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Discussions

Review "Structural flood-protection measures referring to several European case studies"

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Abstract

The paper presents a critical review of structural measures that were taken to cope with floods in some cities along the Danube River, such as Vienna, Bratislava, Belgrade, and Barcolennette area along the Ubaye River. These cities are also taken as case studies within the KULTURisk project. The structural measures are critically reviewed and compared to each other. Based on this review some suggestions are given how to improve the flood defense in flood prone areas.

1 Introduction

Flooding is the most common of all environmental hazards (Smith, 2001). Catastrophic floods endanger lives and cause human tragedy as well as heavy economic losses. Between 1998 and 2009, Europe suffered over 213 major damaging floods, including the catastrophic floods along the Danube and Elbe rivers in summer 2002. Severe floods in 2005 further reinforced the need for concerted action. Between 1998 and 2009, floods in Europe have produced around 1126 human fatalities, the displacement of about half a million people and at least 52 billion in insured economic losses (EEA, 2010). In addition to the economic and social damage, floods can have severe environmental consequences as well.

Based on this and because in the coming decades there are likely to see a higher flood risk in Europe and greater economic damage, a new EU floods directive "Directive 2007/60/EC" has been proposed by the European Commission. Its aim is thus to prevent and reduce the damage caused by floods (e.g. environmental damage, damage to the cultural heritage and economic activity, and so on), and to emphasize that despite the fact floods are natural phenomena, their likelihood and impacts can be significantly reduced if adequate and coordinated measures are taken. In view of this, there is an ongoing project called "Knowledge-based approach to develope a culture of risk prevention" or shortly "KULTURisk". It focuses specifically on water-related hazards and

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aims at developing a culture of risk prevention by evaluating the advantages of different state-of-the-art risk prevention measures such as early warning systems, non-structural options (e.g. mapping and planning), risk transfer strategies (e.g. insurance policy), and structural measures.

The focus of the present paper is solely to present the structural measures that have been developed over the years to protect against flooding in selected KULTURisk case studies. The structural measures of each case study will be reviewed. Finally, some conclusions and further suggestions will be given.

2 KULTURisk – project description

The main goal of the KULTURisk project is to focus on the improvement of the culture of risk prevention. This is planned to be done by a comprehensive demonstration of the benefits of risk prevention measures taken to cope with natural disasters like floods. Thus, a development of a culture of risk prevention requires an improvement of:

- memory and knowledge of past disasters,
- communication and understanding capacity of current and future hazards,
- awareness of risk, and
- preparedness for future events.

The principal objectives of the KULTURisk project are to develop a risk-based methodology for the evaluation and accounting of risk prevention measures, and a promotion of a culture of risk prevention by using the KULTURisk outcomes as examples to:

a. increase the risk awareness of the public via improved communication;

b. shape risk perception of inhabitants in an appropriate and responsible way; and

c. train professionals, regional authorities, officers of municipalities, consultants, academics and students to better evaluate the socio-economic benefit of risk prevention techniques for water-related risks.

The developed risk-based methodology will then be applied and validated through a variety of European case studies characterized by various socio-economic contexts, different sorts of water-related hazards, such as floods, debris flows, landslides, storm surges and many others, and different space-time scales and transboundary areas. Finally, the outcomes of the project will be used to efficiently educate the public and train professionals in risk prevention. Moreover, the applicability of the KULTURisk approach to different types of natural hazards (e.g. earthquakes, forest fires) will also be analysed.

3 Case studies

The main objective of this section is to provide and review several KULTURisk case-studies mainly on flood protection measures collected from various European regions and river basins, see Fig. 1. This case studies are the following; see e.g. http://www.kulturisk.eu/case-studies:

– Zürich, Alpine catchments (floods and landslides)

– Danube, Many countries Trans-boundary large river (large-scale inundations)

– Barcelonnette, France; Mountainous catchment, (landslides and debris flows)

– Carlisle, United Kingdom; Urban area (urban floods)

– Soča-Isonzo, Slovenia Italy; Trans-boundary Alpine catchment (floods and landslides)

– Somerset, United Kingdom; Coastal area, (storm surges)

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The main emphasis which will be put in the next subsection will mainly be oriented in reviewing the structural measures for flood protection in the cities along the Danube River, such as Vienna, Bratislava, and Belgrade, and Barcelonnette area along the Ubaye River.

3.1 Danube

The Danube River is the largest Central European river. It rises in the Black Forest mountains of western Germany and flows for approximately 2850 km to its mouth on the Black Sea. During its course, it flows through four Central European capitals and passes through or touches the borders of ten countries, see Fig. 2.

The Danube case study of the KULTURisk project focuses specifically on the socio-economic effects of large-scale inundations in transnational rivers by applying the risk-based methodologies developed in this project. Besides, these case studies will further pay attention also to a critical and comprehensive review of the flood mitigation measures taken to cope with flood along the Danube.

