Risk Nexus

Central European floods 2013: a retrospective

Flood resilience review 05.14

As part of Zurich's Flood Resilience Program, the Post Event Review Capability (PERC) provides research and independent reviews of large flood events. It seeks to answer questions related to aspects of flood resilience, flood risk management and catastrophe intervention. It looks at what has worked well (identifying best practice) and opportunities for further improvements. Since 2013, PERC has analyzed various flood events. It has engaged in dialogue with relevant authorities. It has begun to consolidate the knowledge it has gained and make this available to all those interested in progress on flood risk management.

Contents

Cover: a location affected by the Elbe levee breach in Fischbeck in June 2013.

About Risk Nexus
Risk Nexus is a series of reports and other communications about risk-related topics from Zurich.

Foreword

This paper was produced to coincide with the first anniversary of some of the worst floods to affect central Europe in recent memory. While anniversaries are often happy occasions, there is little to celebrate when recalling the floods of June 2013, the costliest global loss event of that year.

Our experts revisited many of the areas in Germany that suffered the greatest damage from these floods. A number of these places were affected by floods of similar magnitude in 2002. Our team spoke to residents, clients, state flood authorities, public officials and flood experts, and gathered insights on current flood risk management practices. While focusing on Austria, Germany and Switzerland, their research included the impact of the floods across all of central Europe. Equally important, they identified issues that offer scope to improve flood resilience and make changes that could help to reduce losses in the next flood. Some of their insights are based on what they learned in the 2013 floods. These observations were strengthened by a review of measures taken to enhance protection since the 2002 floods.

We undertook this study because at Zurich, we believe that our expertise and skills can make a contribution toward reducing flood risk. In 2013, Zurich launched a five-year flood resilience program. We are working with the International Federation of Red Cross and Red Crescent Societies and international development NGO Practical Action, as well as two research partners, the International Institute for Applied Systems Analysis (IIASA) in Austria, and the Wharton Business School's Risk Management and Decision Processes Center in the U.S. Together with these alliance partners, we aim to better understand floods and help communities become more resilient to flooding.

Our thanks go to the authors of this paper: Michael Szönyi, Senior Flood Resilience Specialist with the Flood Resilience Program at Zurich, Oliver Gywat, a senior research manager who is part of Zurich's Government and Industry Affairs unit, and Achim Dohmen, a senior claims specialist at Zurich. We also thank Ian McCallum at the Ecosystems Services and Management Program (ESM), and Reinhard Mechler, Deputy Director of Risk, Policy and Vulnerability, both at IIASA in Laxenburg, Austria. We also acknowledge the help and support of many others, too numerous to mention here, for their valuable contributions of time, knowledge, and insights.

Flooding affects more people globally than any other type of natural hazard. We believe dialogue, education and awareness are important in helping to increase flood resilience. Flood hazard and flood risk information should be publicly available and we need an active dialogue aimed at helping communities and nations better manage floods. By sharing the information in this paper, we want to make a contribution to communities and others elsewhere in the world facing the personal and economic risks of floods.

We know that 'after a flood' is really just 'before the next flood.' Therefore, time is of the essence when it comes to using what we have learned from past floods to prepare for the next one. With such knowledge, communities can increase flood resilience, save lives and contribute to the well-being of those affected by floods.

Michael Kerner

Mike Kerner,
CEO General Insurance, Zurich

Executive summary

As every flood event is different and brings new challenges, each one also provides an opportunity to learn. It should be standard procedure that in-depth, 'forensic' analysis is undertaken after large flood events. The insights then need to be shared and exchanged widely. This paper is intended as a contribution toward this approach. It was written to mark the first anniversary of the devastating floods that affected central Europe in June 2013. It follows an earlier review of this event published in August 2013.

This report looks in detail at the major floods in 2013 and 2002, particularly in Germany and to some extent Austria and Switzerland, and the impact they had on communities. It looks at what was learned. It draws conclusions and provides insights into what has changed since the 2002 flood, and where changes are still needed.

Much of the information presented here was gathered during on-site visits by Zurich's flood specialists. They visited some of the places worst-affected by the floods and spoke to local experts, water authorities and customers. They also met people in communities who experienced the floods first-hand and had to deal with the aftermath: cleaning up and getting their lives back to normal. In some cases, this process is still continuing.

Section 1 describes the weather patterns, including heavy rain in May 2013, that set the stage for severe floods that inundated wide areas of Germany, Austria and the Czech Republic in June of that year, killing 25 people and forcing thousands to evacuate. Along hundreds of kilometers of rivers, flood stages were the highest ever recorded. Estimates of the total combined economic losses caused by these floods run from EUR 11.9 billion (USD 16.5 billion) to EUR 16 billion (USD 22 billion). Insured losses were calculated at between EUR 2.4 billion (USD 3.3 billion) and EUR 3.8 billion (USD 5.3 billion).

For Germany alone, economic losses were reported to be EUR 10 billion and insured losses EUR 2.4 billion.

One of the places our experts visited was the city of Passau in Bavaria, which was hard-hit by the 2013 floods. Located where three rivers meet, it is no stranger to floods. Its vulnerability highlights the need for serious study of the risks and factors that can mitigate, or exacerbate these events.

While the 2013 flood caused significant losses, things could have been worse. The floods of 2013 (like the floods of 2002) mainly affected the Danube and Elbe watersheds. While there was some flooding along the Rhine, it was relatively minor. An event that could simultaneously affect all three of Germany's major watersheds has not happened in recent memory. But that does not rule out such an event in future. It is also important to note that the 2013 floods could have caused more widespread loss, which emergency intervention prevented. Luck will not always be on the side of those dealing with floods. Near-miss events also underscore the need for contingency planning to defend key infrastructure and institutions that serve as lifelines.

Until 2002, many people in central Europe were unaware that flooding was possible on such a large scale. **Section 2** compares the 2013 and 2002 floods, drawing on insights from our field research. We highlight the similarities and the differences between the floods of 2002 and 2013, starting with the meteorological situation at the outset, then showing the flood stages measured at the main three watersheds and ending with a series of purpose-built maps that identify the areas most affected by the two flood events and the locations where levees failed. This section also provides information on the economic and insured losses of the two events and how they were affected by protection measures that were put in place since 2002.

Section 3 looks at which flood protection measures worked well and which did not. In the German state of Bavaria, where measures to increase flood protection included increasing the height of a dam and risk reduction measures along the Isar river, Munich and Landshut avoided serious flood damage. Park-like areas created to give the Isar more space, reducing its destructive force, can be used for leisure when no floods threaten. Such success stories show that flood protection can even enhance people's quality of life. Another way to effectively mitigate flood risk is to create 'polders,' areas set aside to retain water during floods. The decision to use such areas depends very much on the will of communities. Polders were shown to work in the German state of Brandenburg. Especially 'controlled polders,' areas that are flooded precisely when they can best curb the flood crest, have proved their worth.

Investing in flood resilience, provided it is done constructively, also offers advantages. Even though flood levels in Salzburg, Austria in 2013 surpassed the levels of 2002, investments – including in mobile flood barriers – paid off and reduced damages and losses.

To address flood risk, more needs to be done. This includes more thorough risk assessments. Improved forecasting tools are needed at times when minutes count in making key decisions that could affect thousands of people. Meteorological forecast models today may not give sufficient advance warning. Measurement stations, too, need to provide more, and better data. Uncertainties related to the so-called 'rating curve' – the curve showing the relationship between water discharge and the flood stage at river gauges – should also be addressed.

We should re-examine how we think about flood protection. Levees offer a critical line of defense against floods. But they also bring with them new problems, including a false sense of security for those living behind them. The fact that levees can fail with devastating consequences was made clear in the town of Fischbeck, Germany, where a levee breach in 2013 led to a risky maneuver to sink three barges in order to plug the gap, a desperate measure of last resort. We can learn from other countries how they deal with flood risk and what technologies they use to solve a particular problem, for example, levee failures.

Political support and the participation of communities is needed to initiate and continue to implement useful and lasting change, including better information and improved education. Some of the possible measures seem quite straightforward. Individuals living in flood hazard zones, for example, need to understand the importance of complying with regulations requiring heating oil tanks to be protected, avoiding contamination that could lead to a home becoming a total write-off after a flood. This type of awareness or willingness to act is frequently missing. To raise awareness among policymakers and individuals, better access is needed to maps showing flood hazards, and the maps themselves should be improved and standardized.

Flood records marked on a derelict house next to the Mulde river in Grimma. April 2014.

Encouraging pro-active risk reduction can be achieved through incentives that reward a sounder approach in rebuilding, or possibly in extreme cases, relocating. Average losses for households affected by flooding in Germany are in the range of EUR 50,000. For large-scale protection projects benefiting towns and communities, on average, the benefit derived relative to the cost can be expressed by a ratio of at least four-to-one, or even much higher.

Not just individuals but also countries need to consider their approaches to flood risk. This includes more centralized decision-making. A national authority can help to accelerate the process of finding agreements acceptable to all regions, parties, and interest groups involved, especially to resolve difficulties associated with relocation, compensating people who provide flood retention space, and addressing other problems. It is also critical to understand how connected risks are, and how stress in one part of the system can have a knock-on effect.

'After a flood' is really just 'before the next flood.' **Section 4** offers recommendations that provide a general guideline for those facing flood risk. It includes measures that could be applied elsewhere, depending on the individual situation. At the same time, it is important to note that flood hazards and flood risk management are very situation- and location-specific. The best approach is to build outside of flood hazard zones.

If this is not possible, then natural retention offers advantages over artificial measures (for example, levees or mobile protection). Beyond this, reducing vulnerability, and stringent planning to deal with emergencies is necessary. Once a flood has occurred, reviewing what worked and what did not work, and finding ways to make improvements, is key. In all cases, communities and individuals need to be given a say not only when a project is underway, but also in the early planning phase.

The paper draws on these findings to provide recommendations that would be useful for communities not only in Germany, but worldwide, to help mitigate the risks and losses caused by floods. There is every likelihood that floods might be bigger and more catastrophic in future. The climate is changing, while asset density in flood-prone areas increases. It is clear that significant changes must be made to address the risks of the next major flood. **Section 5** looks at a future flood event, the hypothetical 'Flood of 2023,' and makes clear that we need to think the unthinkable. The floods of 2002 and 2013, though devastating, could be overshadowed by the next major flood. Beyond changing the mindset that 'a flood of the century happens only once every 100 years' (which is clearly not the case), action is needed now to address the risks and look to the future.

Introduction

Floods have affected more people and caused more damage globally than any other natural hazard. The June 2013 floods in central Europe caused 25 fatalities. They were the costliest global loss event of that year. In addition to the human suffering, the floods caused major losses. The losses were especially high in Germany and the Czech Republic. Other countries such as Austria, Switzerland and Hungary also suffered damages, though to a lesser extent.

In 2002, central Europe was already struck by a flood event of comparable extent, as well as damage and losses. The term 'Flood of the century' was frequently used to describe that event after it happened. However, this expression is borrowed from statistics and might be misleading without providing the necessary technical context. Although much has improved since 2002, many people were surprised that such a severe flood could happen again only 11 years later. But the frequency of flood events is assessed retrospectively, looking into the past, and does not allow us to predict when such events will happen in the future. Flood statistics are also based on 'point measurements' and only tell us something about a specific location. Where events are concerned, the human mind is tempted to make false assumptions based on statistics. Changing how we subjectively perceive the chances that floods will occur is crucial for flood preparedness.

Let us look to the future. While it is impossible to predict floods, much can be done to reduce or prevent the damage floods cause to communities. Flood resilience also has both universal and local characteristics, and the lessons learned at a specific site can to some extent be applied elsewhere. We are still learning from the experiences of 2013. As we learn, it is clear that some measures to enhance flood resilience have worked, while others did not, and some might even have unforeseen consequences.

This paper focuses on flood resilience in Germany, looking at the 2013 floods, and comparing them with the floods of 2002. While taking into account certain universal aspects of flood resilience, we also offer insights regarding the impact the floods had on communities in Austria, the Czech Republic and Switzerland. In Germany the authors gathered information by visiting many sites that had been affected by floods, conducting interviews with experts and local authorities in Bavaria, Saxony, Saxony Anhalt, Brandenburg, Lower Saxony, and Schleswig-Holstein, covering the watersheds of the Danube and the Elbe. The team was guided by the following questions: Which measures to improve flood resilience were identified after the 2002 flood? Which have been implemented, which were not, and why? Did the implemented measures improve flood resilience in the 2013 event? Have new lessons been learned? And what would happen in, say, 2023, if a similar magnitude of flooding was to occur in central Europe again?

- **Section 1** provides an overview of the June 2013 flood event in terms of event severity and probability, people affected and losses sustained.
- In **Section 2** we then compare this disaster with the flood of 2002, trying to understand what was similar and what was different and how it affected insured and economic losses.
- **Section 3** provides insights from our field research. We highlight success stories we encountered, and make a summary of 'pressure points' we identified – issues that still need to be addressed.
- **Section 4** offers a series of specific recommendations to enhance flood resilience, and suggestions how these can be implemented in the future. These are provided to raise awareness, increase preparedness, reduce vulnerability and help communities to become increasingly resilient and can be read as a general guideline to flood risk management in independence of the rest of the report.
- **Section 5** focuses on our hypothetical example of a major flood event, the hypothetical 'Flood of 2023,' and describes the ensuing challenges and possible risks, as well as the efforts still required to improve overall flood resilience.

Please see the map on pages 22-23 for the locations of places mentioned in the text.

At Zurich, we are in business to help our customers understand and protect themselves from risk, making their lives more secure and helping them to grow their businesses. We believe that the insurance industry can play a significant role that goes beyond providing flood insurance coverage: addressing and reducing flood risk through event analysis, research, and sharing knowledge about best practices. Through Zurich's flood resilience program, we seek to enhance insights and foster public dialogue around flood resilience. We hope this paper provides a stimulus to the ongoing discussions on flood risk management and awareness. Flood resilience includes controversial aspects, and flood protection measures typically come at a cost. While we are aware that some questions generated by this discussion cannot be fully answered yet, we would like to invite you to consider the points raised in this paper. It should not be understood as a complete catalogue, but rather as a contribution to the ongoing dialogue on flood risk management.

Section 1
The floods of 2013

The flood channel flowing through Landshut offers an appealing place for a stroll when no high water threatens.

The flooding that affected many areas of central Europe in June 2013 began as heavy precipitation. The month of May 2013 had already been very wet, leaving the ground saturated in vast areas. When heavy rainfall set in, surface run-off produced large volumes of water which accumulated and turned to floods that moved down tributaries and major rivers, affecting communities across wide areas of Germany, Austria, and the Czech Republic, along with those in some other countries along the Elbe and Danube and parts of the Rhine river watersheds.

Our team from Zurich visited the most affected areas in 2013 immediately after the floods. When they returned to many of the same sites again in April 2014, it turned out that much additional information had become available, giving us new insights. This section provides an overview of the 2013 floods and expands on the knowledge provided in our earlier review from August 2013[1] which was based on the preliminary information available in June 2013.

Flood losses in 2013

The floods of 2013 resulted in 25 deaths in the countries affected. In Germany alone, an estimated 52,500 people along the Danube and Elbe had been forced from their homes (CEDIM, 2013). Flood stages were the highest ever since recordings began along hundreds of kilometers of rivers – but it must be acknowledged that larger floods have happened in the past – just without any reliable records. Estimates of the total combined economic losses caused by these floods run from EUR 11.9 billion (USD 16.5 billion) to EUR 16 billion (USD 22 billion). The broad range of estimates is in part due to different methods used to calculate economic losses.[2] Insured losses were calculated at between EUR 2.4 billion (USD 3.3 billion) and EUR 3.8 billion (USD 5.3 billion). For Germany alone, economic losses were reported to be EUR 10 billion and insured losses EUR 2.4 billion. The state of Bavaria, which suffered some of the worst damage, estimated losses for its region in the area of EUR 1.3 billion, including repairs totaling roughly EUR 110 million to state-owned water infrastructure alone (levees, flood walls, pumping stations, etc.).

How floods formed in central Europe

Large central European floods (1997, 2002, 2005) are often characterized by what meteorologists call a 'V-b' pattern (or, 'Five b', based on a classification scheme by German meteorologist van Bebber); it functions like a conveyor belt whereby low pressure systems pick up lots of moisture from the Mediterranean, transporting it to central Europe with a northeastward flow toward the Alps, creating intense precipitation. The weather pattern in June 2013 was very similar to this.

The weeks before the floods in central Europe in 2013 were very wet and in some places unseasonably cold. Throughout all of May, large parts of Germany received twice the average monthly precipitation. Across a wide region from Schleswig-Holstein in the north to Bavaria in the south, precipitation reached 250 percent of the monthly averages. In some locations in Germany, it even exceeded 300 percent. The ground was soaked. In May about 40 percent of Germany's land area had a soil saturation level never observed since regular measurements began in 1962.

During the final days of May and into early June, heavy precipitation fell in central Europe, caused by three low-pressure systems, 'Dominik', 'Frederik' and 'Günther.' The latter originated in the northern Adriatic and moved northwest towards the Alpine arc (similar but not identical to a classical V-b track). From May 28 to June 3, these low-pressure systems brought extraordinary volumes of precipitation to an area centered over southeastern Germany. The Bavarian Ministry for the environment (LfU 2013) reported that in both a 72-hour and a 96-hour period, the total rainfall at a weather station in Aschau-Stein (near

[1] Zurich's study on how to improve flood resilience in Europe, download at http://www.zurich.com/aboutus/corporateresponsibility/flood-resilience/flood-resilience.htm

[2] Ranges are based on published figures from Aon Benfield (2014), MunichRe (2014) and SwissRe (2014).

Rosenheim) was a '500- to 1000-year return period.[3]' At 10 German weather stations precipitation reached or exceeded the 100-year return period. In Switzerland this large-scale ('synoptic') pattern brought rain as well, although less heavy (generally a return period of 5-10 years). Yet even here, some localities received heavy rainfall. Weesen at lake Walensee had the highest absolute measurement in Switzerland in this event, receiving 179 mm of rain in 48 hours, an amount that statistically occurs on average every 20 years. St. Gallen, close to Lake Constance, received 136 mm, an event expected in that location only once every 50 to 100 years.

As it had become virtually impossible for the heavy rain to seep into the ground, the stage was set for massive floods. Water started to make its way down tributaries and emptied into major rivers, leading to the worst floods in at least a decade in southern and eastern Germany, Austria, Hungary and the Czech Republic. In some cases floods reached stages or levels[4] never before recorded since modern measurements began. Besides Germany, Austria and the Czech Republic, parts of Switzerland and Hungary also faced floods. Budapest was able to keep the Danube at bay with sandbags, but in some other areas of the country, hundreds were forced to flee.

