Central Europe Flooding, August 2002

Event Report

Risk Management Solutions

INTRODUCTION

Severe flooding affected parts of Austria, the Czech Republic and Germany for three weeks during August 2002. Heavy rainfall from storms that crossed central Europe during early August triggered sequential flood waves along two major river systems. The flood waves moved down the River Danube through Austria and down the Vltava, Labe and Elbe rivers in the Czech Republic and Germany. Unprecedented flood heights, with return periods of up to 500 years, were recorded and over 110 people died. These were the most costly floods affecting Europe in years. As of December 2002, total economic damage estimates exceeded 15 billion Euro, of which about 15% is insured. Germany was the hardest hit, with over two-thirds of the flood's total losses. In particular, the state of Saxony (capital Dresden) sustained nearly half the total loss. The largest loss after Germany was in the Czech Republic, with over 3 billion Euro in damage, of which over a third was concentrated in Prague. Low penetration of flood insurance means that governments will incur most of the repair costs, with some help from the European Union (EU) and voluntary donations.

Damage exceeded that of 1997, when the River Oder flooded large areas of the Czech Republic, Poland and along the Polish-German border. A primary driver of the large loss in 2002 was the flood's costly impacts on Dresden and Prague, where massive flooding affected both residential and commercial properties. Flood defenses along the river systems were temporarily extended and strengthened, but water still inundated protected areas in a variety of ways. Underground seepage and dike breaches were two main causes of water ingress.

Figure 1. Major rivers and cities affected by the August 2002 floods

This report summarizes research into the causes of flooding and resulting damage, focusing on a case study of Prague where RMS conducted a damage survey shortly after the flood peak. Total damage in Prague is estimated at nearly 1 billion Euro. The districts of Lesser Town (Malá Strana), Old Town, the Jewish Quarter (Josefov), and Karlin suffered particularly heavy losses. Below-ground entry of water to basements caused most of the damage in the Old Town and Jewish Quarter, while overland flooding affected both the Lesser Town and Karlin. Ancient and unmapped tunnels exacerbated the problem in this historic city.

FLOOD EVENT CHARACTERISTICS

The catastrophic flooding that occurred in Austria, the Czech Republic, and Germany was the result of two periods of intense rainfall. The first period of rain on August 6 and 7 fell on southwestern Czech Republic and northeastern Austria, immediately north of a weak area of low pressure. Rainfall accumulations across this region were generally less than 125 mm (5 inches) over this two-day period, but values of up to 255 mm (10 inches) were observed in some locations.

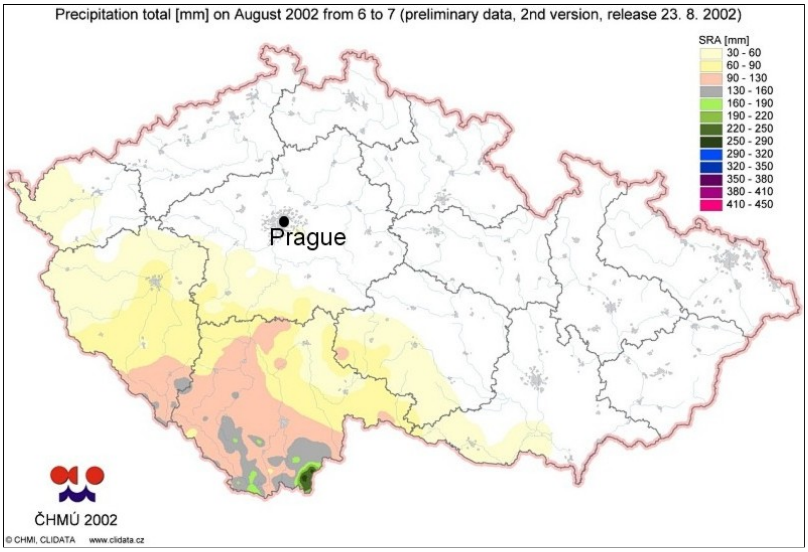

Figure 2. Rainfall totals (mm) for the initial period of rain on August 6 and 7 (Czech Hydrological and Meteorological Institute, CHMI)

Although this initial phase of rain produced some localized flooding, much of the water runoff was contained by a series of reservoirs (known as the Vltava Cascade) upstream of Prague. Water was gradually released from the dams over the following days, but the increased capacity was insufficient to prevent the flood wave that followed less than a week later.

Figure 3. River Vltava in Prague on August 10 after the arrival of water from upstream rains on August 6 and 7

A second more expansive and intense period of rain fell from August 11 and 13. It was produced by an extratropical system classified as the Genoa Cyclone Type Vb, typified by its track from the north Adriatic Sea toward Poland (Figure 4). Genoa Cyclones of this type commonly occur in the spring. However, two specific features of the August Genoa Cyclone led to the extraordinary amounts of rain. First, this cyclone moved more slowly than is commonly observed in the spring. Second, water temperatures in the Adriatic and Mediterranean Seas are significantly warmer in August than in the spring season. These factors caused substantial amounts of atmospheric moisture to advance north from the Adriatic Sea, fuelling the extreme rains. Past flood events in this region have also been associated with this type of storm, such as the River Oder floods in 1813 and 1997.

