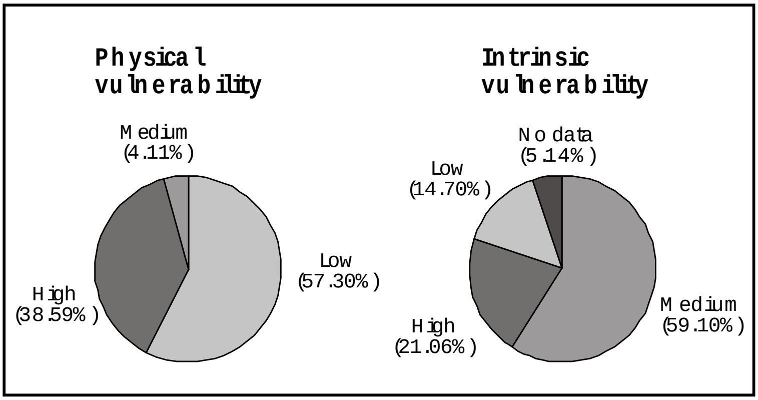

Figure 2. Distribution of physical and intrinsic vulnerabilities

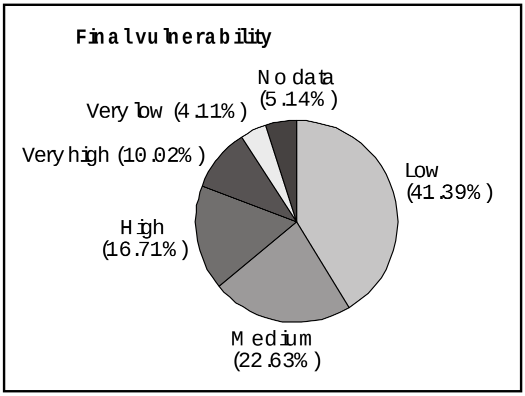

Figure 3. Distribution of final vulnerability

In terms of total vulnerability, most elements (161) belong to the low vulnerability class (41.39 percent). The next category in importance is the medium vulnerability class with 88 elements (22.63 percent) elements inventoried. Sixty five elements (16.71 percent) present a high final vulnerability; 39 (10.02 percent) a very high final vulnerability, 16 (4.11 percent) a very low final vulnerability, and for 20 elements we have no complete data.

4 CONCLUSION

The highest final vulnerability is observed in those elements belonging to the industrial heritage closest to the river and located away from urban areas. These elements present the highest states of abandonment and degradation. The lowest final vulnerability is observed in housing units located in the areas farthest from the river, both in urban and in rural settings. These elements feature the best states of conservation and a more regular use. In some 20 % of elements analyzed, final vulnerability does not coincide with physical vulnerability. This proves that intrinsic vulnerability has a role in determining the final vulnerability. Hence, vulnerability cannot be defined according to physical exposure alone, and the characteristics of each element must also be taken into account.

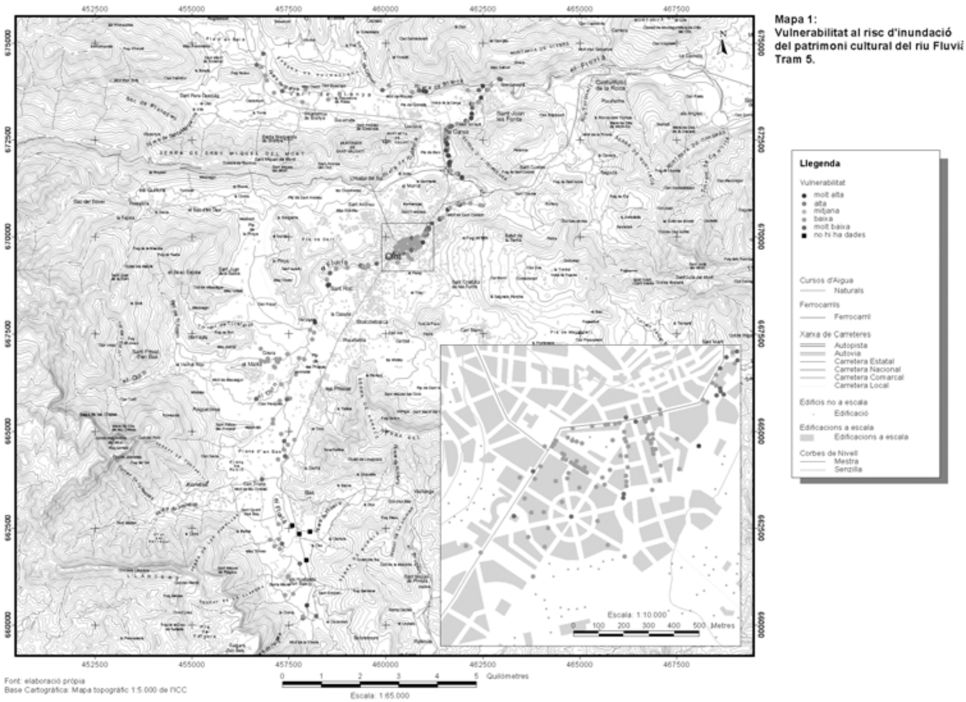

Figure 4. Example of a map showing the vulnerability to floods of the cultural heritage in the Fluvià river basin

This research has been coordinated by the Catalan Water Agency (Department of the Environment of the Catalan government) under the Interreg II-C Programme: "Cartography of Floods and Cultural Heritage in the European Union"

54. FLOODING AS A MIXED RESPONSE OF HYDROLOGY AND LAND USE TRENDS TROUGH RECENT HISTORY: THE PISUERGA RIVER BASIN PATTERN.

R. Martínez-Alegría[1], J. Luís González[1] & A. Almunia[2]

(1) Civil Protection Spanish Services. Delegación del Gobierno en Castilla y León Valladolid..
(2) Civil Protection Spanish Services. Delegación del Gobierno en Aragón. Zaragoza.

ABSTRACT

The Duero River Basin covers 78.000 km^2 of the spanish territory, before portuguese lands are reached. The spanish main contribution (18.000 km^2) comes from the northeastern Pisuerga River, an equilateral triangle shaped basin that drains to the southweste, near the city of Valladolid. This paper illustrates an overall scope of the Catalogue of recent historical flooding on the lower Pisuerga basin.

1 INTRODUCTION

Recent historical flood evidence is recorded from this area, where more than thirty one events have been reported for the last forty two years. This paper aims to first introduce the Catalogue of recent historical floods on the lower Pisuerga, modern meteorological and hydrological settings being furthermore typified. Flooding boundaries for the most recent event on March 2001 are additionally drafted and these contrasted with the official limits otherwise established by the Confederación Hidrográfica del Duero.

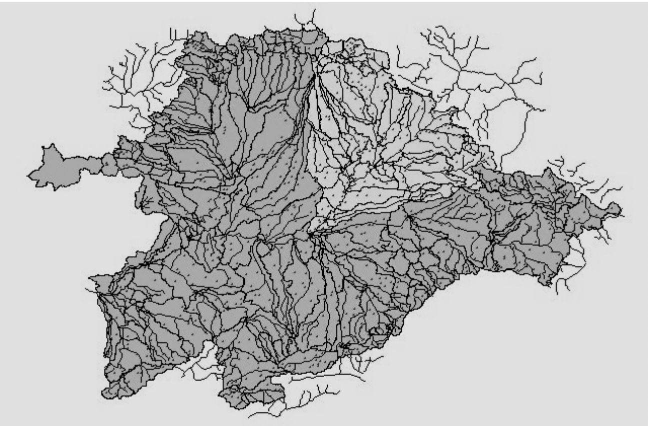

Figure 1. The Pisuerga study basin in the NE of the Duero basin

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2 METHODOLOGY

Procedure steps set on the "Guia Metodológica para la Elaboración del Catálogo Nacional de Inundaciones Históricas (*Bustamante and Gonzalez,* 1997)" to provide systematic treatment for the overall spanish watersheds complex have been succesfully adopted: with uniform implementation on data collecting, loading and accesing being therefore achieved with reference to the national project.

The time interval particularly selected for the analysis ranges from 1959 to the present, so long as high order hydraulic structures' (dams, channels) construction has begun by then, which could thereafter sensitively condition the flood properties within the area. The spatial scope for the study has been confined to the Pisuerga watershed, which is one of the main tributaries of the Duero River (Figure 1).

