CH EF

Cultural Heritage Protection against Flooding

Miloš Drdácký, Luigia Binda, Insa Christiane Hennen, Christian Köpp, Luca G. Lanza and Rosemarie Helmerich

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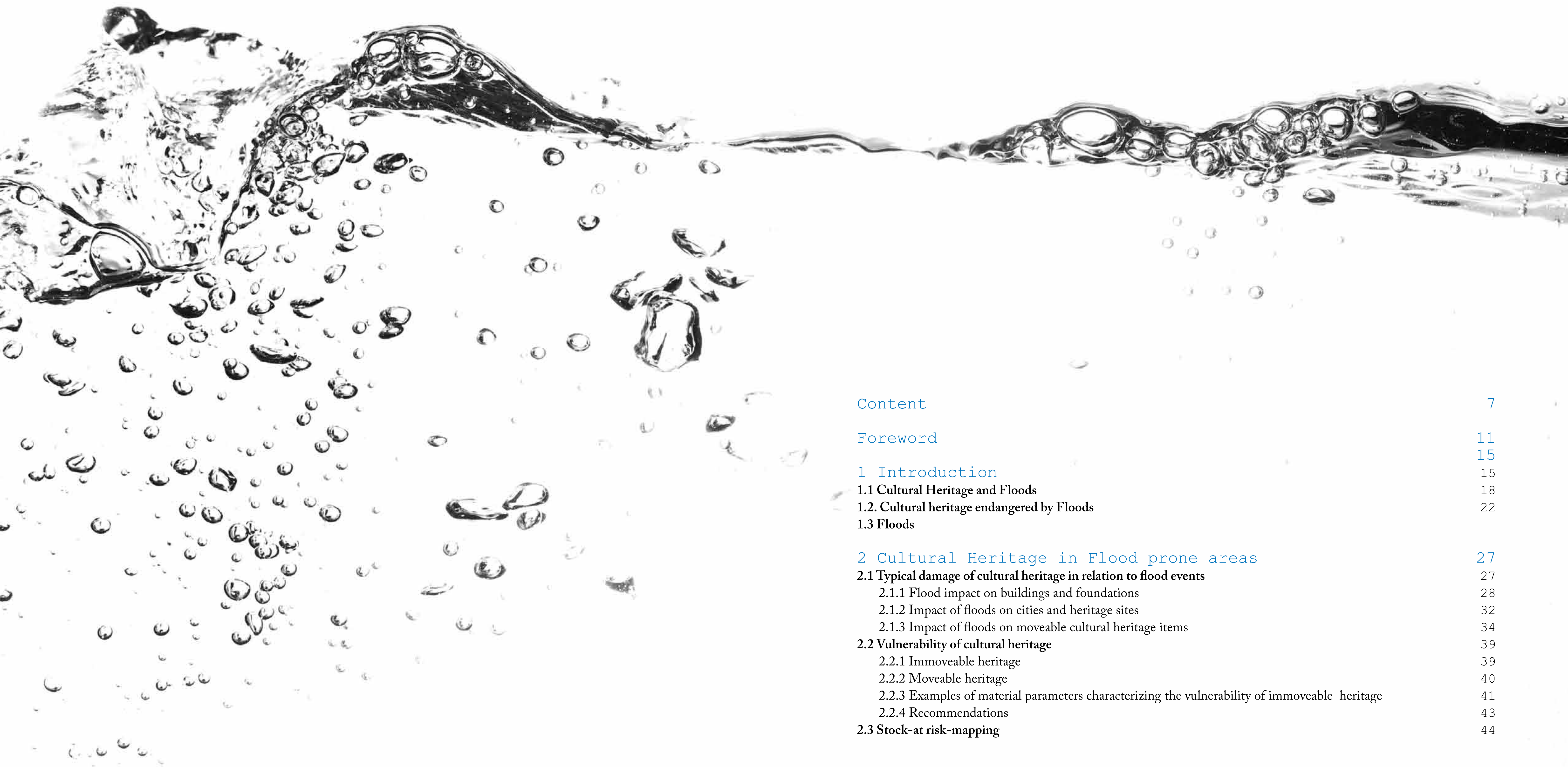
Content



Foreword

Figure 0.1:Dresden, Zwinger during the flood in 2002. Source: CHEF.

The European Commission funded the CHEF - Cultural Heritage Protection against Floods research project in the 6th Framework Programme between 2007 and 2010. This project had been supported, because it proposed to connect flood protection and monument protection. Up to now the particular demands and requirements of cultural heritage have only been considered in flood management plans to a limited extent. Although a lot of knowledge about flood protection is available and although much experience has been acquired in recent years, still there is a lack of strategies for dealing with cultural heritage objects, because, due to their uniqueness, conventional protection measures often cannot be applied.

According to the European Floods Directive 2007/60/EC on the assessment and management of flood risk, released on November 26th 2007, the Member States have to identify areas that are potentially at significant flood risk. The threat to human health, to the environment, to infrastructure and property, including cultural heritage at risk in these areas, has to be made visible. Flood hazard maps (showing the likelihood and the flow of the potential flooding) and flood risk maps (showing the impact) must be available in all EU-member states by December 20th 2013.

These maps help to set up appropriate flood risk management plans (showing measures to decrease the likelihood or impact of flooding) and to take adequate and coordinated measures to reduce this flood risk. The European flood directive also protects the right of the public to access this information and to contribute to the planning process.

National countries and National Federal States have introduced flood warning systems with web-based information, but the risk for cultural heritage is usually poorly (superficially) included, although it was explicitly mentioned in the flood directive.

For the protection of cultural heritage objects in flood-prone areas it is important to analyse the surrounding of the object, and to consider the topography, the hydrological and morphological characteristics of the environment. It is necessary to be aware of the presence of flood plains and retention areas and to know the effectiveness of the existing artificial flood prevention infrastructure. For areas with a significant potential flood risk, plans (flood risk and flood hazard plans) must be available, which also show the specific vulnerability of cultural heritage objects, a characteristic which is very difficult to determine.

CHEF provides knowledge about flood protection of cultural heritage objects and directly supports the European Floods Directive by giving recommendations on how to assess the vulnerability of monuments. A comprehensive analysis of protective measures BEFORE, DURING and AFTER a flood has been carried out within the project, including technical and administrational measures. An overview of these measures is given, followed by recommendations on how to establish the most effective protective strategies.

The book “CHEF Cultural Heritage Protection against Flood” summarises the available knowledge and shows in a comprehensive series of case studies, which kind of protective measures have been taken during recent flood events and if they were successful or not. It shows very clearly how different the flood situations were and how careful protective measures have to be chosen. Furthermore it will become clear that flood protection is not at all restricted to the use of technical means during a flood. The most effective flood protection happens before the event and the key to successful flood management is awareness and preparedness.

The book shows how to identify and analyse flood risks. In order to avoid or mitigate flood damage to cultural heritage objects, many factors have to be considered, including the historic significance and context of the object, its building structure, its location in a risk area, and its vulnerability to floods. The risk can only be assessed if the flood characteristics of the different types of floods are known.

It helps to analyse and classify damage to historic materials, structures, buildings and sites. It is necessary to describe typical damages in an attempt to evaluate the severity of the observed damage and to select the most suitable and effective restoration methods. One chapter of the book includes an analysis of the damage processes in different materials, structures and sites (static and dynamic loading, mechanisms of moisture and salt transport, effects of contamination, erosion, etc.).

The book assesses preventive, emergency and after-flood measures (technical and administrative). In the project a compilation of existing regulations and laws was set up and an analysis of national emergency management has been carried out. Conventional restoration and repair techniques for materials, movable heritage, structures and sites have been described and evaluated according to their effectiveness.

Figure 0.2: CHEF consortium Kick-off Meeting in Brussels. Source: T. Drdácký.

A large number of case studies for cultural heritage objects including buildings, cities and landscapes is included in the book. Various representative cultural heritage objects have been investigated in various ways. The aim of the investigations was to find out, what happened during the flood, which damage or loss occurred, which countermeasures have been successful, and what can be learned from the experience that has been gained. A lack of documentation, unspecified structural condition and assembly, unknown material characteristics and unknown flood parameters often lower the effectiveness of the case study. The analyses of the different cases have shown what kind of information should be available in order to set up appropriate emergency management.

Many recommendations on flood protection have been derived from the analysis of the case studies. Together with the scientific results achieved in the project the authors have compiled a large amount of information and provide an overview about preventive measures before, during and after flood.

1 Introduction

1.1 Cultural heritage and Floods

Miloš Drdácký

Throughout human history, floods have been very important phenomena with negative, and sometimes positive, impacts on cultural heritage Floods lead to the loss of historical monuments, to devastation of sites and changes in the cultural landscape, and also to the disappearance of intangible heritage. In recent years we have witnessed an increased frequency of major floods and related events that pose a substantial threat to cultural heritage worldwide. Let us mention the floods in Central Europe in 2002, the New Orleans flood in 2005, and numerous floods in South Asia in 2007 and 2009. Recent experience of major floods has provided very sound and solid background knowledge and experience about the impact of flooding on historic objects and sites, and can serve as a basis for establishing guidelines and recommendations for effective protection and safeguarding of cultural heritage in emergency situations.

River floods are considered to be the most common type of natural disaster in Europe (EEA, 2004). There are studies pointing to a significant increase in the frequency and severity of river floods due to some hypotheses about the possible development of global warming (Ciscar 2009). Other studies however lead to opposite conclusions (see e.g. Lindzen 2005), arguing that the same hypotheses would result in less intense rain and flood events. The JRC PESETA report (Projection of Economic impacts of climate change in Sectors of the European Union based on boTtom-up Analysis) provides an estimation of the threat to densely urbanised coastal regions posed by a possible rise in sea level. Although these works typically focus on the impact of floods on human life and housing, and on the productive infrastructure, there can be no doubt that the damage would be significantly increased by the loss of cultural and natural heritage assets. The results and conclusions of these studies will probably influence EU policy in developing adaptation strategies to mitigate possible adverse climate change effects. These adaptation strategies should include appropriate measures and tools for safeguarding cultural and natural heritage. The final report of the European Commission funded 6th Framework Programme NOAH'S ARK project included several recommendations. Even in the absence of any climate change, the loss of cultural and natural heritage assets should be considered as a relevant risk in any flood management strategy.

The supra-national nature of the problem provides an opportunity and space for effective world-wide collaboration. The recent Hoi An Declaration can serve as an example for our future endeavour. It expresses the need for collaboration very well in the chapter on Reducing Disaster Risks for Historic Districts through a Coordinated Strategy of Risk Mapping, Community Training and Appropriate Technical Interventions: *Over the last decades and increasingly with the scientific development over global climate change, a strong international consensus has been reached to reduce the risk of disasters resulting from natural phenomena* *or human activities, including the risk to cultural heritage. As a result, authorities need to ensure that historic districts are given proper attention in disaster management and in post-disaster reconstruction schemes at the personal, local, regional, national and international levels. Conservation strategies for historic districts and their individual heritage structures or facilities must include measures to prevent losses before, during and after a catastrophe. Identifying risks provides an opportunity to engage the community alongside experts and institutions. Traditional knowledge and methods for preventing disasters, including traditional land, water and forest management systems, should be documented, shared and used in conservation as well as in new constructions.*

State support for remedial actions in the face of a range of disasters related to cultural heritage rely on close cooperation among those directly involved with cultural heritage objects, the police and fire services, and in major disasters, the army. Various legal documents support such an approach on a national level, following the principle of subsidiarity. Preparedness to respond to natural disasters is solely in the hands of, and within the responsibilities of, the individual states, which can ask for help or assistance from the European Community in Europe. However, the capacities built up in each of the Member States might be advantageously used in an emergency situation in other EU or non-EU countries. Numerous EC legal documents and recommendations support such international assistance.

Any decision about future strategies and measures to protect cultural heritage against the effects of natural disasters must be justified by reasonably reliable knowledge of the European cultural heritage stock at risk. The situation in this field varies significantly from country to country in Europe, and is strongly dependent on the level of national information systems and technology. The few existing databases are fragmented and incomplete, and do not contain some of the information that is essential for natural hazard risk assessment processes and risk management approaches and tools. In addition, the databases are not standardized, harmonized or coordinated for effective exploitation when combatting disasters. Immoveable cultural heritage is mostly listed and registered in inventories without systematic geographical positioning, without a technical description of the materials and structures, and without information about its current state, all of which are decisive for its vulnerability to adverse natural actions. A standardized GMES-supported (Europe's Global Monitoring for Environment and Security) and constantly maintained European cultural heritage stock database that can monitor changes in sensitive cases would provide invaluable and unprecedented support for planning measures to reduce the impact of natural disasters on European Heritage, and also for targeted operations by rescue teams.

Similarly, there are only incomplete maps of potential natural hazards related to cultural heritage throughout Europe. Only mapping of flood hazards receives some support in the EU Directive on the Assessment and Management of Floods. In order to make an assessment of the risks and to predict the extent of catastrophic events, it is essential to have maps of the European cultural heritage stock at risk, related to maps of natural hazards and potential threats. Such essential information is lacking over most of the territory of Europe. The newly-planned European remote sensing and global positioning systems will make it possible to monitor the data necessary for modelling adverse situations and giving an early warning. Together with *in situ* monitoring, this will substantially improve the function of preventive and operational measures in Europe.

National governmental bodies have issued guidelines and national action plans for combatting various types of natural and man-made disasters, including floods. These are mostly legal documents, and usually reflect situations that lie within the responsibility of one of the Ministries. The logistics of dealing with disasters are not addressed, nor is cultural heritage frequently mentioned. Similarly, international bodies and institutions have tended to publish general declarations and guidelines in which cultural heritage is not properly treated. The specially created International Committee of the Blue Shield (ICBS) suffers from lack of adequate funding and difficulties with effective coordination with international and national agencies responsible for disasters. The ICBS tends to operate within the framework of some of the funding bodies, namely ICOM and ICOMOS.

Generally, cultural heritage protection is treated as a marginal issue by politicians and governments in most European countries. Cultural heritage tends to be eclipsed by environmental issues, which attract greater political attention due to their close relation to health and nature conservation. The importance of cultural heritage is not always well articulated, and it receives little support from the media.

This book does not itself deal with these shortcomings and deficiencies. It aims to help the local authorities, cultural heritage owners, managers or users, and also rescue teams not experienced in the field of conservation, in their efforts and actions to reduce or eliminate damage and loss of cultural heritage assets in flood situations. It publishes many results of the CHEF (Cultural Heritage Protection against Flood) joint European research project that can help professionals to assess damage, to increase the safety and reliability of partly damaged buildings and structures, and to design preventive or protective measures.

Figure 1.1.1 Historic city center of Dresden and the Elbe valley during the flood in 2002, Photo: CHEF

Although individual actors play a very important role in safeguarding cultural heritage in public, private and family collections, the key role of coordinated and concerted actions should not be overlooked. For example, the Central European floods in 2002 confirmed the crucial role of coordinated knowledge-based crisis management. Loss of cultural heritage assets could have been much lower if many mistakes of human behaviour had been avoided (Jirásek 2003). A real-time road management system based on good mapping of crossings of roads over rivers and in situ data, together with Earth Observation monitoring during flood events is necessary for evacuation operations. In flash floods, water levels rise suddenly and generally in a small area. For example, during the Gard event in southern France in September 2002, more than 200 rescue vehicles were lost on flooded roads. Even a crude assessment of this type of hazard would considerably help Civil Protection services to manage road traffic and to coordinate rescue actions. Blocked roads and blocked access to endangered cultural heritage has been a frequent problem, and has caused many losses due to delayed evacuation or delayed rescue operations. For example, during the 2002 flood in Prague, uncoordinated roadblocks and premature evacuation of citizens and personnel, together with inadequate and inaccurate information, caused much higher losses in museums (e.g. Roztoky 8,5m flooded) and in private archives (family photographs, etc.) in the Troja district (flooded to a depth of up to 7m). Nevertheless, this major flood provided all stakeholders with experience which can be utilized in future mitigation and preventive measures.

The wide diversity of situations, materials and climatic conditions typical for cultural heritage objects and sites prevents any simple generalization of the problems and solutions. This book therefore gives substantial space to presentations of case studies showing good as well as bad practice, and provides the reader with lessons and knowledge that can be applied in similar situations.

The CHEF team would appreciate comments, suggestions for amendments, examples of experience or damage, stories of good or bad practice, or any other feedback from users of the book on the project website www.chef.bam.de .

1.2 Cultural heritage endangered by Floods

Christiane Hennen

Typology of cultural heritage

The term *Cultural Heritage* includes all kinds of objects and ideas connected to past times that bear an outstandingly high value for humankind as a whole, or for private persons. Art objects, documents of political history, of religion and piety, of technical, scientific and cultural development and progress constitute cultural heritage, as do private souvenirs like photo albums or record collections. Besides the material substance of each cultural heritage object there is generally an intangible component: the objects bear in remembrance persons, experiences, events and achievements from former times. A historic castle documents the technical standard of the time when it was built (and maybe later changed), and also the ideas of potency and representation of its owner. Its masonry and timber works stand for the abilities and motions of craftsmen who lived centuries ago. The origin of the wooden beams as well as the stones which were used can provide an impression of the economic networks of a historical period. The sequence of rooms gives an impression of the life carried on in this location until the present time.

Cultural heritage objects can be divided into moveable items, e.g. paintings, sculptures and archive materials, and into immoveable items, e.g. churches and houses. Cultural heritage sites cover a wide range of different objects:

- landscapes with roads, bridges, woods, vineyards, rivers and channels,
- towns and villages with town walls and historic streets and squares,
- single buildings (including their immoveable and moveable furnishings),
- archaeological sites,
- parks and gardens.

Figure 1.2.1: Pillnitz Castle during the Elbe flood in 2002. Source: CHEF.

All cultural heritage objects are characterised by an individual uniqueness. Their loss cannot to be compensated, they are irreplaceable. Damage to these objects generally means the loss of parts of their value. On the other hand, their specific uniqueness is often the reason for the high level of empathy people feel towards such objects, which are important identification points. This factor is not only to be considered in the case of masterpieces of art but also when thinking e.g. about the simple and normally imperfect timber frame or wooden houses which are found in various styles in the villages all over Europe. Many people associate feelings of home with these traditional buildings of everyday life; they feel familiar with them.

Figure 1.2.1: Flooded Elbe valley with the Semper Opera House in the historic city center of Dresden in 2002. Source: CHEF.

Settlements near water

Many cultural heritage sites are intentionally closely related to water (see D1.4). Cultural landscapes such as the valleys of the Rhine or the Danube or the Dessau-Woerlitz Garden Kingdom (Germany) are also part of the natural heritage. Exposed places have been chosen for outstanding buildings, for example close to waterfronts. Especially the architects of the renaissance and baroque period often played with the mirror effects of the water in front of a church or a palace. The masters of landscape gardening followed the philosophy of upgrading nature when they were trying to avoid big changes to the "wilderness", and to get by with small corrections – an attitude similar to the opinions on education of the teachers of the enlightment. Various art concepts from the ancient world dealt with the four elements: air, earth, fire and water.

Manifestations of the "simple life" are also closely connected to water. There is no human life without water. The fact that the witnesses of ordinary life are often not adequately appreciated explains the loss of many of these objects in the event of a flood.

Floods are a natural phenomenon. For centuries, users of buildings in flood-affected regions lived with the fact that the cellars of their houses were periodically submerged. Smaller or more costly maintenance measures had naturally to follow the spring or autumn flood. Today the management of cultural heritage objects, which are often primarily seen from the touristic and economic point of view, does not reflect these everyday necessities. It appears that a slight change of attitude toward historic buildings and simple measures in these directions – a suitable use and the acceptance of some "natural" limitations – can in some cases be more useful than expensive protective measures. This is for instance to be considered in the case of drying buildings after floods. This can be done either in the "natural" way by airing over a long period of time, or with highly technical efforts to bring down the humidity within a short time period.

Finally, many historic flood prevention measurements are bequeathed, e.g.dikes, which sometimes themselves form part of the cultural landscape, water drains or the use of water resistant materials. These traditional protective measures are often forgotten today, together with historic monitoring instruments like high water marks, which are often placed on the walls of historic buildings. Historic water levels can be regarded as threshold levels: the buildings survived these floods. They are documents of the possibility of living with periodically recurring floods.

Cultural heritage : typical flood damages

It is to be noted that cultural heritage objects mainly consist of materials susceptible to moisture. Therefore they should not come into contact with water at all. At this point, all possible forms of flood protection and damage mitigation come into the focus, especially flood plans with integrated cultural heritage assets. In general, all efforts should be made to avoid floods in sensitive "cultural heritage regions". For example, by installing or strengthening dikes, or by providing retention areas for flood water. It is necessary to assess the individual risk of an endangered cultural heritage object on order to develop

Figure 1.2.1: Praha - National Technical Museum – Archives of Architecture. Source: NPÚ Praha.

suitable protection measures and to make a cost-benefit analysis in order to find the relation between the cost of protective measures and the (possible) costs for repairs, if anything remains after the anticipated flood that can be repaired at all.

Immoveable cultural heritage objects are made of a very wide range of materials and combinations of materials:

-Wooden structures,

-Buildings made from stone, brick or clay, normally in combination with mortar,

-Parks and gardens laid out in their specific grounds: on earth of various qualities where specific and exceptional plants are cultivated, sometimes even on artificial islands.

Moveable cultural heritage objects are made of even more varies materials and combinations of materials:

- Stones (often with plaster),
- Wood (often with coloured surfaces),
- Paper (written on with ink),
- Metals,
- Leather,
- Colours (often in several layers),
- Textiles, etc

Accordingly, there are various symptoms and categories of damage resulting from contact with water. The weakest part normally determines the degree of damage to the structure or to the object as a whole.

The following damage classification can be made:

- No damage or failure,
- Destruction, total collapse or failure of a part of an object/building,
- Relative displacement or rotation of a part of the whole object,
- Deformations – elastic or irreversible (deflection, buckling, compression, etc),
- Cracks in structures (including detachment and delaminations),
- Loss of material (corrosion, delamination of plaster and/or colours, etc.),
- Material disintegration (alteration),
- Moisture (capillary, hygroscopic, hydroscopic),
- Biological attack,
- Material or structural heterogeneity,
-Changes in appearance (efflorescence, discoloration, structural change, soiling, etc.),
- Wrong interventions.

These categories are very rough and in some cases overlapping. For practical use in damage description the categories are usually more structured and refined, and are supplemented by typical samples, etc. In the case of flood damage, this rough classification seems to be appropriate, and it is taken into account when ranking structures and elements from the point of view of their vulnerability to flood action (see chapter). This ranking has been suggested within the EC FP6 NOAH'S ARK project, which deals with the effects of climate change on cultural heritage objects. It has proved to be practical for categorising preventive and protective measures.

Bearing in mind the widespread possibilities of cultural heritage objects and the endless number of materials and material combinations that can be affected by floods, and the resulting variety of damages, it is easy to understand that the protection of cultural heritage objects and damage mitigation need to be organised on various levels and within various frameworks. Flood protection in the framework of cultural heritage can mean protecting landscape parks against the uprooting of centuries-old trees as well as preventing the soaking of composite materials, such as books, works of art or even foundations of buildings. Chapter 4 shows several case studies representing various types of cultural heritage objects. These studies include buildings, bridges, parks and gardens as well as art objects like the "Mirakelmann".

More detailed examples are given in the chapters on flood protection (3.1 Before a flood), actions during a flood (chapter 3.2) and measures after a flood event (chapter

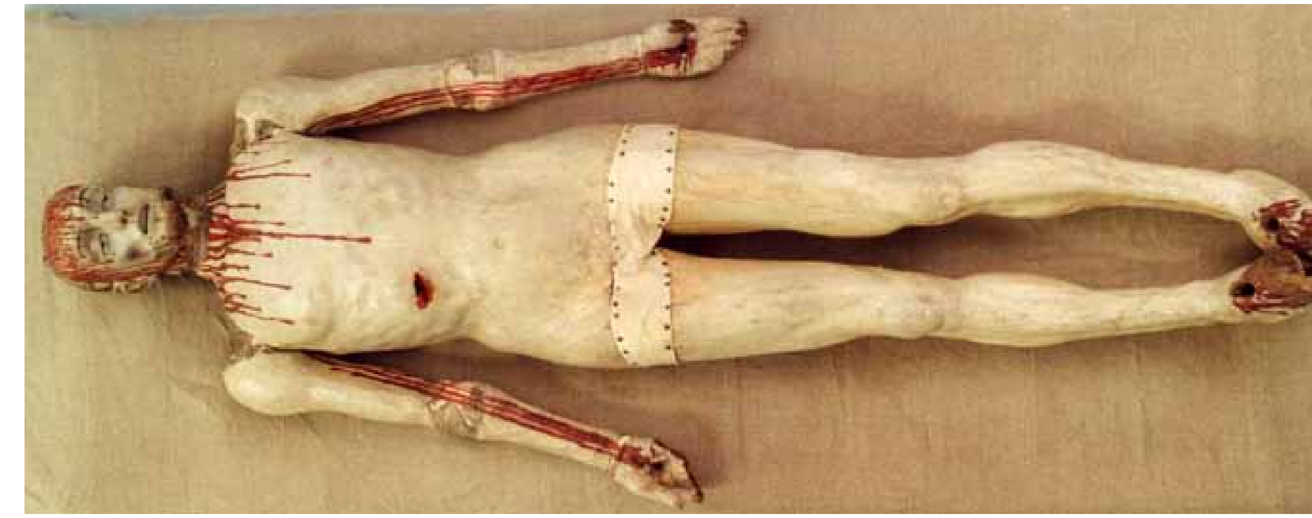


Figure 1.2.3.2: The Mirakelmann (church in Döbeln, Germany) during restoration after a flood. Source: Restauratorengemeinschaft J. Bösenberg, E. Kless und F. Wosnitza

3.3). Some general points are to be considered, though each cultural heritage objects has to be regarded as an individual and singular case.

At the level of EC policy and legislation, it is necessary to integrate cultural heritage into civil protection. Risk assessment and risk mapping should provide a basis for damage prevention. Public and private owners and responsible administrations of cultural heritage objects have raised awareness of the problem. They need financial support for risk assessment and for developing emergency plans. Task forces or networks of experts in cultural heritage matters, e.g. EC MIC, need to be installed and supported. The general public needs information about these networks.

On a national and regional level it is necessary to ensure communication among the various bodies responsible for civil protection and the cultural heritage experts. Understanding the point of view of others forms the basis for developing adequate protective measures. The training of private and public owners (staff) and civil protection relief units can help to prevent losses of unique items in the event of a flood. This training should be carried out by experts in the field of conservation.

Administrative bodies responsible for monument preservation should be enabled to collect data concerning endangered objects before the anticipated flood, in order to make an individual risk assessment and to give advice for protection and damage mitigation. In the same way, it is necessary to exchange experience after a flood event.

It is better to be prepared than to have to carry out repairs and reconstruction work.

1.3 Floods

Luca Lanza

Floods are the most frequent type of natural disaster, and they have an increasingly adverse impact in urbanized areas. They vary considerably in extent and duration. They range from small inland or coastal floods, with only a local impact, to disastrous events affecting large territories and several countries. They cause damage and failures due to static and dynamic loads (water pressure, water flow, uplift forces), impacts from floating objects, wetting of building materials (which is difficult to treat), and the effects of soluble salts, chemical pollutants and biological infection. Though floods are usually of relatively short duration, repairing the consequences can take a very long time and can require enormous efforts. Floods can damage or even destroy historic buildings, infrastructure, cultural landscapes and gardens, and in many cases also moveable cultural heritage.

The term "flood" has been defined in a number of ways, the following definitions being reported by Parker (2000):

- A flood is a relatively high flow which overtaxes the natural channel provided for the runoff (Chow, 1956);

- Extremely high flows or levels of rivers, whereby water inundates flood plains or terrains outside of the water-confined major river channels. Floods also occur when water levels of lakes, ponds, reservoirs, aquifers and estuaries exceed some critical values and inundate the adjacent land, or when the sea surges on coastal lands much above the average sea level (Yevyevich, 1992);

- A flood is a body of water which rises to overflow land which is not normally submerged (Ward, 1978).

The latter most general concept is the one assumed by the European Flood Risk Management Directive (60/2007). A short classification is also provided by the U.S. Federal Emergency Management Agency, which includes coastal flooding (waves greater than three feet, tsunamis, etc.), riverine flooding (alluvial fans, ice jams, etc.), lacustrine (lake) flooding, and water ponding. According to Kelley (1994), this classification omits at least the following further types of floods: mud flows; headwater, storm water and drainage flooding; structural failures of dams and levies; erosion; high water table; sewer back up; expansive soil problems.

Such a variety of flood events cannot be addressed 'at a glance', making no distinction between geographical areas based on landscape geomorphology and on the typical hydrological and meteorological/climate characteristics of the region of interest. Such a 'global' approach would generate confusion, since the characteristics of floods and their space/time scales of evolution differ in different regions of the world. Flooding in Bangladesh or Pakistan, for example, cannot be addressed, for the purposes of flood control and mitigation actions, with the same prediction tools and defence strategies as flooding in the Mediterranean. The morphology of Mediterranean catchments is quite specific, and must indeed be considered in relation to the distribution of urban and industrial settlements. This is what makes the landscape 'vulnerable' to flood events. So-called flash floods, characterised by a rapid rise and fall of floodwaters with peak flows occurring within hours of heavy rain, are typical of mountainous regions. They are quite dangerous for cultural heritage, namely for archives and museums. A rising sea level threatens many areas, e.g. Venice and the east coast of England, and can result in catastrophic flooding.

Although floods are commonly associated in the general understanding with human activities and with land use, it is worth noting that they are basically a natural phenomenon. Floods occur in regions with no human settlements and it is the recurrence of e.g. river floods that determined the present landscape morphology in many areas of the world, with large benefits from the use of valleys e.g. for agricultural purposes. A flood hazard is essentially a natural hazard. It is also true that flood effects in developed areas are greatly enhanced by the human activities, and it can some cases result from the failure of structures or infrastructures developed by man. However, what is really

influenced by human activities in any flood-prone area is the risk associated with flooding – i.e. the exposure and vulnerability of people and property.

The term "flood risk" is an estimation of the expected value of the overall losses (victims, injured, economic and social damages) caused by a flood of a given intensity in a given area. The risk is defined by a combination of three factors: hazard, vulnerability and exposure. The hazard is the probability of the occurrence of a flood that is likely to produce damages in a given place or within a given area, and within a certain period of time. Vulnerability is the probability or degree of losses of a given element at risk (persons, goods, economic/commercial activities) due to the occurrence of a given event. Exposure is represented by the characteristics (consistency, value, position) of the elements at risk that could be either directly or indirectly affected by a hydraulic/hydrological event.

The flood risk largely depends on the population density, the quality of the buildings and the preparedness of the authorities and the population itself to face such emergencies. Comparable levels of risk can therefore be attained in very different situations: e.g. in cases where some low to moderate hazard is coupled with a high level of vulnerability or, conversely, in cases where high hazard levels are associated with slight vulnerability.

Any model developed to perform an assessment of the hydraulic/hydrological risk in a given region should include the following basic elements:

-An estimate of the hydraulic/hydrological hazard,

-Identification of the elements at risk (exposure),

-Derivation of a vulnerability curve for any given element at risk, to describe the relationship between the specific loss and the severity of the event,

-An assessment of the hydraulic/hydrological risk for any element at risk and the related coefficient of relevance within the overall volume of losses,

-An evaluation of the total risk in the region under consideration.

Scientific investigations have largely addressed the flood hazard assessment issue by developing accurate tools for both hydrological and hydraulic modelling, and determining efficient tools for risk mitigation, within a "structural" perspective and a "non-structural" perspective. The assessment of vulnerability and in particular the vulnerability of cultural heritage is less advanced. Vulnerability consists of the likelihood of an "element" (person, good, activity) suffering any damage due to a given hydraulic/hydrologic event; it is therefore a measure of the loss or reduction of efficiency as well as the residual capability to undertake the functions that the element usually undertakes in normal conditions. Vulnerability analysis, however, must also identify and quantify the effects determined by the failure of individual elements on the functionality of other elements. In this sense, direct vulnerability is defined as the likelihood of a single element (building, bridge, settlement, etc.) suffering damages; induced vulnerability is defined as the critical effect generated by damage to or the collapse of a single element over a wider complex; deferred vulnerability is defined as the effects appearing during the post-event phases.

For an appropriate definition of vulnerability it is therefore necessary to identify:

-A parameter able to define a measure of the severity of the hydraulic/hydrological event,

-A parameter able to provide a measure of damages,

-A correlation between severity and damages able to provide a unique evaluation of damages for any given hydraulic/hydrological event.

The main consideration is the action exercised by water on the built heritage (hydrostatic pressure, flow velocity, flow energy or momentum associated with the impact of water on structures, etc.) The capacity of the structures to interact with the flood in a way that will equilibrate the forces and bear the deformations is therefore the central point. Similar prerogatives depend on the quality of the building, the quality of the materials and the geological conditions at the site. Notwithstanding the improved building technologies and the advanced technological tools available for significantly reducing the physical effects on the built environment, especially for avoiding loss of human life, economic losses have been recorded in recent years. This is because the initiatives for reducing the impact of critical events have been partially counterbalanced by the appearance of new sources of vulnerability due to inappropriate land use (e.g. settlements developed on alluvial deposits due to lack of space and easy communications/connections) and the installation of highly vulnerable infrastructures that have a strong impact on the economic-productive sector if they collapse.

The risk of flooding is characterized by various typologies according to the principal causes of the presence of water over urbanised areas, the characteristics of the water flow (velocity, depth, duration, etc.) as well as the "technical" reasons why the natural/artificial drainage

Table 1.3.1: Residual probability r [%] of events with a given return period T over various life-spans L from 5 to 100 years.

T [years] \ *L* [years]	5	10	20	50	100
50	9,5	18,1	33,0	63,2	86,5
100	4,9	9,5	18,1	39,3	63,2
200	2,5	4,9	9,5	22,1	39,3
500	1,0	2,0	3,9	9,5	18,1

system was not able to convey the storm waters adequately and avoid critical hydraulic conditions. Kelley (1994) – following the experience gained after the Mississippi flood in the US Mid West in 1993 – proposes that we categorise the nature of flooding and its impact on structures as follows:

- Standing water. This is a common form of flooding that occurs at a historic site. Standing water may cause entire buildings to be soaked, filled with sediments, and subjected to fungal growth.
- Flowing water. It can cause much of the same damage as does standing water. In addition, structures can be subjected to soil erosion, scouring, lateral displacement, and movement of building frames off of their foundations (This was the most dramatic damage produced by the Mississippi flood in 1993).
- Water seepage. With this type of flooding, the water level in the soil rises though actual standing water never reaches the structure. The consequence is water seepage into the basement, rising damp, and problems with hydrostatic pressure on foundation walls.

Floods have a number of measurable characteristics (Parker, 2000), of which flood depth or "stage" (i.e. height) is the most common. Flood depth has direct consequences for humans. Low velocity floodwaters 1 m or more in depth are usually considered to be a threat to humans, and urban flood damage has been found to correlate with flood depth so that depth-damage relationships may be plotted (Penning-Roswell and Chatterton, 1977). Flood discharge is another common index of flooding and provides the basis for most methods for predicting flood magnitude. Flood duration also has effects on flood damages. Rainfall-runoff lag time is a measure of the time between the beginning of a rain event and the peak of flooding. Where the lag time is short the flood may be described as "flashy", as discussed above. Flood damage is also associated with floodwater velocity. Floodwater less than a metre in depth can present a serious risk to humans if the water is flowing fast, and floodwater 1 m in depth flowing at 1 ms-1 can be very destructive to property.

Flood frequency is a statistical measure of the probable occurrence of a flood of a given magnitude, and is a common measure of flood hazards. The return period T [years], namely the expected value of the period of time between two subsequent occurrences of events of the same magnitude, is often used in order to quantify this probability. In Italy, for example, the delineation of flood prone areas for the purposes of planning and regulation is based on an estimation of the areas flooded in the case that an event with T = 50, 100, 200 and 500 years should ever occur (note that a once-in-a-hundred-year flood has a 63% residual probability of occurring at least once in a life-span L = 100 years, and about a 20% residual probability of occurring at least once in L = 20 years – see Table 1.3.1).

The solid content of flood waters is also variable and has implications for flood losses. For example, floods with a high sediment, mud or debris content provide additional damage mechanisms. Sediment and mud may bury buildings and people, and debris (e.g. boulders, trees, etc.) will cause additional impact damage. Contaminants are a further source of flood damage. Coastal or seawater flooding contains salt, which can damage flooded buildings by creating damp conditions even years after the event.

The type of action exercised by water on the built heritage and the elements of the buildings that can be subjected to significant damages are the relevant characteristics of the flooding phenomenon. The main parameters can be identified as follows:

- Flow velocity,
- Depth of water outside/inside the structure,
- Residence time of water inside the structure,
- Chemical factors due to the water quality,
- Quantity and size distribution of the materials transported by the flow.

Flow velocity is able to induce serious damage to a building and to produce structural settling because of the soil erosion in the vicinity of the foundations. The suspended solid materials transported by the flow contribute highly to structural damages, producing direct erosion at the base of the piers or walls of the building, and also mud depositions. The water depth reached in the vicinity of the building and the residence time contribute not only to direct damages due to wetting but also to the presence of humidity. Rising humidity is an important consideration. It is a function of the residence time of water in contact with the structure and the structural characteristics of the building materials of walls. The same type of water impact can produce very different damages according to the building material.

Unlike other types of hazard (e.g. seismic hazards, where the intensity of the earthquake can be assumed as a suitable parameter for a single building or even a town), in the case of flood hazards the characteristics of the action of the water on the buildings can be rather variable, even for the same event and within the overall flooded area.

Aimed at identifying the severity of a given hydraulic/hydrological event, a measure is required for the effects produced over categories such as the natural environment, structures and people. A conventional scale can be introduced based on a qualitative and only partially quantitative description of damages, allowing a discrete intensity value to be assigned to the event under investigation. This methodology, based on simple and direct observation of the effects of a specific event, does not need any particular instruments or skills for the on-site surveys, and also allows past events to be taken into account, provided relevant historic documentation is available. Whenever possible, specific analytical investigations may provide better information.

The conventional scale can be created as a function of two parameters: on the one hand, by identifying the various structural typologies of the existing assets over the examined territory, with appropriate reference to the materials and building characteristics that may influence the response to hydraulic events; on the other hand, by defining a few vulnerability classes, each of them including a set of assets not necessarily belonging to the same building typology but rather presenting the same behaviour as a consequence of the hydraulic events. In this way, assets belonging to the same typology may be ascribed to different vulnerability classes also as a consequence of specific factors, such as the state of preservation and the peculiar building characteristics, or the presence/absence of elements aimed at defending/mitigating the effects of a given hydraulic event (micro-structural flood-proofing interventions). The relationship between the asset and the vulnerability classes can also be stated in probabilistic terms, so that a given typology does not exactly fit a single class, but rather a set of classes determining a range of vulnerability.

Unlike other natural hazards, e.g. seismic hazards, the definition of objective parameters for a vulnerability assessment of the historic-architectural heritage against flood hazards is quite complex, due to the specific features of the phenomenon and their high spatial and temporal variability. This is especially true in densely urbanised areas, where it is difficult to establish the hydrodynamic modalities of flood propagation and the related effects on the built environment.

2 Cultural heritage in flood-prone areas

2.1 Typical damage to cultural heritage in relation to flood events

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Flooding can damage architectural heritage, historic infrastructure consisting of individual structures, buildings and objects, as well as objects of art standing alone or firmly attached as an integral part of buildings. All these objects are subjected to various forces and actions during flood situations. These forces can be categorized according to the types of damage that they can cause: horizontal static pressure of raised water, upward hydrostatic pressure, dynamic low velocity streams, dynamic high velocity streams, dynamic impact of waves, dynamic impact of floating objects, compacting of soils or infill, changes in subsoil conditions, saturation of materials with water, contamination of materials with chemical and biological agents, formation of barriers, ice floes, and post-flood effects. These typical actions may occur in combinations and work in synergy.

Damage to cultural heritage can occur on various scales: on rather small, movable archive museums and art collections as well as on buildings, historic or archaeological sites, gardens, parks, waterworks and entire landscapes (see Fig. 2.1.1). Damage to immovable cultural heritage due to flooding certainly exhibits manifold facets, but also common features that can be classified for the purposes of better planning of preventive or remedial strategies and measures for safeguarding the built cultural heritage. The same basically applies for water-induced deterioration of movable cultural heritage items, which are usually fragile and composed of a variety of different materials. In the following, only material and structural effects are discussed. The social impacts and problems and failures of administration and management are touched on elsewhere, as they are better identified in relation to preventive measures or case studies.

The authors' experience and the data gathered in the damage catalogue on historic structures and sites (see Annex 7.2), supported by a digital database, indicate that flooding causes widespread damage to architectural heritage. In many cases, direct flood damage leads to further damage later, and failures can result from processes generated after a flood. This chapter presents the most important phenomena, illustrated by examples gathered during historical or recent floods, see e.g. (Drdácký 2010).

Figure 2.1.1: Flooded heritage site at the Dresden Zwinger (left) and landscape around Pillnitz Castle (right), Elbe flood 2002. Source: CHEF.

2.1.1 Flood impact on buildings and foundations

Horizontal static pressure of raised water

The horizontal static pressure of raised water creates loads proportional to the height of the water, and can damage or even destroy lightly-constructed shutters of openings in buildings, for example, doors and windows, especially glazing, and this may facilitate other and more severe damage. However, horizontal static pressure is dangerous above all for long free-standing walls and fences, where the load acts non-symmetrically and can be intensified by the dynamic action of streams and flows. Raised underground water increases the soil pressure on basement walls if water penetration into the basement space is delayed. This phenomenon may also be observed on retaining walls. This action typically causes a total failure of walls or excessive deformation of plate-like structures (e.g. glazing) with well-articulated plastic hinges. Shifts of small structural elements may be observed, as well as cracks around the supports of heavily-loaded, well-anchored structures. For example, a baroque wall around the church in Zöbing and the terrace walls of historical vineyards in Wachau (both Austria) were destroyed by water pressure (Kohlert and Huber 2002). A garden wall of Wesenstein Castle in Saxony (Germany) collapsed during the flood in 2002.

Upward hydrostatic pressure

Upward hydrostatic pressure raises all moveable objects in interiors, and typically unhinges doors, which can float away or can create barriers in interiors or block other doors. Upward hydrostatic pressure raises floors, roofs and whole objects, decreases their stability against overturning and facilitates damage to them by horizontal forces. Together with flow forces, it can move historic objects long distances from their original positions. If the danger of such a state is approaching, flooding of the basement can counterbalance the uplift force. It also causes water penetration through sewerage systems into areas protected by vertical flood barriers or structures and areas where there are floors below the surrounding high water level. This kind of action is especially dangerous for urban areas. In buildings and open spaces, pavements, especially wooden pavements, or floor structures are frequently distorted and repositioned by upward hydrostatic pressure.

Low velocity stream action

This type of action is typically observed inside closed buildings, where floating objects move and are displaced, e.g. furniture is moved from one room into another, and in many cases overturned due to a synergetic effect of raising unbalanced objects. Long-lasting flood action can even wash out subsoil or clay mortar from masonry. Low-velocity movement accompanied by quite high horizontal forces and pressures is typical for ice floe dragging. Ice floes transport floating objects and create barriers. This phenomenon substantially impacts the geotechnical conditions and may cause severe damage due to the formation of caverns or additional subsidence.

Dynamic high-velocity stream action

Irrespective of the volume of water transported, high-velocity streams can have an extremely dangerous impact on structures. They can be generated when water under high pressure emerges through a small opening, as in the case of Chateau Veltrusy, where water jetted through a single broken pane of glass in a window into a house and excavated a hole approximately 150 cm by 200 cm in a 60-cm thick adobe wall. High-velocity streams typically damage the banks of river channels, and are responsible for most of the severe damage to bridges, and also to earth structures (e.g. dams), and to masonry weakened by joint mortars and individual stones being washed out.

Undermined foundations of piers inside a river and also on the banks have been the most frequently recorded failures observed on large historic bridges during disastrous floods. They mostly occur when the waterway under the arches is obstructed by floating barriers of ice, wood or other materials and objects. This raises the velocity of the stream along the river bed, and turbulence washes out the subsoil layers and undermines the piers. Bridges founded on piles or directly on rock are usually less heavily damaged than those standing directly on gravel without piled grids, unless they have been provided with protective walls. In all recent repairs of historic bridges, protective walls are added.

Historic parapet walls also suffer from this type of loading. They are usually quite high, because they were built and used for defence purposes. For example, the early medieval Queen Judith Bridge in Prague had parapet or “breast” walls 2 metres in height and 30 cm in thickness. The original Charles Bridge had walls 160 cm in height. In very heavy floods, the waterline reaches levels some way above the deck of the bridge, and the parapet walls are too weak to sustain such dynamic pressure. Fig. 4.4.1.1 in Chapter 4 shows a typical case of the collapsed parapet walls of the medieval bridge in Písek (Bohemia). Here the wall ashlars were saved from the river after the flood and were used for reconstructing the parapet wall.

Dynamic impact of waves

Wave impacts are typical for sea storm or river flash floods, and they can destroy or displace whole structures and objects, e.g. small buildings or sculptures in valleys. This phenomenon is also dangerous for boats and ships in historic towns. When a flood wave strikes a building, a part of the structure is usually cut and transported away, or the house partly fails. During flash flood events, bridges are typically destroyed and bridge elements are swept away, above all on small rivers or brooks.

Dynamic impacts of floating objects

Dynamic impacts of floating objects mainly endanger bridges, water mills and other objects inside or close to river channels. Ships and boats, timber cottages, barrels and even vehicles and logs are frequently-observed dangerous floating objects.

Formation of barriers

Uplift forces in combination with flow may cumulate floating objects (wood logs, ice floes, modern building materials, especially foam insulation plates) and create barriers on river banks, before or on top of slightly immersed bridges and similar objects in the water stream, or inside buildings. These barriers raise the water level, and can prevent rescue teams from entering buildings during or after flood events. The barriers further increase the danger of scouring the subsoil under bridge piers.

Soiling of cultural heritage objects

During floods, mud and debris are transported and then deposited in and on the surfaces of cultural heritage objects.

Ice flood dragging

Winter floods are frequently accompanied by ice floe transport. Bank and river barriers form and move slowly, damaging building structures due to a combination of high pressure and flooding. In modern times, effective tools are available in many countries that reduce the threat of ice floe dragging action. However, the hazard still exists and preventive measures must be taken.

Flood effects on ground and foundations

Strong rainfalls and/or snow melt preceeding a flood cause not only a rise of the water level in rivers but also a rise of groundwater table. Thus, during a flood a change in the state of the subsoil below buildings and other structures can be expected. Soil becomes water-saturated, the water menisci between grains disappear, cemented brittle contacts may dissolve, if they are soluble, and the effective stresses reflecting intergranular forces decrease.

There are several flood-induced phenomena that can influence the foundation function and, as a result, endanger the stability and integrity of the whole structure. Flood effects on foundation subsoil and foundation structures can be roughly divided into the following categories:

1 soil collapse in the case of first time saturation
2 internal erosion of soil
3 external erosion (scour) of soil
4 decreasing soil stiffness due to reduced effective stresses
5 soil heave due to water saturation
6 excessive uplift forces on structures
7 deterioration of foundation material (especially in the case of wooden piles)

Not all effects appear simultaneously, and it depends on local conditions which effects prevail and how severe their consequences will be.

Collapse settlements

In general, collapsible soils are dry or partly saturated soils which become flooded for the first time. The most problematic are collapsible soils having an open type structure with large void spaces, giving rise to a metastable grain skeleton. Flooding events can lead to a sudden volumetric compression of the soil, which damages and destroys the overlying structures. For example, in the archaeological site of Abu Mena (Egypt) (UNESCO World Heritage) a rise in the groundwater table induced by an extensive land reclamation in the previous decade led to substantial softening of the clayey subsoil. Several historic buildings dating from the first millennium have collapsed due to this effect (Benedini and Cleere 2005).

Internal erosion

In groundwater flowing at high velocity (high hydraulic gradients), fine particles can be washed out from the voids between large grains (so-called suffosion or piping), which makes the soil skeleton looser and eventually susceptible to collapse. If a layer of fine-grained soil is in contact with a layer of coarse-grained soil, the fine particles can be transported by water into the pores of the coarse-grained soil. In this way, the permeability of the coarse-grained layer decreases (so-called colmatation) and the void space in the fine-grained soil grows progressively (so-called contact erosion).

Erosion processes are strongly influenced by the grading of the subsoil and by the seepage velocity. They can frequently be encountered in river sediments. They require oscillations in the groundwater level and groundwater flow with sufficient hydraulic gradients. According to Darcy's law, the seepage velocity is proportional to the hydraulic gradient and hydraulic conductivity. An increase in the hydraulic gradient and an increase in hydraulic conductivity (permeability) thus favour soil erosion.

The density of eroded soil decreases as the fines are washed out and transported away. This loosening can increase soil compressibility, and thus settlement of the overlying structure can happen. Brauns et al. (1985) have shown that the erodibility of soil is also affected by the surface load acting on the soil layer. Subsidence may cause further damage to the infrastructure, e.g. sewers and pavements. Masonry partition walls with a shallow foundation on infills, which frequently occur in historical architecture, typically suffer from this kind of damage.

Internal erosion was the presumed reason for uneven settlements of the Laudon Pavilion in the garden of Veltrusy Castle close to Prague. Water flooded a dry channel below the pavilion, causing a downward movement of the building abutment on one side. Repair works consisting of grouting of the ground voids were necessary to stabilise the historic structure (Bradovka 2008).

Erosion of the soil surface (scour)

Scour is the gradual removal of soil surface layers by flowing water resulting in a deepening of the soil surface (Terzaghi et al. 1996). Consequently, holes can arise at the ground surface, mostly at the contact with more erosion-resistant materials. It is a common phenomenon not only at bridge abutments or piers1 but also at the foundations of buildings in flooded areas (National Trust for Historic Preservation 1993). Exposed foundations are not supported by subsoil from the bottom or cannot reach their design bearing capacity due to the lack of soil overburden. Erosion can lead to the loss of a significant soil volume below foundation structures, thus producing deformations and cracks in the superstructure. Uneven settlement or a collapse of the whole structure can appear.

During the floods in Central Europe in August 2002, Prague was severely hit. The affected objects included the famous Charles Bridge over the Vltava River. Scour had taken place at bridge piers 8 and 9, endangering the stability of the pier masonry (Masopust, 2006). The main reason for the scour impact was insufficient protection and the low foundation depth of the piers. Extensive repair works had to be performed after the flood (Masopust 2005; Masopust 2006; Witzany and Cejka 2007).

Changes in the mechanical properties of soil

Damage to foundations is not necessarily limited to direct flood actions. Fluctuations in the groundwater table are responsible for changes in soil effective stresses. Since most of the mechanical properties of soil depend on the effective stresses, a rise in groundwater level is related to a decrease in soil stiffness and shear strength, and vice versa. Variations in effective soil stresses during groundwater oscillations are equivalent to load cycles, thus yielding a gradual settlement of the ground surface, as can be observed e.g. in Venice (Gajo et al. 1997). This problem can consequently arise, especially in periodically flooded areas. Due to the natural non-homogeneity of soils, the ground deformations are usually non-uniform in this case.

In fine-grained soils, an increase of water saturation and thus a reduction in the effective stresses can produce swelling effects. We can distinguish between mechanical and osmotic swelling in this case. While in the first case a rebound of the reversible skeleton deformation takes place, in the second case a bounded water layer grows around/in fine grains . As a result, the soil volume increases and the ground surface can heave. Low-weight structures are more susceptible to this effect than heavy large buildings.

Scour is one of the three main causes of bridge failures. It has been estimated that 60 percent of all bridge failures result from scour (e.g. Huber 1991; Kattell and Eriksson 1998).

Excessive uplift forces

As discussed above, in extreme cases the whole building can be heaved by buoyancy. A further negative impact of uplift forces can be cracks in the foundation. Water inflow into the object can take place through these cracks. If there is unsuitable grading of the underlying fill, internal erosion can take place and cavities can be created below the foundation. These cavities may irregular settlement or even laed to the collapse of the foundation.

Deterioration of foundation materials

Deterioration of organic foundation material such as wood usually accompanies the exposure of submerged wooden piles to air after lowering of the groundwater table. However, in the case of floods, dry sections of wooden piles can be submerged in water for a comparatively long period of time. After withdrawal of flood water, increased wood moisture and the presence of air can lead to fungal and bacterial deterioration of pile foundation elements (Goldscheider et al. 1997). Excessive deformations and cracks in the whole structure may reflect the incapability of a rotten wooden foundation to transfer the building loads into the ground.

Saturation of materials with water

Full immersion into water accompanied by saturation of materials causes a wide variety of actions and damage related to volumetric changes, chemical action, loss of strength, etc. Not only sensitive soils, described above and elsewhere, but also dried clay, adobe and decayed timber are materials which may easily collapse due to saturation. Even fired bricks lose their strength, and the load-carrying capacity of under-dimensioned masonry and/or the stiffness of masonry decreases considerably and can lead to overall failure of a structure or a building. Saturated ancient and deteriorated timber also fails easily. Sound timber structural elements swell and expand without breaking. If constrained, they can develop considerable reactions, acting as loading jacks. This phenomenon generates cracks in masonry, displacement of walls, buckling of timber joists and floor beams, causing typical floor dome-like deformations. Saturated ceiling infill and/or thermal insulation layers increase the weight of the ceiling, and this may be worsened by deposits of mud and other floating debris, resulting in the destruction of overall ceiling or suspended layers.

Stone masonry with lime mortar is quite stable, but adobe masonry and some marly limestone (argillite, "opuka") may suffer from detachment and spalling of surface layers during drying. Soluble materials can be washed out from cultural heritage objects, e.g., pigments from painted walls. Materials held together by glue are usually split into their elementary parts. The strength reduction of stones also varies with their moisture content (Peschel 1977, Kocher 2004), see Annex 7.3.

Contamination of materials with chemical and biological pollutants

High-rise water usually transports various chemical substances and microorganisms, which may cause chemical deterioration or biological infection. A change in pH influences the solubility of various materials, namely calcites in acid environments and silicates in alkaline environments. The organic compounds in frescoes are very sensitive to pH level, and are easily dissolved in alkaline environments. Sulphates (gypsum architectural details) are also fairly sensitive even to pure water. Ferrous materials can be attacked by chlorides, which is dangerous for the reinforcement in old concrete structures. Contamination with soluble salts with subsequent efflorescence may lead to increased soiling. Wet materials are easily colonized by biological infections, which may be intensified due to contaminated water. The growth of dormant agents may be restarted.

Post-flood effects

The period after floods is almost as dangerous as the flood itself, and much damage originates or appears after the high water has abated. Examples include cracks due to differential settlement, volumetric change during drying effects, salt efflorescence during drying processes, biological attack and growth, inappropriate remedial interventions, especially rapid pumping of water from cellars and subsoil, loss of cohesion of some materials when quickly dried (e.g., adobe), changes in interior climate (high humidity), etc.

Flooding may accelerate surface damage to masonry caused by salt crystallisation and frost/defrost action, which appears as exfoliation (delamination) and/or powdering. The damage proceeds from the exterior to the interior of the surface, in most cases leaving the rest of the material undamaged. The damage assessment can therefore be carried out in a non-destructive way by detecting the variation of the surface profile and hence determin the loss of surface material due to deterioration over time. The impact of salt crystallisation is a rather complex problem, and more details are available in the literature (Van Balen et al. 1997, Binda, Cardani, Zanzi 2010).

Figure 2.1.2.1 - Praha - Libeň separation of columns in Karlin public park. Source: T. Drdácký.

2.1.2 Impact of floods on cities and heritage sites

The impact of floods and damage on urban areas (including historic towns, archaeological sites, gardens, parks, waterworks and landscapes) has a more complex and long-term nature than the impact of floods on individual objects. For the purposes of describing and analysing all effects, we can differentiate between damage caused by the water itself during the flood and damage related to measures taken after the flood (and before the next flood).

Urban areas are constantly developing and changing environments (reflecting the evolving demands on space organization, functions, social and economic needs), and floods can play an important role in accelerating these changes. Defining the limits of acceptable change and setting new requirements should be a prime focus when assessing the damage and also when rehabilitating the affected areas.

Figure 2.1.2.2: Flooded part of Karlin with Florenc metro station) Source: NPÚ, Praha.

Figure 2.1.2.3: Collapsed building in Karlin. Source: NPU, Praha.

Damage to Heritage Urban Areas

No change (reversible damage)

- drying after the flood,
- repair, restoration, rehabilitation, same residents, same ownership

Temporary or permanent change in

- Fabric
- Urban structure
- Public spaces (fragmentation, separation, walls, barriers)
- Parks, greenery
- Function, serviceability
- Infrastructure (technical, transport)
- Socio-economic structure of residents
- Ownership (in a physical and social sense)
- Public involvement

Losses

- Demolition - clearance of buildings and blocks
- Changes in urban pattern, townscape (scale of public spaces, character)
- Loss of the "place memory",
- Loss of cultural values

Material damage

Damage to the built fabric has been fully described above. There is also often heavy and costly damage to infrastructure, failures of subsoil lines and pipes, damage to roads, transport systems, bridges, etc.

Functional impact

Temporary or long-term damage to transport systems and inaccessibility of affected areas can delay rescue services and restoration processes. The functions of a city are affected in various ways. Traditional local ways of life can be permanently changed - there can be changes in the use of public spaces and waterfronts, changes to greenery, street furniture and to open areas in general. The traditional relations between historic communities, villages and towns and their waterfronts may be abandoned in the name of safety and in response to new laws and regulations.

Psychological impact

An important issue is so-called flood memory. People who have experienced a flood keep a memory of it and are able to cope with subsequent floods much better than people in areas where floods have not occurred in living memory. However, if there are minor floods on regular basis the situation can easily be underestimated in the early stages.

Positive changes in human behaviour are often observed during floods. However, strong empathy, solidarity and mutual help decrease rapidly after the event, and neighbourly relations can suffer.

Socioeconomic impact

The economic impact of disastrous floods involves more than just enormous material losses of property and cultural values. We also have to consider the lost profits of local industry, commerce and tourism, and the influence of a flood on the labor market. Old workplaces may be closed down, and new types of workplaces may replace them. Local policies and measures taken to uphold local employment play an important role in stabilizing the post-flood situation.

Demographic changes are closely linked with economic changes. The demographic structure of the population can easily be changed by people losing their jobs and therefore being forced to move away. However, in many cases people tend to remain in the same place for the whole of their lives. It has been shown that, even in extreme danger e.g. of floods, many people are inclined to continue to live in the same place.

Here we come to the importance of personal attachment to a place. If the resident is the owner of the property and has personal links with the place, she/he will put much effort into restoring the place and continuing to living in it. We can observe great differences in property relations and attachment to the place between big cities and villages.

Development, change in character, structureand townscape

Disastrous floods also provide opportunities to redevelop towns and cities, and can be seen as refreshing and progressive events. The expectations of the city administration, cultural heritage bodies and developers should be balanced with the needs of the local community through a long-term process of informing and involving all relevant individuals, bodies and organizations. Some positive and problematic examples are described in Chapter 4.

2.1.3 Impact of floods on moveable cultural heritage items

Moveable cultural heritage is a superordinate term for such different materials as paper, leather, covers, wood, metal, paintings, ceramics, bones, and even plaster and building stone. Archaeological finds and archives often preserve information about our cultural origin and document changes in world view. When these items are lost, it is not only a matter of valuable works of art. Our historical memory is also often irreversibly damaged.

The character and development of damage to such items depends strongly on the parameters of a particular flood, e.g. duration, height, temperature, contamination and flow rate. The resulting damage is complex, and each material reacts differently to water. Crucial for the vulnerability of an item are its material properties, e.g. water uptake, pore size distribution, porosity, swelling and drying behaviour and, of course, vulnerability to mould. Water usually does not directly destroy cultural heritage, but leads to a variety of undesirable damaging outcomes, which have to be combatted as soon as possible. Generally, three types of damage can be distinguished: biological, chemical and mechanical (after http://www.schempp.de). The characteristics of these types of damage are summarized in Table 2.1.3.1. Some general remarks are made and some case studies will now be discussed.

Moveable cultural heritage is a superordinate term for so different materials like paper, leather, covers, wood, metal, paintings, ceramics, bones or even plaster and building stone. Often archeological findings or files preserve information about our cultural origin, document changes of philosophical world view, which's loss would not only be an artistic disprofit, but also often badly damage our historical memory.

The character and development of damage on such items strongly depend on the particular flood parameters like duration, height, temperature, contamination and flow rate. Resulting damage are manifold and each material reacts differently to water. Crucial for its vulnerability are material properties like water uptake, pore size distribution, porosity, swelling and drying behavior and of course vulnerability to mould. Usually, water does not directly destroy cultural heritage, but leads to a variety of undesirable damaging consequences, which have to be fought as soon as possible. Generally three types of damage can be distinguished, that

Physical	Biological	Chemical
- swelling (water uptake into the cell wall of fibres) and shrinking (uneven drying will lead to cracking of the material) - abrasion (more intensive when there are particle impurities in the water)	- water allows fungal growths on surfaces, if the water activity of the material is above 0.6 - bacteria will grow only when there is comparatively high water activity - surface growth, using organic matter from soiling processes (dust, mud) leading to discoloration and edging by organic acids (often secondary metabolic products of mould fungi). - all materials can show surface growth.	- inherent hygroscopic salts can attack water from the air and can increase in volume. Such a chemical reaction leads to mechanical stress and can damage an object.

Table 2.1.3.1 Classification of damage

Figure 2.1.3.1: Fénélon, Télémaque, an early printed book from the central depository of the Library of the National Museum, Theresienstadt (Terezín, Czech Republic); left: damage from the Elbe flood in 2002, leather dirty and scratched, paper tag lost; edges of the cardboard book covers have split; parts of the leather cover on the back and at the edges are missing; the binding has been loosened, some quires (bifolios) are falling out; the first two or three quires have been completely loosened, leaves are torn or partially lost; right: the book after restoration. Source: Petra Stefcova, Department of Preventive Conservation, National Museum, Prague (Czech Republic).

is biological, chemical or mechanical (after http://www.schempp.de). Their characteristics are summarized in Table 2.1.3.1. Some general remarks and a few case studies are discussed in the following.

Physical deterioration

Uptake of water usually causes swelling and then drying causes shrinkage. These changes in dimension are ruinous for many covers and bindings of books. While the weight of wet paper and cardboard increases with water content, their stability decreases significantly, often leading to deformation and other mechanical damage. The paper swells, and the covers burst. Folders containing files lose their stiffness and become deformed. An example of a damaged early printed book from the Czech National Museum in Terezín is presented in Fig. 2.1.3.1.

Chemical deterioration

Water is a powerful solvent. Ink, coloured paper and binders are washed out or flushed away, and bondings are loosened. This happens particularly in coated materials, where water causes binders to swell entire surfaces, and sheets may be glued together during subsequent drying. This is a common phenomenon in the case of art prints, coloured paper, photographs or finished textiles, which were widely used for construction drawings in the 19th and 20th centuries. If the waters carry pollutants, these are much more difficult to remove wet than dry. Remains of sewage from defective outfall pipes, leaking heating oil tanks or hydraulic pumps are very problematic.

Materials such as stone, ceramics and archaeological finds often bear hygroscopic salts, which liquefy above a certain relative humidity (RH)

Below this value they crystallize and may cause cracks and delamination due to their volume extension. Depending on which salt is present, the critical RH values can vary: for example the critical value is about 45% RH for calcium carbonate, and 32% RH for calcium chloride. In the case of salt mixtures, the liquidization point can drop.

Sodium chloride (table salt) is one of the most important salts. It liquefies above 75% RH. Sodium chloride is present in organic matter (silk) and binds water at 55% RH, and for this reason this value is important to know in case of high humidity.

Figure 2.1.3.2: A Savonarola type folding armchair with brass incrustment from India, depository of the Náprstek Museum, Liběchov (Czech Republic). Savonarola arm chair damaged during Elbe flood 2002, before and after restoration (page 34), Pairs of details before (upper photograph) and after restoration (below). The damp absorbed by the woodden parts caused a considerable increase in relative humidity; the surface varnish (shellack) was badly damaged (partially converted to dust), mould, fungi; the wood was cracked, the brass incrustment has been loosened or lost; the upholstery has been affected by mould.
Source: Petra Štefcová, Department of Preventive Conservation, National Museum, Prague (Czech Republic). Savonarola type folding armchair with brass incrustment, from India, depository of the Naprstek Museum, Liběchov (Czech Republic).

Colours and ink leach or bleed out: written documents can be made of various materials or papers and can be produced with various kinds of print or written media. Even within a single file, there can be various types of damage, which may be difficult to assess and deal with.

Documents and pages of books can be glued together due to quickly setting pastes. In the case of art prints, very brief contact with water causes superficial gluing together that is difficult to disconnect. An attempt to separate the sheets mechanically leads to an information loss on the printed surfaces. Only painstaking professional work can avoid this loss of information. It is generally much easier to disconnect these bondings after freeze-drying the documents.

Biological deterioration

Mould grows when there is high relative humidity. However, the incidence of mould growth depends rather on the water content of the substrate than simply on the actual relative humidity. Each material has a different (balance) water content at one RH. However, 60% RH may be taken as the lower limit for mould development, since mould at 25°C needs relative humidity of at least 61% (Scott 1994). This holds only for some mould species that grow very slowly between 60 - 65% RH; most species need even higher humidity. Measures for the future often include regular checks on the recurrence of microbial attacks, and local cleaning, if necessary in combination with local applications of a biocide.

Mould grows within a few hours within moist cellulose, and subsists in it. Material degradation due to fermentation not only causes persistent colour changes, but also irreversible reduction of rigidity. Once an object has been affected by mould, spores are built up, and there is an ongoing risk of further mould growth. Mould also poses a health risk to humans, which makes this kind of spoilage even more serious.

As biological attacks occur so quickly, even a slight increase in the water content in an object can have disastrous consequences. The damage that can be done is great, and if no appropriate restoration measures can be taken cultural heritage can be totally lost. When the material is deteriorated by fungi, the substance of the cultural object itself is metabolised; the fungi grow into the material and use it as a source of nutrients. Depending on their level of moisture and oxygen, all organic materials can be deteriorated (e.g. paper, leather, textiles, wood). Aerobic deterioration is much more common and often more rapid than anaerobic degradation. For growth, most micro-organisms need:

- a nutrient source (cellulose itself)
- water
- oxygen (anaerobic organisms are very slow as cellulose degraders)
- temperature above 0°C

Therefore, the following steps can be taken to hinder microbiological growth. First, wipe off all debris on the object in order to limit the nutrient sources; then, if blast freezing is not an option, keep the temperature as low as possible; third, deplete the oxygen by gassing with CO2 or sterilise with Ethylene oxide or by gamma-irradiation.

2.2 Vulnerability of cultural heritage

Jeannine Meinhardt, Miloš Drdácký, Heiner Siedel

Cultural heritage assets refer to a large variety of different objects which, in turn, consist of very diverse materials and combinations of materials. Considering cultural heritage sites and their vulnerability in the context of floods, it is above all necessary to accept that there are always complex interactions between the ground, the object and the flood event. There are no normalised building materials or technologies.

Water always influences the physical and chemical stability of materials. Biological agents are often activated when sensitive objects come into contact with water, which is more often than not polluted. Under the influence of water, materials are more or less soluble and their mechanical characteristics change. Their vulnerability also depends on the conditions outside the object: on the characteristics of the flood, the properties of the surroundings, the environment after the flood, and the protective measures taken before, during and after the flood. Concerning the vulnerability (weakness) of cultural heritage and its relation to adaptive or protective measures, it is useful to differentiate between moveable and immoveable heritage objects. The vulnerability of moveable heritage is closely related to the sensitivity of the materials to flooding, which depends on the amount of water and the duration of the water contact. The sensitivity of the material also influences the response of architectural heritage to flooding. However, buildings and structures are typically subjected to higher external loads or environmental effects, see above.

2.2.1 Immoveable heritage

Historic materials, structures and territories (landscape, gardens, etc.) are subjected to unusual loads and actions. First of all, we must bear in mind Archimedes' Law: all flooded objects are uplifted and some may even float away from their original position, even inside interiors, where streams can also occur. Static and dynamic pressures can destroy structures as well as trees, and this phenomenon may be multiplied by the impact of floating objects or by the formation of barriers of floating objects or by erosion of the subsoil under foundations. Wet materials and structures mostly lose their strength and stiffness characteristics, and exhibit substantial volumetric changes. In addition to mechanical actions, substantial chemical attacks also occur during and especially after floods, mostly due to water pollution and salt efflorescence during drying processes. It is therefore much more difficult than in other situations to make a general ranking of structures and elements according to their sensitivity to floods. In addition, many effects occur after the flood, e.g. compacting of infill, which can cause failure of partition walls, buckling of floors as a consequence of uplift forces, cracks in vaults due to uneven settlement after the flood, etc.

