Referee #2		
We would like to thank the Referee for convenient suggestions and comments. Below are responses on his/her comments.		
No.	**Reviewer's comments**	**Authors' responses and revisions**
Specific comments		
The paper has been reviewed by the professional anglicist and the paper has been corrected accordingly to her suggestions.		
P248/L12-13	You write "Severe floods in 2005 further reinforced the need for concerted action." But you don't mention where these floods caused damage; try to be precise throughout the text	The text has been updated with the specific information where the floods in 2005 happened.
P249/L1-4	Who/which institutions are involved in KULTURisk? I think this is information that you should necessarily give; either here or in section 2	We think that an interesting reader could easily find the partner in Kulturisk project…we add the URL to the project web page…we think that this information does not belong into the text.
KULTURisk – Project description		
P249/L12 P249/L14 P249/L18-20	I guess section 2 (KULTURisk – project description) could be drastically shortened and easily integrated into the introduction (second paragraph). Some statements made here are repetitive (e.g. development/ improvement of the culture of risk prevention at lines 1 and 10). P249/L12: any kind (organizational and structural) of "risk prevention measures"? P249/L14: Does that imply an improved record keeping of past damage events/disasters? P249/L18-20: again, this is repetitive. You mention the goals/objectives of KULTURisk (e.g. the "promotion of a culture of risk prevention") here even though they were already address above (P249/L1 and P249/L10). Please try to be concise in the description of KULTURisk.	The section "KULTURisk – project description" has been removed from the paper. Instead of repetitive description, the URL address of the project, namely http://www.kulturisk.eu, has been inserted in the **Introduction** where a few words about the project KULTURisk has been written. Thus, an interested reader could find additional information about the project.
Case studies		
P249/L17-23	Why are case studies listed here that are not discussed in the article (e.g. Zurich, Carlisle etc.)? This is very confusing. I think it is important to very clearly and unambiguously distinguish between the KULTURisk project and the investigations described in the present paper. If you must present all case studies, I suggest you do it in section 2, or in the introduction (cf. comment above regarding the project description). However, I do not think it is necessary.	We agree. The KULTURisk case studies that are not discussed in the paper are removed from the text.
	What is the basis of your choice? I think you should add a sentence or two explaining why	Agree. We add a sentence to explain why the cities like Vienna, Bratislava and Belgrade were

	you picked the Danube cities (Vienna, Bratislava and Belgrade) and Barcelonnette. At P251/L8 you mention that the Danube River flows through four European capitals. Here too, I would like to know the basis of your choice (Vienna Belgrade and Bratislava). Why is Budapest not included in your review?	chosen in the Danube case study. In fact, we choose those cities because we have data regarding to flooding in those cities. In the future, it will be necessary to include the Budapest in the analysis.
	For the Danube case studies (Vienna, Bratislava and Belgrade) I miss a short table, giving some basic information: (i) distance from source; (ii) catchment size for the location of the respective city; (iii) discharge data available (years, resolution); (iv) peak discharge for flood with 100y return period.	The table which gives some basic information has been added to the text.
P251/L17-18	Give approximate information: when was Vienna founded?	This has been done.
P251/L17-18	Again, to what age/epoch/century does the following sentence refer to? "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."	This has been done.
P251/L21	When was decision taken to control the river? The answer is given at line 25 (1869). Please minimize the repetition!	The text has been slightly changed.
P252/L5-8	Can you give a few details (just 1-2 sentences) on the 1897, 1899, and 1954 flood events (which was the worst flood? which areas were flooded? was there much damage?).	This has been done.
P255/L2-3	I would start this description section by putting the Bratislava case study into relation with the Vienna case study (3.1.1). For example: how far downstream from Vienna is Bratislava? Also, did the huge flood protection project in Vienna (New Danube/New Danube Island) have any influence on the occurrence and size of flood events in Bratislava?	This has been done.
P255/L4	Do you mean Danube floods? ("These regions have been prone to floods for many years…")	Yes. We mean the Danube floods. The text has been changed. The adjective "Danube" has been added to floods.
P255/L5-6	Does the statement "Historically the Danube floods at Bratislava most often occur in May and June." also apply for Vienna? After all, the two cities are located close to each other. Also I think the three following sentences from line 6 to line 10 ("The flood of August 1501 […] (1594, 1598, 1670, and 1682).") should be integrated in 3.1.1 (somewhere between lines 5 and 12 at page 252) because they apply to both the cities of Vienna and Bratislava. In any case there is a need to better coordinate the two site descriptions of Vienna and Bratislava.	The text "an also at Vienna" has been added where we said that "Historically the Danube floods at Bratislava most often occur in May and June." Now: "Historically the Danube floods at Bratislava (an also at Vienna) most often occur in May and June." The suggested sentences have been moved to the section 2.1.1.
P255/L21-23	Please be accurate! When (year) were these main flood protection measures taken?	This has been done.