3.1.1 Vienna

Description

The city of Vienna has been exposed to severe flooding of the Danube since its foundation. Only the very oldest part of the city, where the roman fort was once established, is not prone to floods. The Danube flowed through a wide belt of marshy meadows severely hampering the trade routes towards Bohemia and Moravia and limiting the expansion of the city. Therefore, it was decided to control the river with structural measures (Starosolszky, 1994). The main goal of these measures was to provide flood protection, but, along with that, also suitable navigation. A secure port close to the city and the construction of permanent crossings were also considered important issues. In 1869, the decision was made to regulate the course of the Danube in the vicinity

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of Vienna. This first regulation project entailed a cut-off through the meandering arms, thereby unifying and straightening the river bed. The Danube controlled bed was 280 m wide and was adjoined by a 450 m floodplain on the left bank and a dike to protect the flat, low-lying surrounding areas. Work on the cut-off lasted from 1870 to 1875. However, shortly after the first Danube regulation was finished, the catastrophic floods in the years 1897 and 1899 gave rise to doubts concerning the estimates used to design the height of the embankments. Furthermore, the 1954 floods clearly illustrated that the protection provided by the embankments was not sufficient. Extensive scientific studies were performed to determine the design flood upon which Vienna's flood protection system should be based. The result was a generally accepted figure of 14 000 $m^3 s^{-1}$, which was the estimated peak flow discharge for the largest flood event of the upper Danube, occurred in August 1501. A number of studies on improving flood protection for Vienna focused on increasing the conveyance (i.e. capacity to covey a higher river discharge). The different proposals called for raising and reinforcing the existing dikes, removing parts of the floodplain, widening the river bed and constructing bypass canals within and in addition to the existing protection facilities. In 1969 the city council supported, against strong political opposition, a project proposing the construction of a new flood bypass canal (the "New Danube") and the use of the excavated material to build a flood-free island (the "Danube Island"), see Fig. 3. In such a proposal, the excess water would be directed through the New Danube during high-water periods; while, for most of the year, the water in the New Danube is kept constant by two weirs, resulting in a calm, lake-like surface. Works for this project started in March 1972; it took 17 yr to complete the New Danube and the Danube Island. The overall project was completed in 1998 with the commissioning of the Freudenau power plant. It is estimated that the return period of the Vienna flood protection system is around 10 000 yr, which is one of the highest safety levels in Europe.

Structural measures

Digging the bed for the New Danube involved excavation of 28.2 million m^3 of earth, most of which was used to create the 390 ha large Danube Island. The New Danube is about 21 km long and has an average width of 210 m. The discharge in the flood relief canal is regulated by means of weirs; three sets of sluice gates control the water level of the New Danube. The inlet structure at the upstream end is used to regulate the flow into the New Danube and, further downstream, two weirs are used to maintain the impounded water level in the New Danube during non-flood periods. When the Danube carries high water, the three gates are opened according to strictly defined operating procedures, and the excess water flows into the New Danube, which can take up to 5200 $m^{-3}\,s^{-1}$.

An overview on the main technical information about the Vienna flood protection project is shown in Table 1. As the works proceeded, sections of the island were opened to the public, and comments made then were integrated into the plans for the final design and landscaping of the Danube Island. As a result, while the original layout had foreseen a strictly trapeze-shaped cross-section for the New Danube, the design was modified accordingly to create banks with a more natural shape. Also, the City of Vienna eventually decided that, in addition to serving flood control, the New Danube and Danube Island would be kept free from civil constructions and would be developed as a recreational area that would also bring ecological benefits. Nowadays, the Danube Island surface area is used mostly as a recreational park.

Experience

The project was implemented by the City of Vienna's Water Resources Department with the financial aid of the Federal Ministry of Transport, Innovation and Technology. No other bilateral or multilateral assistance was included. The budget was planned on a long term basis together with the Ministry and decided on annual construction rates. The planning and permitting process took approximately 4 yr, while the construction of

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the main elements (New Danube and Danube Island) took about 15 yr. New components to the original project became necessary since in the 1990 a hydropower plant was built on the Danube, within the project area. The flood protection project led to ended up being not just a successful solution in terms of economic advantages, but it also facilitated the development of large green areas within the city, recreation and ecological improvement. The impact of the project was even more positive than envisioned during the decision and design period. The project also made possible the transformation of parts of stagnant wetlands into functioning ecosystems by strongly enhancing its once river controlled dynamics. Groundwater has also shown benefits from the implementation of the project. Overdraft of groundwater has occurred over many years and due to the construction of the New Danube, infiltration in the aquifer has improved strongly. On the Island, new wells were built for the Vienna Water works to supply drinking water. At the same time as the construction of the flood protection system, the sewage collection system was also improved.

After the completion of the project, the urban development on the left banks of the Danube took place more rapidly. Of course other factors, such as a new subway line, also increased the attractiveness of the area, but proper flood protection made sure that investments in property were more secure. The once neglected districts on the other side of the Danube became the major development areas for services and industry as well as for new housing projects. Since the implementation of the project, the population in these two districts approximately doubled. Due to proper planning and involvement of people affected by flooding, the project finally received a high level of acceptance. Although recreational aspects were already included during the design period, it was not foreseen that the 21 km long island will become such a major attraction for all Viennese.