Floods, warnings and forecasting

Early flood warnings and preparations were impeded right from the start. It was hard to forecast where precipitation would occur exactly, and which local areas would be affected, by how much, and when. The difficulties meteorological forecasters faced reduced the quality of the flood predictions. Not only forecasters, but also flood models were affected by some uncertainties related to river gauge predictions and the water flow after levees failed. This made it harder to predict how these failures would affect areas downstream.

Flood chronology along major watersheds

While it is hard to analyze floods both sequentially and geographically, this review looks at the 2013 flood along the paths of major rivers, including a discussion of flood risk management which comprises risk reduction, intervention, repairs and post-event analysis. Locations in **bold** are shown on the overview map on pages 22-23.

Passau's Old Town at the city's heart is right in the middle of a flood zone. In some floods, water has reached the second floor of some buildings. It is a major tourist destination, due to its setting where three rivers meet – the Danube, the Inn and the Ilz. In April 2014, the damage from the 2013 floods was still clearly visible throughout the town. Most businesses have reopened. Some were able to open just three or four days after the flood waters receded, in particular some hotels and restaurants, relocating critical operations upstairs, provided mobile food tables if restaurants were destroyed, or redecorated entire restaurants and terraces to serve summer holiday guests.

But the impact of floods goes beyond economic and insured assets. The water distribution system in Passau was overwhelmed by the flooding from the Inn and the Danube and had to be shut down for a while. The city's water supply had to be chlorinated until early October. Nearly one year after the floods buildings were still so damp from flood waters that plaster and paint was coming off the walls, requiring re-plastering and repainting every other month. The historic buildings including the massive walls of centuries-old churches soaked up huge amounts of water. People may need to make do with alternate locations for Christmas celebrations in 2014 or even 2015.

[3] Flood probabilities and event occurrences are often indicated as 'return periods' and signify a statistical average based on past events. A '100-year' flood has a one percent chance of occurring in any given year. Yet a home in a 100-year return period flood zone faces greater than 26 percent chance of being affected at least once by a 100-year flood over a period of 30 years, and a chance greater than 64 percent of being affected by such an event over a 100-year period. Therefore, annual probabilities (for example, a '1 percent chance') are often better to explain the risk. But given that many weather events are referred to in terms of their probability of occurring over a given period of years, in this report we generally refer to 100-year, 500-year, etc. return periods.

[4] A flood stage or water level is the depth of a river at some point and is a function of the amount of water flowing through the river cross section at e.g. the measurement point of the gauge.

Status of repairs in Passau (top) and Pirna (below) in April 2014, 11 months after the floods occurred. The situations are comparable to each other and repairs are far from being completed.

Danube watershed:

Along several parts of the Danube watershed in Germany and Austria, the 2013 floods resulted in the highest water levels ever recorded. Massive levee breaches occurred in Germany, causing towns to be submerged by two meters of water and cutting off major highways. While large cities fared well, losses were high in certain areas that were particularly affected, such as Deggendorf.

One success story for flood protection comes from the area of Munich and Landshut on the Isar river. Tributaries carried significant amounts of water as they emptied into the Isar. Flooding became increasingly severe downstream, reaching levels with over 100-year return periods north of Munich. The Isar flows through Munich, but no losses were reported there, thanks to flood protection that includes a dammed lake. Protection levels between Munich and close to the confluence with the Danube were at or in excess of a 100-year return period. Both the Isar and the flood protection channel 'Flutmulde,' which bypasses the main Isar channel in the city of Landshut, reached 100-year flood levels in the 2013 event. The Isar would have caused considerable losses if the systems providing protection had not been in place.

In contrast to the examples just cited, flood awareness was low in the town of **Fischerdorf**, located on the Danube, and across the confluence of the Isar with the Danube near **Deggendorf**. This lack of awareness was partly due to the trust put in a levee along the Danube. This levee was built to withstand a 100-year flood. However, there was a gap in protection along the Isar river, located in a nature reserve a few kilometers away from the village. While the Isar flood protection was up to a 100-year standard from Munich downriver close to Deggendorf, at the Isar mouth this was not the case – that particular levee only protected to a 30-year return period. The chance of such a levee being breached was absent from the minds of Fischerdorf's residents. But, in fact a portion of the levee along the left bank of the Isar was topped by more than one meter of water and ultimately collapsed on June 4 and 5. As a result, Fischerdorf was inundated (see Figure 1).

When our team visited these Isar levees in April 2014, significant work was going on to complete repairs on a section along the levee that had been breached over a length of one kilometer. Work included repairs on the main body of the earthen levee, with an internal pile wall as a reinforcement being added for stability. It also included a wider access corridor behind the levee, to arrive at, and defend the levee during floods. Still, this will leave the Isar levee in the Fischerdorf area at the same 30-year protection level. A new levee, roughly 1.2 meters higher, will be built behind the old levee, stretching 3.5 kilometers along the Isar. The project has already begun, but it will need significant time to be completed. When it is finished, this will finally close the last gap in providing protection to a 100-year level along the Isar.

Figure 1: Sketch of Fischerdorf location and flood extent

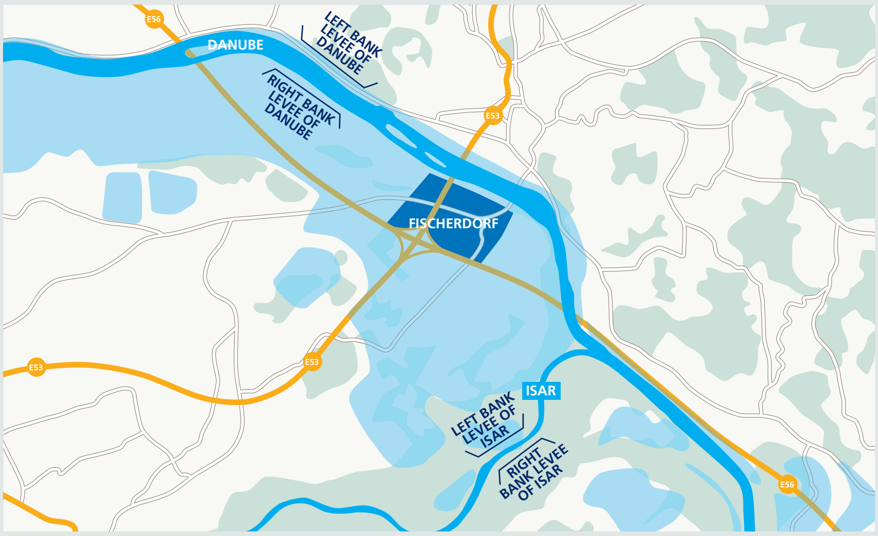
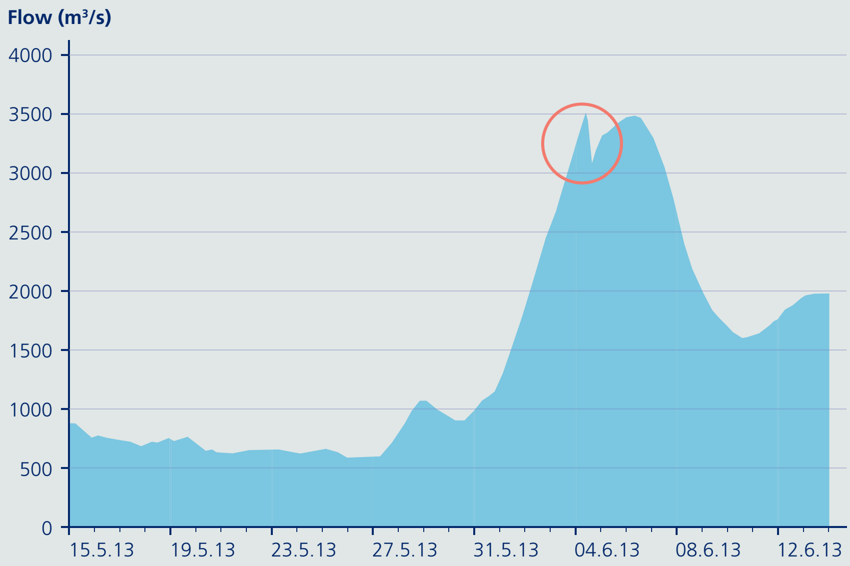


Illustration showing Fischerdorf along the right bank of the Danube and the left bank of the Isar near a nature preserve, close to where the Isar flows into the Danube. Built to a lesser protection level than the Danube levees, the Isar levee failed in the 2013 flood. This 'protection gap' is now being closed. (Illustration: Zurich)

Success was reported just upstream from Deggendorf on the Danube, where an existing levee on the right bank at Natternberg had been relocated earlier, creating additional protection and greater capacity for water storage. The project was begun in 2012 to reposition the levee along a 2.5-kilometer length, reinforcing it along another 1.2 kilometers. During the flood of 2013, the levee worked well, but was tested to its 100-year return period limit with almost no freeboard left. This confirmed that, together with significant contributions from the Isar flood waters, floods along the Danube did indeed reach the 100-year return period levels.

Further downstream along the Danube at **Hofkirchen**, the levee failures at Deggendorf Auterwörth reduced the flood crest. The river gauge station there measured only a 20- to 50-year event. The fact that water was flowing into flood plains after the levees failed seems to have significantly affected downstream flood peaks. This is clearly visible in the graph showing water flow measured at Hofkirchen (see Figure 2).

Figure 2: Water flow at Hofkirchen



Water flow in cubic meters per second recorded at Hofkirchen along the Danube showing the peak on June 4, 2013, and the impact of levee breaks near Autherwörth upstream along the Danube, indicated by the sudden drop of water flowing past the gauge (circle). Reproduced with permission based on http://www.hnd.bayern.de

It is still unclear to what extent people were generally aware of the gap in the 100-year protection along the main parts of the river, given that there was only 30-year return period protection at the confluence of the Isar with the Danube. It is also unclear if more should have been done to advise the population of the dangers of an immediate levee failure, or if better precautions should have been taken to manage an emergency situation and reduce losses in a place where levees are prone to failure. This topic will be taken up again in the section examining the events at Fischbeck (page 15).

Passau is located where the Inn, Ilz and Danube rivers meet. The flood waters crested in Passau on June 3 at 12.89 meters, an event with a return period of roughly 500 years, with the Inn's flow contributing decisively to the flooding. The Inn tributaries in the vicinity of **Rosenheim** on the German border with Austria carried extreme volumes of water. The water levels were higher than the 100-year return period on the Mangfall river. Flood protection and retention schemes had just been completed or improved there. These were tested to their design limits. Levee failures at Kolbermoor were barely avoided and would have led to catastrophic flooding, especially in Rosenheim's city center. But some flooding still did occur in populated areas of Rosenheim and Bad Aibling, located west of Rosenheim along the Mangfall river.

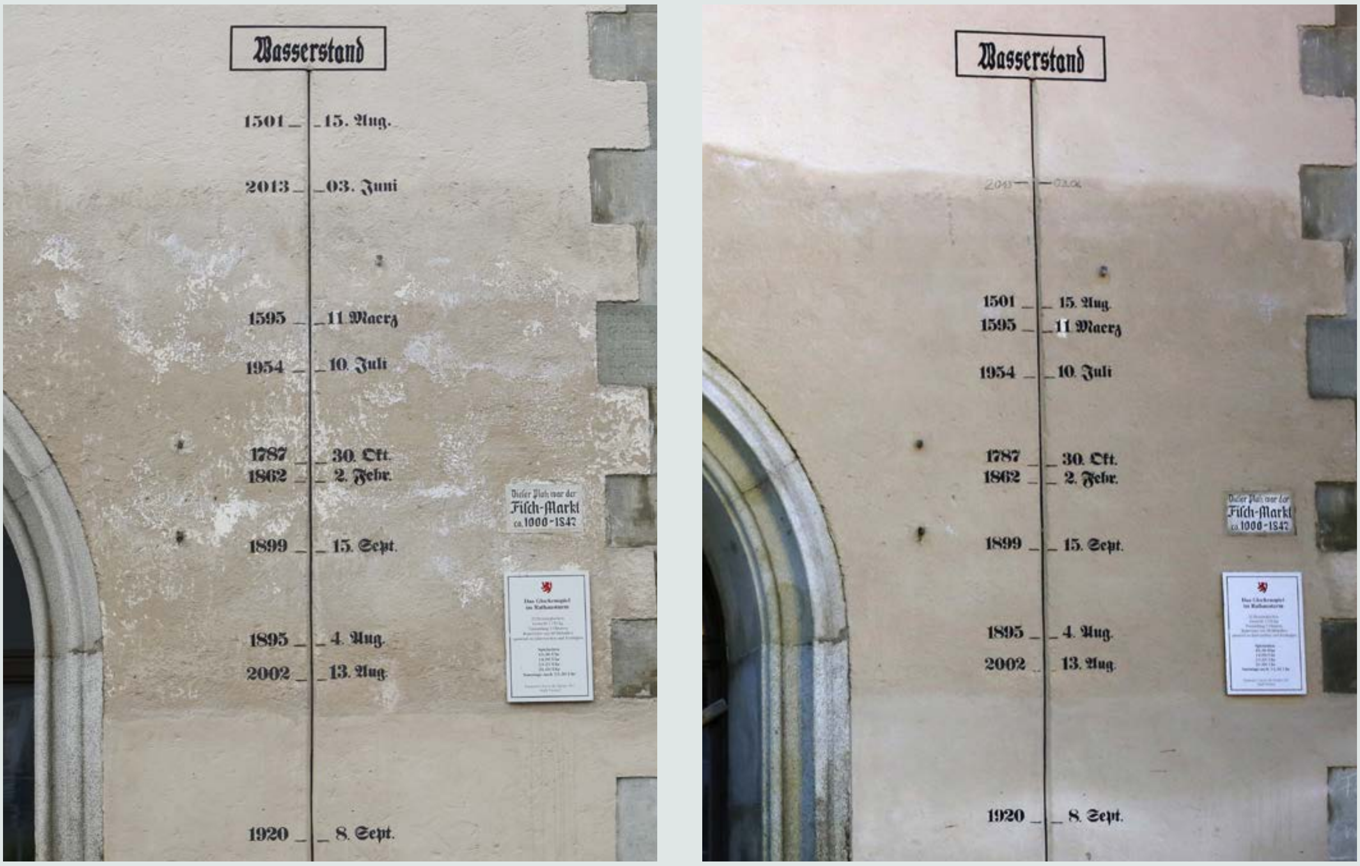
According to authorities in the state of Bavaria, all the protection systems implemented since 2001 as part of a bigger flood protection program worked well and provided adequate protection during the 2013 floods. These authorities also observed that flood levels and scenarios change over time, and that protection systems built before 2001 need to be reinforced locally and upgraded to maintain their protection levels. This includes the need to rapidly complete the Danube protection upgrades, which are desperately needed between **Straubing** and **Vilshofen**.

Austria

Along the Danube from Passau on downstream and well into Hungary, the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Management (Lebensministerium, 2013) attributed a return period of more than 100 years to the June event, which in large areas exceeded the flood of 2002. Along the Danube in Austria, water at many river gauges reached levels that had not been observed in the past 200 years.

Overall, the flood protection in Austria worked. It kept losses low in many parts of the country. One example is the town of **Grein**, with a history of severe floods, where success was reported based on the levees of the 'Machlanddamm,' one of the largest such protection projects in Europe. This protected Grein – if only barely. Like some sections along the

Historic floods recorded on Passau’s town hall



The photo on the left was taken in April 2014 and shows the level of flooding including the high-water mark from June 2013. The photo on the right, taken in June 2013 right after the floods, shows levels prior to when they were ‘adjusted.’ After reviewing history records and recalibrating various gauge levels, the 1501 flood still remains the worst in Passau’s recorded history. Could the next flood top recorded levels? (See also text on opposite page).

German Danube, the water rose so that very little freeboard at the top of the levee remained; it would have taken very little to top it. **Vienna** was saved by its protection designed to a level of up to a 500-year return period, supported by the bypass channel of the ‘Neue Donau,’ which was able to keep the flood peak below a level that would have caused damage in the city. Only some local businesses were flooded on the ‘Copa Cagrana’ along the Danube waterfront, and in the aptly named ‘Sunken City,’ with its restaurants and bars. But these areas are in a designated flood zone. The important role that retention areas upstream of Vienna played in reducing floods in the city was affirmed. While a discharge of more than 10,000 cubic meters per second had been observed only three times along the Vienna section of the Danube basin – in 1899, 2002 and 2013 – 2013 set the absolute record, measured at an estimated volume of more than 11,000 cubic meters per second.

As planned, once the 7,000-cubic meters per second limit was reached, the polders of Tullnerfeld and those northeast of Vienna were ‘activated’ and flooded in controlled fashion. Outside the Danube basin, the flooding was exceptional as well, but fell short of being catastrophic in terms of losses.

One notable, and unfortunate, exception was the city of **Melk** located in the state of Lower Austria, where work on mobile dam systems was not completed in time and the historic city center was flooded. The famous monastery towering over the city was unscathed. The floods of 2013 led to increased flood protection action in Upper Austria (Oberösterreich) – flood protection levels will be increased and, where missing, upgraded to meet the 100-year level. The lowland of the Eferdinger Becken that includes the town of Eferding in Upper Austria was flooded for several days. However, parts of the lowlands are very difficult to protect. It would be an immense task. Plans for relocation are underway.

Elbe and tributaries:

Many flood events occurring in the Elbe watershed start in the Vltava, the longest river in the Czech Republic. The flood extended over a wide area, and situations were critical in many places along the middle Elbe between Magdeburg and Wittenberge, losses especially in large cities were less severe.

Levees failed in different places than in 2002. These mainly were affected by the main flood crest from the Elbe overlapping with the crests from two tributaries, the Saale and Mulde. A large breach on the right Elbe levee near Fischbeck caused hundreds of square kilometers of agricultural lands and a number of villages to be inundated.

The Vltava, the Elbe's main tributary, flows through the center of **Prague**. The Vltava cascade, a series of dammed lakes and reservoirs along the river before it enters Prague, helped to keep the flood's peak to only under a 40-year return period event. Along with structures providing protection (fixed and mobile) in the city, this reduced damage significantly. Even so, some 3,000 residents had to be evacuated due to flooding in Prague's suburbs, smaller cities and industrial towns downstream.

The Elbe's flood peak entered Germany and reached **Dresden** on June 6. It reached 8.78 meters, about 0.62 meters below the maximum flood levels of 2002. This corresponds to roughly a 50- to 100-year flood. But there was some uncertainty related to the relationship between water discharge and water levels that affected the quality of the measurement and the ability to forecast the flood's progress further downstream. At **Lutherstadt Wittenberg**, the flood level peaked on June 8 at 7.91 meters, just 0.15 meters below the 2002 event. Flood risk reduction measures had mostly been effective in this area, and losses were significantly lower than in 2002.

The state of Saxony-Anhalt reported that along a 250-kilometer long section the Elbe rose to levels never before recorded. Tributaries left of the Elbe in Saxony and Saxony-Anhalt were heavily affected, mainly along the Mulde river in the state of Saxony, where 19 levee failures were recorded. However, this was less than in 2002, when there were over 100 levee failures. There were five large breaches on the Elbe in Saxony in 2013 (see also map on pages 22-23).