P256/L2-5	Are the activities described here ("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") the same as described above (P255/L21-23)? When were they planned? When were they built? Specify please.	The text has been slightly changed.
P256/L8-9	The last sentence of this section is a bit out of context. Maybe it needs to be reformulated. What is the estimated "water level"? Do you mean the water level for a 1000 year peak flow?	The text has been changed from flow…to…a peak flow in Bratislava.
P256/L8	Reading section 3.1.1, one could infer that a runoff of 14'000 m_3/s represents a flood with a 10'000 year recurrence interval in Vienna. Here it is stated that a 13'500 m_3/s runoff has an estimated return period of 1000 years. Is it possible that similar discharges result in such a large difference of the return periods?	Yes, the values for Q10000 (Vienna) and Q1000 (Bratislava) are close together. We did not calculate those discharges, but, on the other hand these discharges were determined by two different group of experts from two different countries (Austria and Slovakia). Which result is better, we do not know…
P256/L11-15	This information is required in the sub-section above (Structural measures, P255/L21-26). Why do you describe the measures taken in the sub-section above, but give the framework information here? Please adapt your text.	The sub-section "**Experience**" has been merged to the sub-section "**Structural measures**".
	P257/L6-7: At the end of the first sentence, indicate the distance downstream between this case study and the former case study (Bratislava) to put them into relation.	This has been done.
	P257/L16-17: Why are no discharge values given here (instead you mention water levels)?	The water levels are given here are because this was the only data that we had, see (Babić et al, 2003). The water level mentioned here is the design level determined by "Iron Gate I Hydroelectric power station".
	P257/L5-25: The two sub-sections "Description" and "Structural measures" are not well coordinated. The latter one contains information required in the upper one (or repeats information already given in the upper one). I guess this should be revised.	The subsetions "**Description**" and "**Structural measures**" have been merged.
	P258/L1: Is the "urbanized lifted area" you mention here the same area that you describe in the sentence before (the new part of the town that was constructed in the 1960s)? Please clarify.	The sentence has been changed.
	P258/L22-24: Which rivers are "the rivers with flash flood regime"? Sava? Danube? Please clarify!	This has been done. "The Danube tributaries"
	P258/L25-26: In "Much of the area is still actually threatened by floods", which area do you mean? Do you mean the city area, the area of the Belgrade municipality? Please clarify!	This has been done "the Belgrade city area"
	P259/L13-24: In the sub-section below, emphasize on the contrast between the three lowland case studies along the Danube (all dealing with large-scale inundations) and this case study which is located in a mountainous	A transition sentence has been given in the beginning of the sub-section.

	environment. The contrast is large and needs a transition (just 1-2 sentences).	
	P260/L1-28: These four paragraphs are not well organized. It is very difficult to figure out what happened when. The authors jump from one event to the next and then back. I suggest introducing and briefly describing the 1957 flood right after the first paragraph. Then describe the flood of 2008 and comment on the damage caused by these two flood events. After reviewing these past events you can describe the present situation and the measures planned for the future. Also, it is difficult to keep the subsections "Structural measures" and "Experience "apart.	The events are related to each other, but it is difficult to describe them simultaneously.
	P260/L1-28: Is the return period of the 1957 and 2008 floods known? If so, state it in the text.	We do not know this data.
	P261/L7-23: The second and third paragraphs of this sub-section are quite confusing and not well written. They should be thoroughly revised and synchronized with the "Structural measures" sub-section. E.g. at line 12 Dutch are mentioned that were surprised by an unexpected flood scenario: have I missed something? Who are these Dutch? Were Dutch people mentioned anywhere in the MS?	The text has been rewritten. The Dutch have been removed from the paper.
	P262/L1: Is the "survey" mentioned here the same as the "study" mentioned at P261/L26? Please clarify.	This has been done.
	P262/L7: Which "plans" are you referring to? Are these plans related to the decision taken by the municipality described at P260/L5-9?	The text has been corrected to "flood protection plans made by municipality"..
Conclusion		
	Consider adding a sub-paragraph to your list in which you briefly discuss risk-communication (e.g. the interaction with the threatened population.	We agree. This would be a very interesting topic to discuss but this will be the subject of our next paper.
	P262/L25-26: What kind of "further flood mitigation measures? I don't think I understand your point. If flood risk cannot completely be eliminated and some residual risk remains, then you have to elaborate strategies to deal with this residual risk. But you can't apply additional measures to further reduce the residual risk. Or can you? Is it not conceivable to accept the residual risk? At some point prevention just gets too expensive and will never solve all problems (as you correctly state in point 3). Also, prevention is often related to ecological problems. And, if minimal residual risk is accepted by decision makers, the communication with population is essential (cf. comment above).	We agree. The text has been slightly changed.
Reference list		

	For a review article, the reference list is rather shortish. Maybe you can add a few references of articles/contributions describing the different Danube/Barcelonnette flood events mentioned in section 3.	Some references have been added.
Technical corrections		
Abstract & Keywords		
P248/L4	change to "and the Barcelonnette area" Barcelonnette is also misspelled at P262/L11	This has been done.
P248/L4	consider changing to "were also chosen" (instead of "are also taken")	This has been done.
Introduction		
P248/L12	it would be more precise to write "in August 2002."	This has been done.
P248/L18-19	rephrase this sentence (syntax error)	This has been done.
P248/L23	change to "the fact that floods are a natural phenomena,"	This has been done.
P248/L24-26	consider changing to "In view of this, a project called «Knowledge-based approach to develop a culture of risk prevention» (KULTURisk) was launched in YYYY. It is currently ongoing and focuses specifically…"	This has been done.
P249/L5	delete "solely"	This has been done.
P249/L6	consider changing to "to protect agglomerations against flooding"; instead of agglomerations you could also use municipalities or cities	This has been done.
Case studies - Danube		
P251/L9	consider changing to "passes through or flows along the borders of"	This has been considered.
P251/L11	consider changing to "in a transnational river by"	This has been considered.
P251/L14	change from "to cope with flood along" to "to cope with flooding along"	The text has been changed.
P251/L23	consider changing to "The establishment of a secure port close to the city…"	This has been considered.
P252/L11	consider changing to "which corresponds to the estimated peak flow discharge during the largest flood event"	This has been considered.
P252/L12	consider changing to "A number of flood protection studies focused on increasing"	This has been considered.
P252/L19	consider changing to "(the «Danube Island», see Fig. 3)."	This has been considered.
P252/L19-20	change to "The excess water would be directed" instead of "In such a proposal, the excess water would be directed"	The text has been changed.
P252/L22-23	change to "Works for this project started in March 1972. It took 17 years to complete the New Danube canal and the Danube Island."	The text has been changed.