Ranking of structures and elements according to their sensitivity to flooding

Sabbioni et al., 2010

F0 Flood-resistant structures

F1 Structures from materials with a high moisture volumetric change

- Timber structures and elements
- Combined structures from different moisture expansion materials
- Certain soils

F2 Structures from materials that degrade in strength considerably due to moisture

- Dried brick (adobe) masonry
- Masonry with clay (low lime or cement contents) mortars
- Decayed timber structures and elements
- Infill subsoil and fine-particle subsoil

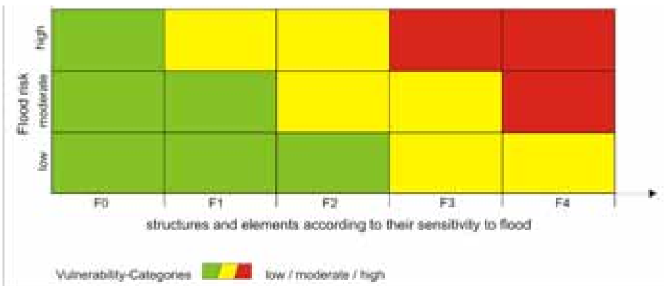


Figure 2.2.1 Graphical presentation of the reationship between flood risk and object vulnerability. Source: CHEF.

F3 Structures susceptible to partial damage due to floods

- Timber parts prone to uplifting and floating away
- Large bridges
- Pavements

F4 Structures and elements vulnerable to overall collapse/displacement due to floods

- Small bridges and walkways
- Free-standing walls
- Light, inadequately anchored objects (summer houses, etc.)

Generally, it is impossible to take all potential impact factors into account and to state with certainty their effect on the vulnerability of an object. In order to show the dependency of the vulnerability of the structures mentioned above on the intensity of a flood, the probability of flooding - the flood risk - must be taken into account. Table 2.2.1 (see page 39) was compiled to illustrate this issue. Using a very simple categorisation with three classes of flood risk, the vulnerability of the structures and element F0-F4 are pointed out. According to this categorisation, for example F2-structures from materials that degrade in strength considerably due to moisture are not endangered in an area with a low flood risk. This is graphically represented in Table 2.1.1.

Materials

Immoveable heritage objects, in particular buildings and structures, can be classified in terms of mineral building materials, or wood species. Threshold levels can be defined for some of these materials. However, it should always be kept in mind that most flood-affected objects, moveable or immoveable, are made of various composite and non-homogeneous materials. Therefore the informative value of the quantitative threshold levels for the vulnerability of individual materials is limited.

Masonry is a composition of building materials, e.g. building stone or bricks, together with a mortar. The mortar itself is also a composition of aggregates, binder and additives. The mortar binder is based on cement or, in the case of many cultural heritage objects, on lime. Additionally, there are regional variants of binders, e.g. gypsum mortars are also widely used.

The interrelations between cultural heritage wood and water depend on the wood species. While spruce and pine, as evergreens, exhibit a rather flat curve in their water uptake over time, deciduous wood species, e.g. beech and oak, show a higher rate of water increase. This reflects the different anatomical structures of these trees. Despite its density, oak takes up water to a much higher extent and at a greater rate. It therefore loses buoyancy much sooner. Spruce, on the other hand, does not take up water easily. Drying of wodden elements occurs at a relatively constant rate.

2.2.2 Moveable heritage

Moveable heritage displays an even wide range of combinations of materials. These combinations bring together various properties with widely differing physical, chemical and biological stability. It is not feasible to define threshold levels. The main approach for flood protection of moveable heritage should therefore be to implement emergency plans and to store cultural heritage objects above a level that is subject to flooding (e.g. a cellar). It is vital to protect moveable historic objects against water action, because statistics show that 68% of the losses in this category of cultural heritage have been due to water-related disasters. (Matthews, 2006).

2.2.3 Examples of material parameters characterizing the vulnerability of immovable heritage

Various parameters characterise (natural) building stones comprehensively in terms of moisture uptake and mechanical strength. The moisture characteristics are determined by measuring total and open porosity, total water uptake and capillary water uptake. Important strength parameters are compressive and tensile strength and the E-Modulus. Changes in volume or length are determined by comparing the hygric swelling of water-saturated samples with dry samples. For mortars, the creep factor must also be taken into account. However, the vulnerability of building materials is mainly a matter of the degree of loss of stability due to moisture penetration. The so-called weakening coefficient n should therefore be used. This is calculated from the strength (tensile and compressive strength) of water-saturated material and dry material (Hirschwald 1908). The duration of flooding or the time of exposure is very important in assessing the vulnerability of materials. The longer a sensitive material is in contact with water, the weaker its stability will be.

The aim of any assessment of the vulnerability of immoveable cultural heritage objects should be to form rough categories of materials or material groups in order to make them applicable for the end-users who have to work with them.

Building stones

Stone building materials are historically strongly linked to the geological setting of a particular area. Because of the development of means of transportation, it has more recently become possible to ship building materials far away. The classification of stone materials is the same all over the world: magmatic, metamorphic and sedimentary rocks. Stone materials, due to their weight, ensure the stability of structures. Magmatic and metamorphic materials have similar water absorption behaviour. Schists, which are metamorphic, behave very differently from igneous rocks. However, this material is not used in endangered areas of a building, and will therefore not be mentioned in this context.

* Three raw sandstone categories exist that require different kinds and amounts of cement or matrix. Concerning vulnerability, several transitions of matrix types need to be taken into account. Another important consideration is whether there are water soluble components in the matrix (e.g. gypsum).

** Limestones and also carbonate-bounded sandstones may contain soluble components that reduce their resistance/ strength when they are wet . Long-term water contact will lead to relocation in the material and probably to loss of stability and to efflorescence. Sometimes these sandstones are categorized for use inside buildings only.

Table 2.2.1 Stone building materials, and an assessment of their vulnerability to water contact

Material	Vulnerability
Magmatic stones	
Igneous rocks	not vulnerable
Tuff	vulnerable
Metamorphic stones (except schist)	not vulnerable
Sediments	
Sandstones*	
Clay-rich sandstones	vulnerable
Silicate-bounded sandstones (mainly)	not vulnerable
Carbonate-bounded sandstone (mainly)	conditionally vulnerable
Limestones**	conditionally vulnerable
Adobe	vulnerable
Brick	conditionally vulnerable
Concrete	not vulnerable

The following schematic diagram (see Fig. 2.2.2) depicts the relations between material and flood parameters and the influence of various flood parameters.

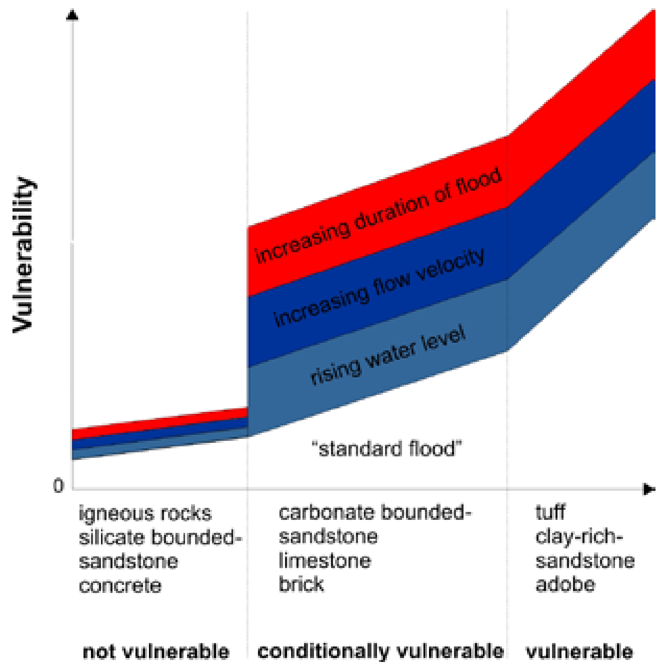


Figure 2.2.2: Vulnerability as the relation between building materials and flood characteristics. Source: IDK.

Mortars

In former times, the usage of mortar materials depended mainly on geological conditions, but nowadays this is no longer the case.

Table 2.2.3.

Material	vulnerability
Lime mortar	conditionally vulnerable
Gypsum mortar*	vulnerable
Cement mortar	not vulnerable

* Gypsum mortar is endangered by flooding or by long-term water contact. Creep deformation is very important in the case of gypsum mortar (see Fig. 2.2.3). The longer the gypsum mortar is wet the higher the rate of creeping, leading to changes in load transfer, cracks and static problems. This example shows the effects of irreversible damage due to moisture contact.

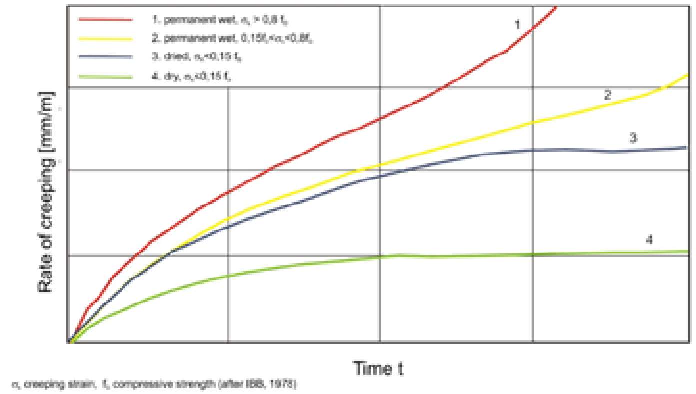


Figure 2.2.3: Relative creeping effect of gypsum mortar over time under the influence of humidity. Curves 1 and 2 represent humid gypsum that cannot withstand loading when wet. The duration of the process is dependent on local conditions. Source: IBB 1978)

All graphs are to be seen relative to each other over time. While dry (or drying-out) gypsum materials aspire to a "final creeping degree" (see curves 3 and 4), wet gypsum materials show divergent behaviour. Curves 1 and 2 demonstrate a gypsum mortar under the influence of permanent humidity. Under a certain load the creeping deformation does not approach an ultimate value. This load-dependent behaviour leads to creep fracture, or to collapse of the masonry. Dislocation of water-soluble components and therefore efflorescence may also be expected for all mortar types after a flood.

2.2.4 Recommendations

The total risk of flood events has to be estimated and referred to in emergency plans.

General recommendations:

- Evacuate retention areas
- Build dikes
- Do not bring into use historically unused parts of buildings (basements)
- Prevent any emissions during flooding

Recommendations for preventing flood damage to cultural heritage objects:

- General risk maps of the affected region should be combined with mapping of cultural heritage objects.
- The specific vulnerability of cultural heritage objects needs to be defined: Which building materials are used? What is the structure? What are the damage mechanisms? Data should be acquired on the initial state of the object, in order to define individual or approximate threshold levels for categorisation in vulnerability classes. An emergency plan should be drawn up for each individual site/cultural object.
- Reference objects that represent the typical building type(s) and technologies in a special region or in a historic town should be defined and investigated. These objects should be studied thoroughly before a flood occurs. Data from recent floods concerning damage and methodologies for drying and repair, and also experience of preventive measures, should be collected and made available to owners of comparable objects. Damage caused by floods should be repaired in an exemplary manner, in order to provide know-how and experience for use in similar cases.
- Highly-endangered objects of outstanding value should be investigated before a flood, in order to collect data about the initial state of the object (materials, humidity content, climatic conditions, use, visible damage or indicators of wear). These objects can also be regarded as reference objects.
- Suitable cleaning and drying methods should be defined on the basis of experience gained in diagnostic and monitoring campaigns after recent floods.
- Regional skills and administrative networks should be set up with well defined responsibilities for flood prevention, emergency actions during and rescue work after flood.

2.3 Stock-at-risk mapping

Luca Lanza, Francesca Pirlone

The development of appropriate tools for mitigating the impact of floods on cultural heritage is based on an accurate definition and assessment of the actual flood hazard, on the one hand, and of exposure and vulnerability, on the other. Although vulnerability is certainly difficult to assess when addressed on a large territorial scale, it is still necessary to develop and improve the assessment of flood hazards and the associated exposure of citizens, economic activities, material goods and assets in many European countries. This is especially true for cultural heritage, since special additional information must be retrieved or produced in order to better fit the requirements of preventive structural and non-structural measures (see Section 3.1 below) and also to support emergency and post-event interventions (see Sections 3.2 and 3.3 below).

Appropriate production and dissemination of flood hazard maps is the first essential step in this picture. Following the European Flood Risk Management Directive adopted in 2007, the European countries are required to finalise the preparation of flood hazard maps before 2014. These maps should contain essential information to support flood risk management plans and strategies. Minimum requirements for the information to be contained in these maps include the flood extent (a definition of the area covered by a potential flood with an associated magnitude), water depth and flow velocity (if appropriate). Many countries already have such maps prepared for large parts of their territory (e.g. UK, France, Germany, Italy) on a national or regional level, and some make them available to the general public via the Internet or other suitable means (CDs, paper publications, GIS, etc.)

Flood hazard maps are developed to support various types of risk management plans, ranging from land-use planning and building code regulations to civil protection, including saving human lives and preserving the operation of transport and economic infrastructures. Each of these specific objectives may require focusing on different aspects of the flood hazard, in terms of e.g. the physical characteristics of the expected flood event, its probability or the residual risk (see Section 3.1), the duration of the event or the post-event emergency conditions, etc. Different types of flood maps therefore present different types of information.

Although the original aim and the present status of their production may differ, it is advisable to establish common methodologies throughout Europe for the preparation, representation and dissemination of flood hazard maps, taking into account the varying features of the landscape and climate on the territory of Europe. The European Exchange Circle on Flood Mapping (EXCIMAP) was established in 2006 to gather all existing experience and know-how in Europe on flood mapping, and to improve flood mapping practices (Van Alphen et al,, 2009). By the end of 2007, EXCIMAP had produced a Handbook with Good Practices (Martini and Loat, 2007) and an Atlas with examples of flood maps from 19 European countries, the United States and Japan (Van Alphen and Passchier, 2007), see Fig. 2.3.1.

The estimation of other parameters than the extent and probability of a flood is rarely addressed, since e.g. the total amount of water and the duration of the flooding are not considered critical for the application of suitable regulations. It should be noted that the classic approach is primarily aimed at safeguarding human lives, and only secondarily at preventing the loss of moveable goods (especially in commercial premises). There is a recognised need to develop efficient hydrodynamic models with very fine spatial resolution, aimed at reducing the present uncertainties in the delineation of flood-prone areas. This would allow a detailed assessment of the dynamics of the flood, by also interpreting the interactions between the fluvial flood waters and the urban storm water, as conveyed through the artificial drainage networks, and would provide a description of the impact of flood waters on the urban territory.

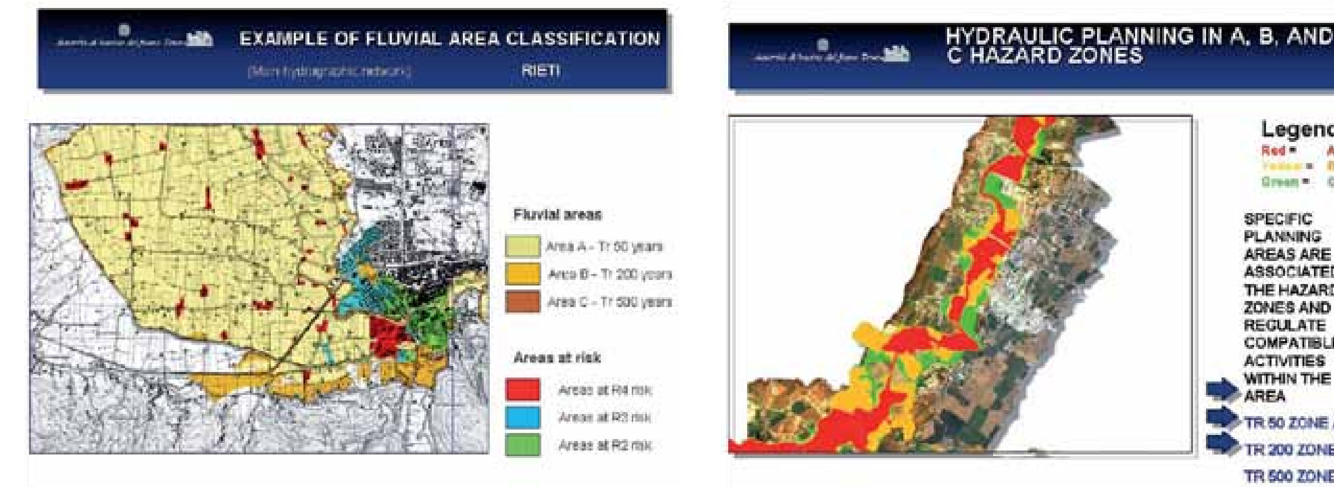


Figure 2.3.1: Examples of a basic flood hazard map (extent of the flood-prone area for three reference return periods) for the surroundings of the town of Rieti, Italy (left) and a land-use planning tool (right) derived from flood hazard maps in the Tevere river basin (upstream Rome, Italy). Source: Van Alphen and Paschier (2007).

Recent developments include assessments of the conditional flood hazard, linked to the impact of floodwaters on the territory and elements related to human activities. This requires a suitable conceptualization of the impact in terms of physical variables and sensitive factors, though this requires very high spatial resolution of the data in order to ensure transparent and agreed evaluation procedures. For such approach to be developed, the types of action exercised by water on cultural heritage must be adequately identified, together with the material elements that can be subject to significant damages (vulnerability). In this way, a definition is made of the specific parameters and characteristics of a flood event that are required as the output of the hydraulic/hydrologic models that are employed.

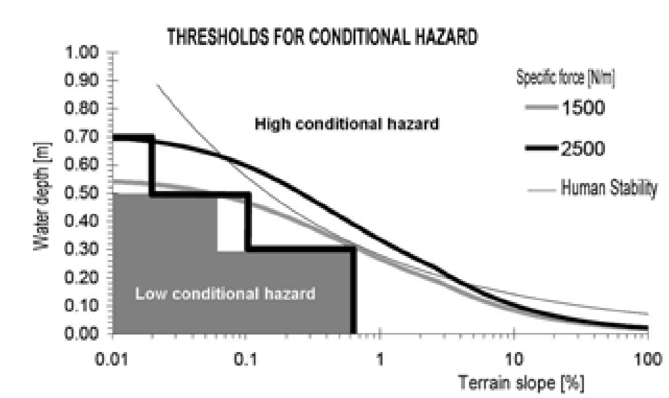


Figure 2.3.2: Examples of conditional hazard thresholds (left) as developed for regulation purposes in the Liguria region of Italy. Source: Rosso, 2003.

The main parameters identified as relevant to cultural heritage protection against floods include:

- flow velocity;
- depth of water inside/outside the building;
- duration of water ponding inside/outside the building;
- pollutants and related chemical reactions due to the presence of water;
- mass and particle size distribution of the material transported by the flow.

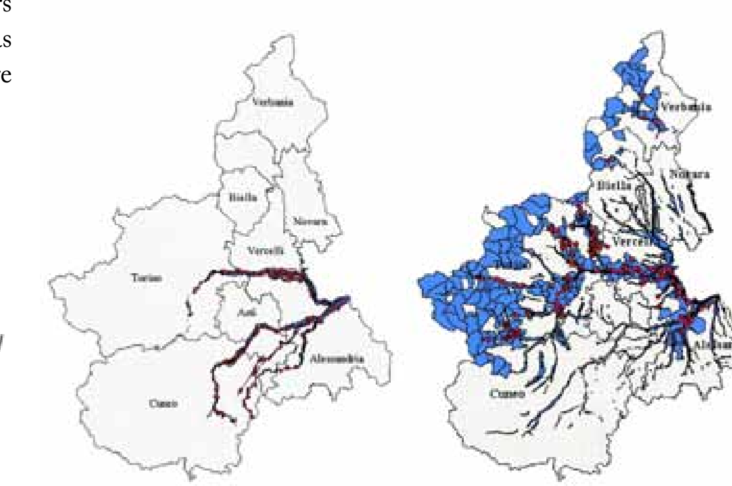


Figure 2.3.3: Mapping of cultural heritage at risk (red dots indicate individual assets) derived from the survey of heritage exposed to potential damage during the floods of November 1994 and October 2000 in the Piedmont region of Italy. Source: CRUIE.

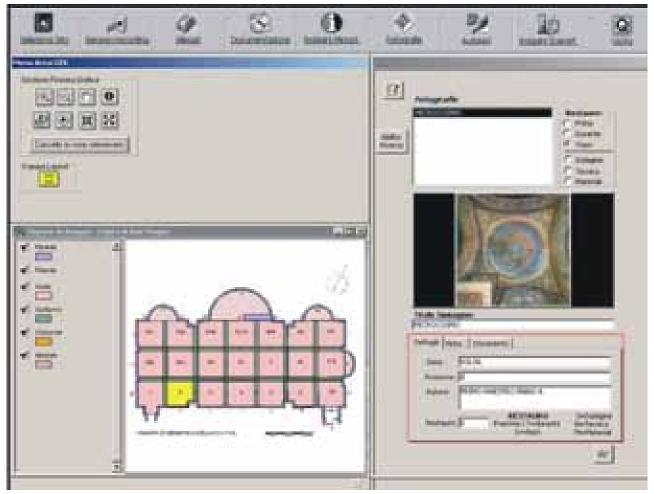


Figure 2.3.4: Element selection from the plan view, and representation of the related alphanumeric information with pictures, Source: C. Cacace, Istituto Superiore per la Conservazione e il Restauro- Ministero per i Beni e le Attività Culturali, 2008.

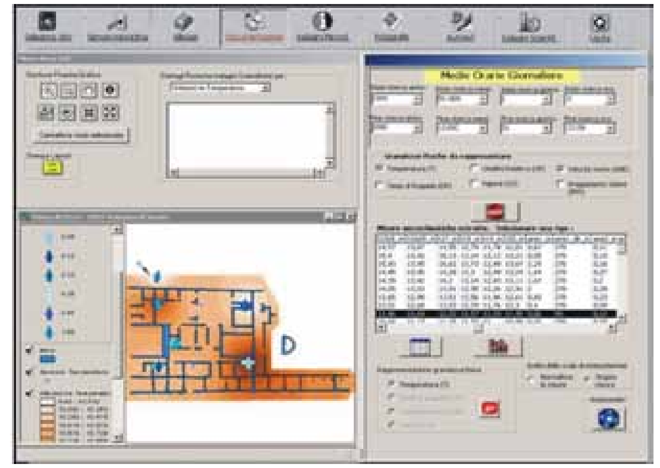


Figure 2.3.5: Overlap of two thematic maps, resulting in the air temperature distribution below the archaeological coverage as a function of wind speed. Source: C. Cacace, Istituto Superiore per la Conservazione e il Restauro- Ministero per i Beni e le Attività Culturali, 2008.

Flow velocity is able to induce serious damages in buildings and to produce structural settling because of the soil erosion in the vicinity of the foundations. The suspended solid materials transported by the flow contribute considerably to structural damages, producing direct erosion at the base of piers or walls, and also mud deposition. The water depth reached in the vicinity of the building and the duration contribute not only to direct damage due to wetting but also to the presence of humidity. Rising humidity is a function of the duration of the flooding and the structural characteristics of the building.

Derived variables, e.g. the energy or momentum associated with flood water, are also suitable for use within a framework borrowed from the refinement methodology that has been proposed for mapping flood risk and for the associated regulations, e.g. in Italy. The method is based on defining the threshold curves that modulate the assessment of the conditional hazard based on the concept of acceptable force conditional on the specific energy of the flow, taking into account the mechanical action exercised by the flow in terms of the applied force and energy. In particular, based on an evaluation of the horizontal specific force (per unit width) over an indefinite vertical wall hit by a uniform flow, a curve is derived to represent the relationship between water depth and velocity in the case of a given force and constant specific energy. Once an acceptable or critical force is defined, the relationship between water depth and velocity, or slope, can be derived as represented in Fig. 2.3.2. This approach should be extended to deal with building structures and materials. This method also requires the grouping of buildings into typological classes according to the materials used, the structural characteristics and the building techniques by defining, class-by-class, a correlation between the event characteristics and the related damage, e.g. expressed in the form of a vulnerability curve or a damage probability matrix.

Determining the actual stock at risk is the first step in assessing the flood hazard threat to cultural heritage. The stock at risk is defined as the list of elements that are potentially subject to the effects of floods, in view of the possibility of flood water reaching any individual asset or historic centre/village within the flood prone areas. A comprehensive definition of the stock at risk derives from accurate mapping of flood prone areas (as discussed above) and from a survey of cultural heritage at risk (see Fig. 2.3.3). Methods for undertaking accurate surveys of cultural assets are however subject to the definition of what cultural heritage is.

The concept of cultural heritage can hardly be defined with a single axiom able to synthesize all its meanings. Cultural assets assume different connotations based on local characteristics, the varying regulatory systems in different countries, the economic and environmental conditions, as well as political considerations. A cultural asset can be a single work of art or craft (or a monument), a building, a portion of a territory (a historic centre), etc.

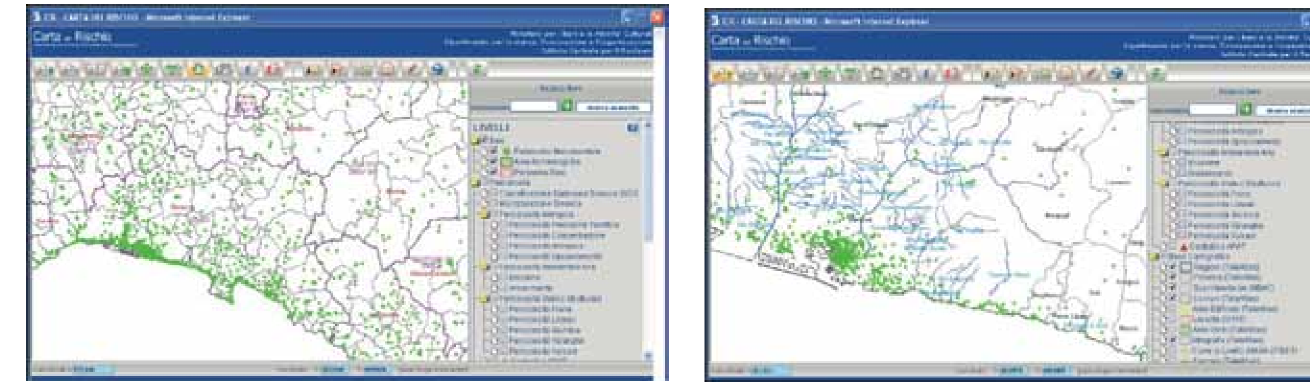


Figure 2.3.6: Sample GIS application – the Risk Map of cultural heritage (Italy), location of valuable assets (left) and the overlap of thematic maps (right). Source: Ministero per i Beni e le Attività Culturali, Dipartimento per la ricerca, l'innovazione e l'organizzazione – Istituto Centrale per il restauro.

Filing-in forms is frequently used for specific data and/or information collection for individual cultural heritage assets. Forms are compiled by the competent authorities, by groups attempting to evaluate vulnerability, or are produced by research bodies and universities, etc. Thanks to new technologies, specific information about every portion of the asset can be included in a suitable database associated with geographic data into a Geographic Information System (GIS). PC- or webbased systems enable researchers to record status-quo information (see Figs. 3.3.4 and 3.3.5), damage scenarios to be assessed, and the resulting cartographic restitutions to be made. There is a recognised need to define suitable criteria for validation and testing of the surveyed data.

Geographic Information Systems necessarily complement the realization of an organic programme of cataloging that is fully functional to allow the competent structures to practice their own institutional assignments of guardianship, in addition to management and maintenance of cultural heritage assets. GIS technology seems the most appropriate for achieving this purpose, thanks to the widespread visualization capabilities and the possibility to analyse the problem by means of thematic maps that can be updated in real time.

The general situation on spatial information in Europe is of fragmentation of datasets and sources, gaps in availability, lack of harmonization between datasets at different geographical scales, and duplication of information collection. These problems make it difficult to identify, access and use the available data. Fortunately, awareness is growing at national and EU level about the need for qualitative geo-referenced information to support our understanding of the complexity and interactions between human activities and environmental pressures and impacts. The need to handle an ever larger number of geo-referenced databases and to link them across borders (in the current context see Directive 2002/49/EC Article 7, 4.) led the EU to develop the INSPIRE initiative. INSPIRE aims at sharing and linking geo-referenced data throughout the EU Member States through "a distributed network of databases linked by common standards and protocols", accessible through interoperable services that will help to produce and publish, find and deliver, and eventually use and understand geographic information over the Internet across the European Union and Accession Countries. This initiative aims to trigger the creation of a European spatial information infrastructure that delivers integrated spatial information services to the users. These services should allow the users to identify and access spatial or geographical information from a wide range of sources, from the local level to the global level, in an inter-operable way for a variety of uses. The target users of INSPIRE include policy-makers, planners and managers at European, national and local level, and also citizens and citizens organizations.

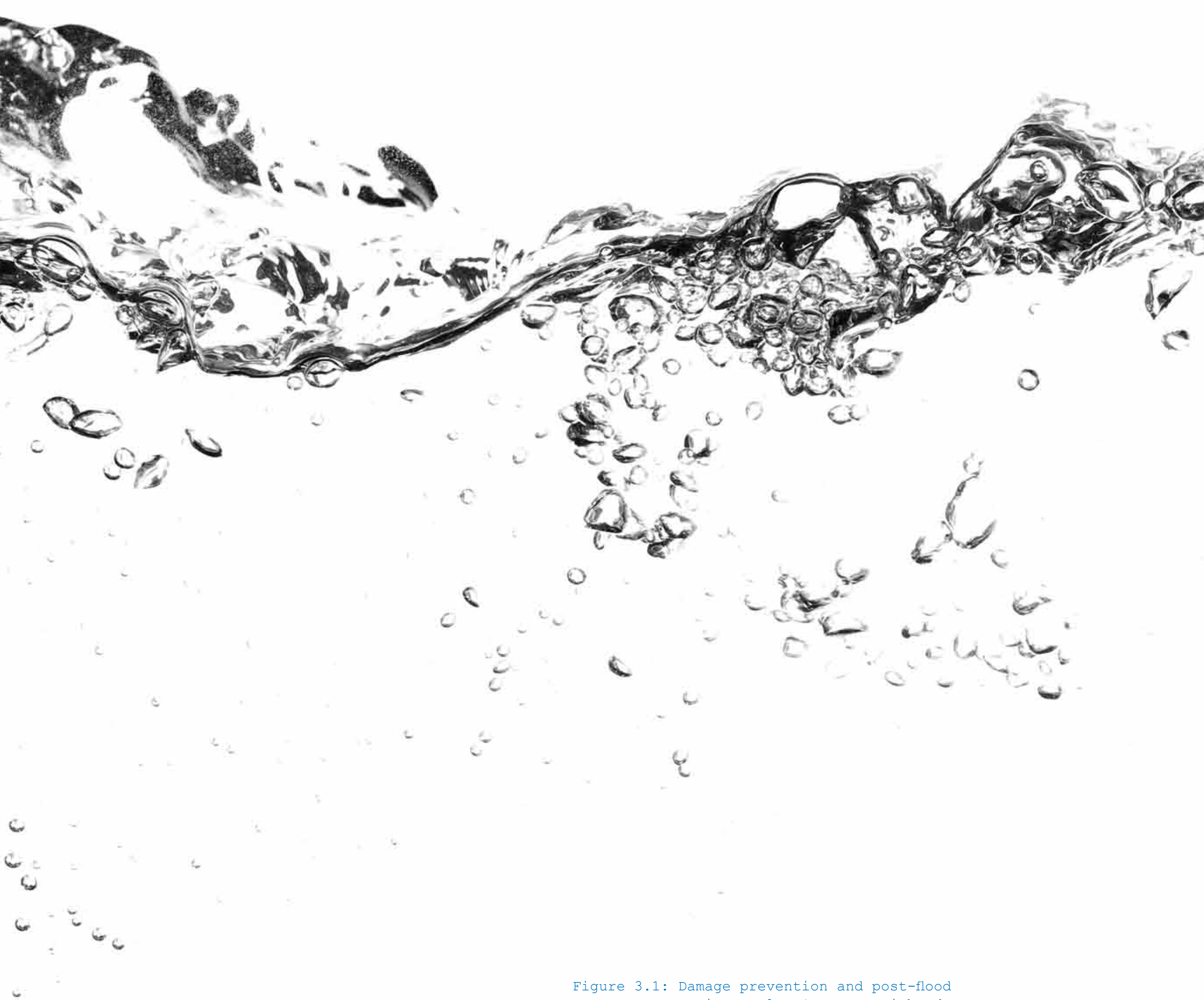
The Risk Map of cultural heritage developed in Italy is a suitable example of the use of GIS in flood hazard mpping and in stock-at-risk mapping for the protection of cultural heritage against natural and anthropogenic hazards. The Risk Map is a project carried out by the Italian Central Institute for Restoration (ICR – Istituto Centrale per il Restauro). The project is divided into two parts:

- Central Pole: a permanent operational structure resident at the ICR Laboratory of Physics for national-scale management of all information related to the conservation of cultural heritage;
- Recognition of degradation of monuments: the launch of a timely assessment of the state of conservation of archaeological sites, monuments and works of art.

Mapping the level of risk provides a synthetic way to view this information as crucial for the life of cultural heritage, and as a valid means of planning (see Fig. 2.3.6).

The computer-based processes developed within the Geographic Information System of the Risk Map enable us at present to calculate the intensity of the risk of loss to which all artistic assets and historical monuments belonging to the Italian cultural heritage are prone, and to make an assessment of their distribution on the territory through an upgradeable thematic cartographic representation. In the Risk Map of cultural heritage, having stored the distribution of all monuments on the so-called Chart of the Distribution of cultural heritage, three categories of risk are analysed: static risk, environmental-air risk and the risk caused by human factors. The first category addresses six phenomenological types of risk which are more likely than others to have an impact on the static performance of monuments. These are not only earthquakes, landslides, avalanches, volcanic eruptions and dynamic coastlines, but also floods. Based on these considerations, the Chart of Static-Structural Hazard was produced. As far as flooding is concerned, it is structured according to the flood-prone areas per municipal territory and the percentage of flood prone areas with respect to the overall municipal surface area.

The filing model exploited in the project is, in practice, basically divided into two sections: the first deals with registry information about the asset, while the second is devoted to data about the state of conservation. To build the structure of the form, the ICR took over the cataloging standard of the Central Catalogue and Documentation Institute (ICCD) for registry identification of the assets. This allows data collected as part of the activities carried out for filing the Risk Map to be integrated and made compatible with data from the Catalogue, while unifying and simplifying the activity of the persons in charge of filing.



3 Measures

The planning of preventive measures before, during and after flooding in a specific target region such as the European Union requires strategic planning of the legal basis at the earliest possible stage. Fig. 3.1 shows a general overview of the measures that have to be considered in a provisionally estimated time scale when focusing on protecting cultural heritage against flooding.

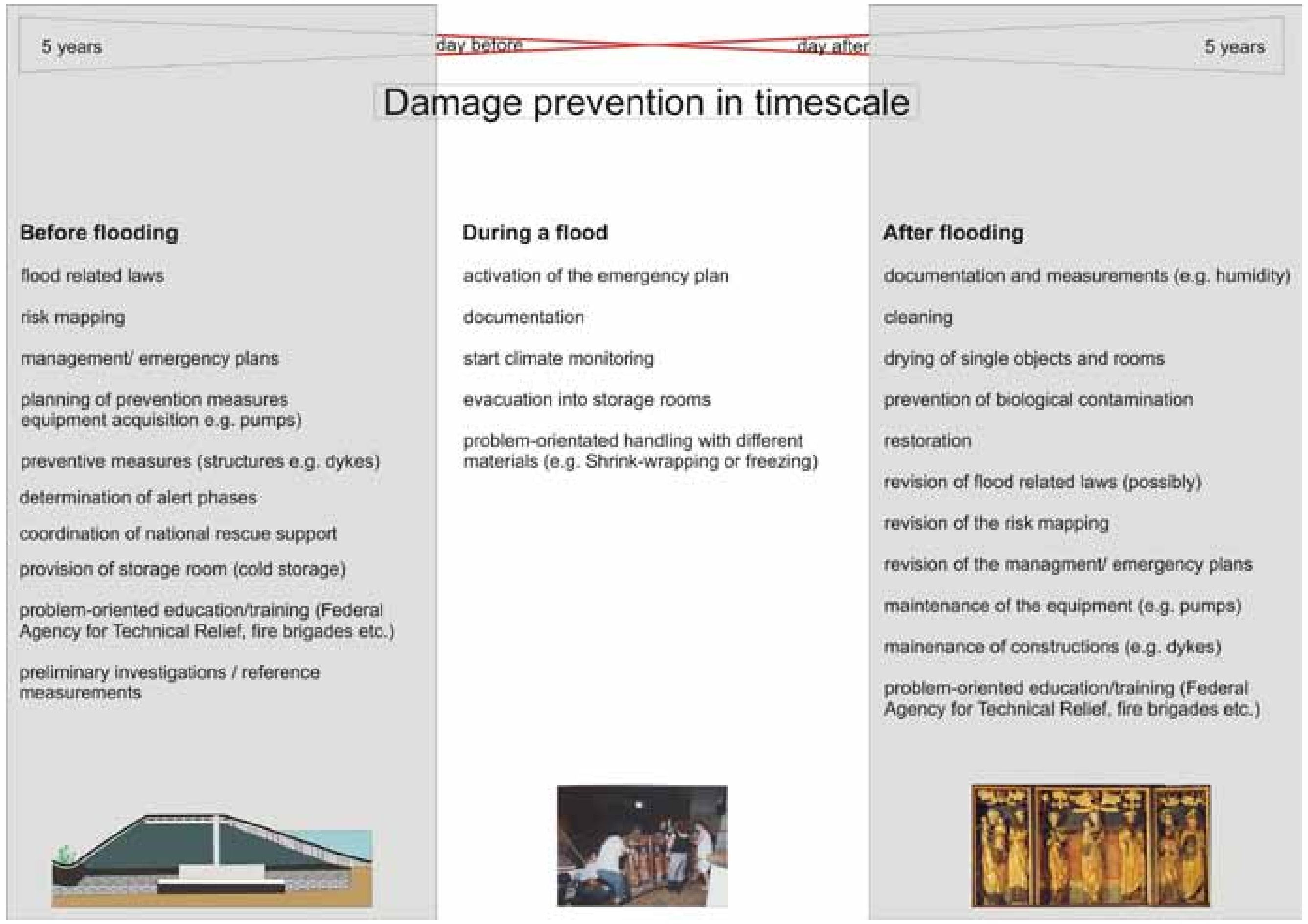


Figure 3.1: Damage prevention and post-flood measures on a time scale. Source: Meinhardt, Hennen with photos from altar rescue works (centre) and altar, church in Priesitz, after restoration (right), with kind permission of the State Department for the Preservation of Historical Monuments and Archaeology, Saxony-Anhalt, see next page.

3.1 Before flooding: Damage prevention and mitigation

Luca Lanza, Rosemarie Helmerich

The risk of losses of cultural heritage can be defined as a combination of the probability of flooding (flood hazard) in the vicinity of cultural heritage sites, structures, museums, archives or private heritage in flood prone areas, on the one hand, and exposure and vulnerability of the cultural assets as a material and structure related parameter, on the other.

Damage prevention before flooding can be achieved by dual action, with a top-down approach starting at the flood hazard level and, at the same time, bottom-up action to reduce the vulnerability or exposure of cultural heritage. Structural and/or non-structural measures can be applied in both cases.

This may involve protecting the site in advance by introducing rules for the protection of cultural heritage, such as preventive non-structural (mostly administrative) or policy measures, as well as installing more traditional defensive structural measures.

Figure 3.1.1: Information flow from European level to national, regional and private household level. Source: CHEF.

3.1.1 Administrative measures

Legal basis

Non-structural measures for preventive reduction of the risk to cultural heritage are predominantly administrative. Correct, well-prepared, timely communication between administrations, founded on a harmonized legal basis, is essential for efficient prevention and mitigation of flood related damages to cultural heritage, whether or not any structural measure is jointly implemented.

The European Commission has introduced a legal basis for environmental activities. The European Flood Directive (EFD 2007) requires Member States to first carry out a **preliminary assessment** by 2011 to identify river basins and associated coastal areas at risk of flooding. For these zones, they will then need to draw up **flood risk maps** by 2013 and establish **flood risk management plans** focused on prevention, protection and preparedness by 2015. The risk management plans for cultural heritage should refer to the assessment and management of the flood risk, previous and ongoing activities. The general EFD requirements also refer to cultural heritage:

- **Prevention**: prevent damage caused by floods to cultural and heritage sites. Effective flood prevention and mitigation requires coordination between member states and coordination with third countries;
- **Protection**: take structural and non-structural measures to reduce the likelihood of floods and the impact of floods in a specific area where parts of the national cultural heritage are located;

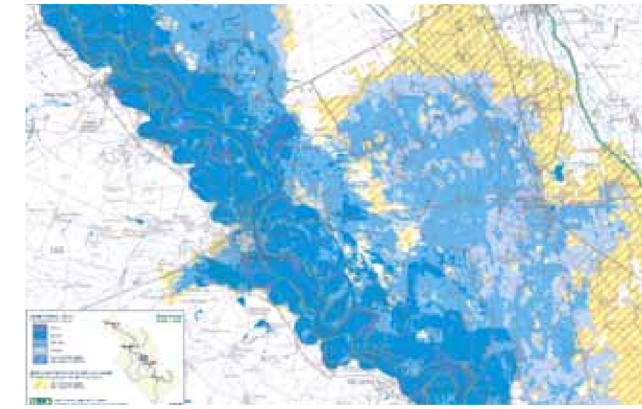


Figure 3.1.1.1: ELLA: the flood action plan includes non-structural measures, e.g. improving the retention capacity of the land in the river basin or adapted land use in flood risk areas

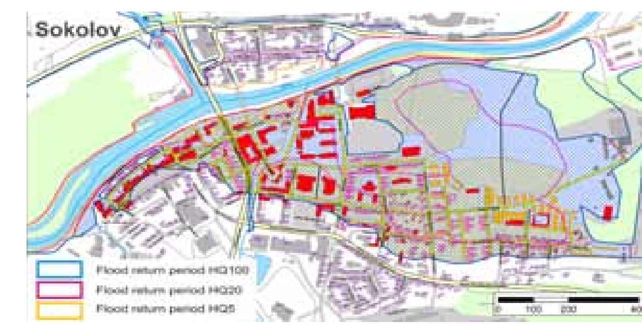


Figure 3.1.1.3: Sokolov CZ, flood risk defined as HQ5, HQ20, HQ100. Source: ITAM.

- **Preparedness**: raise awareness, with a focus on cultural heritage embedded in the overall hazard information systems informing the population about flood risks and what to do in the event of a flood;
- **CHEF Definition:** The cultural heritage to be protected against flooding is stock-at-risk, defined as the amount of movable and immovable cultural heritage that is potentially subject to the effects of floods, taking into account the possibility of flood water reaching any individual asset or historic centre/village within the flood-prone areas.

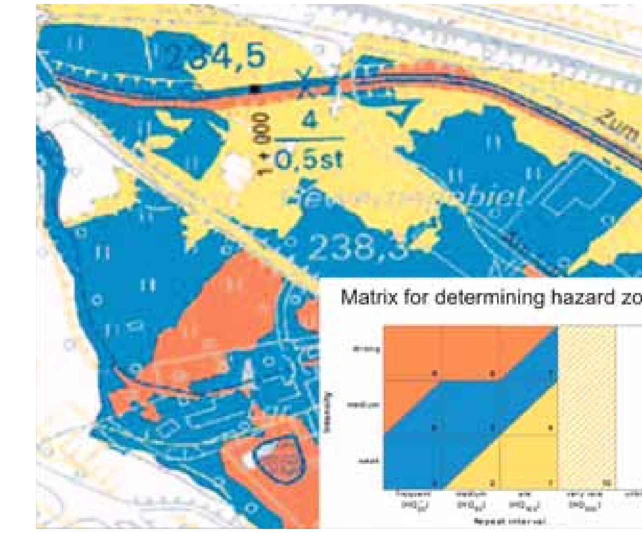


Figure 3.1.1.2: Example for determining hazard zones Source: both plans with kind permission of the ELLA Interregio project. Source of both plans: Ella

Transregional activities

After the fatal floods in recent decades, the European Commission has introduced transregional research targeted on coordinating transnational activities for the preparation of assessment, management and risk maps of river basins from the spring to the mouth of the river, including all feeding streams. Examples of these projects carried out in the INTERREG III and IV-programmes are ELLA (Elbe-Labe river basin in Central Europe), followed by LABEL, Oderreg (Eastern Europe), MOSES, SAFER (coastal flooding in Western Europe), CRUE ERA-NET, Noah/FLIWAS (Flood Information and Warning system in North West Europe).

Several websites provide user-friendly risk mapping in the regions of the project partners. Other providers offer risk maps on a CD. Unfortunately, the maps are based on different parameters, such as flood return periods or flow rates, and do not include specified Heritage layers.

In the case of immoveable heritage, suitable mapping of the flood hazard over the territory forms the basis for issuing appropriate regulations to limit permitted activities and landscape modifications in the vicinity of the target heritage object. The population involved, and also managers and staff need to be aware of the risk to cultural heritage, in order to improve preparedness and support for further planning of risk management strategies (structural or non-structural).

Non-structural measures

Systems introduced at European level, e.g. INSPIRE, enable the Member States and their neighbours to use the Infrastructure for Spatial Information in the European Community. The available tools can be used for further implementation of Heritage-related data sets.

Non-structural measures are based on initiatives that do not involve any construction work, installation of man-made artefacts or technological systems, and therefore have no ability to prevent, block or deviate the flow of flood waters and divert them from the target area or the cultural heritage asset. These measures are generally not intended to be effective against the flood hazard. Rather, they aim to reducing the exposure and vulnerability of the territory and the cultural heritage within the territory by acting in accordance with risk management plans.

When dealing with various categories of moveable CH objects, it may be easier to act on the exposure side of the risk by preventing the objects themselves being affected by flooding. The actions and measures must be included in appropriate risk management plans, e.g. for museums, traditional or media libraries, depositories, etc.

In the case of immoveable assets, where the exposure is hard to define, modified non-structural measures are more difficult to apply and may involve preparedness and training, as well as continuous monitoring and maintenance of the material structure of the work of art, building or natural object. Note that barriers, which are in most cases physical systems installed on the territory or applied to the object, either interposed between the flood and the structure or directly between the water and the surface or internal materials, should be regarded as structural measures aimed at reducing the exposure or vulnerability of cultural heritage objects.

Risk management plans play a major role among effective non-structural measures, especially in the case of moveable cultural heritage. The plan should contain all information concerning the objects, their value and their exposure to a range of potential hazards – including those related to floods, the associated vulnerability, and all actions to be taken during and after a flood. The risk management plan aims to provide a reference set of practical rules, actions and some "dos" and "don'ts" for the staff in charge of safeguarding the cultural heritage asset, rescue team members, volunteers, etc. These rules will enter into force in the event of an emergency due to various types of risks, either natural (earthquakes, floods, etc.) or human made (fire, vandalism, burglary, etc.)

In many real cases, however, the available risk management plans for cultural heritage (if any) do not include flooding among the potential threats, even for sites where the risk is actually high or at least significant. This is usually due to a lack of knowledge about the actual threats on the part of the personnel in charge, and consequent lack of awareness of the risk. Information campaigns and targeted staff training are of paramount importance for effective damage prevention. Even very simple information initiatives, e.g. based on leaflets or short guidelines, can be very effective in increasing awareness of the risk, and therefore preparedness, damage prevention and damage mitigation.

Suitable location and use of buildings is another basic non-structural measure, and may include relocating or re-organising the positioning of moveable objects within a building (or distributing them among separate buildings) according to their vulnerability to flooding. These measures can be permanent or temporary. Temporary measures should be linked to the issuing of flood warnings and severe weather forecasts, where available. Moving delicate objects in response to flood warnings can be rather expensive and requires time and resources, and reliable forecasts are an essential support for measures of this kind.

Awareness raising

Examples have been given of non-structural measures such as flood hazard mapping and associated administrative and regulatory restrictions, risk management plans, education and training for staff, etc., but there is still room for improvement. For cultural heritage, it is advisable to employ a person or a group responsible for knowledge transfer between flood experts, rescue teams, decision makers and responsible staff in the field of cultural heritage. Workshops, seminars, flyers (see Fig. 3.1.1.4), programmes on TV and radio, as well as articles in journals, may be organised on all levels of decision-making. Organising seminars and workshops at universities or in scientific organisations (e.g. URANIA) can increase the awareness of people in flood-prone areas. To raise awareness, Saxonia organises exhibitions, animated film shows, and a painting contest for children, produces a calendar and provides information for use in TV and radio programmes.

For more information about these flyers, please see Annex, Chapter. 7.1.

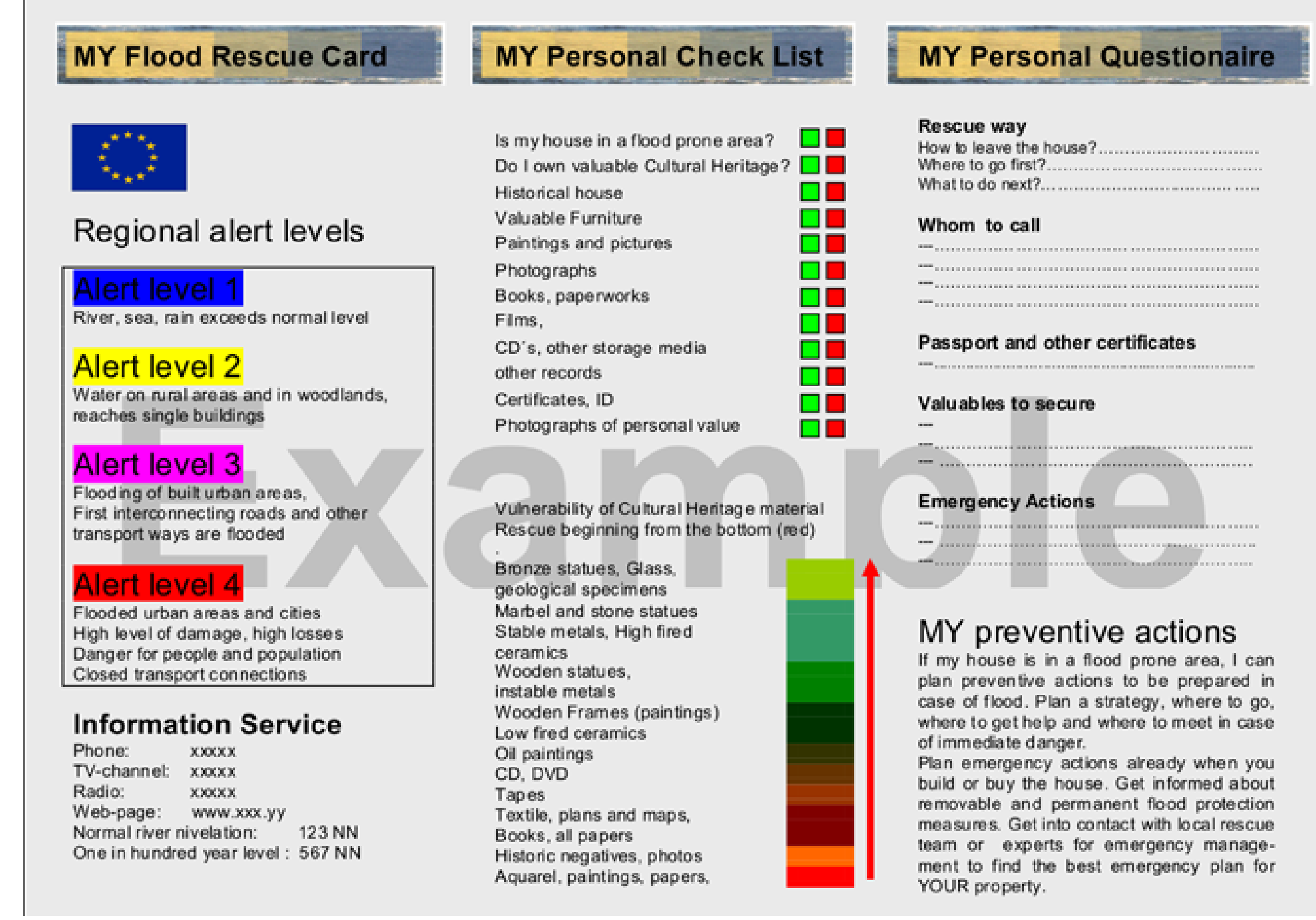


Figure 3.1.1.4: Example of a suggested Flood Cultural Heritage Info-CARD (CH-Info-CARD) Source: R. Helmerich, C. Köpp.

After suffering in the flood in 2002, some federal state administrations started to take protection more seriously, and developed flood risk plans supported by the European Regional Development Fund. Unfortunately, current administrative measures do not refer specifically to cultural heritage. For public or national cultural heritage, the responsible staff need rules, tools and training for better communication among different authorities, as well as more knowledge about stock at risk and good flood hazard maps.

Moreover, public owners and private households are sometimes not aware of the value of their own cultural heritage or the impact of flooding. A fast and simple measure that can be taken is to design two versions of a CH Info-CARD and distribute it to private households and public cultural heritage sites, communities, stakeholders, managers, etc.

3.1.2 Practical measures

Responsibilities for planning and executing preventive measures

At regional level, the practical actions in the event of flooding must be clarified in advance. This includes

- -defining responsibilities
- -organising knowledge transfer and communication

Preventive measures for the protection of cultural heritage should form part of the general flood prevention system of a region. Regional systems have been developed within the Interreg programme, and information transfer and communication are already organised in many regions, e.g. the Odra-Nisa region and the Elbe/Labe-Mulde region. An addendum to existing flood warning systems should provide extra information about the special needs for protecting cultural heritage.

The person in charge represents and links the community, hazard prevention and cultural heritage sites. She/he can be an employee of the community council, or a new position can be established, depending on the amount and value of the cultural heritage in the region.

The person in charge and her/his deputy responsible for the link between cultural heritage in the region and the hazard system should develop strategies and be informed about all key aspects of dealing with cultural heritage before, during and after a flood. The person and her/his deputy are responsible for awareness raising, workshops, seminars, publications, listing regional cultural heritage, and for installing and testing early warning systems in cultural heritage structures.

The community or municipality, e.g. in Dresden, uses public schools, evening schools and universities for training, seminars and workshops on flood prevention. If an information campaign is already running, cultural heritage should be integrated into the current programme schedule.

Public cultural heritage, e.g. historic sites, historic structures, museums, castles, churches and archives, need to appoint and train a person to keep in contact with

- national and regional hazard prediction websites, radio and other early warning systems, and
- urban rescue teams that function as multi-hazard specialised teams (e.g. the German Technisches Hilfswerk)

Privately-owned cultural heritage

People in flood-prone areas with annual floods are usually well prepared for flooding. They do not live on the ground floor, and have parking lots there instead. However, private households in communities that do not suffer from annual floods may be affected by more unexpected flood events, e.g flash floods or once-in-a-hundred-year floods. In these places, life is not organised round protecting the property from flooding. People may not be aware of the possibility of flooding.

Awareness-raising and providing information:

- about floods, and
- about treatment of cultural heritage

are major themes in raising awareness and preparedness in the population. Information and awareness-raising can be achieved by educating and training voluntary rescue and fire workers, and also by distributing the CH Info-CARD to households.

3.1.3 Identifying the individual risk of cultural heritage objects (examples), flood diagnosis

The state-of-the-art for the design of preventive and protective measures for any structureconsists of estimating the value of a loss and comparing it with the costs of preventive measures.

R (Risk) = (P) Potential loss x (D) Probability that a flood will occure and cause damages

However, because of the lack of a lobby for cultural heritage and the economic power exerted on behalf of industrial facilities, commercial centres and private housings, the value of cultural heritage has tended to be underestimated, and public funds have not been made available for necessary preventive measures. Loss of cultural heritage is not acceptable.

The individual risk to Cultural heritage consists of the potential value of the loss and the probability that a loss caused by a flood will really occur. None the less, in case of cultural heritage, the loss is not acceptable.

The following structures and materials are considered to be at high risk under the impact of water with a high flow rate:

- Free-standing walls,
- Light-weight structures (historic timber bridges),
- Water-absorbing materials (straw, paper)
- Sensitive structural details, e.g. open joints that enable water to come into a building

Identifying the materials used in historic houses, e.g. clay, water soluble paint or timber, can be decisive for the choice of appropriate rescue measures. Rescue teams must be trained to understand the behaviour of historic materials and historic structures, e.g. the different behaviour of clay, plaster and cement under the influence of water, salt, dirt and humidity.

Thus the individual risk to movable cultural heritage (photographs, water colour paintings, archive papers, timber figures, old furniture, oil paintings, old clothing) has to be assessed for often unique heritage objects according to their behaviour under flood conditions. The value of an individual object as part of the risk assessment can only be assessed in comparison to some similar or related object.

One-page information sheets (Chapter 7) may help in analysing vulnerability. A priority list for cultural heritage will be helpful for rescue teams. If exhibitions of movable heritage objects are planned in flood-prone regions, the exhibition should not be planned in the basement of a castle or museum, but on a higher floor.

3.1.4 Traditional means and instruments of prevention: dikes, retention areas, suitable use of buildings

Structural measures

Initiatives involving construction or installation of man-made artefacts or technological systems to protect of life and property from the action of flood water are known as structural measures. These structures and systems may be permanent or temporary. Temporary measures are generally installed only when there is a flood or when a flood event has been notified.

The initiative generally aims to reduce the hazard by physically preventing the flood reaching the site where the CH assets are located. It also may prevent water (or humidity) reaching a part of the building or some material or component of the structure that needs to be protected. The measures basically act on the exposure component of the risk. In many cases, the measures that are undertaken form some kind of barrier preventing water reaching a vulnerable part of the structure.

Figure 3.1.4.2 (above): Gabion walls in Romania to prevent damage from the annual spring flood. Source: BAM.

Figure 3.1.4.1 (below): Bored pile protective wall for Grimma Castle. Source: BAM.

Barriers can assume multiple shapes and can use various construction techniques. They range from very large embankments and dikes to protective layers of limited thickness over the walls of buildings and appropriate treatment of the surfaces of a structure.

However, not all structural measures are physical barriers. They may be temporary water storage facilities, diversions, spillways or other hydraulic devices, used in combination and distributed in the territory. They may also use pumping stations, flow regulation devices, drains, filters, etc.

Structural measures reduce the impact of a flood. They are usually very effective over the range of the design flow rates (return periods), water content and hydrograph shapes, though they are generally expensive and have a strong impact on the territory or structure. Temporary structural measures can sometimes deal effectively with higher flood magnitudes than are anticipated for the design floods, and have the advantage that they are not a permanent part of the landscape and do not impact the sightlines of a historic building or city center. They are used to reduce the adverse impact of very extreme events.

By directly influencing the flood hazard, i.e. the probability that a flood of a given magnitude will strike the target, large scale structures are also effective for a wide range of cultural heritage assets, both moveable and immoveable, over scales ranging from a single work of art to the entire historic centre of a large town.

There are many examples of large structural measures, e.g. the project developed in Genova (Italy) to exploit the existing underground ancient cisterns used for harvesting rainwater as storage volumes to reduce the risk of flooding in the medieval historic centre (Le Strade Nuove and the system of the Palazzi dei Rolli have been on the UNESCO world heritage list since 2006). The feasibility of the project was demonstrated within the EC-funded LIFE-ENVIRONMENT project under the title IMOS (Integrated Multi-Objective System for Optimal Management of Urban Drainage) in 09/01/2001 - 08/31/2004, and a part of the system is now operating in Genova.

One major disadvantage of structural measures is the high cost of constructing, implementing, maintaining and operating them. The investment involved may be considered by politicians and decision-makers to have an insufficient yield, and the necessary funding is often found only after a catastrophic flood has aroused public opinion (e.g. Florence, Dresden, Venice, etc.) The design and materialization of structural measures also requires various special competences and an interdisciplinary approach.

It is worth noting that the failure of a flood protection system based on structural measures may lead to greater damage than the previous uncontrolled situation would have produced, due to the increased confidence of the population and public and private owners of cultural heritage assets in the (partially) protected environment. The exposure and vulnerability of cultural heritage in target sites can even be increased, due to overreliance on visible and "safe" structural measures. The risk of failure of structural measures and the residual flood hazard after the structural measure is implemented (see Section 1.3) should therefore be accurately taken into account, and appropriate actions must be included in the relevant risk management plans.

Environmental Measures

- River regulation in and above cities should be decided carefully, since the natural retention areas must retain their functionality
- River catchments
- Retention areas
- River regulation

Geotechnical and structural measures

- Impermeable underground barriers (e.g. sheet pile walls)
- Dikes and levees
- Protection walls (e.g. concrete or gabion walls)

Structural measures for historic cities, parks and infrastructure

Permanent structural measures to protect immovable cultural heritage from heavy rainfall, river flooding and sea floods usually form part of the preventive measures in local action plans. These action plans are updated according to the latest state-of-the-art. They do not focus only on preventive protection of immovable and movable cultural heritage. Defensive walls for historic cities or districts are proposed and decided on a regional community level. In recent years diaphragm, bored pile and sheet pile walls have been used to shelter individual buildings such as castles, churches and other structures of historical value. Discussions at community level may bring together concerned parties with different interests. The communities are in charge if the discussion deals with historic bridges. Although anti-scour protection of bridges or horizontal stiffening of bridges against flood water may be the only solution that will enable a bridge to survive the

Table 3.1.1: Preventive measures can be generally categorized as follows:

Traditional instruments for prevention		
Instruments for prevention	Risk reduction	Responsibility
Dikes Levees	Risk reduction to castles, churches, parks near rivers	State, cooperation between neighbouring states (Interreg Program), Levees along the Elbe river
Retention areas, River catchments	Rethink the regulation of rivers with respect to cultural heritage	National and Federal States, transnational planning of river regulation
Suitable use of buildings	Storage of vulnerable materials in higher floors of buildings	
Strengthening of bridges	Strengthening of foundations and horizontal resistance against flood water, increasing the profile of bridges	Municipalities, authorities for water management, road and railways
Gabion walls, sandbags	sandbags and gabions should be stored as a precaution against floods	
Advanced tools for preventive reduction of the flood risk to cultural heritage		
Instruments for prevention	Risk reduction	Responsibility
Sheet pile walls Diaphragm walls Bored pile walls	Flood risk reduction for single buildings: castles, churches, museums, prevents increasing ground water penetrating into cellars: Grimma castle is provided with a bored pile wall along the river front	Communities, houseowners, administration
Aperture control		
Mobile flood gates, Sliding locks	Reduce the risk of flooding to buildings behind them: A flood gate was installed in Dresden, Ostraufer (closed if the Elbe exceeds 4,5 m)	
	A sliding lock in Prague protects the historic city centre at the mouth of the Certovka	
Preventive measures for movable heritage		
Measures for prevention	Risk reduction	
Terminated exhibition	Do not allow exhibitions in flood-prone areas	Directors in charge, supported by a team of conservators, hazard-related staff, specialists in material degradation
Transfer movable heritage to higher levels of buildings	Prevent exhibitions in flood-prone areas in basements	
Document movable heritage for valuation	Transfer documentation (e.g. one-page information) to rescue teams	
Provide training on vulnerability to flood, dirty water, salt, and make a ranking order	A ranking order can help rescue teams to know what to save first	

next once-in-a-hundred year (HQ100) flood, communities and preservationists may disagree on the desirability of such a measure.

It is necessary to be careful about surface protection layers in large communities. In the event of flooding, the sewer systems are usually overloaded, and unpaved city areas in cities have an important drainage function. Natural stone pavements of streets and squares are preferable to total coverage with layers of concrete or asphalt.

The vulnerability of immovable and movable heritage varies according to the individual material parameters, as well as the structural conditions. Immovable heritage structures such as bridges, churches, castles and parks may need strengthening in order to resist surface water and to prevent water destroying materials that are sensitive to humidity. Investment in flood protection measures reduces the risk to vulnerable cultural heritage. Both traditional and advanced measures need to be applied.

3.1.5 Recommendations

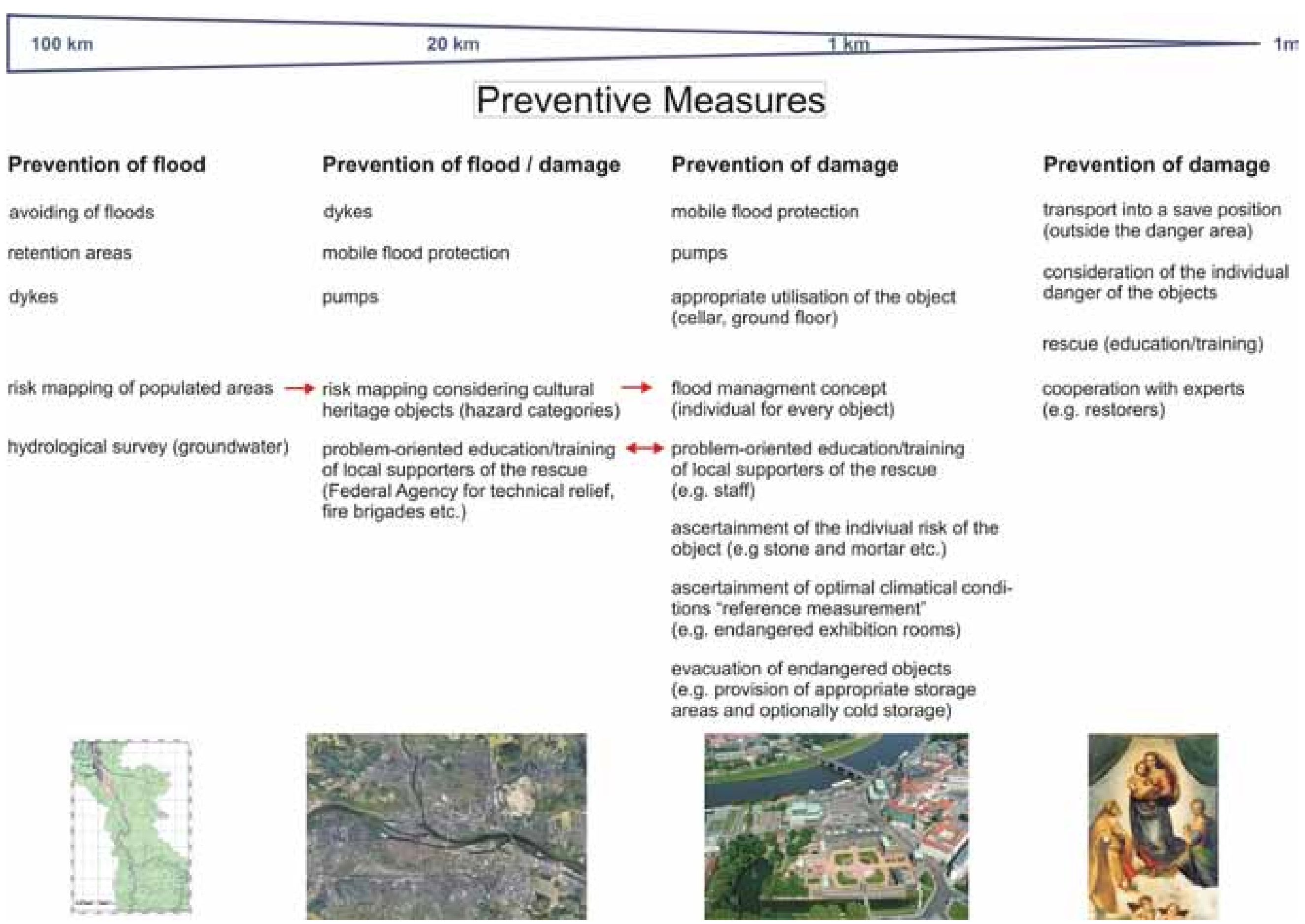


Figure 3.1.5.1: Preventive measures in relation to the potential flooded area size.
Source: J. Meinhardt, I.C. Hennen, C. Franzen, with small photos a) catchment area of the River Mulde, used and modified with kind permission of the Helmholtz Centre for Environmental Research (UFZ), b) aerial photo of Regensburg, with kind permission of DOP © Landesamt für Vermessung und Geoinformation Bayern (permit number: Az: O 1419 VM A - 0806/10), c) aerial photo of Dresden (Zwinger), with kind permission of Adconsys Corporation, d) Sistine Madonna (Raffael), Gemäldegalerie Alte Meister (Old Masters Picture Gallery), Staatliche Kunstsammlungen Dresden, Elke Estel/Hans-Peter Klut.

On an EU level

A summary of preventive measures points to some measures that need to be taken. European Commission policy provides tools for further steps to implement cultural heritage into ongoing strategy in the European flood directive by 2015.