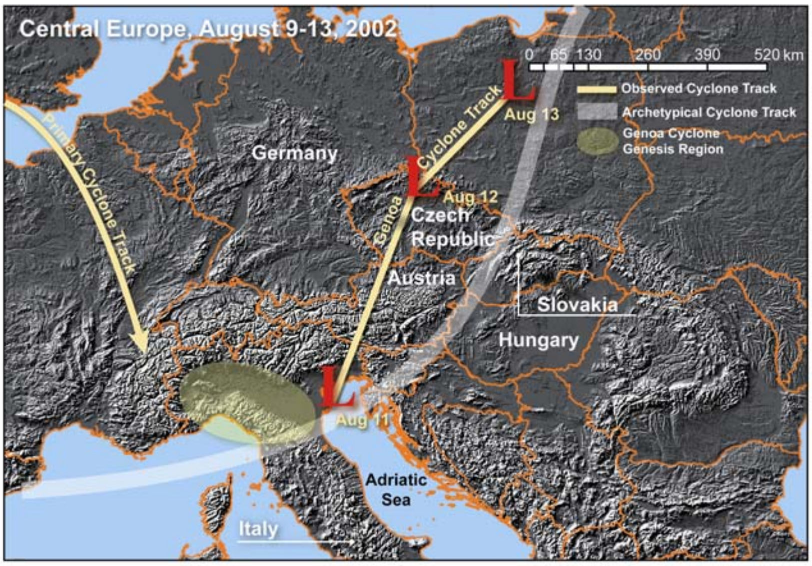

Figure 4: Path of the cyclone track between August 9 and 13

Rainfall from the cyclone was focused in two areas: 1) near the Czech/German border in the Erzbirger Mountains and 2) in south Bohemia and northern Austria. Although similar amounts of rain fell in south Bohemia on August 6 and 7, the rain footprint was much more expansive on August 11 and 13. The rainfall triggered flood waves in the upper portions of the Danube and Vltava catchments. One flood wave progressed down the Danube through Austria, Slovakia and Hungary, causing minor damages in the region. A more catastrophic flood wave progressed down the Vltava through Prague and down the Elbe through north Bohemia and Germany.

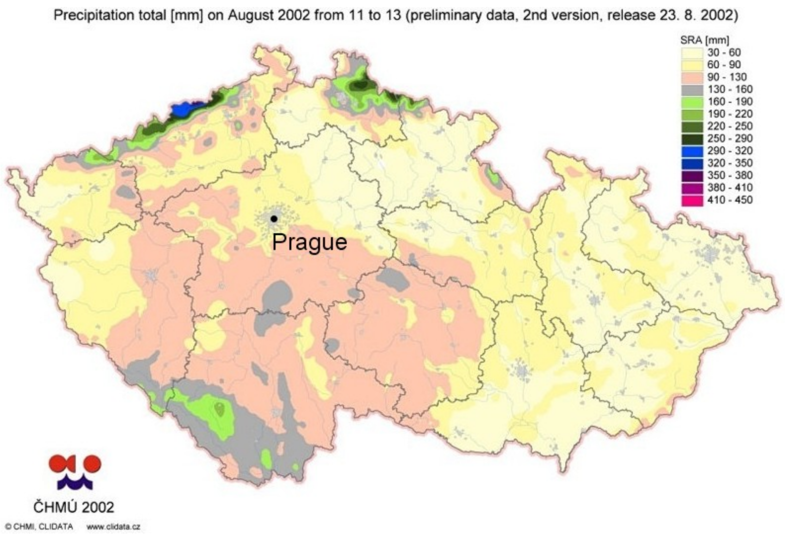

Figure 5. Rainfall totals (mm) from the Genoa Cylcone between August 11 and 13 (CHMI)

The intense rainfall of nearly 320 mm (12.5 inches) over two days in the Erzbirger Mountains was related to a process where upper-level clouds "seed" low-level clouds over the mountains, enhancing rainfall production. Runoff rapidly entered the River Weisseritz, a tributary of the Elbe in Dresden, causing initial flooding of the city on August 12.

At the same time, the Vltava flood wave overtopped reservoirs and rapidly progressed downstream to Prague. The flood wave combined with another wave entering the basin from the River Berounka, just south of Prague, to create an unprecedented river discharge of 5,300 cubic meters per second (187,200 cubic feet per second) in Prague on Wednesday, August 14 (Figure 6). The CHMI estimate a discharge of this magnitude has a 500-year return period. At the beginning of the month before the rain, discharge was recorded at 400 cubic meters per second (14,130 cubic feet per second). River gauge records show the rapid onset of the flood in Prague (Figure 7).