The high water and high discharge levels of the Saale and Mulde tributaries resulted in extreme flood levels downstream near Magdeburg and beyond. At the Elbe gauge station of **Aken** near the mouth of the Saale, the peak reached an all-time high of 7.91 meters on June 9. That topped the 7.66-meter level of 2002. The Saale discharge was the highest since records began. For the lower Saale near its confluence with the Elbe, return periods were between 150 and 200 years. At Halle, the Saale topped out at 8.11 meters, 1.28 meters higher than the peak of 2002. There were significant levee failures along the Saale, in particular near **Klein Rosenburg** at the 'Elbe-Saale corner,' and another at Breitenhagen. While the Saale's main flood crest arrived two days before the Elbe's highest flood peak, there was a large volume of flood water flowing downstream. The combined Saale and Elbe discharges increased flood levels downstream from where the Saale meets the Elbe.

Flood levels of 2002 were topped significantly in **Barby**, **Magdeburg** and **Tangermünde**. On June 3, after flood waters reached a critical level of 5.92 meters at the gauge station of Barby, the historic Pretziener Weir was opened to allow up to a quarter of the Elbe's total discharge to be diverted through another channel to bypass Schönebeck and Magdeburg. The weir remained in operation for more than two weeks. Even so, the Magdeburg-Strombrücke flood gauge recorded a peak of 7.47 meters, 0.67 meters above the 2002 peak. There is some uncertainty in calculating the return period from these measurements, but it is estimated to be in the range of 200 to 500 years.

> Despite opening a weir to divert the Elbe's discharge, flood levels in 2013 were higher in some places than in 2002."

Fischbeck, located on the right bank of the Elbe, was badly hit by floods after a levee failed on June 10. At first, a length of 50 meters gave way. The breach rapidly grew to more than 100 meters. This led to inland flooding in an area of approximately 200 square kilometers between Stendal and Tangerhütte. In terms of area flooded, this approaches the biggest river levee breach ever recorded in Germany, which occurred in Dautzschen in 2002 (see also map on pages 24). The flow through the breach was estimated at 1,000 cubic meters per second – equal to approximately one fifth, or even one quarter of the Elbe's total discharge at this point during the floods. Two kilometers away, as a result of this breach, Fischbeck was flooded "within minutes," according to Jonkman et al (2013). This relieved the flood peak further downstream in combination with the controlled flooding of the large, dedicated 10,000-hectare Havel polder system. This helped to reduce the peak at **Wittenberge** by about 0.40 meters based on simulations by the German Federal Institute of Hydrology (BfG). Still, the Havelberg gauge station recorded its highest-ever flood peak of 4.52 meters. The flood peak at Tangerhütte was 8.38 meters, also topping the previous record, and the flood crest at Wittenberge peaked at 7.85 meters, 0.51 meters higher than in 2002, the highest level ever recorded there. The old town of Wittenberge was evacuated but withstood the floods thanks to a mobile flood wall.

As the floods moved downstream, **Hitzacker** in Lower Saxony was struggling with the rising Elbe, experiencing intense floods that lasted from June 9 to June 12. The old town of Hitzacker was evacuated. Thanks to a EUR 63 million flood protection project concluded in 2008, Hitzacker was saved, unlike in 2002, when the old town was almost completely flooded. The flood peaked at 8.18 meters, a new record, leaving very little freeboard at the new flood wall. The length of the Elbe flood crest had by then extended to over 40 kilometers that needed to squeeze through the lowermost parts of the Elbe river before it last affected the little town of Lauenburg in Schleswig-Holstein, about 50 kilometers away from **Hamburg**. In contrast to 2002, the old town of Lauenburg had to be evacuated in the 2013 flood, and the houses facing the waterfront were flooded knee-high. Only a few kilometers downstream, at the weir of Geesthacht, the devastating Elbe floods ended. This weir restricts the tidal movements of the Elbe river to the downstream section, which is called the lower Elbe. Below Geesthacht, the riverbed becomes deeper and wider, and the high water levels dropped to levels that were no longer critical, sparing the lower Elbe completely from flooding. The city of Hamburg was not affected by the 2013 floods.

Public transport

The German federal railway, Deutsche Bahn, noted in its 2013 annual report[5] that "especially as a result of the floods in Germany" its business operating profit fell by EUR 30 million. Losses are still being calculated and could also include a number of passengers who will not return because they have switched to other means of transport, which could lead to further profit lost in the future. One of the biggest problems occurred in early June 2013, when a critical rail line between Hanover and Berlin was flooded near **Stendal**. A five-kilometer section was damaged and remained closed until early November 2013. To cover the overall cost of repairing infrastructure including railway stations, the German government is providing a total of about EUR 100 million to Deutsche Bahn through 2015. The flooding near Stendal significantly affected rail transportation: the 10,000 people who travel daily on the Hanover-Berlin line experienced delays of up to an hour as a result of the disruptions.[6] Some rapid city-to-city rail (InterCityExpress or 'ICE') services were cancelled, such as those serving Wolfsburg, where Volkswagen has its headquarters. Due to the re-routing, delays were experienced throughout the rail network. ICE maintenance faced delays, reducing the overall availability of rolling stock. An interim train schedule had to be introduced.

[5] http://www1.deutschebahn.com/gb2013-de/start.html (figure provided as adjusted EBIT).

[6] http://www.zeit.de/reisen/2013-07/deutsche-bahn-hochwasser-elbe-sperrung

But these problems, though costly and inconvenient, could have been much worse. The flooding near Stendal forced the closure of the railway bridge at Hämerten across the Elbe. Trains crossing over the Elbe were diverted to another bridge at Wittenberge, which put significant strain on traffic in that area. In addition, a transformer station serving the railway's electricity grid was acutely threatened by the water levels at Wittenberge. This was a problem that had not been foreseen. It was only thanks to an emergency operation by the German army (Bundeswehr) that the station was protected from floods. Had the operation failed, this part of the railway network could not have provided electricity to power trains. That would have resulted in an even bigger rail network failure.

Relief units, volunteers and social media

At the height of the floods, the Bundeswehr put over 20,000 soldiers on standby for immediate deployment. During one critical period more than 7,200 were on active duty at various locations, helping to shore up levees, provide logistical support and ensure material was where it was needed. Alongside the army, local fire brigades, police, and members of the German Federal Agency for Technical Relief (THW) worked tirelessly for about two weeks to do what could be done to keep the waters at bay and protect property and infrastructure. Alongside these paid professionals, volunteers turned out in great numbers, many of them mobilized through social media channels such as Facebook, who worked to secure weak levees and provide logistical support. Efforts included filling and positioning sandbags and other tasks. In the state of Brandenburg in northeastern Germany, 3.35 million sandbags were filled, transported and put in place along rivers. Of these, 1.98 million bags were used in the area of Prignitz (discussions during a flood protection conference in Brandenburg, April 2014[7]). The topic of sandbags is revisited in the recommendation section (see page 49).

Thur with flood space fully used and bridge flooded (at left) and during dry times (at right).

The photos on this page and the opposite page of the Thur river show what flood spaces look like during flooding and normal periods, when these are often used for agriculture or leisure pursuits showing the Thur at the bridge at Pfyn, Switzerland.

Rhine:

The Rhine experienced less severe flooding. Even so, it is important to take the situation on the Rhine watershed into account, as an event that would include all three major river systems – the Danube, Elbe and Rhine – would strain available resources even more than the 2013 floods. This is a scenario that was used for a risk analysis by the authorities responsible for civil protection in Germany. While such an event has not occurred yet, is not unrealistic to assume that it could one day.

In June 2013, floods along the Rhine were most severe in an area that includes the smaller tributaries of the Upper Neckar watershed and those near **Lake Constance** in southeastern Baden-Wurttemberg, Germany. Here, levels were greater than 100-year return periods. The Rhine reached levels at or below the 30-year return period where it flows along the border between Switzerland and Germany. The Aare and Thur rivers that flow in Switzerland into the Rhine flooded in some locations. But damages were limited. Use of flood plain areas and flood control measures were largely effective. In most cases, the water reached 20-year return periods. One exception was at a gauge on the Thur at Andelfingen near Switzerland's border with Germany. Here, just before the Thur empties into the Rhine, the return period was calculated at between 30 and 50 years (BAFU, 2013).

Flooding was easy to observe along the Thur. The Thur is a wild alpine river – throughout its course, it has no significant water retention areas, such as lakes. This means the Thur rises quickly when heavy rains occur. Projects to restore the Thur to its natural state (Thur-Korrektion) provided important areas of arable land that can be covered with water during periods when flooding does occur. The need for these areas to allow overflow was amply demonstrated in May and June 2013, as the photographs show (see this page and opposite page). Further downstream along the Rhine below Rheinfelden, the flood event was fortunately insignificant for the Rhine watershed – a large flood event in the three major watersheds of Danube, Elbe and Rhine in Germany would have stretched the capacity of the country's national responders and civil protection agencies to the limit.

[7] http://www.mugv.brandenburg.de/cms/detail.php/bb1.c.361891.de

Section 2
Comparing the 2013 and 2002 floods

The Rothensee district in Magdeburg was severely flooded. Piles of ruined possessions left for trash collectors suggest that all the houses on this street were probably affected by floods.

In order to look ahead and understand what could happen in the next flood, we ought to first look back to previous flood events. Our first report published in August 2013 concluded that, while much was done to mitigate flood losses, more can still be accomplished. To better understand what was learned and implemented already, and identify areas where we need to know more, we are comparing the floods of June 2013 with those of August 2002.

The 2013 flood shares many characteristics with the 2002 flood. This starts with high soil saturation followed by a similar weather pattern, and when floods occurred, a number of river gauge stations positioned on the Danube and Elbe and their tributaries recorded similar water levels. When looking at the events in more detail, patterns emerge that show both similarities and differences. A meteorological analysis highlights that, while comparable to 2002, the large-scale weather pattern was different in its details in May and June 2013.

In 2002, the so-called V-b extratropical cyclone that brought extreme precipitation over central and eastern Europe, drawing moisture from the Mediterranean to central Europe, was of shorter duration but more intense. At one German Weather Service (Deutscher Wetterdienst, DWD) weather station, precipitation in one 24-hour period totaled 352 mm, the highest ever recorded. The previous record was set in 1906. In 2002, Dresden received 158 mm in 24 hours (Rudolf and Rapp, 2003).

By contrast, during the period of heavy rainfall in 2013, only 73.2 mm were measured as the most intense over 48 hours at the same station, a Federal Institute of Hydrology report showed (BfG, 2013). In 2013, a series of three cyclones started to bring intense precipitation around May 28 and lasted until June 3. Even prior to the extreme precipitation these systems brought, May 2013 had already been the wettest May in some areas for the last 50 years, leading to soil saturation that increased the volume of run-off into streams and rivers.

Until the 2002 floods happened, many people were not aware that flooding on such a large scale was possible: 110 deaths are attributed directly or indirectly to the floods, and economic losses were estimated at more than EUR 15 billion. Only 15 percent of those losses were insured (RMS, 2003). Economic losses in Germany amounted to approximately EUR 9 billion, EUR 3 billion in the Czech Republic and a further EUR 3 billion in Austria. According to Swiss Re (2014), total reported losses from the 2002 event now stand at EUR 14 billion, and insured losses are now thought to be EUR 3 billion. The greatest damage occurred in the state of Saxony in northern Germany, amounting to between EUR 7.5 and EUR 8 billion, thus this state bore half of the total losses. Saxony was followed by the Czech Republic with EUR 3 billion, where losses in Prague alone amounted to EUR 1 billion. The flooding here not only contributed significantly in terms of the overall losses. On the basis of the losses associated with it, many changes, improvements and recommendations to strengthen flood risk management and ultimately to reduce flood risk were made.

While many areas were affected just as seriously or more severely in 2013, such as Passau, Pirna, Meissen or Grimma, other communities and cities had prepared for floods and provided protection. Those that were well-prepared included Prague and Dresden, where total losses from the 2013 floods were low compared with the losses resulting from the 2002 flood. In 2002 there were 12 major levee failures along the Elbe in Germany, including the largest single river levee failure ever in Germany, flooding over 220 square kilometers near Dautzschen (see also page 28). In 2013, only five large breaches were identified on the Elbe in Saxony and, with the Fischbeck failure, the largest one in Saxony Anhalt. Despite the lower number of levee failures, some areas still faced very high losses in the 2013 flood, as outlined in Section 1.

In 2002, the areas that suffered the greatest damage along the Elbe were those south of Magdeburg, upstream from where the Neisse and Saale flow into the Elbe. This included the devastation in Dresden (page 14). In Prague, the entire subway system flooded. By contrast, in 2013, some of the most significant losses were recorded along the Danube (Deggendorf and Passau, pages 10, 12) and the lower parts of the Elbe where it merges with major tributaries (Magdeburg and Fischbeck, pages 14, 15).

Comparing losses of 2002 with those of 2013, it can be said that some of the measures taken to address the problems revealed by the losses in 2002 were proved to be effective. However, other measures had not been taken or measures taken were not effective. What is also significant is that the locations of major flooding and losses shifted. For example, areas where the Elbe flood crest was exacerbated by the high flood crest of the main tributaries showed weaknesses and omissions in protection or behavior towards flood risk reduction. This is discussed in detail later in this report. Table 1 compares flood stages and return periods at select gauge stations with measurements made in 2002 and in 2013.

Table 1: River stages

Location	Gauge 2013	Date, return period (y)	Gauge 2002	Return period (y)
Lake Sylvenstein (Isar)	3.87m	June 3, 10-20y	–[8]	–
Munich (Isar)	4.32m	June 3, 20-50y	3.16m	2-10y
Landshut (Isar)	4.03m	June 3, 100y	3.39m	2-10y
Rosenheim (Mangfall)	4.94m	June 3, >100y	3.12m	n/a
Rosenheim (Inn)	5.11m	June 2, 20-50y	4.48m	5y
Passau Ingling (Inn)	11.59m	June 3, 100y	9.72m	20-50y
Salzburg (Salzach)	8.51m	June 2, 100y	8.30m	50-100y
Ingolstadt (Danube)	5.87m	June 4, 10y	–[9]	–
Oberndorf (Danube)	6.84m	June 4, 20y	6.30m	10-20y
Hofkirchen (Danube)	7.30m	June 4, 20-50y	6.64m	10-20y
Passau (Danube)	12.89m	June 3, >100y	10.79m	50y
Korneuburg/Vienna (Danube)	8.09m	June 4, 200y	7.89m	85y
Ústi nad Labem (Elbe, CZ)	10.72m	n/a, 50y	11.86m	>200y
Dresden (Elbe)	8.78m	June 6, 50-100y	9.40m	>200y
Coswig (Elbe)	7.66m	June 8, n/a	7.54m	n/a
Vockerode (Elbe)	7.94m	June 9, n/a	7.81m	n/a
Rosslau (Elbe)	6.94m	June 8, n/a	6.74m	n/a
Aken (Elbe)	7.91m	June 9, n/a	7.66m	300y
Barby (Elbe)	7.62m	June 9, 150y	6.98m	55y
Golzem (Mulde)	7.83m	June 3, 100-200y	8.68m	n/a
Trotha (Saale)	8.16m	June 5, 150-200y	<7.00m	n/a
Greiz (Weisse Elster)	4.90m	June 2, n/a	3.63m	n/a
Magdeburg-Strombrücke (Elbe)	7.48m	June 9, 200-500y	6.70m	n/a
Tangermünde (Elbe)	8.38m	June 9, n/a	7.68m	n/a
Wittenberge (Elbe)	7.85m	June 9, 50y	7.34m	80y
Hitzacker (Elbe)	8.18m	June 11, n/a	7.50m	n/a
Hohnstorf/Lauenburg (Elbe)	9.55m	June 12, n/a	8.70m	n/a
Beutelsau (Lower Argen, Rhine)	2.51m	June 2, >100y	2.30m	50y
Andelfingen (Thur)[10]	3.19m	June 2, 30-50y	n/a	n/a
Eyach (Neckar)	2.99m	June 1, >100y	<2.55m	n/a
Rheinfelden (Rhine)[11]	3.16m	June 2, 10-30y	2.56m	n/a
Worms (Rhine)	7.08m	June 3, 15y	n/a	n/a

River stages of the June 2013 floods compared with 2002. Note that over a dozen of the gauges selected show return periods of 100 years and above in the 2013 flood. Sources: BAFU (2013), BfG (2013), LfU (2013), BLfW (2002), LfULG (2013), Noel (2013).

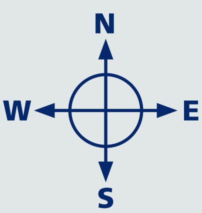
[8] According to the Bavarian Water Authorities (Landesamt für Wasserwirtschaft), the Sylvenstein retention lake took up 23.3 mio. m^3 of water, reducing the flow into the Isar towards Munich from 530 to 30 m^3/s and avoiding dangerous flood levels downstream.

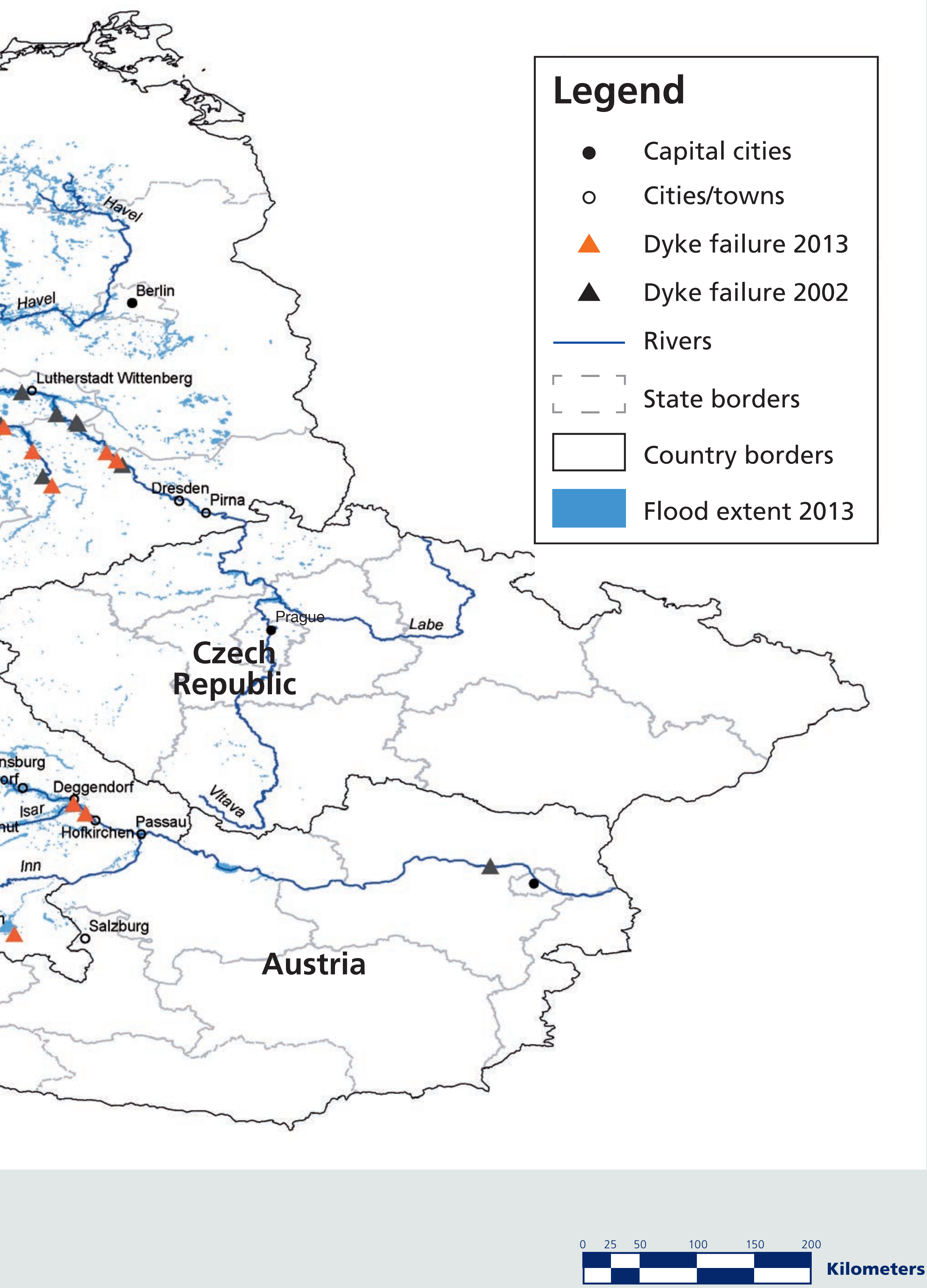
[9] In August 2005, the highest flood recorded in Ingolstadt reached 6.32 m.

