A CONCEPTUAL PLANNING TOOL FOR HAZARD AND RISK MANAGEMENT

Bruno Mazzorana[1*], Sven Fuchs[2]

ABSTRACT

Following the premises of integral risk management, comprehensive mitigation concepts have to be elaborated in a structured manner aiming to fulfil the requirements of effectiveness and efficiency. In order to achieve the optimal protection level against hazard processes, the planning process has to follow distinct guidelines that allow for a consistent management process. Thereby, the necessities of efficient risk reduction have to meet other commensurate requirements, such as ecological sustainability, technical reliability, feasibility of the concept itself even under changing system loadings, as well as an adapted maintenance strategy. Until now, only little work has been done to conceptualise such necessities from an integrative point of view. So far, most of the engineering strategies aimed either at maximising the hydraulic discharge capacity or the bed load retention, or at consolidating the streambed and limit the rate of bedload production. To overcome these shortcomings we propose a revision of the underlying planning process by means of a step-by-step approach. This approach will gear functionally efficient mitigation measures that are able to provide a higher degree of risk reduction than conventional mitigation strategies by including possible alternatives already in the early planning stages.

Key Words: Torrent processes, System life-cycle engineering, Inventive problem solving, Risk reduction, European Flood Risk Directive

INTRODUCTION

In recent years, increasing numbers of natural hazards and associated losses have shown to the European Commission and the Member States of the European Union the paramount importance of the natural hazards issue for the protection of the environment and the citizens (Barredo, 2007). There is a strong scientific evidence of an increase in mean precipitation and extreme precipitation events, which implies that extreme flood events might become more frequent (Christensen and Christensen, 2003; Kundzewicz *et al.*, 2005). In parallel, exposure to floods might increase across Europe as well as flood vulnerability due to population and wealth moving into flood-prone areas. Thus even without taking climate change into account an increase of flood disasters in Europe might be foreseeable (Mitchell, 2003). However, alternative sources reporting on quantifying studies both on flood hazards at a continental level (United States of America and Europe) as well as other mountain hazards at a regional level suggested a trend in the opposite direction (e.g., Fuchs and Bründl, 2005; Oberndorfer *et al.*, 2007; Barredo, 2009; Fuchs, 2009).

---

1 Department of Hydraulic Engineering, Autonomous Province of Bolzano, Cesare-Battisti-Str. 23, 39100 Bozen, Italy, (*Corresponding Author; bruno.mazzorana@provincia.bz.it, Facsimile +39-0471-414599)

2 Institute of Mountain Risk Engineering, University of Natural Resources and Applied Life Sciences, Peter-Jordan-Str. 82, 1190 Vienna, Austria, sven.fuchs@boku.ac.at

Nevertheless, these circumstances have produced a reaction in the European Commission, and a Directive on the Assessment and Management of Flood Risks addressed to the Member States was issued (Commission of the European Communities, 2007) as one of the three components of the European Action Programme on Flood Risk Management (Commission of the European Communities, 2004). Within this Directive, it has been officially acknowledged for the first time that flood events (defined in its broadest sense including torrent processes) are natural phenomena which cannot be entirely prevented. Such events have the potential to severely compromise economic development and to undermine the economic activities of the Community. Due to an increase of human activities in floodplains and the reduction of the natural water retention by land use activities and consequent streamlining of the watercourses, an increase in the likelihood and adverse impacts of flood events is expected. Therefore, concentrated action is needed at the European level to avoid severe impacts on human life and property. However, society increasingly realised – also on the political level – that despite of considerable amounts of public money spent for conventional technical mitigation and hazard mapping, a comprehensive protection of settlements and infrastructure against any loss resulting from hazard processes is not affordable and economically justifiable (Weck-Hannemann, 2006; Fuchs *et al.*, 2007). People and political decision makers are increasingly aware of this situation, thus, in some Alpine countries a paradigm shift took place from hazard reduction to a risk culture (PLANAT, 2004 in response to Nationalrat, 2000) while dealing with natural hazard risk in other countries still remains conservative until now (Fuchs *et al.*, 2008a).

In order to have an effective tool available for gathering information, as well as a valuable basis for priority setting and further technical, financial and political decisions regarding flood risk mitigation and management, it is necessary to provide for the establishment of flood hazard maps and flood risk maps which show the potential adverse consequences associated with different flood scenarios. Accordingly, as a first step towards these requirements information on risk has to be compiled.