P252/L24-26	The protection system does not have a return period, the flood does; thus, consider changing to: "It is estimated that the Vienna flood protection system can manage flows with a return period of around 10000 years, which is one of the highest safety levels in Europe."	Agree. The text has been changed.
P253/L7-8	consider changing to "two weirs are used to maintain the water level in the New Danube"	The text has been changed.
P253/L10-11	consider changing to "whose discharge capacity amounts to about 5200 $m^{-3}S^{-1}$." instead of "which can take up to 5200 $m^{-3}S^{-1}$."	The text has been changed.
P253/L17	consider deleting "accordingly"	The word "accordingly" has been removed.
P253/L21	delete "surface" or even delete "surface area"	Done.
P253/L23	consider changing to "The flood protection project was implemented"	This has been considered.
P253/L27	Please clarify the difference highlighted below: 4 years (P253/L27) + 15 years (P254/L1) = 19 years P252/L22: "it took 17yr to complete […]"	
P254/L2	consider changing to "since in the 1990s, a hydropower plant…"	This has been considered.
P254/L3	delete "led to" at the end of the line	Done.
P254/L5-6	consider changing to "…within the city, and led to ecological improvement."	Done.
P254/L7	change to "The project allowed for the transformation of…"	The sentence has been changed.
P254/L16	consider changing to "…such as the introduction of a new subway line,"	Done.
P254/L18-19	consider writing "on the left side of the Danube" instead of "on the other side of the Danube"	The sentence has been changed.
P254/L24	use "would become" instead of "will become"	Done.
P255/L4-5	write "storm rainfall events" instead of "storm rainfalls events"	Done.
P255/L6-7	change to "The flood of 1501 can be considered the highest flood…"	Done.
	add a bracket → "(1594, 1598, 1670, and 1682)."	Done.
P255/L18-19	Simplify as follows "Since 1920, there have been two such floods, they occurred in July 1954 and in August 2002."	The sentences have been simplified.
P255/L23-26	Poor phrasing, repetitive; consider changing, e.g.: "These measures were established to address gaps in the existing Danube flood protection system and to cope with under protected areas on Slovak territory in general and the Bratislava area specifically."	We agree completely. Done.
P256/L4-5	consider changing to "These structures include dams, levees…"	Done.
P256/L7	consider changing to "All these structures are designed for a peak flow in Bratislava corresponding to…"	Done.
P256/L14-15	I would change the text as follows: "… while the construction started in 2007 and was completed in December 2010. The objectives of the project «Bratislava – Flood protection» are listed below; they were all completely achieved."	The text has been changed.

P257/L3	delete “were completely achieved” (cf. comment above)	Done.
P257/L7	add reference to Figure 2 → “… and the Sava Rivers (Fig. 2).”	Done.
P257/L11	consider changing to “of the area” (instead “of this area”)	Done.
P257/L12	Because it is a new paragraph, it would probably be good here to state again that you are speaking of “the left side of the Sava (?) River bank” (instead of referring to “the area” again)	The sentence has been rewritten.
P257/L12-13	change to “the government of the Federal People Republic of Yugoslavia.	Done.
P257/L15-16	The sentence “The layer of excavated sand from the Danube main channel…” seems a little out of context here and difficult to understand. When was sand excavated and why?	Premisli in napiši.
P257/L19	consider starting the sentence as follows “Subsequently, a study was…”	Done.
P257/L23	use “km^2” instead of “square kilometers”	Done.
P257/L23	delete “Serbia”, it has been mentioned before and is obvious here	Agree. Done.
P258/L4	consider writing “most of the urban flood protection” (instead of “the largest volume of urban flood protection”)	Done.
P258/L9	do you mean “only 3.5km of levees have been built and approximately 1.6 km of Sava River banks was regulated”?	Yes. It is better to write the sentence this way.
P258/L11	change to “Nowadays, flood control along the Danube and…”	Done.
P258/L15-18	some information in this paragraph is repetitive (cf. P257/L16-17; consider rephrasing	This has been done.
P258/L21	use “significant decrease” instead of “significant reduction”	Done.
P259/L1	do you mean “the potential risk of flooding still exists”?	Yes, the sentence had been rewritten.
P259/L4	the comment on maintenance is repetitive (cf. P258/L20); I suggest you delete it here	The sentence has been deleted.
P259/L7-12	this could be concisely rewritten as follows: “…a new implementation of the flood-protection system of the city of Belgrade has to be proposed as soon as possible. The level of flood-protection should be increased to provide security against floods with a 200 year return period. Eventually, the goal should be to assure protection against 1000 year floods. The latter can be achieved with the combination of fixed facilities with prefabricated or mobile elements (Kreibich and Thieken, 2009).”	The text has been concisely rewritten as suggested by the reviewer.
Case studies - Barcelonnette		
P259/L16	add a reference to Figure 6 at the end of the sentence	Done.
P259/L17	“km^2” instead of “km^{-2}”	Done.
P259/L19	add a reference to Figure 7 at the end of the sentence	Done.