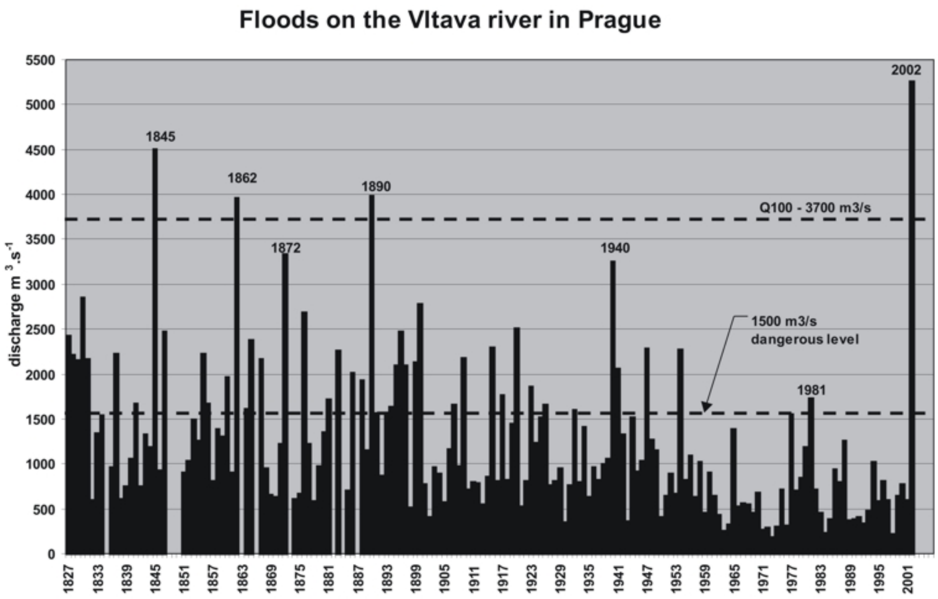

Figure 6. Historic river discharge (cubic meters per second) recorded on the Vltava in Prague since 1827 (CHMI)

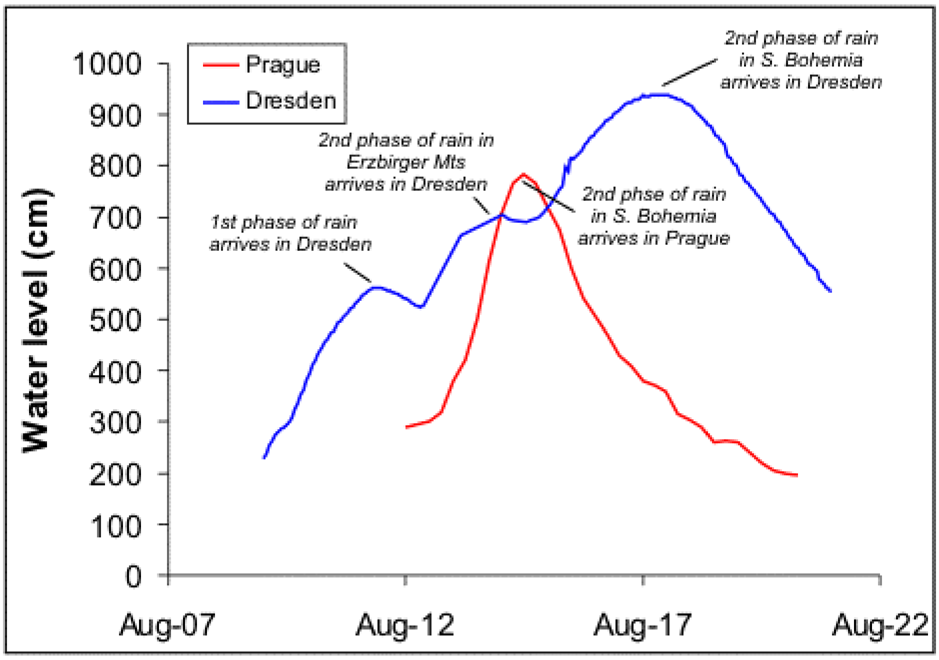

Figure 7: River heights in Dresden and Prague during August

The flood wave continued down the Vltava into the River Labe (known as the Elbe once it crosses the Czech/German border) and into Germany. On the morning of Saturday, August 17, the river level in Dresden peaked at a record height of 9.4 m (30 feet), superseding the previous record of 8.8 m (29 feet) set in 1845. The increase in river height in Dresden was more gradual and of greater magnitude than the flood peak in Prague. The 160-km (100-mile) progression of the flood wave from Prague to Dresden spanned three days. In total, the flood wave took around 12 days to travel from the upper reaches of the Vltava to the mouth of the Elbe in northern Germany, a distance of over 1,000 km (620 miles).

Flooding Damage and Losses

Most of the loss (over 11 billion Euro) came from the River Elbe catchment, which covers 64% of the Czech Republic and 27% of Germany. A further 2 billion Euro damage was caused in Austria. Key contributors to the large loss were damages in Prague, Dresden in the state of Saxony, and Germany (Figure 8). Saxony and Prague together sustained over 7 billion Euro of damage.