- **Set up a project and guidelines for implementing CH layers into existing flood risk mapping**
- Harmonize data and classification systems throughout Europe for characterising flood-prone areas (e.g. into three classes HQ20, HQ100, HQ200)
- Make use of the Interreg IVb programme or Inspire to implement knowledge gained on movable and immovable cultural heritage
- Develop European guidelines for setting up teams to estimate flood risks to cultural heritage and to prevent or limit flooding
- Set up education, and training and workshops for new staff
- Raise awareness of hazards and disseminate information about cultural heritage in primary and secondary schools.

On a regional level

- Verify whether cultural heritage objects and structures are located in a flood-prone area (>HQ100-200)
- Include CH data in regional Risk mapping
- Check the cultural heritage in your region according HQ-classification
- Check cultural heritage according to vulnerability
- Prepare complete documentation about CH sites, objects and collections (value, vulnerability, photographic documentation)
- Education, training and workshops for new assessment and rescue staff.

Cultural heritage is a socio-economic value and forms a part of people's identity. The roots and identity of places, regions and the nation should be treated with great care.

3.2 During a flood

Christoph Franzen, Insa Christiane Hennen

3.2.1 Introduction

It is not easy to evaluate actions affecting cultural heritage that take place during a serious flood event. The first priority is to protect the life and health of human beings. After this, prioritisation becomes more complex. It is highly recommended to follow the work flow of an emergency action plan which, of course, has to be developed in advance and has to be known by the persons involved. Regular training is essential. Management plans for emergency events should be formulated in an openly modifiable matter, as hazards tend to emerge in unpredictable ways. Management plans prepare affected persons to react in the best known way to avoid or mitigate damage to cultural heritage. Without careful preparation, unique cultural heritage objects and stuctures are liable to be damaged or even totally destroyed.

During a flood event, too, it is necessary to differentiate between movable and non-movable cultural heritage objects. The following general recommendations do not replace the proposed emergency planning, which has to take into account the specific features of the site and the cultural heritage objects. Thus movable and immovable structures and objects will not be considered independently. The discussion will refer to the wide range of movable cultural heritage objects located in a immovable cultural heritage environment.

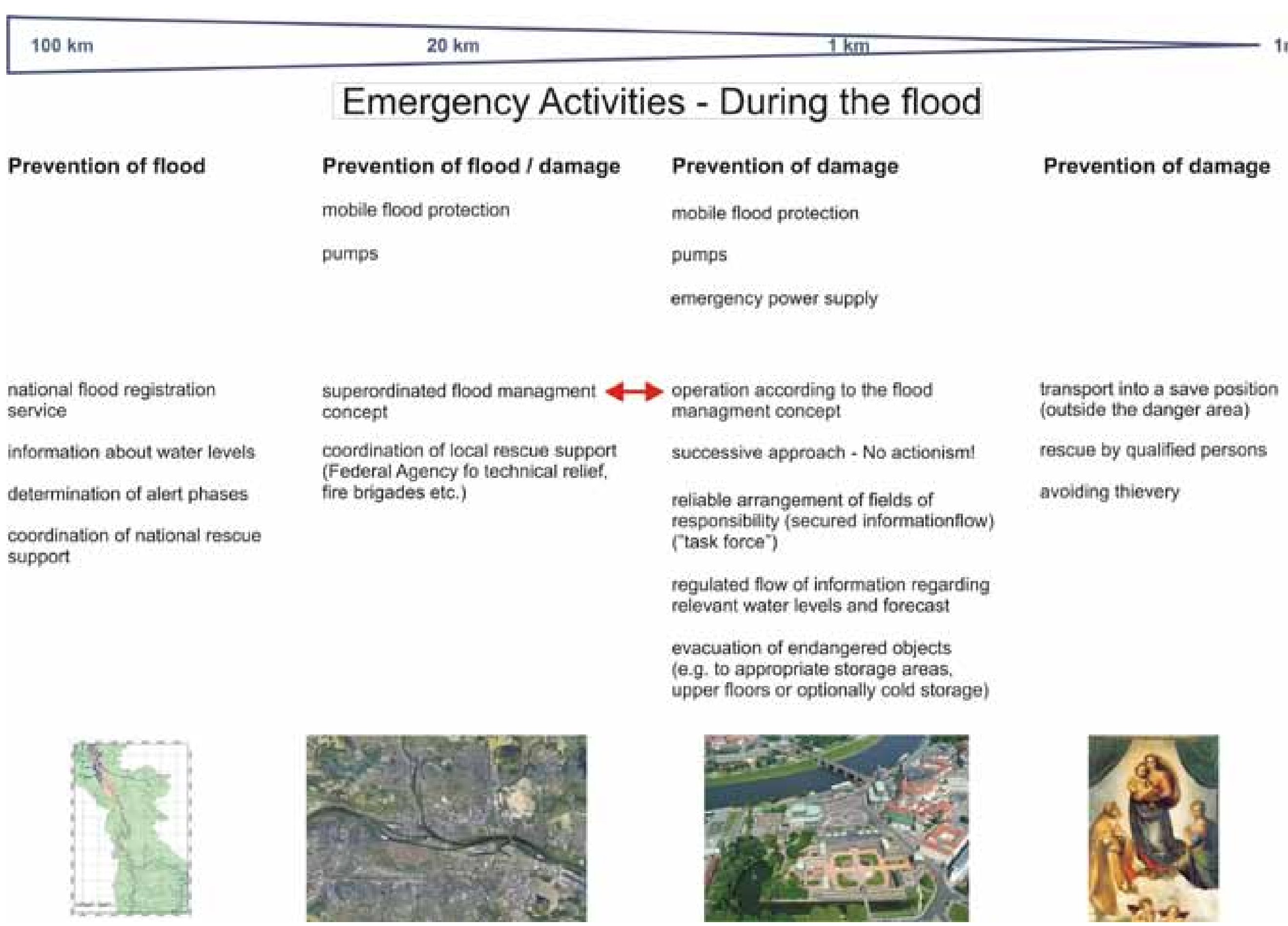


Figure 3.2.1.1 Emergency activities during a flood deepending on the distance to the flooded area. Source: see figure 3.1.5.1.

3.2.2 Rescue action during a flood event

Critical review of activities during a flood

When we evaluate documents and reports on historic floods, it becomes clear that specific actions during the flood event tend to go undescribed. Specific information of this kind is gathered mainly in interviews with eye witnesses. Much significant experience can be drawn from case studies.

In some cases, the civil protection agencies were not prepared for handling cultural heritage. Other bodies (e.g. civilian volunteers) involved in the emergency case were often overstretched. At the same time, the authorities and persons in charge of cultural heritage were only rarely prepared or trained to handle catastrophic emergency situations. The decision making was sometimes hectic. Communication among people on site rescuing cultural goods and specialists for handling thesegoods was established by accident or by personal networks, but was by no means well organised. After various flood events, the situation changed, and cultural heritage experts were increasingly involved. The communication between different local, regional, national and international water and flood management actors has generally changed and improved during the course of the CHEF project. However, the needs of cultural heritage seem to have received insufficient consideration.

Recommended activities/emergency actions during floods (or during an emergency caused by water)

Emergency actions often suffer from a lack of calm. This is due to the dramatic situation, but the need for a calm head should always be stressed in training courses. This is the first requirement for any rescue worker. If emergency plans exist, they should be followed. If not, a smoothly functioning communication hierarchy has to be installed.

1. Reconnaissance of the site and portfolio

Knowledge of the site is of primary importance in emergency actions. Only people who know where to go and where to find things are able to take effective action. The entire heritage site, including service areas and unused areas should be known to many persons, including all staff members, firemen and members of other rescue services. The entire portfolio of the museum should also be well known and well documented. Every object and its location needs to be registered. Inventory systems are helpful, as they provide good access to objects and their documentation data. The documentation should include a description of the normal state of the site (e.g. moisture content and climate) and any existing damage to objects.

2. Ensuring safety during a flood event

Flood events typically occur unannounced, and heritage sites are not primed by strategic emergency plans. Materials, heritage objects and technical equipment may be kept in low-lying areas of heritage sites. The electricity system will first become dangerous and then go down. Electric shocks are a threat at first, followed by loss of lighting, loss of electricity supply for elevators, ventilation and pumps. When movable objects need to be transported and stored in safe areas, the loss of power supply is an important factor that needs to be taken into account.

3. Installing a communication system

During a flood, it is necessary to establish an internal communication system within the site area and with the outside. It is also important to have a good idea of how the situation is likely to develop in the near future. In a flood, it is important to know the velocity of the rising of water level. It is necessary to be able to communicate with the nearest flood control centre and with the nearest local authority in order to give and receive information about the situation on site.

4. Beginning of rescue and salvation works

In all actions, it is necessary to avoid inhibiting later efforts and to make sure that efforts will not need to be repeated. For example, technical equipment, e.g. tubes of water pumps, should not block pathways, and equipment transported to a rescue site should stored in an area that will be safe for the entire event, and not only for the next three hours.

In the case of most movable cultural heritage items, removing water-sensitive objects out of the area of water risk is enough to rescue them. Some limitations may be mentioned. There can be a danger of too much action. Mistakes happen in hectic decision making. Items can be damaged in the course of evacuation, especially due to rough transportation or inadequate storage conditions in their new place. Moreover, heritage objects can be rescued but then go astray due to theft or lack of information on their whereabouts. Careful supervision is always indispensable.

5. Documentation

Almost all aspects of documentation are of major importance during a flood event. Firstly, photos and handwritten notes during the emergency can provide documentation of objects and about the site. Documentation of the flood itself and its side effects is also of high value after the flood. Flood characteristics should be documented in as much detail as possible. The most important data to record is: the duration and height of the flood, water temperature, salt content, particle content and any chemical contamination. Flood events are often unanticipated, and observation tools may not be available. Time can also be at a premium. Photography is a quick and effective way or recording useful data. Even if no gauges are installed nearby, water levels can be recorded by taking photographs or by leaving markers.

3.2.3 National and international cooperation

During flood events, rescue services need to interact, and are generally willing to do so. However, the civilian administration in the different European countries is not well coordinated.A weak point all over Europe is the knowledge gap in all public services about handling cultural heritage. Improvements need to be made on a quite broad scale. Emergency plans normally arrange for communication between the sites and the civil administration. However, staff need to be trained. Training courses can easily be set up with the participation of experienced experts e.g. from non-governmental and non-profit organisations, such as ICOMOS and ICCROM.

When a major catastrophe occurs, the implementation of a Monitoring and Information Centre (MIC) needs to be considered.The MIC should contain a section dedicated to and trained for the special needs of cultural heritage protection. The MIC operated by the European Commission in Brussels is the operational heart of the Community Mechanism for Civil Protection. It is available 24/7, and is staffed by duty officers working on a shift basis. It gives countries access to the community civil protection platform. Any country affected by a major disaster, inside or outside the EU, can launch a request for assistance through the MIC.

During emergencies the MIC plays three important roles:

Communications hub: Being at the centre of an emergency relief operation, the MIC acts as a focal point for the exchange of requests and offers of assistance. This helps in cutting down on the administrative burden of the 30 participating states in liaising with the affected country. It provides a central forum for participating states to access and share information about the available resources and the assistance offered at any given point in time.

Information provision: The MIC disseminates information on civil protection preparedness and response to participating states and also to a wider audience of interested parties. As a part of this role, the MIC disseminates early warning alerts (MIC Daily) on natural disasters, and circulates the latest updates on ongoing emergencies and Mechanism interventions.

Supports co-ordination: The MIC facilitates the provision of European assistance through the Mechanism. This takes place at two levels: at headquarters level, by matching offers to needs, identifying gaps in aid and searching for solutions, and facilitating the pooling of common resources where possible; and on the site of the disaster through the appointment of EU field experts, when required.

3.2.4 First-aid Measures

Cultural heritage objects that at the time of their rescue have been in contact with water must be handled with special care. First, they have to taken to a safe place out of risk of being flooded a second time. Trivial as this may sound, it is an important outcome of the evaluation of earlier disasters that transporting objects to places that can be described as safe is not always easy. For fragile cultural heritage objects, it is not advisable to "clean" them immediately. The same is true for drying. It is essential that all actions on these materials be done or supervised by a specialised restorer or conservator. Most of the material should taken to cold stores to avoid ongoing damage, e.g fungi or mould growth. Data on probable causes of damage is documented as basis for diagnosis and further assessment.

3.2.5 Recommendations

Flood protection of cultural heritage covers several stages. cultural heritage sites need to be integrated into overall flood protection strategies in such way that their unique value is preserved, as far as possible. Independently from all flood protection strategies, it is necessary to establish how to act when water enters the site from any source or direction. In the great majority of cases, a flood hazard develops from below and then rises. Assessing and taking into account the risks of flood damage in any space can avoid serious losses. The use of cultural heritage structures in flood-prone areas has to be discussed thoroughly between owners, users and emergency experts. An appropriate configuration has to be identified, and equipment and management need to be provided that can endure flood events without unnecessary loss of unique cultural heritage.

3.3 After the flood

Zuzana Slížková, Heiner Siedel, Luigia Binda, Giuliana Cardani

3.3.1 Introduction

Interventions made after a flood must avoid worsening the damage to cultural heritage . This requires joint action by cultural heritage owners or managers in collaboration with specialist restorers and engineers. Soon after the flood, they should outline a plan for immediate interventions and also for repairs and restoration. It is recommended to set up a team that includes all parties concerned with the interventions, even though some of the members may have conflicting interests. All disputes and discussions must be supported by as much factual information as possible, and proposals should be weighed using cost-benefit approaches. Some recommendations and best practice advice for moveable objects and buildings are presented below. More examples, dealing also with sites and other cultural heritage categories, are shown in Chapter 4.

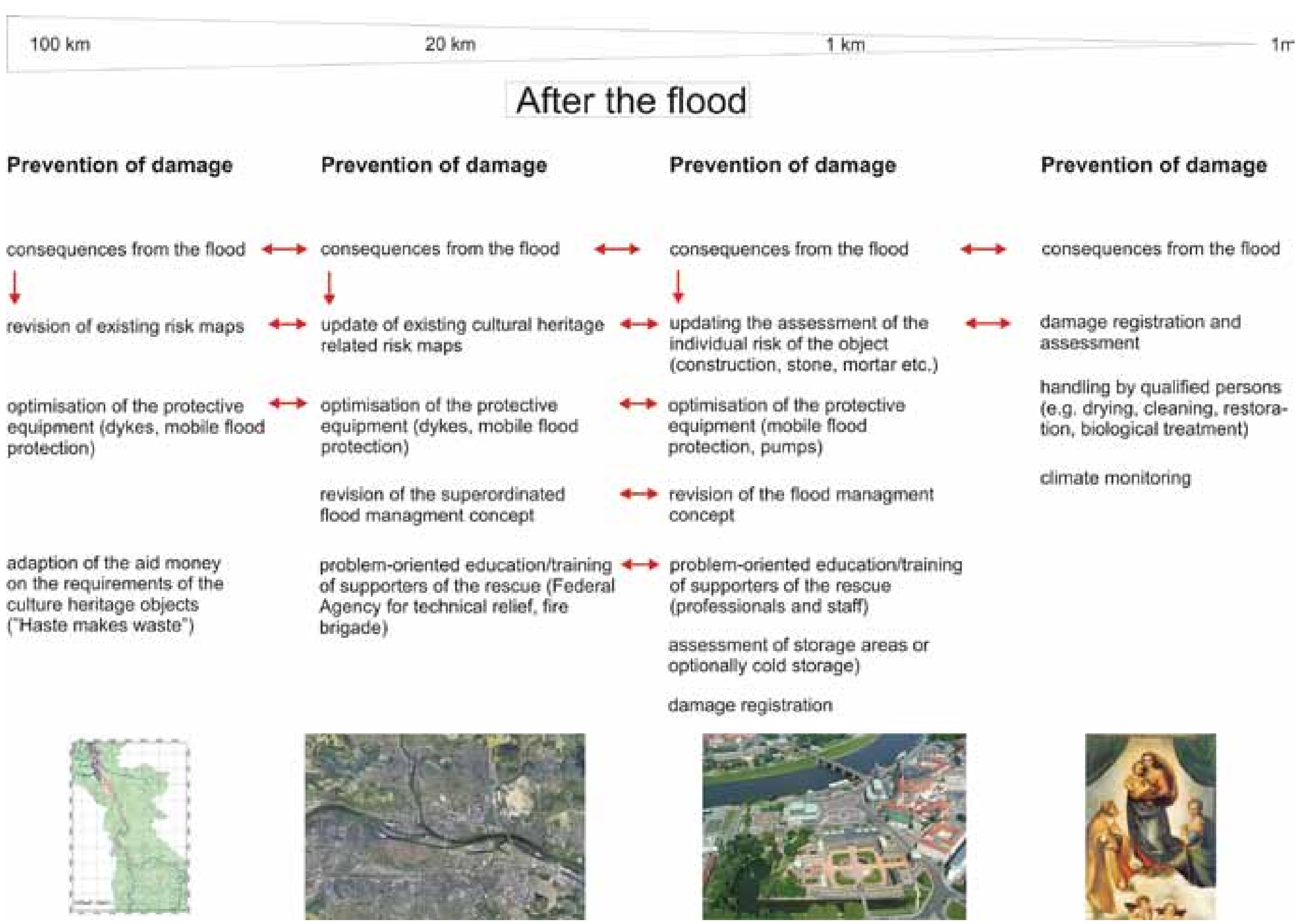


Figure 3.3.1: Rescue actions for prevention of damage after flood depending on the distance. Source: see figure 3.1.5.1.

3.3.2 Restoration and repair techniques for movable objects and materials

Recommended sequence of activities immediately following a flood (or an emergency caused by water)

1. Make a reconnaissance of the site (documentation, preliminary determination of damage, operative modifications to the crisis plan to cover the particular situation). With the consent of responsible persons, it is necessary to walk the affected areas, to handle the objects, and to carry out an evaluation of the type of the damage according to the external appearance of the collection items. In accordance with the crisis plan, provide help for persons who need it, and ensure that the required rescue equipment, materials and services are made available in adequate quantities. Collection items that have not been affected should be relocated to a distant place where they are not affected by the flood event.

2. Ensure stabilized conditions (protect objects against additional consequences of the event – stabilize the temperature /provide moderate heating/moisture/ dehumidifiers, ensure air circulation/provide ventilators/ move wet objects and moveable heritage out, remove useless equipment, sterilize shelves, walls, floors and ceilings).

3. Start the rescue work (sort the objects, make schedules of objects to be moved, place objects in marked boxes, file everything carefully, recording the packing and transportation of the collection items).

4. Renovate the activities and functions of the institution (museum, archive) and provide information for the media and for the public, apply for funding for further work, consult and negotiate with rescue services (implementation must be carried out by professionals and experts), document all operations and the temporary locations of collection items).

Recommended procedures for redeveloping/ saving collection items damaged by water

Paper (books, graphic arts, Blue Books, etc.)

Wash mud off the objects, using clean water (graphic arts should be unglazed). Do not open or unpack books or bound files, only wash the outsides and spines of books in an upward direction, preferably using a hose with a fine water flow. Ensure continuity in bringing the collection items out and washing them (do not allow contaminated items to dry out). When selecting the method for drying, consider particular conditions and options; printed books and documents that have only been exposed to the actions of humid air, or that have only been minimally wetted, can be dried in air (not in direct sunshine), at the lowest possible atmospheric moisture and with good air circulation (relative humidity of air below 50%, max. temperature 21°C). If the electric power supply has not been discontinued, partially wet books can be dried with the help of hair driers. Heap the material intended for freezing into crates or pack them in PE foil, if necessary. Freezing must be applied rapidly (to a temperature close to -30°C), in freezing vans used for transporting the material to a high-capacity freezing plant. The valuable material of collection items is then lyophilised (freeze drying is applied - sublimation of water under a vacuum), disinfected and restored. This method is not suitable for illuminated manuscripts. These salvation measures should be carried out within 48 hours after the event; if it is carried out later the probability of full success of the operation is significantly reduced, due to massive formation of micro-organisms (moulds).

Photographic material

First, remove mud from the material by rinsing it in cold water. First document the photographs in historical passe-partouts and then, if possible, redevelop the passe-partouts separately (old passe-partouts are acidic, and contain glue). For this activity, use baths with clean water; wash the photographs separately in horizontal position, hold them by the edges and avoid contacting the emulsion, as far as possible. If a minimal amount of non-ionogenic tenside (detergent) is used for better wettability, the item must be properly washed with clean water. The last rinsing water should have up to 10% ethanol added to it. Dry photographic materials in free air in horizontal position, or hang them up on ropes. Photographs on metal pads (daguerreotypes, ferrotypes) should be dried very slowly in horizontal position. After they have apparently dried, store them in an air-conditioned room (RH below 50%). Do not dry photographic materials under a vacuum (little experience of freezing photographic materials is available).

Paintings on canvas

First remove dirt and mud from the painting (also from the rear of the painting) carefully, mechanically and with the help of soft brushes dipped in clean water. The paintings should dry very slowly in horizontal position (especially if the paint is crackled or released, under the supervision of a restorer. The frames of pictures should be removed immediately. Avoid distorting the paint, and ensure that the canvas remains tight during all phases of drying. Disinfection (if any) of the painting to prevent the propagation of moulds must be carried out very carefully. Test the disinfection agent on a small area (preferably on a place that is hidden beneath the frame) in consultation with a restorer or a conservation scientist. Never use chlorine-based, hydrogen peroxide-based or peroxoacid-based agents.

Wall paintings

Immediately after the water recedes, rinse wall paintings with clean water and to treat them against moulds. Select a disinfection agent according to the same considerations as for hanging paintings. Do not make the restoration intervention before the whole building, or the wall supporting the wall painting, has dried out.

Wooden artefacts

First wash the wood with clean water, disinfect as a preventive measure against propagation of moulds and fungi, and leave to dry out slowly (rapid drying can result in deformation and structural damage to the wood). Massive wood without surface finishing suffers the least damage. Document marquetries (as they might fall off) and fasten them mechanically, if necessary, until they dry out and until they are handed over to the restorer. If possible, separate furniture accessories from the furniture and treat them separately. If this cannot be done, at least loosen wood screws to prevent them corroding.

Metals

Remove mud, which can contain corrosive, aggressive substances, from the objects, using a brush and clean, flowing water. Metals can be dried more quickly and more intensively than other materials. They can be dried at high temperatures (105 °C), except in the case of archaeological objects. For smaller objects, a vacuum drying oven is ideal, as the drying process is intensive even at quite low temperatures. Finally, rinse archaeological objects with distilled water. After the material has dried it can be preserved.

All objects that have been flooded, including objects that were only partially immersed in water and had to be treated as described above, are vulnerable to various types of degradation attack. Therefore they will need to be stored in an optimal climate, and their condition will need to be checked frequently while in storage.

Treatment of collection items affected by floods entails certain risks. Use protective aids and disinfectants. Follow the instructions given by hygiene professionals.

Due to the wide range and variety of collection items (various materials, crafts, etc.), it is impossible to offer a uniform procedure for cleaning, restoration and preservation. The chapter on examples and case studies therefore gives only some generally valid principles for particular materials, along with examples of procedures for cleaning up and restoring a small number of specific cultural heritage objects affected by a flood (including pictorial documentation prior to and after restoration). Types of commercially-produced disinfection and conservation agents and their main active components are given in Chapter 4.4.3, together with a reference to the www pages of the producer, where possible).

3.3.3 Restoration and repair techniques for immoveable objects and materials

Recommended procedures for immovable heritage

After a flood event, the strategy for restoration and repair should follow a stepwise procedure about which all partners must be informed in detail, in order to avoid misunderstandings. The stages in the strategy should be as follows:

1. Site visit

During the site visit, all post-flooding problems are selected and identified. All damage is documented, according to the risk. On this basis, an analysis is made of the owners' needs and available resources (available staff, specialists, consultancies and funding). If necessary, structural engineers/consultants are called in to identify critical details of buildings (churches, castles, historic city centres) or historic structures, e.g. bridges. Once identified, the list of measures to be taken is attached to the self-support guide.

In case of largely diffused damages, templates should be used to document the failure mechanisms (see Section 3.4.4)

2. Scope of restoration

The scope of the restoration and repairs will include the work to be done, the strategy and the time schedule. The character of the damaged CH, the risk to people and to the environment, and also the historical significance of the buildings and objects will be taken into account for a rapid ranking of the work to be done. When ranking the restoration and repair work, vulnerability classes V0 – V6, proposed in Chapter 2, can be utilized. The vulnerability classes take into account the flood risk in the region and also the sensitivity of the materials (building materials, textiles, paintings, archives, etc.) to high moisture.

Before the repair work begins, it should be made clear which preventive measures are planned. It would cause double expenses if a new water protection wall or new door and window locks need to be installed after finishing restoration works and repairs to a facade. It is therefore necessary to clarify in advance which work needs to be done immediately, and which work can be postponed for a short time or for a longer time.

3. Carrying out the restoration work and repairs

Restoration and repair work should proceed in a way that will save cultural heritage and prevent further damage. Some examples, and an overview of restoration and repair works, are presented in this book.

4. Plan routine inspection

It is necessary to check protective measures planned for cultural heritage, such as structural measures or control systems, climate data loggers or climate control systems. According to the historical significance of the object, together with the risk, the vulnerability and the available resources, a plan for a routine survey, maintenance and an alert to-do plan for implementation in the event of further floods will help to provide preparedness for future hazards. Figure 3.3.3.1 gives an overview of the work flow.

General suggestions for restoration and repair techniques for building materials

The behaviour and deterioration of building materials (bricks, wood, plaster or tapestry) during a flood is mainly dependent on their main physical parameters, e.g. porosity, water absorption, compression strength, and, in the case of bricks, it is dependent on their mineralogical composition and on the firing temperature during the production process.

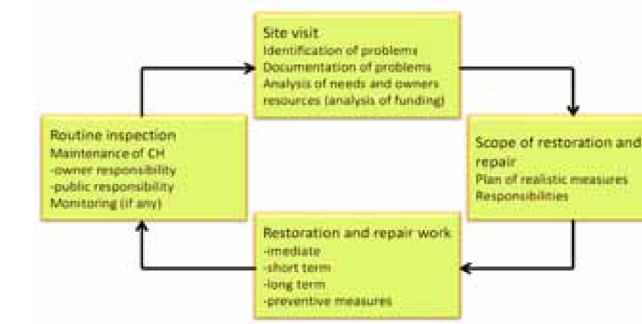


Figure 3.3.3.1: Planning for restoration and repair measures after flooding.

Removal of surface layers that prevent ventilation of air around the structural element must be considered and, in properly justified cases, implemented, so that air drying can be started as a first step. In the case of masonry with dried bricks, plaster may be helping to preserve integration, and removal of plaster may not be recommended. High moisture in masonry may result from capillary suction from the subsoil, due to the temporary elevation of the water table level, and may not be directly connected with immersion of the masonry into water.

Drying of masonry walls

The drying rate of masonry is influenced by many factors: by air circulation, and also by air humidity and air temperature. The humidity is higher in summer time than in winter, and the drying rate is slower. Drying is significantly influenced by the size and structure of material pores and also by the permeability of the surface of the masonry. Finishes of low permeability - some coatings, ceramic tiling, and also plasters with a high cement content slow down evaporation.

A brick dries out at about one inch per month, so have in mind that it may take several months for brickwork to dry out completely. The time needed for natural drying of masonry from a wet condition to a natural steady state can be computed using the Cardiergues relation T = k * b2, where T is time needed for drying in days, k is the evaporation rate factor (for brick masonry = 0,28), and b is thickness of the wall (in cm). For example, a brick wall about 45 cm in thickness will take about 1,5 years to dry.

Bricks suffer from flooding and high moisture content, if the porosity, capillarity and water absorption of the brick are high. In all regions, the quality of historic bricks varies. The physical parameters and the resistance against water depend on the brick-making process and the raw material. The lower the firing temperature was during the brick production process, the higher the absorption of water. Regional clays with a range of parameters were used in historic structures. Floods are particularly dangerous for air dried clay bricks. Air dried bricks are most sensitive to flooding, since their matrix has not been fired and hardened. They lose their solid consistency in water. Clinker bricks usually have lower water absorption, and are therefore not very sensitive to wetting.

Freezing expands the volume of the material (bricks and mortar) and causes enhanced cracking, spalling and deterioration. If there is heavy damage, the deterioration of bricks must be evaluated in regular inspections or in refined structure-related investigations.

How drying can be accelerated

After the water has receded or has been drained, mud and alluvium must be removed from the interior and exterior. For better vaporization of water, it is desirable to apply intensive ventilation supported by cross ventilation, by heating in cold weather, and by keeping enough space between the wall and the furniture, to prevent mould infections of organic materials (wood, paint binders, etc.)

Ventilation of a basement with massive masonry may be problematic, because it has high thermal stability, and can maintain quite a low air temperature (not more than 18 °C even in summer). Such spaces therefore need to be force-ventilated, or tempered. In winter, it is important to ventilate the whole building very often, including spaces that have not been flooded, because water vapour diffuses against the temperature gradient and can worsen the state of the indoor climate.

In addition to taking these elementary measures, wet surface layers of structures can be removed in justified cases, in order to support evaporation. This includes not only plaster but also floor layers and coats of PVC, timber, thermal insulation, etc. In wet rooms, it is recommended to remove all wooden items (windows, doors) that can be deformed by higher humidity or can be attacked biologically. However, every intervention into the building structure (removing the plaster, scratching mortar, etc.) must be done in consultation with a structural engineer. It is necessary to consider carefully whether the benefit of quicker drying of masonry compensates the material and cultural loss. Historical lime plasters have a relatively high drying rate. There is also a danger of disturbing the static stability of a structure, especially in structures made of unfired bricks.

In the first stage of drying out a building, space heaters or air-heating sets can be used together with ventilation. There is usually no electric power supply in flooded houses, so gas or oil is used. Fired products containing water vapour also need to be ventilated. Masonry has to be dried moderately to avoid cracking. It is recommended to work from bottom upwards, in adjoining rooms – walls should be dried from both sides. A condensing or absorbing dehumidifier can be used for drying interiors. They are used wherever there is a danger of damage from high air humidity.

Condensing dehumidifiers work on the principle of a heat pump: the vent air is cooled down in the evaporator of the cooling aggregate, and the condensed humidity is collected in a reservoir or is drained away directly to the waste water system. Dried air is brought into the interior, and the heat from condensation is used for warming the dry air. Long-term ventilation brings the humidity down to the required level. The optimum output is achieved at a temperature of more than 15°C (10 – 50 litres per 24h). If a dehumidifier is used, all openings in the room must be sealed so that only the air inside the room is dried.

Absorbing dehumidifiers are much more efficacious (up to 2000 litres per 24h). The vent air circulates in a rotor with a silica gel surface, and the humidity is bound physically. Redundant humidity is vented away in a hosepipe and removed from the building. These devices operate reliably even at temperatures below 10°C.

Flooded objects take a long time to dry. Water absorbed by masonry can usually only be released with ambient air, and is removed from the building. The size of the evaporative area, air circulation, and reduced air humidity support the transport of water from masonry to the ambient air. The ability to absorb evaporated water from the air increases with rising temperature. Drying can be supported by microwave heating. It is not necessary to reduce ventilation during frost or cold weather. The basic principle is to enable moist air to leave the building. It is therefore useless to heat spaces without ensuring that there is sufficient ventilation. However, there is an exception is when using condensing dehumidifiers: it is necessary to seal the space in order to avoid withdrawing humidity also from air coming from the outside.

It is important to have in mind that cold air is heavier than warm air. It stays down by the floor and is more quickly saturated by steam. If the exhaust openings are placed just below the ceiling, less humid air is withdrawn. In such a case, it is important also to provide vertical ventilation.

Desalination and decontamination of building materials

The exteriors of historic buildings and of immoveable objects made of porous construction materials, such as stone, brick, mortar joints and plaster, have typically been exposed to environmental influences for centuries. Thus, the surfaces may be contaminated with soluble salts, such as sulphates, nitrates, and chlorides. High concentrations of these salts lead to material damage (see also Annex 7.3). The concentration of salts in building walls may be particularly high near the ground, where salts have been transported upward from the ground with rising damp. These are the parts of buildings that are first reached and penetrated by floodwater.

While it is penetrating, floodwater dissolves the salts in the pores. Part of the salt load may be extracted right at the surface by ion diffusion into the surrounding water. Another part of the salt load, however, is moved deeper into the material, together with the water, by capillary transport. As soon as the drying process starts with evaporation at the surface after the floodwater recedes, a part of the dissolved salt ions in the porous material will move back to the surface with the water by capillary transport.

This effect leads to newly-formed efflorescence, or to sub-florescence, depending on the evaporation rate, i.e. the drying conditions. Salt efflorescence is a frequently-observed phenomenon on mineral construction materials after flooding. Massive sub-florescence may form, especially in the case of weak material surfaces that have already before been affected by salt weathering. Thorough drying of flooded objects under normal climatic conditions is a slow process that may result in salt action on the surface, even some weeks or months after the flood.

Recommended measures

In the case of vulnerable objects, e.g. plasters with wall paintings, and sculptures, the application of wet cellulose poultices to the surface immediately after the flood may avoid salt crystallization and deterioration of sensitive paint layers on the surface. Thus, the evaporation zone is moved into the poultice layer, and the salts will mainly crystallize there. In order to prevent material loss of the substrate, it may be useful to apply a permeable and well adhering intermediate protective layer, e.g. Japan paper, to fragile surfaces. Poultice desalination is a special restoration technique that must be executed by, or at least supervised by, experienced restorers.

Systematic investigations of fully water-immersed sandstone sculptures in the course of water bath desalination have shown that the activation of salts by deeply penetrating water can be used for more effective poultice desalination (Franzen et al., 2008). If contact between the surface and the floodwater lasts for some days or weeks, the effect of water penetration and of salt activation will be much more intensive than if there were local pre-wetting of the dry surface before routine poultice desalination.

In many cases, the surfaces of stone objects are soiled, and layers of mud have to be cleaned away after the flood. Cleaning is often one of the first emergency measures to be carried out immediately after flooding to prevent drying and hardening of mud on the surface of an object. Wet cleaning with fresh water again leads to penetration of water into the stone.

Since many objects, e.g. sculptures, will in any case have to be desalinated in the course of restoration after the flood, it is more effective to use their moist state and the current salt activation due to flooding and cleaning for desalination immediately after cleaning.

The advantages of this are as follows:

- Salt efflorescence and sub-florescence and subsequent deterioration can be minimized.
- The desalination (salt extraction from the material into the poultice) is more efficient.

In the case of stable surfaces, desalination while drying can be performed by direct application of wet cellulose layers. More detailed recommendations on desalination can be found in the WTA Guidelines (2005). Supervision by experienced restorers is recommended. (See also www.bk.tudelft.nl/desalination).

Drying of wet stonework or brickwork of buildings in cellar rooms or on the ground floor is often artificially accelerated by technical means. Extracting water from the walls by heating, applying electric fields, etc., may also move soluble salts to the surface. Efflorescence and sub-florescence may even be reinforced by rapid, artificial drying of a structure.

This should be taken into account when active drying of salt-laden structures is planned. In the case of stable surfaces and a salt-resistant material, it may be sufficient to brush off efflorescing salts during and after drying. In other cases (vulnerable materials and surfaces), combined drying and desalination may be necessary. Appropriate measures should be planned in close cooperation with experts in the field of drying (engineers) and desalination (restorers).

During drying, it is useful to check the humidity of the surface of the masonry. It is also important to make regular checks on the presence of rot or biological films on the surface or on service ducts, and to disinfect mildew spots.

Frost protection

If masonry is not sufficiently dried before winter, there is a threat of damage from water expanding to form ice. There may be static disturbances to the structure, especially in masonry with clay mortar or made from poorly-fired bricks. Wet masonry has decreased thermal insulation resistance, and water condensed from the air raises the water content. It is therefore good to insulate wet masonry with polystyrene boards or mineral mats. A ventilation space up to 1cm should be left between the insulation and the masonry.

Further repair tips

Before renovating interior paints, it is recommended to remove remainders of the old paints and to use only mineral paints (lime or silicate), which are vapour permeable. There is a danger of biological corrosion in organic binders. It is also recommended to delay repairs or restoration work to façades for at least one year after a flood.

It is recommended to take an individual approach to repairs to waterproofing, based on a proper survey and revision of the existing insulation. It is not necessary to renew the waterproofing in flooded buildings. The way in which reconstruction should be carried out also depends on the character of the subsoil. If the building is founded on gravel sand, beyond the reach of the water table, it is worthless to provide horizontal waterproofing, because the water drains away naturally. It should be borne in mind that buildings can be subject to repeated flooding. All measures have to be adjusted to this fact: the choice of materials, the types of new structures, the placing of installations, etc.

Even at times of disaster, there is a real danger of dishonest people trying to take advantage of the situation to offer miracle drying agents and equipment. It is highly recommended to consult professionals before making purchases.

Brickwork, particularly old bricks, may deteriorate and require repair work. Wet brickwork is susceptible to frost damage and can spall and flake, or even crack. Bricks may shrink or crack as they dry. Record any cracking. Once the crack movement has stabilised and the cracks are fully open, fill them. However do not re-point or repair cracked brickwork or masonry until the foundation soil has dried out and foundation movements have stopped. During the drying-out stage, you may observe a white salt growth on bricks and concrete. This will stop when the wall is fully dried, and should be removed with a bristle broom. If the brickwork is painted, allow it to dry fully before attempting to re-paint. Wet brickwork will stain through emulsion and lift off oil-based paints.

Do not light fires in brick fireplaces for at least 2 weeks after flooding, and then light only small fires until the firebricks have dried out.

Wooden window frames may jam when wet (due to expansion after long-term water absorption) and become distorted as they dry. The distortion may cause the paint on the frame to flake off. Therefore check the moisture content of the wood and also check for signs of rot. Once dry, the frames can be redecorated. In churches, the wooden frames of paintings and the basic material of paintings (e.g. the wooden material of altarpieces) may expand and/or rot if they are exposed to floodwater for a longer period, due to the high moisture content and dirt. When they dry, the painting of the frame or the painting itself may peel off. The first step is slow air drying.

Reuse of flooded objects and structures

Furniture should be placed in such way so that the space underneath it can ventilate. The walls and floors under the furniture should be regularly checked, and any appearance of rot must be eliminated by suitable disinfection. If painting is needed, use a vapour permeable material, e.g. ordinary whitewash. Whitewash allows vapour transfer and it also has a strong initial disinfection effect. There are nowadays modified whitewash paintings that have better covering efficiency together with sufficient permeability.

Floor coverings should also be chosen with reference to permeability for vapour. Carpets made from natural materials can be used. Synthetic materials are less acceptable. Flooring materials should never be glued to the board.

In all cases, the future use of cultural heritage objects in flood-prone areas should be thoroughly discussed. An appropriate function should be identified, and equipment that will mitigate or reduce future losses should be recommended.

3.3.4 Emergency action after flooding of immovable heritage

Luigia Binda, Giuliana Cardani

Soon after the flood, once the water leaves the building, the mud and debris are at least partially removed so that the damaged buildings can be accessed. First, all the movable objects should be recovered and taken to places were they can be collected, further cleaned and repaired. In the meantime, buildings should be inspected for damage. The following operations should be carried out: a) survey the damage, b) declare the structure fit fit, or unfit, for habitation, c) suggest safety interventions to avoid partial or total collapse of the damaged structures, d) prepare a preliminary rough calculation of the cost of reopening the buildings for its users, see Modena & Binda (2009).

Teams of professional architects and engineers, together with firemen, to ensure the safety of the team, should visit each damaged cultural heritage building and collect all possible information about the damages (physical and structural). In order to guide the team and facilitate its work, special templates should be prepared that list all possible types of damages that may occur to materials, structural elements and the structural system. This will enable even a team that is not perfectly prepared to recognise and define the type of damage. The templates should be divided into sections on: damage description, any emergency intervention with provisional structures, a declaration about possible reuse, and some calculation of costs. The national or regional Civil Protection Department should organise this emergency intervention in collaboration with the cultural heritage offices.

An example of a possible methodology for organising an emergency intervention is reported in the next section. It refers to the emergency management applied after the L'Aquila earthquake in Italy on April 6th, 2009. For the first time, an emergency was very well and quickly managed in Italy, following a methodology set up by the Civil Protection Department in collaboration with the Italian Ministry of cultural heritage and some Universities.

Lessons learned from an earthquake

The earthquake that hit the Abruzzo region on April 6th, 2009 provided an opportunity to develop a methodology for a damage survey of monuments that are particularly vulnerable to seismic actions. This method, already tested after previous earthquakes, has largely proved its suitability and reliability. Two forms were used as operational tools in the investigation (the damage survey forms for Churches and for Palaces). These are a sort of expert guide to an examination of the buildings, and led to a systematic analysis of damage and vulnerability.

A similar methodology can be suggested for emergency management after a flood:

- nominate a commissar who is responsible for the collaboration of the main organisation involved in the emergency action: the Civil Protection Department, the body responsible for cultural heritage (e.g. a Ministry), and the fire service. They will work with trained and skilled volunteers (architects, engineers, historians, etc.);
- have available well-prepared templates with a description of the building, the structural elements, the materials, etc., and a well-defined list of damages and failure mechanisms, illustrated by appropriate drawings. The templates should also have other sections: one for decisions on fitness for habitation, another for emergency interventions, and another for calculating costs;
- disseminate the design for emergency structures and tools to the fire service and private contractors.

4 Examples and Case studies

4.1 Historic houses

Miloš Drdácký, Rosemarie Helmerich

4.1.1 House in Prague - Podhoří (Czech Republic)

Characterisation of the case study structure

Mixed (brick and mainly stone) massive two-leaf masonry walls, flat brick arches and vaults on the ground floor, timber joist ceilings on the first floor, a timber roof framework covered with ceramic tiles, no basement, good subsoil conditions. Flooding had caused the thin brick veneers to separate from the original log house walls. A part of first floor walls was constructed of logs, but this was not visible and not known, Fig. 4.1.1.1. The house was located on the bank of the Vltava River in a very flood-prone area, Fig. 4.1.1.2.

Hydrological situation

The disastrous flood in 2002 affected a large area of Prague, and in some areas the water was as much as 8 metres in depth. Prague Podhoří is a part of the Prague Troja district, one of the most flood-endangered areas in Prague. A house located in this area was selected as an example of

Figure 4.1.1.1 Log wall discovered after destruction of a brick veneer. Source: M. Drdácký.

Figure 4.1.1.2 Situation of the case-study house in 1975. Source: Courtesy Municipality of Prague – Troja.

Figure 4.1.1.3: The high-water level is visible on the roof. Source: M. Drdácký

Figure 4.1.1.4: Wooden cottages floated into the garden. Source: M. Drdácký

the consequences of the flood for a historic structure. The house was almost totally immersed in water (Fig. 4.1.1.3.), and the stream in the vicinity of the house was probably quite strong during the flood event. This is illustrated by the number of small cottages that were floated into the garden of the house from quite far away (Fig. 4.1.1.4).

Flood impact and damage

Immediately after the release of the water, the house was inspected in order to assess its safety and reliability, before volunteers were allowed to enter the house and start cleaning it up. The damage was quite extensive, but it was not critical for the overall stability of the building. There was no basement, probably due to the location very near to the Vltava River and experience from frequent flood situations. The ground floor, made of stone masonry (walls) and brick arches, suffered from very high moisture, which led to an increase in the deflections of the quite flat arches, Fig. 4.1.1.5. On the upper floor, the wooden ceilings exhibited large deflections, swelling defects, distortions of planks and detachment of paints, Fig. 4.1.1.6, 4.1.1.7. The whole house was heavily soiled with fine mud (see Fig. 4.1.1.8, which also shows the ceiling deflection). Local defects and damage included the typical buckling of timber parquet floor layers. In this case, the individual staves were not nailed, and they buckled in "saddle roof" patterns.

Figure 4.1.1.5: Deflected flat arch with an open crack decreasing the safety of the ceiling and requiring strengthening repairs. M. Drdácký

Figure 4.1.1.6: Timber joist ceiling with apparent deformation of its elements. Sources: M. Drdácký.

Figure 4.1.1.7: The wet and deformed timber joist needed to be dried after removal of all lime wash paints and mortar fillings. Source: M. Drdácký

Figure 4.1.1.8: The exceeded deflection of the timber ceiling is well visible, as is the soiling of the building with mud. Sources: M. Drdácký.

Repair and restoration

It was recommended to clean the attics from mud and all other infill materials in order to allow proper drying, which could be further improved by opening the masonry around the joist supports, Fig. 4.1.1.6. The timber joists had to be dried after removing all lime wash paints and mortar fillings, in cooperation with restorers. In such cases, this is indispensable. Though the house survived the flood, with serious but repairable damage, like many other houses in Prague it did not survive the subsequent development pressure. The owner took advantage of the flood damage and gained permission to demolish this protected building.

4.1.2 General repair practice

Wooden structures

Historic floors are usually made of wood. The floor surface, whether boarding or concrete, should be exposed as far as possible. Carpets, sheet vinyl finishes, tiles and similar should be removed, and the floor area should be sufficiently ventilated. In the case of suspended wooden floors, some boards should be lifted away and any water present in the cavity should be removed. This can be achieved by draining through air-bricks, cutting holes in perimeter walls or using a pump. However advice should be taken (from an expert builder or a damp-proof expert) before cutting holes in walls. Spaces beneath suspended concrete floors should drain naturally and dry out through existing air bricks or drain holes, though forced ventilation may be needed. Wet mineral wool insulation and pipe insulation should be removed and replaced, and aluminium/metal foil around the insulation should be punctured to drain off any water. Electrical connections and junction boxes must be checked by an electrician.

Floor joists showing signs of rot should be replaced, and the surrounding area should be treated to prevent any spread. Distortion or twisting of joists can be prevented by stiffening the joists with struts or battens.

The best way to tell when the flooring is dry is by using a humidity meter, which will give a percentage humidity reading. This reading should generally be below 24% between October and May, and below 22% between June and September.

When replacing floorings, consider using materials that are less vulnerable to damage from flooding, or that are more easily moved following a flood warning (e.g. rugs rather than fitted carpets).

Masonry

Wet masonry has a significantly lower load-carrying capacity, and its weak points (pillars, large window openings) should be inspected and in many cases temporarily underpinned.

Heavily deteriorated stones should be replaced. Surface spalling and washed out mortar layers may sometimes be observed in the wet-dry zone, especially in clay mortar masonry. Washed out mortar layers or heavily deteriorated mortar should be supplemented or replaced. The repair mortar should be equal in strength to or lower in strength than the brick.

Be careful when hydrophobing the surfaces of bricks or stones (in tempered buildings) that have high porosity or that have high ability to absorb water in areas where freezing temperatures can occur. Hydrophobing and also tiling prevent "breathing" (and thus drying) of the masonry. As a consequence, condensation of water vapour can appear much more easily than in cases of non-protected surfaces.

Pointing of masonry walls and arches is the most common repair work for loose or lost mortar in joints. Re-pointing replaces loose or damaged mortar in the joints between bricks. It is an important step in maintaining the brick, as it prevents moisture from entering the joint, potentially causing more damage.

Table 4.1 Summary of some general rules for safeguarding cultural heritage structures.

Type of structure	Preventive measures before flood	Preventive measures during flood	Preventive measures after flood
Ancient masonry bridges, viaducts	Stabilisation against horizontal load from water and debris, Stabilisation of foundation against scour	Close to traffic at high water to keep the total summary load below the limit state	Air dry the structure, remove debris, plan a special inspection for a more detailed investigation
Steel bridges, viaducts			
Wooden bridges, canopied wooden bridges			
Churches, abbeys, monasteries, castles	Geotechnical measures: dykes, levees, pile walls, for preventing penetration of flood water into the CH	Geocell walls, modular temporary walls, mobile K-systems, sheet mobile barriers	Air dry the structure, remove debris, plan a special inspection for a more detailed investigation,
Historical city centres			
Museums (even modern buildings for CH exhibitions)			
Special requirements for buildings	Structural measures: flood doors, aperture control, backwater check valves	Close flood doors, windows, ventilation flaps, swing check valves	Plan aperture control if not done yet
Movable Heritage	Store sensitive materials in higher floors of the building	Remove all CH from flooded levels and treat	Plan storage of sensitive high-value CH outside flood areas

4.2 Historic towns

4.2.1 Genoa (Italy) - flash floods

Simona Lanza

Characterisation of the case study site

The town of Genoa is located in the Liguria region, in northwestern Italy, where earthquakes, landslides and floods have historically been the major natural hazards. Fig. 4.2.1.1 presents an overall map, in which the location of Genoa is indicated, together with the study area (inner rectangle) (see Fig. 4.2.1.2). The graded tones indicate the topography in terms of slope, dark grey being associated with steep gradients and light grey with almost flat zones.

In the Liguria region, 78 rainfall events between 1900 and 1992 produced 195 flooding episodes in 84 different river courses, with damage at 100 sites, affecting 30% of the municipalities in the region. An inspection of the spatial and temporal distribution of the flooded sites shows that the area of Genoa is statistically the most affected, and most of the events are concentrated in the autumn season. The flooding in Genoa in 1970, which led to 19 casualties, 500 homeless and losses amounting to about $60 million in the productive sector, first brought attention to the vulnerability of the local monumental heritage to floodwaters. Genoa has one of the largest medieval centres in Europe, with about 150 noble palaces (declared World Heritage by UNESCO in 2006) and many valuable works of architecture.

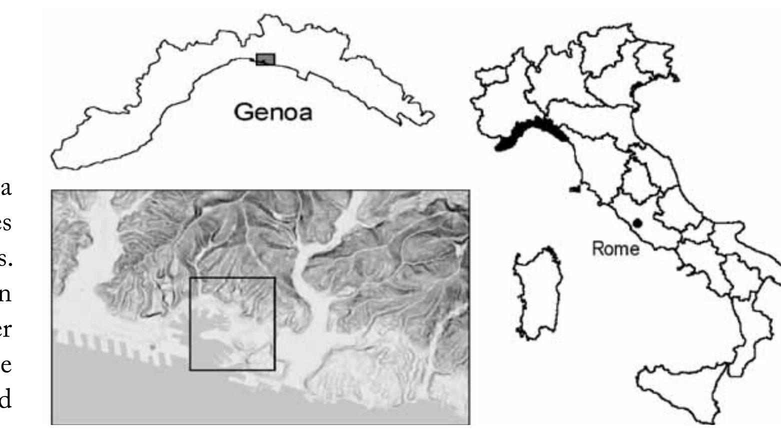


Figure 4.2.1.1: Location of Genoa and the position of the study area (inner rectangle). Source: CRUIE.

Figure 4.2.1.2: Map of the urban texture and the limits of the historic centre within the rectangle indicated in Figure 4.2.1.1. Source: CRUIE.

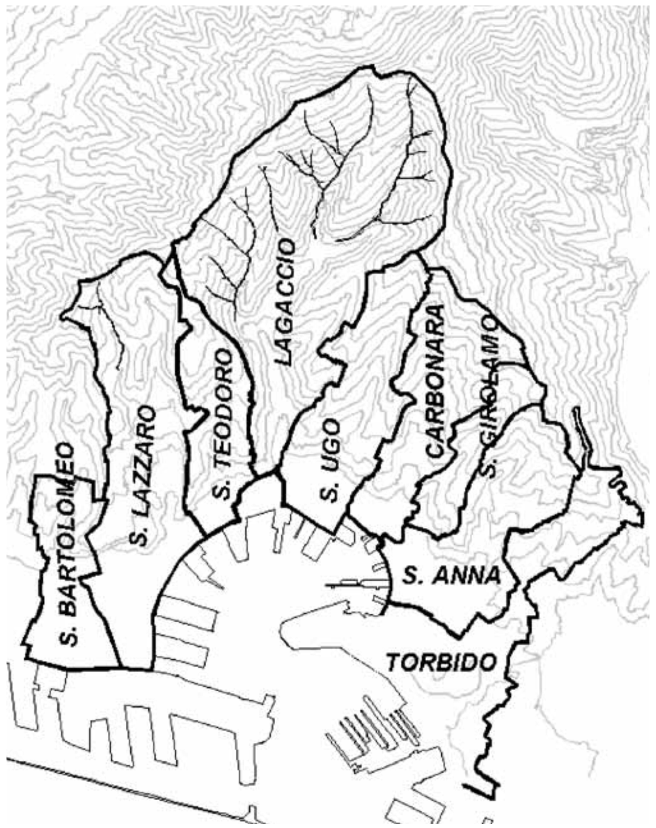


Figure 4.2.1.3: Delineation of the drainage basin for the streams of the historic centre of Genoa. Source: CRUIE.

Table 4.2.1.1: Characteristics of the eight urban streams draining the historic centre of Genoa. Source: CRUIE.

River course	Total length (km)	Area (km^2)	Urbanisation (% approx.)	Conveyance ($m^3 \cdot s^{-1}$)
S. Bartolomeo	2.2	1.61	50	64
S. Lazzaro	2.1	0.95	75	38
S. Teodoro	1.9	0.49	80	19
Lagaccio	3.5	3.50	30	140
S. Ugo	2.1	0.78	100	31
Carbonara	1.9	1.20	90	48
S. Anna	1.7	0.79	100	31
Torbido	3.2	0.75	90	30

No major river course able to cause flooding of the whole urban area flows through the historic centre of Genoa. However, all minor ephemeral streams in the area have been progressively conveyed during various historic periods (with the exception of a few hilly zones) and are now totally absorbed by the urban texture. Therefore, the risk of flooding is essentially due to potential failures of the conveying structures (the present-day sewer system) following intense rainfall events. The steep slopes of the area accentuate the risk, making the historic centre particularly subject to critical hydraulic events due to failures in the artificial drainage system. The consequences for the integrity and stability of the important historic and architectural heritage of the town have not yet been fully quantified.

The historic centre of Genoa is one of the most important in Europe, because of its extent and because of the preserved medieval characteristics. The structure of the medieval road system, based on an ancient rigid comb-like scheme hinged on the coastal axis that lies behind the house of Ripa Maris (1133), from which the four main branches originate, can still be recognized and walked through. Between the 13th and 15th centuries the urban area was enriched by important works. In the 52 hectares of urban area, the population increased to 45,000 in the middle of the 15th century. This brought about an increasingly rapid process of building renovation and saturation of the remaining clear areas. Notwithstanding the stimulus of the renaissance, the renovation between 1450 and 1540 was strongly bound to the ancient settlements, adapting the new architectural forms to the existing medieval buildings.

Although there were town-planning and building initiatives in the "Genovese Century", between 1536 and 1640, land saturation in the ancient town was still the main focus. First the late medieval walls were renoved, and later the harbour walls were built, preventing any further possibility of expansion. After the new walls were completed, between 1628 and 1636, there was no further urban development, because the walls were traced out too far from the suburbs, along the divides of the surrounding hills. The crowding of properties into a very limited area, as a result of speculative initiatives based on transforming the medieval buildings into modest houses for rent, and the eventual movement of the richer classes to areas outside the walls are the two accompanying processes that, between the second half of the 18th century and the first half of the 19th century reduced the ancient town to a "historic centre".

The medieval layout of the town is still perfectly readable, and the same can also be said about the medieval architectures. The medieval nature of the historic town can be detected in the Ripa palaces, the Sea Palace, the numerous surviving towers, and also in the primitive parish churches and gentilitial chapels, surrounded by the residential palaces. Some of them were modified in the 16th and 17th centuries, while others still preserve their medieval aspect, though some were subject to restorations in the 19th century. The 150 hectares of the historic centre of the town contain about 200 residential buildings, including more than 40 with medieval origins, a large number of terraced houses associated with the lower classes of the 12th and 13th centuries, and blocks of houses for rent built for speculative investment in the 18th century.

The urban drainage network consists of eight watercourses crossing the town centre and flowing out into the harbour basin. From west to east (see Fig. 4.2.1.3): S Bartolomeo del Fossato, S. Lazzaro, S. Teodoro, Lagaccio, S. Ugo, Carbonara, S. Anna, and Torbido, all of them nowadays covered over (see Table 4.2.1 for the relevant hydraulic characteristics).

The relationship between the town and the streams has influenced urban development through the centuries. Channelling and conveying the streams, constructing buildings with bridging foundations, displacing their outflows and including them in the wharf structure, and transforming them into a sewer system: all this established a delicate equilibrium that has many times become critical, leading to disruption and damages. Typical examples are the construction of S. Giorgio Palace, the ancient seat of the town government, built right over the outflow of the S. Anna stream, with a respectful attitude toward the stream that allowed it to flow through the palace, the Paupers' Hostel, built over the bed of the Carbonara stream after canalising the stream and deviating its course, and the Commenda di Prè, built on the S. Ugo stream after it had been covered with a masonry structure.

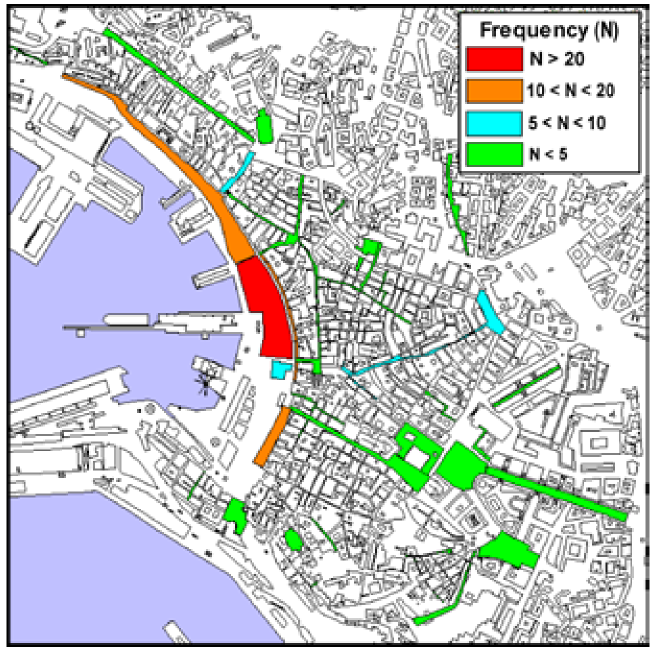
Stock at risk mapping as preventive measure

The flood hazard has been evaluated for the case of the historic centre of Genoa, by investigating about 100 documents (mostly newspaper articles) covering the period of time from 1900 to 1999, with much finer resolution than the scale available at the national level. A single street, and in some case a single work of art or monument, were considered, and the occurrence and the number of flooding events were surveyed for the relevant sites. An analysis of the frequency of flooding episodes shows that the most affected areas are those surrounding the harbour basin, where the outflows of the streams are located. Figure 4a shows the results of the historic survey in terms of a map of flooded sites over the whole study area, where the different patterns represent the number of times each site was flooded in the investigated period. Table 4.2.2 provides a list of flooded sites together with the observed frequencies (number of episodes in the survey period).

Table 4.2.2: Historically flooded sites with the associated frequency (number of episodes in the survey period). Source: CRUIE.

Site name	Number of episodes	Site name	Number of episodes
Caricamento Square	24	San Giorgio Palace	7
Sottoripa	16	Soziglia Square	5
Downstream areas	12	Cavour Square	4
Via Carlo Alberto – Via Gramsci	10	Matteotti Square – Palazzo Ducale	3
Via delle Fontane – Porta dei Vacca	9		

Once the flood hazard has been quantified in hydrological terms over the area under examination, an assessment of vulnerability is essential for defining the actual risk. This task was fulfilled by considering the distribution of the monuments and sites that are presently under the



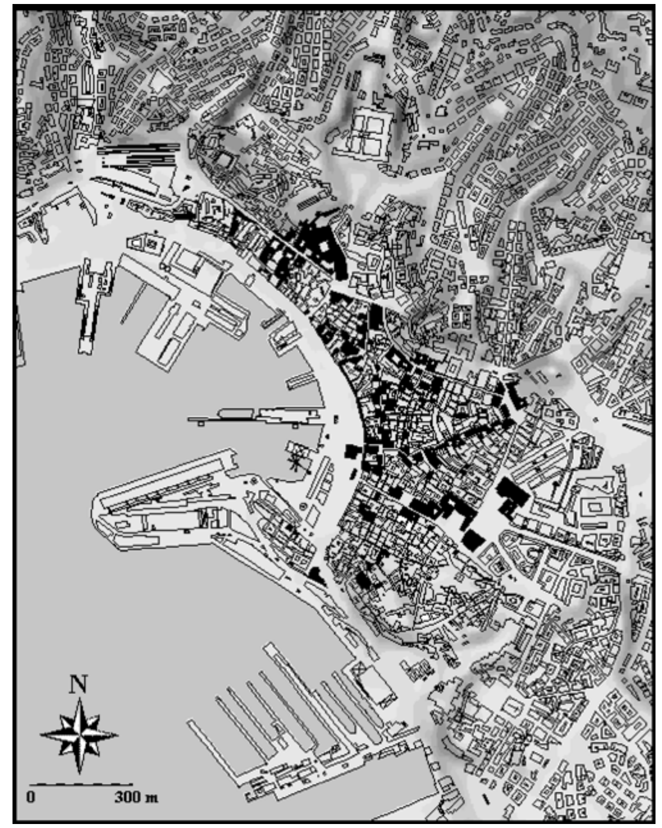


Figure 4.2.1.4: Historically flooded sites and a map of cultural heritage at risk in Genoa. Source: CRUIE.

protection of the Superintendence of the Environmental and Architectural Heritage of Liguria (in accordance with law No 42 dated 2004).

Based on the approach described here, a map was produced (Lanza, 2003), containing the distribution of the buildings presently lying under the protection of the Italian Superintendence of the Environmental and Architectural Heritage within the historic centre of Genoa. The use of GIS in this analysis enabled the areas to be delineated. The two thematic layers above are actually superimposed, so that this is precisely a map of stock at risk for the artistic and architectural heritage in Genoa. This is reported in Fig. 4.2.1.4 (right), where only the buildings exposed to flood hazard threat are represented throughout the study area.

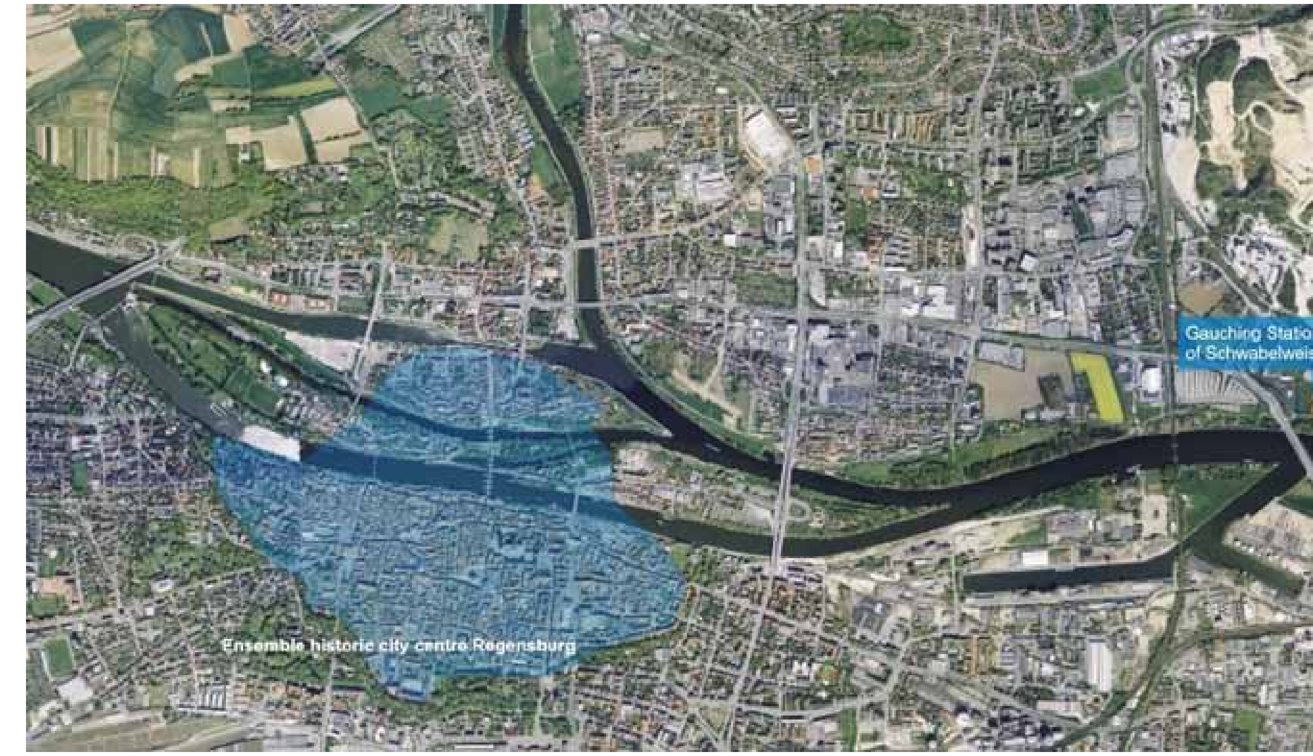


Figure 4.2.2.1: City map of the historic city of Regensburg (aerial photo of Regensburg) with the Danube and Regen rivers (coming from the north) Source: with kind permission of DOP © Landesamt für Vermessung und Geoinformation Bayern (permit number: Az: O 1419 VM A – 0806/10).

4.2.2 Regensburg (Germany) - large river flood in a historic city

Jeannine Meinhardt

Characterisation of the case study site

Regensburg is one of the oldest cities in Germany. It is situated at the northernmost point of the river Danube in central Bavaria. Regensburg has 133.525 inhabitants. Because of the substantial history, the townscape contains a huge number of cultural heritage objects. The historic urban core is almost entirely preserved. On November 26, 2007 the Old Town of Regensburg with Stadtamhof was inscribed in the UNESCO World Heritage List. Because the river flows very close to the historic city (Fig. 4.2.2.1), the city and the heritage objects have very often been affected by flooding in the course of history. For this reason the municipality and also the residents are used to the floods. Accordingly, effective flood prevention equipment is on stand-by and modern protective systems are available. At the beginning of the second millennium, discussions about a holistic approach to flood protection of the 2000-year old cathedral city became more intense. Searching for an optimised flood protection concept for the city of Regensburg, a Europe-wide competition was initiated by the municipality and the Bavarian government. The purpose was to find solutions for a kind of flood protection that would meet all the needs of water management and hydraulic engineering, urban design and preserving cultural heritage , as well as nature conservation. Priority was given to the special appearance of the historic townscape of Regensburg.

Hydrological situation

The geographical position of Regensburg is a kind of a gateway – a transition point between topographical constriction and wide expansess. The Danube, with an overall catchment area of 817.000 km², is leaving the uplands and flowing into the plain. The affluent rivers Naab and Regen flow into the Danube close to the city

Figure 4.2.2.2: IBS K-system on the historic Danube promenade. Source: Xaver Storr.

Figure 4.2.2.3: IBS K-system, K-rack fixed with a peg on the pavement (water-side). Source: Xaver Storr.

centre, and so they contribute considerably to the danger of flooding. The map in Figure 4.2.2.1 reveals that large parts of the town are surrounded by the rivers Danube and Regen. At the nearby gauging station of Schwabelweis, the catchment area of Danube features almost 36,000 km². The high discharges in the Regensburg result from the large Danube river basin.

The rivers Altmühl, Naab and Regen flow into the Danube from the low mountain range in the north, while the rivers Iller and Lech come from the Alps in the south. Because of this, the potential for large river basin flood retention upstream of the city is very limited, and cannot deal with the catastrophic floods with a recurrence interval of 50 to 100 years. Storage reservoirs can be very effective methods for controlling floods in the upper reaches of rivers. In the middle reaches, where Regensburg is situated, however, the retention areas along the rivers have been reduced due to interference from human activities, e.g. infrastructure, settlements and industry. The retention of the huge discharges resulting from extreme rains in combination snow melting is therefore currently extremely limited. Thus, the city can be protected only with the use of levees, walls and, on a small scale, by mobile protection systems.

The highest amount of precipitation falls between June and August, with a monthly average of 74 - 93 mm, while the minimum precipitation is in March and November, with 33 - 39 mm. The Danube has many dykes in the area of Regenburg down to the city of Passau to prevent the riverbank from overflowing. The influents from smaller drainage areas must therefore be fed into the Danube using numerous culverts. In the event of flooding, these culverts are closed to avoid a backwater flood into the bordering areas. In this event, water drawing machines pump the water from the influents over the dykes.

Development of flood protection measures

The demand for agricultural land led to drainage of the land close to the river, starting in the 15th century. Regulation measures for the meandering river in the form of massive cuttings to straighten the flow were carried out from the 16th century onwards. Dykes in the areas around Regensburg have been mentioned since the 1860s.

Ambitions for modern flood protection in Regensburg reach back to 1954. In that year, the municipality applied to the Bavarian government for suitable measures. In 1983, the financial and legal planning prerequisites were fulfilled, but after a fierce public debate and increasing local resistance, the city council decided in 1987 to cancel the approval of the plans. This was accepted by the Bavarian government. The local protest culminated in the slogan: "We do not want to be walled in for a thousand years just to avoid getting wet once!"