P259/L20-21	consider changing to “natural hazard processes” instead of “natural hazards”	Done.
P259/L22	delete the sentence “Figures 6 and 7 show a map of the study area.” (cf. comments above for Figs 6 and 7)	The sentence has been deleted.
P259/L22-24	consider changing and simplifying as follows to “Because records of hazards covering the period from 1850–2006 show that the area is mainly affected by floods (Weber, 1994), the emphasis of this case study will be devoted to the flash flood problem.”	The text has been changed and simplified.
P260/L2	change to “The Barcelonnette basin has an elongated form which makes it highly …”	Done.
P260/L6	“happens again” instead of “happen again”	Done.
P260/L6-9	simplify as follows: “the municipality has decided to take the following measures: increase the dike height by 1.5 m in some areas, renovate sections of the river banks, reinforce the concrete embankments, build sheet piles at the “shoreline of scouring”, and increase the height of the embankment of the bridges.” Please specify when this was decided by the municipality!	The text was simplified. The time when this was decided has benn stated.
P260/L11-15	There is something wrong with the syntax of the long sentence that starts at line 11; please rephrase. Try to write in short and concise sentences.	The sentence has been rewritten.
P260/L1-28	spell dyke/dike consistently throughout the text	Done.
P260/L15	“These actions” instead of “This actions”	The text has been deleted.
P260/L22	be consistent with units, use the same units throughout the article (here 0.6 m instead of 600 mm)	Done.
P260/L22	change to “Also important to note is that the construction of check dams along the tributaries is a continuous process. Every year new infrastructure is being built to reduce the…”	Done.
P260/L28	write “is to find a solution to…”	Done.
P261/L4	change to “…the risk of flood events, such as the 2008 flood…”	Done.
P261/L20-23	Just one example of three poorly written sentences; consider changing to “Therefore, a flood event of that size or greater may have an even worse impact on the current Barcelonnette population since more people reside in the area. Moreover, the 1957 flood occurred more than 50 years ago and thus may not be remembered by many residents and may be unknown to recent settlers.	The text has been included in the paper.
P262/L1-2	consider changing to “…respondents had been directly affected by a flood event, the majority of them…”	Done.
P262/L4	consider changing to “While the municipality is enthusiastic to implement…”	Done.
Conclusions		
P262/L10	consider changing to “in three cities along the Danube (Vienna, Bratislava, and Belgrade)	Done.

	and the Barcelonnette…"	
P262/L11	consider changing to "These cities were also selected as case studies…"	
P262/L16-19	this point is a bit confusing, change to "In the cities of Vienna and Belgrade the construction of flood-protection systems started in the 1970s, but could not be finalized yet. Because local communities usually cannot afford the costs resulting from large mitigation projects, significant investments by governments are required." However (!), at P254/L15 you mention the "completion of the project", which is contradictory to the statement you make in Point 1 of the conclusions. Was the "New Danube" project ever finalized or not?	Done.
P262/L20-21	consider changing to "The level of protection in the city of Vienna is assured against floods with a recurrence interval of 10'000 years."	Done.
P262/L22	write "level of protection" (instead "level of this protection")	Done.
Specific comments on figures and tables		
Figure1	In my opinion you should only indicate the location of the case studies discussed in the present study. As many of the KULTURisk case studies are not further described, it's rather confusing to see them on this overview.	Agree. A new figure 1 has been placed to the text.
Figure4	What does the inset of this figure show? It's unclear. How are Fig. 4 and Fig. 5 related? What structures are planned along the "flood protection lines"?	In the caption it is stated that this figures shows flood protection lines that were proposed by the project of flood protection in the city of Bratislava. It is not intended to specifiy which measures are taken where…but just to show where are some measures taken…
Figure5	Put a reference to Table 2 in the caption: "Various structural flood protection measures in the city of Bratislava (cf. Table 2); …"	The reference has been placed.
Figure6	The black dots seem to represent towns/cities. Is the city within the case study Barcelonnette? And what does the white dot represent? What do the names in *italics* represent?	Fig. 6 has been removed from the text. See comment below.
Figure6/7	Do you need both figures?	Agree. The figure 6 has been deleted because all the information is already shown in Fig.7
Table 1 and 2	I think the two tables should be better coordinated (e.g. why is there no information on the design flood for Bratislava) Furthermore I think the reader would benefit from information on the Belgrade flood protection system/measures.	The flood Q100 of all Danube case studies is now given in Table 1. All this information is given in the text. With a new Table the information will be repeated.

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

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Abstract. The paper presents a review of structural measures that were taken to cope with floods in some cities along the Danube River, such as Vienna, Bratislava, Belgrade, and Barcelonnette area along the Ubaye River. These cities are also taken as case studies within the KULTURisk project. The structural measures are reviewed and compared to each other according to the type, duration of application, the return period of design flood event, how the project measures are integrated into spatial planning and the problems that occur today in the flood defences. Based on this review some suggestions are given how to improve the flood risk management 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 August 2002. Severe floods in 2005 caused by tributaries of the Rhine in Switzerland and Austria, and by several tributaries of Danube in Germany, Austria and Hungary, as well as in Serbia and Romania, further reinforced the need for concerted action. Between 1998 and 2009, floods in Europe caused around 1126 human fatalities, the migration of about half a million people and at least 52 billions Euros 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 we are likely to see a higher flood risk in Europe and greater economic damage, a new EU flood directive "Directive 2007/60/EC" has been proposed by the European Commission. Its aim is to prevent and reduce the damage caused by floods (e.g. environmental damage, damage to the cultural heritage and economic activity, etc.), and

to emphasize that despite the fact that floods are a natural phenomena, their likelihood and impacts can be significantly reduced if adequate and coordinated measures are taken. In view of this, a project called "Knowledge-based approach to develop a culture of risk prevention" (KULTURisk) was launched in 2010. It is currently ongoing and focuses specifically on water-related hazards. It 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. For further details about the project an interested reader is referred to http://www.kulturisk.eu.