Figure 8. Overview of rivers and towns affected

The weekend of August 10 and 11 saw the first wave of significant damage, as flash floods and landslides were triggered across northern Italy, the state of Bavaria in southern Germany, Austria, Romania and the Baltic Sea coast of Russia. On Monday, August 12, the River Danube in Austria burst its banks at several points in the provinces of Salzburg, Upper Austria, and Lower Austria, which are in northern and central parts of Austria. An estimated 10,000 houses in these areas were damaged or destroyed.

Across the border, intense rainfall entered the headwaters of the Vltava, causing extensive damage in the southern Czech Republic (southern Bohemia) during August 12 and 13. Cesky Krumlov, Ceske Budejovice, Plzen, Pisek and Stratonice, which all lie along the Vltava, were covered by up to 1 m (3 feet) of water and hundreds of properties were flooded. As the floodwaters approached Prague, around 50,000 residents were evacuated, all bridges across the Vltava were closed to traffic, and temporary flood barriers nearly 3 m (9 feet) in height were erected along the banks to protect the Old Town. The river flow peaked on Wednesday,August 14 and the flooding was described as the worst in over a century. Many historic buildings were flooded to the first floor, and the state emergency declaration lasted util October 31.

The flood wave continued to travel downstream toward the German border and into the River Labe, severely damaging several towns and villages. Across the Czech Republic, 17 people died and some 220,000 people were evacuated.

As the flood moved downstream, towns were generally flooded for longer periods of time. In Dresden, about 200 km (124 miles) from Prague, the River Weisseritz (a tributary of the Elbe which flows from the south near the Czech border) initially broke its banks on August 12. Subsequent flooding submerged the main railway station and parts of the historic city center. Water levels continued to increase as the flood wave on the Elbe approached from Prague, peaking on Saturday, August 17. On this morning, the river reached a height of 9.4 m (30.8 feet) from its usual level of 2 m (6.5 feet). Water inundated low-lying suburbs along the river, as well as basements and ground floors of several important historic buildings in the city's center. Fortunately, flood warnings allowed many original paintings and treasures to be removed from the lower levels of these buildings.

More catastrophic flooding occurred further downstream around the towns of Dessau and Bitterfeld, close to the confluence of the River Mulde and the Elbe. On August 19 and 20, runoff from the intense rainfall near the Czech-German border entered the Mulde and converged with the leading edge of the flood wave on the Elbe. Around 30% to 50% of the towns of Torgau, Wittenberg, Dessau and Bitterfeld were submerged and water covered a 12 km (7.5 miles) wide area, as shown in the satellite image below (Figure 9). Estimates derived from satellite imagery are that 592 square kilometers (229 square miles) of Germany's land was flooded, of which 480 square kilometers (185 square miles) was in the state of Saxony-Anhalt.

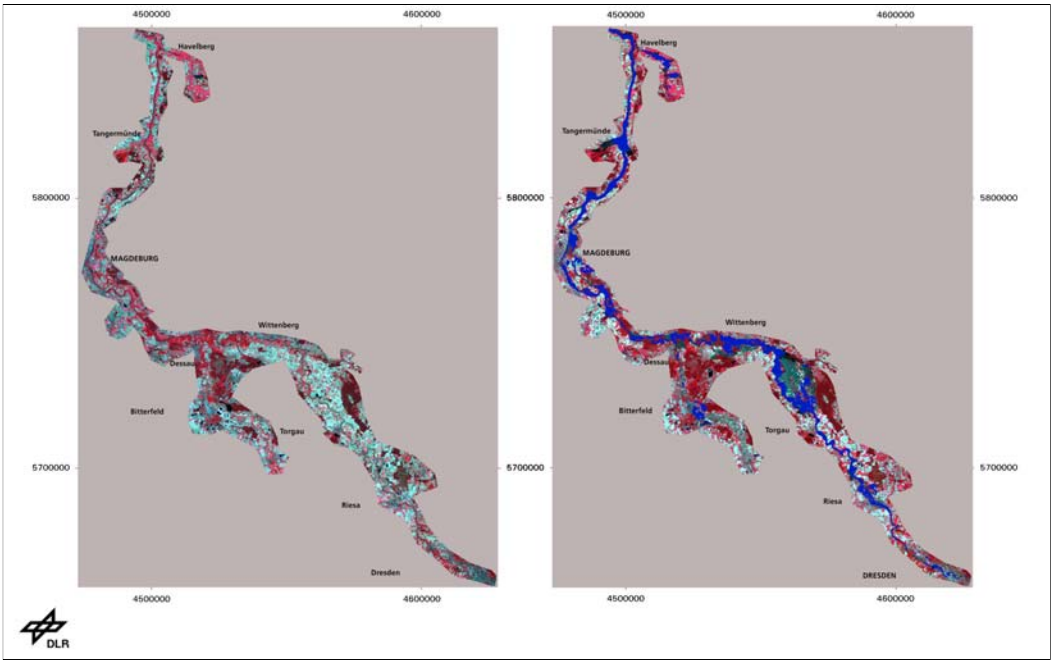

Figure 9. Satellite image of the River Elbe between Dresden and Havelberg before (August 14) and after flood inundation (August 20). Water is shown in blue, vegetation in red, and non-vegetated areas (such as urban land cover) are shown in gray. [Image courtesy of DLR, German Center for Air and Space Travel]

Earth dikes run alongside each bank of the Elbe through this relatively flat, low-lying area. Two weeks of heavy rain and high water saturated the dikes, causing them to weaken dramatically. Despite reinforcement with millions of sandbags, pressure exerted by the flood peak on these sodden defenses caused several breaks during August 17, 18 and 19. Thousands of military personnel and volunteers participated in this reinforcement exercise.

