HRPP 300

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Reproduced from a paper published in
Journal of Disaster Research
Volume 2, No 3, 2007

EXAMPLES OF RECENT FLOODS IN EUROPE

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Abstract

Some significant flood events that have occurred in various European countries in the last decade are described. They are used to illustrate the widespread nature of flooding, its economic impact and the resultant loss of life. The underlying hydro-meteorological causes of each flood are outlined, followed by a brief chronology of the flood event and the subsequent consequences. The flood events have been drawn from countries with differing climatic conditions, and from river basins that differ in both size and topography. The selection includes floods from the following countries: the Czech Republic, France, Germany, Hungary, Poland, Switzerland and the UK. The events include examples of both flash floods and slower basin-wide floods. The important lessons that may be drawn from these events are highlighted, as are the economic impacts such floods might have in the future due to climate change.

Keywords: Europe, floods, hydro-meteorology, restoration, rivers

Introduction

Widespread flooding has occurred in many European countries over the last decade. The floods have been caused by both long period rainfall, lasting several days or weeks, and short-term very intense rainfall, lasting for just a few hours. The following sections summarise a selection of some of these significant flood events, and include the following examples (with the year date and countries in which they occur): Oder (1997, CZ/DE/PL), Boscastle (2004, UK), Elbe (2002, DE/CZ/), Rhône (2003, FR), Danube (2006, HU/RO), Carlisle (2005, UK) and Alpine rivers (2005, CH).

In each case, a brief description of the underlying hydro-meteorological causes of each flood is given, followed by a brief chronology of the flood event and the subsequent consequences. Detailed statistical information on these exemplary cases is excluded, but further information may be found in the references cited. In the light of these examples, some general comments are made on the lessons learnt concerning flood risk management, future research, the economic impact such floods might have in the future and the possible impact of climate change on fluvial flooding.

Oder (1997, Czech Republic / Germany / Poland)

The Oder (or Odra) is the second largest river in Poland. It rises in the Sudety mountains in the Czech Republic (CZ) and flows North-West towards the Baltic Sea, forming the border between Germany (DE) and Poland (PL). It has a length of 854 km and a drainage area of 118,861 km^2 (89% in Poland, 5% in Germany and 6% in the Czech Republic). Typically there are two periods of high flow, one related to ice/snow melt in the Spring and the other due to intense precipitation in the Summer. The long-term mean annual precipitation is 592 mm, and the mean runoff for the basin as a whole is 145 mm/year.

In July 1997 a devastating flood occurred in the Oder and Vistula river basins, affecting the 3 riparian countries of the Czech

Republic, Germany and Poland[1&2]. Over 110 people died and 200,000 had to be evacuated. The economic loss was estimated to be $3bn. It was officially the largest flood in Polish history, with both discharge and stage records being broken at many locations. In the lower Oder the flood was estimated as a 200 year event, but in the upper Oder it was estimated to be several orders of magnitude larger, making precise calculation meaningless[1]. For example, based on a recorded maximum discharge of 3,260 m^3s^{-1} at the Raciborz-Miedonia gauging station, a linear exceedence probability plot yielded a recurrence interval of 10,000 years!

The main cause of the 1997 Summer flood in the Oder was due to exceptionally high rainfall on land that already had a very high soil moisture level. The rainfall occurred in 3 waves on the following days: 3-10, 15-23 and 23-24 July. In the first wave, recorded rainfall over a 5 day period at selected stations ranged from 585 mm to 58 mm, not particularly high in comparison with world record standards. However, for the month as a whole, the precipitation was more than 300% of the monthly mean in many regions, and in the mountainous regions reached values of 400%. It was this precipitation that caused the flood event, with the maximum flows in the Oder rising to around 3,300 m^3s^{-1} at many locations, almost double the previous recorded maximum.

The hydro-meteorological conditions that caused the record precipitation and ensuing flood were related to warm air masses from the Mediterranean region being convected Northwards and meeting colder air masses from the Baltic. In addition, weather patterns in the Atlantic normally track Eastwards and can create low depressions to develop, in this case, over northern Italy in the lee of the Alpine mountains. In July 1997, three low areas of depression combined and were virtually stationary over the Carpathian mountains. The relatively warm air from the South was convected upwards into the colder air mass already stationary over the upper Oder catchment, nourishing the clouds and leading to the intense precipitation.

The passage of the floodwave along the Oder, the warning of the impending flood given to the population and the need for better flood warning have all received extensive comment on account of the loss of life (60 in CZ; 54 in PL: 0 in DE) and serious damage to infrastructure and property ($2.4 bn in CZ; $3.4 bn in PL: $0.44 bn in DE). Clearly the worst effects were experienced by the people in the Czech Republic and Poland. Many towns were inundated, many bridges destroyed (See Fig. 1) and serious damage done to sewage treatment works, railways and industrial plant. With regard to the loss of life, it is now clear that many deaths could have been avoided if the flood warnings had been heeded, both by local government officials and by the people themselves. In some cases the warnings did not reach the right people, and even when they did, were not taken seriously. As a result, there has been a vigorous public debate in Poland about future flooding. The 1997 flood was a 'wake-up' call to the politicians. As Kundewicz has succinctly stated: "The flood has taught humility to arrogant politicians and militant environmentalists alike"[1]. The Deputy Environment Minister, who headed up the emergency committee during the course of the flood, heralded the flood as "the largest natural disaster in the 1,000 year history of Poland"[2]. With a flood disaster of this magnitude, it behoves all to realise that damage costs are inevitable, but that deaths are not, given a robust and effective flood warning system. As a result of the 1997 flood, strategies for flood protection of major Polish towns, such as Wroclaw, Legnica, Opole and Lwowek Slaski were revised, better warning systems were created, and new management plans for the appropriate use of washlands, reservoirs and control structures along the river Oder devised.