An MS-ACCESS database application has been necessarily developed that provides support for such a large and complex data amount and variety, in order to get a structured and homogeneous record on damage information that gives support for future spatial analysis through GIS tools (Figure 2).

Figure 2. Window picture of the data loading Application

Hydrologic and meteorologic gauging data for each flood event have been recorded as instantaneous and cumulative rainfall maps, flow maps and others , as well as satellite images (Figure 3), so that they can be used as layer coverages inside a GIS.

3. RESULTS AND DISCUSSION

Two main flooding patterns have been recognized among the series analysed. Extensive flood events seasonally (Winter, Early Spring) involving the region's main rivers have been distinguished as the first category. Meteorological settings of continuous western oceanic wet fronts and episodic fast snow melting phenomena have been identified in association. Main damages are particularly reported within the most important cities (Palencia, Valladolid, and others).

A second category has been identified for the flood series on the area, which is featured by local cloud evolution related to summer storms, that show highest severity in short and high sloped creeks with no hydraulic structures.

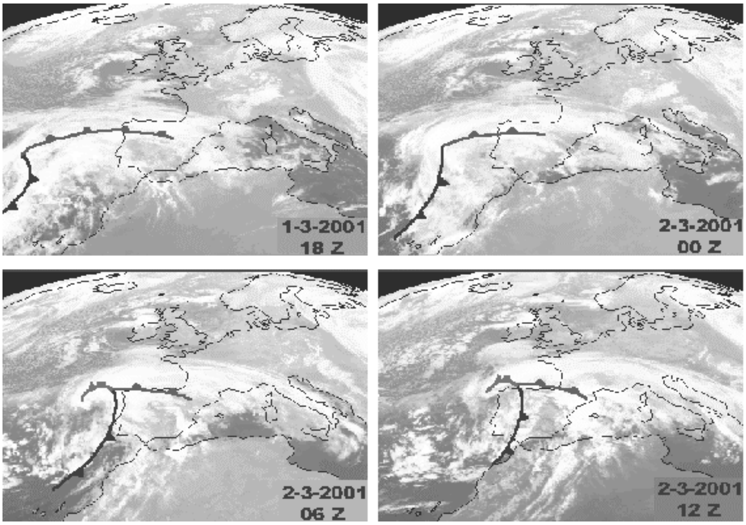

Figure 3. Meteosat image showing the evolution of the hot and cold wet atlantic fronts over the Iberian peninsula during the 1st and 2nd of march 2001

The lower end of the Pisuerga River Basin confining the province of Valladolid has been revealed, all through the 31 flood events analysed, as an area greatly exposed to flood risk. Its extreme location at the end of the draining watershed yielding very high flows, as well as river bed stress resulting from intense recent urban development within this area, have been identified as immediate grounding factors for both flood exposure and vulnerability increase.

The last flood event on March 2001, with more than 2.600 m^3/s flow gauged at the city of Valladolid, refers to the highest water level and the associate 500 year recurrence period estimates, its spatial limits then revealing very close to the present active Pisuerga alluvial plain (Figure 4).

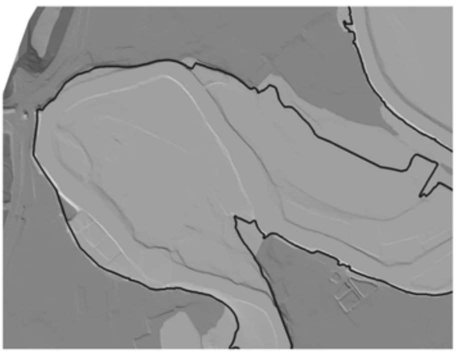

Figure 4. Digital Elevation Model of the Pisuerga Alluvial Plain and in black line the 2001 March flood limit.

The flooding surface for this event has been mapped on a high precision scale (1:2000) with the help of an an ortho rectificated aereal photograph (Figure 5).

Figure 5. Ortho aereal photograph showing the flood outer limits (black line). The thicker grey line marks the limit of the 500 year flood estimated by the Confederación Hidrográfica del Duero.

Related damages were mainly reported on crops and lower flats within buildings (Figure 7), landslides associated effects (Figure 6) also being registered. Economical losses of more than 38 million euros were estimated, although no victims were reported on that occasion.

Figure.6. Landslide affecting a house foundation, during the March 2001 flood event (left). **Figure.7.** High water level affecting garages and basements in Valladolid (right).

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55. HISTORICAL FLOODING IN SPAIN: THE SPANISH NATIONAL CATALOGUE, A CIVIL PROTECTION SCOPE

A. Almunia[1], R.M-Alegría[2], M. Jiménez[3], S. González[4], F. Opla[1], A. Herrero[1], A. Bustamante[5] & G. Pascual[5]

(1) Spanish Services of Civil Protection. Ministerio de Administraciones Públicas, Delegación del Gobierno en Aragón, Plaza del Pilar s/n, 58071 Zaragoza, SPAIN – e-mail: aalmunia@aragon.map.es
(2) Spanish Services of Civil Protection. Ministerio de Administraciones Públicas, Delegación del Gobierno en Castilla y León.
(3) Spanish Services of Civil Protection. Ministerio de Administraciones Públicas, Delegación del Gobierno en Madrid.
(4) Spanish Services of Civil Protection. Ministerio de Administraciones Públicas, Delegación del Gobierno en Murcia.
(5) Spanish Services of Civil Protection. M. del Interior, Dirección General de Protección Civil. Quintiliano, 21. 28002 Madrid.

ABSTRACT

Flooding has been a major concern for the spanish government since the "National Technical Board for Flood Emergency (C.T.E.I.)" was set up in the eighties, to report on flooding hydrometeorological and related socioeconomical (damages)within the spanish context. The search of an effective empirically supported pattern for identifying flood risk areas and that could help emergency planning optimization and other civil protection purposes, led to a second attempt that started by themid-ninetees involving the systematic collection of historical data. The Segura River Basin (18.869 km^2) cataloguing (Gonzalez et al., 1995) served to extensively instruct (Bustamante et al., 1997) on standardization of historical flood information management (data collecting and updating) for the whole spanish drainage networkt, where eleven peninsular basin management Departments and eight more insular are found over extensions ranging singly from about 12.000 to 85.000 km^2, a total of more than 494.000 km2 being accounted. From the ninetees onwards the Spanish Catalogue on Historical Floods (S.H.F.N.C.) has been developed that focuses on the natural drainage basin, with both the North Athlantic and South Mediterranean regions incorporated. . The application proves efficient for flood zonal analysis as it leads to succesfully combine hydrological, meteorological and socioeconomical data field information, support for efficient data management, systematic collecting and updating and standard accessing being succesfully provided. A later stage will follow to set additional hydrological and hydraulic model needs for critical areas.

This paper presents building strategies systematics for the catalogue set (technical teams constitution, records generation, computer application design, single basin catalogues integration on the CNIH set), occurrence of single particular fittings (starting dates, hydrological particular sources, specific solving questions and stages) being also mentionned. A reference to the current state of the project , its expected closing time,

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quality control and filtering devices as well as tools and technical features is additionally given.

1 INTRODUCTION

During the eighties the CTEI was formed for the unique and unprecedented documentation, at a national scale, of identification, delimitation and analysis of river flooding influencing the Spanish peninsular zone. It was mainly aimed to "the study of corrective and preventive actions to be undertaken by the Spanish Government on the flooding of the most habitually damaged zones, in order to either avoid or reduce the effects".

During the late ninetees, the Segura River experience,of identification, analysis and ranking of historically flooded zones, guided the Spanish National Work Team on Flood Risk Analysis towards systematization and homogeneization of data collecting procedures at a national scale.

The CNIH (S.H.F.N.C.) has been developed from the late ninetees onwards and records the set of Historical Flood Catalogues for Spanish islands and the autonomous cities of Ceuta and Melilla. It records ephemeral stream flooding episodes, in addition to river flooding within the peninsular. The final results will be integrated into the Spanish National Data Base on Flooding Zones established by the "Directriz Básica de Planificación de Protección Civil ante el Riesgo de Inundaciones", that must include at least the following: " ...the most relevant information on flooding and associated geological phenomena that may happen every time human beings and goods colectively are endangered".

