Modern flood protection and rehabilitation concepts at pre-alpine alluvial rivers

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ABSTRACT

In Switzerland, the big pre-alpine alluvial river corridors are embedded in urban, industrial, agricultural or recreational zones. Planning and construction of flood protection and restoration measures on these rivers require consideration of various interests and is strongly influenced by restrictive constraints in time and space.

Three examples of flood protection projects reveal challenges met during planning and construction stages. All measures presented were subject to various actors' opinion and implemented under particular site conditions. A large flood plain was exploited for widening the Aare River upstream of Berne, enhancing wetlands of national interest. Residential and industrial zones at the Kleine Emme River at Littau only allowed increasing flood capacity by heightening the cross section. However, the ecological and recreational environment was enhanced by instream restoration measures such as flow structures, low flow channels as well as micro groins. The Linth Channel project included both river widening and instream restoration. In each case, excess flood evacuation concepts guarantee the functionality of implemented protection structures under even more severe flow conditions.

KEYWORDS

Flood control; river restoration; river widening; instream river training; excess flood evacuation

INTRODUCTION

Today's flood protection measures aim at controlled and safe run-off of a specific design flood on one hand, and an enhancement of ecological conditions and fish habitats on the other hand. Thus, if on a given river reach civil engineering works for flood control are planned a detailed analysis of possible restoration measures has to be carried out simultaneously. If local conditions allow, river widenings present a very suitable solution for both flood protection and ecological diversification. If widening cannot be considered due to densely built or sensitive surroundings, specific local measures in the river section have to be considered such as flow structures created by instream restoration measures, low flow channels and micro groins. This is in accordance with the Federal Act on the Protection of Waters which defines the legal context for planning and construction on Swiss rivers.

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The environment in the Swiss Midland is dominated by urban areas and most of the big pre-alpine alluvial river corridors are embedded in urban, industrial, agricultural or recreational zones. Consequently, if a certain river reach is planned to be enhanced by flood protection and restoration measures, all these different parties become somehow involved in the project. Thus, during planning and construction phases of flood control measures for Swiss pre-alpine alluvial rivers, a big variety of actors, different and sometimes contradictory interests as well as multiple constraints in time and space have to be considered. Solutions and compromises have to be found to reduce flood damages, improve river habitats and, after all, achieve public acceptance and satisfaction of the involved partners.

According to Swiss standards the design flood discharge Q_{dim} depends on the potential of damage. For urban areas or relevant infrastructure the discharge Q_{dim} often has annual probability of P = 0.01 and the dam heights account for a safety margin of typically 0.5 m to 1.0 m with regard to the water level at design discharge. In any case and in addition to a solution for the design flood, an evacuation concept has to be proposed for the case of an excess flood event. For such events either extreme discharge with an annual probability of occurrence of $P < 2‰$ (corresponding to a 500-years return period), extreme bedload or extreme driftwood transport are assumed. The excess flood evacuation concept includes the definition of an emergency and alerting concept as well as constructive measures to assure the functioning of the flood protection measure during the extreme event, for example by a controlled flooding of less populated river corridors.

The paper focuses on two basically different approaches that can be adopted regarding flood protection measures and river restoration - solutions with and without river widening - based on three practical examples of executed or planned flood protection works on the Swiss Rivers Aare, Kleine Emme and Linth which were or are to be carried out under challenging site conditions and particular constraints. Furthermore, concepts and specific solutions to handle the subject of excess flood control are discussed.

FLOOD CONTROL INVOLVING RIVER WIDENING AND RESTORATION

In the beginning of the 20th century, flood protection concepts often included straightening and channelizing of river reaches. Nowadays and based on new laws on water protection and hydraulic engineering the idea consists in giving back terrain to the rivers, allowing them to regain their meandering or braided character and to flood specific areas where a certain degree of damage can be accepted. The challenge consists in controlling the effects of the morphological processes to reach a sustainable situation for both nature and civilization. Constructive measures include protection of eroding banks, stabilization and structuring of the cross section invert as well as increasing flow diversity to reach optimum ecological conditions.