Figure 1 Flood damage in the Oder River basin, July 1997 (Courtesy IIHR)

Boscastle (2004, UK)

In contrast to a long period flood on a large catchment, such as the Oder, described previously, the flood at Boscastle in the UK was an unusually localised one and of very short duration. On 16 August, 2004, a flash flood occurred in the village of Boscastle that was one of the most extreme ever experienced in the UK[3-5]. The expert review commission from HR Wallingford set up by the Environment Agency later estimated the risk of a similar or greater flood recurring at 400 to one in any year. Boscastle lies at the foot of a steep valley on the North coastline of Cornwall in the South-West region of the UK. The Valency river flows through the centre of the village and then on a short distance to a small harbour. A combination of humid sub-tropical air masses and slow moving frontal systems were key factors responsible for the intense rainfall that fell on this particular catchment, affecting a total area of less than 140 km^2. The drainage and topography of the steep-sided valley inevitably accentuated the run-off, causing a surge of water, reported by eye-witnesses to be some 3 to 4 m high, to travel down the valley and through Boscastle at an estimated speed of 65 km/h, causing serious damage and distress (see Fig 2).

The trigger mechanism appeared to be an unstable warm moist south-westerly airflow returning from the mid-Atlantic converging with light southwesterlies over Cornwall. The convergence line was roughly parallel to the coastline. High ground, notably Bodmin moor, caused the moist air to rise above its level of free convection, and large cumulonimbus clouds to develop. Almost constant rain, lasting 5 hours, then occurred, beginning in the early afternoon. Over a 24 hour period, some 200 mm of rain fell, with most of it in a 5 hour period giving a peak intensity of 300 mm per hour (5 mm per minute). The storm was, however, very localised, with 4 of the 10 nearest rain gauges, all within a few km of Boscastle, recording less than 3 mm.

By early afternoon, at around 13.15 p.m. the rain was torrential, and at 15.30 the river was at bankfull. Soon it had burst its banks and was a raging torrent, cascading through the streets of the village. By 15.45 p.m. the village was awash and an official disaster rescue mission began. Cars and camper vans floated down the main street and into the harbour. In all, some 70 cars and vehicles were swept away from a car park in the upper part of the valley, through the village and into the estuary. Roads were ripped up and buildings washed away. A 17 ft boat was swept out to sea and found eventually 135 km away. Water rushed through buildings and hotels, with people having to climb upstairs and in some cases break through the roof tiles in order to be rescued. Over 100 people needed assistance, many being winched to safety by 7 helicopters. Mercifully, there was no loss of life or serious injury, but serious damage was done to many buildings, their contents and the environment. A considerable amount of debris, including 20 m tall trees ripped from the hillside, was swept through the centre of Boscastle and over 1.0 m of mud was deposited in many properties. The rescue continued until evening and the overall effect of the flood on such a small community was considerable, and caused over \$100m of damage.

A comparison with Lynmouth flood[6] of 1952, on almost the same day (August 15 1952), but some 52 years earlier, is instructive. In the Lynmouth disaster, a similar heavy cloudburst occurred on a steep valley, and led to 34 people being killed, the destruction or subsequent demolition of 93 houses and buildings, serious damage to or destruction of 28 bridges and led to 132 vehicles being destroyed. A major cause of damage was caused by debris building up behind bridges and at narrow constrictions, obstructing the flow and creating minor dams. When these eventually were breached, walls of water swept down the narrow valley and streets, leading to significant damage to structures by boulder impact and to loss of life. Landslide, damming and blockages were not so evident at Boscastle, due to somewhat different geological conditions and less hydraulic obstructions.

Following the disastrous flood event at Boscastle, the flood risk was reassessed, but in a different way from that at Lynmouth. The Environment Agency commissioned a post-event analysis[7] drawing on the expertise of the UK Met Office, the Centre for Ecology and Hydrology (CEH) and HR Wallingford in assessing the causes and probable frequency of the event. A post event topographic survey was undertaken to support the simulation of the flood with the InfoWorks-RS modelling software. A key component of the investigation was to generate a spatial distribution of the rainfall based on combination of data from rain gauges, radar imagery and numerical weather prediction models. The runoff from the event was assessed by CEH using the unit hydrograph method of the Flood Estimation Handbook (FEH), but in this exceptional storm, percentage runoff rates exceeded significantly those usually found, lying close to 100% in the later stages of the storm. The FEH run-off method was iterated with the hydrodynamic simulations until the peak discharge in Boscastle was acceptable both from a hydrological standpoint and also from the hydraulic simulation. The hydraulic simulation took account of the blockage of the bridges in Boscastle by cars and large trees, as well as estimates of the river resistance in these exceptional conditions. Historical information on flooding in Boscastle was used to set the 2004 event in the context of other floods in the past 100 years or so. Although the 2004 flood was the worst in the period, evidence was found of other significant floods. As a result a flood frequency curve was developed for the Valency at Boscastle which indicated that the 2004 discharge of 180 m^3s^{-1} from this 20 km^2 catchment had an annual probability of about 0.25%.

These studies not only helped in understanding the passage of the flood wave in hydraulic terms, but also ensured that the planning of new flood alleviation measures was based on sound science. New culverts, bypass structures and widening of some tributaries were implemented. Following the experience of Boscastle, the Environment Agency compiled a register of catchments in England and Wales where heavy rainfall is likely to give rise to very rapidly rising river levels and where the velocity of flow could cause extreme risk to life. This register will help the Agency to make its flood warning systems more effective, to focus its public awareness campaigns better, to increase its influence on local authorities and to assist in the preparation of more appropriate emergency response plans. The importance of swift action taken by local residents and the emergency services was a key factor in eliminating the loss of life at Boscastle.