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3.1.2 Bratislava

Description

Some parts of Bratislava, particularly Devín and Devínska Nová Ves, are vulnerable to floods. These regions have been prone to floods for many years due to storm rainfalls events especially during the snowmelt period. Historically the Danube floods at Bratislava most often occur in May and June. The flood of August 1501 can be taken as the highest flood that was ever observed in the upper Danube reach (and also in Bratislava) according to reliable historical records of the Austrian Hydrographic Service. The peak discharge at Vienna was estimated up to 14 000 m^{-3} s^{-1}. There is also some evidence of floods in the 16th–17th centuries 1594, 1598, 1670, and 1682). The first flood records in the Slovak portion of the Danube date back to 1526 and are documented in the municipal archives of the city of Bratislava. However, the morphology of the watercourse was different at that time. In the medieval ages, there were either none or only very low flood-preventing dikes alongside the river. The stream channel had low capacity and the water often flooded the lower parts of the city (including a part of the city's downtown - Main Square). From the whole 130-yr series of mean daily discharge of the Danube at Bratislava in 1876–2005, it is encountered a total of 4 floods with peak discharge exceeding 10 000 m^{-3} s^{-1}. Since 1920, there have been two such floods. Such extreme floods occurred once in July 1954 and in August 2002.

Structural measures

Main flood protection measures taken to cope with floods are located in the southwestern part of Slovakia on the border with Austria and Hungary and include the capital area of Bratislava with its neighbourhoods, see Fig. 4. These measures were taken to address gaps and under-protected areas of the Danube flood protection system in the Slovak territory, which was built to protect the vast territory of Bratislava in Slovakia and western regions. High flow of the Danube during extreme floods can have disastrous consequences such as the flooding of the 383 km^2 built-up urban area and 2000 km^2 of agricultural land, which would directly affect some 490 000 people. The structural flood mitigation measures include reconstruction of existing and construction of new flood control structures on both sides of the Danube. These flood protection structures are dams, levees, reinforced concrete protective walls, and mobile elements, and so forth (Fig. 5). For technical review of the type and amount of the measures built see Table 2. All these structures are designed for flow corresponding to 13 500 $m^3 s^{-1}$ which has an estimated return period of around 1000 yr. For the Danube, the requested security freeboard was 0.5 m above the estimated water level.

Experience

The structural measures constructed within the project named Bratislava – Flood protection, project number "CCI 2004 SK 16 C PE 007", were implemented by the Government of Slovakia and co-financed by the Cohesion Fund (up to 85 %). The planning and permitting process started in 2004, while the construction started in 2007 and finished in December 2010. All objectives of the project

- construction of new flood protection lines in urban and suburban areas of Bratislava,
- complete restoration (replacement and increase) of the initial flood protection line in Bratislava Old Town,
- increase of the flood protection line in the municipality Petržalka Bratislava,
- increase of the safety of levees on the left side of the flue channel Gabčikovo municipalities,
- prevention of economic damages in the project area including the capital city Bratislava and its neighbourhood municipalities,

– prevention of environmental damages in the project area including prevention of contamination of drinking water sources,

were completely achieved.

3.1.3 Belgrade

Description

Belgrade, capital of the Republic of Serbia, is situated on the confluence of the Danube and the Sava Rivers. The old part of the town develops along a hilly area on the right side of the Sava River. The left side of the river bank used to be unpopulated wetlands. The first construction in this area was a fortification, which was built in 1720 by the Austrian monarchy on the border between the Ottoman Empire and Austria. Some first discussions on the development of this area started after the First World War.

After the Second World War the development of the area was hardly supported by the government of Federal People Republic of Yugoslavia. Federal government buildings built on elevated areas in New Belgrade and some new parts of the city started to be developed. The layer of excavated sand from the Danube main channel is about 3.5 m thick, on average. The water level elevation corresponding to the 100 yr return period flood is estimated to be about 76 m, one meter below the surface elevation. The highest water level recorded since 1921 is around 76 m, observed in 2006. No damages were caused by the surface water, while the groundwater was affected. A study was carried out to investigate the impact of flood duration on groundwater rise.

Structural measures

In the 1950's, large wetlands containing a few meters of sediment dragged from the rivers, covered more than 10 square kilometers in the area of Belgrade, Serbia where there is the inflow of the Sava river to the Danube. Later on, in the 1960's, a new part of the town was constructed there. During the Danube flood in 1965, and later floods,

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there was no damage or disturbance in the heavily urbanized lifted area. The built-up area is arranged with a friendlier landscape and safer, less land is dissipated than with levees (Brilly, 2001).

Besides, on the territory of Belgrade city, the largest volume of urban flood protection was made in the period from 1972 to 1989. At that time, about 8.3 km of coastal fortifications and nearly 234 km of embankments were built or reconstructed, more than 97 km of basins have been regulated and also three small reservoirs have been built. After 1989 the investment in flood protection system was significantly reduced. Thus, between 1989 and 1995, only 3.5 km of levees have been built and regulated approximately 1.6 km of Sava River banks (Babić et al., 2003; Milanović et al., 2010).

Nowadays, flood control against flooding of Danube and Sava Rivers in Belgrade city is mainly provided by:

- concrete flood-protection walls (within the inner city circle), and
- levees (outside the inner circle of the city).