After several subsequent flood events (Fig. 4.2.2.3), the municipality requested that the government reopen the flood protection planning. On the basis of the lessons learned from earlier failures, the Bavarian government, together with the city of Regensburg, decided to involve the citizens intensively in the ongoing planning process. In this way, it was possible to communicate the complexity of the problems to the citizens and to call attention to the potential hazards of floods. It was important to convince the

Figure 4.2.2.4: IBS K-system, transport container with side-opening doors. Source: Xaver Storr.

affected people of the necessity of the intended activities. The experts were working groups with special knowledge in hydraulic engineering, in cooperation with architects and landscape architects. Interdisciplinary collaboration of this kind was necessary to optimise the harmonic coexistence of mobile and stationary flood protection structures together with the sensitive riverside architecture.

Because of the fact that there are only greatly reduced retention areas in the middle reaches of the rivers that affect Regensburg, the only option for the city is local flood protection realised by implementing actions directly in the city area. As far as mobile flood protection systems are concerned, there is always the problem of inaccurate high water prediction. In the past years, the relative failure of 24-hour predictions at the Schwabelweis gauging station was ± 15 %. In view of this possible error, an expected 100-year flood HQ 100 could easily lead to discharges between HQ 50 and HQ 500. If the approaching high water is overestimated, the mobile elements will be installed for no purpose. On the other hand, if the expected water level is underestimated there can be catastrophic consequences. However, walls and levees are often rejected out of hand by public opinion. Permanent structures always interfere with the cityscape near rivers, and the unique cityscape of Regensburg has developed in the course of centuries.

Results of the flood protection planning competition

As a result of the overall optimisation process, the conceptual basis for the technical flood protection of Regensburg was presented early in 2006. Implementation of the project began in 2007. The flood protection concept is scheduled for completion in 2020. The following flood protection measures are generally available: land filling and land shaping, levees, walls, mobile elements, building protection, and combinations of all options.

Landfill cells (polders) cause changes in the groundwater level. Klaus Heilmeier, from the Department of Archive and Preservation of Monuments and Historic Buildings in Regensburg, is concerned that historic buildings may be damaged because of the associated subsidence mechanisms.

The competition collected together many ideas aimed at solving the problems of designing and implementing appropriate flood protection measures for Regensburg. The competition did not result in one single winner, and none of the presented proposals will be implemented in its original layout. All the ideas of the winning groups will lead to a concept. The priority of the competition has shifted strongly into urban and landscape considerations. Drainage, which maintains the ground water level inside the protected area, will be a major aspect of the final design.

For example, IBS (Industrial Barriers and Fire Protection Technology) is the company that developed the mobile flood protection walls. The so-called K-system is an abbreviation for Catastrophe Protection System (German:

Figure 4.2.2.5: Pictures of the flood in Regensburg, August 2002. Source: Andy Schwierskott.

Katastrophe = catastrophe) (Fig. 4.2.2.2 and 4.2.2.3). This system does not require any preparatory structural measures on asphalt up to a flood height of 1.30 m and can therefore be applied flexibly in different locations (length 1300 m, area 1700 m²).

A special feature of the K-system is that the water pressure applied by the flood water makes a positive contribution to the stabilisation of the system.

Due to its modular design, the system can be extended in any direction, depending on the requirements, and can also be optimally adapted to the topographic conditions. The system is capable of compensating ground unevenness of up to 15 mm, curves in the terrain with a radius greater than 20 m, and differences in height. The manufacturer recommends anchoring the system when using it on rough concrete surfaces and pavements to prevent slipping.

Avanced storage technology has been designed for the K-system. This ensures contact-free storage of the dam beams and K-trestles through spacer blocks made of waterproof bonded wood. The system is stored in hot-galvanised steel palettes equipped with fork tracks, stackable palette feet and tension belts. Due to the contact-free storage of the individual parts on steel palettes, they can be simply rinsed off with a water hose after use. If the system cannot be stored in a suitable location, it can be delivered and stored in containers (Fig. 4.2.2.4).

Flood protection that is directly installed on a building protects a certain number of openings at a height that depends significantly on the buoyancy of the building. It is only to a limited extent possible to protect entire city districts or towns against flooding with the use of static methods.

Flood impact and damage

Because the river flows very close to the historic city, this area has very often been affected by flooding. For this reason, the municipality and the residents are used

Figure 4.2.2.6 Pictures of the flood in Regensburg in August 2002, with special regard to flood blocking measures. Source: Andy Schwierskott.

to floods. According to a telephone communication with Klaus Heilmeier (see above), cultural heritage objects are not endangered in particular. Normally cellars have been flooded and dried out after the flood. However, a very common problem nowadays is the use of the cellars for tourist interests (e.g. holiday flats). During the flood of March 1988, swathes of the urban area were flooded. The countable amount of loss in 1988 was Euro 5 million. The flood peak was 4 metres above the normal level. The flood in August 2002 caused less damage. Because of the constricted width of the Danube the discharge capacity [m³/s] has changed. The floods from former times would therefore have higher levels if they were to occur nowadays. The floods of 1988 and 2002 are to be assessed as HQ 25. If the floods from 1988 or 2002 had been real HQ 100 events, the damages would have been enormous. Against the background of this fact, a digital terrain model showing the actual danger of flooding was prepared (Blauer Plan HW100, "Blue Plan HQ100").

During the flood in August 2002 the old city was partially flushed (Fig. 4.2.2.5). Specific gangways were installed in order to provide temporary accessibility to accommodation facilities.

Various blocking measures were applied (Fig. 4.2.2.6).

Figure 4.2.3.1: Historic relation to the river, and the original protective walls. Source: Municipality of Troja.

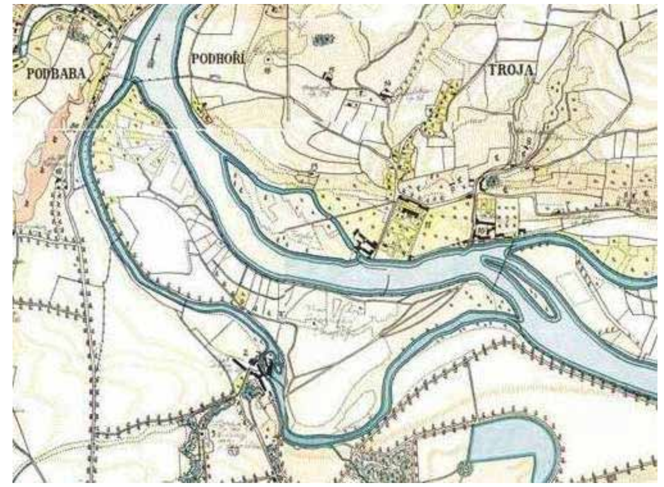


Figure 4.2.3.2: Historic map of the Vltava river in Praha - Troja. Source: Municipality of Troja.

4.2.3 Praha (Czech Republic) – a large river flood in a historic district

Tomáš Drdácký

Case study object characterisation

Praha –Troja, once a small village outside of Praha, became part of the capital city of the Czech Republic in 1921. The area remained relatively rural and village-like conditions until the end of the 20th century, and as such is protected as Natural Park. The fishermen's village known today as Rybáře is legally protected as a Village Heritage Zone.

After the disastrous flood in 2002, it was decided to protect the district with a massive engineering structure. This raised some questions, as it would change the townscape. There would be losses as well as opportunities.

Hydrological situation

The Vltava River plays a crucial role in the setting of the town, and was the decisive element in creating the morphology of Prague, with its terraces and side valleys.

The oldest written reference to floods in Prague goes back to 938 AD, when the bridge connecting the present-day Old Town with the the settlement under Prague Castle was damaged. There is a good record of major floods throughout the centuries. The biggest summer flood up to 2002 was in 1890, with a river level of 5.82m and a water flow rate of 3975 m^3/sec. In 2002, the water level reached 7.85m and the water flow rate was 5700 m^3/sec. For comparison, the one-year maximum flow rate is about 765 m^3/sec in the river relief, and the annualaverage flow rate is about 148 m^3/sec.

Flood impact and damage

In 2002, Praha - Troja was one of the most affected districts of the city, with the water level reaching 8 metres in the Troja - Podhoří area. Due the collapse of the transport system in the city, and the fact that the main road was under water, the area remained inaccessible for several days. Water flooded the streets and about 100 buildings – the elementary school, the local administration offices, the sports club, accommodation facilities, private houses and properties.

Material loss

There was vast damage to the infrastructure. The surfaces of the streets and sidewalks were covered with mud, and in some places water undermined the asphalt and grubbed it out. Some parts of the town were completely inaccessible. The sewage system was overloaded and had to be renewed. The electricity supply was cut off for several days.

Figure 4.2.3.3: water flooded half of the Praha - Troja district. Source: Gefos.

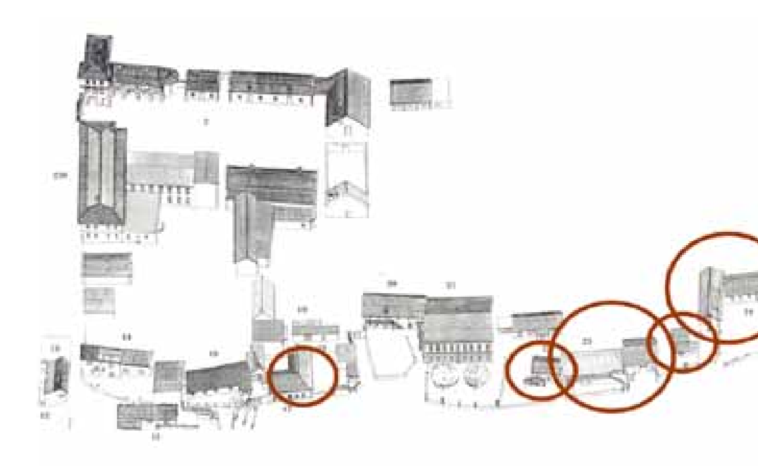


Figure 4.2.3.4 "Village" protected zone. "Fishermen's homes" in Prague Troja District. Heritage lost after the flood in 2002 is circled. Source: Municipality of Troja.

Socioeconomic impact

Neighbours helped affected families and provided accomodation and material help immediately after the flood. Thanks to the strong attatchment of the local inhabitants to Troja, most of the families retained their properties, repaired or reconstructed the houses and have continued to live in the place.

Impact on cultural heritage

Troja Chateau, a prime cultural monument, was restored and the collapsed baroque garden wall was reconstructed. The structural damage to the buildings was not very significant, because most of the structures are made from stone and the water did not affect them. Several protected houses were demolished. However, the situation regarding the finishes and the equipment and furniture inside the houses was much worse. Private archives, photographs and works of art were lost. No guidance was made available for private citizens on how to deal with flooded objects and printed material.

Psychological impact

The first warning came, and people had to leave their properties four days before the culmination of water. Residents left all their belongings behind.

Repair and preventive measures

The management immediately after flood was successful, but the local authorities now face disagreement over the flood protection and prevention measures. The importance of public involvement in decision making was underestimated, and the riverbed regulation project of was not sufficiently publicized and not enough discussion was invited. The State Institute for Monument Protection made a mistake, misjudging impact of the proposed adjustment on the historical appearance of the site.

Development of flood protection measures

In the search for an optimised flood protection concept for the City of Prague, a rather technical approach was chosen. While in the centre and in the UNESCO World Heritage site the measures were designed to be of high aesthetic quality and mainly "invisible", in the outskirts of the city, attention was given only to the function of the barriers.

Figure 4.2.3.5: Traditional way of protecting the living area, which is located on the first floor. Source: T. Drdácký.

Figure 4.2.3.6: The original situation and the line of the new dike. Source: Municipality of Troja.

Flood protection design and construction

In Praha – Troja (which forms part of the buffer zone for the historic centre of Prague) a combination of a dike and a solid concrete wall up to the level of 2002 flood was proposed. After involvement of the local authorities, the part of the structure in front of the protected zone was redesigned, and the solid concrete wall was modified into a system of stable pillars with mobile barriers in between.

Problem assessment

The technical design and a lack of a broader complex view led to a solution with a very strong impact on the environment of Troja. The important link to the river and to cultural heritage values, the centuries-old stable typical vista and panorama of the district was changed. The local community was not invited to participate, and no identification of needs and values was carried out.

The protective measure created a visual, spatial and functional barrier in the area. However protection of the district should have been an opportunity to provide new

- Development + spatial growth, apartments, houses, employment
- Quality of urban life
- Social interactions
- Public space enhancement
- Use and restoration of cultural heritage

Collaboration with schools of architecture has brought some ideas and solutions for minimizing the effect of the barriers. The question arises - how to make the most of the new functional and spatial situation. It will never be the ideal solution that might have resulted from a better planning and design process.

As an example we present a list of local urban values to be taken into consideration and protected (identified by citizens of Troja through questionnaire surveys), in connection with flood barriers

- Genius loci, character, DNA of the place
- Urban landscape with cultural monuments
- Visual integrity of the townscape
- Visual integrity of the public spaces (interior of the area)
- Green territory, free open space
- Easy access to the river
- Image of the district, quality of urban life orientation, perception, ownership…“hometown“
- Scale of the public spaces, pedestrian zones, houses…. in relation to the walls

Bad practice

The key, crucial failure was insufficient involvement of the public in preliminary discussions, problem assessment and decision making. In addition, there was no guidance for private people on how to deal with flooded objects and printed materials.

Figure 4.2.3.7: Difference between the scale and detail of the historic wall of Troja Chateau with decorative terracottas and the new concrete wall. Source: T. Drdácký.

Figure 4.2.3.8: During the flood in June 2009. Source: T. Drdácký.

Figure 4.2.3.9: Concrete wall up to 6 m in height. Source: T. Drdácký.

Figure 4.2.3.10: Originally designed as a solid wall - modified after pressure from LA, Source: T. Drdácký.

Lessons and conclusions

- Balance the impact of disasters (floods) with the impact of permanent measures (flood barriers)
- When places are changed it is not necessary to change values, too
- There are limits to the acceptability of changes to valuable zones and places
- Involve the public in time - participatory decision making on design and on land use
- It is necessary to present the long-term positive effects of risk preparedness and protective measures.

Figure 4.2.3.11: New view of Troja with its concrete wall. Source: T. Drdácký.

Figure 4.2.3.12: A student project. Source: architect Daniel Novák.

Figure 4.2.3.13: Detail of the finished concrete wall with gabions. Source: T. Drdácký.

Figure 4.2.3.14: Concrete wall from the village side. Source: T. Drdácký.

Figure 4.2.3.15: New mound and wall, compared to the human scale. Source: T. Drdácký.

Figure 4.2.3.16: New mound and wall separating the area next to the river from the inner part of the district. Source: T. Drdácký.

4.2.4 Dresden (Germany) – a large-river flood (2002) in a historic district

Christoph Franzen

Case study object characterisation

Dresden is situated in the south-eastern part of the Free State of Saxony, which borders not only on other German regions (Bavaria, Thuringia, Saxony-Anhalt and Brandenburg), but also on the Czech Republic and Poland. The city lies in a marked widening of the Elbe valley. The foothills of the Eastern Erzgebirge Mountains, the Lusatian Granite Uplands and the Elbe Sandstone Mountains characterise the wonderful surroundings of the Saxon capital. Its geographical data is latitude: 51° 02' 55" N, longitude: 13° 44' 29" E. The elevation of the river Elbe in town is 102.73 m a.s.l. In terms of area, Dresden is the fourth largest city in Germany, after Berlin, Hamburg and Cologne, with an area of more than 325.00 km2. The total population is half a million. During the flood in 2002 the area around Dresden was one of the most flood-impacted parts of Germany.

Hydrological situation

The River Elbe flows through Dresden. The Elbe (Czech: Labe) is a central European stream, having its source in the Czech Republic, crossing eastern and northern Germany and flowing into the North Sea. The Elbe is the only river draining Bohemia, which is surrounded by low mountain ranges, into the North Sea. There are several rivers belonging to the drainage area of the Elbe: the Vltava/Moldau, the Schwarze Elster, the Spree, the Saale and the Müritz. The river has a total length of about 1094 km. The length of the stream within the city of Dresden is 30 km. The total catchment area is 148.268 km^2. The basin spans four countries, with its largest parts in Germany (65.5%) and the Czech Republic (33.7%). Much smaller parts lie in Austria (0.6%) and Poland (0.2%). The cities along the Elbe are: Pardubice, Ústí nad Labem, Dresden, Meißen, Wittenberg, Dessau, Magdeburg, Hamburg and Cuxhaven. The river basin is inhabited by 24.5 million people.

Figure 4.2.4.1:The Elbe in Dresden, 2006.Source: IDK.

Figure 4.2.4.2:The Elbe in Dresden, 2006.Source: IDK.

Impact of the flood on cultural heritage in and around Dresden

In August 2002 a serious catastrophe struck Saxony. After torrential rains on August 12th and 13th, the normally gentle Müglitz and Weißeritz brooks swelled into streams with destructive power. At the same time, the Freiberger Mulde rose within a few hours to form another stream, which combined with some feeders that rolled everything in their path downstream. In the catastrophe, twenty people died, many were injured and several houses were demolished.

Figure 4.2.4.3:Elbe Flood in Dresden 2002, here: Zwinger with the state art collection.Source:CHEF.

Figure 4.2.4.4: Flood in Dresden 2002, Elbe valley. Source: CHEF.

Damage due to high floods on the Elbe feeder rivers

After the breakdown of a retention basin, large volumes of water destroyed Glashütte, Weesenstein and Schlottwitz. The historic town of Pirna was totally flooded to a height of one metre. The Wießeritz brook overflowed the Malter dam. It flooded large parts of Freital, Tharandt and Dresden. The damage to about 20 electric power transformation substations led to a power breakdown in Dresden. On August 13th, the historic centre of Dresden, the Zwinger and the Semper Opera House were flooded. In Meißen, the historic quarter was flooded by the Triebisch. The side arms of the Elbe fooded about 13 museums. The state art collections (Staatliche Kunstsammlungen) in the Zwinger (see Fig. 4.2.4.3) and in the Alterinum were under great threat. The German Hygiene Museum and the Dresden City Museum were heavily damaged, as was the external depot of the Dresden Traffic Museum. Due to their more favourable location, some other museums in cities with a major flood impact suffered no damage or risk of damage(see Fig. 4.2.4.4). However, the main photo archive of the Saxonian newspaper, the Dresden city archives and the Olbernhau city archives were demolished.

Flood damages in the catchment area of the Mulde

On August 12th, the Freiberger Mulde flood reached Döbeln. The Freiberger Mulde was fed by the swollen influxes of the Zschopau and the Zwickauer Mulde. Within three hours, complete rows of houses in Grimma were submerged. The county museum in Grimma, the city archive, the Epochal and Parochial Archives and the outpost of the Nimbschen monstery were flooded, and the famous Pöppelmann Bridge, (see Fig. 4.2.4.6) and the Historic Mill in Grimma, (Fig, 4.2.4.7), which had just been restored, were destroyed. A total of 18 museums in the catchment area of the Mulde were affected. The flood damaged 14 pictures, three crucifixes, one epitaph, one memorial stone and a freshly-restored 17th century wooden panel painting. In the Nikolaikirche church in Döbeln, seven paintings, one Renaissance pulpit and the Miracle Man, a wood and material mix work of art, were not rescued early enough and were seriously damaged.

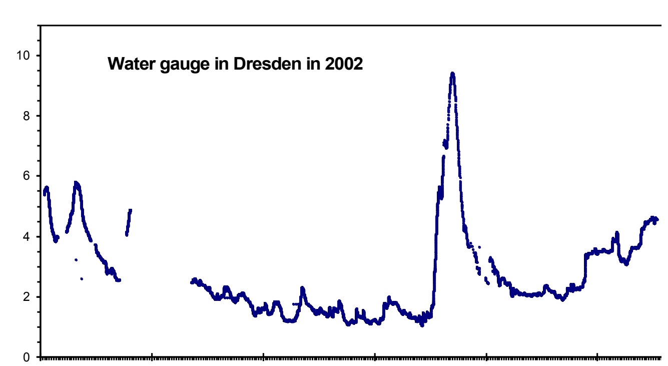


Figure 4.2.4.5 Water gauge in Dresden in 2002. The flood event in August is clearly visible. Source: IDK.

Figure 4.2.4.6: The famous Pöppelmann Bridge in Grimma: destroyed during the Mulde flood, 2002. Source BAM.

Figure 4.2.4.7: Historic mill after the Mulde flood, 2002. Source: BAM.

Damage due to the Elbe flood

After the main flood from the Elbe feeder fluxes, the main high tide of the Elbe itself began to arrive. The river rose hour-by-hour. Large amounts of water made their way further downstream from Bohemia. On August 14th, the market place in Bad Schandau was flooded and the city archive was heavily damaged. The next day, the high tide reached Dresden. On August 17th, the Elbe reached a height of 9.40 m, the highest level ever recorded. Several city districts were completely flooded. The electricty supply was cut off and telephone communication broke down. A thousand people evacuated their homes and went to stay with friends or relatives, or were cared for in emergency accommodation centres. Hospitals were evacuated. The State Art Collection (the Museum of Decorative Arts in Pillnitz, the Old Masters Picture Gallery, the New Masters Gallery and the Sculpture Collection), six other museums and the crypt of the former royal family in the cathedral were severely impacted. The most severe destruction was in the local history museum in Bad Schandau and in the town museums of Meissen and Pirna. The historic quarter of Meissen was under water for a second time. The town museum in Pirna and the Kraszewski museum in Dresden fell victim to the two catastrophes. Due to a fairly long period of advance warning prior to the Elbe flood, together with succesful mobilisation of volunteers, most of the inventory of the affected museums was rescued. However, due to damage during transportation and improper storage, a large amount of restoration work had to be done on the objects. One of the main problems was the damage to the museum buildings and the damage to the technical facilities, which were most often located in low-lying parts of the buildings. In the Catholic church in Pirna, a late-Gothic winged altar and a Gothic mural painting were damaged, as were many of the assets of the town archives.

Flood damage to heritage in Saxony in 2002

A brief summary of the damage to cultural heritage due to the flood event in 2002 is presented in the following:

Two thirds of the surrounding property along the river banks was affected, including cultural heritage (CH).

There were two groups of flood types: flash floods occurred along small, steep brooks (the Müglitz, the Weißeritz, the Triebisch and the Mulde) and brought severe damage in Weesenstein, Dohna, Freital, Tharandt, Meißen and Pirna. There were similar situations in Grimma and Döbeln, where parts of houses and complete houses were washed away. In Weesenstein, 10 buildings were severely damaged, including 4 Baroque heritage buildings

The other type of flood was the river flood in the Elbe Area, which affected Bad Schandau, Pirna, Dresden, Meißen, Heidenau. In these places, the damage was due to the high tide level of the Elbe and slow-flowing water. In comparison with the overall total damage, the damage to CH was low. The damage to CH buildings was mainly to wooden parts, e.g. windows, doors, wooden ceilings, and to structural elements such as stones, especially in the drying phase. Wooden ceilings and the half-timbered frameworks of the upper floors were affected only in rare cases.

First-order historic artwork, paintings, historic plaster and similar items were damaged only in rare cases in the 2002 floods, because losses of this type had already occurred in much earlier flood events.

General observations

At first, there were problems with getting immediate response by the LfD state department, the communal heritage administration, the museum board, the board of restorers, the architectural association and the engineering board.

It was observed that there was a massive demand for demolition permits, especially for objects that had already been in danger prior to the flood event. Also unused empty buildings were in extreme danger. If they were not cleaned and secured, they would be totally demolished within a few months. Damage occurred also due to subsequent subsidence of the building ground. This led to the conclusion that long-term care and management of the affected monuments was therefore required.

Damage, observed at different types of monuments

About 150 cases of damaged Evangelical buildings, parsonages and parish buildings were recorded. There was only limited damage to heritage and to valuable church interiors. No details are available about Catholic properties. This number includes parsonages and parish buildings, etc., and to a lesser extent churches, which also tend to have been built on high ground.

Examples:

- Grimma: 14 paintings, 3 crucifixes, 1 epitaph, 1 memorial tablet
- Döbeln, Evangelical - Lutheran church: Mirakelmann, 7 paintings, 1 Renaissance pulpit
- Dresden, Cathedral: crypt, metal coffins
- Pirna, Catholic church: late-Gothic winged altar, Gothic mural painting

Typical damage features: mud sediments, moisture expansion of wood, opening of wood bondings, weakened and loose paint layers, intensive infestation with moulds, risk of loss of paint layers due to drying and shrinking of wood.

In all cases where damage was brought to the attention of the monument department in time, emergency first aid was immediately organised, thanks to a resilient network of department restorers and freelance restorers. The work was coordinated by the department. The first action was to recover the objects from the location at risk, to fix the material and inhibit moulds. In response to an appeal by the board of restorers, numerous offers of help were received from restorers in all specialities from all over Germany. Their efforts were greatly appreciated.

Examples of damage occurring at other building types

- Castles and noble mansions were rarely affected, as most of them were constructed on high ground
- Severe damage occurred in Bad Schandau, Grimma, Döbeln, Dresden Cathedral
- Heritage, most often sacral heritage and church interiors, was affected within a manageable extent. Calculated costs: € 600 thousand, mainly demolition of pews
- Middle-class housing in ancient city centres were the main group of damaged structures: parts of buildings which had been remediated before the flood were not in danger of total loss, but subsequent restoration has required enormous efforts
- Immediate aid at a level of €5 000 to €10 000 per case was provided by the Deutsche Stiftung Denkmalschutz for historic doors and windows. The application procedure was simplified
- Private owners, in particular, were in need of aid
- Owners were supervised by the national and communal monument protection offices
- Houses that were not remediated houses in a timely manner were more severely affected (Pirna, Lange Straße; Grimma, surrounding the ancient city centre)
- In Saxonia, many technical monuments were severely damaged: many bridges, mills, sawmills, mining monuments (e.g. Rothschönberger Stolln) partially collapsed, the Frohnauer Hammer water wheel (Annaberg-Buchholz) was destroyed, Pöppelmann Bridge (Grimma, 1719) was destroyed, the Weißeritztalbahn railway bridge at Pockau (Erzgebirge) was a total loss
- Many graveyards were affected, e.g. Alter Kath. Friedhof Dresden was severely damaged
- Gardens and parks at Weesenstein, Pillnitz have suffered massive damage.

It was necessary to monitor the flood-affected monuments. Wooden ceilings and mural paintings were often not directly damaged but were affected and in danger in the long term, due to moulds and other water-supported actions, e.g. salt deterioration. In these cases, targeted action was necessary to avoid more extensive damage.

4.2.5 Grimma (Germany) – a small-river flood in a small walled town

Thomas Will, Heiko Lieske

Case study object characterisation

Grimma is a small town with about 18,000 inhabitants in the Mulde River valley, not far from Leipzig. What distinguishes it from many other towns is its unusually well preserved setting in a river landscape. Historic urban and landscape ensembles of great beauty make the city attractive both to the local inhabitants and to visitors. Grimma is exceptionally rich in historic urban structures and monuments, some of the most valuable of which are situated along the riverside, e. g. the medieval city wall, the castle, the Convent Church, the Princes' School, the baroque mill ensemble and the historic District Administration Building (Figs. 4.2.5.1 and 4.2.5.2).

The historic town of Grimma is situated on a floodplain confined by the ridges of the surrounding hills. The geomorphological conditions make for a special town-river relationship. On the one hand, the proximity of the river provided the very reason for the foundation of a settlement here. Over the centuries, the river has formed the economic foundation of the town as well as lending the place its special appeal. On the other hand, Grimma has always been threatened by floods, and this risk cannot be avoided either by riverbed corrections or by relocating buildings.

Figure 4.2.5.1: Town and river in their geomorphological setting, listed buildings marked in red. Source: T. Will, H. Lieske.

Hydrological situation

August 2002 brought unprecedented amounts of rainfall to Saxony. Within a few hours small creeks were turned into terrifying torrents and calm rivers into devastating masses of muddy water, flooding the entire old town of Grimma. The loss of lives, of houses and properties, of places of work, and of infrastructure abruptly boosted people's awareness of the high risks of living by a river, and of the need to meet that risk with preventive measures. It also convinced the Dam Authority (LTV Sachsen) to update public flood protection on both a regional and a local scale.

According to the legislation in Saxony, flood control structures in general have to be dimensioned to withstand flooding events up to a level of HQ 100, i.e. events that, according to the statistics, occur once in 100 years. Because of the limited space in the narrow river

Figure 4.2.5.2: The Mulde River, the castle as seen from Pöppelmann Bridge, 2005. Source: T. Will, H. Lieske.

valley, such structures need to be rather high to protect Grimma, in some sections along the Mulde river as high as 3.7 metres. Given a short flood forecast lead time of only about 8 to 12 hours, it is unfortunately not possible to employ temporary elements such as stop logs in the town.

Preliminary planning

Quite soon after the 2002 event, the Dam Authority presented comprehensive flood control concepts for all the bigger rivers and their catchment areas. Providing substantial information on a strategic level, these concepts led to the commissioning of more detailed flood control planning, carried out by local hydraulic engineers. An initial proposal for flood protection in Grimma called for a monolithic concrete wall stretching 1200 metres and rising to a height of as much as three to four metres (Fig. 4.2.5.3). The proposal was presented to the permit authority and to the city council. It was promptly rejected in both cases. It was obvious that its realization would inevitably involve severe and irreversible damage not only to the river landscape, but also to the functional and aesthetic qualities of the town as well as to the historic fabric and the visual experience of the architectural heritage.

Subsequent controversial discussions led to general agreement that, for a place like Grimma, flood control planning based solely on hydraulic and monetary parameters is insufficient, if not counterproductive, since it is likely to screen off, to damage or even to destroy those elements and features that (in addition to its foremost task of safeguarding the population) the planning is supposed to protect. As a consequence, it became clear that flood control in the historic urban areas needs to be integrated with other related activities, like town planning and urban design, historic preservation, environmental protection and design, the local economy and infrastructure, recreation, and tourism.

Stakeholder participation and professional expertise

Stakeholder and expert meetings supported the generation of new options. Finding out about the image of the city as perceived by its inhabitants, about their shared values and future conceptions, and about their fears and hopes for flood protection contributed as much to the integrated planning as did the expert opinions of hydraulic engineering professionals and architectural analyses. For example, stakeholder participation allowed the perceived absolute and relative benefits of some of the main issues to be rated, i.e. flood control, adaptability to heritage preservation, townscape and public access to the waterfront.

Figure 4.2.5.3: The Mulde River, the castle, the flood protection wall, preliminary proposal by the Dam Authority. Source: T. Will, H. Lieske.

City, landscape, and cultural heritage considerations

The history of flood protection measures, like the histories of city walls, railway tracks and other large-scale buildings, provides evidence that these heavy structures do not necessarily interfere in a degrading or disintegrating way with their respective urban or landscape environments. Planning for flood protection structures should rather provide an opportunity to enhance the conditions along the urban waterfront by improving pedestrian and bicycle access, by upgrading the riverfront as a place of leisure, and by reviving visual and functional city-river relationships. To this end, comprehensive analyses were made to describe and visualize topographical, spatial, environmental, aesthetic and functional qualities. An evaluation of all of these findings led to the formulation of certain principles to be applied in the design of the Grimma flood control system. Four main strategies were defined:

(1) reduce the maximum height of the structure (HEIGHT)
(2) push its alignment as far as possible beyond the river banks (POSITIONING)
(3) differentiate the structure according to the various site specifics by articulating or emphasizing either their architectural/urban or their landscape character (TYPOLOGY) and
(4) adjust the measures visually to their surroundings (SURFACE/TEXTURE)

Integrity in diversity, legibility

In terms of spatial and structural implementation, the planner is given the difficult task of integrating a monumental structure into the delicate and highly detailed fabric of a historic town. Given the spatial and geometrical restrictions on concealing a very long storey-high wall, it proves crucial to subdivide the structure into manageable segments and to further detail these segments by meaningful design that corresponds to the respective surroundings. Yet merging the wall into the urban fabric is not the same as hiding it from view. Flood protection measures are exceptional endeavours in response to severe disasters and threats. For this reason they should be given an adequately visible presence, they should be visually consistent, and they should be recognizable for what they are. These demands can be met by conceptual variation and by the recurrence of certain geometries, materials, details and finishes.

Figure 4.2.5.5: District Administration Building, flood protection integrated into the historic building, 2009 (note the U-profiles in the window reveals, with covers temporarily removed, to hold stop logs). Source: T. Will, H. Lieske.

Figure 4.2.5.6: Site of the District Administration Building, monolithic flood protection wall, preliminary planning stage, photomontage. Source: T. Will, H. Lieske.

Figure 4.2.5.7: Site of the District Administration Building, dotted line indicating flood protection integrated into the historic building. Integrated planning proposal, photomontage. Source: T. Will, H. Lieske.

Retrofitting buildings to withstand flooding

Some of the monumental riverside buildings were examined, and proved to be substantial in withstanding floods. These buildings thus became components of the overall flood protection system while leaving the existing situation almost unchanged visually. This strategy applies to the historic buildings of the castle, the Princes' School, the Convent Church and the District Administration Building. Measures have been taken to seal the joints on the outer wall masonry, while the windows and doors have been fitted with hatches and stop logs.

The medieval city wall

One of the most outstanding features of Grimma is its city wall, stretching 450 metres along the waterfront. Investigations into its inner composition revealed that this structure is unfortunately not suitable for retrofitting through structural reinforcement. Following a controversial discussion of its considerable values and its benefits for the cityscape, it was decided that the historic wall should be closely flanked by a new concrete flood protection wall that will be clad with an assortment of local stones much like the stone that constitutes the medieval wall.

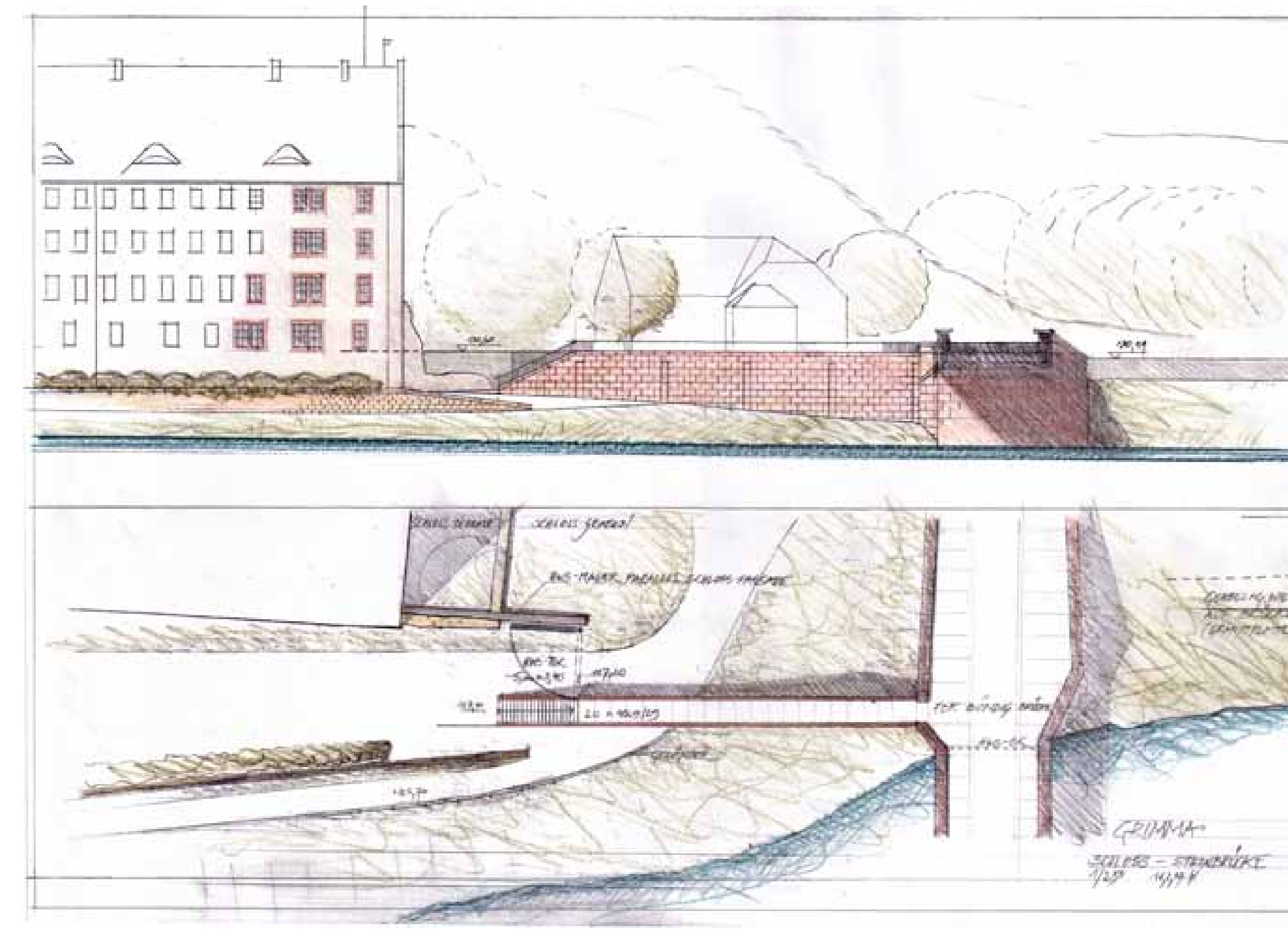


Figure 4.2.5.7: Flood protection wall supporting a new promenade approaching the historic bridge. Integrated planning proposal, layout and elevation (cf.Figs. 4.2.5.2, 4.2.5.3). Source: T. Will, H. Lieske.

Historic stone bridge / castle

The arched bridge by the famous Baroque architect M. D. Pöppelmann marks the main entrance to the town, adjacent to the castle. A monolithic concrete wall, as suggested initially, would certainly spoil the sense of place here. (Fig. 4.2.5.3) A subsequent proposal to set the flood protection back from the river proved, however, to cause too much interference with the archaeological site at the location of the former castle moat. The final solution integrates the flood protection wall with a new promenade approaching the historic bridge (now restricted to pedestrians), thus defining a confined urban space that can be developed into an attractive new plaza. (Fig. 4.2.5.7)

The new waterfront park

North of this site, the project provides an opportunity to enhance substantially the present-day rather disappointing large riverside parking lot. A new waterfront park will be laid out for the recreational benefit of the public. Naturally contoured river banks and a landing place for boats will allow people to reach the waterside. Shady trees, paths and benches will be provided. Here the flood protection wall is designed in wavy segments that stretch out through the park in a dynamic S-shaped curve. Apart from its sculptural qualities, the wall will screen off the parking lot from the waterfront park.

Conclusion

Flood control planned only from a hydraulic engineering perspective can easily do damage to the very values it was intended to protect. It needs to be integrated with issues of urban function, cultural heritage, and city and landscape aesthetics. Realization is subject to appropriate funding, and requires considerably more complex planning and construction processes. As the project in Grimma shows, this extra planning effort as well as stakeholder and interdisciplinary expert participation more than pay off, if the long-term flood protection structures on a large scale can be designed to merge successfully into the valuable fabric of a special place. In some cases, the measures can even lead to improvements beyond mere floodproofing, and can add extra beauty and amenities to these places.

Figure 4.2.5.8: New waterfront park with the sculptural flood protection wall. Integrated planning proposal, photomontage. Source: T. Will, H. Lieske.

4.2.6 Český Krumlov (Czech Republic) – a small-river flood in a small town

Klára Nedvědová

Case study object characterisation

Český Krumlov is located in the southern part of the Czech Republic near the Austrian border. The town is situated in the Vltava river valley in the foothills of the Blansky Forest Nature Reserve. The first mention of the town was in 1274. Český Krumlov was established essentially in two stages. The first part, called Latran, was built spontaneously below Krumlov Castle and was settled mostly by people who had some administrative connection with the castle. The second part of the town, called the Inner Town, has a typical colonization ground plan with a quadratic square in the centre and streets from its corners leading to the town walls.

Figure 4.2.6.2: Meanders of the Vltava in Český Krumlov. Source: Lubomir Mrázek.

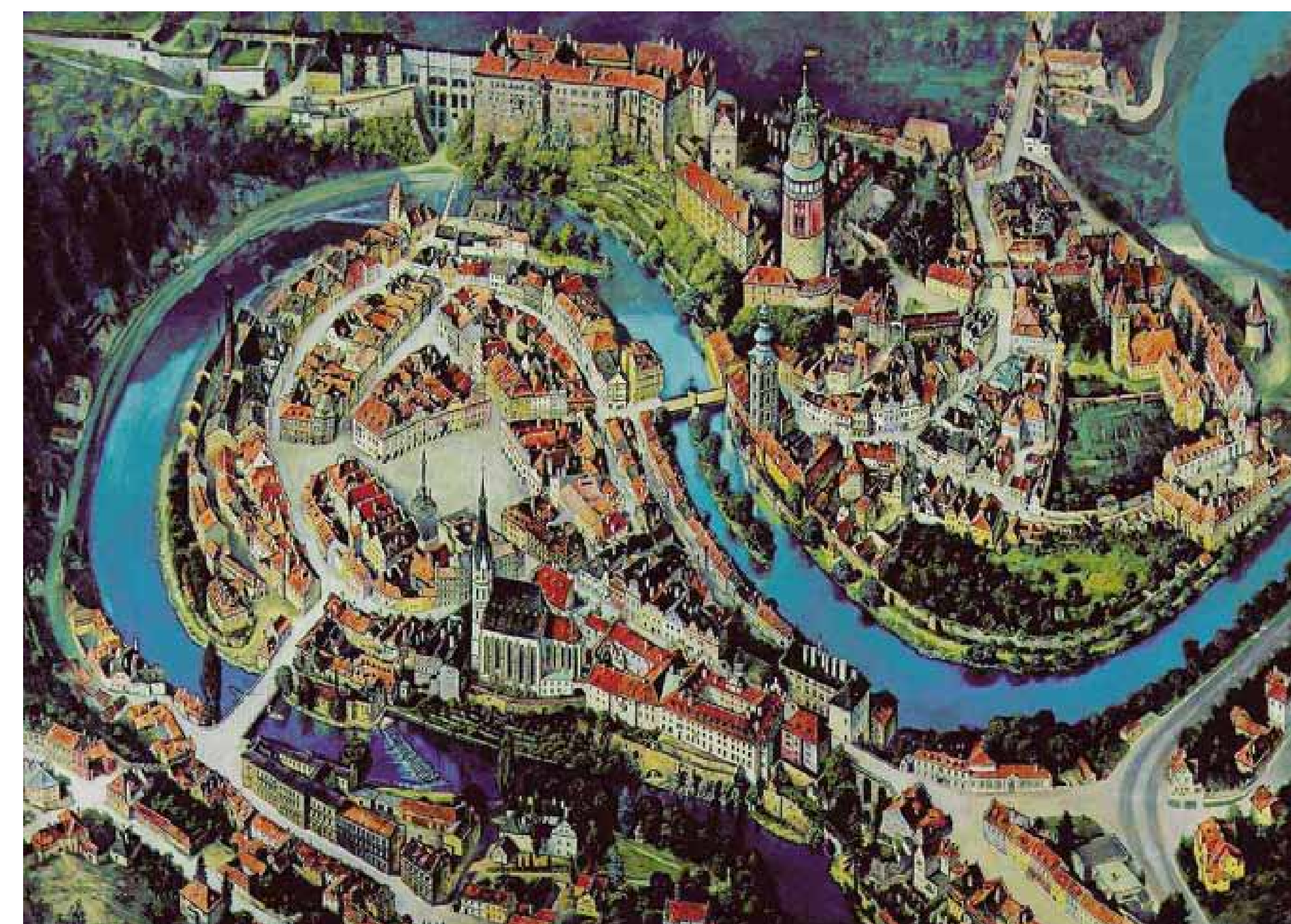


Figure 4.2.6.1: Český Krumlov – Latrán, with the Castle and the Inner Town. Historic picture, free of photo property rights.

The town as well as the castle flourished particularly under the rule of the Rosenberg family (1302 - 1602). In the 16th century, the town acquired its present-day appearance. Town houses as well as the Castle were reconstructed in Renaissance style. During the 18th century, the aristocratic residences in Český Krumlov reached the level of the leading aristocratic residences in Central Europe. The aristocratic court and the standard of living followed the example set by the Emperor's residence in Vienna. The town ceased to be an aristocratic residence in the 19th century, and has maintained its Renaissance-Baroque character until nowadays. The more recent structures are not significant.

Since the mid 1960s, special care has been devoted to preserving the historical merits of Český Krumlov; and in 1992 the town was included in the UNESCO List of World Cultural and Natural Heritage. After Prague, Krumlov is the most visited place in the Czech Republic. It contains about 300 protected buildings in the historic centre, the second largest castle complex in the Czech Republic, and the oldest Baroque theatre in the world, the Egon Schiele Art Centre, the International Art Gallery, 7 museums and 4 galleries, and numerous art shops. The town hosts 5 music festivals and several theatre festivals, and the open-air theatre has a revolving auditorium.

Hydrological situation

The Vltava River plays a crucial role in thesetting and environment of the town. According to legend, the name Krumlov is derived from the German "Krumme Aue", which can be translated as "crooked meadow". The name comes from the natural topography of the town, specifically from the tightly-crooked meander of the river. The Vltava springs from under the Black Hill in Šumava as the Black Brook, and it takes the name Vltava after it joins with Cold Vltava River. Its total length from the spring to the junction with the Labe is 430 km². The Vltava is the longest river in the territory of the Czech Republic. Thanks to the flabelliform character of the river basin, it reliably gathers up the high flood water waves of all its affluents. The Vltava runs through the large Lipno water reservoir before it reaches Krumlov. Its role during floods is a frequently discussed issue. It is generally the case that dams and reservoirs can manage a certain amount of high water, but when their capacity is exceeded the areas further down the watercourse can be impacted more strongly than if the water had been allowed to flow uncontrolled.

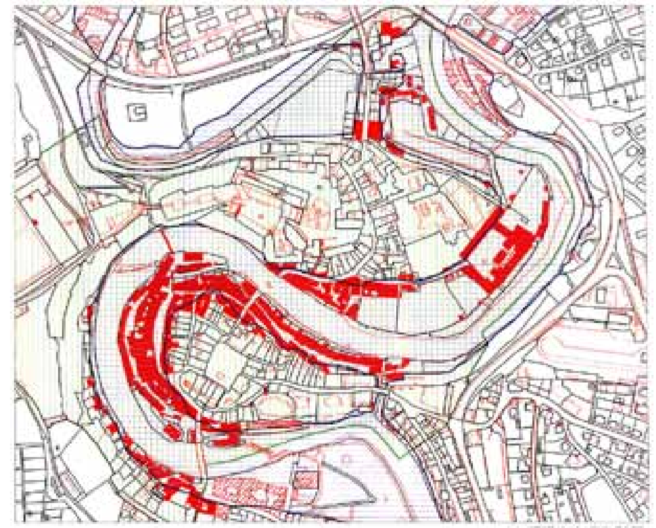


Figure 4.2.6.3: Number of flooded historic houses. Source: Tibor Horváth, (GIS Municipality Český Krumlov).

Flood impact and damage

Having in mind the setting of the town, it is obvious that floods are nothing unusual in this location. The most vulnerable part is the Inner Town. The back tracts of the houses lie right at the water level, and the river is a very important place-creating element. In the past, the ground floors of the buildings were usually used for service and work purposes, in order to minimize the losses when there was high water. Valuable property was kept in the upper floors. Nowadays, the ground level is usually used for commercial activities - shops, restaurants, hotels, art galleries, etc. Spaces are loaded with goods that are not tolerant to water damage.

The flood in 2002 exceeded all expectations. The flooded area was about 140 ha in extent. About 300 houses were flooded in the Český Krumlov monument protected area, and a total of about 800 in the whole town. In some places, the buildings were under as much as 5 metres of water. The supply system collapsed. The Inner Town, lying in the meander of the river, was completely cut off from the surroundings. The bridges were under the water. All inhabitants had to be evacuated, and the army took over control and closed the whole area.

Material loss

The material loss was different in character than the losses for example in Švihov (see Section 4.2.7). Old houses in the town centre did not suffer much structural damage. The worst registered damage was the collapse of the bridge near the Eggenberg brewery, and the Schindel roof at the Egon Schiele Art Centre was cracked due to the heavy rain. None of the buildings had to be demolished or required special static support. The damage to the finishes and to the inner equipment was much worse. In terms of historic value, the damage to the interiors was much more serious than in the case of Švihov. All the buildings in the town centre are listed. If the interiors were to be ruined, there would be a great loss of information that has been held there for centuries. Fortunately, the UNESCO listed status of the town attracted special attention from the Institute of Monument Protection, and the awareness of the owners was also much higher than in Švihov.

The damage to the infrastructure was vast. The street surfaces and the sidewalks were full of mud, and in some places water undermined the asphalt and grubbed it out. Some parts of the town were completely inaccessible. The sewerage system was overloaded and had to be renewed. The drinking water supply was contaminated. The electricity supply was cut off for several days.

Socio-economic impact

Český Krumlov is economically dependent on tourism. Huge numbers of tourists visit the town throughout the year, bringing a lot of money to the town. During the summer, in particular there are festivals of water sport, music and theatre, as well as other cultural events, and the town is crowded. The flood reduced the level of tourism by about 90 percent. The industry in Krumlov (the brewery and furniture production) was stricken by the flood. All this had a major impact on employment and on the local labor market.

Impact on cultural heritage

Of course, the flood left its aftermath. The structural damage to the buildings was not very significant, because most of the structures are made from stone and are therefore not greatly affected by water. However, the finishes and the interior equipment were impacted much more severely. Though much more attention was paid to the right approach toward clearance and reconstruction than in other places, the memory-of-place was affected. In addition, exhibits were not evacuated in time from many museums and art galleries, and the collections incurred losses.

Psychological impact

There was much solidarity and cooperation, not only among individuals but also between towns and villages. In 1997, when devastating floods struck in Moravia support came from Bohemia. The floods in 2002 mainly affected Bohemia, and the Moravian towns and villages responded in like kind.

The importance of personal attachment to the location was an issue when the flood protection arrangements for the river banks started. Local residents, especially the owners of houses by the river bank that are most vulnerable to the flood, called for a more sensitive approach and for an open debate on this topic.

Problem assessment

The Flood in 2002 in Krumlov was the same flood event as in Švihov in that year. The circumstances were similar (both rivers spring in the same area): rainfall (about 50 years frequency) over an extensive area and local extreme rainfall (more than 100 years frequency) that occurred within the course of a single week. This situation could not have been forestalled, because the soil has a limited drainage. However, the damage could have been reduced if there had been some disaster preparedness and if there had been precise guidelines for limiting the damage after the flood, especially for the owners of listed historical buildings. Another problem was the implementation of the flood protection measures. The local residents did not agree with the extensive adjustment of the river banks and with the failure to introduce an alternative plan.

Repair and preventive measures

Financial and material help arrived from everywhere. Many volunteers came to help with the clearance work. The local authorities immediately launched media campaigns under the slogan "Bojujeme o vlastní záchranu" (We are fighting for our own rescue), aimed at

Figure 4.2.6.4: Vltava River before channel dredging. Source: Klára Nedvědová.

Figure 4.2.6.4: Vltava River during removal work. Source: Klára Nedvědová.

encouraging companies to keep on their staff, and "Český Krumlov znovu ožívá" (Český Krumlov is reviving) ,aimed and winning back tourists and informing them about the activities and services that were available. Many events usually take place in Krumlov in the summer, and efforts were made to retain as many activities as possible from the original programme. People were encouraged to visit Krumlov by the slogan: "If you want to help, come and spend some pleasant days in our town". The town made the most of its reputation and its UNESCO status. Many important figures from the world of the arts and politics came for a visit and offered their support, for example US ambassador Craig Stapleton and Austrian Foreign Secretary Benita Ferrero-Waldner. Many beneficial concerts and other projects were held in support of the town. This was easier to do in a well-known town like Krumlov than in numerous unknown towns and villages. The local authorities in Krumlov were aware of their advantage, and agreed to transmit some of the help and support to other places faced b a similar crisis.

Although the management immediately after flood was successful, the local authorities nowadays face disagreement over the flood protection and prevention measures. The river bed was deepened and widened to be able to absorb HQ 100. Due to these measures, the water level was reduced by about 80cm. However, the river is a very important element in the town, and is fully involved in its life. Houses have their gardens by the riverside, and the river forms part of the living environment. Lowering the water was a major intervention to the historical setting. In addition, a small alluvial island was removed. Though it was not a real island, just a soil deposit, it has its place in historical portrayals of the town. The importance of public involvement in decision making was underestimated, and the river bed regulation project was not adequately publicized and discussed. In addition, the State Institute for Monument Protection made a mistake and misjudged the significance of the impact of the proposed adjustment on the historical appearance of the town.

Bad practice

Some failures that occurred during the flood:

- No flood protection system;
- No effective guidelines for owners, especially for those occupying listed buildings
- Insufficient involvement of the public in decision making
- Underestimation of local residents' attitude to changes in the historic UNESCO site

Lessons and achievements

The municipality tackled some aspects of the extraordinary events successfully through:

- Very good management during the flood and after it, especially in distributing humanitarian help and accessing financial resources
- Good use of the fame of the UNESCO site for its media campaign;
- Support leading to rapid revival of ordinary activities;
- Support for local businesses to retain staff threatened by employment.

4.2.7 Švihov (Czech Republic) – a small-river flood in a town with a water fortress

Klára Nedvědová

Case study object characterisation

Švihov is a small town of village character situated in the valley of the river Úhlava. It is located about 30 km to the south of Pilsen, on the main road to Germany. It has 1160 inhabitants, and about 10 other villages fall into its subregion. The town contains a number of cultural and natural heritage sites. The most significant of them is Švihov Castle, a water fortress that is the dominant feature of the town. It is listed as a national cultural monument, and it attracts many tourists during the summer season. During the flood in 2002, Švihov was one of the most flood-affected towns in the Czech Republic.

Hydrological situation

The source of the Úhlava is on the slopes of Pancíř Hill in Šumava, and it joins with a brook from Lake Černé. The basin of the Úhlava has an area of 929 km². The total length of the river is about 100 km. The river does not run through the centre of Švihov but runs through the meadows to the east of the town. The problem during high water is that the town centre, including the castle, lies only slightly above the surrounding meadows, which serve as a natural inundation area. Floods are therefore an annual event in Švihov. Every year there is a threat of flooding in spring and summer. Though the region itself does not suffer from heavy rainfall, the Úhlava rises in the Šumava Mountains and has a many small feeding rivers and streams. Upstream, the large Nýrsko water reservoir regulates the water level and thus helps to prevent flash floods. Regulating its water level can have a great influence on the flood flow. The discharge from the reservoir can be regulated, but when the water exceeds the capacity of the reservoir it can do great harm, because it flows without any control.

Flood impact and damage

In the past, floods were not a great issue in the town. They were usually managed without major losses, until 2002, when the town underwent a very unpleasant experience. The town was damaged by flood with twice the volume of a HQ 100 flood. The depth of the river, which is normally about 1,5 m in this area, reached a level of about 5 m. The width, which is normally 10 m was extended to about 400m. There was about 1,8 m of water in the town centre. Half of Švihov was under water. The streets and meadows were transformed into the bed of the flooded river. The Castle was cut off from the neighbourhood. Transport was possible only by boat.

The damage in Švihov can be divided into several categories: physical and material losses, the impact on cultural heritage , the socio-economic impact, and the psychological impact.

Material losses

The greatest and most significant losses during the 2002 flood were the material losses. 116 houses were flooded. About 30 of them had serious static defects. Their walls and ceilings needed to be supported. Finally 14 of them had to be demolished. Most of the domestic animals did not survive. Gardens and courtyards were soiled with mud. Little of the interior equipment could be saved.

The main problem with the most flood-affected houses was that they were built from unburned bricks. This material did not survive waterlogging, and collapsed. Most of the owners were not aware of the kind of structure that was hidden under the modern coating. All owners did their best to save as much as they could, and in some cases they did the almost impossible to save their homes, whatever the financial cost.

Immediately after the water level had come down, cleaning and removal of debris began. All facings and insulation, as well as the floors and plaster coatings were removed. Everything that was wet and that obstructed the drying of the structure was removed.

Streets and sidewalks in the centre of Švihov were destroyed. The sewerage system was flooded and filled with mud, and had to be completely repaired. The water wells were also affected, and had to be cleaned out. The municipal electricity transformer was also flooded, and a back-up source of electricity had to be provided for the town.

Figure 4.2.7.2: The former Gothic church, near the town centre. Source: Photoarchive Švihov.

Figure 4.2.7.1: In some places the water rose to 1,7 m. Source: Photoarchive Švihov.

Socio-economic impacts

Damage to property damage amounted to CZK 50 million. Thanks to good management by the local authorities, the town has gained a maximum level of financial support from government sources. Nevertheless, these losses will burden the local economy for several years. In addition, the income from tourism decreased for couple of years, because the town became less attractive after the flood. Surprisingly, the disaster did not lead to major demographic changes. None of the residents moved away, though they were offered compensatory housing elsewhere in the region.

Impact on cultural heritage

The most important cultural heritage building, Švihov Castle, survived without major changes. Only the courtyard and some of the service buildings were flooded. All the other important buildings in the complex were constructed above the water level. The situation was worst in the downtown area, where many unique houses with the original vernacular architecture had to be demolished. Unfortunately, there were no guidelines or contingency plans for such a situation, and in the first wave of clearance most of the historically valuable finishes were removed.

Psychological impact

The whole situation evoked a very high level of solidarity, at least in the short term. The observed behaviour revealed quite important information about how people act in a critical situation. Another observation is that in 2002 people paid little attention to the flood warnings, as they thought there would only be another of the harmless situations they had known from the past. Now, after 2002, every flood warning causes some hysteria, mainly among old people. The negative experience is still fresh in people's minds. Even talking to older people about what happened 7 years ago can reduce them to tears.

Problem assessment

This situation was caused by a combination of extensive area rainfall (about 50 years frequency) and local extreme rainfall (more than 100 years frequency), which occurred in the course of a single week. The drainage basin was saturated from the first rainfall wave and could not absorb the second wave. There was no way in which this situation could have been forestalled.

Repair and preventive measures

In the first three years after the flood, the town changed beyond recognition. Thanks to the good management and the personal commitment of the mayor, the town received millions of Czech crowns from EU funds, charity contributions and Czech Government support.

The local authorities in Švihov started immediately on renewal and remediation. Within just 2 months after the flood, the Švihov Municipal Authority called on all relevant authorities, institutions and companies to take part in developing a flood protection study for Švihov.

Figure 4.2.7.3: Protective rampart. Source: Photoarchive Svihov.

Figure 4.2.7.4: Reconstruction of the fortification wall. Source: A. Hřibal.

Figure 4.2.7.5: Švihov Castle during low water. Source: I. Froliková.

The suggested measures included the erection of a protective rampart on the right side of the water channel, passing round the castle. The original suggestion was for a terrain barrier in the close vicinity of the castle. This would

Figure 4.2.7.5: Švihov Castle during the high water in 2002. Source: T. Bartoníček.

have completely changed the panorama of the Castle and also its communication with the landscape. Fortunately, the local authorities were open to alternative solutions and a competitive plan was worked out. The mayor wanted to involve the people of Švihov in the decision making process, and he called a public meeting to discuss the matter and vote on the final solution. Part of the discussion was on where to find funding, as the Castle-friendly version was ten times more expensive than the original suggestion of a protective rampart. With only one or two exceptions, the residents of Švihov agreed that part of the money received from charitable collections should go for the project.

The old fortification wall was renewed and become a part of the flood protection rampart. The visible surface is made from stone masonry identical with the masonry of the castle. The wall is optically isolated from the rest of the barrier. It is not connected with the dike. It is brought tight together by a movable flood-protection barrier only when there is a flood threat .The structure of the rampart itself is spilled and is homogeneous with the sealing detent. Seepage of the subsoil is ensured by a clay sealing rug. The castle water channel was locked by a new flood gate.

Lessons and achievements

The municipality proved its ability to tackle the extraordinary events through:

- very good management during the flood and after it, especially in obtaining financial resources for remedial measures;
- constructing a new infrastructure in the town centre;
- renovating the whole town centre;
- constructing an acceptable flood protection system for the town centre and the Castle
- involving the public in the decision-making process

Bad practice

Some failures that occurred during the flood situation:

- there was no well-functioning flood protection system. The bridge was not able to let such a large amount of water pass through, and became a water barrier. The weir and stop planks were out of function;
- the residents underestimated the situation. People paid inadequate attention to warnings, and refused to leave their houses;
- there were no effective guidelines for owners, especially for those occupying listed buildings. People were not aware of the loss of value that was likely be caused by abrupt massive clearance of materials, not least cultural heritage items and items of sentimental value;
- the local authorities lacked experience and guidelines for dealing with such a disastrous situation;
- wrong instructions were issued from the regional disaster management committee.

4.3 Gardens and parks

Miloš Drdácký, Christoph Franzen, Klára Nedvědová, Zuzana Slížková

4.3.1 Pillnitz Castle (Germany) - park and museum

Christoph Franzen

Case study object characterisation

Pillnitz Castle is an extraordinary ensemble of architecture and landscape gardening. It is situated about 10 km up the Elbe from Dresden. It is a beautifully integrated part of the Dresdner Elbtal heritage site. The Castle, built in the early 18th century in Asian style, is an outstanding example of Chinoise water and garden palace architecture.

In the history of Pillnitz Castle, the elector Friedrich August the Strong became the owner after he inherited the kingdom when his brother died. The policy he made in Pillnitz Castle played a central role in his dominant regency.

Between 1720 and 1724, the water and garden castle was constructed to the design of the sculptor and architect Pöppelmann.

Nowadays, the Baroque Pillnitz Castle, defined by its Chinese style, consists of three main buildings: the Wasserpalais (Riverside Palace), built in 1721 on the right side of the river Elbe, the Bergpalais (Hillside Palace) founded in 1723/24 in front of it at the side of the garden, and the Neues Palais (New Palace), constructed between 1818 and 1826 in the middle, with a pleasance between them. They are connected by several buildings (1788-1791) and are surrounded by a very beautiful natural park, in which the so-called Englischer Garten (English Garden), 1780, is located, with its Englischer Pavillon (English pavilion) and the Chinesischer Pavillon (Chinese pavilion) added in 1804, an orangery, and the old Camellia (1767/ 70).

Figure 4.3.1.1: Wasserpalais, north façade, view from the Bergpalais. Source: IDK.

Figure 4.3.1.2: Historic flood record in Pillnitz castle. Source: IDK.

Figure 4.3.1.3: Water gauge at the Wasserpalais. Source: IDK.

Figure 4.3.1.4: Water gauge at the Wasserpalais. Source: IDK.

Since 1993, the entire complex of Pillnitz Castle has been managed by Staatliche Schlösser und Gärten Dresden (State Palaces and Gardens, Dresden), which oversees its maintenance. Since 1963 the Wasserpalais, the Bergpalais and the basement of the Neues Palais have been used by the Kunstgewerbemuseum (Handicraft Museum), which belongs to the Staatlichen Kunstsammlungen Dresden (State Art Collections, Dresden) as showrooms, conservation laboratories, storage spaces and the director´s office.

Hydrological situation

The site of the castle has been periodically flooded by the Elbe since time immemorial. The respective architects therefore responded with measures that took flooding into account. Nevertheless, the catastrophic flood in 2002 resulted in heavy damage to the site and pointed to weak points for damage prevention to the heritage site. The flood event revealed some of the historical strategies that had become buried over time. In the framework of the CHEF-Project, the flow of events in 2002 was analysed, and the main lessons learned from the catastrophe have been summarized.

Flood impact and damage

The flood of 2002, between August 12th and August 18th, led to massive damage along the Elbe. The district of Pillnitz, an incorporated village located in the eastern suburbs of Dresden, was severely affected. The major cultural heritage structure in this area is the Baroque Pillnitz Castle.

The damages were a result from the coincidence of two different flood types. The heavy rainstorms of the previous days led on August 13th to the Friedrichsgrundbach stream, which flows along and through the castle gardens, flooding the gardens, destroying the surrounding wall of the park and large parts of the Englischer Garten, and also the technical facilities of the glasshouse of the camellia.

In parallel, the water level in the Elbe was rising. At that time, the Elbe had already swallowed the stairs of the perron up to the Wasserpalais. Only the upper ends of the walls with the sphinxes were visible, and a large amount of flotsam and jetsam was already drifting with the stream.

In the following days the water rose enormously. The water gauge reached its highest level in the morning of August 17th, and measured about 10.0 m at 9:00 am. With a further 80 cm, the exhibition rooms would have been flooded. The water finally covered the heads of the sphinxes on the perron. The cellars of the Wasserpalais were flooded. In the Fliederhof (Lilac Yard) the water level was about 2 m high. The Doric columns at the entrance to the wood conservation laboratory in the basement were under water. Only the tops of the lilac trees were still visible. The Alte Schlosswache (Old Castle Guard) and the parking lot were also under deep water. The final level was only 5 cm below the high-water marks from 1845, the biggest flood until then. The 1845 level was exceeded by about 5 cm in the chapel and cookery house, which are situated on the southern side of the Neues Palais.

From August 18th, the water level began to fall.

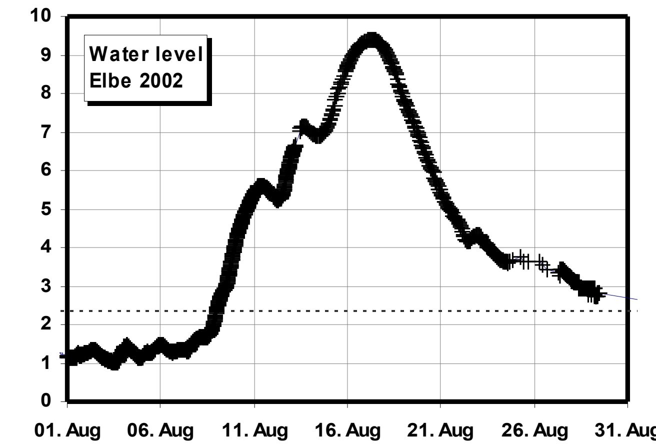


Figure 4.3.1.5: Water gauge in August 2002. Source: IDK.

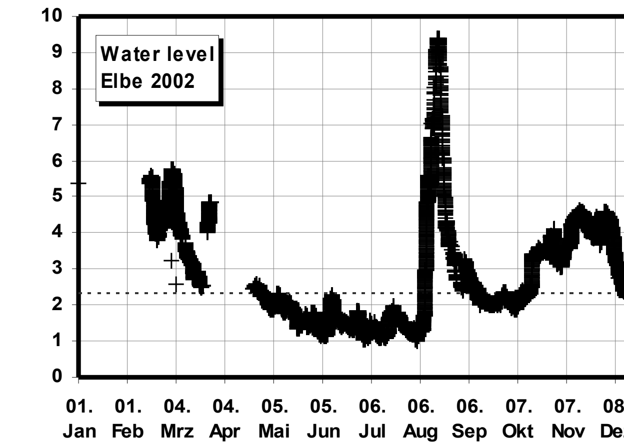


Figure 4.3.1.6: Water gauge in 2002. Source: IDK.

Observations during the flood

August 14th: only the most important items were transported to a higher floor

August 15th: Fire brigades from Hamburg and Erfurt worked together with the staff and volunteer helpers in the wood conservation laboratory, trying to seal it up using sandbags and suction pumps, and carrying art objects to a higher floor, to the banqueting hall of the Neues Palais. For safety reasons, work in the laboratory was stopped. At that time, the electricity supply and the security system broke down. Several employees decided to stay overnight in the grounds of the castle to supervise it.

August 16th: the fire brigades gave up attempts to save the Castle Hotel, after fighting for a long time with many helpers. High embankments of sandbags had been erected. At about 4:00 am, the Director of the Kunstgewerbemuseum, Drs. André van der Goes decided to have the exhibition at the Wasserpalais cleared, after discussions with the Director General of the Staatliche Kunstsammlungen Dresden, Prof. Dr. Martin Roth. The work started with the use of only pocket lamps. Light art objects were deposited in the storages on the upper floor of the Wasserpalais, while the furniture was carried to the upper floor of the Bergpalais. At noon, the ground floor of the Wasserpalais was completely cleared. Then the decision was made to clear up the exhibition on the ground floor of the Bergpalais, and also some of the furniture storages in the Neues Palais. This work went on until the evening. All in all, more than 2 500 artworks weretransported to higher floors on time.