Over the last two decades, several flood events of the Aare River affected the Selhofen-Zopfe region (Switzerland, Figure 1a), a zone involving agriculture, drinking water supply, protected wetlands of national interest as well as a small international airport. The flood event in 1999, when the discharge of the Aare river reached about Q = 610 m³/s corresponding to a 500-years-flood, caused considerable damages to the local communities and infrastructure. In addition, the existing levee as well as the concrete groin structures built in the early 20th century were in need of reconstruction. Therefore, a flood mitigation project was launched by the Canton of Berne. Various actors and interests had to be considered during planning phase; on the left river bank, flood protection measures had to be compatible with zones of important drinking water wells for the city of Berne as well as a recreational zone including the protected wetlands. The right river bank also hosts two drinking water wells, a very popular walking path along the river as well as a public swimming pool.
The flood mitigation measure thus had to satisfy multiple technical, environmental and also public requirements.

On the outer bank, the existing damaged longitudinal concrete groins (Figure 1b) were dismantled and replaced by riprap to increase the river cross section. Three new micro groins were built to guide the main flow back into the center of the cross section to increase flow diversity and to prevent outer bank erosion (Figure 1c). This rough and permeable waterfront protection allows both stabilizing the outer bend and protecting the drinking water supply zones. The excavation of a new secondary channel (Figure 1d) and the implementation of new longitudinal gravel bars enhance the natural fluvial environment and assure the conservation of the attractive walking path with direct access to the river for the local population. Punctually, flood-proofing measures were taken to protect existing infrastructure

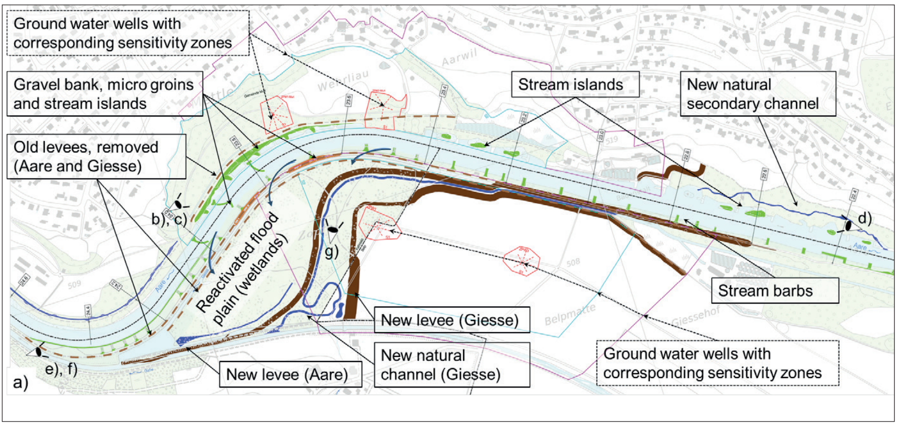

Figure 1. Overview of flood mitigation and restoration measures on the Aare River upstream of Berne, b) old longitudinal concrete groins and c) new enhanced erosion bank protection with micro groins and gravel bank, d) new natural secondary channel, inner bank widening during normal (e) and flood conditions (f), and g) enhanced Giesse Channel.

Figure 1b: Flood mitigation and restoration project Aare River: right bank initial state

Figure 1c: Flood mitigation and restoration project Aare River: right bank enhanced state

Figure 1d: Flood mitigation and restoration project Aare River: right bank natural secondary channel

Figure 1e: Flood mitigation and restoration project Aare River: left bank widening normal discharge

Figure 1f: Flood mitigation and restoration project Aare River: left bank widening flood discharge

Figure 1g: Flood mitigation and restoration project Aare River: left bank natural Giesse Channel

such as a small restaurant on the river side or the already enhanced confluence between the Gürbe and the Aare River.

The existing flood protection levees on the inner bank were removed and rebuilt at the very possible limits of the most sensitive drinking water zone. Such, the river could be widened by up to 200 m (Figure 1e and f). Stream barbs along the new levee as well as small stream islands form a rough and permeable element against erosion. Within the widened zone the so called Giesse Channel, a small side channel fed by groundwater, was also partially moved and given a new meandering course with instream structures for fish shelter and wooden protection at the outer bank (Figure 1g). Most of the construction works, clearing and truck transports took place in the nature conservation area and were therefore restricted to a very minimum.