[10] Based on a station reference height of 356.0 m, as BAFU (2013) reports discharge and absolute water levels in m ASL.

[11] Based on a station reference height of 262.0 m, as BAFU (2013) reports discharge and absolute water levels in m ASL.

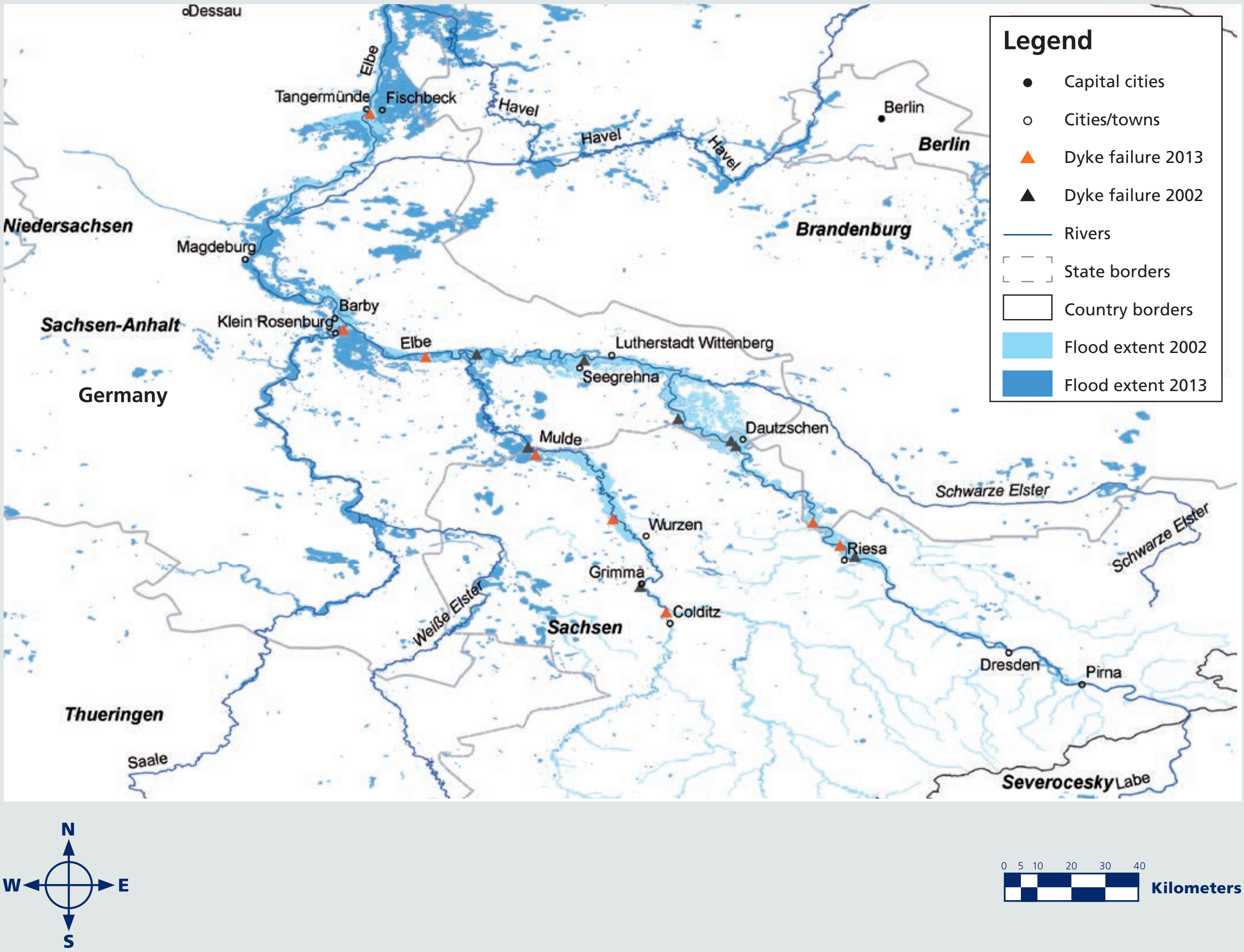
Figure 3: Flood extent of major river systems in 2013





Legend
Capital cities
Cities/towns
Dyke failure 2013
Dyke failure 2002
Rivers
State borders
Country borders
Flood extent 2013
Havel
Havel
Berlin
Lutherstadt Wittenberg
Dresden
Pirna
Prague
Labe
Czech Republic
Deggendorf
Isar
Passau
Hofkirchen
Vltava
Inn
Salzburg
Austria
0 25 50 100 150 200
Kilometers

Figure 4: Flooded areas of major rivers in 2002 and 2013



Flooded areas in Saxony in 2013 (dark blue) and 2002 (light blue), kindly produced by IIASA. The information about the 2002 flood extent provided by DLR/ZKI (copyright DLR/ZKI, 2002) and Sächsisches Landesamt für Umwelt, Landwirtschaft und Geologie (LfULG). The information about the 2013 flood extent provided by the German Ministry of Interior through the ZKI-DE framework contract (2014) and PERILS, field-cross-checked with information from Willis.

Section 3
Insights on what worked well and what did not

A road near Fischbeck along the Elbe was flooded after a major levee break that left entire towns and large areas of farmland under water.

Section 1 provides an overview of what happened along the rivers most affected by floods in 2013, and Section 2 compares it with the flood of 2002. The ensuing damage and losses raise many questions. We know that the damage caused has been investigated. Repairs and rebuilding is underway. One key observation must be made here. Often, the overriding concern is to get back to normal, the 'status quo,' as quickly as possible.

Opportunities to learn from the events and improve the overall situation not just now but also for the future, may be missed. This report is not intended as a complete catalogue of all improvements undertaken, along with those that were not. But we do want to offer insights that can be applied beyond the affected areas in Germany, helping to enhance flood risk management elsewhere. To do this, the following questions guided us: Which measures to improve flood resilience were identified after the 2002 flood? Which were implemented, which were not, and why? Did the measures implemented improve flood resilience in 2013? Were new lessons learned from the 2013 flood?

3.1. Success stories and best practices worth sharing

The case for retention and flood storage – protecting Munich

Along the Isar, flood protection designed to shield Munich and Landshut (see next page) have worked well. The Sylvenstein Dam is credited with saving Munich from the full destructive force of the Isar during massive floods in 1999. Yet in June 2013, the dam would not have stood up to the floods had its height not been increased from an earlier level. The local water authorities had originally requested an extension to the top of the dam by an additional six meters to store more flood waters before running down the Isar. But protests from neighboring towns and nature conservancies led them to settle on a compromise of just three meters. The new storage volume was desperately needed during the floods of June 2013. The Isar's peak flow near Munich was measured at 770 cubic meters per second, as opposed to an estimated 1,300 cubic meters per second, which would have been the case if the dam had not been in place. If the higher volumes of water had come through Munich, this would have overwhelmed the local protection systems and caused significant flooding with unpredictable consequences. The lake behind the dam itself has saved Bavaria many times from flood losses that otherwise would have amounted to several hundred million euros in losses.

"I don't even want to imagine what might have happened to Munich if floods of the magnitude of those elsewhere in Bavaria had gone through Munich. Without Lake Sylvenstein [a reservoir that is connected to the Isar river], Munich would have been hit," according to Martin Grambow, head of the department of water management in the state of Bavaria's Ministry of the environment, as reported in an interview. Besides raising the level of the dam to increase the reservoir capacity, the German state of Bavaria has introduced measures to 'renaturalize' the Isar system, despite pressure to build in potential flood zones. "It is wiser to treat the areas of potential flooding [Hochwasserräume] with respect, otherwise (if the warnings are ignored), you will be taught to respect them." [12]

[12] June 12, 2013, Münchner Merkur online, http://www.merkur-online.de/lokales/muenchen/stadt-muenchen/hochwasser-darum-blieb-muenchen-verschont-2951076.html

[13] http://de.dwa.de/tl_files/_media/content/DWA_Presse/2007/09%20-%20Gewaesserentwicklungspreis.pdf

Giving space to rivers (and people): flood prevention can improve urban dwellers' lives – Munich and Landshut

Besides the dam, a series of additional measures protect communities downstream, including the award-winning[13] restoration ('renaturalization') of the Isar's channel where it flows through Munich. In Germany, the state of Bavaria was one of the first to introduce extensive flood protection measures. In the 1980s and 1990s these projects included widening an 8-kilometer long stretch of the Isar, freeing the river from its narrow channel to provide room for floods, while also providing green areas for people living in the city, thus demonstrating that flood protection not only can reduce damage from floods, but also benefit urban dwellers by providing more green spaces.

Just an hour's drive from Munich, the city planners of Landshut have also shown that planning ahead and making space for floods can be very effective. The Isar destroyed Landshut many times. Spurred by the memory of devastating floods of 1940, Landshut decided to build a wide flood bypass ('Flutmulde') right through the city, a pioneering project completed in 1955. When no floods threaten, the bypass channel serves as a popular park for city dwellers. During floods it can divert up to 400 cubic meters per second of water from the Isar before it enters Landshut. The excess water is shunted north around the stretch of the Isar that runs through the city. Passing through this channel, it rejoins the Isar downstream of Landshut. "Without the bypass channel, Landshut would have drowned in the 2013 event," recalled one city official.

The flood channel that flows through the middle of Landshut makes for an idyllic picture. When no floods threaten, it provides a green park in the city center that offers a popular retreat for city dwellers.

The flood channel that flows through the middle of Landshut makes for an idyllic picture. When no floods threaten, it provides a green park in the city center that offers a popular retreat for city dwellers.

Giving rivers space – polders in Brandenburg

The state of Brandenburg offers an example that proves the merit of finding and setting up flood polders such as the restored floodplains near Lenzen, or the polders along the river Havel. In the 2002 floods, some farmers were skeptical that such a system, which allows crop land to be used to contain flood waters, would work. After the polders were used in flood events in recent years, confidence among the Brandenburg farmers increased. Landowners affected by the introduction of polders now believe they can contribute to flood risk management, and are no longer opposed to polders provided they receive adequate and fair compensation for the loss of arable land during floods.

While these three examples in Munich, Landshut and in Brandenburg provide important examples of how space for the river to flood can also provide additional benefits to enhance the quality of life and incomes, there are many problems that other flood-prone areas face, where there is a need to find and agree on a solution that would require space and provide more natural flood plains for rivers. In Bavaria, for example, problems related to finding room for polders are still being discussed (see section 3.2). Could Bavaria benefit from Brandenburg's experience?

“In 2013, the main threat to Dresden came from the Elbe.”

Where combined new measures have worked – reducing losses in Germany and Austria

Several protection upgrades and reinforcements, including the creation of new retention areas, have worked well along the Elbe. In 2013, there was much less damage in the area around Lutherstadt Wittenberg between Dresden and Magdeburg, where damage had been quite significant in 2002 and where the creation of new flood space and the relocation of levee sections had been completed prior to the 2013 flood event. A levee failure at Dautzschen between Torgau and Wittenberg on the morning of August 18, 2002, caused approximately 315 million cubic meters of water to flow out of the river, covering an area of 220 square kilometers. As mentioned (see page 20), this is believed to have been the largest river levee failure ever in Germany. More breaches occurred near Coswig and Pratau. In total there were 15 levee failures, which led to significant flooding, but they also reduced peak flood levels downstream by up to 0.9 meters based on simulations. Villages were inundated, forcing many people to evacuate. Just the levee failure at Dautzschen meant that 28 towns in the states of Saxony and Saxony-Anhalt were under water. These levee failures did not repeat in the 2013 floods in the same areas – but levees still failed in others.

In Salzburg, in 2002 calculations showed that an additional 0.1 meters to the recorded flood levels of 8.30 meters of the Salzach river, a tributary of the Inn, would have devastated the historical inner city. That level was surpassed in 2013 with record flood levels, but investments in protection systems including mobile flood barriers paid off, reducing damages and losses.

New flood scenarios considered – Dresden

As far as Dresden is concerned, the losses and damage that resulted from the 2013 floods were less severe than in 2002. In 2013, less rain fell in the watersheds feeding small streams and rivers that flow through the city. There was no catastrophic inundation from rapidly rising, fast-flowing rivers like the Weisseritz. Pictures in 2002 showing Dresden’s flooded train station, and historic buildings also affected by floods including the Semper Opera House and Zwinger Palace, are still hard to forget. In 2013, the main threat came from the Elbe. Its water volumes were managed thanks to a combination of various installations that protected the historic city center. Dresden had not experienced a severe flood like the one of 2002 in recent memory. Thus, before 2002, flood prevention and preparation was no longer deemed to be a high priority. Most of the protection, including fixed structures combined with flood walls and mobile barriers and gates, had been completed or were obtained only after 2002. These helped keep the water out in 2013 and saved the center of Dresden. Two parts of the city still flooded, mostly where flood protection projects had not yet been completed. Damage to these places was very much the same as in 2002, when opportunities to increase resilience during reinstatements had been missed and vulnerable buildings and installations were merely restored to the same state as before the flood, and thus to the same level of vulnerability.

Most of the losses in 2002 in Dresden were caused by the swift, small and dangerous Weisseritz. Today, given its potential to cause large losses within the city’s perimeters, the Weisseritz carries a protection level of a 500-year return period.

The state of Saxony paid for building protection up to the 100-year level, and the extra cost to reach the 500-year level was borne by the city of Dresden. The experience of past losses indicates that absolute protection thresholds, such as the widely aimed-for 100-year level, may need to be re-examined in order to take a more risk-based approach to protection levels.

Learning and implementing – insights from the Kirchbach Commission in Saxony

To improve protection along the Elbe river in Saxony, a commission chaired by Hans-Peter von Kirchbach, a former German army general, was asked to analyze the 2002 flood event. The changes suggested by the Kirchbach Commission were implemented by the State of Saxony. These reduced flood risks, and increased preparedness while improving emergency warning systems. Providing coordinated warnings through a new centralized state flood agency ('Landeshochwasserzentrum') worked well, and was mentioned (by those with whom we spoke) as making a crucial difference during the 2013 floods.

This shows the value of post-event analysis, including the analysis of the 2002 floods. Recommendations provided by independent review bodies such as the Kirchbach Commission can reduce losses in future events. Such a review should have been conducted for all of the affected areas, and not just in Saxony in isolation. A second Kirchbach Commission, which was put into effect after the 2013 floods, acknowledged that improvements had been made in the state between 2002 and 2013. While we can be sure that lessons were learned in other German states as well, they may not have been as thoroughly and consistently analyzed, nor implemented, in as much depth as in Saxony.

Thinking in new ways – mobile dams and relocation

In Austria, the floods of 2013 led to increased flood risk management action in the most strongly affected states of Upper and Lower Austria (other states were affected as well, largely by more localized flooding and landslides). Flood protection levels along the Danube will be increased and, where these are lacking, upgraded to meet the 100-year level. Mobile dams, which have been used widely in Austria in scenic locations to avoid blocking the view with permanent flood walls, will continue to be implemented. Protection around feeder rivers with large loss potential will be tackled as a priority. Where no sound and affordable protection is feasible, incentives will be offered for permanent relocation.

Due to the prohibitive costs involved, the Eferdinger Basin near Linz is one of the very few areas along the Austrian Danube that neither has protection nor a project underway to achieve a 100-year level of protection. But after the bitter memories of those living in the area, including in some cases being forced to take refuge from rising water by scrambling to rooftops, many inhabitants of the Basin or 'Becken' are now considering moving away. Those weighing a new start outside the flood zone will now receive government subsidies as incentives over the next two years: There are 138 homes in a 24-square kilometer area within the 100-year flood zone. National and state governments will pay 50 and 30 percent, respectively, of the total value of homes, and try to help with financing solutions to enable households to move to a suitable home elsewhere. The loss of land, however, will not be compensated. Beyond these measures, there will be a ban on new buildings in that zone (Direktion Umwelt und Wasserwirtschaft des Landes Oberösterreich, 2013).

There was a similar community relocation in Germany after the 2002 floods. Röderau Süd comprised a small number of homeowners and small businesses located in a flood plain close to where the levee failed at Dautzschen. The history of Röderau Süd only goes back to the 1990s, when following German reunification, the area in what was formerly East Germany saw a surge in demand for new industrial and commercial zones. Old warnings of the flood hazards in the area around Röderau were determinedly ignored. The town of Röderau Süd came into existence. After the floods 2002 put a good part of Röderau Süd underwater, it was impossible to ignore the flood risks any longer. It was clear that those who got flooded again would not get another chance to rebuild. A decision was made to relocate. Around 400 people, homes and small businesses were resettled. While Röderau Süd is an example where resettlement probably worked because it had to work, lacking alternatives, discussing the relocation of existing communities is very difficult. Röderau Süd is also a reminder that fast growth often comes at the cost of neglecting to do risk analysis, and failing to take risks into account when making decisions.