The focus of the present paper is to present the structural measures that have been developed over the years to protect agglomerations 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 Case studies

The main objective of this section is to provide and review the two KULTURisk case-studies focusing mainly on flood protection measures collected from two European regions and river basins, see Fig. 1. These case studies are the following:

- Danube case study (many countries, trans-boundary large river, large-scale inundations)
- Barcelonnette case study (France, mountainous catchment, landslides and debris flows)

For information on the other KULTURisk case studies see e.g. http://www.kulturisk.eu/case-studies The main emphasis of the next subsection will be mainly on the review of the structural measures for flood protection in the cities along the Danube River, such as Vienna, Bratislava and Belgrade. Furthermore, the Barcelonnette area along the Ubaye River was also chosen as a case study where flash floods often occur and thus different structural measures were considered compared to the Danube case study.

2.1 Danube

The Danube River Basin is shared by 19 countries and there is no river basin in the world shared by so many nations. Europe's second largest river basin with a total area of about 800.000 km^2 is also a home to 83 million people of different cultures, languages, and historical backgrounds (Brilly, 2010). Besides, 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 flows along the borders of ten countries, see Fig. 2. An interesting review of hydrological processes and many other things related to the Danube River basin are presented in

The Danube case study of the KULTURisk project focuses specifically on the socio-economic effects of large-scale inundations in a transnational river by applying the risk-based methodologies developed in this project. Besides, this case study will further pay attention also to a critical and comprehensive review of the flood mitigation measures taken to cope with flooding along the Danube, specifically in Vienna, Bratislava, and Belgrade. Some basic information about these cities related to the Danube is given in Table 1.

2.1.1 Vienna

Description

The city of Vienna has been exposed to severe flooding of the Danube since its foundation, i.e. since 500 BC. 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 in the 19^{th} century. The establishment of 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 of Vienna with structural measures (Starosolszky, 1994). 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 had been 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, especially concerning the right bank of the Danube at Handelskai ("Trade pier"). Furthermore, the largest flood on the Danube in the last century, in July 1954, 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 flood of 1501 can be considered the highest flood 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 14000 m^3 s^{-1}. There is also some evidence of floods in the 16^{th}–17^{th} centuries (1594, 1598, 1670, and 1682). Thus, the result was a generally accepted figure of 14000 m^3 s^{-1}, which corresponds to the estimated peak flow discharge during the largest flood event of the upper Danube, occurred in August 1501. A number of flood protection studies 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). This was done by a political decision supported by the referendum. Hence, 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 years 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 Vienna flood protection system can manage flows with a return period of around 10000 yrs, 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 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, the discharge capacity amounts to about 5200 $m^3\ s^{-1}$.

An overview on the main technical information about the Vienna flood protection project is shown in Table 2. 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 to create banks with a more natural shape. Also, the City of Vienna eventually decided that, in addition to serving as flood control, the New Danube and the 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 is used mostly as a leisure park.

Experience

The flood protection 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 bi-lateral or multilateral assistance was included. The budget was planned on a long term basis together with the Ministry and earnmarked in annual construction rates. The planning and permitting process took approximately 4 yrs, while the construction of the main elements (New Danube and Danube Island) took about 15 yrs. New components to the original project became necessary since in the 1990s, a hydropower plant was built on the Danube within the project area. The flood protection project 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, and led to ecological improvement. The impact of the project was even more positive than envisioned during the decision-making and design period. The project allowed for 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 introduction of 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 left 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 would become such a major attraction for all Viennese.

2.1.2 Bratislava

Description

Bratislava is the capital city of Slovakia. It is situated in central Europe. Bratislava is situated approximately 62 km from Vienna. The Danube river distance from Bratislava to Vienna is only 65 km, see Table 1. That is way the flood regimes for both cities are very similar. As a result, some parts of Bratislava, particularly Devín and Devínska Nová Ves, are vulnerable to the Danube floods. These regions have been prone to the Danube floods for many years due to storm rainfall events especially during the snowmelt period. Historically, the Danube floods at Bratislava (and also at Vienna) most often occur in May and June. 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, a total of 4 floods are encountered with peak discharge exceeding 10000 $m^3 s^{-1}$. Since 1920, there have been two such floods, they occurred in July 1954 and in August 2002.

Structural measures

Main flood protection measures taken between 2007 and 2010 to cope with floods are located in the south-western part of Slovakia on the border with Austria and Hungary and include the city area of Bratislava with its neighbourhoods, see Fig. 4. These measures were established to address gaps in the existing Danube flood protection system and to cope with under-protected areas in the Slovak territory in general and the Bratislava area specifically. High flow of the Danube during extreme floods can have disastrous consequences, such as flooding of the 383 km^2 built-up urban area and 2000 km^2 of agricultural land, which would directly affect some 490000 people. The above-mentioned structural flood mitigation measures include reconstruction of existing and construction of new flood control structures on both sides of the Danube. These structures include dams, levees, reinforced concrete protective walls, mobile elements, etc. (Fig. 5). For technical review of the type and amount of the measures built see Table 3. All these structures are designed for a peak flow in Bratislava corresponding to 13500 $m^3\ s^{-1}$ which has an estimated return period of around 1000 yrs. For the Danube, the requested security freeboard was 0.5 m above the estimated water level.