All these flood-protective structures are built up to 1.5 to 1.7 m above the average height of the high water level corresponding to one hundred year flood placed at the confluence of the Sava and Danube, which is estimated to be 76 m above the sea level (Babić et al., 2003).

Experience

A multi-year reduction of investments in regular maintenance of protective structures has led to a significant reduction of the facilities safety, and hence, to the reduction of the degree of protection in relation to the earlier situation. Due to an inadequate maintenance and use of river beds, the banks of the rivers with flash flood regime are particularly threatened.

Hence, the current flood-protection system it is not fully sufficient. Much of the area is still actually threatened by floods. The reason for that is because even where the

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protection system has been built, the potential risk of flooding exists, since the protection facilities are often not appropriate and the flood-protection system is usually built only locally and thus no closed areas of defense are provided. In addition, it is also observed that the flood-protection structures have not properly been built and maintained (Babić et al., 2003). Thus, we can conclude that the most densely populated city area is not adequately protected from flooding of Danube and Sava Rivers. From this perspective, a new implementation of the flood-protection system of the city of Belgrade against flooding of Danube and Sava Rivers has to be proposed as soon as possible. The level of flood-protection should be increased from current 100-yr to at least 200-yr flood. Finally, the goal should be to assure protection against 1000-yr flood. The later can be achieved with the combination of the fixed facilities with the prefabricated or mobile elements (Kreibich and Thieken, 2009).

3.2 Barcelonnette (Flash floods)

Description

The Barcelonnette basin is situated in the southern French Alps, in the department "Alpes-de-Haute-Provence" at an average elevation of approximately 1130 m. The basin extends over an area of 200 km^{-2}, with a length of 22 km, and a maximum width of 10 km, and is drained by the Ubaye River. High crests, reaching altitudes from 2800 m to about 3100 m, enclose this basin. Due to its local climatic, lithological, geomorphological and landcover conditions the region is highly affected by various natural hazards such as floods, landslides, earthquakes, debris flows, avalanches, rock falls and soil erosion. Figures 6 and 7 show a map of the study area. Because records of hazards 1850–2006 show that the area is mainly affected by floods (Weber, 1994), in what follows, the emphasis will be devoted to a flash flood problem in the region.

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Structural measures

The Barcelonnette area is situated in an elongated form. The elongated structure makes it highly dependent on structural measures such as dykes levees, dams and flood related channels, see Fig. 8.

Since the levees that have been repaired after the 1957 flood event do not offer enough protection if a flood of the same magnitude happen again, the Municipality has decided to increase the dike by 1.5 m in some areas, to renovate sections of the river banks, to reinforce the concrete embankments, to built sheet piles at the "shoreline of scouring", and increase the height of the embankment of the bridges.

Thus, at the moment, the town of Barcelonnette is consulting widely on how to better defend the town from flood risk and debris flow. Therefore, prior to the flood event of May 2008 the implementation of dike raising in Jausiers (approximately 1.5 m) , the reconstruction of a new bridge with a bigger clearance, appropriation of land to increase the flood plain and a municipal law that all new construction should be built 1.5 m above the ground level. This actions protected the town from the flood event of May 2008.

Parts of the Barcelonnette were inundated during the June 1957 flood event as a result of a breach of the dyke caused by a bridge with a low conveyance capacity. The inundation extent and location of the dike breach was determined using a post event analysis of the deposited debris (Lecarpentier, 1963). Consequently, reconstruction of one of the destroyed bridges was done and portions of the dike were reconstructed and raised a further 600 mm. Also important to note is that that the construction of checkdams along the tributaries is continuous process every year with new infrastructure being built to reduce the sediment load into the main channel, thus reducing the chance of damming and cutting communication lines. Maintenance activities are also being carried out along the dikes to clear vegetation that could increase the roughness of the channel and also to maintain the dike integrity. The most challenging issue at the moment is a solution to increase the conveyance capacity of the bridges in

Barcelonnette (to accommodate at least a 100-yr flood event), which have a potential to cause obstruction and consequently overtopping of water into the town area.

Experience

Although several mitigation measures have been put in place, the risk to flood events, such as 2008 flood, still exists particularly due to the expansion of the city to accommodate tourists, industrial activities, ski resorts and houses.

Even though structural measures such as embankments have been used as a mitigation measure, research has shown that people feel a strong sense of security when a disaster is not prevalent or has never occur in an area for a long time. This is the case of Barcelonnette that experienced the last major flood event in 1957. This event caused severe damage to infrastructures, buildings and resulted in one death. Like the Dutch who were surprised by an unexpected flood scenario in 1953 and who were once again under another threat in 1995, Barcelonnette had a near flood event in 2008 that has reinforced the possibility that a flood can happen in the area (Henry, 2010).

The 2008 near flood event is a constant reminder of Barcelonnette's vulnerability to flooding. As indicated in Fig. 7, the occurrence of a flood in Barcelonnette is not merely a probability but has demonstrated some level of certainty that it can happen. Furthermore, the 1957 flood event is proof of the devastation that can happen in the area. The only difference is that, the area was not inhabited by a lot of people then. Therefore a flood event of that nature or greater may have a more devastating impact on the lives of the current Barcelonnette Populous since more people resides in the area. The 1957 flood occurred many years ago and so may not active in the minds of the residents and may be unknown to the new migrants.