Improving intervention and thinking ahead – the new Federal Office of Civil Protection and Disaster Assistance and its flood scenarios

In the 1990s, Germany began to dismantle some of the offices it had established to provide Cold War-era civil defense. Planning to deal with national emergencies became something of an anachronism. Partly in response to the consequences of the 2002 floods, Germany's government established the Federal Office of Civil Protection and Disaster Assistance (BBK)[14], whose main task is to "ensure the safety of the population, combining and providing all relevant tasks and information in a single place." In addition to providing central access to resources before and during disaster intervention, the BBK also plans ahead, formulating strategies to respond to any potential threats and hazard scenarios that might need to be considered. While in both 2002 and 2013, it was fortunate that not all three major watersheds in Germany (Danube, Elbe, Rhine) were affected by the floods. A scenario involving all three, for example a major snowmelt flood in the spring, is not unthinkable and is considered by the BBK among its potential disaster scenarios.

During our visits we learned of innovative ways to encourage people to relocate out of flood zones. In areas where damaged homes were still at risk and could not be adequately protected, owners were offered compensation equal to 80 percent of the damage sustained, but this was not restricted to any specific use. Rather, the money could be used at homeowners' discretion to mitigate flood risks. The entire community worked with those affected, identifying vacant homes outside flood zones that could be remodeled with the money. These alternative homes might even have been offered at below-market prices, according to some accounts. Some people took the money and relocated, staying in the same community, but outside the flood hazard zone. Authorities could also take the land where the damaged buildings were located and 'renaturalize' it, using it for flood retention space. This resulted in a win-win situation. Such an approach would not work everywhere, but it shows that innovative solutions between various interested parties can lead to workable, efficient and acceptable solutions. Such solutions need to be fair, however, and not allow certain interest groups to acquire land, using flood improvements as an excuse to exploit financial resources.

[14] http://www.bbk.bund.de/EN

Austria’s experience

Despite exceptional, and for many gauges, record, flooding in Austria, losses incurred in 2013 were much lower than in the 2002 event (EUR 0.9 billion vs. EUR 3 billion). The 2002 floods exhibited some different characteristics – they came later in the year, and affected many tributary rivers that had less protection – prior large-scale events including the 2002 floods (and also floods in 2005) provided learning opportunities and offered key insights to reduce damages and losses (UBA Flood Risk Studies I and II, Habersack et al., 2002, 2009).

Higher risk awareness: Municipalities can participate in risk assessment exercises, which they do. Risk analysis and training (based on a Swiss model) allows them to identify major risks and actions required. Active participation helps the communities to identify areas at risk and make decisions on land use, building and rebuilding, all decision largely within the remit of municipalities.

Giving priority to natural and soft solutions: Keeping retention areas vacant in order to allow them to flood without overmuch concern for agriculture and structures built in these areas is now generally regarded as the preferred option in efforts to keep risk low. This proved effective, for example in flooded retention areas around the town of Tulln (see Section 1), that faced about a third of the peak flood discharge in 2013). Here, mobile dams made a difference, not collapsing in their first real test. These are erected on fixed concrete platforms (buried up to six meters deep). While this type of protection is associated with high cost (about EUR 6,000 per square meter), it proved a valuable way to preserve scenic regions with tourist appeal, such as Austria’s Wachau region. In order to work, an effective and reliable early warning system is important. This is the case along the Austrian part of the Danube.

Clear lines of responsibility among individual states: A great deal of effort went into determining clear lines of responsibility. Beyond this, training is carried out regularly for decision-makers at both the municipal and state levels. This proved very effective in 2013. Greater cooperation between states, as well as between countries bordering the Danube, is still needed.

Recognizing the need for integrated and interdisciplinary solutions: Collaboration is needed, especially as there are no one-size-fits-all solutions; even mobile dams have to be integrated into a system that includes pumping stations as a second line of defense, pumping out water seeping out onto the land side of the levee. Permanent protection and retention areas are necessary, both upstream and downstream in places where floods pose a risk. Proper land use and regional planning needs to be also integrated into flood risk management. Incentives to rebuild in a better way, encouraged by compensation payments, are also important policy instruments.

Permanent evacuation as a last resort: In some instances, incentives were provided to inhabitants living in high-risk zones to permanently resettle elsewhere. Those decisions were the result of a participatory process, which allowed for appropriate incentives that seem to have been well accepted by those affected.

3.2. Pressure points where more needs to be done

Better understanding the hazards: models and measurements

We identified problems with forecasting and measurements at rivers in all watersheds that we investigated in Germany. These problems included a lack of sufficient knowledge, or lack of experience regarding how upstream catchments behave, specifically how changing weather patterns affect these, and how the data are interpreted. Forecasts by meteorological and hydrological services were sometimes not accurate enough, for example, when it was necessary to make important decisions based on these. This included the Czech Republic where the upper part of the Elbe catchment (Labe and Vltava rivers) is located. Due to changing weather patterns, such as the track and the moisture content of V-b-associated cyclones, it was not possible to provide more accurate or earlier warnings using existing models. As a result, valuable time was lost that was needed to prepare and implement protection measures.

- **Meteorological measurements**
  The problem associated with these types of measurements is not unique to the Elbe catchment. It affects those threatened by floods in major watersheds around the world. The problem is due to the lack of sophisticated high-resolution models and real-time data to feed them. Current models do not provide enough advance forecasting time. The problems arising from gaps in meteorological forecasts are compounded by the limited coverage of measurement stations – in particular rain gauges, which play a key role in predicting river flows based on precipitation. The issues were discussed in flood reviews of the 2002 flood. To address them, a European Flood Forecasting System EFFS was created (Rudolf and Rapp, 2003). The EFFS was moved to the European Floods Portal of the European Commission's Joint Research Centre (JRC) and is now called the European Flood Awareness System EFAS. EFAS provides warnings for possible river flooding to occur within the next three or more days, based on probability bands of so-called ensemble forecast models[15]. The site aims to increase the forecast lead time. National hydrological services can use the information to complement their own national data (De Roo et al., 2011). But at the national level, there seems to be little awareness of, or use of this portal.

- **Hydrological measurements**
  Currently, full and realistic 3-D river modeling is limited. Most flow models are based on three elements: point measurements taken from river gauges, a cross section of the river at that point, and a model of the terrain through which the river flows. Technology has not yet progressed to the point where complete 3-D river modeling is possible. We are not even able to completely understand river gauge measurements. Gauges typically work well when water is at comparatively normal levels, but tend to work poorly during extreme droughts or floods. It is precisely at these periods when gauges are most needed. Several gauges failed completely at extreme flood levels, including those at the stations Passau-Danube and Passau-Ilzstadt (Bavaria). Gauges themselves can suffer from floods. Economic damage to measurement stations in Bavaria alone was reported at EUR 300,000 (LfU, 2013).

  Today, there is still uncertainty in the so-called 'rating curve,' meaning the curve showing the relationship between water discharge (Q) and the flood stage (W) at a given gauge. This relationship is especially important during floods. But during periods of extremes (drought, flood) the relationship expressed by the curve becomes unreliable due to the dynamic nature of the water and the changing topography of the riverbed.

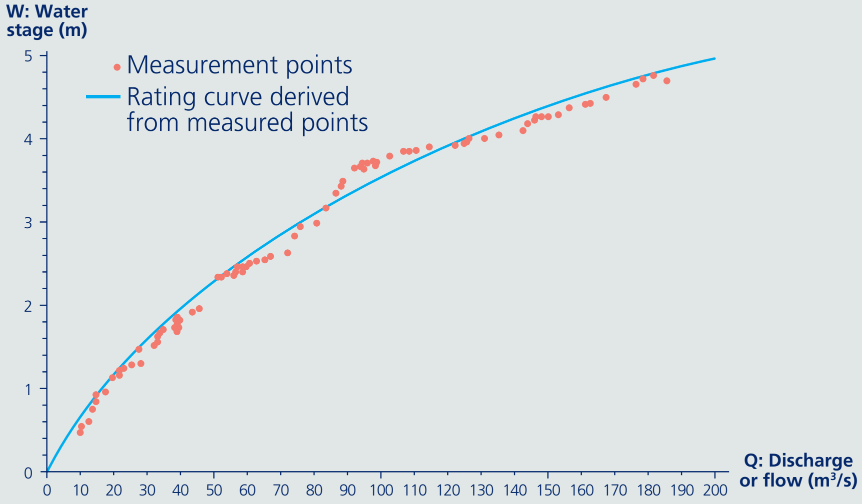
[15] http://floods.jrc.ec.europa.eu

This in turn affects forecasts for downstream gauges, compounding the error from one gauge to the next. An excellent explanation how the rating curve is produced is provided on a webpage from the University of Berlin.[16] See also Figure 5 for an example of a 'hypothetical' rating curve.

Better measuring stations and models would allow more time for warnings, and the ability to be more precise about forecasts for flood stage levels and the expected arrival of flood peaks. More robust gauges that can withstand extreme flood events are necessary – the loss of river gauges also means loss of data density, which decreases the ability to make forecasts downstream.

Better, more reliable gauges would increase warning time and greatly facilitate intervention before and during catastrophes. Decision-makers would receive better information, helping them to choose whether, for example, to evacuate or move assets located in the likely flood zone out of harm's way. A fraction of a meter difference in the flood crest that is forecast could mean everything when time comes to decide whether to defend a levee or evacuate. Unclear forecasts in 2013 created tense situations and led (in hindsight) to what might possibly have been the wrong decisions in Passau on the Danube, and Wittenberge and Magdeburg on the Elbe. If forecasts are revised at very short notice, it might be too late to change a decision as to whether people in the area should stay put or evacuate.

Figure 5: Hypothetical rating curve



An artificial rating curve showing the relationship between water flow (m^3/s) and water stage (m) based on a series of points where the river cross section was measured at the river gauge station. (Source: Zurich)

[16] http://www.geog.fu-berlin.de/~schulte/animationen/abflusskurve.htm, German only

In the district of Prignitz, the local authorities were very aware of the tense situation and problems they faced with forecasts during the 2013 floods. They also had to take into account that uncertainties are often not included when forecasts are communicated: Decision-makers frequently receive the forecast as one water level based on the most likely of all potential outcomes from the forecast. The range of the forecasts, that is, the uncertainty, is not communicated. Such uncertainty is difficult to handle even under normal circumstances. But in emergencies, it must be weighed as part of decisions. Local authorities therefore planned their next steps cautiously based on the information they received. "You only decide once in those types of flood intervention situations. Once a decision has been taken, it needs to be the best possible one, as you cannot change it afterwards when thousands of people are putting together material and preparing logistics to defend a particular levee location," according to District Administrator Hans Lange.

New hazards – better understanding the Inn

One of the major problems for Passau, the city situated on three rivers, is posed by one of these rivers, the Inn. The river, which starts in Switzerland, was a major contributor to the 2013 flood crest as recorded at Passau's town hall. Part of the EUR 3.4 billion flood protection reserve that the state of Bavaria wants to invest until 2020 in its new flood protection strategy, '2020plus,' will be spent on an in-depth study of flood risk management along the Inn. In particular, the state will seek to identify potential retention areas along the river before it enters Passau. One could ask why the Inn had not been in focus earlier. That the Inn was not better researched previously has partly to do with coordination problems between Austria and Germany, as both these countries border on the Inn. Much of the upstream Inn is in the hands of hydropower companies, which have provided good protection for an event with a 100-year return period. The problem for communities, however, lurks in the lowermost stretch of the river just a few kilometers before it reaches Passau, where the Inn empties into the Danube. The study aims at identifying new retention areas, and how flood peaks affecting Passau can be lowered.

Finding space for retention areas and flood areas – polders in Saxony and Bavaria

According to Germany's Federal Institute of Hydrology (BfG, 2002), prior to the 2002 floods, an area equal to only some 14 percent of what was originally 6,172 square kilometers remained for retention along the Elbe. Particularly sections along the Danube, the Inn and certain parts of the Elbe and Elbe tributaries witnessed the most significant repeat damage in 2013, compared with 2002. Controlled flood polders would help immensely here to reduce flood peaks at times when this is needed most. In areas of dense land use and community settlements, however, it is difficult to make space for dedicated polders to lower flood peaks, allowing water to flow into fields or other areas. Most discussions on this topic focus on agricultural land use in areas where there is low to medium flood hazard. In such areas, land can be used for water retention during the infrequent periods when large floods occur, and farmers who otherwise use the land to grow crops could be compensated.

The Kirchbach Commission (2013) found that after their 2002 flood event review, the authorities had identified opportunities to relocate 49 levees and create polders with a total of 7,500 hectares in Saxony. After intense consideration and scrutiny, 36 projects totaling 5,200 hectares were considered feasible. However, by the time the 2013 flood hit, only 140 out of the 7,500 hectares had actually been created,

> Polders might be controversial, but 'controlled' polders have worked in some areas."

while other projects for 1,850 hectares were still under construction.

In Bavaria there have been long and problematic discussions how to set aside land for flood retention along the Danube. These discussions ended without agreement. Positions were too far apart to reach an outcome. After the 2013 flood, however, there has been renewed willingness to re-examine positions, and discussions are starting again. Bavaria has been considering expropriating land, an approach that has met political opposition. Whether or not this is the only solution that will allow Bavaria to move ahead remains to be seen. Perhaps positive examples such as those in Brandenburg (page 27) or the Iller will convince all sides to look for new solutions.

Even here, there has been progress. The only functioning flood polder in Bavaria so far has worked well. It is on the Upper Iller in the Allgäu region, where the city of Kempten has successfully been protected by a polder system that lowers the peak flow of water by up to 100 cubic meters per second. Total investments for the entire flood protection concept along 25 kilometers of the Iller river amounted to around EUR 100 million. That compared with losses of EUR 60 million in Kempten in 1999 alone due to floods. The protection system proved up to the task in 2013, keeping Kempten out of harm's way.

Yet polders have been controversial in some areas, especially those 'controlled' polders where flood gates are opened, serving to reduce flood peaks. These are different from polders that flood when water reaches a certain level, which do not necessarily provide the best results (because, for example, the retention area would be filled before it is needed, rendering the polder ineffective). The 'uncontrolled' polders often provide very little benefit to alleviate floods during periods when waters reach maximum levels, according to Germany's Institute of Hydrology (2013) and others. Such polders also offer little benefit compared with the cost, as they require more space to achieve the same flood reduction impact than do 'controlled' polders. There is a need for better understanding of how polders influence river floods, and what can be done to alleviate floods during periods when waters crest. This could help increase acceptance of polders; only that which is widely understood will be accepted or gain support among the general population.

Building levees the right way, and at the right time

Authorities in both Bavaria and Saxony confirmed our view that levees for flood protection should only be relied upon to protect densely populated areas or cultural heritage sites, but not to increase the value of assets in areas along the river that the levees protect. This would just preserve the status quo. But it is also a political decision and could be hard to uphold. Once land is protected to the 100-year return period, it seems very tempting to continue building there. Some parties may wish to promote construction in these flood hazard zones. However, it would be wrong to assume this is safe – protection works only up to the design level threshold of that particular levee or other system. This problem is called the 'shadow of the flood wall' or 'levee effect' (Tobin, 1995). Thus, we need to increase our awareness that there is always a residual flood risk and that – as has been proved many times – levees can and will fail.

When protection levels are exceeded – the 'overload' case

In Switzerland, crucial lessons were learned after devastating floods in the summer of 2005. These lessons also apply to 'handling the overload case' – in other words, how a structure must behave when it is overloaded and fails. The need for a gradual and non-catastrophic failure in case of overload has been recognized and is now implemented as a best practice when completing new flood protection structures. This means that when the structure fails, people and/or

Building levees – large construction works near Fischbeck along the Elbe-Havel Canal in April 2014.

assets it protects are not in immediate danger and overwhelmed by flood water, but the structure provides a residual protection for some time. In Germany the importance of considering the overload case has apparently only been recognized by many people after large structures were overtopped and failed in 2013. In future, we must acknowledge that events may become more severe, more unpredictable and have greater consequences, especially in small watersheds. Thus, the inherent design of an overload case should be applied to both newly-built and existing flood protection structures. The Swiss Federal Office for the Environment (BAFU), as well as the individual cantons, have gained significant experience with regards to situations where the 'overload case'[17] is a critical factor. In a parliamentary debate[18], the Swiss government confirmed it must be taken into account when designing structures, to achieve the highest standards when new flood protection concepts are considered in Switzerland and corresponding guidelines were published (BWG, 2001).[19]

Time and knowledge are of the essence – levee failures

Many levees failed in the 2002 and the 2013 floods. In Saxony, 19 levee failures were recorded in 2013, although failures were fewer than in 2002, when over 100 levee failures occurred (see also page 14). There were five large breaches on the Elbe in Saxony in 2013. In Germany it is currently not possible to do much real-time monitoring of levees using technical equipment that could indicate if a situation is critical and failure might be imminent. There is an established system in which, above a certain emergency threshold (for example, a 'level 3' or 'level 4'), volunteer levee patrols ('Deichläufer') are stationed on 24-hour duty along the levees to monitor the situation. This is done to allow the condition of the levees to be tracked relying on heavy deployment of people and resources. The system includes a complicated list of instructions and equipment (e.g., as described by the Ministry of Environment, or Landesumweltamt, Brandenburg, 2003). However, compared with the means employed by some other countries and the technology available, this type of approach seems to belong to the past. If better analysis and forecasts or inventories regarding the current condition of the levees were available and implemented across Germany, and if emergency plans for potential high-risk levee failures (in populated areas, in areas of cultural heritage, etc.) were present, it would allow much valuable time to be gained to develop an intervention strategy (Vorogushin et al, 2011). Some even say that a disaster like the large-scale levee breach in **Fischbeck (Elbe)** (page 15) could have been averted if this type of technology had been used in Germany. The conditions under which levees are assessed, and the ability to do so, needs to be improved and action taken – the Kirchbach Commission stated in 2002 that the condition of 85 levees with a combined length of 202 kilometers (roughly one third of the total length of levees in Saxony) were classified as 'poor' or 'insufficient.' A risky maneuver to sink three barges in order to close the Fischbeck breach and plug the gap in 2013 was certainly an impressive operation. But this could not be described as a 'preplanned' strategy selected as the best among a number of options. It was chosen in desperation to try to close a huge gap that flooded over 200 square kilometers of otherwise dry land.