Observations after the flood

After the water had receded, the cleaning-up operation started, on August 19th. It was not clear where to start, because flotsam and jetsam in combination with mud covered the entire outside area, while pieces of furniture lay one above the other inside the rooms. More than 1 000 cubic metres of sand, mud and garbage were removed within the first 10 days. About one hundred helpers arrived, mainly from the surrounding area, and the staff of other institutions also contributed to the cleaning operation. Staatliche Schlösser und Gärten Dresden were supported by the staff and equipment of the Bundesanstalt für Züchtungsforschung (Federal Institute of Cultivation Research), the Grünflächenamt der Landeshauptstadt Dresden (Office for Green Spaces), the fire brigade and private construction companies. The Kunstgewerbemuseum, which belongs to Staatliche Kunstsammlungen Dresden, received help mainly from colleagues in other museums. In addition, employees of the ministries and the Landesamt für Finanzen (State Office for Finance) arrived, as did schoolteachers with their pupils. Although their goodwill was greatly appreciated, serious problems arose because they did not know much about the building complex with the museum and its exhibition, and especially not about the conservation laboratories or any of the rooms for technical facilities, e.g. in the cellars. The volunteers had difficulty finding their way round the castle, as there was not enough staff available to teach them. In addition, they threw away whatever they thought was not worth keeping. Some work had to be done twice, just to check that valuable items had not been thrown out, and to pull them out of the trash, if necessary. A huge number of selected and expensive timber

Figure 4.3.1.7: Elbe Flood near Dresden 2002, here: Pillnitz Castle. Source: CHEF.

Figure 4.3.1.8: Flood near Dresden 2002, Elbe valley. Source: CHEF.

species were thrown out, as well as ivory or other precious materials used in the wood conservation laboratory which could not be removed on time. Several rubbish containers placed in the Fliederhof (Lilac Yard) were filled with things removed from the cellars.

Soldiers were stationed in the castle grounds to provide security for the whole complex, but this did not prevent the Schlosshotel (Castle Hotel) being looted. For safety reasons, the gates to the castle park had to be supervised or closed to control people leaving the complex. However, this made it difficult to get back into the castle when the entrances were closed. It was impossible to call anybody, because the telephone networks were down, and many people had to climb the wall surrounding the park. They were able to get back into the castle without the soldiers or their dogs recognizing what had happened. There was also a lack of drinking water and electricity, which made it difficult to provide people with food and other basic services.

The flood disaster took everyone at Pillnitz Castle by surprise. The situation could have been handled in a much better way if a proper emergency plan had been drawn up in advance.

4.3.2 Jaroměřice nad Rokytnou Castle (Czech Republic)– a cultural heritage park and garden

Jiři Bláha, Klára Nedvědová

Case study object characterisation

Jaroměřice nad Rokytnou Castle is one of the largest structures of its kind in Central Europe. The Renaissance castle was built on the site of a late 15th century Gothic water keep, which was enlarged to its present appearance at the time of Count Jan Adam Questenberk between 1700 and 1737. The new castle was designed by the Austrian architect Jacob Prandtauer. St Margaret's Church, with its remarkable dome-shaped roof, is smoothly linked to the castle edifice. There are three green areas in the vicinity of the castle – the adjacent French garden, situated on the left bank of the River Rokytna, the so-called Theatre Island, on the opposite side of the stream, and somewhat farther away, the English park. The intensively maintained French-style garden is located at the lowest level, but still above the high water culmination point. High water does not affect this part of the park. The English park is in fact an inundated meadow lying lower than the path along the river, and this is the area with the highest risk of flooding.

The Rokytná River plays a very important role in the composition of the chateau gardens. It was one of the most distinctive constituents in the design of the garden project, which was inspired by the system of water canals in the gardens encircling the famous Château Versailles in France. The Jaroměřice Castle garden architects, Jean Trehet and Johann Anton Zinner, decided to extend the 4-6 m wide stream of the Rokytná to a width of 22 m to enable the monumental architecture of the château to be compellingly reflected in the surface of the water. Count Ouestenberk's guests could use small boats and gondolas to be conveyed round the artificial Theatre Island. The river definitely provided a very positive visual impression, but at the same time it presented a risk during high water events.

Flood impact and damage

In the naturally evolved inundated forests, flooding is just an inherent part of their normal life, but the situation is different in the park. Both the newly-planted young trees and the fully-grown rare specimens suffered from the adverse effects of a sudden intrusion of water. The trees and bushes planted in parks and gardens are chosen for their shape and color, but they are usually not native to the area. Most are cultivars, which are even more vulnerable.

Damage to trees can be divided into two types - damage that is visible immediately after the water level decreases, and damage that shows up later. The first category includes mechanical and static damage, for example damage to tree bark, exposed roots, etc. Changes that are not visible tend to be more serious. Trees usually do not perish immediately after a calamity but react after several months or even years. Destruction of fully-grown trees is a very serious long-term effect, and can change the whole appearance of the park for decades.

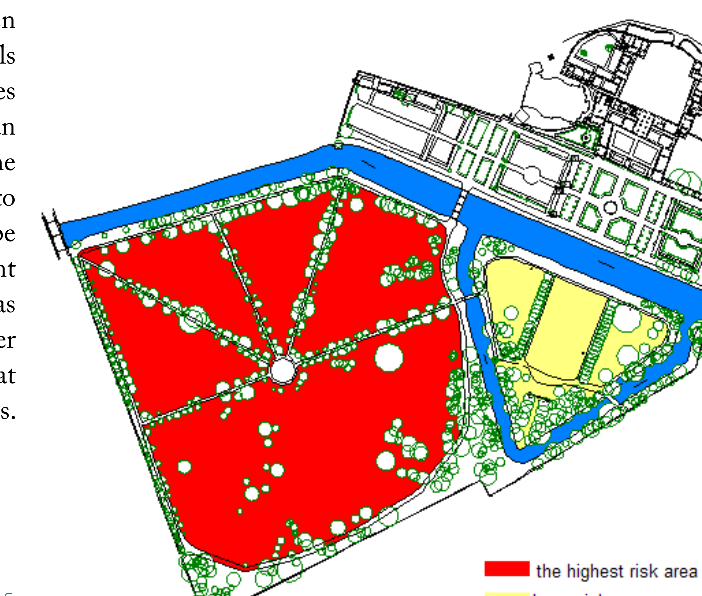


Figure 4.3.2.1: Castle and garden plans. Castle of Jaroměřice n/R management. Source: Petr Radim and Klára Nedvědová.

Figure 4.3.2.2: Uprooted aged willow. Source: Jiři Bláha.

Figure 4.3.2.3: Pools of water obstruct maintenance of the garden. Source: Jiři Bláha.

Unlike trees, plants and flowers are immediately affected by water. The most vulnerable are bulb and tuber plants, e.g. tulips, irises and narcissuses, which are drifted out or rot away. Grass and natural meadow withstand high water and waterlogging best. Fortunately, the part of the park that suffers most from flooding is the English park, which has many natural grass areas. However, pools of water that stand for a long time due to lack of functional drainage are also harmful for natural meadow and grassland.

Plants and trees are not the only things that may be affected by high water. Floods usually cause soil erosion and displacement. Erosion and underwashing can affect landscaping and garden architecture. During the flood in 2002, the breast wall of the Theatre Island was badly damaged.

Problem assessment

A comparison of the tree orthophotomaps referring to the last 60 years shows the changes to the main components of the original flood protection system:

The oval-shaped mud settling lagoon, which originally had the function of accumulating the suspended sediment, was converted to a fish pond. The weir on the river used to hold the water back to keep the canal wide. The system enabled the flow to be regulated when there was high water. Now the weir is embedded in concrete, which has resulted in siltation of the channel. The sediments in the river bed have reduced the absorbing capacity of the channel.

Lessons and preventive measures

Bad practice has led to the following obstacles experienced by the property management:

- complicated ownership rights: weirs, pond, river and land all have different owners. The whole situation needs active intervention by one of the owners, or the intervention of a mediator;
- even small changes in the relief of the park (e. g. raising the pathways) has to be approved by the culture heritage authorities;
- there is still no project for revitalizing the green areas.

Proposed measures - remedial suggestions:

- revitalize the original high water regulation system components – a mud settling lagoon, a movable weir, channel widening;
- raise the level of the meadows in the southwestern part of the grounds with material that which will be dredged from the channel in the course of cleaning;
- improve the drainage system for dewatering the meadows;
- repair the brick lining of Theatre Island before the stonework inside is affected.

4.3.3 Veltrusy Castle (Czech Republic) - landscape park and sculptures

Zuzana Slížková

Case study object characterisation

Veltrusy Castle is a very important Baroque complex with close links to the surrounding cultural landscape. The castle and its farm buildings are surrounded by an immense park that passes smoothly into agricultural fields. The park is animated with water channels supplied from the nearby Vltava River. This provided an opportunity to build several romantic little bridges, pavilions and sculptures in the park, as well as more practical facilities, such as a water mill and a gamekeeper's lodge.

The castle was built by V. A. Chotek as a summer house around 1720 on an island between two branches of the Vltava. The landscape park was founded around 1864 on an area of 285 ha, with a forested area of about 132 ha. The castle complex was listed as a National Cultural Heritage Monument in 2001.

The castle masonry is composed of various materials, including dried bricks, all plastered or rendered, as was fashionable at that time. The sculptures are carved in rather fragile, low-quality sandstone.

Hydraulic situation

The castle was built on very flat terrain on a site that is frequently flooded. The island was probably created in 1712, and the area suffered about 15 floods between 1750 and 1800. The flood in 1764 totally destroyed a Baroque garden at the castle, and the area was transformed into a landscape park. The hydrological situation changed in 1784, when the west branch of the Vltava was deepened and the east branch vanished. It was later replaced by an artificial water channel (in 1790), which suffered from numerous floods, the most serious of which were in 1845, 1862, 1872 and 1890. The last of these (1890) also severely damaged the central part of Charles Bridge in Prague.

In 2002, the castle survived an exceptionally high flood. The water reached a height of 3,5 m in the park and in some of the structures, and this was accompanied by a quite strong water stream velocity. The maximum flow volume attained in Prague was 5500 m^3s-1, which corresponds to a so-called 500-year flood. The area was flooded for about nine days, Fig. 4.3.3.1. (Photographs Zděnek Rieger)

Figure 4.3.3.1: Veltrusy Castle during the flood culmination. Source: http://www.radio.cz/en/article/108349/ pictures/zamky/veltrusy_povodne.jpg.

Flood impact and damage

The total cost of the damage was estimated at CZK 250 million (about EUR 10 million). The stream broke through the protective dike along the river, and devastated the landscape over an area of about 30 ha, on which sand and gravel was dumped to a height of up to 2 m, see Fig. 4.2.b. In the park, the water stream undermined or felled about 1000 trees and damaged thousands more. There will be more losses in future, due to delayed effects of the flood , Fig. 4.3.3.3. All roads and paths in the park were damaged or destroyed. The piles of objects that drifted on to the fields contained many dangerous or unknown agents, Fig. 4.3.3.4.

Small romantic buildings, mainly channel bridges, were damaged by the strong high water stream, which in some cases reached a height of. 3 m. For example, the Laudon pavilion was split into two parts with heavy cracks (30 mm in width) after uplift and subsidence of the bridge supports. One of the dams was washed away, and wooden foundation beams were washed out, facilitating the origination of voids and caverns. A small bridge in the allee suffered from undermined foundation masonry and

Figure 4.3.3.3: Fallen trees in the landscape park. Source: Milan Dropka.

Figure 4.3.3.2: Sand and gravel transported into the park. Source: Milan Dropka.

Figure 4.3.3.4: Dangerous debris deposited in the forest. Source: Milan Dropka.

partial destruction of a rail pillar, and had to be temporarily supported. An interior adobe wall in the gamekeeper's lodge was partially destroyed by a high-velocity water stream.

The main palace was fortunately attacked by only about 1 m of water. It exhibited more than 40 cracks due to foundation movement, and masonry, frescoes, stone elements and pavements were highly wetted. The behaviour of the cracks was monitored at intervals of one month.

Some non-structural damage occurred quite a long time after the flood, e.g. stone masonry efflorescence appeared after several months on the sculptures, and after two years on the Laudon pavilion.

Conditions before the flood

There was remarkable difference between objects which had been properly restored before the flood, e.g. a stone bridge with a Sphinx, and objects which had been neglected or incorrectly restored, e.g. the sculptures on the monumental stairs of the castle, Fig. 4.3.3.5. Although the bridge was totally immersed in a high water stream, it only needed to be cleaned with water and with low pressure steam after the flood. As a delayed effect, some hair cracks and slight mortar disintegration were visible in masonry joints in 2004. After repeated flooding in 2006, some minor restoration work was done to the bridge (colour retouching, plaster repairs) Fig. 4.3.3.6.

On the other hand, the sculptures had been repaired long before the 2002 flood in a way that had applied Portland cement and polyvinylacetate consolidation. This substantially decreased the water and vapour permeability and retained water inside the material. This led to increased contamination by salts, bio-colonization and surface detachment and disintegration patterns up to a height of 3 m. Freezing, moisture dilation and crystallization damage required a very substantial restoration intervention, Fig. 4.2.e. The sculptures were inspected before the flood, and the following defects were identified: biological colonization – algae, lichens (Lecanora muralis), moss (Tortulla previsima), common microorganisms on damp building constructions, black crust formation – a 0,6 mm thick compact layer (OM, cross section), on unwashed areas gypsum, calcite (XRD), polyvinylacetate (FTIR), cracks (splitting) on the plinths (along bedding planes), differential erosion, loss of material (loss of the clay-rich component), detachment and exfoliation. On the surface of the stone monuments, many sections repaired with mortar in the past were of different quality and colour. No water soluble salts were detected, apart from gypsum on the surface.

Tests determined that contamination of the stone by water soluble salts increased the salt efflorescence on many stone areas after drying of chlorides and nitrates. The flood provoked higher intensity of biological vegetation, and influenced detachment and disintegration patterns to a height of as much as 3 m, in combination with freezing of water (winter), different moisture dilatation coefficients of different stone components (non-homogeneities), and crystallization or hydration pressures.

Figure 4.3.3.5: Incorrectly restored sandstone sculptures. Source: Vojtěch Adamec.

Repair and preventive measures

Cleaning everything required a substantial amount of work, and would not have been possible without massive help from the army, using their heavy excavation and transportation vehicles. A lot of material also had to be removed manually from the interiors of the buildings, Fig. 4.3.3.7.

The palace walls were left to dry naturally, with the support of forced ventilation and only slight tempering to avoid freezing during the winter period, Fig. 4.3.3.8. The plaster was removed only in minor areas, partly because of the valuable wall decorations (frescos and mosaics), partly due to the assumption that plastering helps to maintain the integrity of the adobe bricks that had been inserted into the mixed burnt brick and stone masonry.

Figure 4.3.3.6: Restored bridge before the flood. Source: Vojtěch Adamec.

A completely new protection levee 450 m in length had to be built along the river, and an area of about 30 ha needed to be restored. Fig. 4.3.3.9. New dikes were built near the Laudon pavilion, and also a channel bridge. Gaps in the foundations and masonry of small bridges were either injected with mortar or walled up.

The sculptures were restored in 2004. During this intervention many old defects were treated, so that the following list of conservation steps is not completely related to the flood damage. The process involved: i) pre-consolidation of the most eroded areas (Wacker OH 100), ii) cleaning I, using low pressure steam, iii) cleaning II, removal of repair mortars, fills and metal fittings using pressurized air and a diamond tool, iv) cleaning III and desalination, washing with warm water, and in specific areas chemical poultices were applied (Remmers), warm water and low pressure steam, v) strengthening of eroded areas (Wacker OH 100), vi) grouting of cracks (Wacker OH 100, Paraloid B 72, Ledan), vii) filling of gaps (quartz sand + Portland cement < 20%w.+pigments), viii) colour retouching (Bayferox pigments (Fe oxides) in ethanol), ix) water repellent treatment (hydrophobization - Wacker 290), x) biocide treatment (Bayer products), xi) replacing a plinth by a cut sandstone replica, xii) pointing with lime mortar (Hasit 566 and 862).

Lessons

The affected territory cannot be protected against such exceptional floods. However, the damage would have been reduced substantially if the water works on the river and park channels, buildings and forests had been properly maintained and had been kept functional and sound. The application of vapour-impermeable materials in the previous restoration and repair work worsened the drying and desalination processes.

Figure 4.3.3.7: Sand piles inside the gamekeeper's lodge. Source: Milan Dropka.

Figure 4.3.3.8: Drying and ventilation of the palace masonry walls.Source: Milan Dropka.

Figure 4.3.3.9: The new protection levée along the river, and the area which was washed away (red line). Source: Ján Bradovka.

4.4 Stone Bridges

Miloš Drdácký, Zuzana Slížková

Figure 4.4.1.1: Stone bridge in Písek after restoration following the disastrous flood in 2002. Source: M. Drdácký.

4.4.1 Medieval stone bridge in Písek (Bohemia, Czech Republic)

Miloš Drdácký, Zuzana Slížková

Characterisation of the case study structure

The Stone Bridge over the Otava River in Písek was built in the second half of the 13th century and it is still in use. This is the second oldest stone bridge built in Bohemia and the oldest preserved bridge in Bohemia. At the present time, the Stone Bridge has seven vaulted arches (six circular arches and one segmental arch), six inner pillars and one abutment (on the right bank). Originally, the bridge had one (or two?) more left bank spans and there were bridge towers on both ends of the bridge (Fig. 4.4.1.1). The segmental arch replaced the two original extreme arches that were torn down, together with one bridge tower, by the flow of ice in the flood of 1768. With the exception of the ice-breakers in the pillar axis on the water face (except for the right bank pillar), the bridge does not have any accompanying structures at the present time.

The bridge line is slightly arched against the river stream. The span of the circular arches is 8.15 m and 13.1 m at the segmental arch. The bridge length, including the apron walls on the left bridge-head is 109.75 m, the net bridge length is 91.37 m, and the clear length between the face surfaces of the bank pillars is 87.27 m. The bridge width is 6.25 m, and the height above the normal river level is approximately 6 m. The pillars on the water face are provided with a sharp batter and pyramidal crown; on the opposite side, they terminate with a half cylinder with a conical crown and a bottom cutting edge at water level to improve the hydraulic performance of the bridge. The width of the pillars is 4.1 m; the total length without the apron is 11.85 m. There are three stone sculptures of saints built on the stone pedestals of the middle two pillars (St. Ann Self-Third, St. Anthony of Padua, St. John of Nepomuk with two angels) and the Sculpture Cross (Calvary). All the sculptures are from the 18th century. The oldest, St. John of Nepomuk with angels, is from the 1720s and 1730s.

The Stone Bridge in Písek was probably built using a classic procedure – repeated damming of a part of the river bed and using the dried out section for building. In gravel sediments, the foundations of the bridge pillars were sunk up to the stone bed from granite rocks. This condition was verified in part during repairs to the bridge between 1941 and 1943. The foundation of the individual pillars is carried out into the rocks of the rock bed, which can be formed of metamorphides (so-called pearl gneiss) or magmatic rocks (so-called Vltava granites). Due to the very good quality of the pearl gneiss, and also from the geo-engineering point of view, the conditions for all the pillar foundations are practically equivalent.

The perimeter shell of the pillars, the bridge arch, the breast wall and the stone railing are built from masonry blocks. The masonry block is jointed and connected in many places with forged cramps. The block material consists of granitic rocks that were exploited in the historical past in local quarries. In most cases, the material consists of amphibole-biotitic granodiorite or biotitic granodiorite. The strength of the rocks used for the blocks (resistance to compression, resistance to shear, tensile strength) is excellent, as is the abrasion resistance. The rocks exhibit no chemical and biological changes (stone diseases), and it is not probable that these will appear in the future. Although the mortar in the joints of the masonry blocks was damaged in many places prior to general repairs (from 1996 to 1998), it exhibited very good adhesion to the natural stones of the given rock types. The interior space of the pillars is filled with heterogeneous stones, originally bound with limestone mortar and with cement mortar during subsequent repairs. These stone components, unlike the binder of the filling, exhibit unchanged quality in the filling composite, and a long lifetime. Cramps connect some pillar blocks and bridge arches in various directions. The overall number of cramps is approximately 1,000. The use of cramps seems to be redundant in most cases, because the compactness and the static function of the masonry block structure is quite satisfactory in the load-bearing system of the Stone Bridge.

Hydrological situation

The hydrology of the Otava River in the Stone Bridge profile (river km 25.465) is characterised by the following quantities:

Minimum flow rate
Q_{min} = 3 to 3.5 m^3/s
Annual average flow rate
$Q_{average}$ = 18 to 24 m^3/s

The known chronology of major floods on the Otava starts in 1432. Before this date the bridge may have sustained the undocumented major flood that destroyed the Queen Judita bridge in Prague, the oldest Bohemian stone bridge, in 1342. Then, in 1432, a big flood is said to have torn down the wooden railing of the stone bridge. The same flood also demolished Charles Bridge in Prague. The flood in 1544 caused substantial damage to the bridge; the carved inscription RESTAURATUS 1544 has been preserved on the 40th block of the water face railing on the right. There are many other records: 1551 – the flood damaged the ice-breakers; 1559, 1582 – floods that did not cause major damage; 1626 – the bridge vault was damaged; 1655 – a violent ice drift tore down the Podskalský weir together with the Dráchovský mill, and seriously damaged the Stone Bridge; 1707 – the flood damaged the pillar foundations and their cladding; 1740 – the flood damaged one pillar and a vault that had to be supported temporarily with wood to secure traffic over the bridge; 1768 – the ice drift and subsequent flood broke down the 1st, 2nd, 5th and 6th pillars; the left bank pillar collapsed together with the adjacent bridge vault and the left bridge tower; 1784 – the flood heavily damaged 4 pillars and the bridge vaults; 1800 – an ice drift destroyed all the ice-breakers and damaged two pillars; under two pillars, ice blocks carved the river bed up to the bottom of the footing; 1841, 1845, 1853 – floods without significant damage; 1874 – the first flood for which the culminating flow rate of 950 m^3/s was determined quantitatively; 1890 – a flood that jammed the bridge vaults, with a flow rate of about 900 m^3/s. In the recent years, the March 1940 flood caused an ice drift. Ice floes up to 50 cm in thickness blocked the bridge arches and the adjacent city streets. The ice jam had to be removed with explosives, which damaged the structure of the bridge and also the buildings in the neighbourhood. The flow rate was estimated at around 700 m^3/s. In 1954, flash flood waters flooded a vast section of the housing zone on the left bank of the river during the night from July 8th to 9th. The army was called in for the evacuation. The magnitude of the culminating flow rate was around 870 m^3/s, which corresponds to the value for a 100-year return period flood. A sudden thaw in December 1993 due to warm rain in the Šumava region (Bohemian Forest) caused a flood with a flow rate of more than 500 m^3/s.

Condition of the bridge before the flood

The bridge in Písek has been exposed to more than 20 floods in the course of its existence that have distinctively endangered its structural condition. From the historical damage, defects and construction interventions, let us only mention some of the more significant and more interesting modifications. Well documented records start in 1707, when costly repairs were carried out to the pillars and their foundations. In 1768, an ice drift at the end of February and the subsequent flood heavily damaged the bridge. The bank pillar on the left bank was undermined and collapsed into the water. This led to the collapse of the extreme vault and the bridge tower, which stood on this vault. Matěj Vyšín, a land hydraulics specialist, determined that the density of the pillars on the left bank was too high and the vaults on them were too flat, so that ice could easily block the bridge openings. He therefore proposed replacing two bridge arches on the left bank with a single arch. In this manner, a segment arch was created on the left bank with greater clearance. In 1784, again at the end of February, an ice drift and the subsequent flood heavily damaged the bridge. It was necessary to repair 4 pillars and to reinforce the loosened vaults with steel wedges. An ice drift and flood damaged two pillars in 1800. The ice rafts abraded the river bed under two arches up to the foundation footing of the pillars and destroyed the block casing. The repair was carried out with wooden grids interlaid with stones. For traffic reasons the bridge tower on the right bank was demolished in summer 1825.

As mentioned above, the bridge itself and the neighbouring buildings were damaged in 1940 when the ice barrier was removed with explosives. All the damage was rectified during the subsequent major bridge repair between 1941 and 1943. Repairs were carried out primarily on the foundations of the pillars undermined by the flood, and the river bed was modified between the pillars. The main defects consisted in loosening and damage to the block casing of the pillars, behind which the inner masonry was heavily damaged or degraded, with disintegrated mortar in many places. Repairs were carried out in the following manner: The masonry blocks were gradually dismantled up to the rock bed at each pillar. Substantial parts of the inner masonry of the quarrel stones were also removed and replaced with concrete, laid as a filling behind the newly bricked casing of the pillars from the original blocks, jointed with cement mortar. Excavation was carried out around the foundations of the pillars for the concrete collar that was lined on the surface with faced quarrel stones. The river bed between the pillars was protected with a concrete layer with stone paving. The wooden log houses between the ice-breakers and bridge pillars were also repaired. No information is available on the repairs to the vaults.

Another major repair occurred in 1953 which, however, lacked sufficient respect for the unique historical characteristics of the Stone Bridge. The main goal of the project was to increase the bearing capacity of the bridge structure by means of reinforced slabs 50 cm in thickness, simply laid on angled thresholds concreted on the present pillars, because the bridge was part of a heavily trafficked major road. The slab structure required partial demolition of the old backing of the bridge pillars around their tops. Together with implementing the slab, the project included a dewatering and insulation system and modifications to the surface of the road with a granite cube pavement. Besides this basic reinforcement of the bridge structure, concreting was considered for reinforcing the vault backs on the bridge vaults, dismantling and new construction of the breast walls and reinforcing them with concrete, dismantling the old stone railing and constructing a new one, and jointing the bridge with cement mortar. The last intervention before retrofitting consisted in laying a bituminous carpet on the bridge road and walkways in 1958.

On the basis of a detailed construction-technical survey between 1994 and 1996, a project was prepared for major repairs to the Stone Bridge (Barták, Slížková, 2010). The final project documentation adhered to all the requirements of the state authority for heritage conservation, primarily the requirement for minimum intervention into the original bridge structure. Already in the preparatory project design it was decided that the concrete bridge slab, made in the 1950s, would not be removed. The reinforced concrete slab has no statically unfavourable effects on the bridge structure during separation from the breast walls. To remove it would have meant a demolition intervention accompanied by distinctive technical seismicity, which would surely have had a very negative effect on the condition of the historical parts of the bridge.

It follows from the hydrological analysis of the region and the historical flood data that the structure of the Stone Bridge is repeatedly endangered by flood flows that assume values around HQ 100. This flow rate, which represents between 800 and 850 m^3/s, raises the surface of the Otava to the level of the top of the bridge vaults, so that the flow profile under the bridge arches is congested. In addition, it was not considered suitable to overestimate the numerical value characterising the flood maximum with a probability exceeding 10^{-2} (i.e. the time of "repetition" in 100 years). Though the assessment is based on relatively long-term monitoring, it is necessary to count with some uncertainty in the estimation and random error, which may be plus or minus 20%. It was taken into account that there is a considerable space between the HQ 100 flood flow rate and the maximum flow that a given river basin can generate. The filling of a river basin with an extreme flood of unknown magnitude and at an unknown time is a real danger. Particularly in the case of the Otava river in Písek, with a water basin of approximately 2,850 km^2, the maximum "possible" flow rate could obviously exceed 2,000 m^3/s. On the basis of these considerations, a limit combination for overloading the bridge was calculated. The level of the upper water was considered at 362.8 m above sea, i.e. 2 m higher than during the flood in 1954 and more than 1 m above the crest of the left bank protection embankment. The level of the bottom water was also considered less favourably than in 1954, so that the design difference between the levels of the upper and bottom water for calculating the hydrostatic pressures was 3.3 m.

The friction coefficient between the pillar masonry and the granitoid rock bed was considered to have a magnitude of $tg\ \varphi = 0.25$. Although this relatively low value was not documented by tests on bored cores, the very bad condition of the pillar fillings at the level of the bottom of the footing found by exploration justified this pessimistic estimation of the friction coefficient. The calculation of the degree of safety from the point of view of the shear stress of the pillar at the bottom of the footing, when considering the full value of the upward hydrostatic pressure, exhibited a very low and alarming value of $s = 1.07$. At an even higher flood level, when different levels of the bottom and upper water cannot be assumed because they are balanced by the water flowing over the protection embankment under the bridge, there is no longer any effect of hydrostatic pressures. The hydrodynamic pressures on the non-flow section of the bridge (including the full stone railing) increase, as do the forces of the upward hydrostatic pressure. Taken together, this has the same negative effects on the stability of the bridge as the effects arising at different levels of the upper and lower water. In this case, the safety measures against the shear of the pillars at the bottom of the footing are also almost exhausted. This is particularly the case if there are reasons to assume the dynamic effects of floating objects of various types, or ice, on the non-flow section of the bridge. A decison was taken to increase the inadequate safety against the shear of pillars at the bottom of the footing using a measure that is certainly not usual in the construction of bridges: the effect of pre-stressed anchors acting vertically in individual pillars. These anchors significantly increase the resistance against the shear of the pillar masonry on the rock bed. For the same purpose, high pressure injection grouting was proposed in the pillars and at the bottom of their footing. This increases the friction coefficient at the contact of the pillar with the rock bed. Nine rock bed anchors were used in each pillar to increase the shear strength of the pillar-rock contact, and this raised the normal force at the bottom of the footing by 3,600 kN at 400 kN/anchor pre-stress. With simultaneous improvement of the friction coefficient to a value of 0.40, the safety against shear of the pillars at the bottom of the footing reached a value of 2.5. The overall length of the anchors is 10.5 m at an assessed injected root length of 2.5 m. The free lengths of the anchors are protected in their entire extent by a coat of epoxy resin applied by the manufacturer, which guarantees long-term secondary anticorrosive protection. After implementing the root and pre-stressing the anchors, the free length was grouted by injecting a cement suspension, which creates secondary protection of the free length of the anchors by means of a hardened cement paste. Cracks found in the vaults were cleaned along their entire length, filled with pointing mortar, drilled through in a cross manner by a system of small diameter boreholes into which reinforcing sections made of reinforcing steel in an anticorrosive modification were inserted and grouted. All the vaults were grouted with micro-milled cement material to supplement the binder in the joints between the individual blocks. In the pillars at the levels of the feet of the vault, horizontal grouting screens with polyurethane gel were implemented against excessive capillary water penetrating the body of the pillar. The current masonry of the pillars and vaults was jointed. Unsuitable partial repairs with brick seals and cement mortar were removed. Stone seals from granite ouches were implemented locally. Some major defects of the

Figure 4.4.1.2: Stone Bridge under culminating water on 13 August 2002 and with a temporary timber rail after the 2002 flood. Source: Petr Brož (cz .Wikipedia/Stone Bridge Pisek, for use in the public domain).

stone blocks were repaired with artificial stone seals. In the framework of repairs to the masonry, one copy of the drain, two new railing slabs and copies of all the stone sculptures on the bridge were made. The cramps with which individual masonry blocks were bound together were renovated and treated against corrosion. The stone masonry of the bridge was finally blasted with pressure water, pointed in depth mechanically to the extent indicated by the survey, and the pointing surface was sealed manually with a special mortar. The surface of the masonry face was hydrophobised with a protective spray, and the bridge deck was provided with waterproof layers. The new bridge road was laid into the sand bed paved with split cubes of Mrákotín granite. The bridge road was dewatered by point gulley holes leading into the original water drains together with dewatering the insulation layer. In the framework of reconstructing the bridge, the ice-breakers were renovated. The entire reconstruction of the bridge took 14 months.

Flood impact and damage

Persistent rains in August 2002 gave rise to the biggest and most disastrous flood ever recorded on the Otava in Písek. The water culminated on August 13th, and the highest measured flow rate (further measurement was not possible) was 1,400 m3/s; the level reached a height of 904 cm above normal. From an approximate extrapolation on the Qn line, it can be considered a more than 100-year return period flood. By the end, the water in the river reached 2 m above the bridge road (Fig. 4.4.1.2). The details on the bridge were heavily damaged or destroyed, apart from a small section between the Sculpture Cross (Calvary) and St. John of Nepomuk, and the railing along the entire length of the bridge was torn down. Fortunately, 90% of the torn-down railing could be retrieved from the Otava river bed. The stone paving of the road and the entire waterproofing of the road were torn down and washed away. Parts of the decorative railing were torn down beside the St. John of Nepomuk and St. Anthony of Padua sculptures, the sculpture of the angel in the group of sculptures of St. John of Nepomuk was torn down and the sculpture of St. Ann with a sickle was under water and shifted by trunks. Three pieces of stone guttering were damaged and six blocks were destroyed under the lamps, together with all the lighting for the bridge. The bridge pillars and vaults withstood the water run, confirming that the structural strengthening of the pillars and all the major repairs between 1996 and 1998 had been justified.

Repair and restoration

Pedestrian traffic over the preserved Stone Bridge was restored within a few days, which was of immense symbolic and factual value for Písek in removing the consequences of the flood. After the river returned to a level that enabled divers to inspect the river bed, it was decided to lift the blocks found on the river bed by means of cranes and divers, and to deposit them on the banks of the river. It was also decided that the restoration of the stone masonry of the bridge railing, waterproofing and the bridge road would be carried out in the same manner as during the reconstruction of the bridge between 1996 and 1998, in accordance with the project drawings for that reconstruction. The idea of additional anchoring of the stone railing to the bridge was rejected, because the front area of the bridge would be considerably increased by this measure during the impact of a catastrophic flood comparable with the flood in August 2002. In simple terms, it is better to sacrifice the bridge railing during the impact of a catastrophic flood than to connect it firmly with other masonry and risk fatal damage to the structure of the bridge.

With the help of photographs and video records, it was possible to determine the layout of the individual layers of the railing, including the shades of the individual blocks. The blocks were carefully cleaned from the residues of mortar and were laid on the original base. Work started on the right bank, on both the left and right side. After reaching the level of the sculpture of St. John of Nepomuk and St. Anthony of Padua, work started from the left bank, because the railing above the segment arch was stoned in the 18th century with a different type of granite. After exhausting the stock of deposited granite blocks lifted from the bottom of the river, approximately 5 metres of the railing were missing on each side of the bridge. The missing blocks were replaced with granite that was as close as possible in structure and colour to the original material. In the bridge railing exposed to the flood, nearer to the left bank, a series of processed blocks is clearly visible, and serves to remind us of the ominous moments in the summer of 2002, when it was quite obvious that something was happening to the structure of the bridge. After finishing the stonework of the railing, the inclined concrete slab was cleaned from the waterproofing residues and the surface was repaired locally. The intake of the dewatering pipes was repaired, and copies of two stone gutters destroyed in the flood were manufactured and installed. Teranap 431 TP waterproofing with Geofelt protective fabric was again laid on the prepared bed. The sand bed was carted on the finished waterproofing, and the new bridge road made of split Mrákotín granite started to be laid. The weather conditions interrupted the work on paving the bridge road. Jointing the stone railing with Petra mortar was postponed until the spring months of 2003, as was impregnation of the stone masonry of the bridge with Porosil (hydrophobic) material and the repair and completion of the public lighting on the bridge.

Lessons and preventive measures

The extreme flood in 2002 corrected with final validity the prevalent assumption until that time in a number of engineering works that the Q100 flow rate (100-year return period flood) is the decisive factor for safe anti-flood measure proposals. It was unequivocally confirmed by the flood in 2002 that there is a considerable margin between the HQ 100 flow rate and the theoretically largest outflow Q_{max}, generated by the maximum possible flow rate in a given river basin. An extraordinarily large flood at an unknown time is a real danger, and not a figment of the imagination.

The evolution of opinion on the reliability of anti-flood protection of large cities or parts of cities tends to the conclusion that they should be protected not against a specific n-year flow (for example, a 100-year return period flood), but against the maximum possible flood. Protection of human lives has the highest priority; it is necessary to differentiate when protecting state, municipal or personal assets, because it is almost impossible to achieve an acceptable profit ratio. Political rather than professional considerations and points of view are therefore usually decisive for projects requiring considerable investments.

It should be pointed out that the measure taken to secure the stability of the pillars statically with the help of pre-stressed anchors, which was proposed and implemented, also had its opponents. The opponents considered that the current safety measures against shear of the pillars were sufficient for any load, and that securing by anchors was an expensive and redundant measure. However, the town of Písek finally decided in favour of the proposed modification. It cannot be determined what part of the shear strength in the bottom of the footing was exhausted during the 2002 flood; nevertheless, it is a fact that the historic Stone Bridge in Písek "survived" the extreme flood in August 2002, unlike many other more modern bridge structures, without any signs of impairment to the position of stability. This was probably due to the additional anchoring of its pillars. There is no doubt that the entire high-quality design and the bridge renovation carried out between 1996 and 1998 contributed to the resistance of the Stone Bridge against more substantial destruction by the flood wave in August 2002.

Figure 4.4.1.3: The stone arch bridge in Regensburg Source: C.Koepp.

4.4.2 Lessons on the flood resistance of historic stone arch bridges

Stone arch bridges are very durable structures. Although these structures suffer severely from floods, usually being built with quite low clearance above the water, we can admire numerous ancient examples throughout Europe. The art of building stone arch bridges was developed by Roman architects, and their basic ideas and typology have survived for many centuries, (see e.g. http://traianus.rediris.es). The ancient bridges in Central Europe also exhibit the construction features of Roman bridges, namely in the foundation technologies of the bridge pillars. In medieval times, arch construction was strongly influenced by French constructors who, however, had also learned from Roman bridge building skills. (Drdácký, Slížková, 2007)

The most dangerous threat to historic stone arch bridges was posed by huge floating piles of material which created barriers, with consequent hydraulic problems that undermined the foundations. Although this danger has decreased, it is still necessary to be prepared to fight with floating objects and ice which might block the free flow through bridges. In modern times, ice barriers are blasted if necessary and floating objects are removed from the water by means of excavators or cranes. The impact of floating objects on the bridge structure can be further softened by ice breakers installed at a distance in front of the stone cutwater edges of the bridge piers.

The historically most damaging undermining of foundations has long been mitigated by means of various protective structures surrounding the foundations and the piers. In addition to measures introduced during the construction of a bridge, improving and protecting measures involve mainly caisson collar walls around the foundation and the bottom masonry layers of piers. In some bridges, the walls extend above the water and the whole structure creates small islands around the piers, e.g. in Regensburg, Fig. 4.4.3. Here the historic perimeter walls of the islands are made from oak piles, and the space between them and the masonry is filled with stone material covered on the top

Figure 4.4.1.4: Protective stone-paved "islands" around the piers and cramps. Source: M. Drdácký.

with stone ashlars. This structure has been now protected with sheet piles and reinforced concrete.

The piers of the Old Stone Bridge in Regensburg, Germany are protected with cutwaters which were frequently jointed together by means of iron cramps (seen in Fig. 4.4.1.3 and Fig. 4.4.1.4). The outer stone ashlars of the cutwaters can be damaged or even extracted by ice friction, especially when the bridge is not maintained, and the stones can be released by growing vegetation. Regular and proper maintenance is therefore a basic and most important mitigation measure for protecting bridges from the adverse effects of floods.

Extensive maintenance and repair measures are currently being undertaken while the traffic load is restricted.

A typical stone bridge foundation used timber grids made from massive beams jointed together with carpentry joints, usually extended with timber boxes made from squared logs, which were sealed with clay and emptied by pumping water with bucket wheels. The piers were then built directly on the river bed gravel with a layer of lime mortar or clay.

The recent catastrophic flood in 2002 tested the resistance of the oldest medieval bridges against the dynamic forces of high water. Bridges of quite low height survived successfully, even though they were frequently overflowed. It seems that the height of a bridge above the water level was less important than the quality of the foundations and the subsoil conditions. However, the bridge in Písek (see above), which resisted high water reaching 2 metres above the bridge deck in the 2002 flood, had been substantially restored in the 1990s. During those works, the piers were anchored into the rock and, therefore, their original strength cannot be assessed. Let us only point out that this bridge had exhibited no major failure in the course of its almost 700 years in operation. Similarly, the bridge in Regensburg, which is not founded on rock but has foundations that are very well protected, has never failed (except when some arches have been blown up in warfare). On the other hand, both of the historic stone bridges in Prague (the failed Judith Bridge, and Charles Bridge) have suffered very greatly in high water disasters, partly because the foundation situation in Prague is not very favourable.

In present-day management of high water situations, the most endangered elements of historic bridges are their parapet walls (and sculptures standing on piers). Dismantling them well before the flood seems to be the most effective way of protecting these structures. This requires perfect documentation for the subsequent restoration works.

From the non-structural protection point of view, suitable hydrophobic surface treatment helps to reduce deep wetting of the structural material and deposition of harmful substances and biological agents.

Salt problems, mainly efflorescence, occur in many cases and may appear intensively more than two years after the flood, in thin cracks between the stone blocks and mortar joints. High crystallization pressures can damage building materials, so the structure should be allowed to dry slowly in order to accumulate salts on the surfaces, from which they should be regularly removed. It is further recommended to check the subsurface salt content, and if appropriate to carry out desalination procedures on the masonry.

4.5 Archives / libraries

Kateřina Šupová

4.5.1 Archive of architectural plans in Prague (Czech Republic)

Characterisation of the case study structure

The flood in Prague in 2002 heavily affected a collection of architectural plans, models and other documents belonging to the Czech National Museum of Technology. About 10% of the architectural plan archive, as well as models and 3D technology collection objects were immersed in water. The archive of architecture and construction has been built up since 1910. Together with the archive of history of technology and industry, it is a very valuable and internationally important collection. The archives contain the inherited private collections of famous Czech architects and engineers, and also records of important industries with documents covering the period from the 18th century until the 20th century.

Flood damage

The water level in the archive area reached a depth of 3,5 m. Collections of architectural plans, as well as archives of the aircraft industry, silver mines, Prague mechanical engineering factories and many other private collections, including photographic negatives from the period from 1880 until 1970, were immersed. 220 cubic metres of damaged materials were frozen immediately after the water relief. (Fig. 4.5.1.1)

Figure 4.5.1.1: Archive of architectural plans in Prague after the 2002 flood. Source: NPÚ Praha.

Restoration work

Restoration of the frozen materials started soon after the flood in temporary workshops. At the end of 2003, the work group separated from the restoration department, and an independent drying department was established within the National Technical Museum structure. The work was accelerated by a gift from the British Council, which equipped the museum with vacuum parcels, a vacuum table and large filtration papers for the "sandwich method" of manual drying. For this process, an old building was refurbished and transformed into a modern drying workshop in April 2004. In a space of 200 m2 there is one room with defrosting tubs and cleaning facilities, two rooms for sandwich and vacuum packing, and two rooms for final drying and wrapping of the dried archive documents. In addition, there is an office, a day room and restrooms. Cloakrooms with showers are located in mobile units adjacent to the building. The cost, including all equipment, was CZK 5,4 million.

Manual drying is very effective and useful for non-homogeneous archive documents (various materials, e.g. paper, canvas, leather, metal clamps, photographs, film negatives, etc. in a single frozen block) and for documents of large size (e.g. design plans). The material can be sorted, cleaned and flattened during gradual thawing. The method seems to be very considerate to the flooded paper. Two approaches are used, according to the size and nature of the treated material:

a)a sandwich method for large-size documents,

b)a method of vacuum parcels for documents up to A3 format size.

Sequence of operations

1. The material to be thawed out is released from the freezing container and subsequently from the freezing box. It is defrosted after about 18-20 hours at room temperature.

2. The defrosted parcels are dismantled and sorted by a curator, in collaboration with a paper restoration specialist. At the same time, the photographs and archive materials that cannot be safeguarded or conserved are digitally recorded.

3. Conservators clean the items, rinsing them with water if necessary, and start to dry them, according to the type of object. Large drawings are inserted between filtration papers. Books and small-format documents are dried using the vacuum packing machine. The drying time is between one day and three weeks.

4. During the next days, the drying material is reinserted into fresh dry papers or rewrapped into dry vacuum parcels. At the end of the procedure it is left to dry naturally in the air.

5. The curators and their co-workers wrap dry material for transport to the Central State Archive for disinfection, and carry out detailed inventory recording.

The details and guidelines are available on the pages of the Department of Restoration and Drying of Frozen Materials of the National Museum of Technology: http://www2.ntm.cz/projekty/vysouseci-pracoviste/ (in Czech)

Lessons and preventive measures

The rescue operations and the subsequent safeguarding measures provided very valuable experience, which is briefly summarized in the following best practice advice.

Best practice

All panic should be avoided during the rescue operation and when first touching the flooded objects – even severely damaged and almost destroyed items can be safeguarded.

Paper documents and namely photographs need to be dried immediately. If this is not possible, immediate freezing of the wet material is necessary, ideally by means of a shock drop in temperature to minus 20 – minus 25°C.

It is recommended to leave all documents in their original envelope or package during freezing in order to facilitate identification and recording during restoration. Alternatively, the envelopes may be slightly washed and inserted in rather small parcels (for better handling) into plastic foil or sacs and put into the freezer.

Do not use a marker for labelling the parcels (it will soak into the materials). Cards with inscriptions written using a soft pencil and inserted into the parcels are the best option.

During shock freezing, water freezes in the form of small crystals and the paper is not damaged. Such frozen documents can be kept even for several years, and thawing and drying can be left until a decision is taken on a suitable way of restoring them.

No agents containing chlorine should be used for disinfection. (In the National Technical Museum laboratory, a benzododecinii bromidum agent distributed under the commercial name Ajatin was used).

Methods for drying wet or frozen paper documents

Aerial drying – the paper sheets are freely stored in a dry room. This is suitable for only slightly moist materials, not for completely wet materials, where moulds may form.

Lyophilization – used for frozen materials only. The items are dried in a vacuum, and the ice transits directly into the gaseous phase by means of sublimation. This is supported by heating the shelves up a maximum of 40°C and cooling the walls to a maximum of 50°C. This method is suitable for books, clean non-deformed material, documents of similar type and nature.

Vacuum drying – a variant of lyophilization, when the material to be dried can be inserted into a chamber while still wet. Vacuum drying enables the documents to be sorted, and items that need not be restored can be removed, e.g. envelopes, packing paper, duplicates. In addition, the paper can be cleaned and flattened.

Drying in hot air – adapted kilns for drying wood are mostly used. The room is typically a space of about 12 sq. m. The air is conditioned to a temperature up to 40°C and 30% moisture RH, and is circulated. The chambers work quickly, and there is a danger of over-drying the paper. This method is not suitable for precious archive documents.

Microwave drying – this method is not recommended. There is a danger of uneven drying and of local burning around even very tiny metal elements.

4.6 Museum objects

Jeannine Meinhardt, Petra Štefcová

4.6.1 The "Mirakelmann" - Miracle Man (Germany)

Jeannine Meinhardt

Case study object characterisation

Movable cultural heritage involves a wide range of combinations of diverse materials that are difficult to categorize. The different properties of these combinations of materials produce a wide range of physical, chemical and biological stability. The following case study will be demonstrate the difficulty of making generalizations about possible damage to movable cultural heritage objects.

Object

The Mirakelmann (Miracle Man) is a late Gothic crucifix with extremities that are free to move. It was made in 1510. The artist is unknown. It has been kept, probably since 1539, in the church of St. Nikolai in Döbeln (Saxony). As this church is located near the river Mulde (see Fig 4.6.1.1), it suffered severely in the summer flood in 2002.

The crucifix had been lying in a grave chest with glass walls. When the muddy waters entered the church the chest floated, but then it overturned, so that the Miracle Man came into direct contact with the water and mud. The figure was not recovered until some days later.

The figure is about life-sized, 1.95 m in height and with a span of 1.90 m. It is made of lime wood, and most parts of the body are massive. Only the head and the upper part of the body are hollow. The void space in the body contains a small vessel, which is connected to the wound in the chest. The vessel was used to release red liquid simulating a bleeding injury during processions (see Fig. 4.6.1.2).

The Christ figure is of high artistic value. Before the flood it had movable joints, i.e. head, shoulder, elbows, hands and hip. In the shoulders there were metal pieces used for the connections, and in the other joints there were leather, nails and cord. The neck and the elbows were filled with sheep wool. The hair of the head and beard was horsehair. The whole figure had an abraded chalk primer and was painted in tempera. Because of its exceptional and multifaceted combination of materials, the object needed special and very sophisticated restoration.

Since the Miracle Man was used in processions, the figure gradually became deteriorated, until it was decided in the 1950s to fully restore it. It was cleaned, the primer was strengthened and most parts of the surface were re-painted, after retouchings had been removed. The lime wood had been attacked in some places by woodworm. Structural conservation was performed with paraloid. The distorted and slightly torn left shoulder joint was repaired and adjusted. Finally, the entire sculpture was coated with dammar varnish. Tempera and water colour were used for the retouching. The figure was probably again used for processions for a few years before it was decided to keep it in safe custody in the church. In 2001, the restoration was finished, but only a year later, in 2002, the object was again severely damaged in a flood.

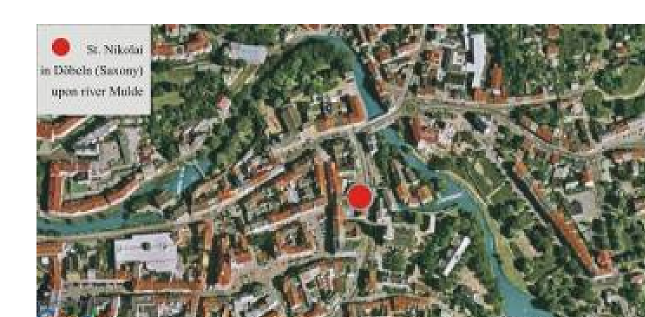


Figure 4.6.1.1: Map of a section of Döbeln. The position of the church of St. Nikolai is marked by the red point. (google maps).

Rescue works

Thanks to the acurate restoration work, it was easy to identify all flood-induced damage to the sculpture. The waters had caused mould growth and swelling of the wood and leather parts. Upon subsequent drying, the leather parts shrank and deformed, leading to damage to the paintwork, too. The retouching of the past restoration had been almost entirelyremoved, and mud covered large parts of the figure. The hair and joints were massively encrusted, and the joints could no longer even be moved. The sheep wool in the joints was so contaminated that it had to be removed. The metal pieces were slightly corroded.

Fortunately, restoration of the passion play figure was funded by the German Environmental Foundation (DBU) between December 2002 and the autumn of 2005, with the objective of restoring and conserving the sculpture. The project was assigned to the crash programme Elimination of Damages Caused by the Environment and Protection against Negative Environmental Influences. After quite a long storage time, the crucifix was finally comprehensively restored in 2004/5. All muddy parts of the figure were carefully cleaned with distilled water. Ventilators were used to purify the inner segments to prevent further mould growth. The wood and joints were treated with RUDOROL SL fungicide, and the body was treated with Thymol (5%). The leather elements were either damped, re-shaped and strengthened with vellum glue (10%) or had to be replaced. The metal pieces were derusted with brass brushes. Microcrystalline COSMOLITH H 80 (test benzine) served as a protective covering. New nails and screws were attached. The retouching was done with water colour and gouache paint.

The restoration has achieved a very good outcome, scarcely distinguishable from the condition before the devastating flood (see Fig. 4.6.1.2). Only the shape of the sculpture has changed slightly, due to the influence of the water. The leather joints are now completely immoveable.

The restored Christ figure is now kept in a new grave chest in the organ loft, above the probable flood level, and will therefore be safe in event of a new flood.

Figure 4.6.1.2: Photographs of the Miracle Man from the front and from the rear, and the head after restoration.
Sources: Restauratorengemeinschaft J. Bösenberg, E. Kless and F. Wosnitza.

4.6.2 Archbishop's carriage - National Museum in Prague (Czech Republic)

Petra Štefcová

Characterisation of the case study object

The archbishop's carriage is a typical museum object composed of many parts made of various materials. During the flood, the individual elements were in different stages of ageing or deterioration, and they responded differently to immersion in water which was, moreover, contaminated with various chemical and biological agents. The carriage was totally immersed, but was located inside one of the National Museum buildings and was thus partly protected against direct deposition of water-transported particles.

Flood impact and damage

Metal parts

The metal parts of the carriage include iron, steel and gilt bronze. They were soiled with remnants of diluvial mud, and were corroded, deformed, with mechanically damaged polychromy after previous dismantling and repairs, and were heavily contaminated, namely the bronze parts, Fig. 4.6.2.1.

Textile parts

The textile parts were made of pressed silken velvet decorated with flower ornamentation (carriage interior). They suffered from mould formation and from mechanical damage to the braids, and they exhibited total devastation (Fig. 4.6.2.2)

Leather

The leather roof of the carriage was torn off and contaminated with mud. The leather floor of the carriage (cow skin) was dirty with mud and moulds. The leather load-bearing belts were torn and were dirty with mud and moulds. The leather cushion of the seat was completely

Figure 4.6.2.1: Metal parts after restoration (upper), and before restoration (lower). Source: Karel Poupě.

Figure 4.6.2.2: Archbishop's carriage (see next page)and Silken velvet after restoration. Source: Alena Grendysová.

ruined; the leather rims of the cabin were over-dried and were beyond repair.

Restoration and repair

Metal parts

After the written documentation had been elaborated and the pictorial documentation had been made, the carriage was partly dismantled and cleaned from flood sediments, using distilled water and Syntapon L. The components with polychromy were stabilized against corrosion with the help of a tannic acid solution with a small content of ethyl alcohol. The iron parts without polychromy were stabilized against corrosion with the use of Synkor 100. The final surface finish was applied according to the type of metal (Revax, Chelaton III saturated solution, or metal varnish).

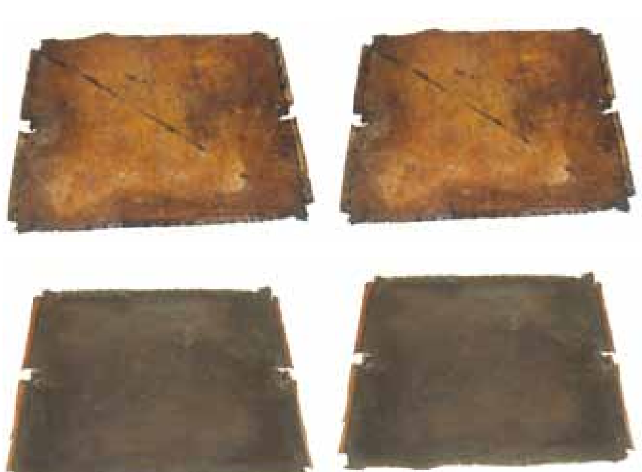


Figure 4.6.2.3: Leather floor of the carriage before restoration, and after restoration. Source: Radek Urban.

Textile parts

The restoration work included disinfection treatment of the damaged textiles attacked by moulds, and redevelopment of the deformed and torn braid decoration: some parts were repaired, and other parts were replaced by new materials.

Leather

After dry cleaning (with a vacuum cleaner) and disinfection (using p-CLm-kresol and butanol evaporative biocides), poultices were applied to rehydrate the leather. The process continued with dry-cleaning with a mixture of 80% isopropanol and 20% water, then with a 1% foam solution of Alveol OMK in distilled water. The cleaning was finished with a solution of isopropyl alcohol, and the object was left out to dry, under irradiation by a sun lamp. Then grease was applied, and leaky and cracked pieces were repaired with a constant application of grease. (Fig. 4.6.2.3)

Recommendations for further storage and preservation

Metal parts

The object will be deposited under suitable micro-climatic conditions (temperature between 18 and 20°C, relative humidity between 40 and 55%) and in an environment without aggressive pollutants, (e.g. sulphur oxides, nitrogen oxide).

Textile parts

Textile objects should be deposited under suitable micro-climatic conditions (temperature between 10 and 20°C, relative humidity between 45 and 55%), and should not be exposed to direct daylight or increased dustiness.

Leather

Leather parts should be deposited under suitable micro-climatic conditions (relative humidity between 50 and 60%), well protected against dust and gaseous pollutants. At least once a year, all leather parts must be treated with grease. The carriage cabin should be firmly supported in order to prevent rupture of the load-bearing leather belts.

4.6.3 Chemical composition of commercial agents

Trade name	Composition	Reference
Revax	dispersion of paraffin and isoparaffinic hydrocarbons in an organic solution with an admixture of stabilizers and inhibitors	www.avioncz.cz
Dispercol	polyvinylacetate dispersion in water, adhesive	www.druchema.cz
Wishab rubber	filled vulcanized latex	www.lascaux.ch
Lignofix Top	Fungicide substances (Propikonazol, IPBC) and insecticidal substances (regulators of insects growth)	praha@stachema.cz
Solakryl BMX	Butylmethacrylate copolymer with methylmethacrylate dissolved in xylene	draslovka@draslovka.cz
Antirezin	Thermoplastic colour paint on metal	www.chytrabarva.cz
Leyland paint		Leyland Trade
Hammerite paint	petrol fraction oil-crude (25-50%), powder aluminium (2,5-10%), zinc orthophosphate (1-2,5%), cobalt salts	duluxtrade_advice@ici.com hammerite.com
Septonex	(1-ethoxycarbonylpentadecyl)-trimethylammonium bromide	
Plextol 360	dispersion of buthylacrylate and methylmethacrylate copolymers	www.sandragon.cz
Klucel adhesive	hydroxypropylcellulosis (HPC)	www.sandragon.cz
Paraloid B72	copolymer of ethylmethacrylate with methylacrylate	info.imesta.cz www.rohmhaas.com
Pulvispray	disinfectant on the base of alcohols with a small content of so-called modern aldehydes	
Acrylkleber Lascaux 498-20X	dispersion of methylmethacrylate and buthylacrylate, 20 % xylene	www.art-protect.cz www.lascaux.ch
Lautercit	fungicide agent	maridad@seznam.cz
Lascaux polyamide powder	thermoplastic resin (Nylon 12)	www.sandragon.cz www.lascaux.ch
Maimeri water paints	binder (mastix resin) + pigment	maimeri.italia@maimerispa.it
Savo	calciumhypochlorite	
HB-SIL rust remover	mixture of orthophosphoric acid with organic solutions	expedice@via-rek.cz
Uhu (adhesive for textiles)	dispersion glue	UHU GmbH & Co.KG
PU adhesive for wood (Fix Flex)	polyurethane adhesive	info@denbraven.cz
Titebond	polyurethane adhesive	www.titebond.com
Antik wachs	wax preparation, containing beeswax	www.clou.de
Sokrat 2802	copolymeric styrene-Acrylate dispersion	www.aquabarta.cz
Shellac lemon	natural resin, containing wax	inchema@inchema.cz
Lefranc preservative varnish	final matt varnish	LeFranc & Bourgeois
Syntapon	Sodium laurylsulphonate	

4.7 Heritage sites

Tomáš Drdácký

4.7.1Terezín (Czech Republic) - bulwark water fortress

Case study object characterisation

Ancient and medieval fortifications all over the world are typically water fortresses. However, the water supply had to be provided by high-capacity resources, usually rivers. This entails a significant threat in the event of a flood. Developments in military engineering introduced a new system called a bulwark. This was "a mound of earth round a place, capable of resisting cannon shot, and formed with bastions, curtains, etc." (Webster's 1828 Dictionary). In such a system, situating the rooms underground was one of the most significant and most innovative features. However, in all suitable terrain configurations water barriers have been been used as the most natural and probably also the most ancient means of defence.

The Terezín fortress is one of the most developed and most strongly fortified bulwark-type sites from the 18th century. Terezín was built between 1780 and 1790. The fortified town is composed of two fortresses: the main town fortress and the so-called Small Fortress, with a large fortified area between the two fortresses, see Fig. 4.7.1. The area between the fortresses, and the large fields to the north, the east and the south could be flooded through a system of inner moats and channels. The total fortified area covers 398 ha, including 158 ha of flooded fields, as metioned above. The river Ohře was relocated and a new 4 km long river bed was constructed. The bulwark wall is about 30 m in width and 3770 m in length, and the bastions are 12 m in height. The fortified system is supplemented by a vast network of underground corridors with a total length of about 29 km.

Hydrological situation

The water and defensive flood control is supported by a sophisticated system of weirs, channels, inlets, wet moats and flooded fields. The system was also used for water mills inside the fortress. The walls were founded just above the underground water level, which prevented undermining of the walls. The water was raised using a dam created from a strong bridge across the Ohře river. 500 metres above the bridge, the first system of water management buildings was created. It helped to flood selected parts of the system. A special moat called "kyneta" was used to empty the system more rapidly. It was also used for draining rainwater. The wet fields were designed as a kind of trap – their level was slightly above the river water level, and they could be flooded as soon as the attacking army occupied them. It was difficult to damage or destroy the system, as the weirs and the bridge were protected by the fortification and were located out of shooting range. It took 11000 men and about 108 days of work to lower the level of the Ohře river.

Flood impact and damage

In 2002, this fortress was heavily impacted by an extreme flood. A wave of raised water arrived from the Elbe/Labe river, about 5 km away. An enormous area was covered with water, see Fig. 4.7.1.2. All houses in the town were flooded, but it was above all the underground defensive corridors that suffered significantly. Some parts were severely damaged or partially destroyed, Fig. 4.7.1.3. The vaults of shallow mine corridors collapsed in some places, and the very poorly maintained parts were also damaged Fig. 4.7.1.4. (Further reading and documentation: http://richard-1.com/terezin/index.htm).

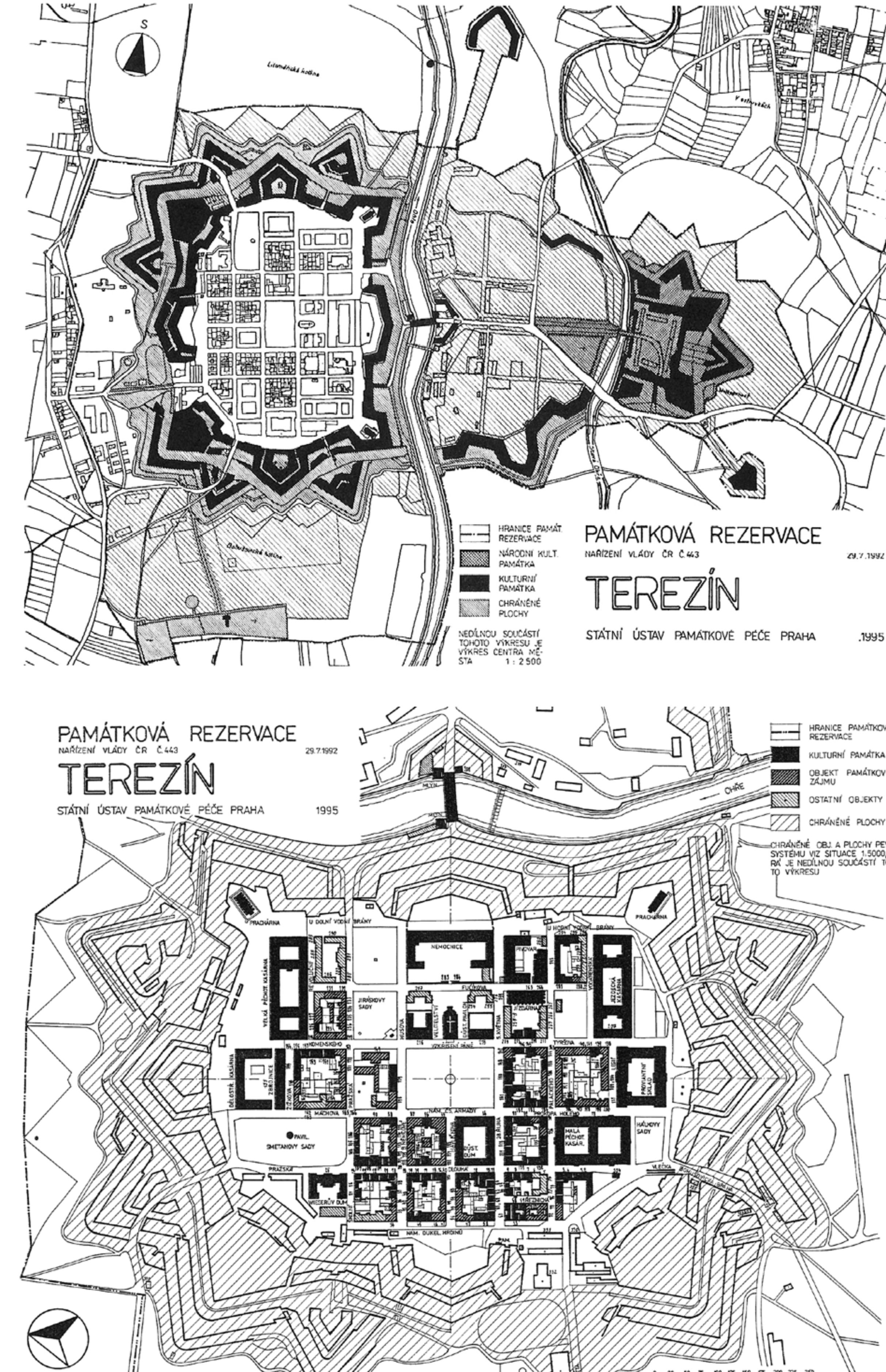


Figure 4.7.1.1: Plans of the Terezín National Heritage town monument. Source: Vladimíra Rákosníková. See next page.

Figure 4.7.1.2: Flooded Terezín town (left) and the Small Fortress, with the area between the two fortresses 16.08.2002 (right). Source: www.povodne.cz

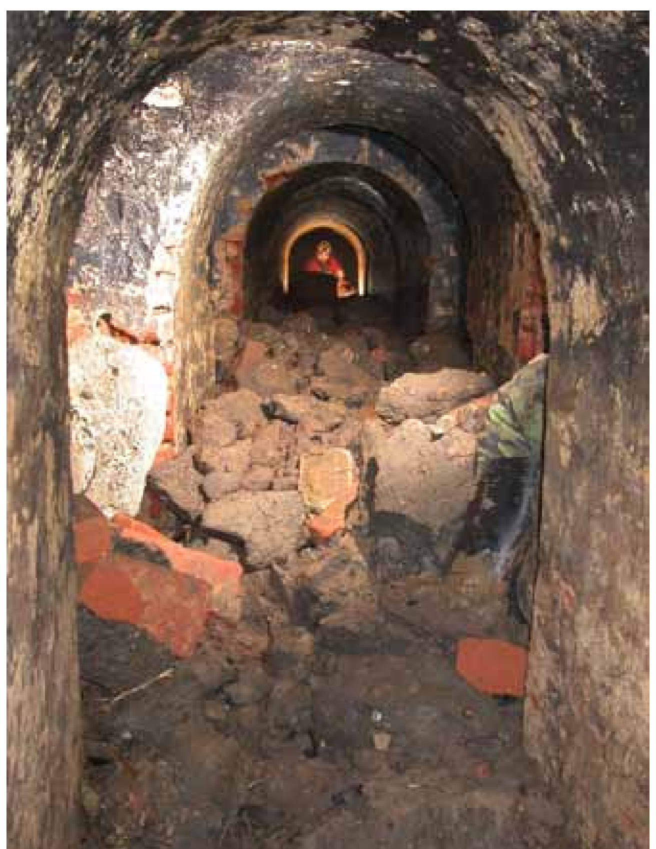


Figure 4.7.1.3: Underground corridors caved with mud and brick (left part), collapsed walls and columns of underground channels. Source: Roman Gazsi.

Figure 4.7.1.4: Sunk soil over a failed vault. Source: Roman Gazsi.

Restoration and lessons

The failures and the subsequent repair works helped in a study of the original construction technology and structural concepts Fig. 4.7.5. The repair work was supported from EU funds, and helped to substantially improve the state of this very valuable heritage strcuture, which is well maintained in the former concentration camp part of the site, but the military fortress part had been badly neglected.

Figure 4.7.1.5: Repairs to shallow mine corridors (left), and to damaged vaults (right). Source: Roman Gazsi

4.7.2 Piran (Slovenia) – the Church of Our Lady of Health, threatened by sea flooding

Mateja Golež, Marjana Lutman, Friderik Knez

Piran (Slovenia) is a typical Mediterranean coastal town, and is full of cultural heritage buildings. However, it is threatened by annual sea flooding, particularly in those parts which are next to the actual coastline. The Church of Our Lady of Health was constructed in the 13th century, and its building tissue has constantly been subjected to the negative impact of saline solutions, leading to salt crystallization. This negative impact has caused severe deterioration of the building, which is now at risk of permanently losing all of its original plasters and decorative elements made from stone. A project was undertaken to improve the condition of the building tissue of the church. During the course of the project, extensive investigations were made into the materials that the church is made of, into the building structure itself, and into the building physics of the church. The object of these investigations was to determine the influence of periodical flooding on the materials and structure, and to prepare guidelines for mitigating sea-flooding related damage in the future.

Figure 4.7.2.2: The Church of Our Lady of Health is located at the end of the Piran peninsula. Source: ZAG.

Figure 4.7.2.1: An old photo of Piran (1920). Source: Alinari.

Figure 4.7.2.4: Sea water, accompanied by salty mist, washing on to the walkway which separates the church of Our Lady of Health in Piran from the sea. Source: ZAG

Figure 4.7.2.3: Enlarged section of the above map, representing the Piran peninsula with yearly (dark blue) and extreme (light blue) flood areas (2006). Source: Kolega.