Various stake-holders are interested in research that is centred towards floods since majority of the research that have been done in the area pertains to debris flow and landslides. There is therefore, the need for a study that incorporates different flood scenarios with perception of the people at risk in Barcelonnette.

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Results from the survey showed that while few of the respondents were directly affected by a flood event, majority of them were aware of the possibility of a flood occurring in Barcelonnette.

While the Municipality is ardent at implementing permanent structural measures, it simply cannot afford the exuberant amount of money that the project would cost especially in an economy marred by recession. Private organizations should therefore provide funding for the plans that could improve the mitigation measures in the area.

4 Conclusions

The paper presents a critical review of structural measures that were taken to cope with floods in some cities along the Danube, such as Vienna, Bratislava, Belgrade, and Barcolennette area along the Ubaye River. These cities have also been taken as case studies within the KULTURisk project. Based on the review of the structural measures in each particular case study, the following general conclusions can be drawn:

1. Because flood defences can be very costly to design, construct, and maintain, the flood control projects are in general very expensive and take years to complete. In the cities of Vienna and Belgrade the construction of flood-protection system started in 1970s, but still has not been finished. Because local communities usually can not afford the great amount of money the significant investment by governments would be required.

2. The level of flood-protection in the city of Vienna is assured against approximately 10.000-year flood. On the other hand, in the cities Bratislava and Belgrade, the level of this protection is assured against 1000-yr flood.

3. Analysing the flood defense system measures in the case studies, it can be concluded that even with significant investment, flood risk can be reduced but not completely eliminated. Thus, almost in all case studies further flood mitigation measures will still be needed to address this residual risk.

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4. For sufficient, appropriate, and successful flood protection along the international rivers, a good transboundary cooperation is indispensable. This depends above all on understanding and respecting the problems and needs of transboundary partners as well as the causes of these problems with respect to natural and social processes. For progress to occur, common goals and agreed strategies are needed, as well as in some cases, compensation mechanisms to balance advantages and burdens. These can be only reached if the partners get to know each other by working frequently together and have shared access to all relevant information, thus creating the necessary level of trust.

5. In the future, the concept of the flood defence system will have to be based on modern world trends, which are to be introduced respecting the current conditions of the system and economic possibilities of the society.

6. As flood safety cannot be reached in most vulnerable areas with the help of structural means only, further flood risk reduction via non-structural measures is usually indispensable (Kundzewicz, 2002a,b), and a site-specific mix of structural and non-structural measures seems to be a proper solution.

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References

Babić Mladenović, M., Knežević, Z., and Varga, S.: Water as a determinant of the development of the Belgrade region (in Serbian), in: Belgrade and its region, Belgrade, Faculty of Geography, 371 pp., 2003. 258, 259

Brilly, M.: The integrated approach to flash flood management, in: Coping with Flash Floods, Edited by: Gruntfest, E. and Handmer, J., Kluwer Academic Publishers, Dordrecht, 103–113, 2001. 258

EEA: Mapping the impacts of natural hazards and technological accidents in Europe, Technical report No. 13/2010, European Environment Agency (EEA), Copenhagen, Denmark, 146 pp., 2010. 248

Flageollet, J. C., Maquaire, O., Martin, B., and Weber, D.: Landslides and climatic conditions in the Barcelonnette and Vars basins (Southern French Alps, France), Geomorphology, 30, 65–78, 1999. 272

Kreibich, H. and Thieken, A. H.: Coping with floods in the city of Dreseden, Germany, Nat. Hazards, 51, 423–436, 2009. 259

Starosolszky, Ö.: Flood control in the Danube countries, in: Coping with Floods, edited by: Rossi, G., Harmancioğlu, N., and Yevjevich, V., Kluwer Academic Publishers, Dordrecht, 653–666, 1994. 251

Milanović, A., Urošev, M., Milijašević, D.: Floods in Serbia in the 1999–2009 period: Hydrological analysis and flood protection measures (in Serbian), Glasnik Srbskog Geografskog Društva, 90, 93–121, 2010. 258

Kundzewicz, Z. W.: Flood protection in the context of sustainable development. The Extremes of the Extremes: Extraordinary Floods, Proceedings of a symposium held at Reykjavik, Iceland, July 2000, IAHS Publ. no. 271., 361–366, 2002. 263

Kundzewicz, Z. W.: Non-structural Flood Protection and Sustainability, Water International 27, 3–13, 2002. 263

Lecarpentier, C.: The flood of June 1957 and its morphodynamic consequences. Ph.D Thesis. University of Humanities and Social Sciences, Strasbourg, France, 319 pp., 1963. 260

Smith, K.: Environmental hazards: assessing risk and reducing disaster, London; New York, Routledge, 392 pp., 2001. 248

Henry, S. T.: Flash Flood Scenario Modelling for Preparedness and Mitigation: Case Study of Barcelonnette, France MSc Thesis Report. Master “Geo-Information Science and Earth Observation for environmental Modelling and Management”, ITC / University of Twente, Enschede, Netherlands, 75 pp., 2010. 261

Weber, D.: Research into earth movements in the Barcelonnette basin, in: Temporal occurence and forecasting of landslides in the European Community, edited by: Casale, R., Fantechi, R., and Flageollet, J. C., Final report, Volume I., Contract EPOCH, European Commission, 321–336, 1994. 259

Table 1. Technical data about flood protection system in the city of Vienna.