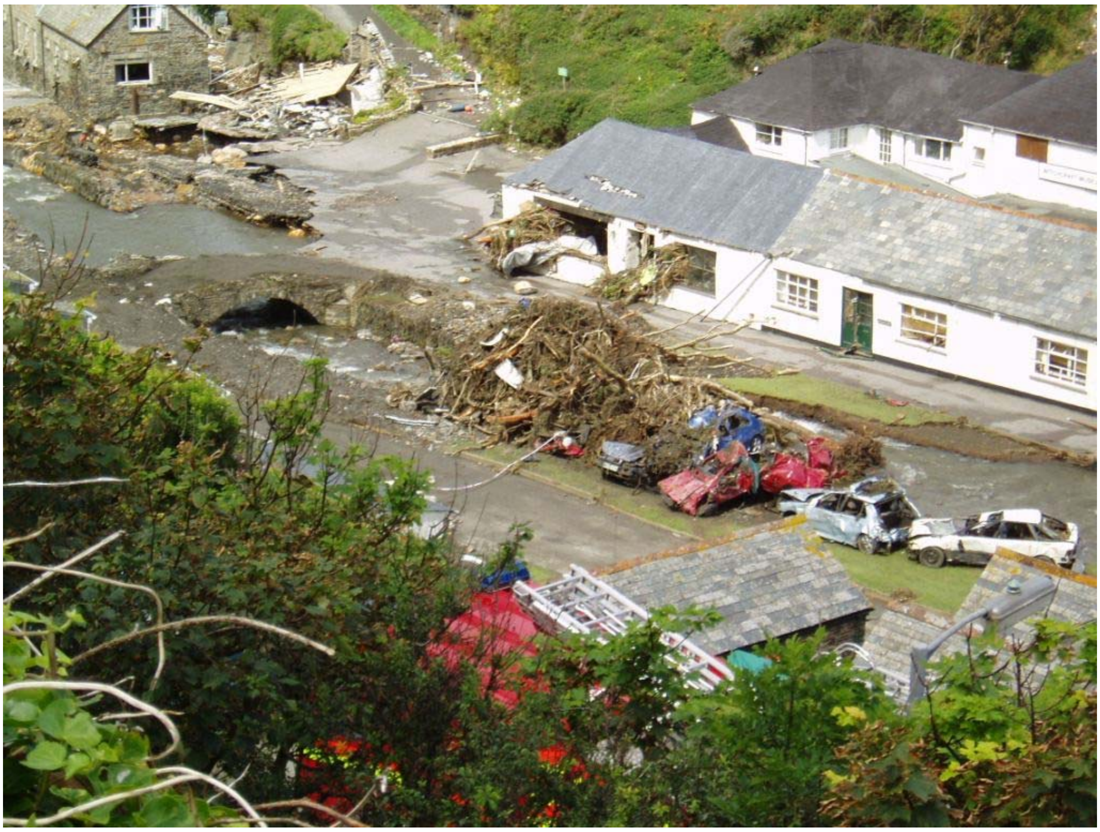

Figure 2 Flood damage in Boscastle, UK, August 2004 (Courtesy HR Wallingford)

Elbe (2002, Czech Republic/Germany)

The river Elbe lies to the West of the river Oder and flows in a similar direction, North-West from the Czech Republic, through Germany, via Dresden, Magdeburg and Hamburg, into the North Sea. An important tributary of the Elbe is the River Vltava, which flows through Prague in the Czech Republic. Like the Oder, the Elbe is one of the larger rivers in that region and drains a significant region of central Europe. In August 2002, extreme rainfall fell for two weeks in the Czech Republic and Germany, causing severe flooding in a number of river basins[8&9]. The total precipitation for the first 12 days of August was 1.5 times the average monthly mean in parts of Northern Germany. In the Southern region, rainfall records exceeded what would be expected to occur once only in every 100-300 years. For example, on 12 August, 312 mm of rain fell at Zinnwald over a 24-hour period, 3 times the mean monthly value, and set a new 24 hour rainfall record for Germany. Furthermore, during that day several high intensity peaks occurred (9 mm in 10 minutes) associated with thunderstorm activity. These inevitably led to a number of flash floods in several rivers in the upper part of the Elbe river basin.

As a consequence of this unusually severe precipitation, a flood wave passed down the Elbe, and the river level at Dresden reached a new record, exceeding the peak water level of 1845. A significant contribution to this flood wave came from the River Vltava, an important tributary of the Elbe, that flows through Prague. At Dresden the discharge peaked at around 5,000 m^3s^{-1} on 17 August. As a result of this flood wave, many historic buildings and the main railway station were inundated, causing damage estimated at \$1.0bn in Dresden and surrounding areas. The high river levels caused the level of ground water to rise by 6 m in the floodplain gravels, twice the previous record, and caused significant flooding in basements, even beyond the extent of the fluvial flooding. Further flooding was caused by more than 10 breaches in the Elbe embankments. The fortuitous timing of these breaches, in conjunction with controlled flooding into areas near the Havel estuary, reduced the flood wave by about 75 million m^3. The peak river flow eventually diminished to below 1,000 m^3s^{-1} by the 17 August. The total economic damage in both Germany and the Czech Republic was later estimated to be \$15bn.

According to Ulbrich et al.[9], the Elbe flood of August 2002 was caused by very humid air at low to mid tropospheric levels arriving from the western Mediterranean basin around the Alps. In the upper troposphere, a cold flow of air was caused by a track of low pressure Eastwards from the UK towards Western Europe. The warmer air from the south was lifted up into the colder region by the mountainous terrain, leading to intense rainfall. Combined with a quasi-stationary front over Southern Germany, this was sufficient to produce this record precipitation. Somewhat similar meteorological conditions occurred in the flooding on the Oder in 1997, and the same conditions are also thought to have been responsible for the flooding on the Vistula in 2001. It appears that extreme Summer rainfall and stationary fronts are a feature of this region. It appears from numerical simulations that the frequency of Summer storms will increase due to climate change.