The flood mitigation works were completed in June 2015. One month earlier, in beginning of May 2015, the passage of a flood with Q_{max} = 510 m^3/s, corresponding to a 50-years return period, confirmed the adequate functioning of the almost terminated flood protection system.

The Linth Channel between Lake Walen and Lake Zürich presented insufficient flood capacity, deficits regarding excess flood evacuation possibilities as well as damaged bank protection. Therefore, the Linth Channel flood protection project including a series of flood mitigation and restoration measures was implemented (Billeter and Keller 2013). The historical Glaner Linth was meandering directly to Lake Zurich before being deviated to Lake Walen by Conrad Escher at the beginning of the 19th century with the purpose of flood protection. This major river correction resulted in a deficit of natural alluvial banks in the so-called Escher Channel. At Klein Gäsischachen, where topography and situation allowed for some flexibility regarding the flood protection along the right river bank, it was decided to remove the right levee partially in order to achieve a local widening that re-substitutes the alluvial bank structures lost by the 19th century river correction. During construction works, the water was led through a previously excavated diversion channel which served as initial secondary channel of the widening section once the existing right flood protection levee was removed and initial breaches allowed flooding of the widening area.

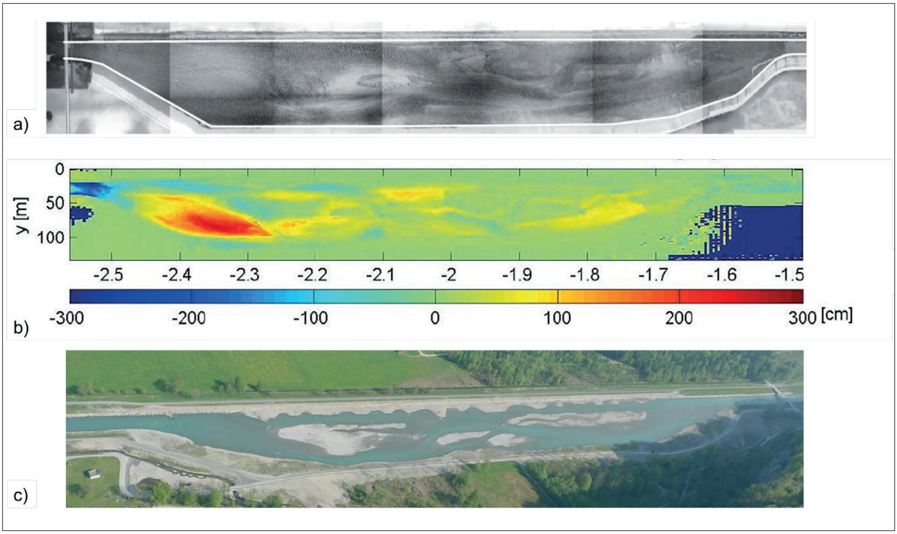

Figure 2: River widening at Klein Gäsischachen (Lindth Channel), a) picture taken during physical modelling tests, b) result from physical modelling tests: river morphology after passage of a flood event (river bed erosion = positive values, redish colours, sediment deposition = negative values, blueish colours), and c) protoype behavior.

The development of river morphology was studied in hydraulic modelling tests at VAW, ETHZ (Figures 2a and b) and the same behavior could be observed under prototype conditions during flood events occurring relatively shortly after the completion of construction works (Figure 2c).

At Hänggelgiessen, a local widening was realized aiming the creation of a new regularly flooded wetland, including a natural secondary channel on one hand and offering a small retention volume of 1.0 Mio. m^3 on the other hand (Figure 4a). In this particular case, the river widening was thus combined with an excess flood evacuation system, presented later on in this paper.