Similar structural weakening was observed in the Oder floods in August 1997 and the Rhine floods of January 1995. According to the International Commission for the Protection of the Elbe, 39% of the 1,200 km (745 miles) of dikes along the Elbe in Germany need structural renovation. In the state of Saxony-Anhalt, 46% of the dikes need repair, and many are over 100 years old. However, the estimated cost of renovating each kilometer (0.6 miles) is 750,000 Euro.

Across the affected region of Germany, 180 bridges were damaged, along with 740 km (460 miles) of roads and 538 km (334 miles) of railway track. The main railway line between Dresden and Prague was closed for more than four months. In the immediate aftermath of the floods, the German Government pledged to reduce construction on floodplains and limit the straightening of river channels.

RMS Damage Survey of Central Prague

Dating back at least to the 10th century, Prague is the capital city of the Czech Republic and one of the most popular tourist destinations in Europe. The River Vltava bisects Prague, running through its central and most historic part. In the city center, the left bank of the Vltava in central Prague rises up steeply to the historic Prague Castle, with the Lesser Quarter (Malá Strana) below, close to the riverbank. The more gently sloping, sprawling right bank of the Vltava includes the Old Town (Staré Mesto), the Jewish Quarter (Josefov), New Town (Nové Mesto), and Karlin (see Figure 9).

High stone walls border much of the river through Prague, protecting large areas from flooding. However, low-lying parts of the Lesser Quarter, Old Town, and Karlin have no significant defenses. Although temporary flood barriers were erected in August to protect the Old Town, the Lesser Quarter and Karlin were left exposed to inundation from the river. An extensive network of tunnels and underground infrastructure also acted as a conduit for floodwaters, penetrating inland into the Old Town and the Jewish Quarter. The combined effects of surface water and underground seepage also flooded the Metro, Prague's primary public transit system. RMS surveyed damage in these districts about two weeks into the flooding. The following sections describe the survey findings.