[17] http://www.bafu.admin.ch/dokumentation/medieninformation/00962/index.html?lang=de&msg-id=21485

[18] http://www.parlament.ch/d/suche/seiten/geschaefte.aspx?gesch_id=20053839

[19] The former BWG is now part of the Swiss Federal Office for the Environment

Figure 6: levee failures near Dautzschen

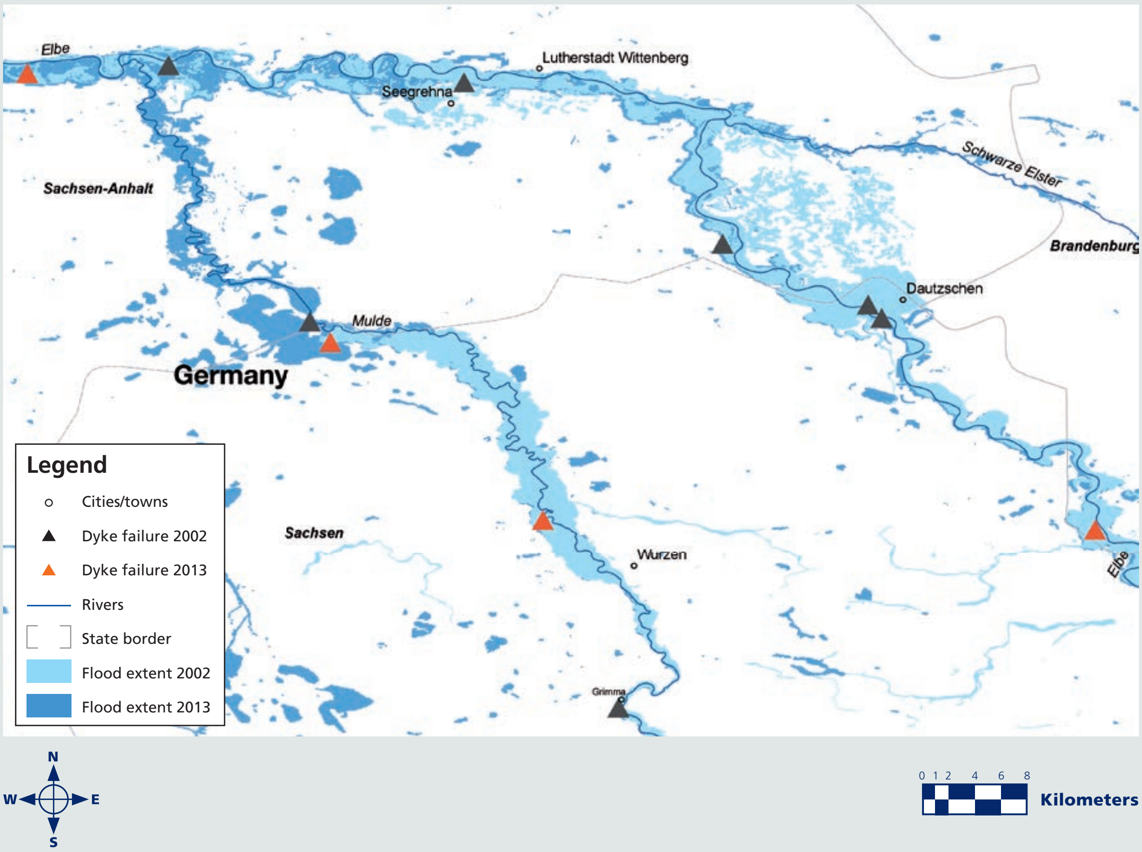
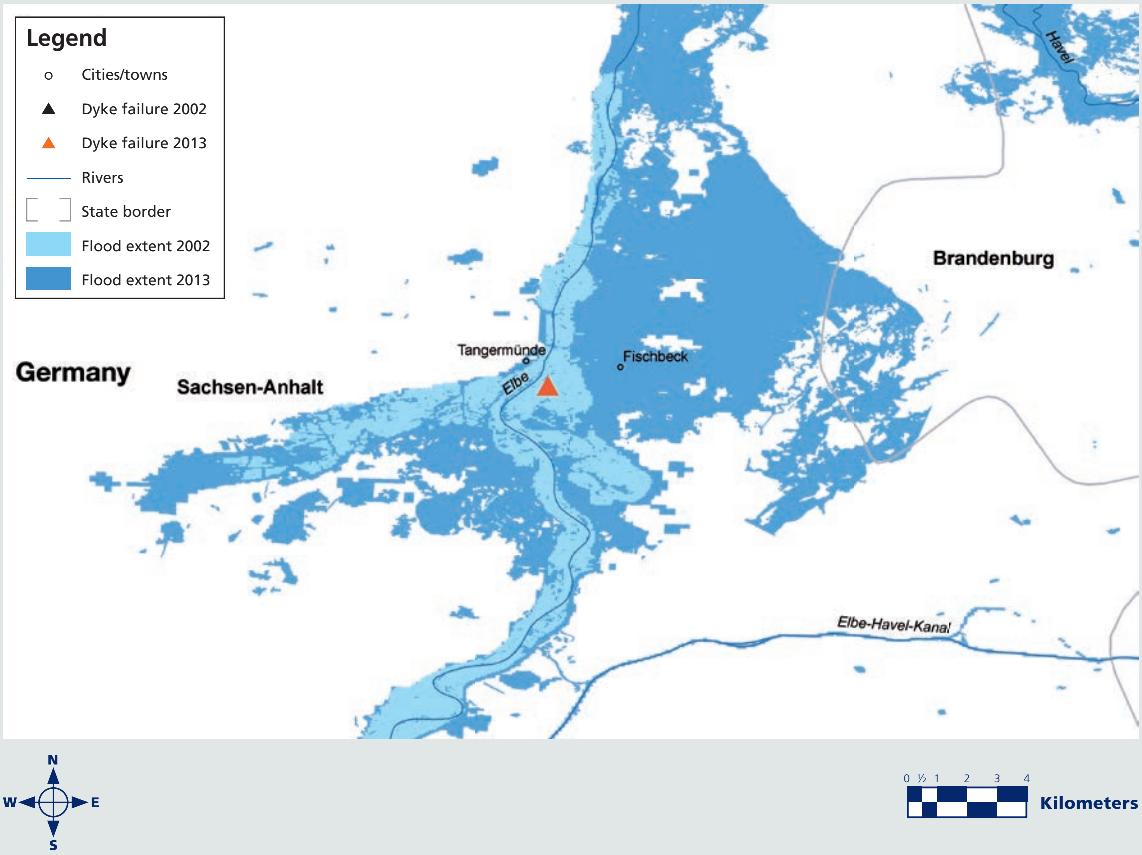


Figure 7: levee failures near Fischbeck



The 2002 flood extent provided by DLR/ZKI (copyright DLR/ZKI, 2002) and Saxony's Landesamt für Umwelt, Landwirtschaft und Geologie (LfULG).

Time is pressing – especially in the 'funding cycle' after catastrophes

The funding of flood protection projects tends to be cyclical. Funding – and a strong desire to complete projects rapidly – is in the spotlight right after a flood has occurred. But often the urgency and willingness to bear the costs start to wane as time passes. Urgently-needed efforts to reduce risk may not be implemented by the time the next large flood hits. After devastating floods, there tends to be a knee-jerk political reaction, which includes making money available for rebuilding and helping those in need: funding for flood risk reduction projects is made available, and existing projects, even those that were stalled prior to the event, gain new momentum. At least, as long as the 'political memory' lasts. Will the 2013 flood be sufficient to serve as a catalyst for investing, providing the political will necessary to invest and see through what has been promised, even if there are no more severe floods for several years?

Enforce existing regulations on flood resilience and flood risk reduction

Enforcing the building requirements has not worked well in many areas in the past. Existing regulations tend to be little enforced, as do the requirements aimed at reducing risks to existing buildings and installations in flood hazard zones. Building new assets is usually prohibited in legally-designated flood hazard zones. However, a number of exceptions exist, and these are usually generously interpreted. Among them is the exception that building is permitted in communities where the entire land area is in a hazard zone. If such rules were strictly enforced, the community could not grow at all. Alternative solutions need to be found for communities located entirely in hazard zones.

People are likely to be unwilling to carry out activities to reduce flood risk if they are unaware of the consequences of not doing so, or if they rely on others to put them in place. For more than 10 years, Germany has had a regulation that require the protection of heating oil tanks in flood hazard zones. Yet people in these zones are unwilling to invest relatively small amounts of money to upgrade their tanks. This often leads to widespread oil contamination during floods and results in a total write-off of houses that could otherwise have been saved. Educating people will provide them with incentives to encourage flood risk-averse behavior: for example, making sure they know that unprotected, these oil tanks can contaminate water during floods.

Educating and informing the public – the 'push' approach

As already described, in Fischerdorf on the Danube, there was low awareness and willingness to protect from residual risk if levees were overtopped or failed. Research conducted as part of our flood resilience program has shown that there are gaps in public risk awareness that can be addressed. These gaps may be partly due to a lack of communication. While some of those interviewed, especially customers in large corporations, confirmed that the information flow between their company and authorities pertaining to flood hazards and warnings was very good, this was not the case everywhere. People need to be informed if they live in a flood zone, especially if a large protection wall gives them a false sense of security, leading them to believe they enjoy absolute protection; this can never be the case. We saw communities that provided no communication on flood hazards at all, not even to people in zones where the hazard is high. In other cases, the authorities wanted to actively inform people who might potentially be affected, but they did not get the necessary material, such as brochures, ready in sufficient quantities to be handed out to everyone. During our visits, however, we encountered a good role model in Straubing (Danube, Bavaria), where citizens living in areas at risk from flooding are actively contacted. They get letters and brochures providing information.

Urgently-needed efforts to reduce risk may not be implemented by the time the next large flood hits."

We would encourage this type of 'push approach.' We believe it works better than a 'pull' approach in which the person at risk needs to ask for information. This first requires that people are aware of the risk they face. Often they are not, or not aware enough to take action.

Public flood map portals – powerful tools

In the past decade there has been a lot of discussion about creating natural hazard maps, and how such maps should be used. The German insurance association (GDV) has developed a tool covering all of Germany, 'ZUERS Geo' (Zonierungssystem für Überschwemmung, Rückstau und Starkregen). It is used to identify and assess flood hazards for the insurance underwriting process. While still part of a pilot project, ZUERS is now publically available in two states, based on an interactive map that evaluates flood hazard.[20]

The EU Floods Directive[21] requires member countries to produce and provide flood hazard and flood risk maps, a process that is ongoing. A lot has been achieved as part of this initiative to display flood hazard and flood risk more transparently, and many states and countries have produced flood maps already. However, such maps are not always easy to find or interpret, as there is no central access point. Switzerland does not yet have a central flood map portal, but it is working on providing a central access point for all cantonal (states) hazard maps. A comprehensive on-line map is provided in Austria, the 'natural hazard overview & risk assessment Austria' or 'HORA'[22].

Incentivizing risk-averse behavior

Some experts believe that compensation following the 2002 floods sent the wrong signals. By compensating affected individuals and property owners 100 percent, and restricting payout with a requirement to build back 'as was' – to the original standard – there was no incentive to encourage risk-averse behavior, or to reduce loss potential. Many opportunities were lost to increase resilience. This could be termed a moral hazard. It is always cheapest and easiest to increase resilience or resistance during reconstruction or during the planning process, as opposed to doing retrofits. Examples of ways such an approach might work include changing the material used to finish buildings and for interior fittings, changing the floor plan (e.g. moving technical installations to safer locations). These are only a few of many things that could be addressed in this context.

By the same token, the way compensation is awarded can also make a difference. Infrastructure losses at a communal level were compensated by a maximum of 80 percent if the community took it upon itself to rebuild. But the community received full compensation if it delegated the responsibility to the state water authorities. Of course, most communities chose to delegate. Thus, a lot of responsibility and work was shifted to the state water authorities. These were then criticized by communities asserting that the calculations for full compensation were based on low estimates, and on exceptions and that work was not carried out as desired. In those cases, an opportunity for communities to take responsibility and ownership for flood protection projects, which would further encourage risk-averse behavior, was lost.

In agreement with many other studies, we underline that pre-event mitigation benefits amount to a multiple of the costs of such measures, when these measures are correctly planned and funded. Average losses for households affected by flooding are in the range of EUR 50,000 for Germany. For large-scale protection projects benefiting towns and communities, on average, the benefit derived relative to the cost can be expressed by a ratio of four-to-one, or even up to 10-to-one, when the primary and secondary benefits are quantified and expressed in monetary terms (obviously some aspects of benefits

[20] http://www.zuers-public.de; http://www.gdv.de/2013/06/zuers-public/

[21] Directive 2007/60/EC, available at http://ec.europa.eu/environment/water/flood_risk/index.htm

[22] http://www.hora.gv.at/

and/or disadvantages cannot be directly quantified). Projects need to be scrutinized for their individual benefits relative to cost. The range can be significant, and decisions must be made on a strict basis related to efficiency and economics as some projects may have unfavorable ratios of below one. Discounting and financial calculations – weighing current cost against future benefits – play an important role, but there is a propensity to use high discount rates that will indicate a strong preference for the present over the future, as a number of studies examining cost-benefit analysis related to reducing disaster risk have shown (e.g. MMC 2005, Mechler 2003, Mechler et al, 2008).

Assessing flood resilience for one's own home can also provide motivation. Insurance companies sometimes provide these consulting services[23], identifying the strengths and the weaknesses of elements contributing to flood resilience, as well as providing an outline of what potential flood losses might occur, and offering advice on how the risk can be reduced. There are also new initiatives to provide independent flood assessments for the general population, including a new 'flood passport' (Hochwasserpass)[24] introduced by the HochwasserKompetenzCentrum (HKC) in Cologne. A hazard assessment identifies the problems that may originate from bodies of water in a particular vicinity. A questionnaire provides early insights, and seeks to raise awareness. A quick glance online can provide an explanation of hazard levels identified. A qualified expert can then analyze a building and its surroundings in detail at a particular location, and identify way to make improvements. Based on the assessment, the 'passport' will be created that can then be used by those who might later buy the property, and by insurers and/or authorities checking to see if rules and regulations are being adhered to.

Lack of a national flood protection strategy

Germany thus far lacks a comprehensive flood protection program or authority at the national level. While the creation of the BBK and national advice on water management from the environment office go in the right direction, a national flood protection strategy needs to go further.

In Germany, flood protection authority is at the level of the individual states. This adds a level of complexity to flood protection and may complicate the situation in the event of a disaster. For example, the levee heights and widths can change abruptly where the Elbe crosses some state boundaries, such as between Brandenburg and Mecklenburg-West Pomerania. For the same reason, the levees on two opposing banks of the Elbe might even be different in certain areas where the river constitutes the boundary between two states, such as Lower Saxony and Schleswig-Holstein. As a consequence, one state would flood before the other. This situation was evident especially during the 2002 floods, and improving the coordination during intervention was already at the heart of the recommendations that came out of the 2002 event. However, aligning protection standards within the frame of a national integrated flood risk management program would take these coordination efforts to an even higher level, and could have potentially huge benefits for future flood programs. A central authority might also be able to accelerate the process of finding agreements acceptable to all regions, parties, and interest groups involved, especially to resolve difficulties encountered when dealing with relocation projects, compensating landowners that provide flood retention space, and other still unsolved problems.

[23] Zurich Risk Engineering: http://www.zurich.com/riskengineering

[24] http://www.hochwasser-pass.de/

Calls for such an authority are not new – while Germany has been considering it, the Austrian Ministry for the Management of Land, Forest, Environment and Water (BMLFUW, 2011) has provided a guideline for a consistent approach on flood hydrography and flood statistics, and promoting a national and transparent approach when evaluating flood return periods. It also aims to improve the criteria used to decide on protection measures, and make these more efficient in terms of costs relative to benefits. The Swiss Environment Office BAFU also acts as a national body for advice and coordination, although the Swiss cantons retain the decision-making authority and the power over implementation.

Critical infrastructure – lack of knowledge about risk interconnectivity

In many past events, when a particular region was flooded, little was known in advance about where 'cascading' failures might occur. A breakdown in critical infrastructure can severely aggravate a local situation, multiply the effects of losses and disrupt companies' supply and value chains. The floods in Thailand in 2011, which inundated thousands of square kilometers including huge industrial estates where large multinational companies had production, brought down entire supply chains of electronics and car parts manufacturers, causing ripple effects throughout the global economy.

Although on a different scale, similar threats or damage to critical infrastructure could be observed in the 2002 and 2013 floods in Germany. Local breakdowns of the electric power grid are very likely to happen in combination with floods, cutting off the supply for emergency equipment such as water pumps, unless mobile power units are available. A relatively predictable scenario can quickly escalate, taking on an unforeseen dynamic when key components of critical infrastructure are not included in a pre-event risk analysis. We mentioned earlier in this publication a key transformer station's narrow escape during 2013 floods (page 16). The station supplied electricity to the German federal railway's alternative Hanover-Berlin line across the Elbe. The threat of such events cascading into multiple failures can also apply to pumps required for waste water treatment plants, as well as the structures and plants that, if they fail, could release harmful chemical, nuclear or biological substances into the environment.

During the 2002 and the 2013 Elbe floods, researchers at Germany's Bundesamt für Seeschiffahrt und Hydrographie measured the changes in the chemistry of the German Bight (Deutsche Bucht) and the Elbe. They detected, for example, a significant increase in the concentration of two isomers of the banned insecticide Lindan, which served as pesticides and have been prohibited since the 1970s. The researchers argued that these chemicals came from disposal sites near Bitterfeld where they were originally deposited,[25] that flooded in 2002 and 2013. They also underscored that this type of chemical release during floods usually has only a minor impact, as the level of concentrations of pollutants in rivers – often including herbicides from flooded agricultural land – typically return to normal after a short while. Further attenuation then occurs downstream and in the ocean. The most significant chemical threats due to floods stem from flooded heating oil tanks and damage affecting structures containing dangerous chemicals, such as those at chemical plants or major hazardous waste dumps. These need to be monitored as part of critical infrastructure.

[25] http://www.bsh.de/de/Meeresdaten/Beobachtungen/Meereschemische_Daten/Elbe2013_Zwischenbericht.pdf

Section 4
Recommendations

The Inn river recorded its own high-water mark during the 2013 floods, leaving a stain on 'Schaibling's Tower in the historic center of Passau, Germany.

Based on what has been discussed in preceding sections, we provide here a concise and structured overview of the recommendations derived from our investigations. These are intended to be used as a guideline for various aspects of flood resilience that can be read independently, without first reading all the details provided in earlier sections pertaining to the 2002 or 2013 floods in central Europe. We caution that flood hazard and flood risk management are very situation- and location-specific. At the same time, most of these recommendations are universally applicable and could be implemented anywhere in the world.

As a general guideline, we recommend the following hierarchy of flood protection measures:

- We recommend building outside flood hazard areas. While we cannot stop nature from producing floods, we can avoid the consequences by putting ourselves out of harm's way, and learn to better cope with floods where we cannot fully escape them. Zoning laws and building regulations support this approach. It is better to be safe in a 'natural' situation, rather than rely on protection to control flooding.
- The best starting point for flood control is to use natural retention capacity upstream.
- If protection structures are needed, we recommend building in redundancies rather than relying on single protection features, such as a levee. If a levee fails, then the whole protection system fails. Redundant measures could include those that provide resilience in operations, as well as the design of a particular structure, including the overload case. Such approaches to protection require authority, control, and maintenance necessary for them to work. They can and ultimately will fail, as was the case in the 2013 floods. This type of flood control can never provide complete protection.
- Mobile flood protection should be considered the prevention measure of last resort in the flood control chain.
- If flood control cannot be achieved using either permanent or temporary measures, then adaptation and reducing vulnerability, and increasing resilience, should be encouraged.
- This approach must be complemented by flood emergency and contingency planning, and an appropriate level of flood awareness and preparedness.
- 'After a flood' is really just 'before the next flood:' reviews are necessary to see what worked well and where plans need to be updated.