2 SPANISH TERRITORIALS: NATURAL HYDROLOGIC AND WATER MANAGEMENT LAND UNITS.

National territory in Spain is managerially organized at present according to seventeen autonomous divisions (Autonomous Communities) and two more autonomous cities, the State General Administration standing for the overall management level. As the Methodological Guide for the SHFNC summarizes (*M.O.P.U.,* 1988; *Bustamante et al.,* 1997), a set of eleven water management Departments (Confederaciones Hidrográficas) are provided traditionally for more than eleven natural hydrological land units (basins) that occurwithin the spanish peninsular territory. Management is, in contrast, conducted for two of them at the Autonomous Administration level by the respective two (intracommunitary) water management Departments, whereas the majority come directly under the State General Administration as (intercommunitary) hydraulic Departments, eight Councils being additionally responsible for the spanish insular territory water management units.

Figure 1 shows a rough image of the Spanish spatial approach taking hydrological natural land units as a main reference, multiple autonomous divisions being found in each one of them for most cases, whereas only a few range over a single incomplete autonomous management land unit. The figure aims to reveal the diversity found among the Spanish data set when only taking into consideration areal extension as the reference parameter, additional differential parametres such as land occupation, population density and distribution, economy and consequent flooding impact not being included. Note the wide differential range found between the scarce 20,000 km^2 of the Mediterranean Segura River Basin, to the larger than 85,000 km^2 the mixed Mediterranean-Atlantic Ebro River Basin.

Suggestive approach of the complexity of the project must confront is also aimed with the figure, as this is just one of the project main challenges. Natural hydrological land units facing hydraulic, civil protection and other administrative land divisions are all of them factors that undeniably condition flooding scenes and evolution on the spanish spatial picture and time historical film, and of course difficult data profitable collection and homogeneous treatment depending on the various information and scenes sources.

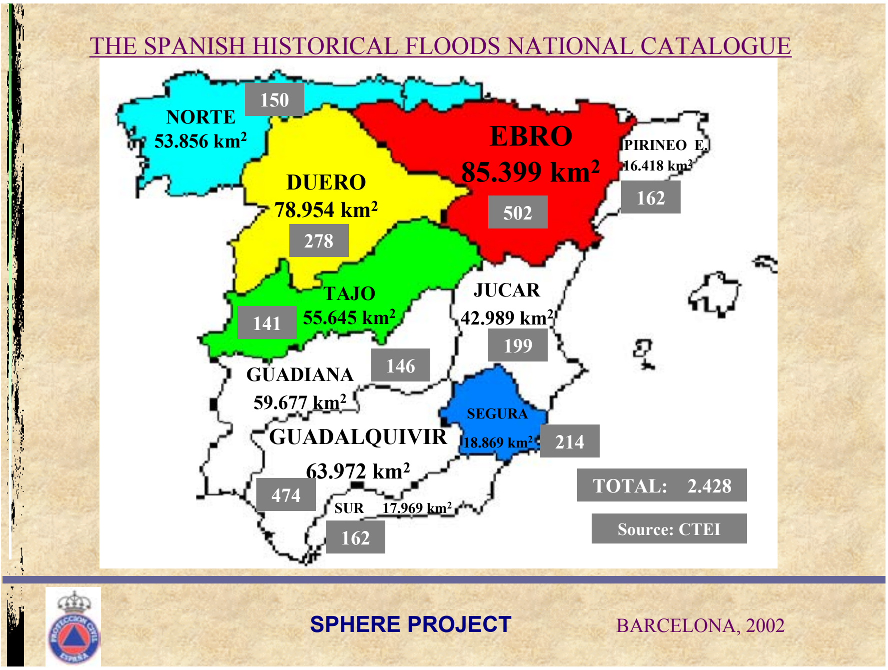

Figure 1. Spanish peninsular water management Department divisions. Natural hydrological units coincide in most cases, but not in all of them (The North Confederation, in light blue, the South Confedeartion or the East Pyrenees one in white, etc.).

3 SINGLE BASIN HISTORICAL FLOODS CATALOGUES

Two attempts have been made up to present the catalogue of historical floods for every single Spanish basin. The CTEI considered only peninsular settings and river caused flooding, whereas the Spanish Historical Floods National Catalogue at present includes both river and ephemeral stream caused flooding, and both peninsular and insular basins.

3.1 The CTEI (FESTB) Catalogue episodes

An extraordinarily valuable effort is recognized to the CTEI for its data collection and information classification work on centuries-old flooding episodes that occured all over the basins covering the Spanish peninsular. It is nevertheless true that even if the Project closure date was about 1986, significant flooding episodes have been steadily occuring during the past recent years that have not helped the updating, with the lack of a methodological procedure offering acceptable guarantees for systematic data collection and homogeneous treatment of such a diverse source information being identified as the main handicap.

The CTEI studie's main aim was to identify and typify flooding causing factors through time so that the most frequently flooded zones in Spain were found. As well as the main national causes of floods, the most frequent damage classes and a relative magnitude ranking criteria would be revealed (important for standardisation) once the data had been gathered together and classified. An exhaustive bibliographic search was specifically carried out for the purpose.

An initial date for the searching and collecting of the historical data was set for each single basin depending on its specific conditions, whereas the final date was fixed for the search closure. A total amount of 2,428 flooding episodes were recorded for the Spanish peninsular in all. Figure 1 includes numerical reference for the peninsular total and basin sectorial contributions. Note the contrast between the scene revealed when remarking that the largest basin (Ebro) is also the most flooded (502 episodes), whereas one of the three smallest basins (Segura) has been flooded less than half the number of times (214).

A card was built for each flooding episode among those registered by then, that included the following information fields:

- Updated map of the Basin containing the zone affected by the particular flooding.
- Flooding date.
- Flood duration period.
- Flooding causes.
- Damages recorded.
- Data and information sources.

3.2 The CNIH (SHFNC) Catalogue episodes

From the Civil Protection view at the general management level, the need for studies on historical flooding within watersheds, drawing a national picture, must focus on exhaustively knowing past river and ephemeral stream flooding and their consequences (especially social) for each particular area, as much as the study of physical parametres and their particular relationships. These must not be forgotten for every event, given that a deeper understanding of future flooding events is sought. Prevision clues give the key for preventive selecting (decision support) of specific protection strategies, among those shaping generical protective action plans (structural and non structural measures, for a particular local area, citizens and private goods) coming from a specific natural (hydrologic) unit.

A historical flood is defined for the SHFNC purpose as "every river, as well as ephemeral stream, flooding event that occured through history on the land of any watershed the national territory that overflows so that inhabitants and their goods have been, subsequently, directly (damages) or indirectly (disturbance of ordinary going, injuries, etc) afffected".

Each basin catalogue includes every flood that may have taken place on its territorial domain (hydraulic department) from the date the CTEI studies ended to present (very beginning of the twenty first century), as well as those the CTEI had gathered by the eighties, even though the checking actually begins for each basin particularly from the first high significative episode identified during the three last decades of the twentieth century. A basic scheme was followed for later pattern card design mainly considering

Meteorological, Hydrological information and Socioeconomical information that includes data, graphical and others.

A pattern card has been set in order to systematize data collection and later treatment and analysis, that includes the fields mentioned below; a computer application has been finally developed for the Data Base running (data loading, accessing and updating). EPISODE IDENTIFIERS GENERICAL DATA: Basin (Name of the hydrologic land unit), Card Number (Cronological position of the particular episode among the basin historical series catalogue), Reference (Documentary Source, a reference here is meant by all the information obtained for a single episode coming from a single documentary source, so that as many cards as references found have been filled for each single episode. A later comparative analysis will allow to smooth the card catalogue), Date: Days (riverbank overflow duration, number of days of previous rainfall) /Month/Year; Name (Can be given by the flooding local cause, the particular date, or simply the local common name). CLIMATIC DATA. HYDROLOGIC DATA. AFFECTED AREA. SIGNIFICATIVE DAMAGES: Population (victims,injuries), Housing, Hydraulic structure, Transport structure, Farming, Agriculture, Industry and Basic Public Services.

4 THE PROJECT SCOPE: STAGES AND PARTICIPANTS

A number of work teams have been arranged to specifically ellaborate a Catalogue for each basin, the following institutions being represented in hte collaboration: Civil Protection Services (UPC´S) on every (provincial distribution) relevant Government Delegation and Subdelegation, competent Hydraulic Departments (Confederaciones Hidrográficas, etc.), Territorial Meteorological Centres (C.M.T.´S) of the Spanish National Institute of Meteorology (I.N.M.), Civil Protection Services of the relevant autonomous communities, pertinent regional delegations of the Insurance Compensation Consortium and project offices of the Spanish Mining and Geological National Institute.