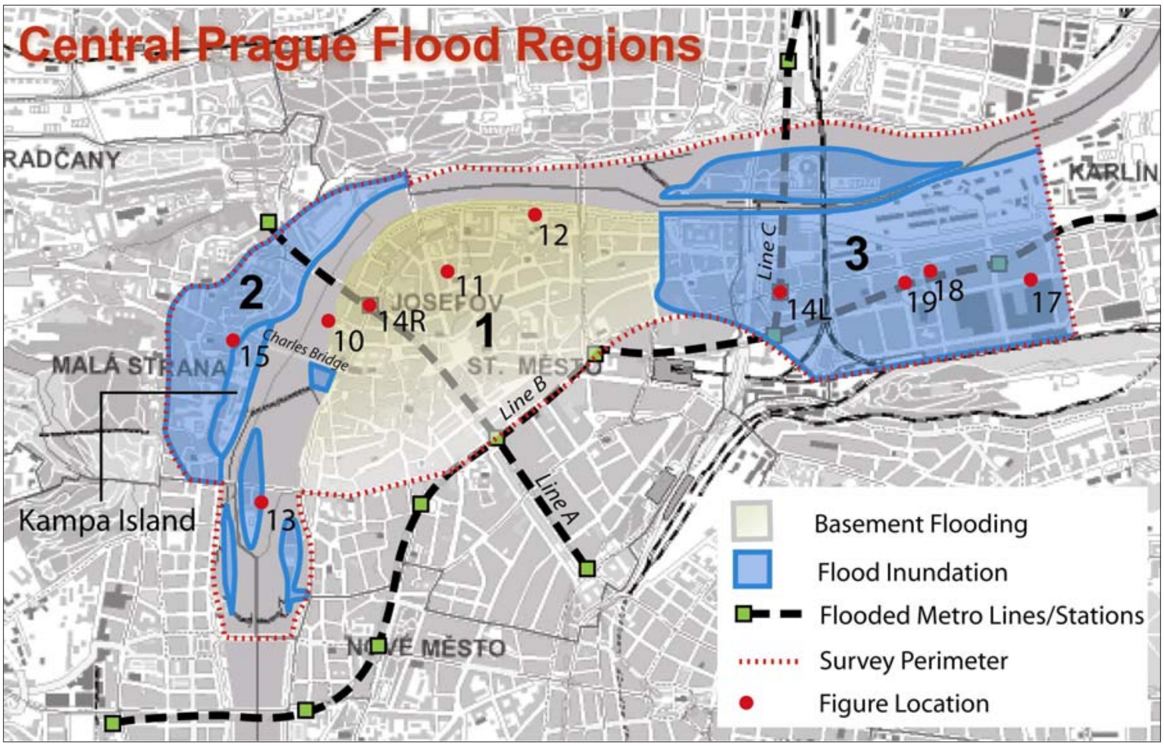

Figure 10. Summary and extent of RMS damage survey in Prague

Old Town and The Jewish Quarter

As warnings of the impending flood were issued, city officials implemented Prague's flood protection plan and erected a temporary barrier along the Vltava's right bank, protecting most of the Old Town. Figure 10 shows the barrier protecting the Four Seasons Hotel and surrounding properties. Prague financed the barrier following severe flooding in 1997. The barrier is made up of 3 m (10 feet) long aluminum bars stacked horizontally in-between support posts that are dropped into pre-sunken holes 6 m (20 feet) deep.

Figure 11. View toward the Old Town showing the temporary flood barrier in front of The Four Seasons Hotel

The barrier was effective in preventing the river water from inundating the streets of Old Town and Josefov, but some property extends out into the river, and remained exposed to flooding. This area (visible in Figure 11) is the inundated area opposite Kampa Island. The barrier was located to the east of these properties, allowing water to run up the south face of the buildings and flow through the ground floors, exiting the rear of the buildings immediately to the south of the Charles Bridge.

Although properties such as The Four Seasons Hotel were protected from direct inundation, basements and much of the city's underground infrastructure were damaged when water entered through the city's sewage system and numerous old tunnels. Building damage in the Old Town largely depended on the condition of each building's foundations and its proximity to any underground sewers, tunnels and other infrastructure. For example, the Four Seasons Hotel sustained enough damage from below-ground water that it is not expected to re-open until July 2003.

The amount of underground flooding in Old Town and Josefov suggest that the city's age played a role in the observed flood damages. Basements in this area are commonly used as residences, businesses and for storage. The contents and interior spaces of many flooded basements were heavily damaged (Figure 12). Site-specific structural surveys were required at many locations to ensure buildings were sound before standing water could be pumped out, as the high external water pressure could cause walls to collapse inwards. Vents to basements of many businesses and homes in the district were left open for several weeks to assist evaporation of the water.

Figure 12. Piles of damaged contents lay in the streets

The seeping waters also heavily damaged Prague and Karlin's utility infrastructure (Figure 13). Gas service to central Prague was cut while workers repaired the damaged equipment and pipes. Electricity was restored to most areas in mid-September, gas in October, and telephone services in November. Some areas, however, were without a fully functioning heating service for several months. Many buildings within these areas were unusable during this time, and for the others the use of portable dehumidifiers and heaters increased business interruption costs. There were also many reported instances of roads cracks and pavements buckling. Warmer weather in spring and summer 2003 may cause more cracks and holes as the earth and buildings begin to expand again after the cold winter.

Figure 13. Repairs to below ground infrastructure were visible throughout the Old Town

The river water submerged islands south of the Charles Bridge, which connects the Old Town to Kampa Island in Lesser Town. Buildings on these islands had visible water marks on the outside, clearly indicating the depth of flooding. There was a notably high quality of construction of the properties on these islands, particularly relative to some of those observed in the Karlin District. Although directly impacted, the restaurant in Figure 14 survived the direct force of the river's current on its south facing wall, as well as impacts from waterborne debris. On the contrary, collapsed buildings in Karlin were located much further inland and far from the water's strongest currents.

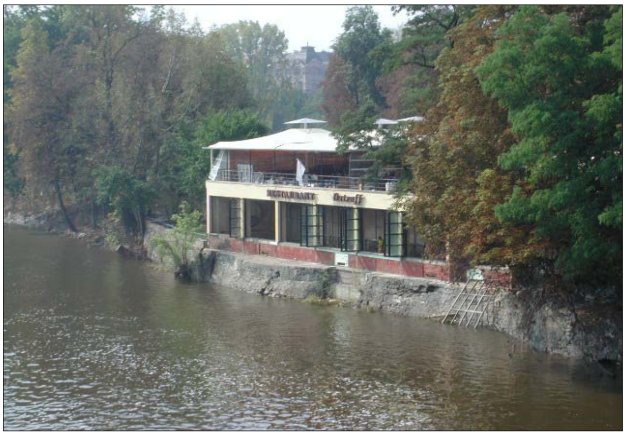

Figure 14. This restaurant on an island south of Legions Bridge survived the flood structurally sound (left picture courtesy of Radio Prague)

Metro Transportation System

Prague's Metro is a modern, below-ground electric mass transit system. Flooding closed thirteen stations and the associated connecting lines (bold dashed lines in Figure 10). Repairs continued for at least 6 months, at an estimated cost of 230 million Euro (Figure 15). There were several methods of water entry that caused the inundation of a large section of the system. Five stations flooded as water poured in from the street. Water leaked into others through poorly sealed electrical cables, which extend through stations and tunnels up to the surface.