Finally, we should emphasize that 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 was completed in December 2010. The objectives of the project "Bratislava-Flood protection" are listed below; they were all completely achieved:

- 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 in the Gabčikovo municipality,
- prevention of economic damages in the project area including the capital city Bratislava and its neighbouring municipalities,
- prevention of environmental damages in the project area, including prevention of contamination of drinking water sources.

2.1.3 Belgrade

Description and structural measures

Belgrade, capital of the Republic of Serbia, is situated on the confluence of the Danube and the Sava Rivers (Fig. 2). The city of Belgrade is situated approximately 450 km from Bratislava. The Danube river distance from Belgrade to Bratislava is 716 km, see Table 1.

The old part of the town developed 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 the area started after the First World War.

After the Second World War the development of the left side of the Sava River Bank was hardly supported by the government of the 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. Besides, the water level of 76 m, is also introduced here because the Iron Gate I Hydroelectric Power Station impacts on water levels upstream the corresponding dam. Namely, the instaled water level of this hydropower station is 76 m. Further, no damages were caused by the surface water, while the groundwater was affected (Stanić et al., 2008). Subsequently, a study was carried out to investigate the impact of flood duration on groundwater rise (Babić et al., 2003).

In the 1950s, large wetlands containing a few meters of sediment dragged from the rivers, covered more than 10 km^2 of the area of Belgrade, where there is the inflow of the Sava river to the Danube. The amount of the dragged material was approximately 6.7 billion m^3 (Hranisavljević , 1963). Later on, in the 1960s, a new part of the town was constructed there. During the Danube flood in 1965, and later floods, there was no damage or disturbance in the heavily urbanized lifted area mentioned above. The built-up area is arranged with a friendlier landscape and safer, less land is dissipated than with levees (Brilly, 2001).

Besides, in the territory of the Belgrade city, most of the 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 were regulated and also three small reservoirs were built. After 1989 the investment in flood protection system was significantly reduced. Thus, between 1989 and 1995, only 3.5 km of levees were built and approximately 1.6 km of Sava River banks were regulated (Babić et al., 2003; Milanović et al., 2010).

Nowadays, flood control along the 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 city circle).

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 100-yr flood placed at the confluence of the Sava and the 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 decrease of the facilities safety, and hence to the reduction of the degree of protection in relation to the earlier situation. Due to inadequate maintenance and use of river beds, the banks of the rivers, i.e. the Danube tributaries in Belgrade, with flash flood regime are particularly threatened.

Hence, the current flood-protection system it is not fully sufficient. Much of the Belgrade city area is still threatened by floods. The reason is because even where the protection system has been built, the potential risk of flooding still 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. Thus, we can conclude that the most densely populated city area is not adequately protected from flooding of the Danube and the Sava Rivers. From this perspective, a new implementation of the flood-protection system of the city of Belgrade has to be proposed as soon as possible. The level of flood-protection should be increased to provide security against floods with a 200-yr return period. Eventually, the goal should be to assure protection against 1000- year floods. The latter can be achieved with the combination of fixed facilities with prefabricated or mobile elements (Kreibich and Thieken, 2009).

2.2 Barcelonnette (Flash floods)

In contrast to the Danube case study, which deals with large-scale inundations, this case study will be about the flash flood problem and its mitigation in mountainous region of Barcelonnette.

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 (see, Fig. 6). 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 the altitudes from 2800 m to about 3100 m, enclose this basin (Fig. 6). Due to its local climatic, lithological, geomorphological and landcover conditions the region is highly affected by various natural hazard processes such as floods, landslides, earthquakes, debris flows, avalanches, rock falls and soil erosion. Because records of hazards covering the period

from 1850–2006 show that the area is mainly affected by floods (Weber, 1994), the emphasis of this case study will be devoted to the flash flood problem.

Structural measures

The Barcelonnette basin has an elongated form which makes it highly dependent on structural measures such as dikes levees, dams, and flood related channels, see Fig. 7.

Since the levees that have been repaired after the 1957 flood event do not offer enough protection if a flood of the same magnitude happens again, in May 2008 the Municipality decided to take the following measures: increase the dike height by 1.5 m in some areas, renovate sections of the river banks, reinforce the concrete embankments, build 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 conducting wide-range consulting on how to better defend the town from flood risk and debris flows. Therefore, prior to the flood event of May 2008, the implementation of a dike raising in Jausiers (approximately 1.5 m) and a reconstruction of a new bridge with a bigger clearance were planned to be built in order to increase the flood protection. This new construction should protect the town from any flood event such as that in May 2008.

Parts of the Barcelonnette were inundated during the June 1957 flood event as a result of a breach of the dike caused by a bridge with a low conveyance capacity. The inundation extent and the location of the dike breach were 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 by 0.6 m. Also important to note is that the construction of check-dams along the tributaries is a continuous process. Every year new infrastructure is 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 to find 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 of flood events, such as the 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 no disaster is prevalent or has not occured 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 took one life.