The following stages have been established for the project development:

I - Work Teams Setting up for each single basin

II – Historical Flooding Catalogue Elaboration for each basin

II.a. – Episodes Selection for Cataloguing

II.b. – Information Gathering

II.c. – Definite Cards Production

II.d. – Data Loading on the computer application

III – Computer Application Design for overall CNIH Management, that uses Data Bases in combination with Geographic Information System application software.

IV – Single Basin Historical Flooding Catalogue Set Implementation on the National Catalogue

Cataloguing has been concluded at present for three (The Segura, Duero and Tajo River Basins) of the nine Spanish intercommunitary basins, whereas work teams for the Canary Islands and the Catalonian Internal Basins are still unsettled. Once National Cataloguing has been definitely concluded it will integrate the Spanish National Data Base on Flooding Zones, as anticipated in the "Directriz Básica de Planificación de Protección Civil ante el Riesgo de Inundaciones", that will include at least the following: " ... the most relevant information on flooding and associated geological phenomena that may happen every time human beings and goods are collectively are endangered".

5 CONCLUSION

The Spanish Historical Floods National Catalogue is being developed for the entire Spanish territory , including all the hydrological and water management land units . The catalogue covers the main aims of the national scale project intended by the State general management level and provides the following facilities:

- Support for complex information management (loading, accessing, updating) at a wide territorial scale and a complex natural and socioeconomical picture, access to historical information from a long modern time series (CTEI cards) being completed and assured.
- Help for quick and easy accesing to the Catalogue references and bibliographic related ones, graphic and mapping information access being also provided.
- Setting of essential connections between rainfall - water surface level - population and goods. Damages for some locations in the Hydrographic Basins.
- Contrast analysis between historical information and meteorological and hydrological forecast systems during emergency situations, giving support for flooding emergency management.
- A tool for historical flooding consulting over both national and single basin scope, immediate updating being helped and assured for new river and ephemeral flooding episodes.
- Support for decision making on emergency management strategies and completion of the Spanish National Data Base on Flooding Zones established by national normative.

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56. SPHERE-GIS: IMPLEMENTATION OF AN HISTORICAL AND PALAEOFLOOD GEOGRAPHICAL INFORMATION SYSTEM

M.A. Casas Planes[1], G. Benito[1], A. Díez-Herrero[2] & M. Barriendos[3]

(1) Centro de Ciencias Medioambientales – CSIC, Serrano 115 bis, 28006 Madrid
(2) Dpto de Ingeniería Geológica y Minera, Universidad de Castilla la Mancha, 45071 Toledo
(3) GAMA Group, Department of Astronomy and Meteorology, Faculty of Physics, University of Barcelona, Av. Diagonal 647, E-08028 Barcelona, Spain

ABSTRACT

Palaeoflood and documentary flood data generated within the EU funded SPHERE project has been organized into relational database systems for its access and management and a geographical information system has been implemented for its storage and analysis. This paper describes the SPHERE-GIS, the structure of the conceptual data model for decision support, the design of an effective interface (GUI) to operate the computational model from a custom toolbar and menus, and the development of some GIS tools, which operate on ArcGIS in order to perform the required analysis and searches and for its explotation in the study and prevention of flood risks.

1 INTRODUCTION

Compilation of data related to past hydrological events has been the subject of different databases worldwide (see Oguchi et al., 2003). Specifically, past flood databases are focused either on documentary information and/or palaeoflood records. Pre-existing historical flood databases include the CLIMHIST database for Continental Europe in (Pfister et al., 1999), British Hydrological Events database for the UK (http:www.dundee.ac.uk/geography/cbhe), the National network of historical flood water level marks for China (Chen Chia-Chi, et al., 1975; Hua Shi-Qian, 1985), and PaleoTagus for Central Spain (Diez-Herrero et al, 1998; Fernández de Villata et al, 2001 and Benito et al., 2003). Geological-inferred flood information has been compiled either on general palaeohydrological databases (e.g. GLOCOPH and PHEIMS described in Oguchi, 2003) or in specific palaeoflood databases at the global scale (Ely and Hirschboeck, 2002) and on the regional scale (Diez-Herrero et al, 1998). Most of these databases are focused on simple data query displays but few of them have real capabilities for GIS spatial analysis.

SPHERE-GIS is a Geographical Information System which was developed to manage the palaeoflood and documentary flood information generated within the EU funded SPHERE project (Contract no. EVG1-CT-1999-00010). The GIS implementation provides an effective way of displaying past flood alphanumerical information within a geographical scenario as well as simple analysis resulting from any particular query (e.g. magnitude and frequency of flood events during a particular time period). Following the latest concepts of software components, SPHERE-GIS is ready to incorporate other software applications on

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flood frequency analysis (e.g. FRESH Software, Ouarda et al., this volume) or hydraulic computation software such as HECRAS (Hydrologic Engineering Center, 2002).
The main objectives are to effectively collect and store palaeohydrologic and historical (documentary) data, to develop tools for spatial and temporal analysis of quantitative parameters (e.g. date, estimated discharge, duration, etc.) and its interpretation both within the context of flood risk analysis and for the study of long-term regional relationships of floods and climatic variability. In this context, SPHERE-GIS provides tools for the application of the query results in Civil Protection risk assessement and management , hazard delineation and civil engineering.

2 METHODOLOGY

2.1 SPHERE-GIS Data Model

2.1.1 Non-spatial data model

The system includes two Relational Database Management Systems (RDBMS): Histo and Paleo, the tables of which were normalized until the third normal form. Both consist of a Basic Data Table which includes the main information of a flood event and complementary data tables containing detailed information related to the main data fields. The Histo Database comprises documentary flood information obtained from official and ecclesiastic historical archives, whereas Paleo database contains palaeoflood records obtained from geological-geomorphological techniques. Paleo also includes two main tables, one with basic data and the other one with the on-board data, which contains information referring to the physical characteristics of the river section (type of river boundary, type of channel bed, drainage area, stream length and channel gradient), the methodology of flood identification (palaeostage-indicator techniques, competency-based techniques, regime-based techniques, historical observations of flows and botanical-based techniques); the methodology used for discharge estimation (type of hydraulic model, hydraulic regimen), numerical dating information (C-14, TL, OSL, etc.) and flow-hydraulic characteristics (flow velocity, stream power, and specific discharge). In addition, the Paleo database includes a group of annexed tables containing source information, sedimentary materials, boulder diameter, and dating methods. Histo comprises a main table including information on the flood date and duration (year, month, day, duration, time of overflowing, time of maximum flood height), flood cause (rain, snowmelt, etc.) and category of the event (ordinary, extraordinary, catastrophic). In addition, several secondary tables describe the flood in terms of damages, hydroclimatology, and bibliographic sources (Affected Areas, Agriculture & Livestock losses, Hydrologic Data, Geomorphology, Housing Damages, Industrial Damages, Infrastructure & Service Damages, Casualties & Evacues, Chronology, Meteorological Situation, Bibliographic Source of Information y Documentary Source of Information). Both of the RDBMS (Paleo and Histo) share, as much as possible, their design and structure.

2.1.2 Spatial data model.

Spatial data structure have been deployed under two models: vectorial data model and raster data model. Vectorial GIS application requires a data model based on topological models, whereas the raster data requires a GRID approach. The vectorial cover (*IntRioMuniMas*) results from the graphical intersection between the rivers (*River*) identified by a unique code (*RiverID*) and the municipality (*Municipality*) with its unique code (MunicipalityID). This cover is linked by a unique code (*HydroCode = RiverID & MunicipalityID*) with the related-table (*Hydro*) which relates the spatial intersectioned cover with the basic table of each RDBMS, Histo and Paleo. Hydrologic data (basin, sub-basins, rivers, reservoirs, gauging stations), geographical data (administrative limits, topography, rail ways, roads, urban centres, parks), digital elevation models of different resolutions, and some orthophotos are also integrated.

3 GIS IMPLEMENTATION

3.1 GIS Data inputs

Digital spatial data is coded in a cartesian coordinate system and must be in the same projection and scale. All spatial data have been transformed into the same coordinate system and into an ArcGIS format. Both of the RDBMS (Paleo and Histo) have been fed using Microsoft Access through a Microsoft Visual Basic application (Jennings, 1999), so they can be directly connected to the GIS, providing an integrated data management policy for all data. Figure 1.a shows the Visual Basic form used to enter the basic data table of the Histo RDBMS, with direct access to the related tables, depending on the information available for each particular event.