Although refuted, the local 9olice reported that some of the heavy doors leading into the stations from outside, as well as pressure-sealed doors that isolated stations from the tunnels, were not closed properly. The pressure-sealed doors were designed to keep gases (rather than water) out, in the event of military attacks; the mechanism for closing them is complicated. Water was also forced into the tunnels by the high water pressure underground. Under normal conditions up to 4,000 cubic meters (140,000 cubic feet) of water has to be pumped from the network each day because of water ingress. Poor quality construction and repair work has also been identified as a possible cause of breakages in the tunnel walls.

Figure 15. Flooding of the Florenc Metro station (left; courtesy Radio Prague) and removal of water at the Staroměstská Metro station (shown on right)

Lesser Town (Malá Strana)

Lesser Town (shown as survey area 2 on Figure 10) is a historic district on the left bank of the Vltava. The district is bounded to the west by the steep hill of Prague Castle, which limits the area at risk from flooding to a 300 to 500 meter zone (984 to 1640 feet). Many of the buildings date from the 17th and 18th century, with some built as long ago as the 13th century when the district was first settled. This high-risk flood zone includes Kampa Island, separated from the rest of Lesser Town by Certovka Creek. Although proposals have been made in the past, a floodgate was not installed on the Certovka Creek to protect Kampa because local officials feared that it might depreciate the historic nature of the surroundings. In August, sandbags were employed along the riverbank, but were overwhelmed by the volume of water. As a result, the water depth reached over 4 meters (13 feet), causing near complete content losses in the ground floor of structures in this area and prolonged business disruption. However, despite its direct exposure to the river's current, there were no structural failures in this area.

Figure 16. Water marks are clearly visible on the outside of this building on Certovka Creek, immediately west of Kampa Island

The primary cause of damage in Lesser Town was from above ground flooding and water entry into buildings. Severe damage was observed on outside walls and in the interiors of building basements and first floors (Figure 16). Water marks were plainly visible on the exterior of buildings and some buildings suffered severe masonry damage. Internal damage, such as ruined plaster and holes in the floor, were also common throughout the flooded area.

Figure 17. Severe masonry damage on the outside, and floor collapse inside a building in Lesser Town (photos courtesy of Radio Prague)

Karlin

Karlin is located downstream of the Jewish Quarter on the right bank of the Vltava. Built in the 18th century, Karlin was the first suburb outside the original city walls. It is a flat, low elevation, mainly residential district, with multi-story buildings. Floodwaters swamped the district and it suffered some of the worst damage in the city. Water entered buildings from both above and below ground. In total 1,100 buildings were flooded, 43 were condemned and three collapsed (Figure 18). Damage to the public housing units in the district is estimated at up to 50 million Euro. Out of Karlin's 25,000 evacuated inhabitants, only 30% were able to return to their homes within the first three months after the floods. Six months after the floods, 33% of the privately owned residences in the district were still uninhabitable. Many people, or their landlords, lack the necessary funds to repair their properties.

Figure 18. This multi-story building collapsed whilst the district was still flooded. The complete failure of one part of the building can clearly be seen (photos courtesy of Radio Prague)

Some buildings settled unevenly as water undermined their foundations and triggered collapses. Karlin's older buildings were particularly susceptible, partly because of the addition of extra stories (and added weight) since their original construction. Localized settling was also visible near several building foundations (Figure 19). Poor soil quality, as reported in this area, also contributed to the failures.

Figure 19. Settling of the pavement soil is evidence that water may have undermined this building. The structure is shored up by temporary supports to prevent collapse

In some rare situations, water levels rose high enough to threaten both the ground floor commercial space and also the residential uses on the second floor. An example is shown in Figure 19, where the water line is visible just below the second story window of the brown building in the center of the photograph. The photograph also illustrates how the percentage of total loss for a structure depended highly on the structure's height and number of stories affected.

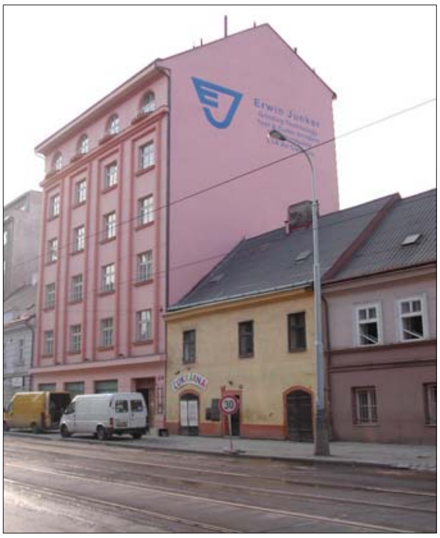

Figure 20. Water lines on these structures mark peak flood heights impacting the first two stories of properties in some portions of Karlin

The flooding of petrol stations in the Karlin district caused additional risks from the associated floodwater contaminations. Health risk warnings were issued for both residents and volunteers. Residents returning to Karlin in order to retrieve their belongings were advised to scrape potentially contaminated mud off their shoes when leaving the district and not to take food out.