FLOOD CONTROL AND RESTORATION WITHIN A GIVEN RIVER WIDTH

In cases where the local environment is either densely built or exploited in a way that no river widening can be realized, other constructive measures have to be considered to increase flood capacity and flow diversity in the given reach. In August 2005, the Kleine Emme River which is characterized by a mean annual discharge of 16 m^3/s carried some $Q = 650\ m^3/s$ in combination with a lot of sediment and driftwood. This flood event corresponding to a 70-years return period caused inundations in the adjacent zones with damages estimated to about 65 Mio. CHF to hydraulic structures and about 200 Mio. CHF to buildings in the vicinity of the river. Therefore, planning of flood mitigation measures was started by the Canton of Lucerne with the objective of both sustainable flood protection and river restoration. Today, the flood protection project is in authorization phase and includes various measures along some 23 km of the Kleine Emme River. River widening as presented in the preceding paragraph is also planned in less populated areas, but upstream of the confluence with the Reuss River at Littau-Emmen (Switzerland) residential and industrial zones close to the river restrict widening possibilities to a very minimum.

Consequently, flood capacity in this river reach will be increased by the implementation of new dams, side walls and local river bed excavation to heighten the existing trapezoidal channel-like cross section. The design flood at the corresponding reach is $Q_{dim} = 700\ m^3/s$ which equals to a 100-years flood. The width and bank height of the enlarged cross section accounts for a safety margin added to water level at design flood allowing a flood up to 1.3 to $1.5 \times Q_{dim}$ to discharge without overtopping (Billeter et al. 2014). However, for environmental purpose and to meet the requirements of the Federal Act on the Protection of Waters, the river bed will be enhanced to improve morphological variability. Instream restoration measures such as flow structures, induced low flow channels as well as micro groins aim at an increased variability of flow characteristics (flow velocity and water height) and a stabilization of the river bed (Mende 2012, Figure 3). At the same time, they allow to enhance fish habitat conditions and the overall ecological and recreational environment.

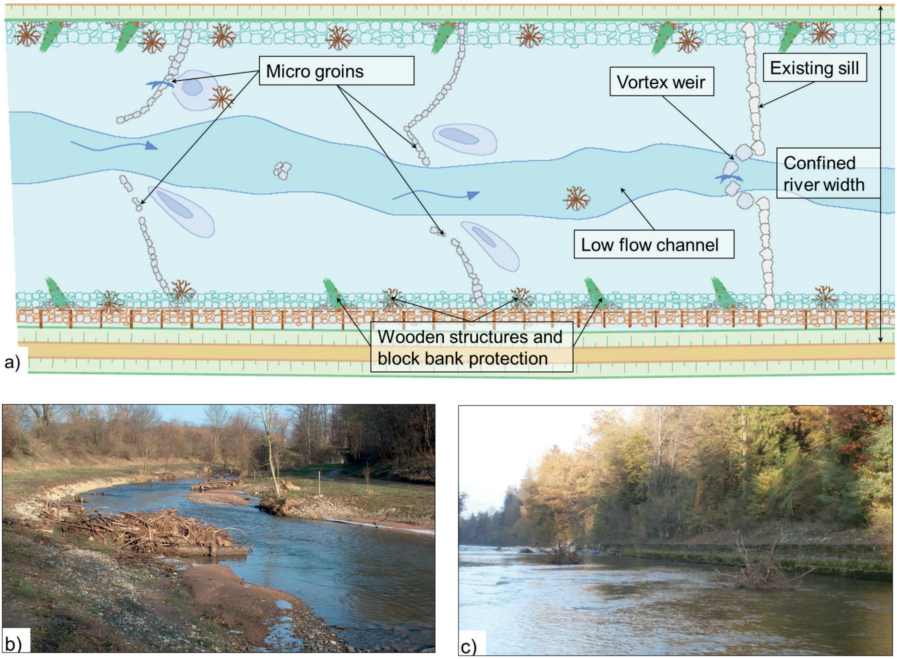

Figure 3: Instream restoration measures at the Kleine Emme in the urban area of Littau-Emmen, a) schematic drawing, b) example of wooden groins at the Kander River (Märkt, Germany, photo courtesy of Erich Linsin), c) example of rootstock structures at the Emme River (Switzerland).