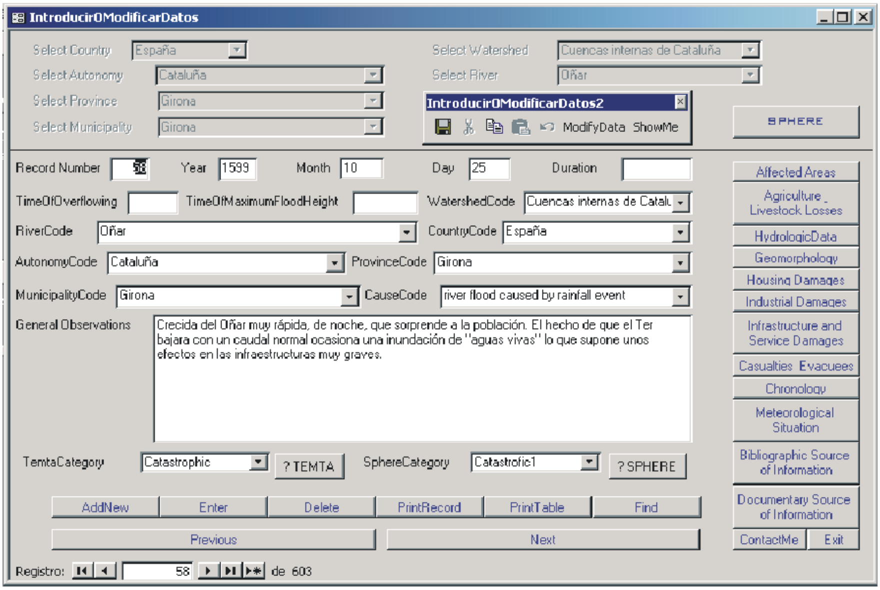
3.2 GIS Tools

The SPHERE-GIS has been implemented with the package *GIS ArcView 8.1,* GIS tools were built using Arc Objects (Environmental Systems Research Institute., 2001; Razavi, 2002) and Visual Basic (Microsoft Press, 1998) and the data format used for these components is the shapefile format. Custom tools extend the functionality of ArcMap to perform tasks specific to a user's need. The GIS functions programmed include: select, buffer, counting, statistics functions , map and data display. A friendly and easy-to-use user interface has been developed using Visual Basic for Applications (VBA), allowing the final user (scientist or technician) to obtain all the information required. The point is focused on detecting which is the functionality that is considered useful for the final user and to implement it on the system. The system is designed to present menus through a toolbar in which to manage the graphical and alphanumerical information and easily obtain the required information and its geographical location though queries, operations and analysis. All through the application, the menus will allow the user to add some graphical information to the map, to access the alphanumerical information, to perform some queries to the databases or to perform some analyses. Thematic selections through different means can be made with diferent criteria: causes, damages in agriculture, bibliography, etc.

3.3 GIS Analysis

Figure 1c shows the menu to make a selection by an exact date in Histo. The result of the query is shown spatially in the basic map and through a form where the selected data is displayed (see Figure 1b). Some spatial data can be added at any time to the basic map like reservoirs, gauging stations, altimetry, urban centres, geographic names etc (see Figure 1d) or the table with the selected records can be displayed.

1a


IntroducirOModificarDatos
Select Country España
Select Autonomy Cataluña
Select Province Girona
Select Municipality Girona
Select Watershed Cuencas internas de Cataluña
Select River Oñar
IntroducirOModificarDatos2
ModifyData ShowMe
SPHERE
Record Number 58
Year 1599
Month 10
Day 25
Duration
TimeOfOverflowing
TimeOfMaximumFloodHeight
WatershedCode Cuencas internas de Catalu
RiverCode Oñar
CountryCode España
AutonomyCode Cataluña
ProvinceCode Girona
MunicipalityCode Girona
CauseCode river flood caused by rainfall event
General Observations
Crecida del Oñar muy rápida, de noche, que sorprende a la población. El hecho de que el Ter bajara con un caudal normal ocasiona una inundación de "aguas vivas" lo que supone unos efectos en las infraestructuras muy graves.
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? TEMTA
SphereCategory Catastrofic1
? SPHERE
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Affected Areas
Agriculture Livestock Losses
HydrologicData
Geomorphology
Housing Damages
Industrial Damages
Infrastructure and Service Damages
Casualties Evacuees
Chronology
Meteorological Situation
Bibliographic Source of Information
Documentary Source of Information
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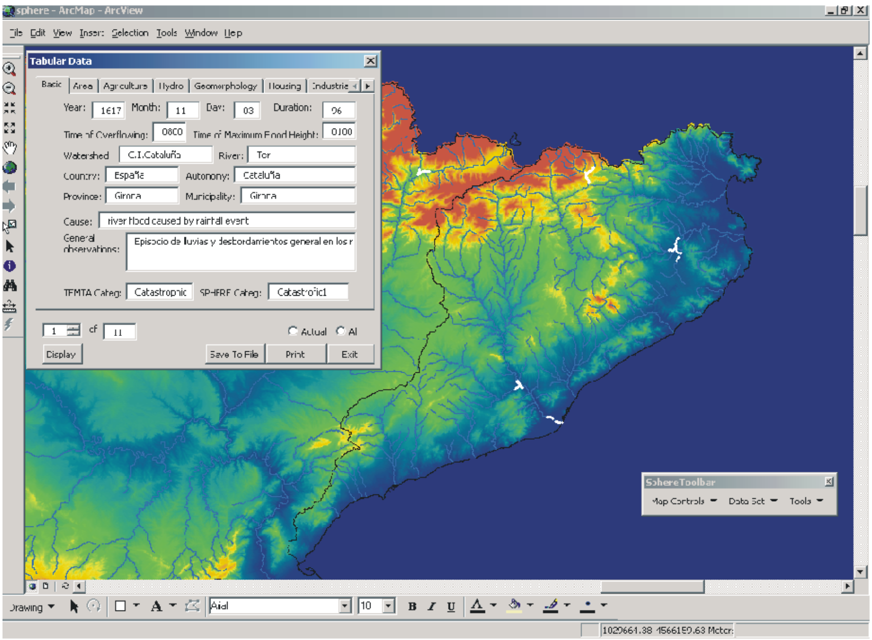
1b


sphere - ArcMap - ArcView
File Edit View Insert Selection Tools Window Help
Tabular Data
Basic Area Agriculture Hydro Geomorphology Housing Industrie
Year: 1617 Month: 11 Day: 03 Duration: 96
Time of Overflowing: 0800 Time of Maximum Flood Height: 0100
Watershed C.I.Cataluña River: Ter
Country: España Autonomy: Cataluña
Province: Girona Municipality: Girona
Cause: river flood caused by rainfall event
General observations: Episodio de lluvias y desbordamientos general en los r
TEMTA Categ: Catastrophic SPHERE Categ: Catastrofic1
1 of 11
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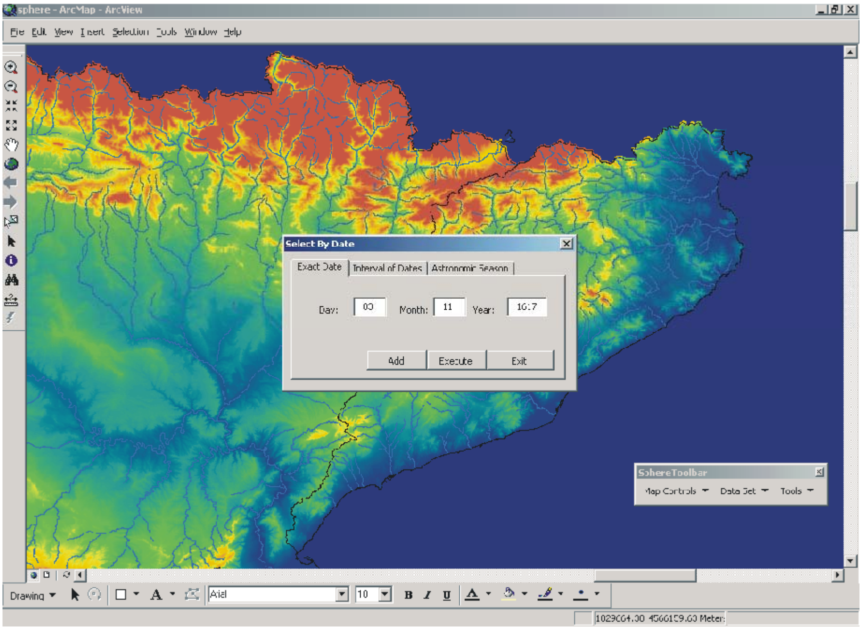
1c