Hydraulic/hydromechanics data	Construction data
– Design flood: 14 000 $m^3 s^{-1}$ – Danube discharge rate: 8800 $m^3 s^{-1}$ – New Danube discharge rate: 5200 $m^3 s^{-1}$ – Length of New Danube/Danube Island: 21 km – Width of New Danube: approx. 200 m – Bed slope of the Danube/New Danube: 0.046 % – Water depth in the New Danube at design high water: 11.5 m – Width of Danube Island: 70–210 m – Flood–free surface of Danube Island: 390 hectares – Intake structure: 5 sluice gate sections, each 24 m wide – Sluice gate 1: 5 sluice gate sections, each 24 m wide – Sluice gate 2: 5 sluice gate sections, each 30.6 m wide	– Amount of material excavated for the New Danube canal: 28.2 million m^3 – Portion used to create the Danube Island: 23.8 million m^3 – Humus: 1.5 million m^3 – Rocks used as bottom protection structure: 1.3 million m^3 – Rocks for bank protection (riprap): 0.5 million m^3 – Length of cycling/walking paths on Danube Island: approx. 135 km – Concrete Edging stones: 390 000 m^3 – Bulkheads: 36 000 m^3 – Quay walls: 7.3 km

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Table 2. Technical data of the flood protection measures taken in the city of Bratislava.

Structural measure	Quantity
Construction underground wall	860 m
Groundwater sealing wall (injection)	14 460 m
The sealing film (foil)	125 000 m^2
Protective levee, dam	2760 m
Flood parapet	5640 m
Mobile elements	3600 m

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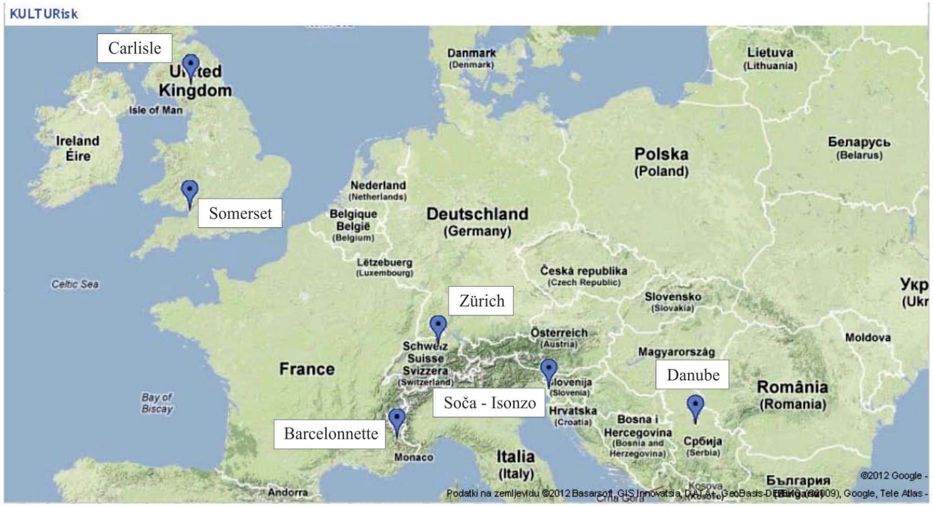

Fig. 1. Map of the Kulturisk case studies.

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Fig. 2. Map of the Danube River Basin; (http://en.wikipedia.org/wiki/File:Danubemap.jpg).

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Fig. 3. The Danube Island; (http://www.viennaresidence.com/files/800px-Wiener_Donaubruecken.JPG).