For an explanation and example of a flood contingency plan, see the Zurich Risk Topic '**Flood Contingency Planning**' currently on:

http://www.zurichservices.com/ZSC/REEL.nsf/265b6656a4289e1fc125728500567e52/20d76d09efe6b004c12575440033da2e/$FILE/flood_contigency_planning_rt_2-7.007_20120613.pdf

“On a national level, a centralized flood protection strategy or coordinating and advisory body is needed.”

For the more detailed recommendations that follow, the points have been ordered according to categories: pre-event mitigation, intervention and post-event analysis. Here we follow the ‘hierarchy’ of natural over structural over temporary protection and intervention measures, as outlined in the preceding section. We invite you to learn from our insights gained from previous floods and apply it to ways to approach future floods, while considering some of the points presented. We believe it is imperative to remind anyone who might be involved in flood prevention that these specific recommendations must always be tailored to the specific situation at hand and implemented only by qualified specialists.

4.1. Flood risk management governance

Improve integrated flood risk management in practice

While there is a general consensus that integrated flood risk management (IFRM) from source to mouth of an entire watershed is the most appropriate way to approach flood control, there is no general consensus as to the best way to implement this. Many variables must be considered when deciding which levees should be built, which retention areas created, which protection levels defined, and when providing guidance on how the overload case (see page 35) should be handled. In Germany, policymakers need to provide clearer guidance as to which flood risk management measures are expected and which direction future protection should take. This guidance needs to be communicated down the ranks to the individual decision-makers in individual states and the local authorities to ensure that IFRM works on a practical day-to-day level.

National flood protection strategies and supra-national coordination

In many countries the oversight of flood warning and flood protection is at the level of individual states, for example in Austria and Germany. By contrast, in other countries such as the Netherlands and France, it is organized at the national level, relying on a strict top-down approach. Both de-centralized and centralized approaches offer advantages and disadvantages. But often in the past, a federal (de-centralized) system of flood protection often stopped at state borders, and coordination was lacking for larger watersheds. Rivers do not respect political boundaries.

On a national level, a centralized flood protection strategy or a coordinating and advisory body is needed, even if federal decision-making and implementation powers are kept by the individual states to ensure a modern, integrated flood risk management (IFRM) approach. A national flood governance body appears to be the most suitable way to reduce risks, prepare for floods, and ensure the information flows between affected states and countries in the event of a disaster. This approach can help to ensure that there are consistent defense heights and protection addressing the same flood water levels, and avoid gaps in protection along rivers or even banks of the same river.

Coordination is needed at the national as well as the international level to ensure that integrated flood risk management works as intended and brings maximum benefit to communities. A centralized national body that observes laws and respects institutions could combine its approach with a flood institution at the overarching watershed level. Some international organizations of this type already exist, such as the International Commission for the Protection of the Rhine[26] and the International Commission for the Protection of the Elbe River.[27] But they cannot exist in isolation. They need to be integrated into active flood risk management and intervention. All these aspects, but in particular the relocation of levees and the creation of flood retention space, insurance schemes and education to raise risk awareness and understanding need to be better coordinated, and the coordination needs to be across watersheds.

[26] http://www.iksr.org/ The IKSR has five mandates, one of which is “holistic flood prevention and protection taking into account ecological requirements”

[27] http://www.ikse-mkol.org/index.php?id=1&L=2

Role of insurance

Insurance in Germany covers only a fraction of the sustained flood losses. In the 2002 floods, only about 15 percent was covered by insurance (RMS, 2003). The German Insurance Association GDV reported that insurance penetration for natural hazards today may be only about 35 percent throughout Germany, and potentially even lower in the most-affected areas. Currently, there is intense discussion whether mandatory insurance coverage for flood or natural hazards would solve the problem – some are asking for compulsory coverage, while others, including the GDV, call for a continuation of the open market and for further risk reduction and flood risk awareness.

For the 2013 floods, the German government offered flood relief of in total EUR 8 billion for those people and businesses most affected without insurance coverage, and to cover infrastructure damages. Establishing an emergency fund is an important step in providing relief. But increased funding prior to any catastrophe to reduce future losses is clearly the preferred route. Post-event relief may reduce incentives for people in high-risk areas to have adequate insurance, and/or discourage investments to mitigate damage. Even when post-event relief is provided, it may be insufficient to cover all losses of those affected. Providing post-event relief exposes public finances to considerable risk, given the uncertainties and relatively unpredictable nature of such events, even apart from the high costs that they engender. There is thus an urgent need to improve the ways in which various stakeholders are engaged in pre-event mitigation and measures to enhance flood resilience. Experience shows that collaboration between insurance operators, government authorities and other key stakeholders is crucial when it comes to encouraging risk reduction in both the public and private sectors (Amendola et al., 2013).

4.2. Flood risk reduction through natural retention and physical protection

Provide adequate, but controlled retention

Flood water storage and floodable land along the rivers, so-called polders, are important means to reduce flood crests. While flood storage without any human intervention or infrastructure (such as artificial basins or inlets/outlets) would be the most natural approach, it is not the most efficient. Uncontrolled polders often flood before the peak of the flood has been reached, and are already 'full' when they could achieve their optimum impact by taking up water. Land along the rivers is also typically fertile, attractive and scarce. Natural polders would require too much space in order to achieve a meaningful peak flood reduction in large flood events.

In contrast, 'controlled' polders offer greater benefits relative to costs. These are filled at the point when they can achieve greatest impact based on the anticipated flood crest. German water authorities have calculated that such polders may need, on average, only one quarter of the space that a natural polder would use to achieve the same effect. But polders and their impact on flood crests are still not perfectly understood. There is need for additional research on how polders work, and what can be done to alleviate floods during periods when waters crest. This could help increase acceptance of polders, as, again, only that which is widely understood will be accepted or gain support among the general population.

Polders, especially 'controlled' polders, have been regarded as a controversial approach in some areas. Landowners upstream and communities downstream must both participate in discussions to find a fair and financially viable solution for all, so as to achieve the necessary protection level. It is hoped that a solution can be found without having to expropriate land. Retention space for flood water is limited, and any additional polder space that becomes available needs to be managed wisely to achieve the best possible flood control.

Flood protection design levels – a risk-based approach

At present, flood protection design and the return period the protection should be built to is typically based on land use. Agricultural land has the lowest protection level, industrial land may have a higher one, populated areas of villages, towns and cities are protected usually to a 100-year return-period flood, and certain special areas may be protected to the level of a very rare event, such as a 1000- or 10,000-year return period event. However, these decisions do not usually reflect a risk-based approach, but instead are applied universally. Yet often it is more sensible to look at the protection requirements from the perspective of undesirable or unacceptable consequences – one might recall the tsunami that overwhelmed a nuclear power plant in Japan in 2011, or the impact that flooding affecting chemical industries or large industrial estates would have. Dresden provides a positive example of a risk-based approach that was used to prevent the city center flooding again in 2013, after the main railway station and historic buildings flooded in 2002. These examples demonstrate how important a more consistent approach to risk-based decisions can be.

When designing protection, it is important to consider the following points. These underscore the difficulties of factoring in variables, quantifying key factors, and/or planning ahead from an economic standpoint:

- **The overload case:** modern protection structures such as levees must not fail in an event that slightly exceeds, for example, the 100-year return period event, even if technically they were designed for 100-year return period events – they must retain a minimum of protection even if they are 'overloaded' and leave enough time and provide options to consider alternatives for defense or repairs and intervention. They cannot simply be allowed to collapse 'catastrophically.'
- **Uncertainty:** it is difficult to deal with uncertainties, especially when constructing a device that will function up to a 'hard' threshold. In order to reduce the probability of failure in a changing and dynamic environment, various assumptions must allow for uncertainties. These include, among other things: the uncertainty inherent in flood statistics used to calculate a 100-year return period (or other protection level) event; the uncertainty that the data available to produce these statistics (usually a few data points for extreme events during a record of the last 50 to 100 years for larger rivers) is representative of the realm of possible events (often it is not); the uncertainty that conditions in the future will remain basically the same, or that future conditions can be anticipated in current protection level design; and finally the uncertainty that the protection system's condition will still meet the design level despite degradation and use over its lifetime.
- **Changing risk:** are the assumptions still risk-based in tomorrow's world, or will a changing risk landscape – or changing requirements and technical feasibility of flood protection – mean that other forms of protection replace the ones in existence? We may need other forms of protection based on the assumption that risk will change in tomorrow's world.

“Generally, it is important to challenge the faith people have in what they believe is absolute safety.”

Include key infrastructure in planning

Critical infrastructure as well as locations with the potential for unacceptable secondary losses (resulting from contamination or other problems) need to be identified and assessed in terms of flood risks well before a flood occurs. This is necessary to avoid further, potentially disastrous knock-on events caused by floods, as well as loss of infrastructure. Risk maps taking key sites into account are needed, as are intervention strategies – planned and rehearsed – to protect against these structures failing or losing the services they provide. These include, but are not limited to, lifelines such as power and water distribution and sewage systems, road and rail infrastructure and telecommunication systems as well as sites with chemical, nuclear or biological agents that can pollute the environment, key public buildings such as hospitals, schools, buildings for responders such as fire departments, police, technical relief agencies (in Germany, the THW), etc. and many others. While it is easy to explain that in the past, many plants and factories were located near rivers that provided an easy source of transportation or power, today our society and economy are critically dependent on the operations continuing, and we also know that these losses can be avoided.

The problem with residual risk and the ‘levee effect’

People generally have a poor understanding of residual risk. They tend to believe in the absolute safety of levees, dams, and other structures. Thus, it is common to see the value of assets ‘behind the wall’ increase. The phenomenon, sometimes called the ‘levee effect,’ leads to the problem that relative losses of assets protected by these structures tend to be higher than otherwise would be the case, if, contrary to expectations, the levee is breached or the dam topped. Generally, it is important to challenge the faith people have in what they believe is absolute safety. There will always be residual risk and people living and working in flood zones need to be aware of this. In particular, it is important to keep in mind that:

- Levees are only built as safeguards to a certain flood level. If that level is topped, they will not provide protection. Levees might be said to shift the losses to the tail-end of the probability curve. But they will not reduce loss potentials, nor will they completely eliminate hazards.
- Levees were designed at one point in time based on assumptions that led to the level the levee will protect to (the design level). Many conditions may change over time and alter how the levee can protect – including what is happening upstream or downstream of a levee.
- Floods can occur due to events other than river flooding (precipitation, groundwater etc.). For such events, levees offer no protection.

Flood protection for individual locations

For individuals, business-owners and entire communities, risk-averse behavior needs greater encouragement. We need better and more examples to demonstrate why pre-event mitigation and risk reduction is important and needs to be favored over post-event relief. While money is an important aspect – risk reduction efforts generally pay off and are less costly than flood losses – there are many additional reasons why losses should be reduced or avoided. These include the distress suffered during and after a loss, the problems associated with temporary relocation when access to property is impossible or restricted, and when memories and possessions are destroyed forever.

In order to incentivize risk-averse behavior and encourage people to protect themselves, including by increasing resilience after major floods, full compensation from the government in the form of relief should be avoided. To encourage people to become more flood resilient, in 2013, obtaining grants and subsidies to install local flood protection and use more resilient materials and installations became much easier. As much as 80 percent of the cost was borne in certain areas, e.g. in Bavaria, by the government. This needs to continue and such an approach could even be enhanced. Risk reduction efforts before the next flood occurs offer important steps toward reducing overall loss.

Misplaced faith in mobile flood protection

Many people put faith in mobile flood protection, but these types of devices can only work under certain conditions. Believing that everything will 'turn out fine' if protection is put in place is a dangerous assumption. For mobile protection to work, sufficient lead time is needed, and information needs to be accurate enough to set up the right mobile protection systems. Placing trust in mobile protection means assuming nothing will go wrong in how and where these structures are installed. At the same time, however, relatively little is known about the conditions under which mobile flood protection measures fail, especially in catastrophe situations when the information flow may be disrupted and response teams are thin on the ground. In the end, mobile protection should be considered as protection of the last resort. These structures work only if many things come together: a well-established and frequently rehearsed flood emergency and contingency plan with clear roles and responsibilities. Natural protection, retention, and fixed structures offer much more reliable flood protection.

4.3. Intervention – Measures taken immediately before and during a flood event

Improving measurement and forecasting quality

Certain things need to be improved to help us better understand flooding. These include the accuracy of meteorological forecasting, and the measurement of precipitation and the subsequent analysis of how the precipitation affects runoff and flood waters in rivers. Data quality from river gauge stations varies along rivers, and this often affects the ability to make predictions downstream that rely on upstream measurements. Many river gauges are destroyed during large flood events and then do not provide any records, while others are imprecise when flow or water stages approach extreme values. More effort is currently being, and should still be invested, in improving network coverage (precipitation and river gauges) to feed better models with more accurate and reliable data based on improved measurements (such as better calibration of the stage-flow relationship).

Declare a state of emergency as early as possible

If forecasts provide earlier warnings when acute flooding is about to occur, this can save property, possibly lives, and give more time to responders to prepare for the flood crest. This principle has been applied with great success by the authorities of the Prignitz district in Brandenburg (see page 34). Valuable time can be gained if decisions are made early, once there are indications to justify declaring a state of emergency. Instead of waiting until a fixed threshold is reached (for example, a certain level of flooding) a state of emergency can be declared when such thresholds are anticipated with, for example, 95-percent certainty, based on forecasts from upstream. This may give responders an additional 24 hours or more to set up emergency structures, rather than waiting until the alarm threshold is actually reached.

Levee maintenance and monitoring

Levees are a technically complicated and often expensive means of protecting assets from rivers. They are often planned, designed and built, using the latest technology and knowledge available. However, it is all too often forgotten that further investment is required to maintain, upgrade and monitor them. Flood protection systems cannot provide absolute safety and will fail if an event exceeds the protection level for which they were designed. Often they fail even before that due to degradation and insufficient maintenance. New methods can provide better protection and more effective response to reduce levee failure

Effective flood risk reduction spans generations."

and allow response teams to react more appropriately if a levee is breached. These include modern prevention and forecasting, real-time levee monitoring, and failure-probability models. While there is the much-lauded German standard ('DIN' or Deutsche Industrienorm) that applies to dams holding back lakes, there is no similar sort of 'handbook' in Germany giving guidance on how levees should be analyzed. In this regard countries with high flood risk, such as the Netherlands, could provide valuable insights for other countries. There is also the International Levee Handbook,[28] a six-nation project that offers sound advice and could be valuable for countries including Germany and others.

Sandbags and other types of mobile intervention

Sandbags are widely used during flood intervention. The logistics in Germany are in place to provide sand and sandbags, and quickly get them where they are needed. Germany's intervention capability is very sound and well-organized, thanks to the country's Federal Agency for Technical Relief or 'THW,' and the Bundeswehr. Sandbags do have limitations, though; these include limits on what they can achieve, possible restricted availability and the speed at which they can be deployed. These days, many countries have opted for other, more modern alternatives to sandbags, such as long and robust plastic tubes, that have many advantages: durability, ease and speed of deployment, reliability and the relative ease at which they can be de-installed after use. Concerns about waste and recycling should also be considered. Customers and authorities alike have voiced concerns that sandbags are often left behind after floods and need to be disposed of by property or site owners. When the bags are contaminated by oil or other material, used bags create huge volumes of hazardous waste. At least some of those who have dealt with the problem in Germany believe that even if the solution is costly, there should be ways to clean and recycle these bags.

Social media

Social media provided an important communication channel in the floods of 2013. In 2002, those channels did not yet exist and dedicated official resources for intervention, as well as volunteers, were found through traditional communication channels. This dramatically changed with the advent of instant messaging, social media channels and smart phones. Facebook, Twitter and other services were used to ask for help, or often to spontaneously organize assistance and volunteers. Despite good intentions, this sometimes overwhelmed those directing helpers and caused some resentment and friction.

Local and regional authorities need dedicated communication concepts for social media channels. There needs to be awareness that volunteers wanting to help during an event can turn from assets into liabilities if things go wrong (in situations where they are not needed, for example, or when they get in harm's way, or start working outside the perimeters of coordinated response, etc.). Social and web-based mass media are great for directing information flows on a large scale, and accessing crowds of people, but they need to be very carefully managed. People managing this aspect of relief need to be well trained.

4.4. Post-event measures

Post-event relief versus pre-event mitigation

Risk-averse behavior and policies to plan ahead need to be encouraged, or incentivized. While relief after a disaster is needed, providing full government compensation for losses in flood zones, especially to the 100-percent level, sends the wrong signal. In addition, questions can arise related to whether it is fair to compensate those who did not purchase insurance, as opposed to those who did.

Flood risk reduction is a task that spans generations. Extreme flood events are relatively rare and changes to protection levels and infrastructure projects to reduce flood risks might be beneficial only to future generations. This should not stop us from tackling the risks now,

[28] http://www.leveehandbook.net/about-project.asp

Greater investments are needed now to cut losses in the future."

especially giving priority to strategies with no regret that offer flexible, adaptable risk reduction that will be beneficial no matter what the future may hold. Uncertainties include increasing asset values, hence greater risk, changes in the environment and climate. Bigger investments are needed now to avoid an unacceptable cost of losses in the future. This requires investments by public bodies (governments), corporations and by individuals affected by flood hazards.

Respecting different community interests

To address conflicts of interest that inevitably arise when flood protection is an issue, people living in communities should be included in discussions, and ways should be sought to allow them to play a part. In Germany, the approval procedure for construction, the 'Planfeststellungsverfahren' – (the consultation process), is anchored in German law. It requires large construction projects to take into account all relevant issues, as well as interest groups that could be affected by a particular project. The procedure allows citizens to demand explanations and at times even to halt projects. Such was the case in the German town of Grimma, where citizens opposed a flood protection wall that blocked their view, or in Mühlbeck, where property owners close to a levee blocked an upgrade. People in the community and those affected by projects need to be involved in the planning and design and have a say in how projects are carried out.

In Germany, based on the legislative process, and depending on how controversial a project is, the consultation period may require several years. To succeed, authorities need to draw on prior experience and get sufficient 'buy-in' from the communities, which should ultimately benefit from the project. However, the time these projects may need to go through all the proper channels means it can often be the case that the next flood strikes before the projects under consideration are completed. Some other countries take a different approach. They involve citizens in the early stages of planning, including them in the overall process instead of waiting until a project is already well advanced before soliciting comments and potential objections. New approaches are needed to expedite projects and make them more effective. Otherwise, the next major flood will occur before critically-important projects can be completed or even started.