1d

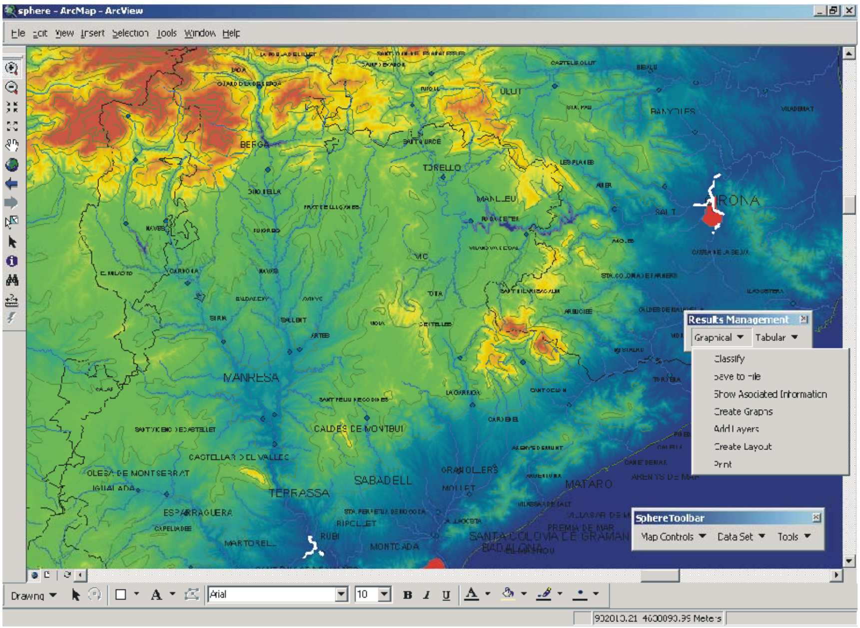


Figure 1. Views of the SPHERE-GIS. **Figure 1a. (previous page)** Data input form for the Historical basic data table with access to the rest of the related tables, **Figure 1b**. **(previous page)**. Menu to make a selection by the exact date, **Figure 1c**. Map with the selected spatial and tabular data displayed,, **Figure 1d**. Menu options to add graphical information to the results.

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57. CATALAN PUBLIC ADMINISTRATIONS AND THEIR ACTIONS REGARDING THE RISK OF FLOODS

M. Sanz Bazán

Sindic de Greuges de Catalunya, J. Anselm Clavé 21, 08028 Barcelona
e-mail: sindic@sindicgreugescat.org

REPORT MADE BY THE OMBUDSMAN OF CATALONIA TO THE PARLIAMENT OF CATALONIA

In November 2000, the Ombudsman of Catalonia (Síndic de Greuges de Catalunya) presented a report to the Parliament of Catalonia, evaluating the sufficiency and level of compliance by public adminsitrations with the legislative measures for prevention and protection of persons and goods from the risk of floods. Several complaints from citizens affected by floods, and the cyclical, catastrophic character of these floods in our territory, constituted the motivating factors for the preparation of this report.

The report begins by making an analysis of risk in our society. It then goes on to describe the major instances of floods that have occurred in Catalonia, also making reference to the situations of other European countries in this respect. The report then analyses the diferent laws incorporating regulations that could affect flood prevention and action in the event of floods. Thus we see that this is a cross-cutting issue, dispersed throughout the different specific rules governing hydraulic policy, territorial and urban planning and civil protection.

After a joint study of the stipulations contained in this arrangement, the identification of their mandates, legal holes, and the level of compliance by public administrations, the Ombudsman made the following series of recommendations and warnings, which referred to the situation by the time the report was being presented:

- Catalonia did not have a map demarcating areas that could be considered flood risk zones, although work had been initiated to define such areas. The best way to continue this research was being studied with special emphasis on the cost of drafting and on high-risk zones. The lack of demarcation of floodable areas resulted in the following:

  1) It prevented the Executive Council from approving the Special Flood Plan for Catalonia –Inuncat– and the Spanish National Commission for Civil Protection from ratifying it.
  2) It prevented the ACA (Catalan Water Authority) from fulfilling the mandate stipulated in Article 16.2.m of the act that created it, Act 25/1998 of 31 December, which was to propose to the Government the establishment of limitations on the use of flood risk zones deemed necessary to guarantee the safety of people and property.
  3) It prevented there being publicly-known criteria based on hydrological studies of flood risk that would allow the ACA and the Catalan Civil Protection Commission

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to report with regard to instruments of town planning and land use planning. It must be kept in mind that these reports are mandatory but not binding.

- Although, as the Ministry of the Interior of the Catalan Government informed, "the operative procedures described in the Inuncat version favourably reported on by the Civil Protection Commission of Catalonia are currently being applied to ensure an effective response in case of flood emergency with regard to activation, structural, organisational and operativity criteria", the risk analysis incorporated therein is based on a study carried out in 1983. The need to update the mentioned risk analysis had been reiterated to the ACA and the Hydrographic Confederation of the Ebro on various occasions by the Ministry of the Interior.

- The two-year term, granted by Act 4/1997 on civil protection, in which to draft the civil protection plans prescribed therein, had passed and the majority of those plans were still pending approval and ratification.

- In Catalan regulations on urban and land use planning, there is no obligation mentioned to establish the planning action according to the identification of zones under risk of natural disaster such as floods, flash floods, avalanches, landslides or forest fires, nor according to the risk of floods or flash floods, nor to adjust this planning to the obligation of establishing sufficient corrective measures in cases where riverbeds or watercourses are intercepted or land becomes impermeable due to development.

- We considered that the Public Administration, administrator of the general public interest, should make special efforts to eliminate or diminish situations of risk within the framework of the responsible and proportionate action of all agents involved, both public and private, with the assumption that it is in no case possible to guarantee zero risk for the whole of society.

Therefore, considering the information and background included in the report and in accordance with the authorisation conferred us by Article 28.2 of our regulatory laws; considering that the safety of individuals and property is a basic and underlying objective of government actions by the Public Administration; considering that this responsibility for public action does not imply the inhibition of private agents, individuals or collectives with regard to the duty of personal attention to and responsibility for one's own actions and decisions; considering as well that safety is the responsibility of all and that it is materially impossible to guarantee zero risk; considering that legal stipulations must be fulfilled and that the citizen trusts in the diligent and rigorous action by the Public Administration; we made the following recommendations regarding flood and flash flood risks to the various administrative bodies responsible for matters related to urban planning, the environment and the interior:

- We recommended that the Ministry of the Environment of the Catalan Government demarcate the Catalan territory under risk of flood or flash flood without further delay, and that it carry out the corresponding risk analysis studies allowing it to definitively approve and ratify the Inuncat, making it fully operative and effective. This, along with the hydrological studies, would facilitate the task of the authorities with competence in land use and town planning, as well as the drafting of the mandatory reports on this subject to be carried out by the ACA and the Civil Protection Commission of Catalonia.

- We recommended that the Ministry of Interior presented the Inuncat to the Generalitat, Government of Catalonia, for approval.

- We reminded the public bodies responsible for land use and town planning of the co-ordination and association necessary between the town planning, hydraulic and civil protection spheres, and we recommended that they keep in mind the criteria and information that can be provided by the hydraulic and civil protection authorities, or, should there be none, those that can be derived from written or collective memory on catastrophes.

- We furthermore reiterated the need, already mentioned in the 1998 and 1999 reports by the Catalan Ombudsman to the Parliament of Catalonia, for a new Catalan Land Act to complement and update the text of legislative Decree 1/1990 from 12 May, which approved the revision of legal texts on town planning effective in Catalonia in order to attend the new stipulations of Act 6/1998 on land regimes and appraisals, adapting it to our situation such that it incorporates the planner's obligation to consider the characteristics of the land with regard to natural disaster risks when defining land use.

- We reiterated the need to revise the different town planning instruments in the light of possible flood risks, modifying permitted uses, declaring non-development areas or areas beyond regulation, and if necessary, in extreme situations, going so far as to expropriate or transfer legal installations located in risk areas. We are nevertheless aware of the procedural and financial difficulties of applying the more extreme corrective measures. In practice, these measures can at times be unfeasible, but precisely because of this, the declaration of developable areas coinciding with flood risk zones, which consolidates realities and rights that cannot later be corrected, must be prevented.