Economic Impacts

Re/insurance Industries

In the immediate aftermath of the floods, total losses were feared to be as high as 20 billion Euro. However, the final costs are now expected to be less than this. In August, loss estimates for Germany alone were as high as 25 billion Euro, following an initial estimate of 15 billion Euro. However, on November 6, the German Ministry of the Interior estimated flood damage from the Elbe and Danube in Germany to be 9.2 billion Euro. The state of Saxony suffered the worst loss, with slightly more than 6 billion Euro in damages, primarily driven by losses in Dresden. Austria had an estimated 2 billion Euro in damages. On November 5, the Czech Government revised its total loss estimate to 2.3 billion Euro, down from an earlier estimate 3.3 billion Euro issued at the time of the floods. Prague's damage alone is estimated to be 0.8 billion Euro. Total economic damages in the Czech Republic following the 1997 floods was similar, with 2 billion Euro in costs.

The 2002 floods caused much greater loss when considering all affected countries. The total price tag for the 1997 flood losses in Europe was only about 6 billion Euro, of which less than 1 billion Euro was insured. The large losses in Germany appear to have driven up the overall losses for the 2002 floods.

In the countries affected by the 2002 floods, flood coverage is not usually included in standard residential or commercial insurance policies. It is, however, generally available at a supplementary charge. The price charged varies according to location. For example, some high-risk areas of Germany are prohibitively expensive. According to the Czech Republic's largest insurer Ceska Pojistovna, only 50% of their household policyholders have this additional flood coverage. This corresponds with loss estimates for the country, which indicates that less than 50% of the total loss was insured. In mid-September, the Czech Insurers' Association estimated that the insured loss in the country was about 1 billion Euro, with 78,000 claims expected

Premiums have risen as an immediate consequence of the 2002 floods. In October, the Czech Republic's second largest insurer, Kooperativa Pojistovna, introduced a new method of evaluating flood risk. It resulted in a 30% rise in premiums for properties inside flood zones. Some smaller companies have stopped insuring properties that have flooded more than three times in the last 10 years. Overall, premiums for flood coverage in the country are expected to rise by 10% to 30 %.

Across Germany, only an estimated 10% of households have supplementary flood coverage. However, in the states that make up the former East Germany, comprehensive policies were offered by the old state-run monopoly Staatliche Versicherung. Following unification, Allianz acquired these policies and around 3 million are still in operation, equivalent to around 30% of households in these states. According to their review, the cost to Allianz, the bearer of the largest share of losses in the 2002 floods, was 700 million Euro. Allianz reports that increases in premiums of 7 to 9 % are likely as a result of the floods and other storm events. Only a limited number of commercial businesses in these countries carry flood insurance. Therefore, a significant amount of commercial losses are being born by business owners.

Government and Local

The lack of private flood insurance across central Europe means that a considerable proportion of the recovery costs are being covered by national governments. Government grants and aid packages are being offered to individuals and local and regional authorities, and charitable organizations are offering some funds through voluntary donations. In order to cover the expected costs, the Czech Republic is revising its tax system in 2003. A new income tax bracket is being introduced for high earners. Indirect taxes, for example on cigarettes and alcohol, are also being raised. In Germany, tax cuts planned for the summer 2002 were deferred for a year. The EU has proposed a 728 million Euro aid package for all affected countries, to aid in restoration of vital equipment and infrastructure. Of this, 444 million Euro will be allocated to Germany and 129 million to the Czech Republic.

CONCLUSIONS

The August 2002 floods were the latest in a series of expensive flood catastrophes on rivers in Europe. They include floods along the River Oder in 1997, the Rhine in 1995 and severe flooding in 1993. Each of these floods has highlighted many of the same issues. Recent and planned developments on floodplains, river channel straightening, and a general under-investment in flood defenses have all contributed to the increasing flood risk. Without much private flood insurance in central Europe, governments frequently carry the burden of damage.

Until recently, flood risk in Europe was generally considered to be a challenge to quantify. As a consequence, public perception is often unrealistic about the level of flood risk outside floodplain areas. For example, recent studies by RMS have shown that off-floodplain flooding in the U.K. accounts for a surprisingly high proportion of overall losses due to flooding (around 40% to 60%).

The German Insurance Association (GDV) has taken an important step in advancing risk assessment methods. It has divided Germany into three flood hazard zones using a new zoning system. Advances in hydrology, geo-information sciences, and data availability and resolution mean that more detailed probabilistic flood modeling is feasible. As risks become more quantifiable, premiums and deductibles can be used to counteract the increasing risk, by creating a more risk-adverse environment. Together with government flood control measures, risk can be transferred from the public responsibility into the private insurance and reinsurance industries. However, compared with the U.S which has a national flood insurance scheme is in operation, the diverse nature of European economies and insurance markets necessitates the need for varying approaches to flood risk management, even though the hazard operates consistently across national borders.

Some of the immediate impacts of the August 2002 floods will include localized increases in premiums and constraints on floodplain development. They are also likely to spawn a heightened interest in future flood risk modeling capabilities for Europe.

ACKNOWLEDGEMENTS

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