The role of the authorities – educate, guide and enforce

Education will add incentives to encourage flood risk awareness. Guidance is needed to allow people to adopt more risk-averse behavior, and learn what can be done to avoid and reduce losses. While new regulations may be necessary to reduce overall flood risk, building regulations already exist that require ample risk reduction. The problem is that these are interpreted in a lax way, and there is a lack of willingness to enforce the rules: People fail to install flood-proof oil tanks, use materials that do not provide adequate flood protection, or (re-)install expensive equipment in the basement or on the ground floor. For example, we often find critical, sensitive machinery that could be easily harmed by floods in at-risk flood-prone industrial areas. Better education about regulations that serve to protect against floods is needed. The regulations need to be better enforced. There must also be a hard line taken on exemptions among those seeking to circumvent these regulations.

Very often, risk-averse behavior provides many additional benefits and opportunities, especially if it is integrated into a project right from the planning stages. 'No regret' or 'low regret' solutions of flood resilience or resistance will provide benefits even when future scenarios are clouded by uncertainties. Even if we do not know exactly how flood hazards will increase, or how extreme precipitation events may unfold in future, the means to address these risks will still provide benefits.

Exchanging information

Flood knowledge is an important asset. There must be an open exchange of information to allow people to better understand floods, and learn about the related hazards and risks, while providing increased risk awareness and insights into how they can protect themselves, On a scientific level, meteorological data, river gauge data and weather models, must be exchanged, including across borders, for example, between Germany and the Czech Republic, to provide full and real-time access to gauge data along the Elbe, to validate forecasts and improve accuracy so that different countries and international bodies can learn from each other. Instead of many different bodies modeling the same thing, the various authorities involved should work together to provide fewer, but better models. The scientific knowledge obtained then needs to be presented in ways that it can be understood by the general public. Campaigns are needed to educate people about hazards and risks. More education is also needed on 'risk-averse' behavior. This should include teaching in school to what extent the population is affected by natural perils such as hail, earthquakes, wind or floods. Understanding these risks should start early in school and be mandatory. Parents can learn from their children. They will listen if their children bring home interesting, relevant information presented in ways they can understand, and relate to their own lives. If children can understand it, their parents can.

Zurich believes that all hazard-relevant information must be available in the public domain, not for sale or hidden and only available to specialists. Some experts compare public flood awareness to the flood hydrograph of a river – a significant peak during the height of a flood followed by a drop. This should not be the case. Having information available also helps to stimulate awareness when no flood is imminent. Flood maps, flood event analyses and related information needs to be on public webpages, distributed through brochures and even sent to households.

Public meetings and talks by flood experts should encourage people to ask questions, learn more, and take an active role in future decisions affecting flood risk management and local protection strategies.

Access to information and providing information

There should be a general move to provide information more on a 'push' basis, as opposed to 'pull,' and education needs to be available for people who need it most. People at risk are often not even aware that there is a warning or a requirement in building codes that applies to them. They might not think that they are specifically at risk or affected by it. They might be aware that flood information is available, or that there is a warning, but they then choose to disregard it, as they believe reading it is unnecessary. With a push approach, government authorities or educational facilities must tailor the information to the audience. They would actively provide information through a range of channels (radio and TV, brochures, house-to-house campaigns, invitations to discussions, etc.). Section 3.2 (page 32) also refers to some good, but all too infrequent, examples.

Improve education on flood hazard and flood risk

To be ready to deal with flood hazards requires ongoing education. Too often the memories of the last flood fade quickly. People who are aware of flood risks and how to reduce them are a more receptive audience. There is also a general misconception about flood probabilities or flood return periods. This is true in particular when it comes to the risks attached to events with a low probability. Research has shown that people will repeatedly tend to ignore or misinterpret small probabilities, which affects their perception of flood risk and whether it is a good idea for them to look for ways to protect property and assets.

We believe that people understand the chance of an 'annual occurrence' better than return periods, which seem to imply an event will only reoccur after a certain number of years. Having experienced a flood, people are tempted to assume that a major flood is unlikely to affect them again in the near future. Thus, instead of referring to a '100-year flood,' it would be better to provide statistical probabilities that do not imply how soon an event could happen. In the German state of Saxony, all major watersheds have witnessed an extreme flood event in recent years. Terminology should be simplified, to focus on the chance of a particular event occurring each year. Having a 10-percent chance of a flood happening in any given year would therefore banish some of the false sense of security that because a '10-year' flood happened in one year, it will not happen again for another decade. In the state of Saxony, authorities were blamed for not explaining following the 2002 flood that another flood of similar magnitude could happen again so quickly. Making it explicitly clear that there is a chance every year for a major flood, some people might have thought twice before rebuilding in the way they did.

Harmonize flood hazard maps, standardize use and interpretation, increase public availability

Flood hazard maps are very powerful tools. They highlight flood hazards and provide a basis for discussion when topics include vulnerability, and the people and assets at risk. Floods are a spatial hazard with high resolution: detailed studies are needed to identify and model flood hazards. A great variety of flood maps are available, but flood maps are currently not standardized. This creates confusion. What is shown on one flood map might be very different from another. This makes maps hard to interpret. As part of an effort to inform and advise on risks, flood hazard maps should be publicly available, easily accessible, and harmonized across watersheds. Ideally, this should be done on an international scale. If every flood map looked the same, these maps would be a much more powerful tool, allowing for greater understanding and use of such maps.

Flood return periods and assumptions about how flood zones are derived (e.g. with or without levee protection) need to be harmonized, too. While current efforts, such as the European Union's Floods Directive, are going in the right direction by providing flood maps Europe-wide, these still fail to provide clear guidance. For example, while a 100-year return period flood is usually chosen for maps as one of the flood probabilities shown, return periods for 'frequent flooding' and 'extreme flooding' are subject to interpretation by EU members. The choice then comes down to the level of individual states in these countries. The result is that a large number of different flood maps are available on a variety of flood web sites and internet portals.

Flood maps should also account for the dynamic of flood risk. As seen in the example of the Inn (page 34), new river sections may need to be analyzed in more detail. Flood maps need to be constantly adjusted and communicated as hazards change – we suggest a regular update of flood maps every couple of years at least. We advocate flood maps that show clear return periods: for example, 10, 50, 100 and 500 years. Hazard maps and risk maps should not be combined into one map. 'Hazards' need to be shown separate from 'event severities,' and both need to be separate from the 'vulnerability of assets' in the flood zones.

Section 5
Would we be ready if the next ‘100-year flood’ happened in 2023?

Aerial view of high water levels on the Rhine, and an industrial canal near the nuclear power plant Leibstadt near Basel, Switzerland.

Now is the time to prepare for the next catastrophic flood

Flood risks along many European rivers are increasing. Reasons for this include changing weather patterns, changes in runoff and water flows due to urbanization, and an increasing asset density in flood-prone areas. Floods are likely to be bigger and more catastrophic in the future.

Without implementing significant changes now, if we continue on the current course losses will keep increasing, potentially getting beyond control. The previous sections provided a review. In this section, we look ahead to discuss what might happen in the future. To underscore the urgency of improving certain aspects of flood resilience quickly, we introduce the hypothetical occurrence of another 'flood of the century' in 2023 to describe what possibly could happen if, within this relatively short time span, the efforts underway to reduce flood risks and increase preparedness are discontinued.

Within just 11 years, all watersheds in the eastern region of Germany experienced extreme floods that exceeded the 100-year return period: In 2002 the Elbe and rivers left of the Elbe (the watershed in the Ore or 'Erzgebirge' mountains); in 2010 the rivers right of the Elbe (including the Spree near the town of Bautzen); in 2011 the smaller water sheds in Upper Saxony and in June 2013 the Elbe, particularly in Saxony from Magdeburg below the confluence with the Saale to Lower Saxony near Hamburg. Cities such as Grimma and Meissen experienced record floods both in 2002 and 2013. When considering the probability of such extreme events, we must keep in mind that flood statistics are backward-looking. They do not forecast the future. An extreme situation on the Elbe that exceeds the levels encountered in recent floods needs to be seriously considered as a possible future scenario. It is also not unlikely that flood events in which not just two, but all three major river systems in central Europe (Danube, Elbe, Rhine) are affected in a major way at the same time could happen in the near future. This would put severe strain on intervention and repair efforts.

We know that the climate has changed in the past. This has happened over millions of years, but also over the course of the last few centuries. The climate will continue to undergo changes. We also know that, in a warmer atmosphere, air can take up and transport more moisture. This suggests that there is an increase in the potential maximum precipitation. As the last report of the Intergovernmental Panel on Climate Change (IPCC, 2011) shows, at the global scale and for Europe, there is evidence that climate change has contributed to more intense and frequent rainfall. Climate models project increased heavy rainfall in the future. Yet, while there is evidence that climate change has caused more intense rainfall globally, based on peak flow measurements there is no evidence for climate-driven changes in the magnitude or frequency of riverine floods in the last decades. Kundzewicz et al. (2014) discuss that projected increases in heavy rainfall would contribute to increases in rain-generated local flooding in some areas. The potential for more frequent large-scale weather patterns like those that brought intense precipitation over central Europe in 2002 and 2013 could also increase. According to the German weather service DWD, based on their 'Climate, Water and Shipping' (KLIWAS) climate models, the 'V-b' and 'TrM' type systems that are often associated with floods could increase in frequency by up to seven days per year by the end of the twenty-first century relative to the middle of the previous century. There is still uncertainty regarding where the highest precipitation – and runoff into rivers – would occur. Smaller watersheds are especially at risk, and vulnerable to potentially seeing the highest water levels ever. Protection levels with 100-year return periods would therefore not be enough to guarantee safety. Protection might have to be increased, especially along smaller rivers that flood rapidly, to keep potential losses within acceptable bounds.

Massive flood gates and walls next to the Mulde river in Grimma.

However, it is worth mentioning that while the frequency or intensity of heavy precipitation events in Europe is likely to have increased since about 1950[29], there is also regional data for central Europe that gives no indication of an increase in frequency of high-intensity precipitation events, analyzing recent events and comparing these with earlier periods[30]. But even if the relationship between climate change and floods offer a lack of clarity that could be interpreted as future trends, we still need to prepare adequately for low-probability events that would have an extreme impact.

When Thomas Jakob, responsible for flood risk management in the city of Dresden, recalls discussions prior to 2002, he says that no one believed it would be possible that gauge levels of eight or nine meters at the bridge in the city center could be reached. Today, he says that people must consider flood events with water levels of nine or even 10 meters. They need to consider how to plan for and act in such cases and even be willing to think the unthinkable – that in an event where waters rose to ten meters, half the city would be flooded.

Areas that in the past have not experienced floods also need to prepare for flooding in the future. It is a common mistake to confuse a lack of flood history with a low flood hazard. Past floods can indicate hazard, but the absence of a flood history does not indicate that floods are unlikely in the future. Only hazard maps and a detailed analysis of the watershed in the area can provide a real indication of the potential for flooding. Such scenarios are often hard to convey to people who have no experience with past flooding, but for whom such indications must be heeded as a warning of what could happen in the future. New maps being produced throughout Europe offer an important tool in this respect. Their use and application is highly recommended.

Adjust and adapt to increasing flood risk uncertainty

We need to prepare for more frequent major events, including some that might be more intense than those seen in the past. Small watersheds in particular might see more frequent events with return periods that normally would be 100 years or greater. But even where large watersheds are concerned, we are still far from potential 'worst-case' scenarios. The most intense rainfall based on what is physically possible has yet to occur. Thus, we have not yet witnessed the most severe flood events possible. A study by Rudolf and Rapp (2003) highlights the fact eastern Germany could potentially receive up to 375 mm of rain in 24 hours and 445 mm in 72 hours. In Bavaria the level could reach 800 mm in 24 hours and 1,340 mm in 72 hours – approaching or even exceeding the typical amounts of total precipitation in certain cities over an entire year, as comparisons with annual averages show: Zurich (1,031 mm average annual precipitation), Munich (805 mm) and Berlin (500 mm)!

Adopt new technology and ideas to protect levees

Some levee failures can be avoided, while others cannot be. If we do not start implementing new and available technologies now to anticipate likely levee failures we could experience much greater consequences from levee failures in the future. New technologies include using probabilistic levee failure models and modern, non-invasive technologies to 'see' into a levee to assess its condition. We also need to plan ahead to better anticipate how we could intervene during a levee breach. The best approach is to avoid levee failures, or anticipate them at an early stage. Strategies can be put in place to determine how to intervene to avoid a breach that would have unacceptable consequences.

[29] http://www.climatechange2013.org/images/report/WG1AR5_SPM_FINAL.pdf

[30] http://www.knmi.nl/cms/content/114016/central_european_flooding_2013

Increased importance of protecting valuables, assets and property

In the next major flood, the hypothetical 'Flood of 2023,' it will be important that individuals are adequately protected and insured. One reason is that state governments are now pulling back from offering full reimbursements. In 2002, many of those affected received 100-percent compensation from a relief fund. This offers no incentive to improve flood resilience. One indicator of that, based on what we learned on-site, is that losses in subsequent events were often higher. By contrast, in 2013, compensation was reduced and tied to requirements of reducing potential losses in future floods. When the next major flood hits, compensation for those who failed to make adequate preparation could be significantly lower than after the 2013 floods. Personal property and valuable assets that cannot be moved need to be made more flood-resistant, and those that can be moved should be taken out of harm's way.

Increase accuracy and reliability of forecasting, take pre-emptive action

In the next decade it seems reasonable to expect that rainfall and flood forecasts will continue to improve due to increased computer power, improvements in technology and better models. This would allow for better advance warning systems and allow those making decisions to be in a better position to respond or take the right actions. Investments are needed in technology and related areas, such as increasing the density of rainfall and river gauge measurements and improving the reliability of these during extreme flood events (in 2002 and 2013, many river gauges failed or were destroyed by the flood). Investments already being undertaken should be continued. This will also help to better understand our changing environment, new or changing weather patterns and how to interpret them to understand the likely consequences.

More investments needed in maintenance and monitoring

Investments in maintenance and monitoring of flood infrastructure are also important when floods are not imminent. This is increasingly urgent. The more levee kilometers built, the greater the budget required for maintenance and repairs. There is a risk that budget will be allocated for new investments for urgently-needed new projects, but not for the increasing expenditure to maintain existing structures. The 2013 flood showed that with proper planning, design, construction and maintenance, flood protection can work well. However, if the work is not done to maintain and strictly monitor structures, performance will not meet the standards envisaged by the designers. If that is the case, some of the flood protection systems can be expected to fail in the hypothetical 'Flood of 2023'.

Upstream/downstream relationships need to be better understood

Upstream/downstream relationships need to be given more consideration in research and analysis. How levees and other flood control systems affect flooding downstream is still subject to much debate. But each flood event is unique and needs to be analyzed as such. It is difficult to generalize that, for example, levee failures upstream significantly reduce the volume of water causing floods downstream, as a flood propagates through a complex river system with additional sources and non-linear effects. But a better understanding of the upstream-downstream interdependence is needed before those involved are willing to trust solutions that might be proposed.

Science can close an existing gap in this regard by studying in greater depth how retention upstream affects water levels downstream under a variety of conditions. This would help to ensure retention areas are identified and built where they are the most efficient. It will also help us to understand how water outflow (from retention, levee failures, etc.) influences the situation downstream. This must be separate from other influencing factors, such as inflow from tributaries and the simultaneous arrival of flood crests from those tributaries.

Identify and protect key infrastructure

We have described how key infrastructure was affected in the 2002 and 2013 floods, and how close some of these (lifelines such as major roads, railways, power distribution or water treatment) came to a collapse. In Europe, we have escaped major, far-reaching and cascading problems that might have unknown consequences – such as the tragic situation in Fukushima. At least – so far. We know from examples of the recent past that such occurrences can and do happen. If we continue to ignore those risks if failure occurs, the consequences may be truly devastating. Therefore we need to identify, assess and improve the way we manage risks that could affect critical infrastructure.

Learn from the 2013 floods and profit from the knowledge to prepare for the 'Flood of 2023'

If knowledge gained from previous floods is not studied and no conclusions are drawn, valuable insights will be lost, which could be used to better equip governments, communities and individuals to face the next flood. Every flood is different and provides new insights. Working together, authorities and researchers can examine the evidence and make better recommendations in the future. Among those who especially benefit from sharing lessons learned and best practices are authorities controlling reservoirs and lakes, those managing polders, and those who design and implement flood protection. Political decision-makers and zoning boards would also benefit from having flood maps that more accurately depict those areas endangered by floods, which zoning regulation and building codes need to take into account. They should also determine which protection level, such as a 100-year return period, is right for communities. Analyses should also take into account the interests of different groups. Discussions and exchanges between experts, national, state and local authorities, and between different countries are an important part of this process. Flood conferences provide forums for discussions and should be held among different states as well as within states.

A flood gauge in Landshut's 'Flutmulde.' Normally on dry land, when floods rise to a certain level on the gauge, water is diverted out of the Isar.

Every flood event has a set of parameters or characteristics that make it unique. Although general laws of nature and how floods work stay the same, the way in which different aspects interact (severity, intensity, duration, etc.) give each flood individual characteristics. Knowledge and experience are absolutely critical to learn about, and take action necessary to prepare for future floods. Detailed analysis and reports on every major flood event at local, regional and national levels is needed to ensure that lessons are communicated and disseminated. This is especially true for areas where floods are rare. Knowledge and education are needed for the benefit of future generations, otherwise the abilities needed to cope with the next flood event will be lost.

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About Zurich

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About Zurich's flood resilience program

In 2013, Zurich launched a global flood resilience program which aims to advance knowledge, develop robust expertise and design strategies that can be implemented to help communities in developed and developing countries strengthen their resilience to flood risk. To achieve these objectives, Zurich has entered into a multi-year alliance with the International Federation of Red Cross and Red Crescent Societies, the International Institute for Applied Systems Analysis (IIASA) in Austria, the Wharton Business School's Risk Management and Decision Processes Center and Practical Action. The cooperation brings an interdisciplinary approach to flood research, community-based programs and risk expertise to generate a comprehensive framework to how community flood resilience can be improved while enhancing the public dialogue around flood resilience.

Zurich Flood Resilience Alliance

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Acknowledgements

We would like to acknowledge the contributions from Ian McCallum, Ecosystems Services and Management Program (ESM), and Reinhard Mechler, Deputy Director of Risk, Policy and Vulnerability, both at the International Institute of Applied Systems Analysis (IIASA) in Laxenburg, Austria. Thanks go also to the following for their support in preparing this publication:

Jörg Adler, Architekt, Büro Adler

Axel Bobbe, Betriebsleiter Landestalsperrenverwaltung des Freistaates Sachsen

Rainer Elze, Stv. Referatsleiter, Landeshochwasserzentrum, LfULG Sachsen

Jan Haaf, Leiter Technische & Sach-Versicherungen, Bilfinger Corporate Insurance Management GmbH

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Photography

All photographs by Michael Szönyi.

Cover photo comparison: The location affected by the Elbe levee breach in June 2013 and the same location revisited in April 2014.

137510A01 (05/14) ZCA

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