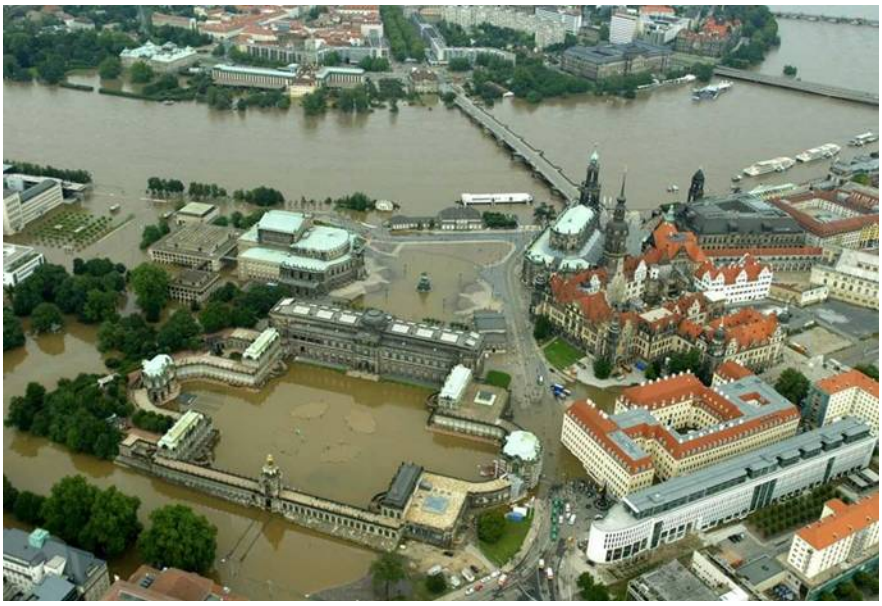

Figure 3 Flooding of the Elbe River at Dresden, August 2002 (Courtesy IOER, Dresden)

Rhône (2003, France)

The River Rhône is 813 km long, rising in the Swiss Alps upstream from Lake Geneva, and flows predominately Southwards towards the coastline port of Marseilles, the second largest town in France. The Rhône is the only major French river to flow directly into the Mediterranean Sea. The river basin is some 98,000 km^2 and forms one of the great economic regions of France. The discharge in the Rhone is related to its genesis in the Alps, and varies typically from a mean flow of 640 m^3s^{-1} at Lyon to flood flows in the Spring and Autumn of around 13,000 m^3s^{-1} at Beaucaire, near the delta.

Following near constant rain in October 2003, river levels rose throughout the Autumn and between Dec 1-3 powerful storms hit the Rhône valley and Marseilles area with 200 mm of rain. In nearby Montpellier half of its average annual rainfall fell in a single night. As a result, the river reached its highest ever recorded level for 100 years (6.42 m at Marseilles). In Avignon, the river was 2.8 m above its normal warning level, and at Pont-Saint-Esprit it reached an unprecedented 4 m above the warning level. The flood inundated some 80,000 km^2, thousands of buildings, and caused 27,000 people to be evacuated, including 193 prisoners who had to be transferred from ground floor cells to upper floors. In the village of Aramon, where 5 people died from floods in 2002, the rebuilt dykes were in danger of over-topping. In Bollene, 80 elderly people had to be evacuated from their home into temporary shelters. The water depths reached up to 1 m in many parts and over 2 m in some industrial areas, causing severe disruption to both road and rail links (see Fig. 4). The number of deaths was estimated to be 15.

The town of Arles was particularly affected as several dykes failed, leading to the shut-down of two of the four nuclear power plants in that vicinity. It was also feared that debris carried by the flood waters would clog the cooling systems at the power plant. There was also concern about radioactive contamination. In the event, subsequent analysis[10] indicated that sediment mass and associated contaminants were transferred from the river to the agricultural soils of the region, but that the general level of pollution in the soils regarding radioactive contaminants was stable. In addition to the loss of facilities to treat waste water, some 250,000 people lost their drinking water supply during this event. The economic losses were estimated at \$1.5 bn and the insured losses at \$1 bn. The total losses were the 5th largest of all natural disasters in 2003. The flood of December 2002 was the 8th in 11 years.

As a result of this particularly devastating flood, serious questions were asked about the new developments that were allowed to be built on the floodplain before 2003, and the assistance and support given to flood victims after the flood. Tougher zoning rules and planning legislation have been suggested for the former, as continual dyke building and maintenance is expensive. However, it should be noted that despite this being worst flood since 1856, and despite some smaller dykes and earth embankments failing, the majority of the 10,000 km main dykes along the Rhône held firm. With regard to post-flood reconstruction, although immediate assistance was given by the State to flood victims, and the cleansing of industrial plant and public infrastructure made a priority, the long term reconstruction and the recovery of business confidence took a longer time. New investment was made and, according to government sources, industrial parks will be planned that are ‘waterproof’.

However, raising the river banks ever higher is now recognised as not being an appropriate solution to the long-term flooding of the Rhône. Rather, Jean-Luc Fabre, the sub-prefect of Arles is quoted as saying “Raising the banks, contrary to what we may think, is not necessarily the appropriate solution. On the contrary, it seems preferable to rehabilitate the river’s natural field of expansion, which men had gradually eliminated due to unbridled urbanisation”. It is encouraging to have such a statement from a politician given the comments made earlier about the flood in the Elbe river being a wake-up call. Such statements are even more necessary, given the fact that some French meteorologists have stated that the Winter rainfall will increase by 20% by 2050, given the level of global warming already predicted for the next few decades.

Figure 4 Flooded street in the Rhône flood of December 2003

Danube (2006, Hungary/Romania)

The River Danube rises in the Black Forest mountains of western Germany and flows for some 2,850 km to its mouth on the Black Sea in Romania. It is the second longest river in Europe after the Volga, and passes through nine countries along its course to the sea.

In April 2006, swollen by heavy rain and melting snow, the river hit its highest level in 111 years and the discharge was approximately twice its normal value, reaching 15,800 m^3s^{-1} in Romania. It broke through various flood defences, and thousands of people had to flee from their homes, particularly along the lower reaches in Serbia, Romania and Bulgaria. In these reaches much of the land is agricultural, making rescue work difficult. For example, in the village of Rast in southern Romania, the authorities had to evacuate 3,200 people and more than 6,000 animals after the Danube breached a nearby embankment.