- Although it was not included in this report, the obligatory insurance regime and system against material damage caused by floods or flash floods must be reviewed and regulated.

- We reminded the municipal and Catalan authorities of the need to intensify informative action for citizens regarding the hydraulic reactions of the land on which they reside, the measures of prevention and response to be adopted in situations of risk, and the personal responsibility acquired by individuals for their actions. In this regard, we remarked that the General Office for Emergencies and Civil Safety, as every year, had provided the town councils with documents regarding the campaign for flood prevention, which include an explanatory summary of the Plan for Forecasting and Monitoring Adverse Meteorological Phenomena, a summary of the Inuncat, the basic procedures for municipal action in case of flood emergencies, and recommendations to the inhabitants of the municipalities.

- The awareness of the general public must be promoted with regard to risk at all times and not just during periods immediately following a disaster, reviving memory of floods in the past. The public must also be made aware of the impossibility of guaranteeing "zero risk" in any situation.

- Given that the defence infrastructures, hydraulic works and automatic hydrological information systems have an elevated cost, and that they are relied upon to react and function in emergency situations, we reminded those responsible of their duty to ensure complete maintenance of these installations, so that they can function as expected when the time comes. We equally reiterated the need to execute those hydraulic defence infrastructure projects that are often planned and committed after serious flooding incidents, as we consider that these commitments are not the result of irrational and disproportionate displays of will, but the product of the need for more effective protection of individuals and property.

Our report was discussed by the corresponding parliamentary commission, obtaining the approval of all the groups represented. The Act 2/2002 of 14 March on town planning, recently approved by the Catalan Parliament, incorporates the observations contained in our report with regard to those aspects referring to town planning and territorial flood risks. Hence, for the first time, the law stipulates the prohibition of development in floodable and flood risk areas for the safety and well-being of individuals, except works related to protection and risk prevention (Article 9.2 of Act 2/2002). At the same time, the ACA, dependent on the Generalitat, has begun studies to demarcate flood risk areas on Catalan territory, which will finally permit the approval and ratification of the Inuncat in the future, as a special plan for emergencies caused by floods.

58. GENESIS OF A PUBLIC POLICY FOR FLOOD MANAGEMENT IN FRANCE: THE CASE OF THE GRENOBLE VALLEY (XVIITH-XIXTH CENTURIES)

D. Coeur

ACTHYS-*Diffusion*, 26, rue Bizanet, 38 000 Grenoble, France – e-mail : denis.cœur@wanadoo.fr

ABSTRACT

Regarding the environmental aspects, we now understand better the consequences of the Little Ice Age on river flow (XVI-XIXth c.). Facing the large floods recurrence what were the political responses? In France, the growth of the State is probably the major political event during this period. To highlight this historical point, we propose to describe the evolution of Grenoble, a city in the Alps. In a first time the mobilization was reduced to the public works. Large dykes have been built along the Drac river between the 1670s and 1680s. The Isère projects really began in the second half of the XVIIIth century downstream of Grenoble, and after 1830 upstream. The technical river space control was also a political control on the local powers who managed the river since the Middle Age (communities, riverside residents). In this point of view, the technical engineers capacities were a deciding tool for the territorially State policy control. But in front of this administrative supervision, a first public works budget had been established on French alpine rivers as early as the middle of the XVIIIth century. At the same time, the local authorities began to organize the management of the flood emergency (people assistance, strategic spots defence, ...). The main organization began one century later, after the 1850s French large floods series, with development of river swellings observation and crossing of the forecast tools and prevention policy.

1 INTRODUCTION

The recent examinations on climate change and its consequences, have, without doubt, a great deal to learn from "history lessons" (*Le Roy Ladurie*, 1967 ; *Pfister*, 1988). The knowledge of extreme scarce natural events, such as massive river flooding, can take advantage of historical information beginning from the moment when protocols of critical collections of this information was validated by the hydrologist and the historian (*Naulet et al*., 2001). The historian himself has other questions.

Amongst questions that the "Little Ice Age" and its trail of extreme swellings pose, those of the form taken by the political engagement of the community, show us to be more urgent that the vulnerability of our contemporary societies, seems to have never been as important face to the return of this type of event. In France, this period coincides historically with the affirmation and development of the State. What place does the fight against the natural destructive phenomena occupy in this movement?

The undertaking of the fight against Drac and Isère river floods in the valley of Grenoble, between the seventeenth and nineteenth centuries, shows us a series of answers. Firstly, until the middle of the XVIIIth century, the mobilization undertaking of this task reduced itself almost exclusively to the realisation of public works. Following large flooding, the authorities agreed that in spite of the important river developments, the

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occurrence of destructive floods was a serious eventuality that there would need to be prepared in order to organize, in advance, the defence and emergency means.

2 FIRSTLY, A PUBLIC WORKS MOBILIZATION

The return of the large swellings of the Drac since the end of the XVI[th] century and of the river Isère until 1650, showed quite rapidly the lack of means of the local authorities (Figure 1). For a while the initiatives of Constable of Lesdiguières seemed to create delay. The intensification of the river crisis after 1630 put under spotlights the shortage of means of the Grenoble police council, who, before the State administration development, were responsible for the public works management. The weakness of the technical management – the intervention of engineers was rare - the financial fragility of the public works companies, and the lack of resources, all prevented to make use of adapted projects on phenomenon scale. Before 1660, the works remained fragile and crumbled along the river banks, without any coherence involved.

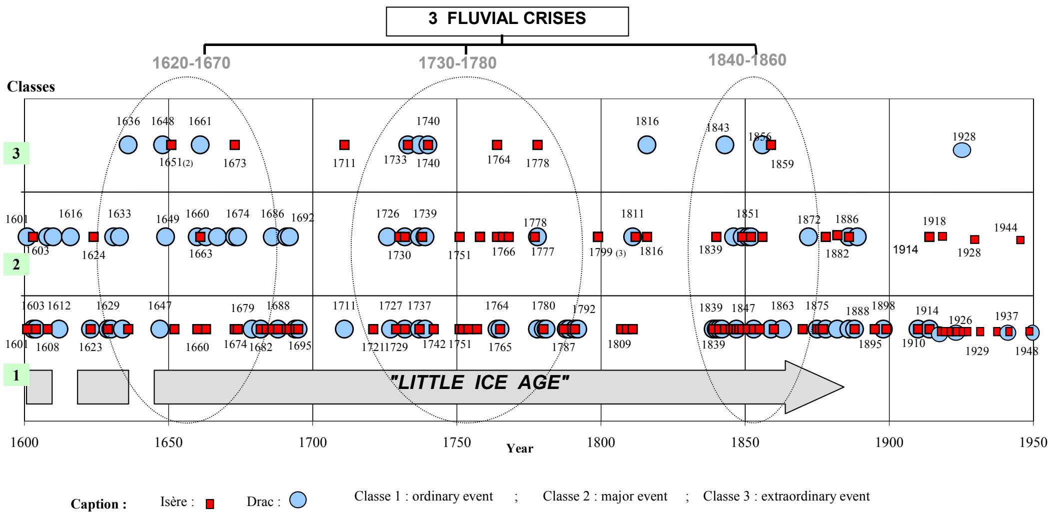


Figure 1. Drac & Isère flood chronologies in Grenoble plain (1600-1950)

2.1 Development of the royal administration

The definitive installation of the state administration services in Grenoble at the end of the 1670s was going to change the situation permanently. Colbert could not be more clear on this point when he wrote, in 1679 spring, to the administrator d'Herbigny : "Sir, the most important factors and those which are necessary require that you give your application for the duration of the job so that the King gives you in the Dauphiné area concern certainly the works which for a long time have had to contain the torrent of the Drac in an ordinary and well-ordered bed (…)". Despite difficulties of realisation due notably to the resistance of local authorities and to an uncertain financial control, the first major work took place along the Drac between 1675 and 1685 with the "Jourdan canal" construction, about 4 km in length. The path of the St-André avenue, now the Jean Jaurès avenue, completed the operation.

On an administrative point of view, the development of the Public Woks service from the 1720s, thanks to the steady growth of his personnel, authorised a better works and markets management. On a legal plan, the State took up new rights along the river with the creation of a reserve belt of 240 meters width in 1698 to better protect works against pillages inflicted by inhabitants, and to retrieve wood to aid with urgent reparations. Some guards were put into place in 1724.