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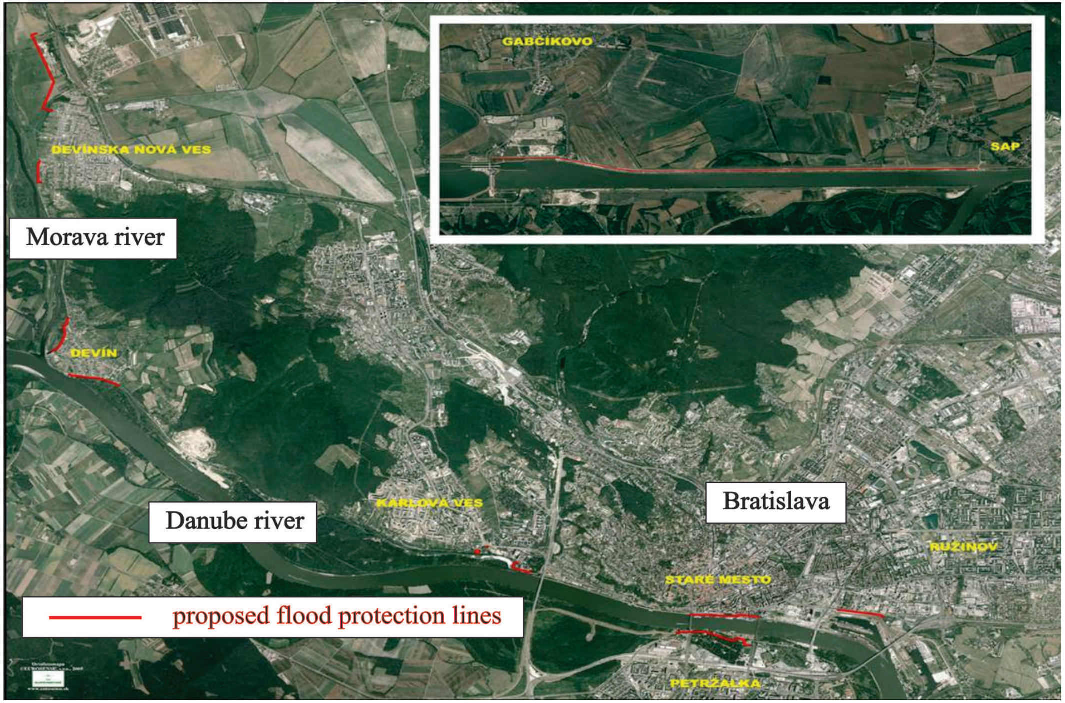

Fig. 4. Proposed flood protection lines in the city of Bratislava and its neighbourhoods.

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Fig. 5. Various structural flood protection measures in the city of Bratislava; **(a)** concrete wall, **(b)** underground sealing wall, **(c)** reinforced concrete wall, **(d)** mobile flood wall.

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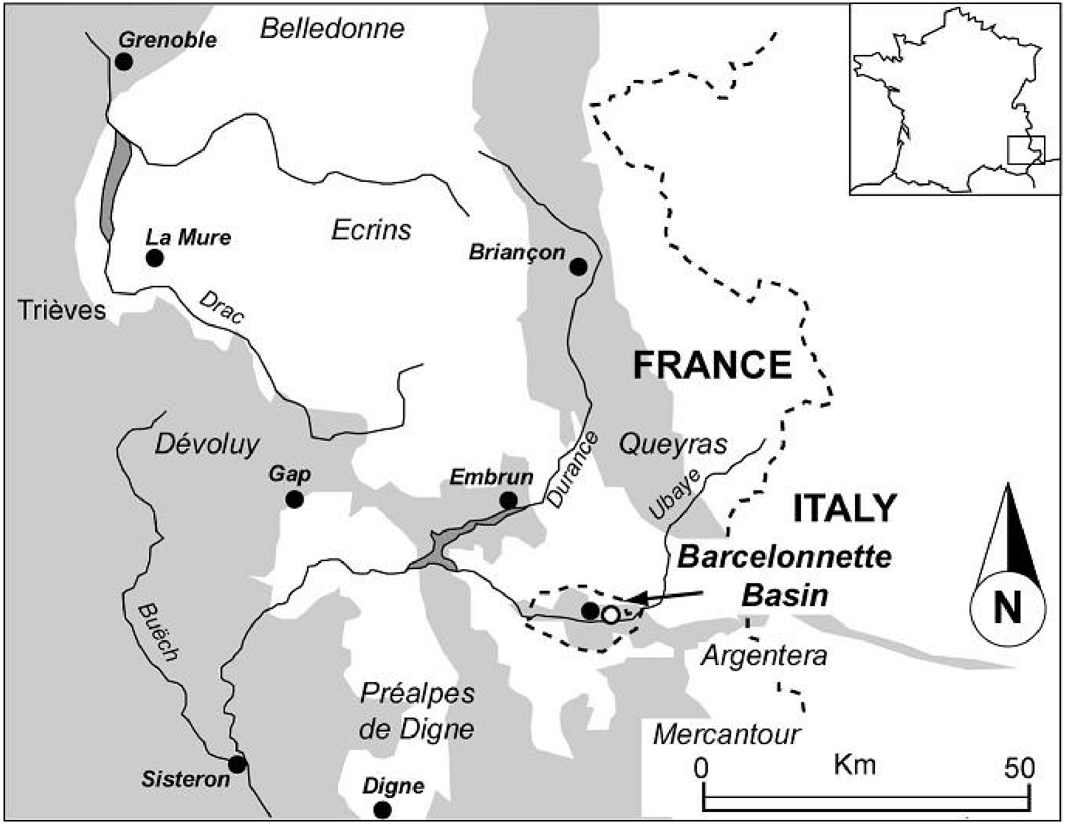

Fig. 6. The location of the Barcelonnette basin; source http://www.unicaen.fr/mountainrisks/spip/spip.php?article47 and (Flageollet et al., 1999).