Hydrological conditions along the Slovenian coastline

Along the Slovenian coast, the probability of sea-flooding is greatest in autumn and in winter, between October and January, although such flooding can also occur in April and in the summer months. The reason for this distribution lies in the high frequency, during the autumn and winter months, of the occurrence of so-called Genova cyclones. These cyclones can cause high tides, but the height of tides and the severity of flooding can depend on wind, undulation, air pressure, moon gravity, weather fronts, and the shape of the coast.

Statistical data about the frequency of flooding in the coastal areas of Slovenia, including Piran, shows that there were a total of 299 floods in the period from 1963 and 2003, corresponding to an average of 7.3 floods a year.

Table 4.7.1: Assessment of the risk of danger to the Church of Our Lady of Health due to long-term exposure to sea flooding, and the results of the investigations performed within the project. Source: ZAG.

Field of investigations	Problems involved	Investigation methods	Results of the investigations	Recommendations
Materials	Sea-flooding related humidity, salty aerosols, corrosion of materials, such as plasters, layers of paint, stone, metals, wood	Visual inspection, sampling, sieve analysis, optical microscopy, SEM and RTG analyses, confocal microscopy, metallographic analysis, potentiometric titration	Categorized list of damage (defoliation of plasters, development of relief surfaces, desalination), binder (lime, cement), aggregate (carbonate, silicate, marine organisms), salts (halite, etringite, gypsum), sulphate corrosion on the façade	Replacement of cement plasters with "sacrificial" lime plasters, removal and desalination of stone decorative elements, consolidation of materials using nano-lime
Building structure	Humidification during the period of sea flooding, salty aerosols, wet foundations because of the presence of salty groundwater	Visual inspection of the walls and foundations, drilling of cores, boroscopy, determination of the compressive strength of stone blocks	Stone and brick walls with significant hollow spaces on the inside of the walls, low compressive strength values of the stone blocks, low cohesiveness of foundation mortars, statically stable structure	Fitting of moveable barriers along the shore during high tide periods, strengthening of stone and mixed stone-and-brick masonry walls by injectinga hydrophobic cement grout into masonry tying all walls with steel ties.
Building physics	A marked increase in humidity in some areas of the building structure, widespread microorganisms on humid surfaces, salt crystallization, high capillary rise of water	Visual inspection, sampling of powder samples, determination of the humidity of materials, thermography, monitoring (T, RH, groundwater), chemical analysis of the groundwater and sea water	High level of groundwater during the winter months, low level of groundwater during the summer months, permeation of the walls with chloride ions up to 6 metres from the ground and throughout the thickness of the walls	Removal of the asphalt paving in the proximity of the building structure, performance of constant monitoring of the building structure


Figure 4.7.2.5: The elaborate work of Venetian stonemasons has deteriorated into fragments. Source: ZAG.


Figure 4.7.2.6: Lengthy needle-like halite crystals are the most frequent cause of degradation of the materials inside the church. Source: ZAG.


Figure 4.7.2.7: Sulphate corrosion of the façade plaster. Source: ZAG.

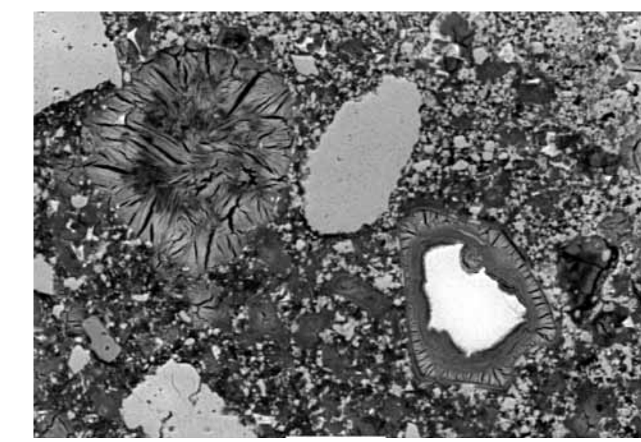


Figure 4.7.2.8: The deterioration of the church façade is caused by the crystallization of etringite (visible in the upper left corner of the image). Source: ZAG.


Figure 4.7.2.9: Degradation of the façade plaster on the west façade, caused by the capillary rise of groundwater. Source: ZAG

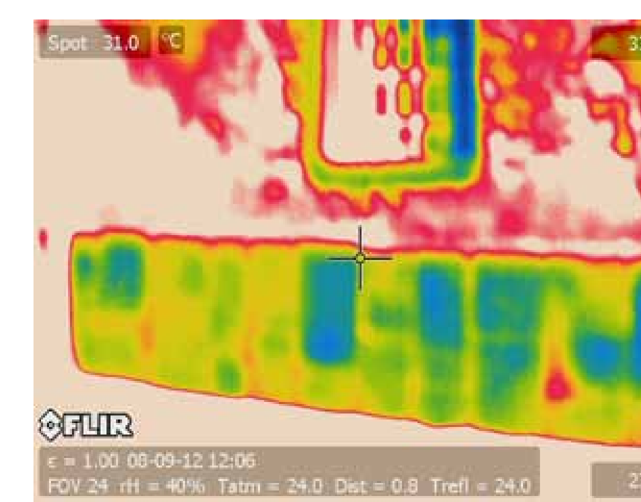


Figure 4.7.2.10: Determining the areas of increased humidity on the west facade, using thermography. Source: ZAG.

Temporary measures

Comprehensive investigations had to be performed, and monitoring of the basic state of the structure had to begin, because of the long-term exposure of the church to sea flooding, and because of the unknown date of the beginning of preventive and protective works to mitigate the impact of flooding. The results of the investigation, and guidelines for recommended further actions, are summarized in Table 4.7.1 and Figures on page 141.

Socioeconomic impact

The Church of Our Lady of Health has now been closed to the public for several years, since the defoliating plaster represents a constant hazard to visitors. The church has been categorized as a cultural heritage building, and is located at the tip of the peninsula on which the town of Piran stands, making it a prominent attraction for tourists. Future studies should be able to determine the ratio between the amount of investment needed for complete renovation of the church, and the financial loss incurred by closing the church to the general public. Good practice examples from other Mediterranean countries have shown that there is a good return on investments in projects to renovate cultural heritage buildings, in cases where the site is available as a tourist attraction.

The human factor

Considering that the frequency of sea flooding, the groundwater level, and the quantity of aerosols in the atmosphere has not changed radically throughout the centuries, and that the crystallization of salt has been intensive, it is surprising that the original stone decorative elements and plasters of the church interior have been preserved at all. According to the church administrators, the marked degradation processes inside the church have become disturbingly severe only in recent years. Their occurrence may be related to repair works that have been in progress in the surroundings of the church. A study of the land register and of available photographs has shown that, until the 1950s, there was no land separating the church from the sea; the church was constructed directly next to the sea. The construction of pedestrian walkways along the entire area of the Piran peninsula and their asphalting has caused an increase in the groundwater level, and has provided a plateau which is easily accessible to seawater in the event of sea flooding.

The biggest problem lies in the fact that the asphalted surfaces prevent the layers underneath from drying out, and therefore humidity can be transported only from the foundations of the church higher into the church walls. During the course of the project, the original hypothesis, i.e. that sea flooding represents the main danger to the church, was proved incorrect by the research, investigations and monitoring that were performed. The main reason for the impact of salt crystallization on the church is the human factor, which could be significantly mitigated if minor changes to the spatial planning conditions around the church were implemented. Similarly, the sulphate corrosion of the façade plaster is a consequence of the choice of an inappropriate binder. Etringite crystallization is frequent in coastal zones, where cement binders are in constant contact with salt water containing sulphate ions. The consequences of sulphate corrosion are reflected in a reduction in the cohesion between the binder and the grains, and in the development of relief surfaces. In coastal zones, the use of mortars prepared with lime binders is recommended.

The results obtained from interdisciplinary studies of cultural heritage buildings such as the Church of Our Lady of Health have shown once more that they are indispensable for each individual cultural heritage monument. Above all, these studies contribute to proposals for more efficient and affordable renovation works.

4.7.3 Harcov (Czech Republic) - retrofitting a historic dam

Milan Zukal

Case study object characterisation

The Harcov water structure, often referred to as the Liberec dam, was originally built on the edge of Liberec, but due to urban development in the past 100 years it has become an integral part of the urban environment of the inner town. It has been inscribed on the list of protected monuments since 1958. The dam was built in response to a series of disastrous floods in the second half of the 19th century (in 1854, 1858, 1860, 1875 and 1888), which damaged many dwellings and industrial buildings in the narrow valleys along the small rivers and creeks in the region. The disaster in 1897 had a heavy impact on Liberec and on several nearby districts. The local authorities and local businessmen set up a "water association to regulate water courses and construct dams in the Nisa river basin for the town of Liberec and the urban districts of Jablonec-nad-Nisou, Chrastava and Frýdlant". In a public lecture held at Liberec Museum on January 13th 1901, Dr. Ing. Otto Intze presented a project to construct six dams.

Construction of the Harcov dam was the first element in this ambitious project and the work was carried out by W. Streitzig, a company from Liberec, and H. Rell, a company from Vienna. This was the only project of its kind in the whole Austro-Hungarian Empire. The dam was completed in June 1904, and in the same year it retained a heavy flood water volume of 230 000 m^3.

Figure 4.7.3.1: Harcov dam in winter, and the spillway with a cascade. Sources: J. Pikous, M. Zukal.

Name of the dam	Water course	Construction	Dam height	Dam capacity
Harcov	Harcovský creek	1902 – 1904	13 m	0,69 mil. m^3
Bedřichov	Černá Nisa (river)	1902 – 1906	15,1 m	2,10 mil. m^3
Mlýnice	Albrechtický creek	1904 – 1906	14,5 m	0,27 mil. m^3
Fojtka	Fojtský creek	1904 – 1906	11 m	0,32 mil. m^3
Mšeno	Mšenský creek	1906 – 1909	15,8 m	2,78 mil. m^3
Oldřichov v Hájích	Jeřice (river)	not built	16,5 m *	0,50 mil. m^3 *

** according to the original plans*

Figure 4.7.3.2: Physical model of Harcov dam. Source: Milan Zukal.

Figure 4.7.3.3: Water flow over the cascade in the model. Source: Milan Zukal.

The dam comprises the retaining structure, two outlets (2x DN 800), a small water power station, a chute spillway and some other facilities. The retaining structure is an Intze-type gravitation dam walled up as stone masonry. Its layout line is curved, with a radius of 120 m, and its height above the foundation level reaches 19 m. The through chute spillway is situated on the left bank and it is composed of five bays each 5 m in width. The spillway continues with a cascade of 7 steps varying in height between 0,6 m and 1,2 m, Fig. 4.7.3.1.

Hydrological situation

In recent years, the manager of Harcov dam has studied the safety of the structure in high water situations. First, the hydrological data was evaluated and assessed. It is obvious that the original design data, more than 100 years old, does not fulfil present-day standard requirements applicable for safety assessment of dams. The required degree of protection has risen from the one hundred year flood value HQ100 to a value one order higher, i.e. HQ1000, a one thousand year flood. At certain very important water works, high water situations corresponding to a ten thousand year flood are even assessed.

The opinions of the experts evaluating the safety of the Harcov water structure confirmed that the situation concerning its safety during high water was very complicated. It was suggested that two types of measures should be implemented to increase the safety of the structure: increase the stability of the dam, and increase the water transfer capacity through the dam to a level satisfactory for the required HQ1000 or even HQ10000 values. The spillway has a present-day capacity of 16,31 m^{3}s-1, and the capacity of the two bottom outlets is 12 m^{3}s-1. The highest flow ever observed on the Harcov creek was 20 m^{3}s-1 (when the dam was designed - July 30, 1897). The present-day value for a one hundred year flood is HQ100 = 30,1 m^{3}s-1.

Experimental investigation on a physical model

The water flow over a cascade is quite a complicated phenomenon, and a numerical solution needs to be complemented by experimental investigations. A physical hydraulic model was therefore constructed in the Laboratory of Hydrology of the Czech Technical University in Prague. The scale was derived on the basis

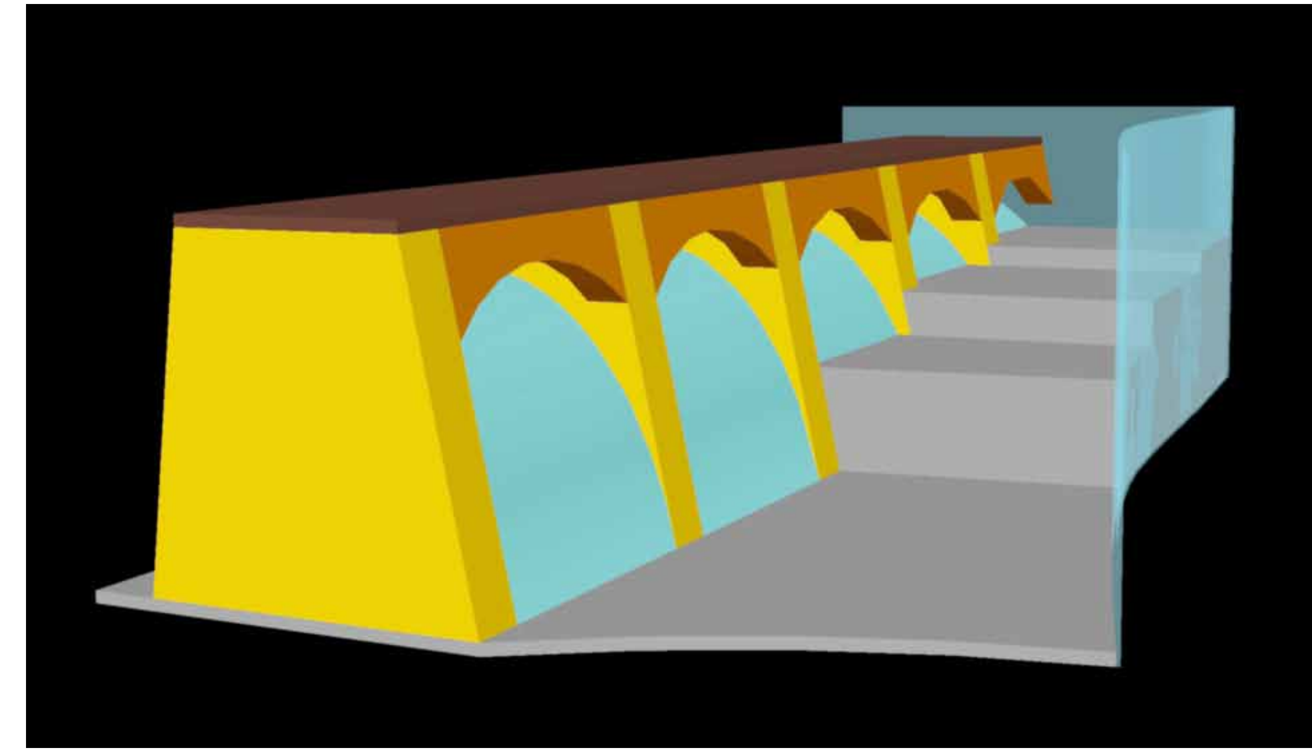


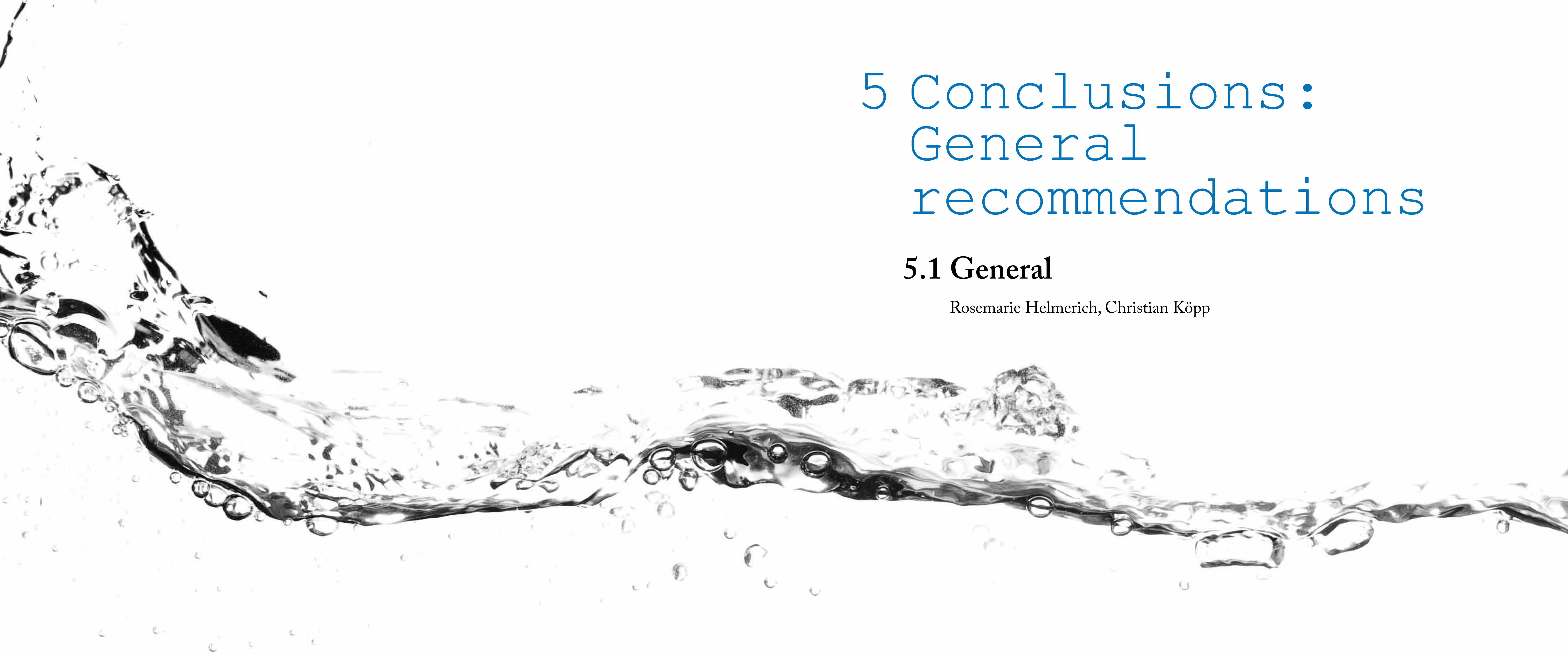
Figure 4.7.3.4 Computer visualization of the Harcov dam spillway and cascade. Source: M. Zukal.

of the limit conditions of model similarity, laboratory capability, construction possibilities and the constraints of a representative investigation. A length scale of 1:20 was adopted. The physical model has dimensions of 100 x 150 cm and it is made of plastic materials. The container above the model dam with dimensions 4 x 5 x 1,5 m has a volume of 30 m3, Fig. 4.7.3.2 and Fig 4.7.3.3.

The hydrotechnical investigations of the Harcov water structure comprised three parts: i) verifying the existing spillway capacity, ii) determining the cascade capacity, and iii) evaluating several designed dam modification options for improving its capacity in high water situations.

The experimental results proved that the capacity of the existing spillway is in reality higher than the capacity estimated using numerical computation. In this way, the physical model has helped to optimize structural design aiming at retrofitting the existing dam.

Nevertheless, numerical modelling of the problem also has several advantages, as any geometrical changes to a physical model are time-consuming and costly. Optimum design variants and modifications can easily be modelled on a mathematical (numerical) model povided that such a model has been calibrated using results from a physical model (or from reality). Such an approach gives satisfactory and significantly precise results. It was therefore used in the design for retrofitting or strengthening the existing water structures.



5 Conclusions: General recommendations

5.1 General

Rosemarie Helmerich, Christian Köpp

Europe suffered from over 100 major floods between 1998 and 2002. In addition to 700 deaths, the economic losses in recent years due to floods have exceeded €25 mil. Following the proposal by the European Commission, the European Directive 2007/60/EC on the assessment and management of flood risks was prepared and entered into force in November 2007. It is planned to prepare flood risk management plans and river basin management plans in coordination with the Water Framework Directive. For the first time in Europe, the European Flood Directive (EFD) included risk reduction to cultural heritage, aimed at reducing and managing the risks that floods pose to human health, the environment and economic activity, see EFD (2007).

In response to the requirements of the EFD and also the Hoi An Declaration and the mandate of UNESCO to preserve cultural heritage, the CHEF project has developed general recommendations for further actions. As emphasised in the EFD, the project proposes public participation procedures in the preparation of these plans. Floods are the most common type of natural disaster in Europe, and coordinated action is needed. All assessments, maps and plans prepared will be made available to the public. Strategies, recommendations and guidance will be put forward on a European level to preserve cultural heritage.

5.2 Raising awareness of flood hazards and vulnerability

Immersion in water, salt or mud during a flood, and exposure to high humidity levels, affects most materials and even the stability of heritage structures and objects. In a very special way, this statement is valid not only for new structures, but all the more for cultural heritage objects and structures. Information about the risk and vulnerability of cultural heritage will be added to available hazard protection strategies. The new tools will raise awareness about the special requirements of cultural heritage care before, during and after flooding. In an emergency situation, municipalities and local communities will be enabled to react in an adequate way, and to contact appropriate experts, rescue teams, etc.

Stock-at-risk mapping

The flood risk to cultural heritage has not until now been included in flood risk mapping. Experience about mapping cultural heritage has been acquired in Italy. The results of national projects show that Geographic Information Systems (GIS) must complement the implementation of an organic programme of cataloging that is fully functional and will allow the competent structures to practise their own institutional assignments of guardianship, and to manage and maintain cultural heritage assets.

GIS technology seems most appropriate for achieving such an aim, thanks to the widespread visualization capabilities and the opportunity to analyse the problem by means of thematic maps that can be updated in real time. To overcome the fragmentation of datasets and sources, gaps and availability, data in Europe needs to be harmonized.

The need to link geo-referenced databases across borders (see Directive 2002/49/EC Article 7, 4.) giuded the EU to initiate the INSPIRE initiative. INSPIRE aims to share and link geo-referenced data throughout the EU Member States through "a distributed network of databases linked by common standards and protocols", accessible through interoperable services that will help to produce and publish, find and deliver, and eventually use and understand geographic information over the Internet across the European Union and Accession Countries.

Vulnerability of materials

The vulnerability of materials is decisive for the degree of damage after movable heritage objects or the materials of immovable structures have been exposed to flood waters. This is a very comprehensive topic and derive general recommendations for different groups of material. For more details please refer to section 3.3.

Risk to structures

In general, preventive structural measures increase the stability of historic structures, sites, city centres, landscapes or parks and reduce the risks due to flowing water, moisture, sometimes containing salt (sea flood) or dirt. Further details are given in Chapters 1 and 2, and also in Annex 7.5, presented as an example with a theoretical background.

5.3 Recommendations on administration and management

Flood risk to cultural heritage on a European level

Reducing the risk of flooding to cultural heritage will be embedded in overall flood management and risk planning measures in Europe. Coordinated flood management and flood risk mapping is under development, particularly on the regional level. The European Commission's INTERREG programme, e.g. ODERREGIO, ELLA, followed by LABEL and Noah's Ark, promotes integrated action on the basins of major rivers including all their feeding rivers, and also coordinated efforts in coastal areas.

Since the level of available information on the cultural heritage stock-at-risk varies throughout Europe, the databases need to be harmonized. Existing databases and data acquisition systems at European level will be used for coordinated data acquisition and harmonization of strategies. Available databases are INSPIRE, and the damage database presented within the CHEF project: dbFailures (www.itam.cas.cz/dbfailures).

A public platform for cultural heritage in Europe can support and encourage exchange of knowledge. It can help to gather the lessons learnt from previous events, to provide information about the vulnerability of materials and the deterioration of structures, and can establish agreed parameters for data acquisition.

Flood prepardness strategy

It has been shown in the past that well-organised preparedness of communities and municipalities can be reduce flood damage can significantly. The flood preparedness strategy should establish clearly defined responsibilities for regular maintenance and hazard management. Maintenance strategies are needed for buildings such as museums, castles and churches, dikes, levees, channels and retaining areas, as well as sewerage systems. These strategies for indivual objects need coordination on a local, regional, national and international level.

To increase preparedness for protecting cultural heritage against flooding, the following examples have to be considered among many others described in greater detail in the documentation of the CHEF project:

- Organise awareness-raising for cultural heritage, develop response plans,
- Implement heritage information layers in risk mapping,
- Transfer information about flood monitoring to historic heritage stakeholders,
- Prepare an inventory on the condition of cultural heritage before flooding, if not already available,
- Prepare information about vulnerability, detection/calculation according to the known behaviour of immovable cultural heritage,
- Clarify communication procedures during a flood,
- Clarify responsibilities for rescue measures, ensure that cultural heritage issues are integrated into training sessions and seminars for rescue teams,
- Begin rescue measures immediately, preferably using rescue teams with special training on the requirements for dealing with cultural heritage. Send out preservation specialists to support protection, restoration and drying measures.

In particular, the database of typical damage to cultural heritage experienced during previous floods disseminated within the CHEF project will provide practical information for museum staff, local communities and hazard rescue teams. More detailed information about the StruFail database (developed by ITAM/ Praha) is available in Appendix 7.2.

5.4 Selecting appropriate measures

Preventive measures before flooding

Preventive and temporary measures against flooding are typically divided into two categories: structural (structure-related and operational) and non-structural (measures not affecting the structure, including administrative and organisational measures). Structural measures are sometimes difficult to apply in the case of cultural heritage protection. The main part of the project is devoted to presenting the state-of-the-art of available protective measures and how they help to minimize the impact of floods on immovable and movable cultural heritage. There are descriptions of how to preserve and how to treat historical materials, historical structures and sites in the event of flooding. A worldwide overview is given of conventional locally-available methods and techniques for carrying out temporary repairs and re-strengthening, with an evaluation of their effect on successful preservation of cultural heritage objects. The longer a sensitive material is in contact with water, the more its stability will be weakened. cultural heritage objects are mainly made of materials susceptible to moisture, and should therefore be kept out of contact with flood water. Every effort should be made to avoid flooding in sensitive "cultural heritage regions".

The following recommendations are aimed at dealing with gaps existing in flood preparedness strategies:

- Set up a project and establish guidelines for implementing cultural heritage layers,
- Harmonize data and classification systems for characterizing flood-prone areas throughout Europe,
- Use available solutions developed in the Interreg-programmes,
- Introduce innovative methods and technologies for investigating flood impacts,
- Assess various restoration techniques and their impact on historic materials,
- Increase the impact of preventive, temporary or permanent measures by implementing and improving preparedness strategies and maintenance measures,
- Evaluate restoration and first-aid techniques for cultural heritage materials and structures,
- Develop methods for a numerical evaluation of the resistance of cultural heritage structures to flood actions.

Measures during a flood

Effective measures during a flood depend on the following main factors

1. Know the site: Rescue units must train staff to know the site, heritage objects and their vulnerability,
2. Undertake safety measures when rescue teams enter the site: Safety of people comes first, reduce the danger due to electricity, lack of lighting, lack of ventilation and the consequences of the breakdown of service infrastructures,
3. Ensure communication between the people on site and the local authorities, in order to provide a forecast of any further rise in the flood level,
4. Start rescue and salvation work. When objects have already come into contact with water or humidity, and in particular with salty or contaminated water, e.g. from the sewerage system or muddy water due to landslides or broken dikes, the vulnerability of specific cultural heritage items to these threats must understood and taken into consideration.

Transnational cooperation through Europe, e.g. in river basins, is supported by the Monitoring and Information Centre (MIC). MIC facilitates the provision of European assistance at headquarters level, by matching offers of assistance, identifying gaps and searching for solutions. For further details, see Section 3.2.

Table 5.2.3: Methods for surveying humidity and water levels, see next page.

Measures after flooding

After flood treatment

After flood treatment, immediate measures and restoration depend on the vulnerability of the movable or immovable cultural heritage. First interventions must avoid worsening the damage. Safety measures must ensure that the structures and objects are safe, and are not a threat to human life during first-aid treatment.

Restoration of movable objects and materials

In consultation with hazard rescue workers, preservators should follow recommended measures. Contaminated objects must be cleaned from mud and other dirt, using clean fresh water. When cleaning photographs, ethanol should be added to the final rinsing water. This book provides advice on how to treat various objects and materials. For example, do not open books and store them spine upwards. Dry all objects in air at low relative humidity and avoid exposure to sunshine. If immediate drying is not possible, freeze drying can be a solution. In all cases, rescue measures should be carried out only by specialists in heritage preservation.

Repairs to immovable cultural heritage

Restoration and repair work on immovable cultural heritage begins with a site visit to the affected museums, castles, historic city centres or historic parks in order to assess and record the damage. More detailed advice is given in Section 3.3 and in the cases studies in Chapter 4.

Measurement and monitoring methods

Measurement methods mainly involve surveys of humidity inside and outside buildings. The moisture content in movable objects is also measured to prevent secondary losses. Since humidity causes delayed damage to most materials by providing suitable conditions for the development of mould, fungi and other efflorescences, periodic or continous monitoring form a basic part of the control, inspection and maintenance measures to be taken after flooding.

For a realistic evaluation of flood-related changes in humidity conditions, we propose that a record should be kept of the basic humidity conditions in all cultural heritage buildings. If these zero conditions are known, a realistic estimate of the difference in humidity content can be made. Continuous monitoring delivers basic data before flooding, basic data, extreme data during the flood, and data for controlling the drying process after the flood. The humidity-sensitive materials of structures should be investigated in advance, so that appropriate measures can be recommended in the event of flooding.

Measurement and monitoring methods	Objectives of the measurement
Quantitative minor destructive methods	
Powder/core drilling	Humidity depth survey, powder from various depths of building materials is taken for humidity analysis
Microwave borehole transmission techniques	The damping of microwaves between two electrodes is used to measure the humidity in a building material
Nuclear Magnetic Resonance (NMR)	A quantitative method for determining moisture
Time Domain Reflectometry (TDR)	
Qualitative non-destructive measures	
Passive Thermography	Moist surface areas or hidden moisture inside structures are detected using dielectric comparisons between wet and dry areas. Moisture influences the dielectric properties
Ground Penetrating Radar (GPR)	Moist surface areas or hidden moisture inside structures are detected using dielectric comparisons between wet and dry areas. Moisture influences the dielectric properties
Ultrasonic tests, including sonic pulse velocity tests with low frequencies	Acoustic signals travel at a different velocity in dry and moist materials. The differences are used as a measure of the moisture content.
Continuous measurement - Monitoring	
Fibre optic relative humidity sensors	Polymer coated Fibre Bragg Grating sensor (FBG), swelling of polymers in a moist environment is used for measuring relative humidity.
Other humidity sensors	Humidity depth surveying, estimation of humid areas

5.5 Lessons learnt from case studies

Bad practice

Analyses has been presented of the impacts of major floods in Europe on cultural heritage. The major obstacles have been summarised, and both bad practices and good practices are pointed out in several case studies. Some examples, together with proposed measures, are presented in Fig. 3.3.1, which shows factors to be considered when preparing hazard strategies and management plans:

- Municipality or community development plans: Changes in heritage structures and in the relief of historic parks need approval.
- Preparedness strategy: Municipalities that have introduced preparedness strategies suffer less damage from flooding.
- Property rights: When weirs, ponds, rivers and land are in different ownership, there is a need for well-prepared cooperation, or for mediation to ensure that agreement can be reached.
- Private citizens: Private citizens in regions with annual floods are generally well prepared and informed about flood risk and what to do, only an unexpected heavy flood could surprise them

More attention needs to be given to rescue measures for historic structures. During a flood, historic buildings in some communities are not made accessible to heritage specialists and preservators before the flood arrives. The experts are sometimes not able to save heritage goods in the period before the flood arrives.

Individual measures

The proposed measures are individual, reflecting the individuality of the cultural heritage that has been created over he course of centuries. Non-structural preventive measures (administrative and strategic measures) and structural measures (dikes, levees, protection walls and measures to protect single buildings) should be integrated into the development planning of structures. The case studies report on experience gained from earlier flood events.

Lessons learnt

Information for the public, awareness-raising, strategies for hazard management and staff training for rescue teams and cultural heritage stakeholders are the key action for flood risk reduction. Preparedness of communities in flood-prone areas must include coordinated actions involving rescue teams and those responsible for preserving historic heritage.

If a community owns valuable cultural heritage, it is advisable to designate a person or a team responsible for coordination between flood (hazard) rescue teams and heritage sites, structures and objects. The coordinator's task is to analyse the vulnerability of the community's cultural heritage, to integrate the heritage items into preparedness strategies, and to rank the Heritage objects according to their vulnerability, value and sensitivity to water, salt and other contaminants. The drying of movable and immovable cultural heritage during and after a flood, must follow predefined measures established in the preventive rescue plans. All actors should be well aware that clean water and electric power will not be available during and after a major flood.

The involvement and cooperation of cultural heritage officials, Civil Protection Departments and fire brigades in the decision-making processes for establishing preventive measures is essential.

Safety issues

Especially during the rescue and drying period, objects must be under surveillance to keep out people who should not be there. Opening doors and windows to help a building to dry out creates many opportunities for thieves to enter. Implement a system for checking identification and controlling admission of visitors.

A selection of reported mistakes

The following selection shows the kinds of mistakes that can be made in emergency situations. Of course, mistakes can never be avoided, but learning from other people's experience can help us to avoid repeating their mistakes. Some mistakes "only" lead to unnecessary damage; others can even have deadly consequences.

- The access road to a cultural heritage building was closed long before the arrival of the flood. Thus it was not possible for preservators to access heritage buildings and save high-value heritage objects before the flood arrived. Of course, safety is a priority. Nevertheless, with better emergency plans the objects might have been saved.
- The flood is arriving, but the persons responsible for emergency management are not available and have not left instructions for anybody else.
- A museum, a church or another heritage building is locked. Damage could be prevented if valuable objects inside the building could be taken to a safe place. However, nobody knows where to get the key or who is able to give access.
- The flood is coming and the sewer system has no backflow valves. Thus the temporary protection barriers will not be effective because the water can pass through the sewer system into the protected areas.
- There are backflow stop valves, air brick or ventilator covers, but when the flood arrives, they have not been closed.
- Materials vulnerable to flooding, e.g. books, paintings and wooden art works, are stored in the ground floor of archives or museums. This decreases the risk of loss through fire, but increases the risk of flooding. What is good in the case of fire may be bad in the case of flooding,
- Drainage prevents water from flowing into the building, but causes changes in the surrounding ground. As a consequence, erosion of the subsoil below the foundation occurs. This can cause the whole structure to collapse. It is necessary to consider the environment, and to adapt protective measures to the circumstances.
- Strengthening the foundations reduces the open cross section of a bridge so significantly that the bridge acts as a kind of dam. The horizontal force as a product of height and flow velocity increases. Faster flowing water (due to the reduced cross section) causes scour on the downstream side of the bridge foundation.
- Despite water reaching the lower chord level of a truss girder bridge, two trains crossed the bridge. The aggregated force of the horizontal load from the water flow with debris and the vertical force from the rail traffic exceeded the material limit states. (Cedar River flood in Cedar Rapids, Iowa, USA, in 2008, boston.com, cited 31.01.10).
- A temporary exhibition is displayed in pavilions on the riverside or in the natural flood plain of a river.
- No damage survey forms have been prepared, or the official teams are not trained to compile damage inventories, emergency provisional structures have not been set up.

6 Index

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6.2 Glossary

Rosemarie Helmerich

Abbreviations of the European Commission and the member states related to organisations and projects dealing with disaster management and cultural heritage.

Abbreviation	Full name	Explanation and Website (if any)
AFEM	European Natural Disasters Training Centre	http://afem.bayindirlik.gov.tr/ana.htm
CCPM	Community Civil Protection System	http://ec.europa.eu/environment/civil/marin/cis/cis_index.htm EC ensures efficient information sharing between MIC and the national contact points
CECIS	Common Emergency Communication and Information System	http://ec.europa.eu/environment/civil/cecis.htm Communication between the MIC with National Authorities to better protect citizens from natural and technological hazards: * Prevention, * Preparedness, * Response
CIS	European Civil Protection	http://ec.europa.eu/environment/civil/marin/cis/cis_index.htm Community co-operation in the field of civil protection aims to better protect people, their environment, property and cultural heritage in the event of major natural or man-made disasters occurring both inside and outside the EU.
CPD	Italian Civil Protection Department	http://www.protezionecivile.it/index.php Example for a national website. CPD has introduced templates to be filled in by specially-trained teams after an earthquake; the templates enable a description of the damage, calculate the vulnerability indices and define the cost of intervention. Same is useful for flood events
CRUE	European Research Project on Flood Risk	http://www.crue-eranet.net/ Inventory and analysis of European Research needs on flood risk management,
DRM	World Institute for Disaster Risk Management (USA)	http://www.drmonline.net/ Definition of four measures for adverse natural disaster effects: i) improved quality of buildings or construction & land use management, ii) education & training, iii) incentives & regulations, and iv) enforcement
EC	European Commission	http://ec.europa.eu/ Whenever its member countries are hit by natural disasters, the EU steps in to help coordinate assistance and fund the reconstruction of essential infrastructure.
ELLA	Project: ELBE-LABE River Flood, Interreg IIIB	Regional transnational mapping of flood-prone areas in Germany and the Czech Republic (available on CD)
ESPON	European Spatial Planning Observation Network	http://www.gsf.fi/projects/espon/ Hazards project (2006) about typology of risks and hazards as well as the risk profile of regions (hazard potential and vulnerability). The result is better understanding and management of risks to facilitate targeted responses and policies, pointing out comparable situations across EU 27+2.
EUMS	EU Military Staff	http://europa.eu/legislation_summaries/foreign_and_security_policy/cfsp_and_esdp_implementation/r00006_en.htm Source of the EU's military expertise. It performs early warning, situation assessment and strategic planning for Petersberg tasks (humanitarian missions, peacekeeping and crisis management) and all EU-led operations.
ECCO	European Confederation of Conservator-Restorers' Organisations	http://www.ecco-eu.org/ E.C.C.O. seeks to develop and promote, on a practical, scientific and cultural level, the profession of Conservator-Restorer of Cultural Property. Through its professional associations, E.C.C.O. represents more than 5.000 members throughout Europe, from 16 countries within the European Union (EU) and the European Free Trade Association (EFTA).
FEMA	Federal Emergency Management Agency	http://www.fema.gov/ Founded in 1979, online disaster assistance of the USA (fire, flood, hurricane, terrorism, tornado, others).
FIS	Flood Information System	http://www.floodrisk.eu/FloodServer/ Website hosting flood data of many projects ISK-EOS, PREVIEW, SAFER, urosense, INDRA, Infoterra France, ReSAC and ROSA:

Abbreviation	Full name	Explanation and Website (if any)
Galileo	European Global Satellite System	http://ec.europa.eu/transport/galileo/index_en.htm State-of-the-art global navigation satellite system, providing a highly accurate, guaranteed global positioning service under civilian control, consisting of 30 satellites and the associated ground infrastructure.
GIS	Geographic Information System	http://www.eionet.europa.eu/gis/ European Geospatial data - Maps - Specifications
GCI	Getty Conservation Institute	http://www.getty.edu/ http://www.getty.edu/conservation/education/disaster.html
GMES	Global Monitoring for the Environment and Security	http://www.gmes.info/ European programme for the implementation a European capacity for Earth observation.
Heritage Preservation	The Heritage Emergency National Task Force in the USA.	http://www.heritagepreservation.org/PROGRAMS/TASKFER.HTM Heritage preservation offers tools and information to cultural institutions and the general public for preparing for and responding to emergencies that affect collections and family treasures.
ICA	International Council on Archives	http://www.ica.org/ The mission of ICA is to promote the preservation and use of archives around the world. In pursuing this mission, ICA works for the protection and enhancement of the memory of the world and to improve communication while respecting cultural diversity.
ICBS	International Committee of the Blue Shield	http://www.ancbs.org/Risk Preparedness for cultural heritage : The Blue Shield is the cultural equivalent of the Red Cross. It is the protective emblem specified in the 1954 Hague Convention (Convention for the Protection of Cultural Property in the Event of Armed Conflict) for marking cultural sites to give them protection from attack in the event of armed conflict.
ICCROM	International Centre for the Study of the Preservation and Restoration of Cultural Property	http://www.iccrom.org/ ICCROM has issued a management manual on risk preparedness for world cultural heritage, which gives a complete set of instructions on how to behave in emergency situation
ICOM	International Council of Museums	http://icom.museum/ ICOM is the international organisation of museums and museum professionals which is committed to the conservation, continuation and communication to society of the world's natural and cultural heritage, present and future, tangible and intangible.
ICOMOS	International Council on Monuments and Sites	http://www.icomos.org/ International non-governmental organization of professionals, dedicated to the conservation of the world's historic monuments and sites.
IFLA	International Federation of Library Associations and Institutions	http://www.ifla.org/ Leading international body representing the interests of library and information services and their users. It is the global voice of the library and information profession.
IIC	International Institute for Conservation of Historic and Artistic Work	http://www.iiconservation.org/index.php The IIC is promoting the knowledge, methods and working standards needed to protect and preserve historic and artistic works throughout the world
IMOS	Integrated Multi-Objective System for Optimal Management of Urban Drainage	http://ec.europa.eu/environment/life/themes/water/best.htm Integrated Multi-Objective System for optimal management of urban drainage, an Italian project on Water Management (projects) in Genova within the Euro-Mediterranean Programme for the Environment
INSPIRE Direktive	European Spatial Data Infrastructure	http://inspire.jrc.ec.europa.eu/ Infrastructure for spatial information in Europe to support Community environmental policies, and policies or activities which may have an impact on the environment.
MIC	Monitoring and Information Centre	http://ec.europa.eu/echo/civil_protection/civil/prote/mic.htm based at EC in Brussels, available on a 24/7 basis for contact with member states , for channelling information and coordinating assistance

Abbreviation	Full name	Explanation and Website (if any)
MS	Member States	National members states in the European Union
NOAH/FIIWAS	Project INTERREG IIIB 2003-2008	http://www.noah-interreg.net/download/noahenglish.pdf EU-project on Flood Information and Warning System
OMC	Open Method of Coordination	http://ec.europa.eu/invest-in-research/coordination/coordination01_en.htm
PBC	Protection des Biens Culturels	http://www.bevoelkerungsschutz.admin.ch/internet/bs/fr/home/themen/kgs.html National Cultural Heritage protection system of Switzerland
SAFER	Project: INTERREG IIIB 2003-2008	http://www.eu-safer.de/project_description.html?&L=1 Strategies and actions for flood emergency risk management
UNESCO	United Nations Educational, Scientific and Cultural Organisation	www.unesco.org One of UNESCO's mandates is to pay special attention to new global threats that may affect natural and cultural heritage and ensure that the conservation of sites and monuments contributes to social cohesion. UNESCO published a report about climate change which claims that several sites of natural and cultural interest may be at risk. (activity 393-1, 2007)
UNFCCC	UN Framework Convention on Climate Change	http://unfccc.int/2860.php The UNFCCC supports all institutions involved in the climate change process, including global warming (legally binding treaty: Kyoto Protocol)
URANIA	Named after the Greek godness Urania	URANIA was founded to transfer the latest knowledge from science, culture and society to people. URANIA is active in Germany (founded in 1888 as the first *Science Center* in the world) and Austria (founded in 1897).
USAR	Urban Search and Rescue Team (FEMA)	http://www.fema.gov/emergency/usr/ Trained national teams for disasters. Urban search-and-rescue is considered a "multi-hazard" discipline, as it may be needed for a variety of emergencies or disasters, including earthquakes, hurricanes, typhoons, storms and tornadoes, floods, dam failures, technological accidents, terrorist activities, and releases of hazardous materials.
WISE	European Environment Agency	http://ec.europa.eu/environment/water/index_en.htm Water information system for EUROPE for EU27
WFD	Water Framework Directive	http://ec.europa.eu/environment/water/water-framework/implrep2007/index_en.htm Europea is included in the WISE system prepared by the EU

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6.4 List of deliverables

Deliverable	Deliverable Name Author (s) Cooperation between	Content
D1.1	Interfaces to running flood and cultural heritage projects Miloš Drdácký (ITAM) ITAM, CRUIE, ECOLAND	This deliverable facilitates synergetic exploitation of results and co-ordination with other European activities related to mitigating damages from floods. It provides the project partners with basic information and connection data to other related national, international and EU projects currently dealing with flooding, and specifically or marginally with their impact on cultural heritage. The analysis also takes into account other natural hazards, e.g. earthquakes, landslides, subsidence, etc., and their threat to cultural heritage. A list of identified projects with short comments on their content and results is presented.
D1.2	Report on experiences from previous and historic floods, a summary of the characteristic parameters of these events Luca G. Lanza (CRUIE) Michael Kupka (TUD) CRUIE, IDK, IMSL, TUD, ZAG, POLIMI	This report focuses on flood characteristics that may have an influence on the threat to cultural heritage, and therefore this is not a study of the meteorological, hydrological and hydraulic aspects of floods in general. Knowledge of flood characteristics is contextualised here in the framework of cultural heritage protection (both movable and immovable) and those characteristics are sought that may help in developing better mitigation strategies at highly vulnerable sites.
D1.3	Report on the state-of-the-art of risk assessment Francesca Pirlone (CRUIE) Ilenia Spadaro (CRUIE) Pietro Ugolini (CRUIE) CRUIE, IDK, TUD, ITAM	Instruments and techniques related to the state of the art of the expected damage to historic and cultural heritage on an EU level and in the various EU countries are described in this deliverable: There are various instruments (e.g. legal instruments for town planning, operative tools, e.g. charts, and information tools). A close examination of the regulatory framework is also an important instrument. This report provides an overview of existing regulations, and shows detailed examples of risk assessment as it is carried out in practice.
D1.4	Report on the vulnerability of CH to flooding (innovation) Insa Christiane Hennen (IDK) Jeannine Meinhardt (IDK) Christoph Franzen (IDK) IDK, ECOLAND, ITAM	This deliverable points out the specific vulnerability of cultural heritage objects in relation to flood damages. D1.4 is primarily addressed to the CHEF project partners as an extract of the results of deliverables D1.1 to D.1.3, D 1.5, D 2.1 and D 3.1. In order to describe the specific vulnerability of cultural heritage objects related to flood events, it is necessary to give a definition of cultural heritage and also of the term "vulnerability", and to give an overview of the different types of floods that cause very different types of damage. The definitions provided in other deliverables produced in the framework of the CHEF project will be regarded from the point of view of art historians and materials experts who are familiar with the specific properties of cultural heritage objects.

Deliverable	Deliverable Name Author (s) Cooperation between	Content
D1.5	Report on legislation and risk mapping initiatives at national level Simona G. Lanza (CRUIE) Francesca Pirlone (CRUIE) Ilenia Spadaro (CRUIE) Pietro Ugolini (CRUIE) CRUIE, TUD	This deliverable synthetically presents , in chronological order, the principal laws that have beene issued at Italian, EU and international level, related to safeguarding and protecting cultural heritage , considered in its different senses (movable and immovable goods, including movable goods in immovable buildings, and also consolidated urban fabrics, e.g historic and smaller centres). The laws are illustrated by means of special records that comprise: law number and title, synthetic text, references to the protection of cultural goods from natural events such as hydro-geological and seismic events. For the sake of completeness, there is a link to the complete text of the laws for each law mentioned in the records.
D1.6	GIS applicable software modules for risk assessment (innovation) Francesco Cumbo (CRUIE) Francesca Pirlone (CRUIE) Ilenia Spadaro (CRUIE) Pietro Ugolini (CRUIE) CRUIE, TUD, ITAM	This deliverable provides an overview of available GISs and the application of GIS in cultural heritage protection. GIS can constitute a very important tool, both in the preventive phase for ensuring the safety of cultural goods and for emergency management to protect cultural and historic heritage during and after a natural calamity. Today, the use of GIS technology seems the most appropriate way to achieve this purpose, because phenomena can be visualized and analyzed in real time by means of thematic maps. Through the use of GIS it is possible to organize data related to the works and interventions, and to use the data in various innovative ways.
D2.1	Damage catalogue related to exposure data, with tips on remedial works – materials and movable cultural heritage (Innovation) Sabine Kruschwitz (BAM) Ina Stephan (BAM) Miloš Drdácký (ITAM) Tomáš Drdácký (ITAM) Insa Christiane Hennen (IDK) Jeannine Meinhardt (IDK) Giuliana Cardani (IDK) BAM, ITAM, IDK, TUD, POLIMI	This report discusses typical damage to movable cultural heritage resulting from flood events. Movable cultural heritage is a superordinate term for very diverse materials, e.g. paper, leather, covers, wood, metal, paintings, ceramics, bones, and even plaster and building stone. In the current form of the report, three case studies from extremely hazardous flood events in Germany, the Czech Republic and Italy reveal the diversity of possible resulting damage. On the basis of our findings, we offer an explanation of the most typical damage mechanisms, which can be physical, chemical or biological in nature.

Deliverable	Deliverable Name Author (s) Cooperation between	Content
D2.2	Report on damage mechanisms in materials and movable cultural heritage (results from experimental and theoretical investigations) (Innovation) Ivo Herle (TUD) Vladislava Herbstová (TUD) Michael Kupka (TUD) Khalil Magdi (TUD) Heiner Siedel (TUD) Rudolf Plagge (TUD) John Grunewald (TUD) TUD, ITAM, ZAG, TUD, UIBK, POLIMI, BAM, ECOLAND	The main objective of this deliverable is to study the effects of flooding on the damage mechanism of materials. To achieve this goal, the deliverable was divided into three sections. First, the changes in material properties leading to damages in historic materials were studied and analyzed through an extensive literature review, case studies and experiments on the mechanisms of collapsible soil. Second, salts and contamination effects on building structures during flooding were investigated, including the effects of sea water, dissolved chemicals forming salts, fresh water from rivers and pre-existing salt contamination of cultural heritage objects. In the third section, numerical modeling taking into account the combined moisture/heat/salt transport was carried out.
D2.3+2.4	Recommendation on threshold levels of exposure of materials and damage to materials Recommendation on threshold levels of exposure and/or damage for movable heritage Sabine Kruschwitz (BAM) Ina Stephan (BAM) Pete Askew (ISML) BAM, IMSL, TUD, ECOLAND	A compilation of possible and common damage mechanisms was presented in deliverable 2.1 of the CHEF project. Based on these outcomes, deliverables 2.3 and 2.4, which were originally designed to calculate threshold levels for movable objects and materials, were combined. The way and the extent to which an object will react to flood-induced strains will always depend on its particular properties (materials, the way in which they were assembled and were treated in the past, whether they provide a proliferation source or support for microorganisms, temperature and duration of the flood, etc.) and surrounding conditions after the hazardous event. The report presents experiments that help to understand how differently materials such as wood and paper will react to water.
D2.5	Guidelines on the application of non-destructive and virtually non-destructive measurement methods and laboratory testing for flood-prone materials and objects. Sabine Kruschwitz (BAM) Ina Stephan (BAM) Gianluca Valentini (POLIMI) Pete Askew (ISML) BAM, TUD, ZAG, ECOLAND, ITAM, POLIMI, IMSL	The goal of this deliverable is to specify guidelines for non-destructive and virtually non-destructive measurement methods for application to movable cultural heritage. As outlined in combined deliverable D2.3/D2.4, few such methods have been available until now. Consequently, some techniques are suggested and some guidelines are provided in this report for assessing water content, the activity of water on wet surfaces, and detection of microorganisms.

Deliverable	Deliverable Name Author (s) Cooperation between	Content
D3.1	Damage catalogue related to exposure data and containing applicability tips for remedial works – immovable heritage and sites (Innovation) Part I – immovable objects Damage catalogue related to exposure data and containing applicability tips for remedial works – immovable heritage and sites (Innovation) Part II – gardens and landscapes Miloš Drdácký (ITAM) Jaroslav Valach (ITAM) Jan Bryscejn (ITAM) Zuzana Slížková (ITAM) Michael Kupka (TUD) Bernd Hofestädt (IDK) Prof. Ramiro Sofronie (ECOLAND) ITAM, ECOLAND, TUD, IDK, ZAG, POLIMI, BAM	The main objective of this deliverable is to set up a damage catalogue for historic structures and sites, supported by a digital database. However, it is almost impossible and would be misleading to generalize all observed types of damage and separate and divide them into individual categories. In many cases, immediate flood damage leads to subsequent damage, or even failure, due to processes which are generated after flood situations. This catalogue therefore presents the most important phenomena, illustrated by examples gathered during historic or recent floods, and it remains open for further amendments and contributions
D3.2	Report on damage mechanisms at historical sites (results from experimental and theoretical investigations) (Innovation) Giuliana Cardani (POLIMI) Luigia Binda (POLIMI) Ivo Herle (TUD) Michael Kupka (TUD) Vladislava Herbstová (TUD) POLIMI, BAM, ITAM, TUD, CRUIE, ZAG, UIBK	Experimental investigations of moisture transport carried out by the Research Units involved in the project are presented here. The results of experiments carried out on masonry specimens were used to simulate historic masonry with its complexity and inhomogeneities. A range of non-destructive and virtually non-destructive techniques were applied in order to evaluate the moisture propagation and drying in masonry walls. In many cases these techniques were applied together on the same area, in order to compare the results and to calibrate them in the presence of moisture. Moisture propagation in building materials and structures, and thus the drying process, is complex and depends on several material and environmental parameters. Especially for historic materials and structures, systematic experimental data considering the efficiency of protective treatments is not available. Such data is, however, needed for planning protective and aftercare treatments.

Deliverable	Deliverable Name Author (s) Cooperation between	Content
D3.3	Guidelines on the application of non-destructive and virtually non-destructive measurement methods and laboratory testing for flood-prone historic sites, including validation reports Sabine Kruschwitz (BAM) Ina Stephan (BAM) Luigia Binda (POLIMI) Giuliana Cardani (POLIMI) Miloš Drdácký (ITAM) Tomáš Drdácký (ITAM) Rudolf Plagge (TUD) Ivo Herle (TUD) Michael Kupka (TUD) Vladislava Herbstova (TUD) POLIMI, BAM, ECOLAND, TUD, ITAM, ZAG	Soon after the flood, a first survey of the observed damages should be carried out in order to define a suitable diagnostic investigation project and to identify the best testing points. The guidelines in this report describe possible applications of diagnostic investigation to historic masonry structures and the conditions for their applicability. The guidelines are made for the user and operator of the method. They do not constitute a manual or a course. Relevant guidelines/standards and scientific literature are listed at the end of the document. ❑ Thermography ❑ Sonic Pulse Velocity Test ❑ Ultrasonic test ❑ Radar test ❑ Powder Drilling test ❑ Core Drilling method ❑ Calcium Carbide test ❑ Nuclear Magnetic Resonance (NMR.) ❑ Complex Resistivity (CR) ❑ Microwave Borehole Method ❑ Microwave Moisture Measurement System ❑ Time Domain Reflectivity (TDR)
D3.4	Recommendation on exposure and damage threshold levels for historical sites Insa Christiane Hennen (IDK) Jeannine Meinhardt (IDK) Christoph Franzen (IDK) Heiner Siedel (TUD) IDK, BAM, ITAM, TUD, ECOLAND, ZAG, CRUIE, POLIMI	The definition of threshold levels for historical materials used historical sites implies that we can define the “normal” state. Many cultural heritage sites have been built near to water in the course of urbanisation and cultural development. Water and flood events are therefore a part of their history. In addition, cultural heritage structures quite often provide a record of historic flood events. Flood records can be found in archives, and flood marks can often be observed on historic buildings.

D4.1	Guidelines on preventive and temporary measures to protect cultural heritage against flooding. Rosemarie Helmerich (BAM) Miloš Drdácký (ITAM) Jeannine Meinhardt (IDK) Zuzana Slížková (ITAM) Christoph Franzen (IDK) Insa Christiane Hennen (IDK) Jeannine Meinhardt (IDK) Dimitrios Kolymbas (UIBK) Michael Holzmann (UIBK) Vladislava Herbstova (TUD) Ivo Herle (TUD) Heiner Siedel (TUD) Ana Virsta (ECOLAND) Ramiro Sofronie (ECOLAND) Luigia Binda (POLIMI) Giuliana Cardani (POLIMI) Mateja Golež (ZAG) BAM, ZAG, IDK, ITAM, ECOLAND, TUD, POLIMI, CRUIE	The objective of this report is to present a state-of-the-art review of available measures, about how to prevent floods impacting immovable and movable cultural heritage , how to preserve and treat historic materials, historic structures and sites in the event of flooding. A worldwide overview is presented of conventional, locally-available methods and techniques for making temporary repairs and reinforcements that will provide maximum preservation of cultural heritage . This deliverable includes an annex with short descriptions of technical measures that help to prevent flood damage.
D4.2	Guidelines on restoration and repair techniques for materials and structures Miloš Drdácký (ITAM) Zuzana Slížková (ITAM) Petra Štefcová (NM Praha) Kateřina Šupová (NM of Technology Praha) Rosemarie Helmerich (BAM) Heiner Siedel (TUD) Ana Virsta (ECOLAND) Ramiro Sofronie (ECOLAND) Dimitrios Kolymbas (UIBK) ITAM, BAM, UIBK, TUD, ECOLAND	This report gathers experience of remedial work carried out after recent floods in various European countries, and presents lessons useful for future restoration and repair activities in similar situations. Short-term post-flooding techniques (drying and dehumidification, temperature reduction, after-flood care, etc.) as well as long-term techniques (pollutant removal, salt removal, desalination, etc.) for repairing damage to historic objects are presented and critically analyzed from the user's point of view. Techniques for repairing structural elements or entire structures are demonstrated. Special attention is given to: • Construction measures for stabilizing and strengthening structures. • Techniques for repairing and strengthening structural elements (walls, pillars, etc.) • Techniques for strengthening foundations and flood levees. • An introduction to flood-proofing systems and protection against erosion.
D4.3	Structural modelling of Cultural Heritage (Innovation) Rosemarie Helmerich (BAM) Thomas Meier (TUD) Erik Nacke (TUD) Ivo Herle TUD, BAM, POLIMI	A general procedure for structural modelling of historic sites and structures representing Cultural Heritage (CH) is summarized according to the current state of the art. Historic sites suffering from damage caused by flooding have often survived many previous floods and also the effects of aging during their lifetime. The resulting structures are a composition of parts constructed in various periods and made of various materials. Thus, the modelling must reflect both the individual structure and the individual load history.

D5.1	Statistical report on earlier floods; Estimated values of losses Ana Virsta (ECOLAND) Ramiro Sofronie (ECOLAND) Dimitrios Kolymbas (UIBK) Michael Holzmann (UIBK) ECOLAND, ITAM, IDK, BAM, TUD	This deliverable describes floods events in various European countries, the damages caused to Cultural Heritage buildings and estimated values of losses. Floods are one of the most common and most destructive natural phenomena. The report gives a European overview of flooding. Chronicles dealing with flood events in most European countries are available from the early 19th century onwards.
D5.2	Flood diagnosis for cultural heritage structures Sabine Kruschwitz (BAM) Ana Virsta (ECOLAND) Ramiro Sofronie (ECOLAND) ECOLAND, BAM	This report deals with with diagnostic tools that can be applied at various stages of a flood event. Obviously the assessment options and suitable technologies vary according to time of use, i.e. before, during or after high waters. The document is therefore divided into three main chapters that treat each of the hazard stages separately. The reported best ways of living through and observing as many flood parameters as possible follow on from the previously published deliverables of the CHEF project, especially those concerned with case studies: D1.1, D 3.3, D 5.4, D 5.5, D 5.6 and D 5.7.
D5.3	Analysis of earlier and current case studies Ana Virsta (ECOLAND) Ramiro Sofronie (ECOLAND) ECOLAND	A methodology for analysing selected CHEF case studies. Recommendations on the kinds of data that should be collected before, during and after a flood event. It is shown how this data contributes to an understanding of the ways in which flooding affects historic buildings and objects, and what kind of conclusions can be drawn from these experiences. This report explicitly presents the data collection in three distinct chronological stages: before, during and after a flood event. Then, after some probabilistic processing steps, the flood risk assessment can be completed.
D5.4	Report on the medieval stone bridge in Písek (Czech Republic) Zuzana Slížková (ITAM) Jiří Barták (ITAM) Miloš Drdácký (ITAM) Vladislava Herbstová (TUD) ITAM, TUD	CASE STUDY: The Stone Bridge over the Otava River in Písek was built in the second half of the 13th century and is still being used. It is the second oldest bridge built in Bohemia and the oldest preserved bridge in Bohemia. The case study tries to answer the question: What will happen to the Stone Bridge, if an unusually powerful, i.e., 500-year return period, flood arrives. It describes the way to resolve this problem and provides the final answer to the question. The question was technically formulated and implemented at a time when there was not idea that such a catastrophic flood would occur in Bohemia in 2002.
D5.5	Report on Pillnitz Castle (Germany) Christoph Franzen (IDK) Roxana Naumann (guest) Andre van der Goes (guest) IDK	CASE STUDY: Pillnitz Castle is an extraordinary ensemble of architecture and landscape gardening. It is a beautifully integrated part of the heritage site of the Dresdner Elbtal. Built in Asian style in the early 18th century, it is an outstanding example of Chinoise water and garden palace architecture. The site of the castle has undergone frequent flooding by the Elbe since time immemorial. The architects have responded by adjusting to this fact. However, the catastrophic flood of 2002 resulted in heavy damage to the site, and pointed to weak points in the measures for preventing damage to the heritage site. The flood event showed up some of the historic strategies that had been buried over time. This deliverable presents the events of 2002 and summarizes the main lessons learned from this major flood.

D5.6	Report on Church of Caldarusani Monastery, Ilfov County, Romania Ana Virsta (ECOLAND) Ramiro Sofronie (ECOLAND) ECOLAND	CASE STUDY: The Calderusani Monastery complex is situated about 40 km north of Bucharest, on the north-western shore of Caldarusani Lake, in the Snagov Plain. The enclosure of the monastery, rectangular, 93 m in length, 67 m in width and about 6 m in height, with walls one metre in thickness, is built of ancient brick. More frequently in recent decades, usually in summer, flash rainfalls have occurred. Over zones of only a few square kilometres, precipitations of 80 to 120 litres per square metre have fallen in less than 30 minutes. In most cases the soil had already been saturated by earlier rainfalls. Since the soil in the yard of the Monastery consists mainly of dense clay, the rainwater accumulates quickly around the church and the water level rises toward or over the inner floor level. Only minutes or few hours, the church was flooded.
D5.7	Report on Belvedere Church in Bucharest, Romania Ana Virsta (ECOLAND) Ramiro Sofronie (ECOLAND) ECOLAND	CASE STUDY: Belvedere Church is located in Bucharest, in an old and highly populated zone with small private houses. The sewerage system in Bucharest is rather old, and often lacks the capacity to collect all the waters. During severe rain events, the waters either flow along the streets or stall in the yards around some buildings. The basement of Belvedere Church has been flooded many times, but funds for radical interventions in the sewerage system have not always been available.
D5.8	Report on castles, villages and landscape in Central Bohemia Zuzana Slížková (ITAM) Klára Nedvědová (ITAM) Tomáš Drdácký (ITAM) Jiří Bláha (ITAM) ITAM	CASE STUDY: Several case studies on historic regions in Bohemia. Český Krumlov is located in the southern part of the Czech Republic near the Austrian border. The town is situated in the Vltava river valley in the foothills of the Blansky Forest Nature Reserve. During the flood in 2002 the surface of the flooded area was about 140 ha. About 300 houses were flooded in the Český Krumlov monument protected area, and a total of about 800 in the town. In some places the buildings were under as much as 5 metres of water. The infrastructure services collapsed. Švihov is a small town of village character situated in the valley of the river Úhlava. The most significant cultural and natural heritage site is Švihov Castle, a water fortress and the dominating feature of the town. During the flood in 2002, Švihov was one of the most flood-affected towns in the Czech Republic. Jaroměřice-nad-Rokytnou Castle is one of the largest structures of its kind in Central Europe. There are three green areas near the castle – the French garden, situated on the left bank of the River Rokytna; Theatre Island, on the opposite side of the stream; and, somewhat farther away, the English park, which is located in the area with the highest risk of flooding. Veltrusy Castle is an important Baroque complex closed linked with the surrounding cultural landscape. In 2002, the Château survived an exceptionally high flood. The water reached a height of 3,5 m in the park and in some structures, and this was accompanied by a rather fast-flowing water stream. The area was flooded for about nine days.
D5.9	Reports on the historic cities of Dresden, Prague, Regensburg and Genoa Giorgio Giallocosta (CRUIE) Simona G. Lanza (CRUIE) Francesca Pirlone (CRUIE) Ilenia Spadaro (CRUIE) Pietro Ugolini (CRUIE) ITAM, IDK, ZAG, CRUIE	CASE STUDY: Several case studies on historic cities in Europe. Genoa is located in the Liguria region, in northwest Italy, where earthquakes, landslides and floods are the main natural hazards in the history of the town. Grimma is located just behind the confluence of three small rivers, the Zwickauer Mulde, the Freiberger Mulde and the Zschopau. During the river flood in summer 2002 in Germany, the Mulde damaged old buildings and the old bridge in the historic town of Grimma.

D5.10	Report on full-scale models (Innovation) Giuliana Cardani (POLIMI) Luigia Binda (POLIMI) POLIMI	This deliverable presents full-scale masonry models that have been constructed at the Polytecnico di Milano. It describes the diagnostic campaigns that have been carried out in the framework of the CHEF project. Some of the old results reported here were used to select the tests to be carried out to simulate the flood and to evaluate the drying process of the moisture content. The results achieved during the CHEF project are reported in deliverable D 3.2.
D5.11	Research Report on the Church of Our Lady of Health, Piran (Slovenia) Mateja Golež (ZAG) Marjana Lutman (ZAG) Friderik Knez (ZAG) Sabina Drnovšek (ZAG) Janko Čretnik (ZAG) Vili Kuhar (ZAG) Rajko Petrica (ZAG) Tadeja Kosec (ZAG) Andrijana Sever Škapin (ZAG) Sabina Jordan (ZAG) Alenka Mauko (ZAG) Ana Mladenovič (ZAG) ZAG	CASE STUDY: Case study on the Church of Our Lady of Health in Piran The Slovenian coastal town of Piran is full of cultural heritage buildings. They are threatened by annual sea flooding and are heavily affected by sea salts. The conditions are particularly severe in those parts of the town which are next to the actual coastline and are occasionally threatened by sea flooding caused by high tides. In order to comprehend the issue in its entirety, the following features were monitored: temperature, relative humidity, level of groundwater and water soluble chlorides. The purpose of the measurements was to determine the basic state of the microclimatic conditions of the building, inside and outside the walls of the structure.
D6.1	Recommendations for preventive activities before flood events Luca Giovanni Lanza (CRUIE) Rosemarie Helmerich (BAM) CRUIE, BAM	This deliverable provides a collection of administrative and structural recommendations to be implemented before flooding. Damage prevention before flooding can be accomplished by using a top-down approach, starting at the flood hazard level, together with a bottom-up approch, reducing the vulnerability or exposure of cultural heritage. Structural and non-structural measures can be applied in both cases. This may involve protecting the site in advance by introducing rules for the protection of cultural heritage, such as preventive non-structural measures (mostly administrative or political), as well as by constructing more traditional defensive structures.
D6.2	Recommendations for activities during a flood Dr. Insa Christiane Hennen (IDK) Dr. Christoph Franzen (IDK) IDK	This deliverable provides general recommendations for activities and preventive measures to be applied during a flood. The first priority is to protect life and health. After this, prioritisation becomes more complex. It is highly recommended to follow the work flow of an emergency action plan which, of course, has to be developed in advance and has to be known by the persons involved, who must receive regular training to implement it. Management plans prepare the people and structures to react in the best known way to avoid or mitigate damage to cultural heritage. Without careful preparation, damage to, or even total loss of unique cultural heritage objects cannot be avoided in extreme cases.