The Barcelonnette had a near flood event in 2008 that reinforced the possibility of a flood happening in the area (Henry, 2010). The 2008 near flood event is a constant reminder of Barcelonnette's vulnerability to flooding. As indicated in Fig. 6, the occurrence of a flood in Barcelonnette is not merely a probability but has proved to be a real threat. Furthermore, the 1957 flood event is an indication 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 size or greater may have an even worse impact on the current Barcelonnette population, since more people reside in the area. Moreover, the 1957 flood occurred more than 50 years ago and thus may not be remembered by many residents and may be unknown to recent settlers.

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

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

While the municipality is enthusiastic to implement permanent structural measures, it simply cannot afford the exuberant amount of money that the project would cost, especially in an economy marred by recession. Therefore, private organizations should provide funding for the flood protection plans made by the municipality, which could improve the mitigation measures in the area.

3 Conclusions

The paper presents a review of structural measures that were taken to cope with floods in three cities along the Danube (Vienna, Bratislava, and Belgrade) and the Barcelonnette area along the Ubaye River. These cities were also selected 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. The flood management measures take some space and have a strong impact on urban space development. The most efficient solution would be if structural measures were made before urban development takes place, e.g. Vienna center, New Belgrade, etc.

2. 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 systems started in the 1970s, but still have not been finalized. Because local communities usually cannot afford the costs resulting from large mitigation projects, significant investments by governments are required. Moreover, political

decisions supported by a referendum could help in successful project development for a long period of time, sometimes even for many election periods.

3. The level of protection in the city of Vienna against floods is assured with a recurrence interval of 10.000 years. On the other hand, in the cities Bratislava and Belgrade, the level of protection is assured against 1000 yr flood.

4. Analyzing the flood defense system measures in these 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 additional flood mitigation measures (e.g. non-structural) will still be needed to address this residual risk.

5. For sufficient, appropriate, and successful flood protection along 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 sharing access to all relevant information, thus creating the necessary level of trust.

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

7. As flood safety in most vulnerable areas cannot be achieved 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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Table 1. Danube case studies - general information

City	distance from source [km]	catchment size [km^2]	mean annual discharge [m^3/s]	Q_{100} [m^3/s]
Vienna (Nussdorf)	916	101731	1900	10400
Bratislava (Devin)	981	131338	2048	11000
Belgrade (Pančevo)	1697	525009	4000	18671

Table 2. Technical data about flood protection system in the city of Vienna.

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

Fig. 1. Map of the case studies.

Table 3. Technical data of the flood protection measures taken in the city of Bratislava (Fig. 5).

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

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

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

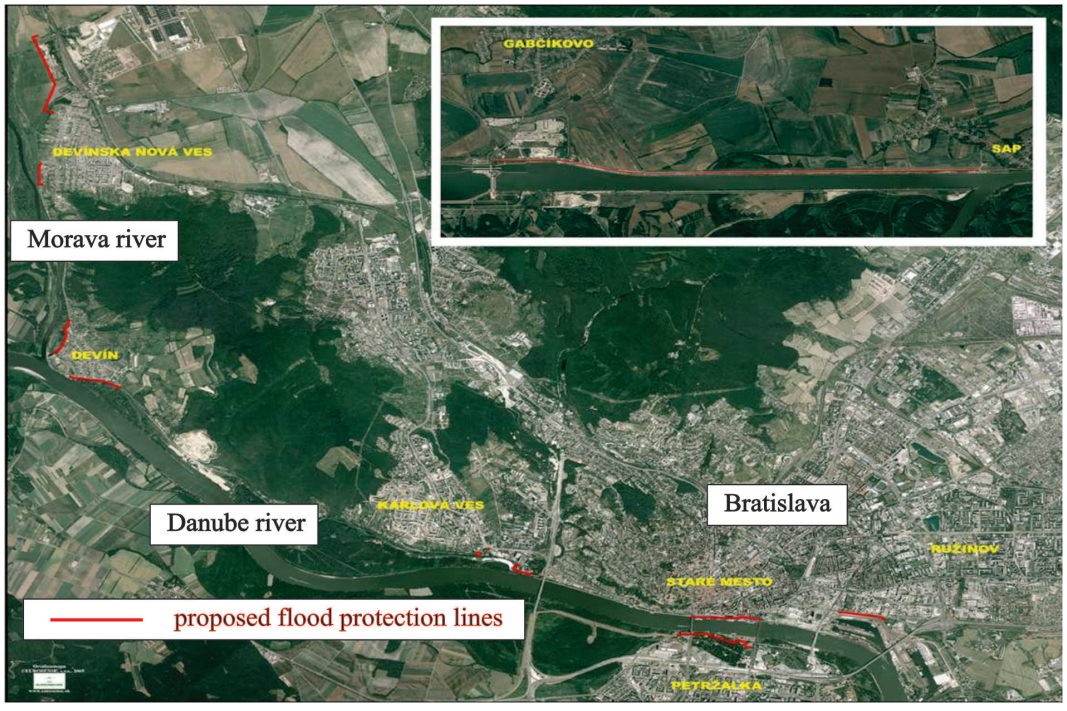

Fig. 4. Proposed flood protection lines in the city of Bratislava and its neighbourhoods.

Fig. 5. Various structural flood protection measures in the city of Bratislava, see Table 1; **(a)** concrete wall, **(b)** underground sealing wall, **(c)** reinforced concrete wall, **(d)** mobile flood wall.