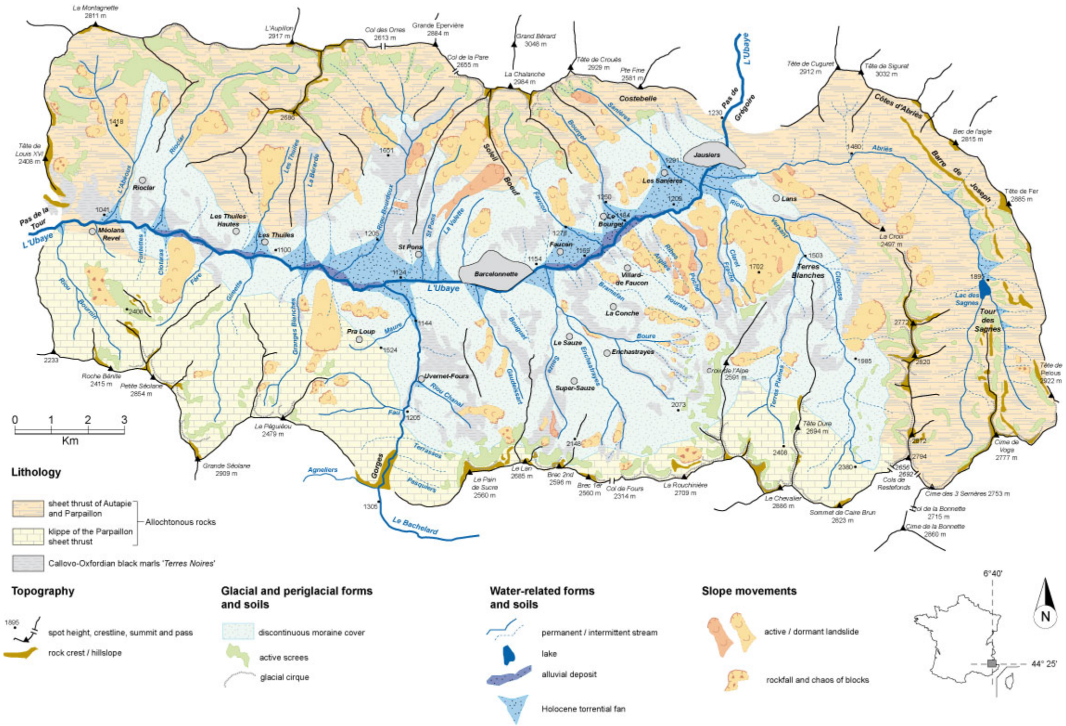

Fig. 7. Geomorphological map of the Barcelonnette area; source: http://eost.u-strasbg.fr/omiv/images/Morpho_Barcelonnette_eng.jpg.

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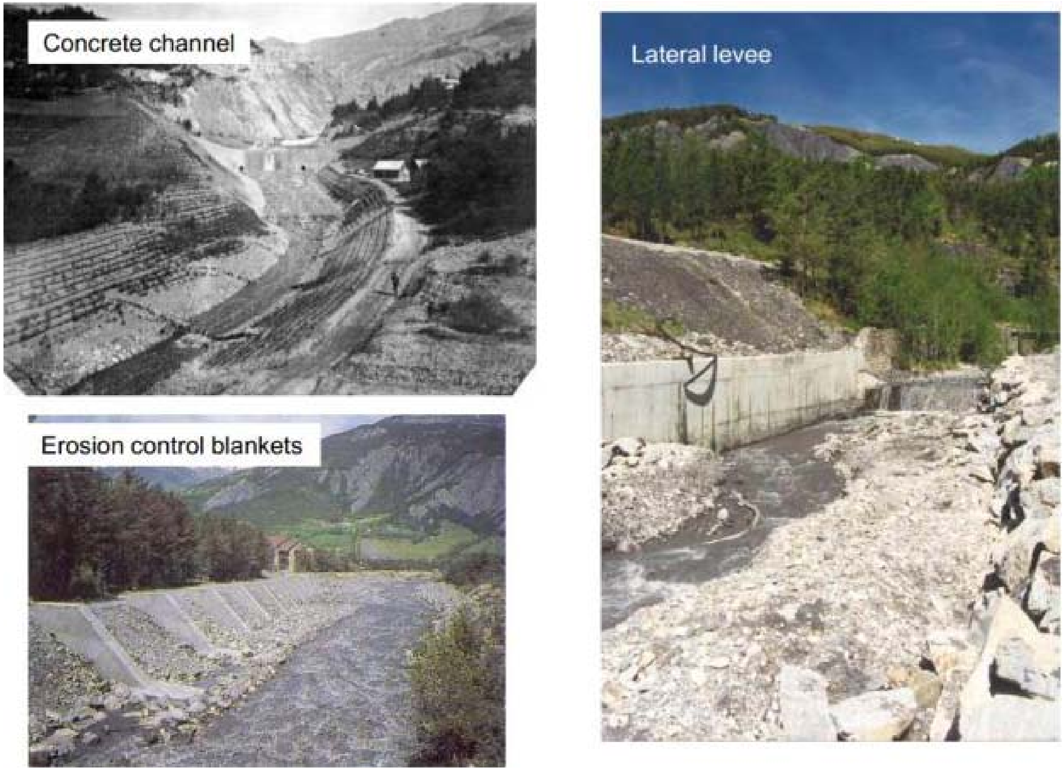

Fig. 8. Some structural measures to cope with flash floods in the Barcelonnette area.

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