D6.3	Recommendations for actions after a flood Zuzana Slížková (ITAM) Heiner Siedel (TUD) TUD, ITAM	This deliverable provides recommendations and best practice advice for moveable objects and buildings. Several examples dealing with sites and other cultural heritage categories are shown in the case studies. Interventions made after a flood must avoid worsening the damage to cultural heritage. This requires joint action by cultural heritage owners or managers in collaboration with specialist restorers and engineers. Soon after the flood, they should outline a plan for immediate interventions and also for repairs and restoration. It is recommended to set up a team that includes all parties concerned with the interventions, even though some of the participants may have conflicting interests. All disputes and discussions must be supported by as much factual information as possible, and proposals should be weighed using a cost-benefit approach.
D7.1-D7.5	D7.1 Periodic Activity Report, including the plan for using and disseminating knowledge (see D8.1.1 to D 8.1.3) D7.2 Periodic Management Report, including justification of costs D7.3 Periodic Report on the distribution of the Community's contribution D7.4 Questionaire D7.5 Collection of Work Package Status Reports BAM	Internal Report on progress of the project. Not for publication.
D8.1	Contribution to interim and Final Report: Dissemination Plan ITAM	Internal Report on progress of the project. Not for publication.
D8.2	Definition of exploitable products, based on project results ITAM	Internal Report on progress of the project. Not for publication.
D8.3	Collection and editing of Guidelines and Recommendations through all WPs Rosemarie Helmerich (BAM) Christian Köpp (BAM) BAM	The CHEF consortium has set up guidelines and recommendations, which were derived from all work packages in the project. This report summarizes the key recommendations emerging from each work package. An Annex to this report provides an overview of the content of all deliverables. While the project reports (deliverables) are written from the researcher's point of view and include very detailed and comprehensive information, this report provides a general overview of the main key recommendations. This report is organised according to the project work packages, and features some main conclusions for each work package.
D8.4	Recommendations for fast and efficient damage prevention Insa Christiane Hennen (IDK) Jeannine Meinhardt (IDK) Christoph Franzen (IDK) IDK	This deliverable provides some major recommendations on fast and efficient damage prevention. The recommendations were drawn up after an evaluation of several deliverables. The report takes the form of a brief summary of some general conclusions. However, in the case of cultural heritage objects, moveable and immoveable, recommendations for fast and efficient damage prevention are not always appropriate. Efficient flood hazard damage prevention requires substantial advance planning based on broad consultation. Each cultural heritage object is an individual case with its own specific problems and individual framework requirements.

6.5 Acknowledgement

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7 Annexes

7.1 Information sheets / leaflets for emergency preparedeness

Christian Köpp, Rosemarie Helmerich

One of the problems in flood protection is the unawareness of people who live or work in flood-prone areas and disregard the possibility of being flooded by a nearby river or even by a small stream, by a sea flood or by flash rain. Although in recent years serious flood events have occurred frequently in many European regions (and also worldwide), and although these catastrophes have been shown on TV, it is obviously difficult for people to accept that living in a risk area really means being at risk of losing property or even their life.

To raise awareness, it may be helpful to distribute very simple and basic information sheets in flood-risk areas. These sheets, shown here in two examples, can be helpful in making people think about the problem for a while. In the best case, they will use the card to organise their most valuable belongings in such a way that they can be saved in the event of a flood. If flooding occurs, it is extremely useful to know whom to call for help, and to know where to get the best information about rising water levels, the position of the flood, or about blocked roads and bridges.

In this example, the phone numbers and official contact and broadcast information are given on the front page of the card, and private information is written on the rear. These proposed "flood rescue and awareness" cards should be created by regional authorities and should be adapted to the environmental and geographical conditions in a specific region. The differences between rural and urban areas can also play a significant role, because emergency strategies and the availability of professional help may be organised in different ways in a city and in the country.

Private owners of historic buildings (and gardens) are often left completely alone with this problem. As long as no hazard occurs, nobody will ask, for example, whether the valuable building and its contents are properly protected from flooding. After the flood, however, the private owner may be required to expain why he did not take the most appropriate protective measures. Another example is shown in Fig. 7.1.2. This card addresses the owners or curators

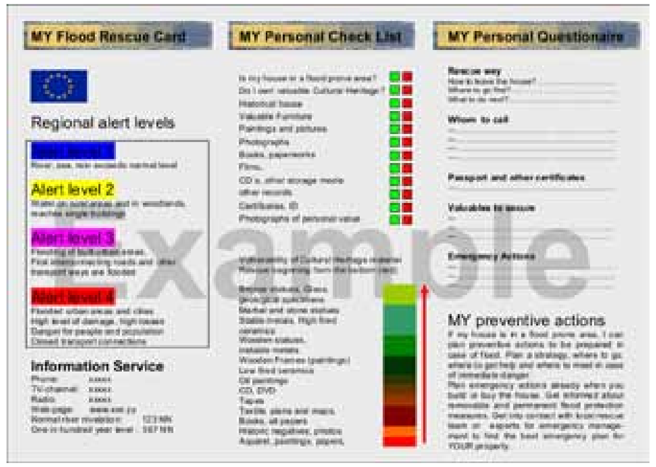


Figure 7.1.1: Flood rescue and awareness card for private households - checklist and questionnaire. Source: R.Helmerich, Köpp

of smaller public places, e.g. regional museums, heritage buildings, public gardens, etc. A card like this, which contains basic information about valuable and vulnerable items, specific security and existing protective measures and provides contact information, should be handed over to the nearest rescue or help team (fire brigade, civil protection).

Here, too, the card needs to be adapted to the circumstances. For small, privately run museums and similar places, a "flood risk inventory" of this kind can in some cases be filled in without the involvement of experts. Just by imagining the hazard and by thinking about the different vulnerable objects, any curator is able to set up at least some protective strategies. Of course for larger monuments or collections it is essential to involve professionals who know how to assess the vulnerability of the objects and who are able to propose efficient protective and emergency measures. The documentation about the objects should clearly indicate how vulnerable each object is. The overall vulnerability is determined by the most vulnerable component of the building or object, and it is essential to be aware of these relations.

It is essential to prepare easy-to-use templates for the after-flood damage survey. The templates should contain a detailed description of the building, the possible failure mechanisms, a damage index, a declaration of fitness for habitation, any emergency safety needed for civil structures, and an estimate of the intervention costs (see also Section 3.4.4).

CHEF	**Cultural Heritage** Flood-Vulnerablity-Self-Check for CH-rescue
Cultural Heritage Site	…….. Museum , ….park
Adress	Old Village street 123
Contact Under normal condition	Name: surname, family name e-mail: surname.family_name@museum.eu Phone number: +01 23 456789
Contact in case of emergency	Name: surname, family name e-mail: surname.family_name @rescueteam.eu Phone number: +09 87 6543210
River basin	Labello river
Description	Building built in ……………., Museum Village, Building materials, structure, exhibitions in ….floor, usage:…….
Flood prognosis	☐ annual flood ☐ once in 10 years ☒ once in 100 years or more
Characterisation	
Value	☐ High ☒ Medium ☐ Low
Type of CH	☐ Movable ☒ Immovable
Group of CH	☒ Building ☐ Transport infrastructure ☐ Museum exhibit ☐ Paperwork
Preventive measures	☒ None ☐ Permanent ☐ Temporary measures
Immediate measures	☐ None ☐ put in freezer ☐ Vaccuum dry ☐ Other
Required rescue team	☒ Single person ☐ 3 ☐ 5 or more
CH-specialist required	☐ No ☐ Yes
Materials critical after minimum exposure time	☐ 1 min ☐ 1 hour ☒ 1 day or longer
Critical after water level	☐ in front of the door ☐ 10 cm ☒ 1 m or higher
Describe permanent measures if any	Bored pile wall around south foundation,
Describe temporary tools	Rubber barriers stored in cellar room SS 01 Aperture control for the entrance gate, if any
Electricity plug off and other switches	Local information: information on where are back flow valve, air bricks, main electricity switch
Comments	Type of building is unique in Northern Europe, put on the World Heritage list, local heritage in ….., built by Pöppelmann
Year of origin	Unknown/ 17th century
Photograph of the CH-Site:  South view (Photo: Helmerich)	**Special information:** Historic masonry, Number of spans, Concrete slab, Special characteristic of foundations
Links, references	www.…museum.eu
Author: BAM	**Contributors:** BAM **Last update of information** :1/22/2010
☐ Information was delivered	☐ Information was used for CH-ranking

Figure 7.1.2: Flood rescue and awareness card for public cultural heritage

7.2 Damage database

Miloš Drdácký, Jaroslav Valach, Petr Křemen, Jan Abrahamčík

7.2.1 Introduction

Overall concept

The CHEF project makes use of the general structural damage information system which was developed at ITAM in the late 1980s and has been adopted by the Czech authorities for collecting and disseminating data from structural failures on the national level. However, protection of cultural heritage against floods involves a much wider range of problems, including damage to moveable objects, archaeological sites and cultural landscapes. The information system structure has therefore been modified and enlarged to accommodate these inputs as generalized classes of objects. As an example, only the form used for immoveable heritage is presented here.

Motivation

Failures of historical and modern structures occur due to various causes, often leading to irreparable damage, loss of value or even loss of lives. Due to the wide spectrum of failure types, recurrences of the same type of failure can be quite rare. It is extremely difficult in the lifetime of a single person to gather vast and representative experience of the various causes leading to failures.

The main objective of the damage information system presented here is to support the collection and sharing of knowledge of documented failures, to share our understanding of what went wrong, and to gather the experience of professionals from various fields of expertise concerning protective measures that work best. This will enable professionals in the field to draw on sound experience acquired by others dealing with previous cases. Conservators, builders and CH managers are invited to participate in building up the knowledge base of structural failures by entering cases well known to them and in this way sharing their experience with the community.

7.2.2 Related Work

To allow easy and flexible failure reporting as well as knowledge base exploration, the information system builds on various fields of expert knowledge – information about construction types, structural parts, typical measures taken to fix a failure, failure result types, etc. One of the closest publicly available approaches to ours is the Failure Knowledge Database. It attempts to formalize the overall concept of structural failures, using so-called Failure mandalas (Hatamura, 2005) – hierarchies for causes/actions/results of a failure, e.g. the results mandala defines "Damage to Environment" as a special case of "Secondary Damage". The database contains approximately 550 cases (failure reports), approxim ately 140 of which are from the field of civil engineering. This knowledge base focuses on the causality of actions/events that might impact an object. In comparison with this approach, our information system provides more formalized and more targeted solutions for capturing knowledge and experience concerning damage to immovable structures. In addition, the Failure Knowledge Database is targeted more at evaluating personal responsibility for the reported damages than at failure analysis and failure prevention.

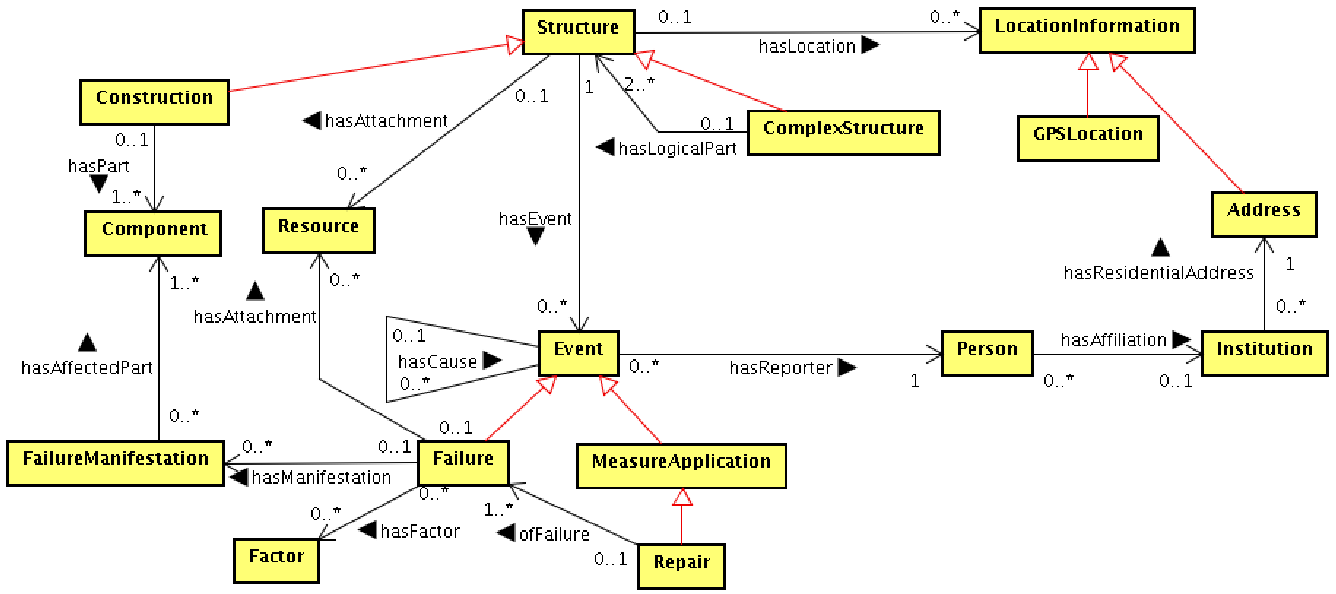


Figure 7.2.1: Basic structural relations between structures, failures and related information. Classes are shown as yellow rectangles, hierarchical information is represented by red arrows, and property associations are shown as black arrows. Numbers on arrows represent cardinalities – i.e. Structure can have assigned zero or many events (hasEvent 0..*), but each event (e.g. failure) must be assigned to exactly one structure (hasEvent 1). Source: J. Valach

7.2.3 Description of the knowledge base

Scope of the Knowledge Base

The information system presented here mainly covers damage to immovable structures due to various causes, and preventive/remedial actions performed to protect/repair them, where possible. Buildings of cultural heritage value receive special attention, as the methods for conservation and repair involve delicate care, and have to take into account the precious nature of the objects. Among the causes of damage, floods are a major issue in many regions, especially when models of predicted climate changes anticipate increased rainfall and changes in weather patterns leaning toward less frequent but very intense precipitation in the not very distant future. Further primary causes, such as other types of natural disasters, human ignorance and negligence, deterioration and weathering are also represented in the knowledge base model.

Structure of the Knowledge Base

As the domain of structural failures involves many natural subsumption hierarchies (structure types, component parts, etc.) the knowledge is stored within a semantic web ontology (Gomez-Perez, 2003) modeled in the OWL 2 language (Motik, 2009). The main differences in comparison with the classical relational database technology are (i) suitability for storing incomplete information, (ii) easy modeling of hierarchies (e.g., "each church is a religious building") and (iii) easy modeling of property characteristics that are enforced by logical reasoning (e.g. "the relation hasPart between two components is transitive, e.g. if A has part B and B has part C then A has part C").

To provide the logical internals of the OWL language in an easily understandable form, the overall schema of the developed ontology is depicted in Fig. 7.2.1 as a simplified UML class diagram (Miles, 2006) – it shows the main ontology classes (sets) and object properties (binary relations). To keep the diagram easily understandable, it does not involve atomic attributes, like name of a Person or analysis of a Failure. Although these attributes are present in the ontology, they are atomic (represented as textual fields), and some of them will be

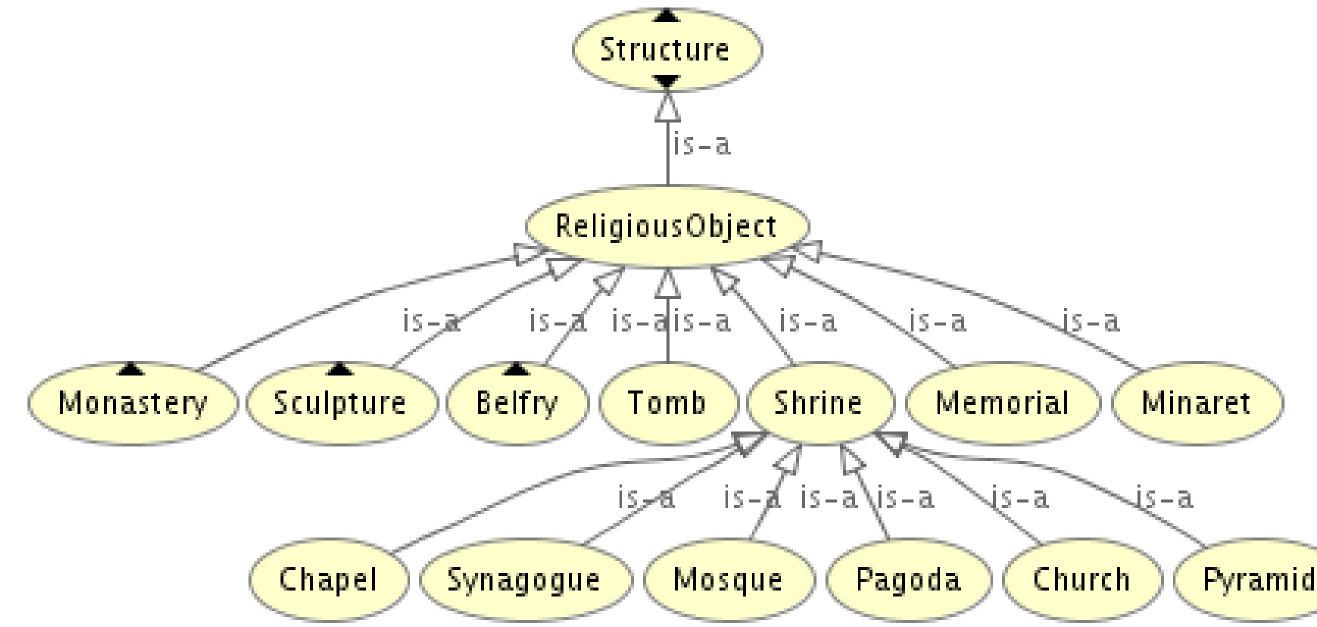


Figure 7.2.2 Structure subhierarchies of various types of religious objects and their subtypes. Source: J. Valach

briefly explained later in this section.

The dominant class of the hierarchy is the Structure class. Each instance (individual, set element) of this class represents a particular structure (e.g. Charles Bridge in Prague), or a complex object (e.g. an airport) that involves many structures (e.g. administrative buildings, runway, etc.) Structure attributes describe the location of the structure, its vulnerability and exposure to floods, the materials it was built from and other characteristics. Each structure can have assigned one or more Events - either failures (e.g. "Salination of building material") occurring to the building, or measure applications (e.g. "Maintenance") performed to fix a failure. In fact, each Failure instance integrates one or more failure Manifestations that occur with respect to the same factors (e.g. "A flood can cause a partial collapse of some walls of a structure, as well as the occurrence of moisture stains afterwards"). Each failure manifestation is connected to a Component (e.g. "foundations, wall") that was affected by the failure. A component can bear information about the Material it was built from.

Many of the shown classes are natural roots of rich specialization hierarchies, namely structure types, components, materials, measure applications and factors. Due to their size (most hierarchies contain tens to hundreds of classes), let us sketch just an example of them. Fig. 7.2.2. shows a structure sub-hierarchy of various types of religious objects and their subtypes. These hierarchies are beneficial for failure reporters both (i) when reporting a failure – to specify their experience to different levels of accuracy (e.g. either Pyramid or Shrine can be used to specify a part that is affected by a failure), and ii) when exploring the knowledge base – to specify their query to different levels of accuracy (e.g. one can query the knowledge base to get typical damages that affect pyramids, or shrines in general.)

7.2.4 Information system

Implementation of the information system

The information system is built on the Java EE platform, deployed on the Glassfish application server v2. The back-end of the system is the OWL ontology described above. The knowledge base can be accessed through a web interface (optimized for Mozilla Firefox v.3.5.6) available at http://www.itam.cas.cz/strufail. All libraries used by the system are licensed under some type of open-source licence.

Figure 7.2.3: Basic user interaction including exploration of damaged structures (menu Structures), their attributes, location on Google Maps and assigned failures. Source: J. Valach.

Usage of the basic system

The web interface allows users both (i) to report new failures, and (ii) to search various types of information about known failure cases. The basic user interaction scenarios involve exploration of damaged structures (menu Structures), their attributes, location on Google Maps and assigned failures, as shown in Fig. 7.2.3. In a similar manner, a list of failure details for a structure can be visualized by selecting one of the failure descriptions in the structure detail screen, or by choosing Failures in the menu.

The data protection policy is similar to the wiki technologies policy (e.g. for Wikipedia). This means that the system is open to the general public for viewing/exploring known cases. Registration to the system is required for failure case reporters, in order to ensure validity and consistency of the data, and to avoid misuse of the system. Registration enables users to refine cases reported by others, e.g. to clean up the terminology.

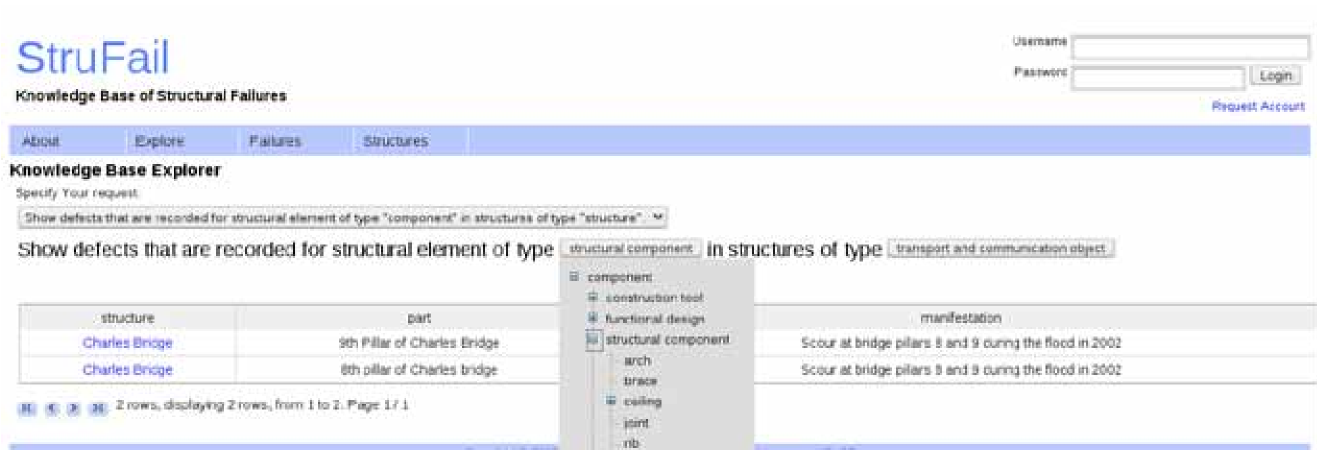


Figure 7.2.4 Exploration of the knowledge base by predefined queries. Source: J. Valach.

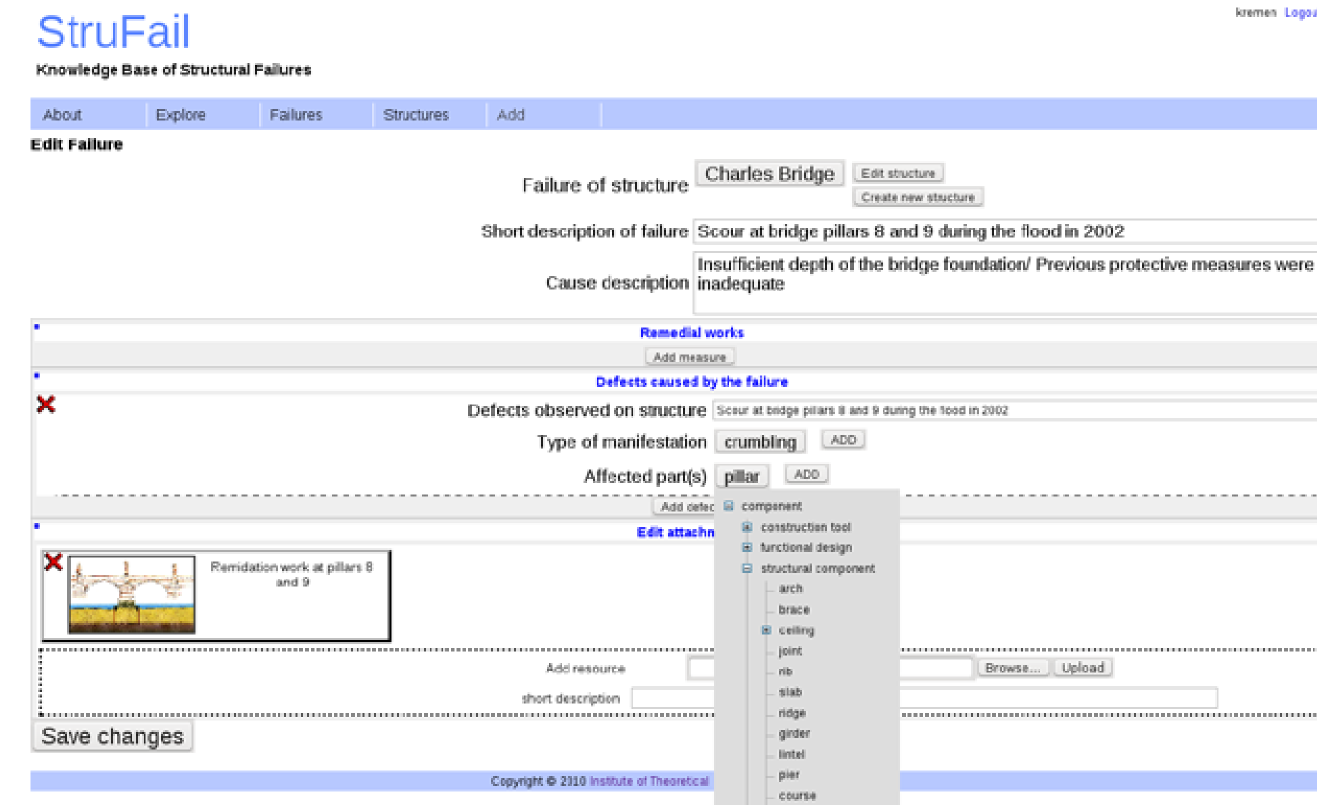


Figure 7.2.5 Failure report. Source: J. Valach.

Exploration of known failure cases

The system allows several predefined queries to be posed to the knowledge base (menu Explore). All queries can be parameterized using predefined categories from particular class hierarchies, as in the case of failure reporting described below. This enables both general and specific queries to be posed, covering a large range of user requirements. An example query is shown (together with its results) in Figure 7.2.4. This query retrieves all manifestations of failures that occur on a specified component (e.g. "structural component" in this case) of a specified structure (e.g. "transport and communication object" in this case). The query result is a table, each row of which displays one particular manifestation of one particular component of one particular structure.

Failure case reporting

A failure reporter can publish his/her failure case in any of the following three ways:

(i) (*preferred*) by directly filling the online input forms using the web application, as described below, or

(ii) (*less preferred*) by filling the forms provided in separate files (the input form is included in the following paragraph 7.2.6 and an explanation of form fields is included in paragraph 7.2.6). The main reason is that data collection can be carried out in the field, on site, where direct access to the Internet is not available. When the form has been filled, the user sends it to the database administrator who ensures that it is included in the knowledge base, or

(iii) (*least preferred*) by providing unstructured failure case documents (a research report, a journal paper, laboratory records) to the knowledge base administrator.

Upon registration, a new user is verified by the database administrator and is given authorization to add new failure cases to the knowledge base. New failures can be reported after logging into the web application using the menu "Failure -Add Failure" (see an example of a completed failure report form in Fig. 7.2.5). When filling in a failure report, special attention should be paid to the categorization of measures, manifestations and affected parts. The reporter is encouraged to classify these attributes to predefined categories (e.g. "pillar" as a sub type of a component, as shown in Fig. 7.2.5). These categories can be chosen from class hierarchies that correspond to the inferred taxonomies for the respective element (component, structure, manifestation type, etc.), see section 7.2.3. Both structures and failures can be supplemented with photos/ other related resources, e.g. documents, measurement reports, etc.

7.2.5 Future Work and Conclusions

The system described here is in its early stages. There are basically two ways of future development: (i) enhancements to the functionality of the information system, (ii) populating the knowledge base with new failure cases.

As far as enhancing the functionality is concerned, the current version of the system covers the whole scenario for failure reporting and exploration. We have focused on the main functionality - failure and object adding/editing, knowledge-based exploration - and have tried to provide failure reporters with some advanced options, e.g. term taxonomies. However, there are many more ideas that are planned to be integrated into the system in the near future. They involve structural failure domain ontology refinement based on expert knowledge and user feedback, and also the development of advanced search options. These advanced search options include full-text search capability, as well as the definition of more predefined query types and even a graphical query editor to allow the creation of arbitrary user-defined queries.

As concerns the user interface, forms fields will soon be equipped with detailed tooltip/popup explanations and with the possibility to add comments on failure cases, thus enabling registered users to engage in in-depth discussion and exchange of experience.

7.2.6 Input form for a failure case (damage description)

CHEF Damage catalogue fill-in form

Reporter

Sex:	M/F
Title:	
Name:	
Middle:	
Surname:	
Affiliation:	
Affiliation address:	
Email:	
Phone:	

Object

* Name:	
* Address - country:	
Address - city:	
Address – street & number:	
Coordinates - longitude (east = positive values, west = negative values):	
Coordinates - latitude (north = positive values, south = negative values):	
Coordinates - altitude (metres above sea level):	
* Type:	
List number:	
Description:	
History age of the object:	
History of changes:	
Object usage:	
Structural system:	
Material:	

Object vulnerability to flood effects

[check the box where appropriate]

Top of Form

Vulnerability type	Reporter	
F0 Flood resistant structures		
F1 Structures made from materials with a high moisture volumetric change		
F2 Structures made from materials with strength highly degradable due to moisture		
F3 Structures susceptible to partial damage due to flood		
F4 Structures and elements vulnerable to overall collapse or displacement due to flood		

Exposure of cultural heritage objects to flood actions

[check the box where appropriate, replicate the row of case "O" if needed and specify in detail]

	Flood action	Reporter	
A	horizontal static pressure of raised water	□	
B	upward hydrostatic pressure	□	
C	dynamic low velocity stream action	□	
D	dynamic high velocity stream action	□	
E	dynamic impact of waves	□	
F	dynamic impact of floating objects	□	
G	compacting of soils or infill	□	
H	change in subsoil conditions	□	
I	saturation of materials with water	□	
J	contamination of materials with chemical and biological pollution	□	
K	creation of barriers	□	
L	soiling of cultural heritage objects	□	
M	displacement of objects	□	
N	post-flood drying effects	□	
O	other	□	

Failure

[replicate table when needed]

* Description of failure:	
Structural system:	
History of failure occurrence data:	
Failure manifestation:	
Analysis:	
Remedial works:	
Prevention:	
Cause of failure:	
Failure impacts:	
Part:	

7.2.7 Meaning of the form fields

Table object

Field	Meaning
Object – type	One of the predefined list of object types has to be chosen, or a new type can be defined in the adjacent text field
Reporter	Name of reporter is added automatically using login data
Name	Name of the object
Address – {country, city, street}	Address of the object
Coordinates {latitude/longitude}	Global (preferably WGS 84) coordinates of the object (the coordinates can be entered in degrees and fractions of degrees, or in the whole degrees and minutes and fractions of minutes, or in whole degrees and minutes and seconds and fractions of seconds)
List number.	Applicable for an object listed in the cultural heritage monuments list. Combination of country identifier (CZ – Czech Republic, D – Germany, etc.) and identifier from the list. For example: the St. Maria statue in Jihlava, Czech Republic has the code: CZ-31274 / 7-4889 If not known, leave blank. If not in the list, write: "Not listed."
Description	Overall description of the form and appearance of the object
Historical period	Historical period, architectural style of the core part of the object
History of changes	Main events in object's history: re-building, additions, damage incurred in past, changes in use of the object, etc.
Object usage	Current use of the object
Structural system	Description of the construction of the object e.g. type of brick binding, roof structure
Material	Details on used materials – stone, masonry, bricks, wood, etc.

Failure Table

Field	Meaning
Failure – general factors	List of main failure keywords used for failure description. Used in order to make the records from various reporters consistent and as uniform as possible. Planned for targeted database queries.
Reporter	Name and affiliation of person adding the record (the person who turned the raw data into meaningful information, not necessarily the person who acquired the data or who is typing in the record)
Object	Link to object record summary display
Description of failure	Description of failure
Structural system	Field describing the materials and parts affected by failure
Failure manifestation	Altered appearance, behavior, properties of (a part of the) object due to failure
Analysis	An explanation of why failure occurred, type of measurement used, what data has been collected, etc.
Remedial work	Work carried out to mitigate the failure, to restore the original function of the object, or to slow down decay or destruction
Prevention	A list of measures to eliminate future occurrence of failure, or measures that, if applied beforehand, would have prevented the present failure.
Cause of failure	Physical/chemical/mechanical explanation of events/processes/circumstances leading to the failure
Failure impact	How the failure changes the function of the object
History of failure occurrence	First records of the failure – its progression, extension, reappearance after remedial work, etc.
Part	Part of the structure in which the failure is located
Keywords	Selection of the most suitable keywords from the list, adding new words – describing failure, material, prevention measures, etc.
Causes	Selection from the catalogued list of failures.
Terminology	An explanation of specialized terms in words understandable to non-specialized professionals, and commercial product names in generic names of compounds
Attachments	Annotated images, plots, tables, reports and other useful information that is provided.

Terminology Table

Field	Meaning
New term	A notion used in fields describing the object or failure, e.g. a specialized name for a particular structural part, procedure or commercial trademark.
Definition	A new term explained in generally understandable words, in the case of trademarked substances or devices explained in generic names of substances or processes
Reference	A citation, a link provided for further information on the subject

7.2.8 Illustrative database outputs on failures of immovable cultural heritage

Unexpected cases – Floods

FAILURE - general factor – Failure of a wooden joist ceiling structure
Reporter – M. Drdácký, ITAM CAS

Description of the failure – manifestation features
Broken timber joists, complete failure of a ceiling with reed rendering

Description of the object/building - structure: Identification - name, place – Material – Structural system (dimensions)
Praha 7, Troja, Povltavská Street. - Single storey house with stone walls and timber joist (approx. 22 cm by 24 cm) ceilings, spanning max 5 metres, with debris infill, reed boarded bottom ceiling surface. Severe timber deterioration caused by insects.

Exposition: use, position, environment
Housing located on the bank of a branch of the river Vltava which was later filled in.

History: age of the object, changes, failure occurrence data
House from the end of the 18th Century, a listed and protected cultural monument, used for housing, attic used only for storage of old objects and hay, failure occurred during the flood in Prague 2002

Graphic documentation:

Cause of failure:
Long term immersion in floodwater, which covered the roof ridge and saturated the debris ceiling infill, overloading the structure with deteriorated and weakened timber joists – caused by ligniperdous insects.

Important parameters for the failure analysis:
Flood data, material characteristics of timber, structural dimensions and loads, moisture of timber.

Remedial works:
During the flood the masonry with only clay mortar, without any lime binder or cement, was partially destroyed, and its stability was substantially reduced. Therefore the authorities agreed for the whole building to be demolished and replaced by a reconstruction.

Prevention:
Special maintenance reducing overloading risks (attic and infill materials with low saturation) and water degradation effects, clay mortar stabilisation and consolidation, temporary strengthening of ceiling joists.

7.3 Effects of flooding on material behaviour

Heiner Siedel, Zuzana Slížková, Mateja Golež

7.3.1 Material parameters

The tables below present the changes in the physical parameters of commonly-used natural stones and other building materials due to water saturation.

Comments to Tables 7.3.1.1 and 7.3.1.2 (Heiner Siedel)

The material data was compiled from the literature and produced in the laboratory in the course of the CHEF project. More details and data sources can be found in deliverable D2.2 of the CHEF Report.

The vulnerability assessment of the materials ("minor, moderate or major change") is mainly based on Hawkins & McConnell (1992) for strength, and on experience from research on the weathering of natural stone for hydric dilatation. The database in this field is smaller, and the vulnerability categories established for natural stone have been applied to other mineral construction materials, e.g. bricks and mortars. A combined discussion of the relevant material changes due to water saturation have led to a more general assessment of the vulnerability of mineral materials, as displayed in Table 7.3.1.3.

The vulnerability categories presented here should not be treated schematically. They are suggested in order to give the end-users a preliminary, rough idea about the vulnerability of the construction or sculpturing materials that their objects are made of. Appropriate decisions immediately before, during and after a flood event have to take into account the material behaviour and vulnerability of immovable cultural heritage . The vulnerability categories established here may provide scientifically-based arguments for decision-makers to take additional measures for certain objects, in order to give the greatest possible protection against direct contact with water.

Table 7.3.1.1: Range of strength reduction and hydric dilatation due to water saturation for various widely-used kinds of building and sculptural stones. Strength reduction of UCS = Uniaxial Compressive Strength and TS = Tensile Strength of water-saturated material in relation to the air dry material (= 100 %), see next page.

Type of building stone or sculptural stone	Strength reduction due to water saturation (UCS) by [%]	Strength reduction due to water saturation (TS) by [%]	Hydric dilatation [mm/m] due to water saturation	Notes
Metamorphic rocks				
Gneiss	no data available	no data available	0.06	Dense structure; total porosity (< 1 vol.-% in most cases) and water uptake low.
Quartzite	no data available	no data available	0 - 0.01	
Serpentinite	no data available	no data available	0	
Marble	4 - 12	no data available	< 0.01 - 0.08	
Igneous rocks (plutonic and volcanic origin)				
Granite	2 - 16	no data available	0.01 - 0.18	Dense structure; total porosity and water uptake low (exception: porous lava).
Porphyry, Basalt	5 - 8	no data available	0.03 - 0.35	
Pyroclastic rocks (tuff)				
Rhyolithe tuff	12 - 84	7 - 41	0.54 - 2.8	High porosity and water uptake; partly swelling clay minerals in the matrix.
Basalt tuff	40	no data available	no data available	
Sedimentary rocks				
Limestone	0 - 21	0 - 30	0.02 - 0.60	Porosity up to 30 vol.-%
Sandstone (quartz arenite)	1 - 22	18 - 20	0.05 - 0.20	High quartz content, poor in clay minerals; porosity 8 - 26 vol.-%
Matrix-rich sandstone	27 - 50, in individual cases even more!	60	0.4 - 3.0	Moderate quartz content; high clay content partly containing swelling clay minerals

Legend:

(yellow)	Minor change	loss of UCS / TS < 25 %	Hydric dilatation is low: < 0.5 mm/m
(orange)	Moderate change	loss of UCS / TS between 25 and 40 %	Hydric dilatation is moderate: > 0.5 - 1 mm/m
(red)	Major change	loss of UCS / TS > 40%	Hydric dilatation is high to very high: > 1 mm/m

Table 7.3.1.2: Range of strength reduction and hydric dilatation due to water saturation for various widely-used kinds of mineral construction materials. Strength reduction of UCS = Uniaxial Compressive Strength and TS = Tensile Strength of water saturated material in relation to the air dry material (= 100 %).

Type of construction material	Strength reduction due to water saturation (UCS) by [%]	Strength reduction due to water saturation (TS) by [%]	Hydric dilatation [mm/m] due to water saturation	Notes
Mortars				
Lime mortar	41 - 45	17 - 25	0.7	
Pozzolanic mortar	25	33	0.11 - 0.22	
Portland cement mortars	no data available	no data available	0.20 - 0.43	
Gypsum (paste)	76	69	no data available	High creep rates when saturated with water!
Adobe				
Adobe	Reduction to 0, total damage to specimens!		High to very high*	* dependent on kind of clay minerals.
Brick				
Industrial clay brick	44	13	0.06 - 0.08	
Historic bricks	no data available	no data available	0.4 - 3.6*	* dependent on burning conditions

Legend:

Yellow	Minor change	loss of UCS / TS < 25 %	Hydric dilatation is low: < 0.5 mm/m
Orange	Moderate change	loss of UCS / TS between 25 and 40 %	Hydric dilatation is moderate: > 0.5 - 1 mm/m
Red	Major change	loss of UCS / TS > 40%	Hydric dilatation is high to very high: > 1 mm/m

Table 7.3.1.3 Vulnerability of mineral construction materials to flooding, according to their physical changes.

Vulnerability category	Reduction in strength due to water uptake	Hydric swelling	Examples
1 (highly vulnerable)	Very high to high	Very high to high	Adobe, gypsum mortar, some clay-bearing sandstones and tuffs.
2 (moderately vulnerable)	Moderate (or high if hydric swelling is moderate)	Moderate (or high if reduction in strength by water uptake is moderate)	Many types of sandstone, clay-bearing limestones, some types of volcanic rocks, lime mortar.
3 (not vulnerable)	Low (or moderate if hydric swelling is low)	Low (or moderate if reduction in strength due to water uptake is low)	Most crystalline magmatic or metamorphic rocks, e.g. granites, gabbros, porphyries, gneisses, and marbles. Purely silica-bound sandstones.

7.3.2 Laboratory tests on typical historic materials

Influence of waterlogging and water soluble salts

Selected building materials were subjected to the action of three different water and salt attack situations which could happen during flooding:

Effect of atmospheric moisture

Specimens of building materials were stored for 90 days in a climatic chamber at 99 % relative humidity and at a temperature of 20±2 °C. This represent the waterlogging of building materials through sorption of atmospheric humidity, which is very high during floods. According to the water sorption ability of the material, the amount of water absorbed during the test varies greatly (see Table 7.3.2.1).

Effect of a short-term attack by liquid water

Specimens of building materials were fully immersed in water for 1 minute. After that, the specimens were wrapped in foil to prevent water evaporation and they were then stored in laboratory conditions till testing. The amount of water absorbed by the specimens was evaluated gravimetrically before the beginning of mechanical tests, and the results are presented in Table 7.3.2.1. The rate of wetting depends in particular on the porous system of the material (pore size, connection between pores, etc.) and also on the surface tension between the water and the material.

Effect of a long-term attack by liquid water

Specimens of building materials were fully immersed in water for 1 week. The specimens were wrapped in foil to prevent water evaporation, and were then stored in laboratory condition. The amount of water absorbed by the specimens was evaluated gravimetrically before performing the mechanical tests. The results are listed in Table 7.3.2.1. The degree of wetting is influenced in particular by the total porosity of the material and by the surface tension between the building material and the water.

Table 7.3.2.1 Water content in building materials after various tests.

Type of building material	Average water content in specimens (% wt.)		
	90 days at 99 % RH	1 minute immersion in water	1 week immersion in water
Opuka Marlstone	2,20	2,26	10,05
Hořice Sandstone	0,50	3,13	8,72
Jura gelb Limestone	0,17	0,24	1,30
Pozzolanic mortar	2,01	9,56	18,39
Lime mortar	2,62	9,09	18,37
Burnt brick	2,58	4,80	16,53
Adobe – unburnt clay	4,62	0,65	destruction

Tab 7.3.2.2 Changes in the mechanical properties of building materials due to exposition in an environment with high relative humidity (T = 20 ± 2 °C, RH 99 %, 90 days).

	Change in average strength		Change in average dynamic modulus of elasticity		Change in avg. static mod. of elasticity
	tension	compression	ultrasonic m.	resonance m.	
Limestone, compact	- 6 %	- 21 %	- 1 %	- 3 %	- 1 %
Marlstone "opuka" porous	- 33 %	- 17 %	- 7 %	- 7 %	- 10 %
Sandstone, porous	- 11 %	+ 2 %	- 3 %	- 14 %	- 8 %
Burnt clay brick	0 %	- 23 %	+ 3 %	+ 6 %	+ 10 %
Adobe - unburnt clay	- 64 %	- 52 %	- 26 %	- 60 %	- 60 %
Pozzolanic mortar	- 17 %	- 8 %	+ 3 %	+ 11 %	+ 9 %
Lime mortar	- 33 %	- 60 %	+ 4 %	- 1 %	+ 29 %

Table 7.3.2.3: Changes in the mechanical properties of building materials due to exposition in water (specimens immersed in water for 1 minute).

	Change in average strength		Change in average dynamic modulus of elasticity		Change in avg. static mod. of elasticity
	tension	compression	ultrasonic m.	resonance m.	
Limestone, compact	- 20 %	- 34 %	+ 3 %	- 8 %	- 4 %
Marlstone "opuka" porous	- 15 %	- 7 %	+ 15 %	- 14 %	- 12 %
Sandstone, porous	- 9 %	+ 20 %	+ 4 %	- 27 %	- 33 %
Burnt clay brick	+ 22 %	- 11 %	+ 78 %	- 10 %	- 6 %
Adobe - unburnt clay	- 65 %	- 27 %	+ 21 %	- 27 %	- 40 %
Pozzolanic mortar	- 44 %	- 34 %	- 12 %	- 10 %	- 17 %
Lime mortar	0 %	- 25 %	+ 132 %	+ 47 %	- 4 %

Tab 7.3.2.4 Changes in the mechanical properties of building materials due to exposition in water (specimens immersed in water for 1 week).

	Change in average strength		Change in average dynamic modulus of elasticity		Change in avg. static mod. of elasticity
	tension	compression	ultrasonic m.	resonance m.	
Limestone, compact	- 14 %	- 31 %	+ 2 %	- 11 %	- 14 %
Marlstone "opuka" porous	- 23 %	- 20 %	- 4 %	- 19 %	- 28 %
Sandstone, porous	- 16 %	+ 10 %	- 4 %	- 22 %	- 42 %
Burnt clay brick	- 13 %	- 44 %	+ 62 %	- 12 %	- 31 %
Adobe - unburnt clay	total damage – destruction of specimens				
Pozzolanic mortar	- 33 %	- 25 %	- 22 %	- 5 %	- 12 %
Lime mortar	- 17 %	- 45 %	+ 90 %	+ 23 %	- 20 %

Tab 7.3.2.5 Changes in the mechanical properties of building materials due to exposition in an NaCl solution (specimens immersed in an NaCl solution for 1 week and then dried at 40°C).

	Change in average strength		Change in average dynamic modulus of elasticity		Change in avg. static mod. of elasticity
	tension	compression	ultrasonic m.	resonance m.	
Limestone, compact	0 %	- 3 %	- 1 %	0 %	- 8 %
Marlstone "opuka" porous	- 18 %	- 23 %	- 14 %	- 12 %	- 13 %
Sandstone, porous	- 9 %	+ 19 %	0 %	+ 3 %	+ 38 %
Burnt clay brick	- 4 %	- 24 %	- 7 %	+ 12 %	+ 12 %
Adobe - unburnt clay	total damage – destruction of specimens				
Pozzolanic mortar	+ 33 %	+ 5 %	- 15 %	+ 24 %	+ 40 %
Lime mortar	+ 117 %	+ 15 %	- 4 %	+ 139 %	+ 104 %

Tab 7.3.2.6 Changes in the mechanical properties of building materials due to exposition in an Na2SO4 solution (specimens immersed for 1 week in an Na2SO4 sol. and then dried at 40°C).

	Change in average strength		Change in average dynamic modulus of elasticity		Change in avg. static mod. of elasticity
	tension	compression	ultrasonic m.	resonance m.	
Limestone, compact	- 1 %	- 14 %	0 %	- 2 %	- 10 %
Marlstone "opuka" porous	+ 17 %	+ 11 %	+ 13 %	+ 13 %	+ 24 %
Sandstone, porous	+ 15 %	+ 15 %	- 11 %	+ 5 %	+ 26 %
Burnt clay brick	- 57 %	- 47 %	- 69 %	- 42 %	- 14 %
Adobe - unburnt clay	total damage – destruction of specimens				
Pozzolanic mortar	total damage – destruction of specimens				
Lime mortar	total damage – destruction of specimens				

Tab 7.3.2.7 Changes in the mechanical properties of building materials due to exposition in a KNO3 solution (specimens immersed for 1 week in a KNO3 sol. and then dried at 40°C).

	Change in average strength		Change in average dynamic modulus of elasticity		Change in avg. static mod. of elasticity
	tension	compression	ultrasonic m.	resonance m.	
Limestone, compact	+ 9 %	- 4 %	0 %	- 3 %	- 3 %
Marlstone "opuka" porous	+ 2 %	+ 9 %	+ 20 %	+ 9 %	0 %
Sandstone, porous	+ 7 %	+ 32 %	+ 30% %	+ 19 %	+ 12 %
Burnt clay brick	+ 48 %	+ 7 %	+ 13 % %	+ 32 % %	+ 43 %
Adobe - unburnt clay	total damage – destruction of specimens				
Pozzolanic mortar	+ 6 %	+ 36 %	- 17 %	+ 7 %	+ 27 %
Lime mortar	+ 150 %	+ 35 %	+ 166 %	+ 25 %	+ 89 %

7.4 Non-destructive methods for assessing moisture in masonry

Sabine Kruschwitz, Rosemarie Helmerich

Influence of water-soluble salts

Specimens were immersed in saturated solutions of NaCl, Na2SO4 and KNO3 for 1 week. Then they were stored to dry out at 50°C. The age of the mortar and adobe specimens was 90 days before salt treatment and 150 days before testing. As a result of the drying process, huge efflorescence appeared on the surface of the specimens.

A range of minor-destructive and non-destructive testing methods are available today for assessing water damages. Some of them yield qualitative results, while others also provide quantitative results requiring no calibration or only a simple form of calibration. CHEF deliverable D 3.3 outlines the advantages and limitations of all these techniques. Table 1 presents a summary of what have generally been regarded as useful tools. The authors consider these the most reliable and most widely-applied types of sensors. However, there are certainly many more moisture probes on the market and no claim is made for the completeness of this list.

Table 7.4.1: Qualitative and quantitative methods for assessing water damages.

Quantitative minor-destructive techniques	Quantitative non-destructive techniques	Qualitative non-destructive techniques
• **Powder (or Core) Drilling Test** • **Calcium Carbide Method**	• **Nuclear Magnetic Resonance** • **Complex Resistivity** • **Microwave Borehole Method** • **Time Domain Reflectometry**	• **Thermography** • **Ground Penetrating Radar** • **Sonic Pulse Velocity Test** • **Ultrasonic Test** • **Fibre Optic Relative Humidity Sensor**

The only two methods that are always fully reliable are the minor-destructive powder (or core) drilling test and the calcium carbide method. Both are based on an analysis of material samples and provide very accurate point information. All the other methods are indirect, and obtain information on water content indirectly via physical properties such as electrical resistivity, dielectric properties, thermal conduction or the acoustic behavior of the material. None of the indirect methods have yet proven to be as accurate as the minor-destructive tests.

The great benefit of non-destructive methods is that they can be applied repeatedly, and drying processes can be monitored on a regular basis. One group of NDTs, including nuclear magnetic resonance, complex resistivity, the microwave borehole method, surface microwave moisture probes and time domain reflectometry, has also proven to yield useful quantitative data, when relatively simple calibration measurements can be carried out. Another group, including thermography, ground penetrating radar, the sonic pulse velocity test and also the ultrasonic test, is more suited for entirely qualitative moisture assessments, since they are very cumbersome or almost impossible to calibrate.

Fibre optic relative humidity sensors work on the basis of polymer-coated Fibre Bragg Grating (FBG). FBG can be used to get early warning information about relative humidity during a long-term survey of critical infrastructure. These sensors have a potential for continuous monitoring, as needed e.g. for Structural Health Monitoring applications, as reported by Venugopalan (2010).

7.4.1 Quantitative minor-destructive methods

Powder/core drilling: Despite the fact that they are minor destructive, powder or core drilling tests are certainly the tools of choice because of their accuracy and reliability. Boreholes of small diameter in the range of 10-50 mm are driven into the object under test, and either the core or the drilling powder is collected for analysis. The weight of the samples (including dry matrix and water) has to be recorded as soon as they are extracted. After Darr-drying them at 105 degC until weight stability the samples must be weighed again and the mass difference is the water content (see also Section 7.4.4).

Calcium carbide test: A second very well established way of moisture testing is the calcium carbide method. It is likewise minor-destructive. A small sample of the object under test has to be chipped off and analysed using a chemical kit that can easily be carried around. Depending on the water content of the sample, it will react with the chemical agents to a lesser or greater extent, building up a pressure in the test bottle that can be measured with a manometer and translated into a water content using a calibration curve.

7.4.2 Quantitative non-destructive techniques

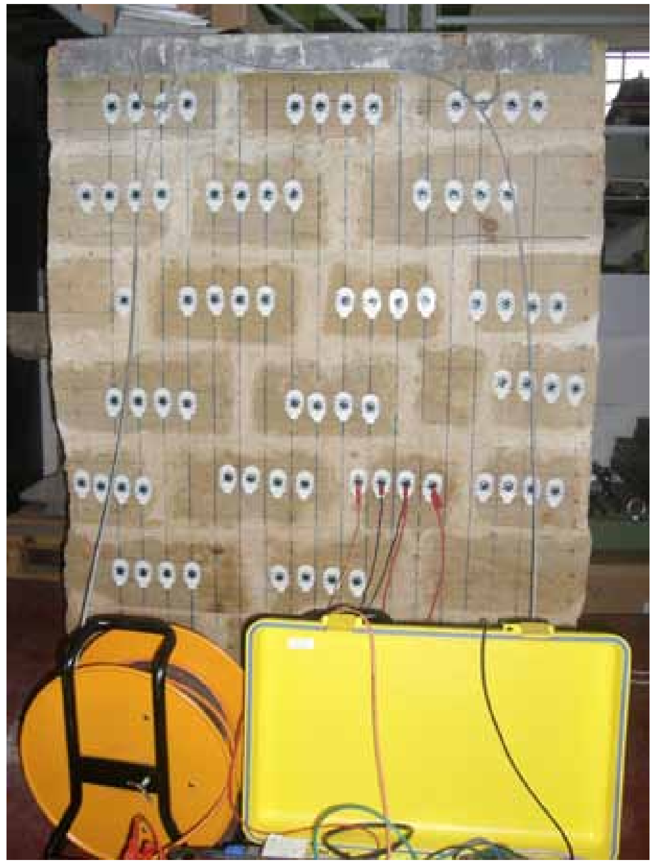
Three experimental research campaigns carried out on the Obelix masonry specimen (BAM, Berlin) on three laboratory scale testing walls (ITAM, Prague) and also on full-scale brick models (POLIMI, Milano) have provided deeper insight into the characteristics of any moisture measurement methods. One finding is surely that a new assessment strategy has to be developed for each test object, depending on its building material, thickness, expected moisture content, etc. For very inhomogeneous masonry, electrical measurements and electrode setups have to be designed entirely differently than for homogeneous materials. In order to make a quantitative assessment, calibration data is needed, and this data has to be collected separately in the lab on small samples. Microwave-based surface sensors usually also need calibration, though the pre-stored data may sometimes suffice. The best way to is certainly to combine as many techniques as possible, ideally before, during and after the flood, and to compare the results to reduce the risk of misinterpretations.

Complex resistivity: The specific electrical properties of a material depend on a variety of textural and chemical characteristics. The most prominent among these are the effective porosity, the degree of saturation and the salinity of the pore fluid. For this reason, it is usually extremely difficult to interpret DC-resistivity measurements if no a-priori information about water content or fluid salinity is available. The effect of fluid chemistry and degree of saturation on the complex electrical behaviour of porous building materials has recently been researched and discussed in great detail by Kruschwitz (2008).

The resistivity magnitudes are usually are recorded relative to a reference resistor (shunt) upon stimulus with a direct or alternating current. If alternating currents are used, the frequency range is typically from 1 kHz to 1 mHz. This is referred to as Spectral Induced Polarization or Complex Resistivity. The application of this device is shown in Fig. 7.4.2.1 (left). For data analysis, it is also possible to use electrical conductivity, which is the reciprocal value of electrical resistivity.

If calibration data cannot be collected, only a qualitative moisture assessment can be made, assuming that the pore fluid is homogeneous throughout the investigated area. An example is presented in Fig. 7.4.2.1 (right). However, calibration data can be obtained fairly quickly in the laboratory, and can be used to relate electrical resistivity values to degrees of saturation, allowing a quantitative interpretation. For the data to be accurate, it is necessary to ensure not only that samples of the same (homogeneous) material are used, but also that the same saturating fluid is used.

Misinterpretations can occur all too easily if no calibration measurements are available. Samples poorly saturated with very saline brine can have very similar electrical properties to highly saturated samples with a low saline fluid. However, systematic laboratory studies have indicated that the ambiguity of resistivity amplitude measurements (direct-current or real part) can be overcome if also the imaginary part of the resistivity is measured, as in the case of Spectral Induced Polarisation measurements.



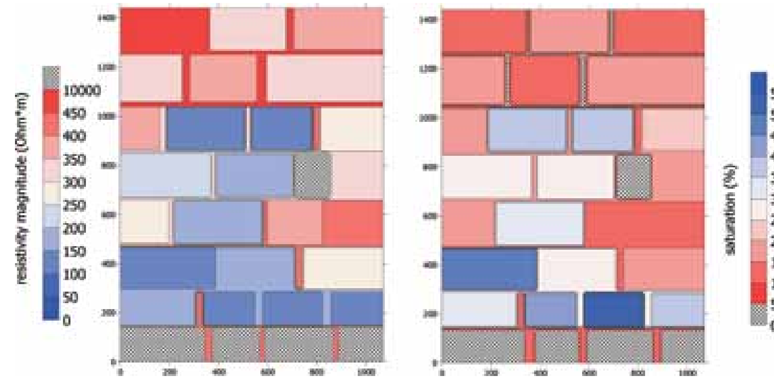
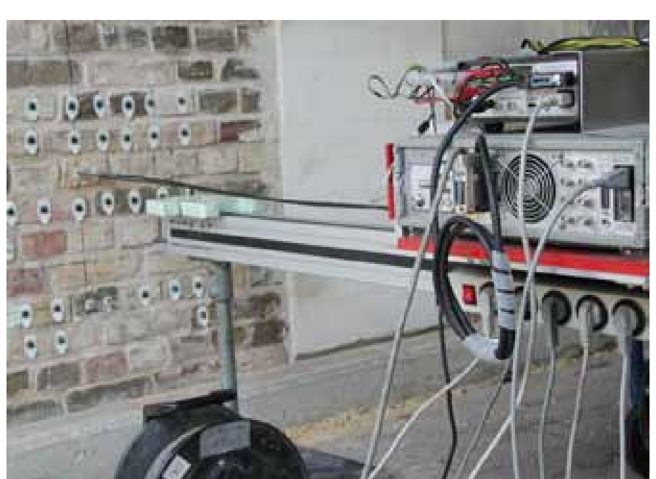


Figure 7.4.2.1: Field size CR measurements on a sandstone testing wall (left). Ordinary medical ECG electrodes are used. This picture shows a four-point Wenner setup. The water distribution was investigated after the wall was flooded for about a week. The results of Wenner (a = 5 cm) measurements of electrical resistivity obtained on single stones are shown on the right. Source: BAM.

It has been observed that these are also sensitive to textural properties, e.g. the specific surface or dominant pore throat size of a material (Kruschwitz, 2008).

Microwave borehole method: To obtain information about the moisture distribution along the cross section of a wall that is homogeneous in terms of material, a microwave borehole system is used at BAM for measuring the absorption of continuous microwaves between two parallel boreholes (Kääriäinen et al. 2001). This method requires two thin boreholes 12 mm in diameter and a distance of about 50 mm apart. This method is therefore only quasi non-destructive. The holes have to be drilled with great precision, and can reach depths of up to 2 m. A step motor controlled stage moves the antennas from the deepest position to the wall surface and conducts a measurement every 10 mm. A continuous signal of defined power is sent by the transmitting antenna, while the receiving antenna measures the transmitted power. The real and imaginary parts of the complex permittivity are calculated from the absorption of continuous microwaves between the two antennas at each antenna position, with the use of optical approximations. Since the absorption depends on the frequency of the continuous microwaves, a measurement cycle comprises 6 measurements in 400 MHz



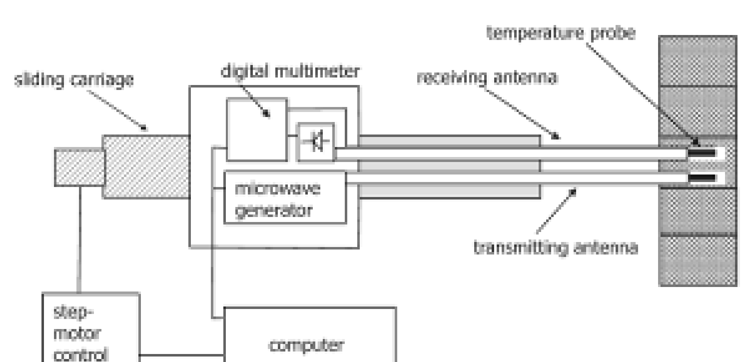


Figure 7.4.2.2: Left: Schematic presentation of the microwave borehole system (. Right: photograph of the microwave borehole transmission technique applied to a masonry specimen. Source: BAM.

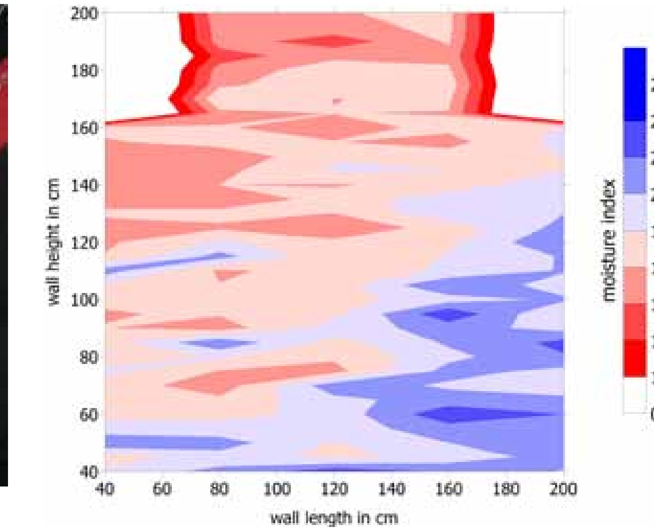


Figure 7.4.2.3: Left: Photograph of the microwave surface sensor being applied to a masonry specimen. Right: Results in terms of the moisture index obtained on a wet basement wall. The source of the water is located in the lower right corner. Source: BAM.

steps, in the range of either 6 to 8 GHz or 8 to 10 GHz to select the optimum dynamic range. Simultaneously, temperature measurements are performed. A photograph of the experimental setup is shown in Fig. 7.4.2.2.

Microwave surface sensor: Microwave methods are based on experimental determination of the dielectric properties of materials. For microwave surface sensors, the wavelength of electromagnetic waves in the frequency range from 2-10 GHz is so small that antennas of quite easily usable sizes can be built. Because of the directivity of the antennas, penetration depths between 2 cm and 30 cm can be achieved.

These probes have to be calibrated for each material. Some "general" calibration curves (e.g. for brick, sandstone and mortar) are often stored in the measurement devices. However, as these were determined on stone samples, they will very likely not reflect the appropriate properties for the particular application in every case. With the pre-stored calibration data, estimates and qualitative moisture values (in mass per cent) will be obtained, rather than reliable quantitative numbers. How calibration curves are obtained is explained in the literature (i.e. Göller et al.

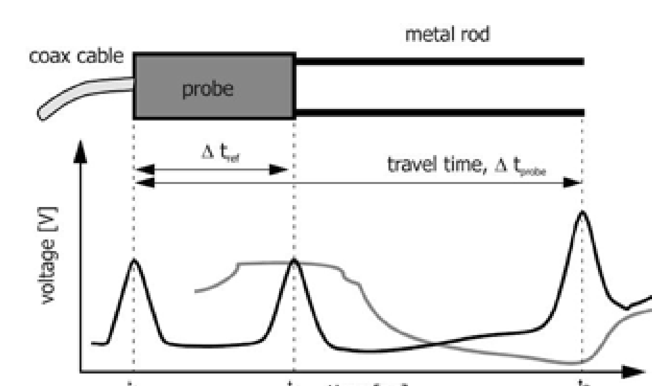


Figure 7.4.2.4: Left: Schematic diagram of a 2-rod probe consisting of two parallel metal rods of defined length. At discontinuities such as the beginning and the end of the metal bars the electromagnetic pulse is reflected. (t0, t1 und t2). The signals are depicted for both a step pulse (grey) and a sine-shaped peak pulse (black). Source: Plagge (2003). Right: Photograph of the TDR technique being applied to a masonry specimen. Source: BAM.

1999a and 1999b). Qualitative moisture assessments can also be made without calibration data. In this case, only so-called “moisture indices” are recorded, which are in many cases sufficient for locating leakages or sources of moisture damages in buildings. Fig. 7.4.2.3 shows a photograph of a microwave surface sensor application on a brick masonry wall (left) and measurement results obtained on a wet basement wall, where the pre-stored calibration data for brick was not used and only the moisture index is displayed.

Time domain reflectometry (TDR): Time domain reflectometry is a minor-destructive method for determining moisture content via dielectric properties. It is based on travel-time measurement of an electromagnetic wave travelling along two thin metal rods placed in a wet material. With increasing moisture content the dielectric constant of the material likewise increases, slowing down the electromagnetic pulse. Some of the energy of the electromagnetic pulse is reflected upon entering and leaving the metal rods, and this can be visualized on the monitor of a sampling oscilloscope. A schematic diagram of the TDR principle is shown in Fig. 7.4.2.4 (left), along with a photograph of measurements being carried out on a masonry specimen (right).

Nuclear magnetic resonance (NMR): This method offers the possibility to determine moisture content quantitatively and non-destructively, and with high spatial resolution. An extensive description of this method is given by (Dixon and Ekstrand 1982), (Kopinga and Pel 1994) and (Pel 1995). To enable quantitative measurements in porous materials, a special apparatus was designed by Kopinga and Pel. For NMR measurements, the magnetic moments of hydrogen nuclei are manipulated by suitably selected alternating radio frequency fields, resulting in a so-called spin-echo signal. The amplitude of this spin-echo signal is proportional to the number of nuclei excited by the radio frequency field. Because of the resonance condition, this method can be made sensitive to hydrogen only, and therefore to water (Dixon and Ekstrand 1982).

7.4.3 Qualitative non-destructive techniques

Thermography and radar have shown very good effectiveness (in terms of time and cost) and sensitivity in detecting the presence of water; while thermography is mostly sensitive to surface variations, and is not affected by processes occurring deeper than 5-6 cm, radar method enables to investigate the full thickness of the sample, and also measures at very high spatial resolution. However, both methods can as yet only be used as qualitative indicators.

Infrared Thermography (IRT): The big advantage of infrared thermography (IRT) is that it can be applied in a fast and accurate, in a time-efficient way, when large areas have to be covered. As in the case of ultrasonic surveys and radar, single-sided access is not an obstacle. In IRT surveys, parts of the structure under investigation are heated up, either actively or passively (explanations will be given below), and the transient heat flux is observed by recording the temperature change at the surface as a function of time. Anomalies such as voids, material changes, differential humidity, etc., can be detected by their different cooling behaviour compared to that of the surrounding material. Information on the depth, lateral size and material of the anomaly can be gained from their particular temperature transient curves. Substantial knowledge has been acquired and comprehensive studies have been conducted on the heating and cooling behaviour of non-metallic materials (Maldague, 1993; Danesi et al., 1998). Infrared thermography can be applied in both reflection and transmission configuration, but the reflection setup, where the heat source and the infrared camera are located on the same side of the test object, is more frequently used (see also Section 7.4.4).

The results of an IRT reflection survey are presented in Fig. 7.4.3.1. The left part of the figure is an ordinary digital photo of a brick section of a masonry specimen, which is partially covered with plaster. The thermogram (Fig. 7.4.3.1 right) was recorded after heating for 5 minutes with an active heat source. The reflection thermogram shows that the water front can be divided into something that looks like a “saturated” horizon and an “unsaturated” horizon. Generally it is easier to work on surfaces that have similar reflection behavior and are homogeneous. Pictures taken on (unplastered) brick masonry, for example, can sometimes be ambiguous to interpret as the indivdual stones often vary in color due to different manufacturing heats. In this case, the heat reflecting characteristics also vary.

Ground penetrating radar (GPR): Ground penetrating radar measurements are high frequency electromagnetic (EM) wave reflection or transmission

Figure 7.4.3.1: Photograph of a brick masonry specimen section partly covered with plaster (left). The specimen is contained in a concrete basin and was flooded with tap water. In the reflection thermogram recorded after 5 min. of heating, two moisture horizons can be clearly differentiated (right). Source: BAM.

surveys. A GPR antenna transmits high-frequency EM waves into the object under test. A portion of the energy is reflected back to the surface from the interface of two adjacent materials (usually layered materials or cavities), after which it is received at the antenna (Fig. 7.4.3.2). Electrical conductivity, as well as the dielectric properties of the material, play a primary role in how a GPR signal will travel through a material. Most directly, electrical conductivity (the inverse of resistivity) affects how well GPR signals can penetrate through a material. Metals cannot be penetrated (even dense wire screens or thin foils are impermeable to GPR); most construction materials (brick, sandstones, concrete, asphalt, etc) are fair to good host materials for GPR. Similarly moisture, particularly when it has an elevated salt content, can also significantly affect a GPR signal. The velocity of propagation is dependent on the dielectric properties of the materials through which the GPR signal passes. The measured time of arrival of each of these signals and their amplitudes are used to measure and estimate (using a calibrated data collection technique) subsurface “target” depths, GPR wave propagation speed, and often the condition of the material.

As the dielectric constant of water is lower than that of dry masonry materials, a high moisture content slows electromagnetic waves down. It also weakens the signal intensity and attenuates the amplitudes. Results obtained on a wet brick masonry basement wall are presented in Fig. 7.4.3.2 (right), (see also Section 7.4.4).

Ultrasonic tests: A number of sensors and sensor arrays for ultrasonic surveys are nowadays available on the market. Sensor units usually consist of several emitting and receiving transducers, all built in the same casing. The emitting transducers generate longitudinal or transversal acoustic waves (ca. 80-500 kHz) into the object under test. These are reflected at the material interfaces and are then recorded by the receiving transducers. When the magnitude of the reflected signal is depicted as a function of travel time, this is referred to as an A-scan. Several adjacent A-scans collected along a profile can be combined into a B-scan with signal amplitudes often plotted color-coded. When the velocity of the material is known, the travel time can be directly converted to the distance the wave has travelled. The better the information that can be gained from the signal forms on the position, orientation and other properties of the reflector, the more transducer-receiver positions cover it.