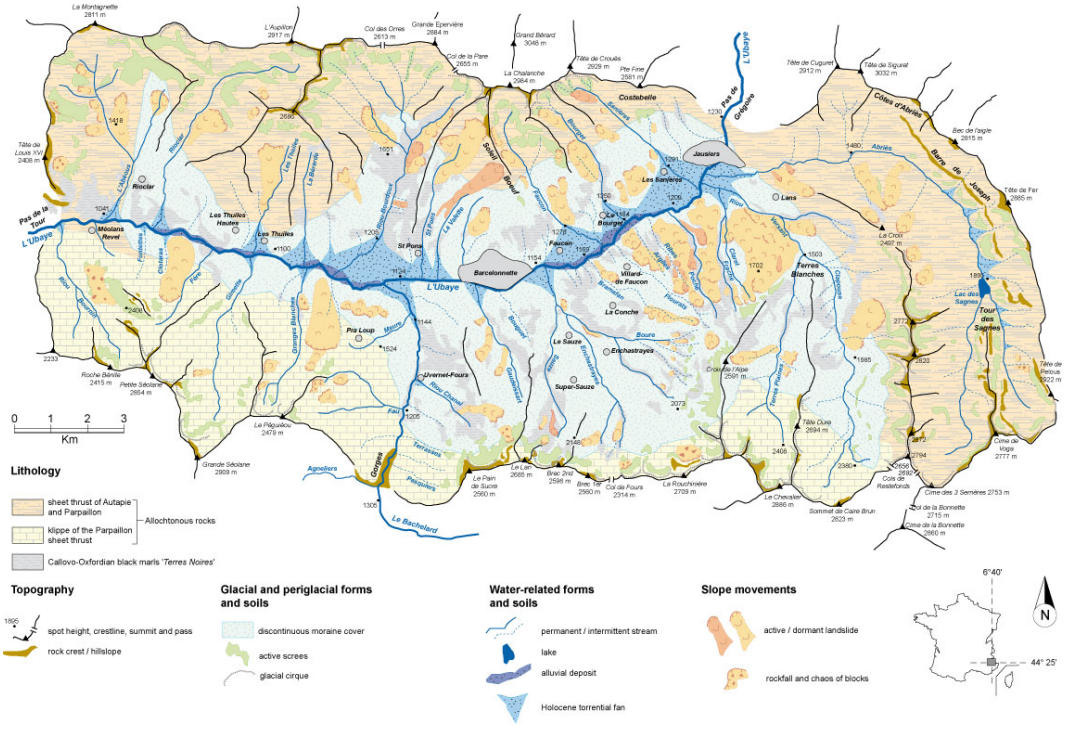

Fig. 6. Geomorphological map of the Barcelonnette area; source: http://eost.u-strasbg.fr/omiv/images/Morpho_Barcelonnette_eng.jpg.

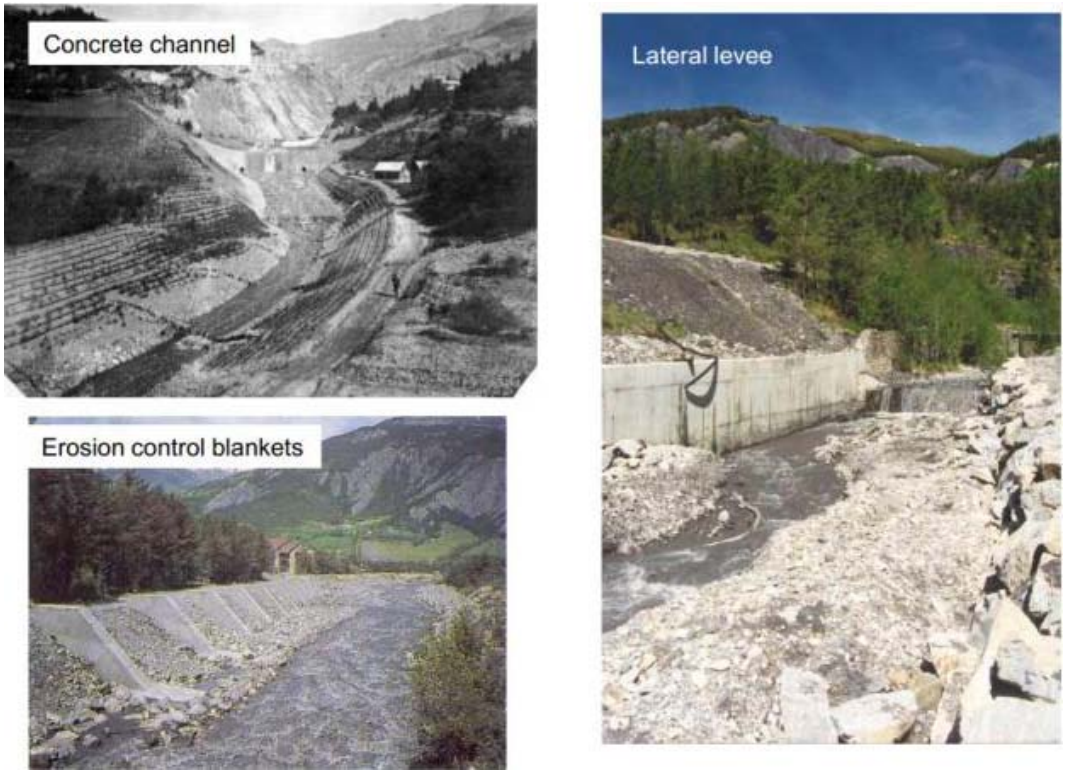

Fig. 7. Some structural measures to cope with flash floods in the Barcelonnette area.