This flood had a significant impact upon the people of Romania. In mid May 2006 Dr Madalin Mihailovici, the general manager of Apele Române, spoke at the European conference on Floods organised under the EU Austrian presidency in Vienna. His summary[11] showed that water levels had exceeded the historic maxima recorded at all gauges in the country and that there had been 12 significant breaches of the river embankments; seven were unintended, two were controlled to use sacrificial storage and three were made to evacuate the flood waters trapped behind the banks as the floods receded. Overall 67,200 Ha of land behind the embankments had been flooded and 1,769 Million m^3 of water had entered the floodplains. The flooding had affected 10 countries with the following aggregated consequences:

- 11,470 evacuees
- 642 houses destroyed
- 3,200 houses inundated

- 36,870 Ha of farmland flooded
- 24 industrial/commercial units flooded
- 62.3 km of roads damaged
- 20 bridges and foot bridges damaged

According to World Wildlife Fund (WWF), the ongoing flooding of the Danube in Romania is the result of bad land use planning and mismanagement along the entire length of the river. As a result of man-made changes, including channelling and construction of dykes and dams for navigation and traditional flood management, the Danube River has lost 15,000–20,000 km^2 of floodplains since the 19th century, with less than 19 per cent of the former floodplains remaining. When natural retention zones are lost on the upper reaches of the river, the problem simply gets transferred further downstream, with increased impacts and damage. The view of the WWF is that an integrated and internationally coordinated approach to flood management that works with nature, not against it, is needed for flood security along the entire length of the river. The new EU Floods Directive could provide the kind of integrated approach to flood management that is needed for flood security in future, but it will depend on the way that the legislation is implemented. The aim must be to ensure that economic activities in flood risk areas bear the costs of flood defence measures and that other EU member states should also promote other flood mitigating measures, such as maintaining and restoring floodplain areas, which can store water and thus limit the impact of floodwaters. An example of a restored floodplain area is shown in Fig. 5.

The management of trans-national rivers, such as the Danube, raises a number of wider issues concerning political co-operation. In 1998, the International Commission for the Protection of the Danube River (ICPDR) was established as an international organisation to manage the whole of the Danube River Basin, including its tributaries and ground water resources. The ICPDR consists of 13 cooperating states and the European Union and is now one of the largest and most active international bodies of river basin management expertise in Europe. Its mission is to promote and coordinate sustainable and equitable water management, including conservation, improvement and rational use of waters for the benefit of the Danube River Basin countries and their people. The ICPDR pursues its mission by making recommendations for the improvement of water quality, developing mechanisms for flood and accident control, agreeing standards for emissions and by assuring that these are reflected in the Contracting Parties' national legislations and applied in their policies.

In December 2004, the Danube countries adopted the 'Action Programme for Sustainable Flood Protection' for managing the risk of floods to protect human life and property. Key elements of the Action Programme included the development of a new international flood warning system, mapping high flood risk areas, giving rivers more space such as creating new water retention zones, and an end to new building in natural floodplain areas. The new flood warning system, overseen by the ICPDR but developed by the Italy-based European Union Joint Research Centre, supplements national systems and give up to 10 days warning of expected floods. Sulfina Barbu, Romania's Minister for Water and Environment, is quoted as saying, "We are convinced that peak flood prevention can only happen in Romania if upstream countries in the Danube Basin are also helping to implement an effective Danube flood action programme agreed to by all Danube states."

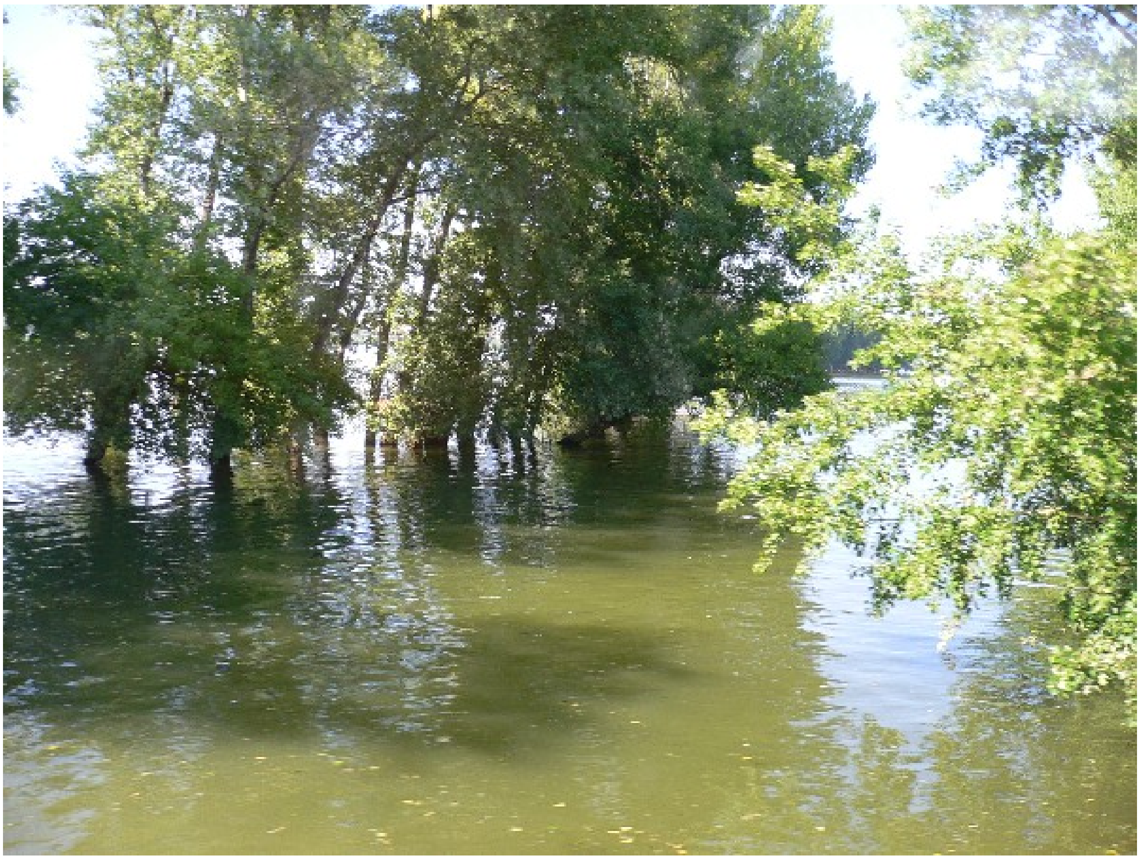

Figure 5 Danube flood retention in the natural floodplain near Galati

Carlisle (2005, UK)