Some probes need coupling agents such as vaseline. The more recent dry-point contact EyeCon ultrasonic transducer unit (also referred to as A1220 on the European Market, manufacturer Acsys), consisting of 24 probes, has been shown to generate good data quality. Another device (also working without a coupling agent) is the Geotron UKS 12, which consists of one signal source and two receiving transducers. The ultrasonic data is analysed in the time domain. Measurements obtained with the Geotron device are shown in Fig. 7.4.3.3. Relative travel times

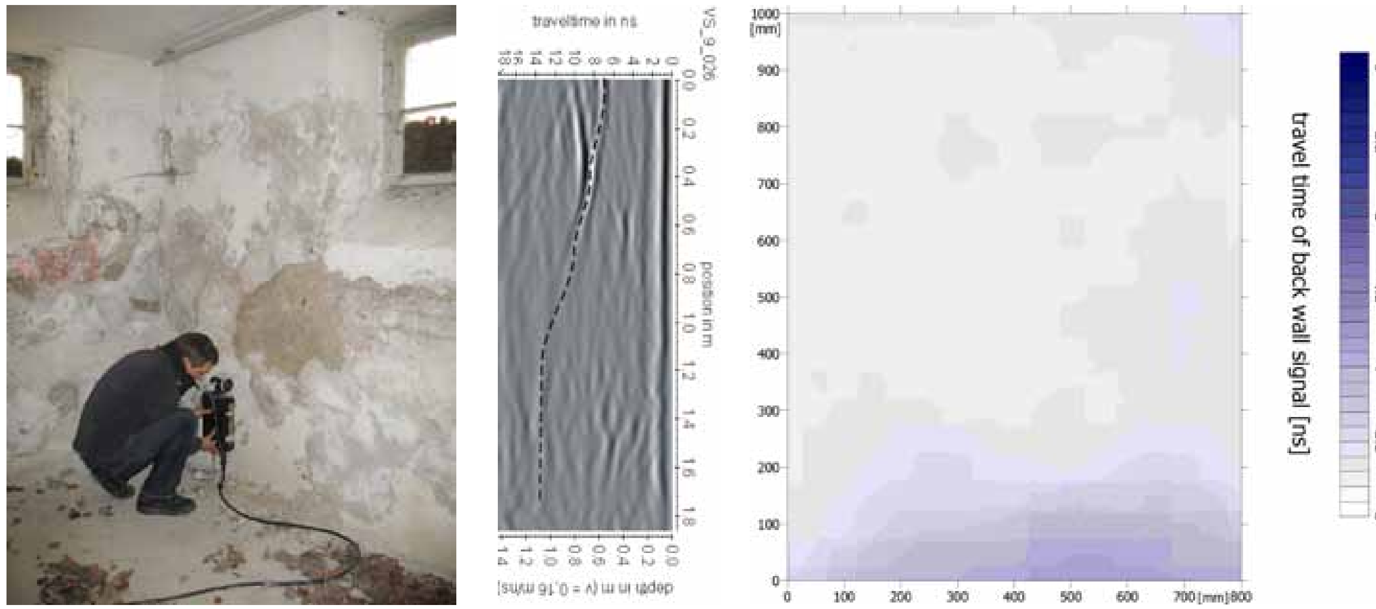


Figure 7.4.3.2: Left: A ground penetrating radar (1.5 GHz, SIR 20, GSSI) survey on a wet brick masonry wall. Centre: The corresponding radargram showing a relatively dry top section and an increasing water content towards the bottom of the wall. Right: Image of the radar travel times (reflections from the back wall) measured on a brick specimen with an increasing water content towards the bottom. Source: BAM.

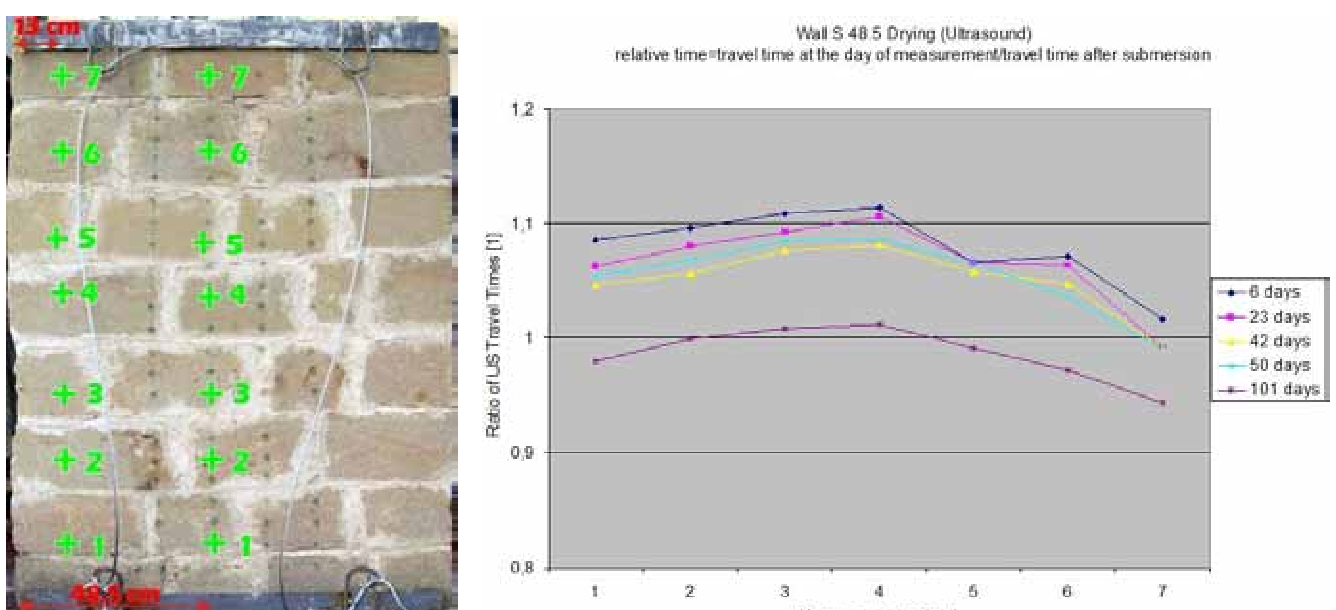


Figure 7.4.3.3: Left: Sandstone masonry specimen (ITAM) with marked positions for ultrasonic travel time measurements. Right: Results obtained at the seven locations marked on the left. The travel times are given as relative values based on the dry state. Source: BAM.

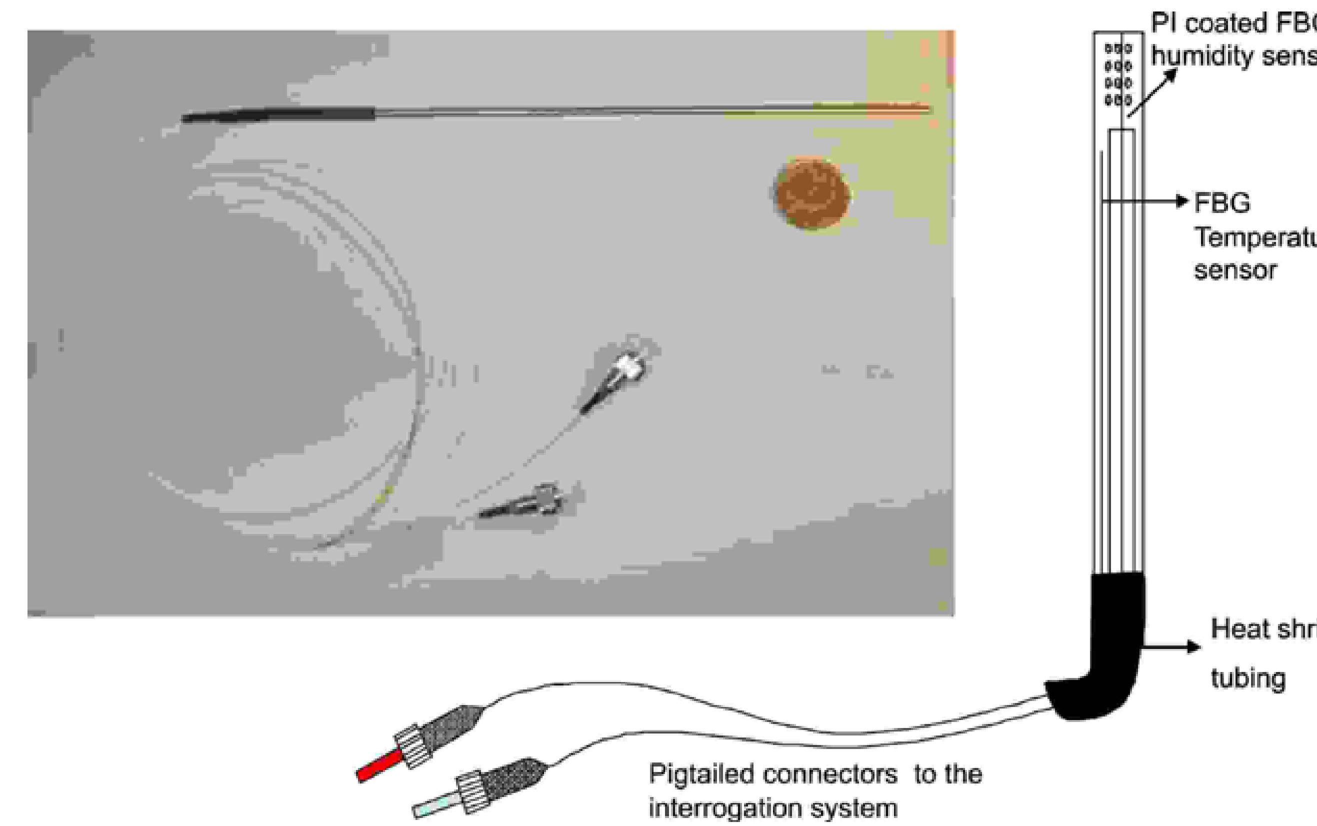


Figure 7.4.3.4: Design of the RH Probe, left: the packaged probe; right: Scheme showing the layout of the two FBG sensors inside the stainless tube. Source: Venugopalan, Sun, City University of London 2010.

between two locations on a wet sandstone masonry wall were measured at different heights (Fig. 7.4.3.3 left). The travel times between two points at the same height were measured and analysed relative to the travel times between exactly the same points when the specimen was dry. An increasing relative travel time indicates the presence of moisture.

Fibre optic relative humidity sensors: Fibre optic relative humidity sensors are based on a polymer coated Fibre Bragg Grating (FBG). With an increase in the moisture level, the coating swells and thus applies a strain to the FBG, causing a Bragg wavelength shift. Since temperature also causes differences in the FBG-signal, an uncoated sensor is added to the same package inside the sensor probe for compensation. The sensors are packed in a stainless tube with perforation at the top to allow the moisture to enter, as shown in Fig. 7.4.3.4. The two sensors have to undergo separate calibration. The RH and the temperature-sensitive FBG, both require calibration for the measurement of temperature. Calibration for relative humidity is required, for the polymer coated sensor only. The wave length shifts as a function of temperature, and the humidity is linear with different slopes at different temperatures. The probe needs at least six hours for saturation and stabilisation, but then the correlation with humidity testers is very good until humidity higher than 95%. Despite the slow response, the sensor is very acceptable for long term monitoring of concrete and other mineral building materials (Venugopalan 2010).

7.5 Effects of Floods on Masonry Walls: NDTs for Measuring Drying Rates

Luigia Binda, Giuliana Cardani, Lorenco Cantini, Claudio Tiraboschi

Introduction

After an investigation of recent floods in Italy, a research programme was set up, involving laboratory experiments and on-site studies using full-scale masonry models that were built in an open field in Milan in 1990. The masonry materials used for the full-scale models were deeply investigated in the past, and the full-scale models were subjected to contamination caused by a solution of sodium sulphate coming from the soil. Some of the walls were also subjected to surface consolidant and/or water repellent treatments. A subsequent investigation studied the durability of these treatments when sulphates were present in the masonry. The walls simulate the state of naturally contaminated walls before a flood. What is more, in this case the main parameters are known and can be controlled.

Within the framework of the CHEF project, a research programme was developed to make a study of the walls. It was observed in the laboratory that the deterioration caused by salt crystallisation diminishes slowly along the time when the material is left to dry; an increase in water inside the material will cause a sudden increase in the damage due to activation of the crystallisation of the salts.

A flood was simulated by adding water to the walls of the full-scale models for a period of several days.

The aim was to use non-destructive testing (NDT) to evaluate the evolution of the decay after the introduction of uncontaminated water, simulating a flood. In addition, an investigation was made of the effect of flooding on walls previously protected by water repellent and consolidant materials.

Description of the full-scale models

The full-scale physical models were constructed in stone and brick masonry, in the open air. The models were intentionally built in a polluted area of Milan; they are one-floor structures with the principal facades divided into modular orthogonal panels facing south and west (Fig. 7.5.1).

Two models, one with a sandstone facade and the other with a soft-mud facing brick facade, have five couples of orthogonal panels each; the third model, mixed stone and brick, has only four couples of orthogonal panels. A panel consists of two facades: a south-oriented facade (3 m large) and a west-oriented facade (1.5 m large). The thickness of the front wall is 38 cm for the brick masonry, 30 cm for the stone masonry, and the thickness of the rear walls is 25 cm. The models are 3.8 m high on the front side and 3.4 m on the rear side (Fig. 7.5.2c). The construction of the models was completed in September 1990.

Buildings, rather than independent walls, were constructed in order to have a thermal-hygrometric gradient inside the walls, as in a normal residential building. The models were therefore indoor heated during the winter.

In order to study the effects of salt crystallisation, artificial deterioration was caused in some areas of the walls by introducing a salt solution (Na_2SO_4) into small containers placed at the bottom of the walls (Fig. 7.5.2a). The subsoil of the models was coated with a layer of bentonite before construction (Fig. 7.5.2b). This operation was done in order to assure the capillary rise of water into the masonry. The water is fed naturally by rain, or artificially. The presence of water in the subsoil is controlled by five piezometers.

Since the construction, the capillary rise of water has been checked by measuring the apparent height of the water level on the facades at selected points.

The evaluation of the treatment performance in the past was based on NDT techniques, both on the surface

Figure 7.5. 1: Three full-scale masonry models in Milan, view of the west and south walls. Source: Polimi.

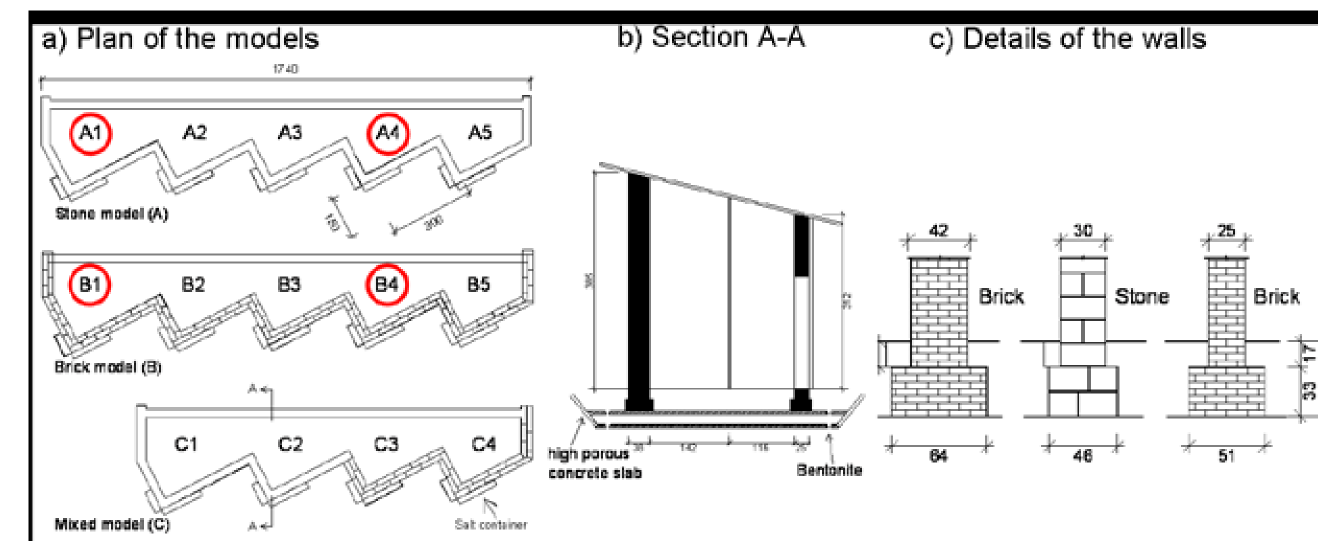


Figure 7.5.2: Full-scale models plan, section and details of walls and foundations. Source: Polimi.

and in depth: 1) Karsten pipe measurements of surface water absorption with low pressure, 2) Artificial Rain Test, 3) Moisture content and distribution in the sampled materials, 4) Surface hardness with the Schmidt Pendulum Hammer PM, (according to Rilem Recommendation MS-D7), 5) Laser profilometer for evaluating the deteriorated material, 6) Thermography for evaluating the moisture distribution, 7) GPR (ground penetration radar) for evaluating the moisture distribution in the depth of the wall, 8) Drilling test (gravimetric method on drilled powder) for quantitative moisture content and 9) thermocouples for temperature measurements [1-8]

Experimental

The research program aimed to verify the effectiveness of NDT techniques for: a) detecting moisture and moisture movements; b) the effect of the drying process; c) detecting the presence of salts; d) selecting the best-performing technique.

A simulation of a flood was carried out on a portion of four panels. First, the subsoil where the models are located was fed continuously with water for a month, and then a tank with additional water was sealed to each wall panel for a period of 4 days (Fig. 7.5.3a,b,c). Tests were carried out above and below the capillary rise level visible due to the deteriorated materials (powdered and exfoliated). Below this level, sodium sulphate salts could still be present. The distribution of moisture in the walls

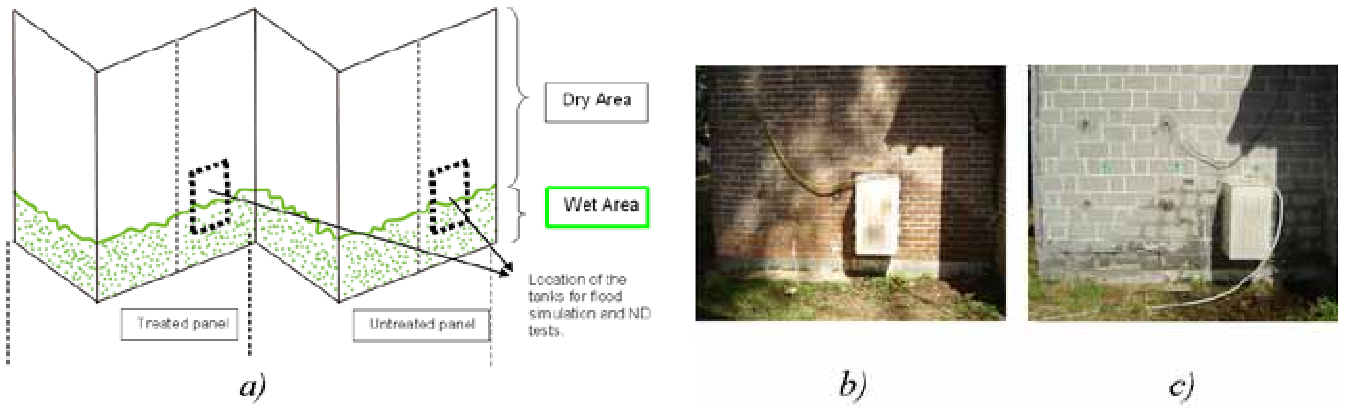


Figure 7.5.3: Flood simulation a) scheme, b) on brick masonry B and c) on stone masonry A. Source: Polimi.

and the drying process were studied, as a function of the masonry materials, of the already present surface treatment and of the presence of Na2SO4.

The walls used for these new tests were: 1) stone masonry panels: A4 untreated and A1 treated and 2) brick masonry panels: B4 untreated and B1 treated (Fig. 7.5.2).

Masonry panels treated with epoxy resin were chosen in order to have the same surface treatment in both models, and in order to evaluate the effect of surface treatment.

The NDT techniques chosen for the research were as follows: Thermography (passive in dry and wet areas); Radar (in dry and wet areas, with a frequency of 2 GHz); a Sonic Pulse Velocity test (low frequency in direct transmission, 3.5 kHz); and a Powder Drilling test (to verify the moisture content and distribution, and also the presence of salts). The tests were carried out at 2 heights and at 4 different depths within the walls.

The tests were performed at T0,T1,...Ti different times: T0 – with models in dry conditions (or, rather, in natural conditions as a function of the environment), and Ti – immediately after the flood simulation and after defined and regular periods of time in order to check the drying process.

The results were expected to give: i) the drying time of real brick and stone masonry, with or without the presence of salt; ii) the effectiveness of all the ND techniques used; iii) the effect of the presence of salt as a disturbance in the different NDTs.

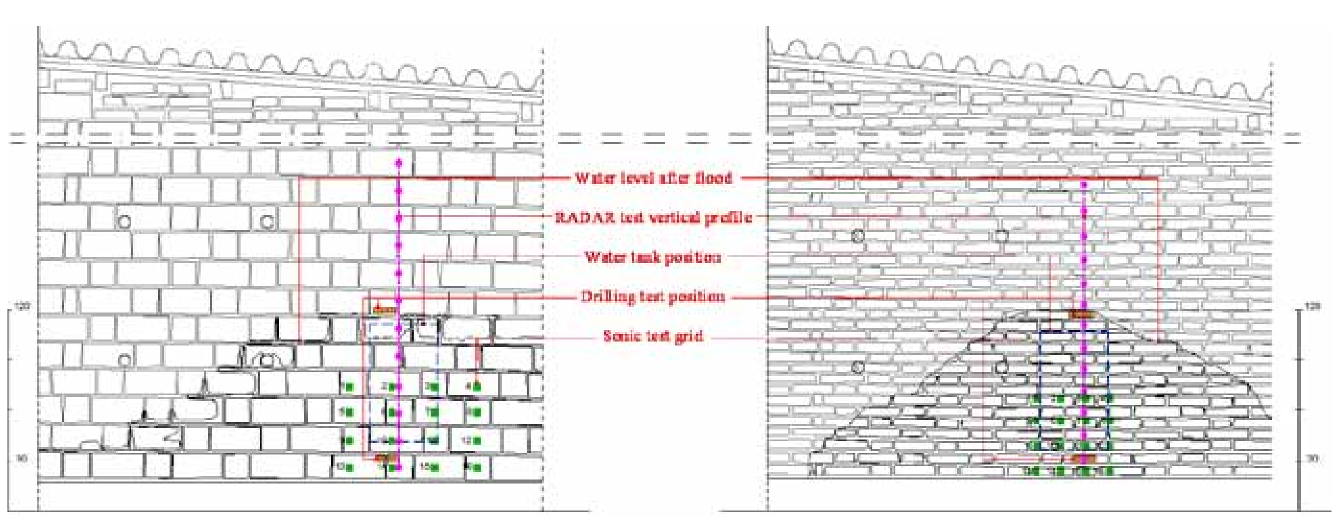


Figure 7.5.4: Localization of the measurements on stone panel treated A1 and brick panel B1. Source: Polimi.

Test description and discussion of the results

A complete investigation survey started in the 4 areas in dry conditions:

- Passive thermography, comparing the lower and the upper part of each masonry panel.

- Radar in the lower and upper part of each panel, along a vertical profile.

- Sonic pulse velocity tests were carried out, using a grid of 5 x 5 reading points, selected across the evaporation line, in order to have some of the measurements in the dry area and some in the future wet area.

- the powder drilling test was carried out at 2 different heights (30 cm and 120 cm) and at 4 different depths, in order to monitor the whole cross section of each masonry panel: a) for stone masonry panels (A1 and A4), where the cross section was 30 cm, the depths were 2 cm, 7 cm and 15 cm starting from the external side, and 28 cm starting from the internal side: b) for brick masonry panels (B1 and B4), where the cross section was 38 cm, the depths were 2 cm, 9 cm and 18 cm starting from the external side, and 36 cm starting from the internal side.

An overview of all measurements is presented in Fig. 7.5.4.

- the ambient temperature and humidity were recorded during all measurements.

Fig. 7.5.5 presents the ambient measurements (temperature and relative humidity) for A4 and B4, as an example, during the drying period: t1 is the time when the flood simulation ended, with the maximum water presence in the walls. The monitored periods of the year for the four panels were spring and autumn, with changeable weather, but with slightly increasing temperature and no significant wind. In addition, thermocouples were positioned directly on the surface of the walls in order to measure the variations in surface temperature over time.

Thermovision results

Figs. 7.5.6 – 7.5.9 show the moisture level and distribution by thermography at time t. This distribution could also be seen by visual inspection.

After the flood, the water level in A4 reached the 5th course, while in B4 the water level reached the 14th course. In A4 the external visible moisture content due to flooding disappeared after a few hours of exposure to sun, leaving moisture only near the interface with the mortar joint and the deepest moisture due to rising damp. In B4, the external visible moisture remained for many days, despite exposure to sun. In A1 the water level reached the 5th course, while in B1 the water level reached the 14th course, as in the untreated cases.

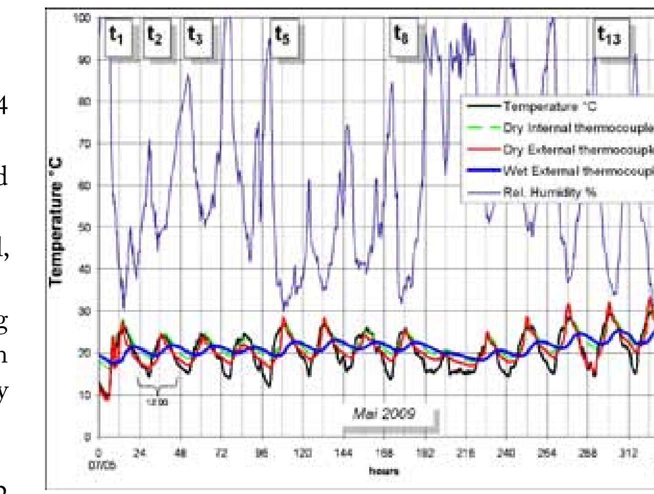


Figure 7.5.5: Ambient and masonry surface measurements during the drying process. Source: Polimi.

Thermovision was able to detect the presence of moisture even when it was no longer visible. Figs. 7.5.6 and 7.5.7 present thermographic images of models A4 and B4 over time, where A4 appears to be dry and B4 is still wet in the lowest part after 12 days. The differences in wall surface temperatures are readable and correlate well with the direct measurements made by the thermocouples, which are able to check the daily variation of the surfaces temperature in the wet and dry area. Figs. 7.5.8 and 7.5.9 show thermographic images of models A1 and B1 over time, where A1 appears to be dry and B1 is still wet in the lowest part after 11 days. The treated walls need more time to dry than the untreated wall, and the area, affected by the presence of moisture seems to be larger in the treated walls than in the untreated walls. The epoxy surface treatment, though applied in 1992 and exposed to a polluted environment, is still present and is able to extend the water evaporation time.

Figs. 7.5.6 – 7.5.9 show the moisture level and distribution by thermography at time t. This distribution could also be seen by visual inspection.

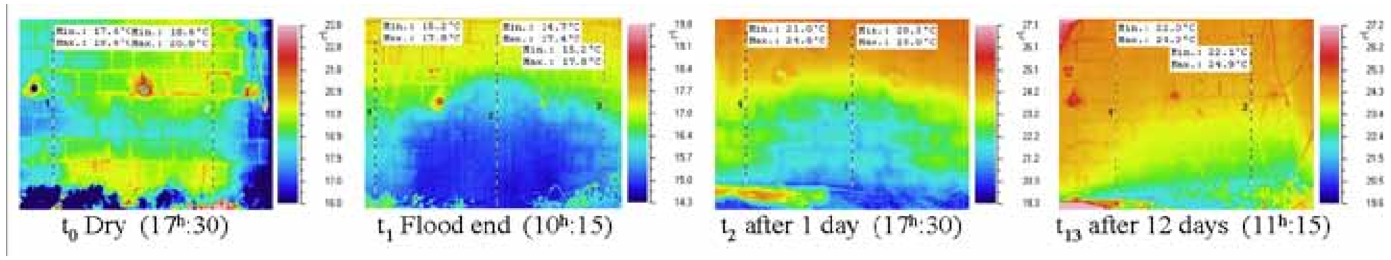


Figure 7.5.6: Thermography of the sandstone masonry wall A4: drying process over time. Source: Polimi.

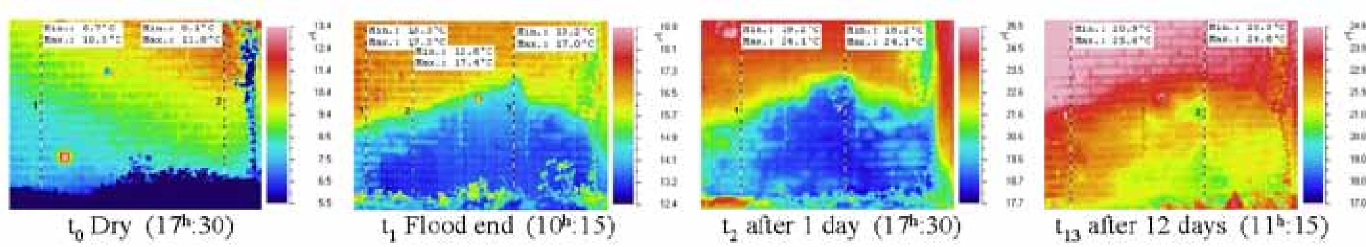


Figure 7.5.7: Thermography of the soft mud brick masonry wall B4: drying process over time. Source: Polimi.

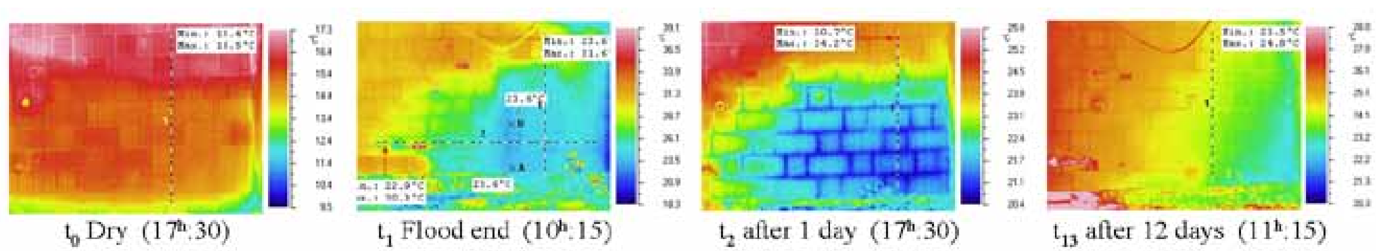


Figure 7.5.8: Thermography of the treated sandstone masonry wall A1: drying process over time. Source: Polimi.

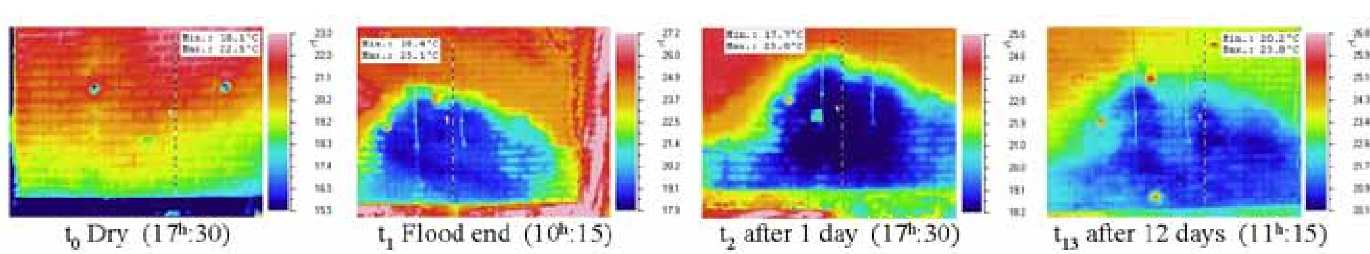


Figure 7.5.9: Thermography of the treated brick masonry wall B1: drying process over time. Source: Polimi.

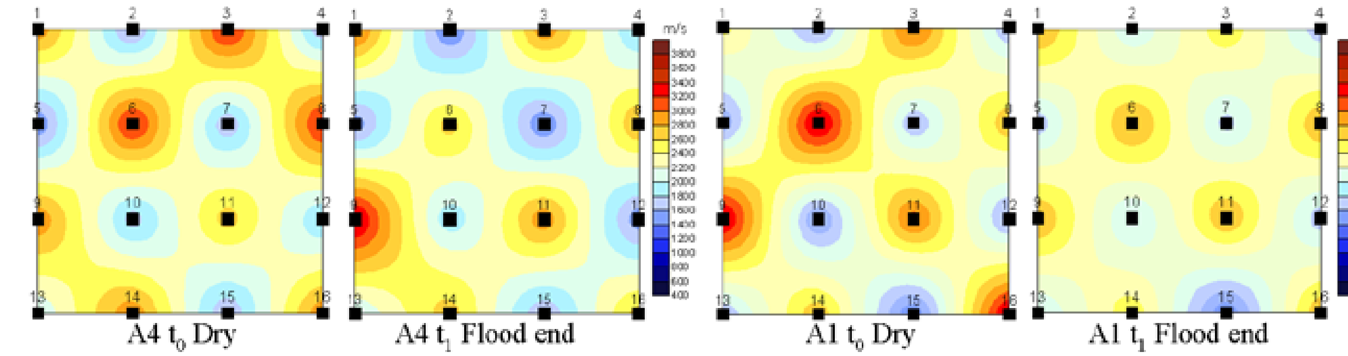


Figure 7.5.10: Sonic pulse velocity maps by direct transmission of stone masonry walls A4 and A1, before flooding (t0) and after a flood simulation (t1). Source: Polimi.

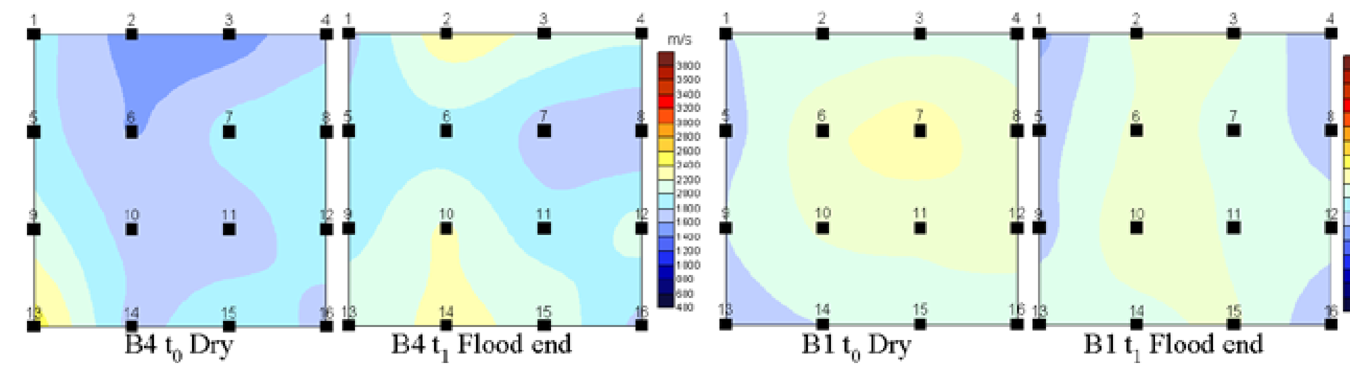


Figure 7.5.11: Sonic pulse velocity maps by direct transmission of brick masonry walls B4 and B1 before flooding (t0), after a flood simulation (t1). Source: Polimi.

Sonic pulse velocity results

The results of sonic pulse velocity tests in Fig. 7.5.10 show the measurements on the stone elements regularly distributed in the masonry. The stone units are regularly cut and are layed alternately as headers and stretchers.

The sonic pulse velocity test in dry conditions clearly shows the presence of the headers, in contrast with the stretchers with a vertical mortar joint in the middle: in the last case, the velocity is decreased by half. The darkest red corresponds to a rate of 3200 m/s, and the palest blue corresponds to a rate of 1200 m/s [9].

After the flood, an overall increase in velocity was observed, due to pores filled with water and perhaps with some salt content in the pore water, but only a slight difference in the measurements is observed during and after the flood. This could be due to the fact that only a 3% maximum moisture content was measured in the stone masonry after the flood simulation. This NDT is therefore

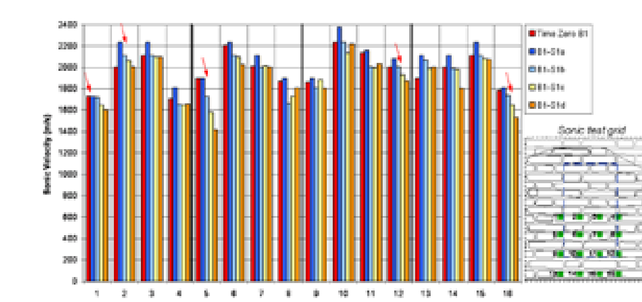


Figure 7.5.12: Sonic pulse velocity plot by direct transmission of brick masonry wall B1 before flooding (t0), after a flood simulation (B1-S1a), and drying over time (B1-S1b, B1-S1c, B1-S1d). Source: Polimi.

not sensitive to such a small change.

An opportunity to observe sonic pulse velocity variation was expected in brick masonry (Fig. 7.5.11), where a 28% moisture content was measured. At time t1 and t2, only a slight overall increase in the sonic pulse velocity could be observed, but it was too small for the moisture

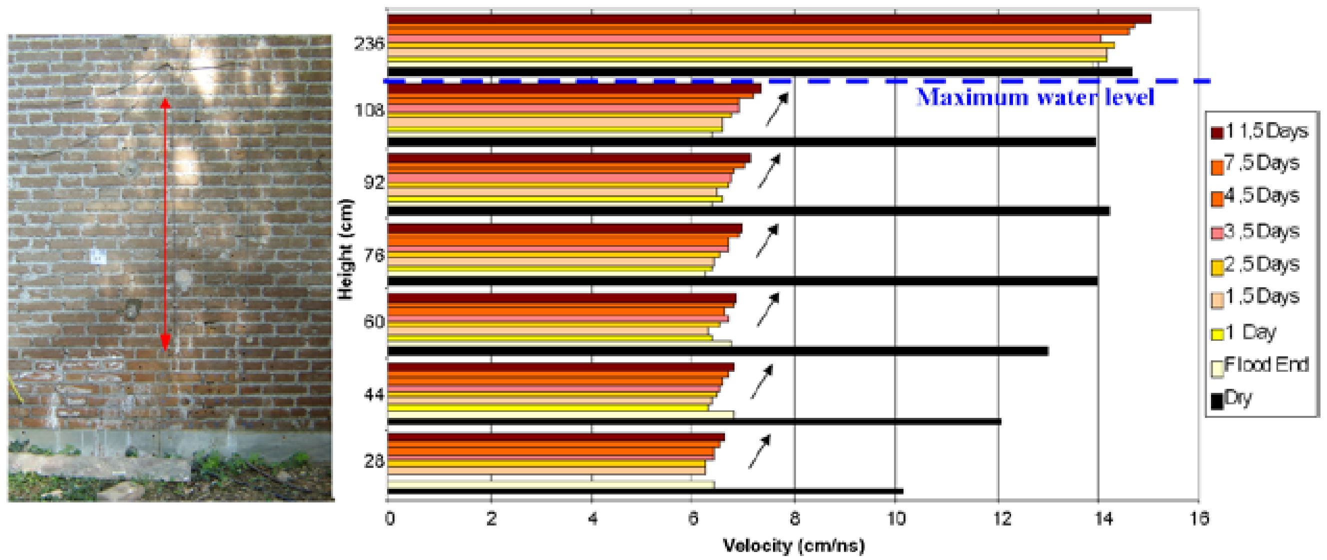


Figure 7.5.13: Velocity values using radar tests on treated brick wall B1. Source: Polimi.

content that was measured, revealing that this NDT is not suitable for measuring variations in water content variation in a masonry wall with low density and non-homogeneous section.

In the case of brick masonry (Fig. 7.5.11), it is more difficult to recognize the variations in velocity during the drying process. Figure 12 therefore presents the sonic velocitiesin a bar chart, which shows their reduction during the drying process, in the case of B1, more clearly. The arrows applied to the bar chart show this phenomenon clearly. However, it is difficult to detect the influence of water.

Radar tests

Radar measurements are sensitive to the electromagnetic properties of materials. Specifically, the velocity of a radar wave in building materials (excluding metals) is influenced by permittivity (real part), while the radar wave intensity is influenced by the imaginary part of permittivity and especially by conductivity. In porous materials, both permittivity and conductivity are strongly influenced by water content. Water is expected to increase permittivity and conductivity, producing a decrease in radar velocity and a decrease in radar wave intensity.

Radar could therefore be a promising technique for evaluating the moisture content in masonry and also in other building materials (e.g., concrete) [10, 11]. Measurements were performed with a high-frequency antenna (2GHz), with several acquisition configurations, and in reflection mode to derive moisture indications from radar velocity. In order to enhance the reflection from the opposite side of the wall, measurements were taken in static mode (i.e., without moving the antenna): on the other side a metal shield faced the antenna for a while and was then removed. As a result, the reflection time from the opposite wall could be measured with high accuracy, because it is clearly indicated by the change in the polarity of the radar wave reflection. The measurements were executed at various heights from the soil on the stone and brick walls before the flood simulations (dry condition), immediately after the flood, and then from time to time during the drying transient.

Fig. 7.5.13, as an example, summarizes the velocity measurements on brick wall B1. The results show that the flood simulation basically affected the walls up to a height of 1m from the soil. Above this level, the flood effects are negligible or too small to be detected with radar velocity. Small oscillations in velocity are observed above 1m, but there is no meaningful correlation with the expected drying transient. By contrast, the data measured below 1m presents a consistent trend (a sudden reduction in velocity comparing dry time with flood time, followed by a gradual return to a higher velocity during the drying process). As expected, and also as documented by other

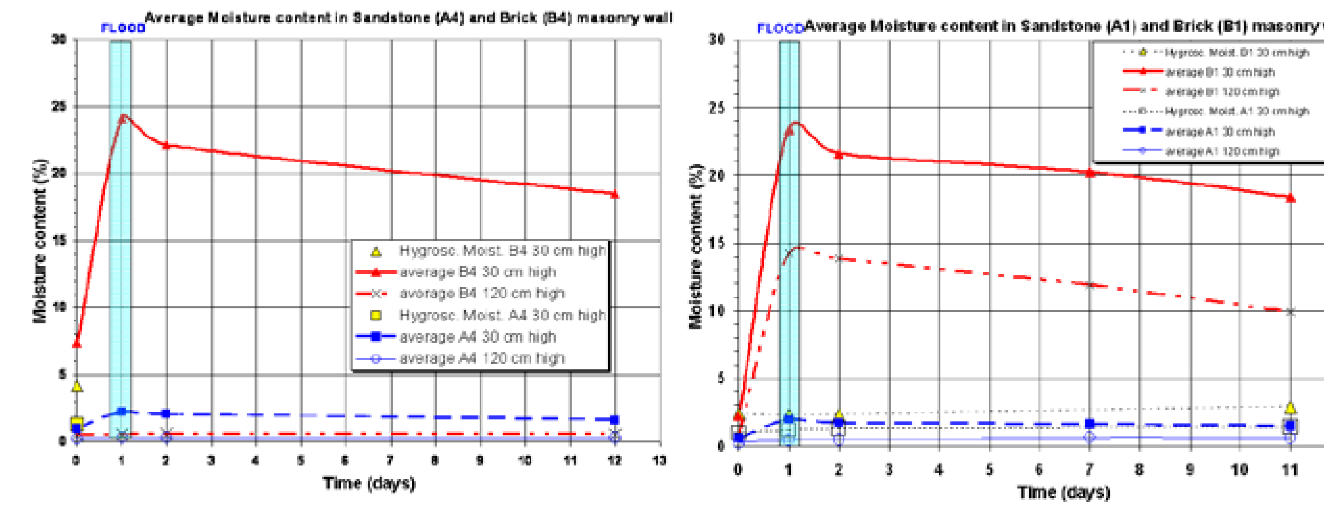


Figure 7.5.14: Moisture content by the powder drilling test in time, during the drying process, at heights of 30 cm and 120 cm of untreated masonry walls A4 and B4 and of treated masonry walls A1 and B1. Source: Polimi.

techniques, the variations in velocity are much higher on the brick wall than on the stone wall because of the different moisture variations created in the two materials by the flood simulation. The images indicate the sensitivity that we can expect from radar velocity.

Powder drilling test

This is probably the only technique that at present provides a quantitative value for the moisture content in materials. This method is useful: i) for assessing whether an external moisture source exists; ii) for assessing the source of moisture (rising damp, rain, hygroscopicity); iii) for obtaining an indication of the presence of salts (if the hygroscopic behaviour is determined at 93% RH, the indication of salts may be considered good). Two heights were selected in order to provide two different conditions: 30 cm with rising damp, and 120 cm without any possible rising damp.

There is a perceptible difference between the moisture content measured at 120 cm and at 30 cm, both for stone model A4 and for brick model B4 (Fig. 7.5.14). The panels at 120cm were not influenced either by rising damp and or by the flood simulation (apart from panel B1, which was influenced by the flood simulation). The porosity of the two masonry units is very different (5.2% for the sandstone, and 35.7% for the soft mud brick), as is the water absorption by capillary rise (0.25 for the sandstone and 2.10 g·cm2·h0,5 for the soft mud brick). There is therefore a strong difference in the moisture content at the lowest height (30 cm) measured in the two models: in the brick masonry, the level is 10 times higher than in the stone masonry. The different porosity of the masonry units influences the moisture content inside the wall: in the stone wall the moisture content is slightly lower inside than outside; however, in the brick wall the moisture content during flooding is much higher inside than outside.

After the flood simulation, it may be emphasized that the sandstone masonry absorbed a very low quantity of water (average 1.2%), especially in the external part of the wall, due to its low porosity, although the wall surface was in contact with 1 m of water for 3 days. By contrast, the brick masonry absorbed a consistent water content (average 20%), with a maximum inside the wall.

CONCLUSIONS

The use of full scale models in a case study was helpful for understanding the behaviour of brick and stone masonries contaminated by salts before, during and after a flood, the rate of drying in the case of highly porous and lowly porous materials, and it will be an important reference for the application of measurement techniques to historic buildings.

The results gathered during the research allow us to make some important observations:

- low porosity materials such as the sandstones in model A can only absorb a small amount of water. Consequently, if the flood does not last more than a few days they will suffer only slightly, even if there are salts present. Problems can appear if surface treatments that cause different behaviour have been applied;

- high porosity materials such as the bricks in model B absorb a large amount of water within a short time and do not release it completely within a short period of time. Therefore they can suffer a higher level of deterioration if salts are present;

- thermography and radar tests have shown very good effectiveness and sensitivity in detecting the presence of water, its distribution and the drying process, both in stone and in brick masonry. These methods can be used for ongoing tests of large areas of walls. As yet, however, they can only be used as qualitative indicators. A comparison of thermovision results with the other NDT measurements shows that thermovision is able to read only the presence of external moisture, where sun can dry the superficial masonry layer, but it is not able to measure the moisture content inside wall panels. A next step in the application of radar methods could be to evaluate the velocity not only as a mean value along the masonry cross section but also to make measurements at different depths.

- sonic pulse velocity tests do not seem to be sensitive enough to detect water and moisture inside masonry. This NDT is not suitable for measuring variations in moisture content in non-homogeneous sections of low-density masonry walls. The reason is that the variability of the masonry is greater than the variability of the measurements due to moisture movement density;

- up to now, the powder drilling test seems to be the best way of measuring moisture content, including variations in time and the distribution inside a masonry section. The power drilling test is currently the only quantitative tool for measuring the rate of drying of a wall after a flood. Since the test can also measure the hygroscopicity of the materials and of the salts, and also the salt content, it also seems to provide the richest amount of information. The main disadvantages of this test are that it is slightly destructive and cannot be repeated at the same points, that it is a local measurement, and that it takes time to elaborate the results;

- a combination of some powder drilling tests with some radar investigations is a promising strategy that will be explored as a quantitative test of moisture level.

Plans for further development of this research will focus on: (i) repeating the flooding and the measurements in other periods of the year, e.g. in winter, (ii) improving the software for interpreting and calibrating the thermography and radar data, in order to obtain quantitative results, (iii) processing the radar data measured in different modes to extract further parameters, e.g. wave intensity and reflection coefficients, (iv) measuring the effectiveness of quick drying methods, e.g. using microwaves.

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7.6 Example - Flood risk mapping

Pavel Fošumpaur, Martin Horský, Ladislav Satrapa

The current way of proposing flood-preventing measures (FPM) is based on a significantly simplified approach to the so-called proposed flood, where the probability of exceeding the proposed flood level is standardized and depends on the nature of the protected territory. In the Czech Republic, this is usually derived from TNV 75 2103 (River Regulation) and TNV 75 2102 (Creek Regulation). These documents recommend a certain level of protection against floods on the basis of the frequency (repetition) of the proposed flow rates. In this approach, the differentiation of risks for different types of territories is very simplified. At present, this approach to determining the proposed level of protection against floods appears to be outdated, as it provides orientation information only. Preference is therefore given to an approach that compares the costs of flood protection measures (FPM) with the potential flood damage. The philosophy of this method is based on a cost effectivness analysis, whereby the costs are the summarized investment value of the proposed measure, or variants of this, and a calculation of the effects, using a risk analysis method. The calculation of the effect of flood-prevention measures is based on summarizing the flood damages that would occur if the proposed measures were not implemented. The probability of the recurrence of such a flood is also taken into account.

The principles of optimizing flood protection are clearly presented in Fig. 7.6.1, where the horizontal axis shows the extent of the flood-prevention measures (level of protection), which determines the degree of flood risk (R). The risk is highest before measures are implemented, and declines simultaneously with the degree of protection of the territory. Conversely, the costs (I) grow along with the degree of protection. The objective is to find an optimal variant that will minimize the aggregate costs and also the flood. In short, it is about identifying the optimal, economically justifiable degree of flood protection in a given locality.

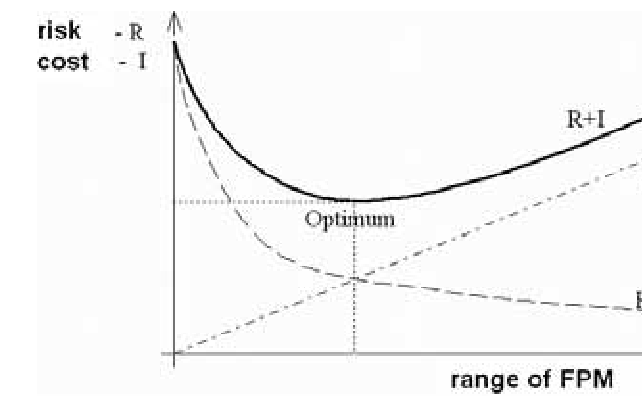

Figure 7.6.1: Philosophy of optimizing flood-prevention and protection. Source: P. Fošumpaur, M. Horský, L. Satrapa.

To estimate the potential flood damage, we apply the methodology of loss curves developed in 2005 by the Department of Hydraulic Structures of the Faculty of Civil Engineering, CTU in Prague. With the aid of this methodology, potential losses in the following categories of assets were identified:

- Buildings and structures
- Furnishings in housing and public utility structures
- Roads
- Railways
- Bridges
- Engineering networks
- Crops and land
- Industries

The loss curves are differentiated by values, and are also divided into curves that are dependent on (in the case of structures) and independent of (in the case of engineering networks, agriculture) the depth of inundation. Individual unit values of assets are derived from official public statistical data maintained by the state, and the loss functions are the result of detailed research.

The risk analysis method renders it possible to make an objective assessment of the flood damage caused by floods with various degrees of probability of occurrence. In general, flood risks depend on the degree of flood damage and the probability of their occurrence, as follows:

Risk = loss x probability of loss

For average flood risk per year, the following applies:

$$R = E(D) = \int_{0}^{+\infty} D(Q).f(Q)dQ \cong \int_{Qa}^{Qb} D(Q).f(Q)dQ \qquad (1)$$

whereby

R = E(D) is average flood risk per year [CZK/year],
D(Q) is the amount of loss at flow rate Q [CZK],
Q is the flow rate [m3.s-1],
f(Q) is the density of probable annual culmination flow rates [-],
Qa,or Qb is the flow rate at which losses begin to arise, i.e., the flow rate at which the loss probability is nearly nil [m3.s-1],
a, or b is the interval of flow rate repetition Qa, or Qb [years].

The current risk value (capitalized risk) is calculated using a discount approach. The calculation of capitalized risk depends on the discount rate. The current discount value derives from a calculation of the annuity bond:

$$R_s = \frac{R}{DS} \qquad (2)$$

whereby

Rs is current risk value [CZK],
R... average flood risk for the year [CZK],
DS ... annual discount rate in decimals [-].

Cost benefit analysis is used for evaluating the economic effectiveness of individual FPM variants in the localities concerned. In most localities, FPM variants are devised for several values of protection against flood (different degrees/levels of flood protection). The purpose of a cost effectivness analysis for each locality is to be able to answer two basic questions:

1) Does it make sense to build FPM in the given locality?
2) What level of flood protection should the FPM be proposed for?

An evaluation of the economic effectiveness of the proposed FPM variants in the localities concerned is based on a comparison of the costs and the current risk value before and after FPM. The effect of FPM is the result of the reduced current risk value after implementation of FPM.

Flood damage and flood risk evaluation is clearly illustrated with the use of a Geographical Information System (GIS). Additional benefits come from the using land-use maps, which contain information about flood areas and types of buildings, roads, engineering networks, industrial areas, crops and land, parks, woods, water areas, etc. An example of the flood risk for the town of Sokolov (Czech Republic) is illustrated in Fig. 7.6.2. A map containing cultural heritage objects is presented in Fig. 7.6.3 (Bohumín). This map was elaborated within the OderRegio INTERREG Project.

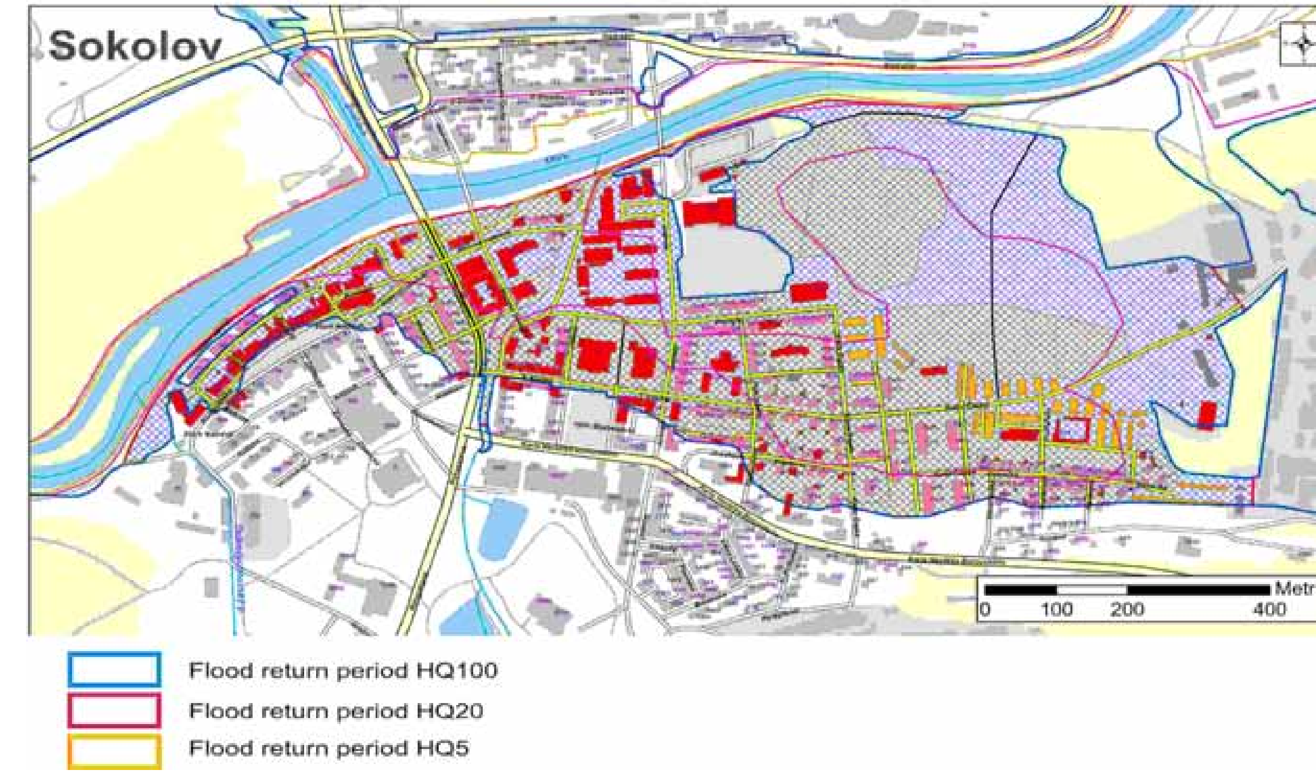

Figure 7.6.2. Flood risk map (Sokolov, Czech Republic). Source: P. Fošumpaur, M. Horský, L. Satrapa.

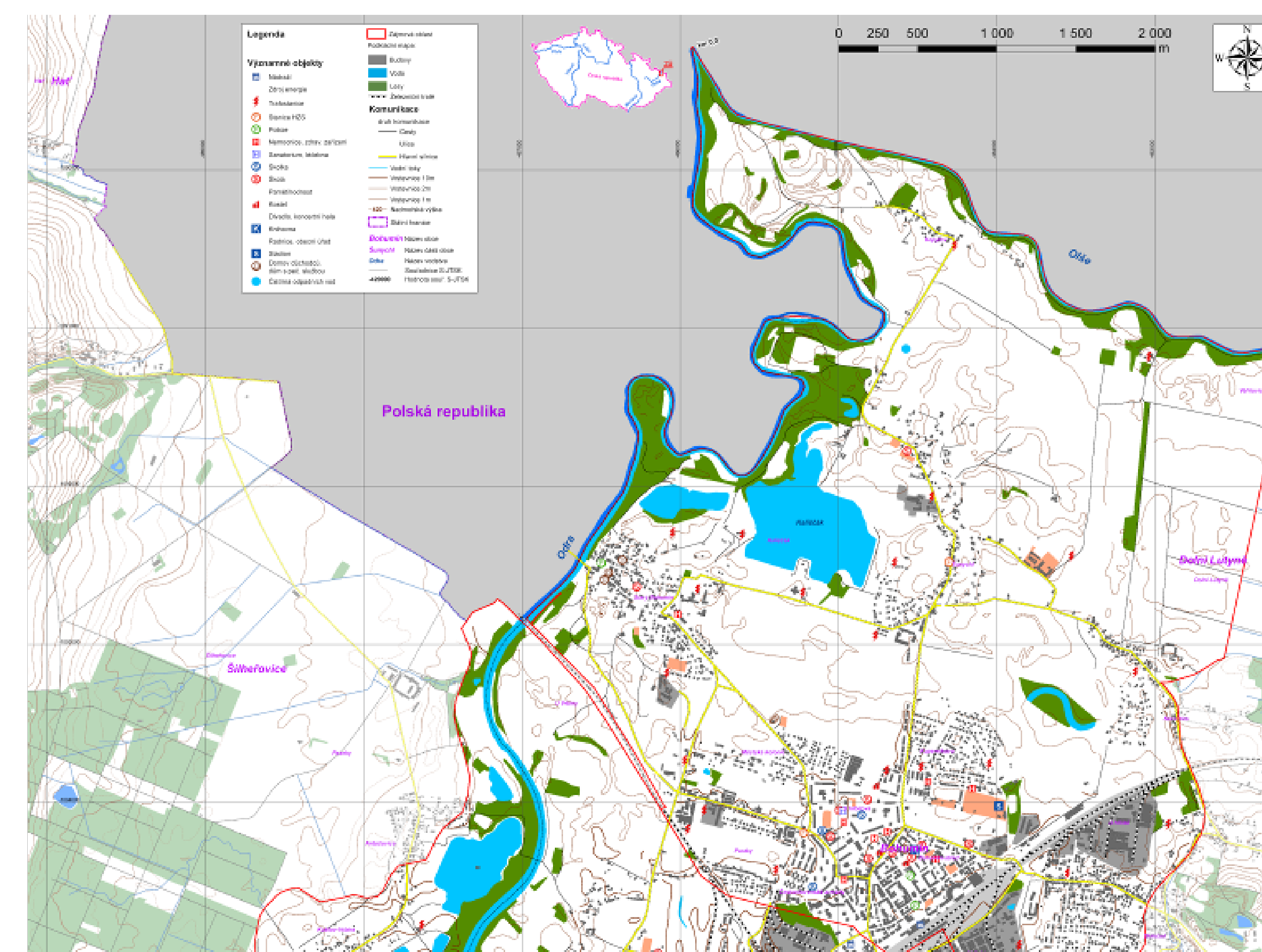

Figure 7.6.3. Flood risk map (Bohumín, Czech Republic). Source: P. Fošumpaur, M. Horský, L. Satrapa.

7.7 An example of cultural heritage emergency management after an earthquake.

Luigia Binda

The earthquake of April 6,, 2009 affected a wide area around the towns of L'Aquila, Avezzano, Sulmona and Teramo. The ground morphology played an important role in the distribution of the structural damage, and the most catastrophic effects were observed along the Aterno river valley. In this valley, not only L'Aquila was impacted but also many other historical centres, including Paganica, Onna, Fossa, Sant'Eusanio Forconese and Villa Sant'Angelo.

Indeed, the safeguarding actions for the historical and architectural heritage in the emergency situation after the event required exceptional efforts. It was necessary to maximize the operative efficiency of procedures and methods that had been developed in response to previous earthquakes, especially after the earthquake that struck the Umbria and Marche regions in 1997. The aim was to reduce to a minimum, though without loss of efficiently, the chain of decision making that leads from damage surveys to the execution of provisional safety measures.

The activities of Function 15 "Protection of cultural heritage" of the Civil Protection Department (DPC), under the direction of the delegate Commissioner, were carried out by the staff of the cultural heritage Ministry (MiBAC), with help from the research centre of L'Aquila (CNR-ITC) and a group of researchers from the Universities of Genoa, Padova and Milan (Modena C., Binda L.). The first objective of Function 15 was to elaborate a provisional list of the protected architectural heritage to be urgently surveyed in the damaged area, and to start the operation of filling in damage survey forms.

The survey task teams consisted of a representative of the cultural heritage Authority, a structural expert from the University, an officer from the fire brigade and a historian from the cultural heritage Ministry. One week after the earthquake, on April 14, 2009, the on-site inspections started with churches located in the historic centre of L'Aquila and in the surrounding areas.

Figure 7.7.1: Firemen at work in an emergency situation. Source: POLIMI.

The forms were filled in, and the list of cultural heritage was constantly updated thanks to notifications by municipalities, parishes and private landlords of protected structures. The collected data was gradually recorded in a database implemented by the Ministry (MiBAC) with support from the research centre of L'Aquila (CNR-ITC). Teams formed of people with a range of skills were allowed to fill in the comprehensive survey forms, giving preliminary indications of the "emergency interventions" for safety measures that would as far as possible take into account the principles of conservation, be efficient from the structural point of view, and could feasibly be carried out by operators who were initially exclusively fire brigade technicians.

The fire brigade teams played a key role in the temporary safety measures, thanks to their professional expertise, operational effectiveness and availability. They were the only group that could deal with the extreme, non-standard conditions (Fig. 7.7.1), thanks to their background and the legal provisions, in particular the possibility implementing legislation on safety at work (Legislative Decree No. 81 dated 9 April 2008, on Health and Safety at Work).

The damage survey

Specially-prepared survey forms were used for the cultural heritage damage survey. They had been prepared by the Civil Protection Service (GLABEC – Working group for cultural heritage) for churches (model A-DC) and for palaces (model B-DP), approved by decree DPCM, dated 23 February 2006. The templates are made up of a number of sections covering: general data such as name, location, ownership and function; information on existing artistic heritage, main dimensions of the building, evaluation of the structural damage and the damage to artistic heritage; certification of fitness for habitation; suggestions for temporary safety measures; economic quantification of the damage.

The structural damage survey is based on identifying the macro-elements that constitute a masonry building and on an evaluation of the level of activation of the kinematic mechanisms associated to the macro-element itself (Giuffrè, 1991). In detail, the survey form for churches identifies 28 possible kinematic mechanisms that are typically detectable in this type of building; the survey form for palaces identifies 22 possible kinematic mechanisms. The kinematic mechanisms detect first-way mechanisms (out-of-plane mechanisms) and second-way mechanisms (in-plane mechanisms) for each element of the analysed typology (Borri et al., 2002).

The result is a form that is easy and quick to fill in on-site, which provides a standardized evaluation of the level of structural damage, substantially free from subjective evaluations by the compiler (Lagomarsino et al., 2001). The survey form for the evaluation of "palaces" was used for the first time in the Abruzzo region, unlike the form for "churches", which had already been tested in previous earthquakes. The increased complexity of filling in the form for palaces is due to the difficulty of bringing together all non-religious historic buildings into a single typology defined as "palaces".

Five months after the earthquake, the survey of the damaged approximately 1 000 churches had been completed, and the survey of (approximately 700 palace buildings protected by the cultural heritage Authority was on track to be concluded.

Further observations and suggestions for further investigations, some of which have already been set in motion, also through in-situ diagnostic investigations (Binda et al., 1999), emerged from the visible and sometimes very serious effects of the earthquake on structural interventions performed in the past.

Emergency safety interventions

The design of temporary interventions for the safety of a historical building starts from the damage survey and from identifying the collapse mechanisms activated by the seismic event, as reported in the damage survey forms. Having damage survey forms filled in is therefore the first tool for formulating a possible project for an intervention aimed at preventing a collapse. It was necessary provide "minimum survival conditions" for what was left of hundreds of badly damaged historic buildings. This needed to be done quickly, and as extensively as possible, and effectively, in terms of structural safety and also in relation to the threat of aftershocks occurring after the main shock). Out of about 1000 churches included in the MiBAC database, the survey showed that only approximately 25% were still fit for habitation. There were a few cases of other classes of use which do not require provisional works. The result was that approximately 65% of the church buildings needed an evaluation for safety measures.

The standard procedure for the design and realization of a safety evaluation with the teams from the fire brigade started by having the damage survey forms filled in, followed by the design of temporary countermeasures. Then the structural engineers (mainly from universities) elaborated a preliminary project hypothesis. These provisional proposals were discussed in daily meetings at the fire brigade headquarters (NCP, nucleus for coordination of provisional interventions), together with fire brigade engineers and an officer of the cultural heritage Authority. In difficult cases, the discussion could be followed by an on-site inspection by structural engineers and representatives of the fire service. Following approval of the final project, inspections were made to determine the best possible solutions for the historic building and for minimizing the intervention costs.

In designing the safety measures, the above-mentioned logistic considerations were supplemented by

Figure 7.7.2: Traditional provisional structures for an emergency situtaion. Source: POLIMI.

Figure 7.7.3: New provisional structures for an emergency situation. Source: POLIMI.

purely structural considerations, concerning the static and dynamic behaviour of buildings damaged by the action of the earthquake. The solutions were based on experience gained in previous earthquakes and also on knowledge developed through earthquake engineering research at the universities and, more specifically, based on the behaviour of the historic buildings subjected to seismic action (Modena et al, 2008). The most widespread provisional interventions are to deal with mechanisms for out-of-plane overturning of walls.

Provisional interventions for the safety of facades can be performed in one of two ways: through traditional propping systems using wooden poles (Fig. 7.7.2), or through tying, with the use of steel cables or polyester bands (Fig. 7.7.3). These two types of intervention involve different structural approaches: the first approach is intended to partially restore the stiffness of the structure, while in the second latter approach, the bands (or the ties) elastically connect the different stiff blocks detected by the activation of the seismic damage and that form the kinematic chain (Bellizzi, 2000). Preference is given to the second method, because it is more practical and does not block access. Interventions performed with traditional props occupy a large area of ground in front of the facade for placing the poles, thus preventing passage. Interventions performed with bands or ties occupy the ground in front of the building onlyto a minimal extent. In addition, they are quicker to apply and to remove. From a structural point of view, interventions with bands or ties connect the rigid blocks identified by cracks caused by the earthquake. The damaged structure has lower overall stiffness than it had in its pre-earthquake condition, and exact positioning of the bands provides a great displacement capacity and can prevent collapse due to overturning.

Project partners

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