The confluence with the Reuss River, the so called "Reusszopf" is designed with two river branches to dissolve the strongly channelized character of the flow. Thanks to the future flow diversity and the possibility to bypass the present confluence sill, the two rivers will be connected and allow fish migration in both upstream and downstream direction.
Where the existing width of the Linth Channel had to be maintained two different concepts were applied to reach an ecological enhancement of the river banks. Initially, the channel was protected by steep and partially solidified riprap (slope 1:1). The restoration project included channel reaches with stream barbs on one hand and reaches with shallow banks on the other hand, allowing a diversification of the strongly channelized flow conditions (Figure 4a).

EVACUATION OF EXCESS FLOOD EVENTS

The planning of flood control is effectuated for a given design discharge. However, some of the implemented protection structures must resist even more severe flow conditions, the so called excess flood. To guarantee the functionality of the overall flood protection concept at a long term, solutions for a secure evacuation of this extreme event have to be planned and built. For the examples described above, excess discharge is released into extended flood corridors.

Upstream of the Selhofen-Zopfe area, the flood protection levees are built to a level which allows lateral overtopping along a very specific bank reach if the discharge in the Aare River is higher than the design flood for the downstream protection structures. The additional discharge is evacuated through a specific excess flood corridor protecting the local airport from flooding.

The same method has been applied at various other rivers e.g. the Kleine Emme River and the Linth Channel, where excess flood discharge is deviated into a specific corridor by an artificially controlled weir structure. Upstream of the widening Hänggelgiessen on the Linth Channel (Figure 4a), the enhanced channel presents a capacity of $HQ_{500years}$ = 500 m^3/s while the capacity of the downstream reach is limited to about $HQ_{300years}$ = 420 m^3/s. The remaining 80 m^3/s are discharged over a weir structure into the secondary channel which is normally draining the so called Schänner plain. If incidentally the extreme flood event coincides with a flood in this area, the proper Schänner plain still presents some topographical depressions with low damage potential assuring an additional accumulated retention volume of 1.0 Mio. m^3 for peak flood routing.

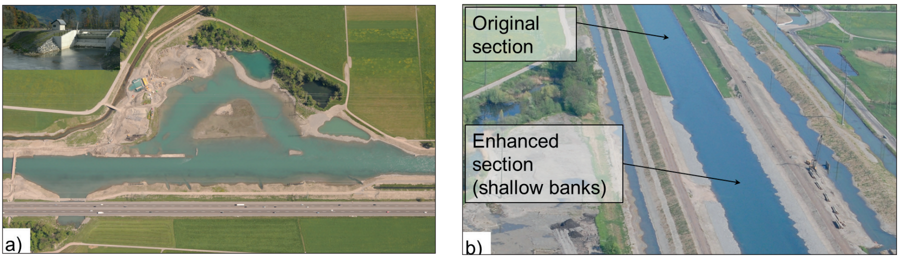

Figure 4: a) Local widening and excess flood evacuation system at Hänggelgiessen on the Linth Channel, and b) comparison between Linth Channel before (above, original cross section with steep bank slopes) and after the realization of the flood control and river restoration project (below, shallow banks).

CONCLUSIONS

Today, hydraulic and river engineers face two main controversial tendencies when planning and realizing flood control and river restoration on big rivers in the Swiss Midland. On one hand, the surroundings are often densely built and/or used for residential, industrial or agricultural purpose which results in a high damage potential during flood events and thus requires intervention. However, possibilities for flood mitigation are restricted due to the little space available. On the other hand, the law requires an enhancement of morphological and habitat conditions and local people often claim access to the river for recreational use, preferring natural river conditions instead of channelized streams.

Whenever local conditions allow, river widening has proven to be very effective on flood mitigation and in connection with the implementation of secondary channels, stream islands and micro groins it allows diversifying flow characteristics to a very high level. This results in both habitat enhancement for fauna and public attraction due to a restored natural river environment. Flood mitigation measures respecting the ecological aspects of river restoration must also be proposed for very confined river reaches. Instream restoration measures present very valuable tools to improve general ecological habitat and fish migration conditions and can be applied in both small and large channel-like cross sections. However, they will not fully restore natural braiding or meandering processes or wetland dynamics. In any of the afore given practical examples, specific solutions were found to guarantee a secure design flood passage on one hand and a habitat enhancement due to instream structures and low water or secondary channels on the other hand.

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