The worst floods for over a century hit Carlisle in January 2005. Over 1 month's rain fell in 24 hours, forcing 6,000 residents to be evacuated from their homes and to be placed in emergency accommodation overnight. The river level rose to over 1 m above its previous highest recorded level on Eden Bridge in 1822. At one point some 3,500 properties and 350 business premises were seriously affected and 70,000 homes were without power. See Fig. 6.

Despite the high river levels, it should be noted that the flooding was due not only to rivers overflowing their banks, but also due to the sewers being overloaded and the drainage system in the city being inadequate. Thousands of tons of waste material were created by the floodwaters. Because of the health risks arising from the non fluvial sources, the police warned people that they should avoid contact with contaminated water and urged children not to paddle in flooded areas because of the risk of gastro-enteritis and Hepatitis A.

From a planning perspective, certain parts of the city were known to be at risk, and a new flood alleviation scheme was already in the advanced stages of the planning process when this particular flood occurred. Despite the fact that this scheme met all national flood standards, the January flood was so extreme that it even exceeded these standards. The return period was later estimated to be of the order of 250 years. The flood damage costs were estimated to be over $475m, including $57m for damage to schools that was met by a direct grant from central government.

Following the January floods, the Environment Agency formed a project board comprising Carlisle City Council, Cumbria County Council, United Utilities and English Nature. The aim was to develop a fully integrated approach to solving Carlisle's drainage problems and thereby underpin the economic renaissance of the city. Two phases of flood alleviation works were proposed, one costing $23m and to be completed by Spring 2008, and the other costing $46m, to be completed in 2010. Both schemes were developed after extensive local consultation with local residents, businesses, councillors and community action groups and envisage a network of earth embankments covered in grass and flood walls faced with natural stone. There will also be improved flood defences along both banks of certain rivers and the existing line of defence will be set back to increase the size of the flood plain.

An important component of the post-flood management action was the holding of a series of meetings with flood victims. The victims of the January flood were invited to a series of free drop-in advice days, held in the Town Hall, where they could discuss with the Environment Agency and other officers all aspects of the flood defences. Further days were devoted to insurance issues, building repairs and flood-proofing, and finally to health and wellbeing. This important aspect of managing flood risk is often overlooked.

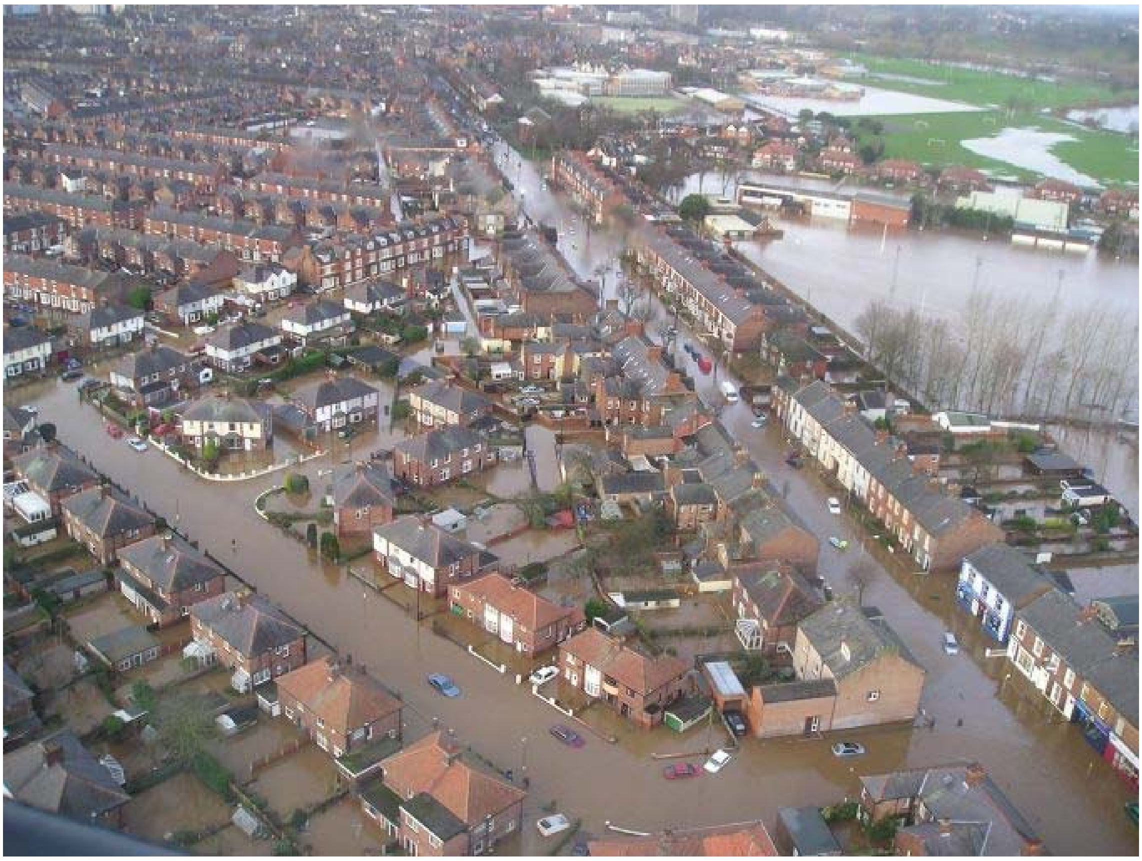

Figure 6 Flooding in Carlisle, January 2005 (Courtesy Environment Agency UK)