2.2 The financial resources

The question of financial resources will be more difficult to resolve. Faced with the important financing needs for the dykes building and for their upkeep, the creation of a real budget came to be necessary. The usual local funding (road tolls, taxes) were not sufficient. The Colbert initiative on this subject were not conclusive. The accounting system of the Ancient Regime stopped for a number of years a healthy management, despite resources progression throughout the XVIIIth century (Figure 2). The 8th July 1768 Patent Letters fixed for the first time under the State control, a general financial framework of delayed tasks and the local actors mobilization. They also recognised, officially, the riverside inhabitants properties unions as a public community (*Cœur*, 2002). These enabled to finance the important works along the Isère downstream Grenoble between 1770 and 1790, and also along several rivers in the Dauphiné province.

Revolution didn't call into question this disposition. On a contrary, the law of 16th September 1807 took a part of the 1768 dauphinois' text, but placed riverside inhabitants unions under the State guardianship surveillance, with an erasing of the community. Unions therefore came to be the elementary cells of the construction and maintenance works. But the increasing number of unions along the Isère during the first half of the XIXth century shortly made the situation worse. The large projects defended by engineers were not able to be realised now without general consensus possibility. The advent of the Second Empire and the 1856 and 1859 river crises enabled the administration to take things into their own hands. The total number of unions was reduced in 1862 lasting from 45 to 8 along Isère and Drac rivers. Important works were to be done in the second half of the century. In 1930, the creation of the Isère-Drac-Romanche Departemental Association added an extra level of coordination between unions and the administration. Was the flood control question completely resolved by it?

3 GENESIS OF AN ALTERNATIVE MOBILISATION AGAINST FLOODS

The return of catastrophic events during the XVIIIth century forced the local authorities to consider other action forms, towards the flooding management itself. This mobilisation was historically organised in two directions: firstly in the event anticipation plan (forecasting of swellings and means of defence preparation), secondly in the inhabitants' assistance organisation.

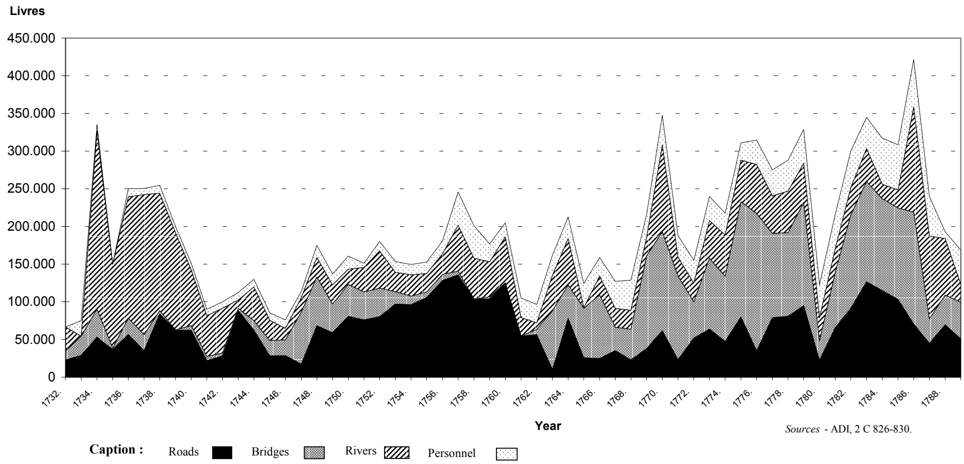


Figure 2. Dauphiné public Works budget (1732-1789)

3.1 Urgency and forecasting management

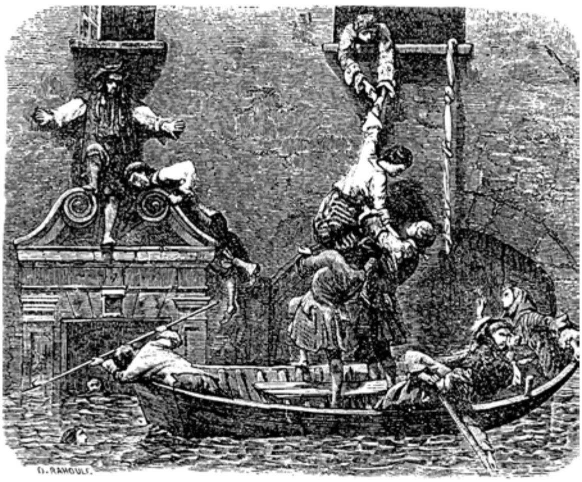
The first urgent actions plan appeared in Grenoble during the second half of the XVIIIth century. But without a good river surveillance system upstream of the city, it was very difficult to relay on an efficient warning. In fact, all measures were taken in urgency with, however, a relative efficiency: closing of the town entrances, protection of wheat stocks, boats requisition, etc. After the October 1778 great flooding, Grenoble consuls put into place a first list of "tasks to be taken if the city is threatened by flooding". This remained in place for the next 80 years.

Installation on the Isère and Drac surveillance system did not occur before the serious floods of the 1850s. Nevertheless, the continual river observation idea was advanced as early as the middle of the XVIIIth century by the military engineers, without real application. Unsinkable embanking projects still had the exclusive favour of authorities. From the beginning of 1840s, a series of elements finally came out to change the situation. The definitive surrender of the Isère general embankment plan (Cunit project) is the most well known, but we can also include the arrival of a new civil engineers generation who were better informed to the hydrological phenomenon knowledge.

At a national scale, the engineer Belgrand created, in 1854, the first flood warning system in Paris. Two year later, after the large event of May/June 1856, the model was developed on several river basins in France, particularly along Isère downstream of Grenoble first in relation with the Rhone Service. The dramatic flood of November 1859 accelerated the finishing of the hydrometric and announcement stations upstream. At the end of 1860s the system was working and floods could be foreseen within 12 hours before reaching Grenoble. Two decades later this plan was coupled with a first "flood defence plan", revised several times during the XXth century. Firstly one looked technically to isolate the city, sealing the holes. Tasks to be followed were detailed according to the level of the water with specific disposition for the public information. To sum up, in a space of one generation, the town was provided with a supervision river plan of surveillance capable of preparing it with several hours of warning before the arrival of a destructive flood.

3.2 Aid and assistance

The undertaking of the organization of aid and assistance is more mixed. Here we have to study the period of submersion just before the departure of the water. During the flood, two priority tasks occupied authorities: the evacuation of people and the distribution of foods (Figure 3). We will not go to detail here. We have to note, however, the specific role taken by the troops which in Grenoble was largely mobilised by one task or an other. In a general point of view, if we are able to notice beginnings of a better crisis management, it’s more related to strategic qualities of principal persons in charge than a pre-established process. Things were different for the period who began after the retreat of water, period naturally assigned to repair.



in BLANC-LA-GOUTTE (F.), *Grenoblo Malhérou*, Grenoble, Dardelet, 1860, p. 80 (dessin de D. Rahoult, gravure de E. Dardelet).

Figure 3. Rescue during the 1733 flood’s in Grenoble

Compensation tools were in place since the Ancient Regime. In the Dauphiné province, the organization of the administrator Fontanieu (20th October 1729 order) was the first statutory text which gave detailed references to the control and to the estimation of post accident losses or natural calamities. Following and management made progress during the second half of the XVIIIth century with an increase of the control since 1764. From a general prospective, the reduction of taxes remains to be the most successful method of indemnity taken by the authorities (*Favier*, 2002). The “24 Floreal an VIII” law’s unified and generalised these dispositions. The main novelty, however, resided in the creation of departmental commissions of aid, a further mark of the State control, even though the aids stayed effectively mediocre in strength. The local and inter-regional solidarity compensated sufficiently for this.

4 CONCLUSION

Finally, if the long term analysis shows that river crises of the XVIIth to XIXth centuries coincide in France with the advent of the State, without doubt the Grenoble example shows only some facets of the political engagement during the period. Conversely, the confluence site dynamic probably increases some specific traits. Several times during the city history the fight against flooding has aroused many debates, underlying that this question was at the heart of its territories production process. In return, the double approach, public works on the one hand, alert and assistance plans on the other, should not force us to think about an opposition between two intervening fields. We have to explore a complex reality. In this manner, there is space to further discover and analyse that which historically relies on political, technical and spatial registers. Notably through the mediate role of the engineer, and in the manner in which he has formed, constituted and extended his competencies and knowledges in the river area direction and beyond.

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