Alpine Rivers (2005, Switzerland)

Cities and towns across central Europe suffered the impact of devastating floods in August 2005, in which at least 42 people were killed. Several Alpine towns in Switzerland were particularly affected by days of torrential rainfall, torrents of water flowing through streets and landslides. As a result, many houses and bridges collapsed, sections of motorways were destroyed and some farms were swept away. Mudslides also blocked roads and railway tracks. At least 11 people died in Switzerland, including two firefighters killed by a landslide in Brienz, and several deaths occurred in both Austria and Germany as a result of the same flood event. Hundreds had to be evacuated from their homes, including 300 from the Swiss capital, Berne, which was hard hit by the flood water. Electricity was cut off and drinking water was contaminated there as in many other towns. Insurers say the economic cost of the flood in Switzerland alone was estimated to be $800m, with the economic losses higher than the insured losses.

In the light of this flood event, and previous ones in 1999 & 2000 in which 20 people were killed, the Swiss are now spending £88m to put back the bends in their rivers. After decades of believing that straighter rivers flooded less, they now recognise that bend-straightening only made the problem of flooding worse. Consequently there is a programme of putting these rivers back on course by rectifying "corrections" that were made previously. This will have the added benefit of re-naturalising the rivers also.

One engineer, U Schaelchi, responsible for this re-naturalisation programme, has stated that the current deaths are the consequences of the "correction" work that was carried out on Swiss rivers and waterways between 1870 and 1940. Dozens of rivers and lakes underwent major dam-building and canalisation work. Water courses were rerouted and canalised to combat the danger of floods and to cultivate swampland. Once the larger waterways had been corrected, almost all other streams and brooks were forced into ‘straitjackets’ as well. The rivers are, is a sense, now "rebelling" and Switzerland is paying a high price for messing with nature. About 100 projects are planned or under way to restore rivers, streams and brooks to their meandering routes.

Concluding comments

Between 1998 and 2005, Europe experienced over 100 severe floods causing 700 deaths, the displacement of half a million people and approximately $32bn (25bn euros) in insured economic losses.

One feature of the flash floods in Boscastle (2004) and Cardoso (1996), Italy, is that of the combined influence of topography and intense rainfall falling for a relatively short time. In very steep narrow valleys, traditional flood defence works are not only inappropriate but also of limited use. In Europe it is flash flooding that causes the greatest loss of life, whether these are localised events or part of larger basin-scale floods such as the Odra and Elbe floods discussed above. In flash floods, structural damage is always likely to occur, and should therefore be anticipated, and more effort directed towards effective flood warning in order to minimise fatalities.

In slower, long-term floods, the orographic influence is seen to be highly significant, as observed in the flood events on the Oder, Vistula and Elbe rivers. Wherever warmer air is lifted up into a colder region by the mountainous terrain and combined with quasi-stationary meteorological conditions, then intense rainfall is likely. The tracking of low depressions is therefore important, as indicated by what meteorologists refer to an important depression track known as Vb. There is evidence that regional scale climate change in the western Mediterranean is increasing the potential for these severe floods[12]. It is in the lower reaches of major rivers that the displacement of population and economic damage are likely to be most significant.

In many flood events, such as demonstrated in Carlisle, it is not just fluvial flooding that causes problems. Very often the sewers and drainage systems also become overloaded, leading to other pathways by which water can spread. In the case of the Elbe, the rise in groundwater levels under Dresden caused flooding outside of the fluvial flooding envelope. Flooding therefore should be seen as a multi source and pathway event, and an integrated view of surface water, ground water and underground services should be taken. Even flow of water over land has many causes, including that of land use, and attention needs to be paid to changes in crop type, urbanisation and agricultural practices, as well as to floodplain topography.

Rivers do not only act to convey water from their headwaters to the sea but also perform the natural function of transporting both sediments and organic matter with the flow. There is a need to understand better the origin, movement and impact of debris (floating and bed load) in natural rivers in general, and their effect on structures in particular. There are still several hydraulics problems requiring further investigation, especially those related to flash floods. These might include free surface turbulence, supercritical flow shockwaves in complex geometries, e.g. narrow streets, and transcritical flow behaviour. The modelling of flooding rivers is still technically a surprisingly difficult problem, and raises many other interesting hydraulic issues. Because of their training, Civil Engineers are uniquely placed to deal with these issues, as well as their significance in relation to other river basin management issues[13].

The European Commission (EC) has funded many research topics on flooding within a broader programme of science on understanding natural hazards and hydrogeological risks. Over 100 projects have been funded since the early 1980s, and are itemised in a report by the University of Birmingham (see actif-ec.net website in Table 1). Much research is also being conducted throughout the world to ensure that we are better prepared for floods in the future[14]. The recent UK Foresight project[15], the current EC Floodsite project[16] and the newly started Peseta project on climate issues all indicate the strength of activity in flood research (see Table 1 for websites). Further details on useful flood related studies may be found in the programmes listed in Table 1. A specifically European perspective on research[16], and an indication of the effects of climate change on flooding[17] may also be found in the references.

Table 1 Links to some useful flood related studies

Project	Link
RIBAMOD	http://www.hrwallingford.co.uk/projects/RIBAMOD/index.html
RIPARIUS	http://www.nwl.ac.uk/ih/www/research/bripariu s.html
MITCH	http://www.hrwallingford.co.uk/Mitch/default.htm
IMPACT	http://www.samui.co.uk/impact-project
University of Birmingham	http://www.actif-ec.net/library/review_EU_flood_projects.pdf http://www.flowdata.bham.ac.uk
CES	http://www.river-conveyance.net
FLOODSITE	http://www.floodsite.net
FORESIGHT	http://www.foresight.gov.uk
PESETA	http://peseta.jrc.es
EU directive	http://europa.eu.int/comm/environment/water/flood_risk/index.htm

It is clear from the exemplary flood events cited above that in Europe flooding is not only widespread but also occurring at an unwelcome frequency. It appears that even in a highly developed part of the world, loss of life still occurs, albeit on a much smaller scale than in less developed countries. The impact on infrastructure is, however, much greater, and the economic and financial losses are consequently also greater.

In response to the evident social and economic problems caused by flooding, the European Commission proposed on January 18 2006, a new directive on the assessment and management of floods to reduce and manage flood risks. It sets out the need for assessments, maps and plans that cover the river basin district including the borders of the river basins, sub-basins and where appropriate associated coastal zones through:

- Preliminary flood risk assessment to identify areas for subsequent investigation

- Flood risk maps
- Flood risk management plans

These assessments, maps and plans need to be updated on a 6-yearly cycle (for details see website in Table 1). It is expected that following political agreement by the EU Council of Ministers on the draft Directive, a final version will be concluded with the European Parliament during 2007.

The recent floods have therefore galvanised politicians and policy makers to review previous flood management strategies. The magnitude of natural flood events, and the greater understanding that now exists concerning the potential effects of climate change, has encouraged a new realism among politicians and environmentalists alike. In many countries there has been an implicit shift from 'flood defence' to 'flood risk management'. Both risk and uncertainty are elements that need to be addressed[18]. This paradigm of Flood Risk Management needs the skills of many different professions to be brought to bear in mitigating the effects of what remains the most widely distributed natural hazard in Europe.

References

1. Z.W.Kundzewicz, Destructive flood in Poland: Odra, Summer 1997, *RIBAMOD - River Basin Modelling and flood mitigation: concerted action*, Proc. Workshop/expert meeting, September 1997, The European Commission, EUR 18853 EN, (1999).

2. A. Bronstert, A. Ghazi, Z. Hladny, Z.W. Kundzewicz, & L. Menzel, Proceedings of the European Expert Meeting on the Oder Flood 1997 – Ribamod concerted action, *European Commission, Environment and climate programme 1994-98, Hydrological and hydrogeological risks*, Office for Official Publications of the European Communities, 1-163, (1999).

3. R.K. Doe, Extreme precipitation and run-off, induced flash flooding at Boscastle, Cornwall, UK -16 August 2004, Boscastle Flood Special Issue, *The Journal of Meteorology*, Bournemouth, UK, (2004).

4. Environment Agency, Boscastle flood study – key findings, *The Environment Agency National Press Office*, Document 014/05, January, 1-2, (2005).

5. D. Rowe, Boscastle: 16 August 2004 – the day of the flood, Truran Books Ltd., Cornwall, 2004, ISBN 1 85022 1936, (2004).

6. E. Delderfield, The Lynmouth flood disaster, ERD Publications Ltd., Exmouth, UK, (1953).

7. C. R. Fenn, R. Bettess, B. Golding, F. A. Farquharson & T. Wood, The Boscastle Flood of 16 August 2004: Characteristics, Causes and Consequences, paper 05B.1, 40th Flood and Coastal Management Conference, July 2005 papers available from http://www.defra.gov.uk/environ/fcd/conference/conference.htm (2004).

8. U. Ulbrich, T. Brucher, A.H. Fink, G.C. Leckebusch, A. Kruger & J.G.Joachim, The central European floods of August 2002: Part 1 – Rainfall periods and flood development, *Weather*, Vol. 58, November, 434-442, (2003).

9. U. Ulbrich, T. Brucher, A.H. Fink, G.C. Leckebusch, A. Kruger & J.G.Joachim, The central European floods of August 2002: Part 2 – Synoptic causes and considerations with respect to climate change, *Weather*, Vol. 58, November, 434-442, (2003).

10. F. Eyrolle, C. Antonelli, C. Duffa & B. Rolland, The extreme flooding of the Rhône valley in December 2003 (South east France): Consequences on the translocation of sediments and the associated contaminants over the flooded area, *RMZ –Materials and Geoenvironment*, Vol. 52, No. 1, 25-29, (2005).

11. M. Mihailovici, "Floods in Romania 2005-2006 - Lessons learnt, response foreseen", presentation at European Conference on Floods, Lebensministerium, Vienna Austria, 17-18 May, 2006 available at http://www.wassernet.at/article/articleview/47659/1/5711/ (2006).

12. M. M. Millan, "Climate change and drought:The role of critical thresholds and feedbacks" paper in the Workshop Proceedings of *Climate change impacts on the water cycle and resources - floods and water scarcity*, 25-26 September 2006, Report EU22422 DG Research, Brussels available at
http://ec.europa.eu/research/environment/pdf/kina22422ens_web_water_and_cc.pdf (2007).

13. D. W. Knight, A. Shamseldin, *River Basin Modelling for Flood Risk Mitigation* ,Taylor & Francis, 1-607, (2005).

14. D.W. Knight, S. Cao, H. Liao, P.G. Samuels, N. Wright, X. Liu, X. and A. Tominaga, Floods – are we prepared?, *Journal of Disaster Research*, Fuji Technology Press, Tokyo, Japan, Vol. 1, No. 2, 325-333, (2006).

15. Office of Science & Technology, *Foresight flood and coastal defence project, Technical Report, Drivers, scenarios and work plan*, Cabinet Office of Science & Technology, UK Government, (2003).

16. P.G. Samuels, The European perspective and research on flooding, *River Basin Modelling for Flood Risk Mitigation* [Eds Knight D.W. & Shamseldin, A.], Taylor & Francis, Chap. 2, (2005).

17. A. Bronstert, The effects of climate change on flooding, *Chapter 4*, *River Basin Modelling for Flood Risk Mitigation* [Eds D.W.Knight & A. Shamseldin], 77-91 (2005).

18. P.G. Samuels, Risk and uncertainty in flood management, *River Basin Modelling for Flood Risk Mitigation* [Eds Knight D.W. & Shamseldin, A.], Taylor & Francis, Chap. 25, 481-517, (2005).

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