The concept of risk has been introduced in natural hazard management since experiences from past years suggested that values at risk and spatial planning should be increasingly considered within the framework of natural hazard management (e.g., Fuchs *et al.*, 2004; Keiler *et al.*, 2006). To meet this goal, the concept of risk seemed to be a valuable instrument to reduce the susceptibility of buildings and infra-structure to natural hazards (e.g., Heinimann, 1995; Kienholz *et al.*, 2004), and to develop strategies for a sustainable use of mountain areas for settlement, economic purpose and recreation. However, the concept of risk is static over time (Fuchs *et al.*, 2004), while losses are the predictable result of interactions among three major dynamic systems (Mileti, 1999): the physical environment, which includes hazardous events; the social and demographic characteristics of the communities that experience them; and the values at risk such as buildings, roads, and other components of the built environment. Even if research on the hazardous events has a long tradition, above all in engineering sciences and with respect to mountain hazards, there is a particular lack of studies related to the spatiotemporal development of elements at risk that are prone to hazards (Fuchs *et al.*, 2008b), and the associated vulnerability of values at risk and of communities (Fuchs, 2009). With respect to the latter it has recently been argued that the reduction of both economic and institutional vulnerability is the prerequisite for the planning and implementation of protective measures in an economically efficient and societal agreeable manner, and thus for a sustainable development in mountain regions (Fuchs, 2009).

An analysis of efforts undertaken to mitigate torrent hazards has shown that approximately 30,000 check dams and consolidation structures had been constructed since 1900 within the Autonomous Province of Bolzano in northern Italy, 16 % of which do not fulfil the requirements of reliability and, consequently, technical efficiency (Mazzorana, 2008). The associated hidden residual risk, in particular in case of events larger than the underlying design events, is obvious. Due to the evolution of elements at risk exposed, resulting from socioeconomic transformation in the entire alpine area since the 1950s (Fuchs and Keiler, 2008), protective goals cannot be sufficiently met in many regions.

Protective goals are closely related to an idealised standard of protection, which from a systems perspective is related to (1) a cost-efficient and effective risk-reducing measure; (2) a highly reliable and easily maintainable system; (3) a highly functional (technical efficiency) system with substantial mitigation effects for both events with high return period and events with low return periods, the latter determined by a respective regulation effect; (4) a system with considerable capacity to regulate sediment transport, above all a progressive reduction of the remaining sediment yield potential (Üblagger, 1973; Armanini and Larcher, 2001); and a system with flexible response capacity to extraordinary loadings (process intensities far beyond the design events).

The objective is to approximate these idealised standards of protection, above all with the overarching aim to reduce institutional vulnerability. This objective implies either preventive mitigation measures if the functional efficiency of a system is given and the maintainability is cost-effective; or a reconfiguration of mitigation measures if the system does not perform satisfyingly or the maintainability is not cost-efficient.

The concept of system life-cycle engineering provides a useful method to meet the requirements of idealised standards of protection (Blanchard and Fabrycky, 2006) due to a structured approach allowing for design, delivery, and maintenance of mitigation systems and capabilities.

THE CONCEPT OF SYSTEM LIFE-CYCLE ENGINEERING

The major principles of system life-cycle engineering are related to (1) an improvement of methods to determine the system requirement according to specific needs already early in the design phase, i.e., the cost-efficient and reliable performance and implementation of mitigation strategies; (2) an assessment of the entire system studied including all necessary elements needed; and (3) a consideration of the intra-relationship between individual system components and interrelationships between higher-order and subordinated levels within the system hierarchy.

By adopting the concept of system life-cycle engineering to the mitigation of mountain hazard risk, a procedure is proposed which is tailored to the specific needs of torrent and avalanche control and contains in a nutshell relevant theoretical principles that have been identified with respect to life-cycle design and integral risk management, including inventive assessment of the problem to be solved (Altshuller, 1984; Ruchti and Litotov, 2001; Mazzorana *et al.*, 2008; Zobel and Hartmann 2009).

According to the system life cycle outlined in Fig. 1, the phases are classified in an acquisition phase and an utilisation phase in order to distinguish between those actions necessary to develop the system and those actions necessary to maintain the system at a high performance level, and to adapt the system if the performance level becomes sub-optimal. The acquisition phase, from a theoretical point of view, starts with the identification of needs (critical system analysis) and extends through conceptual and preliminary design to detailed design and development. The utilisation phase is characterised by the use of the product, re-configuration and phase-out. System life cycle engineering includes thereby concepts of the product life cycle, which is restricted to the manufacturing process, and concepts of maintenance and support capability as well as re-configuration processes; the latter being of particular importance with respect to existing hazard mitigation strategies that have proven to be sub-optimal and should therefore be enhanced. Possible starting points for such a system life-cycle approach in integral risk management may include (1) an analysis conducted on a regional scale showing a need to increase the protection level against natural hazards in a highly exposed area; (2) a survey carried out by the respective administrative agency highlighting a particular need to maintain and/or enhance the technical functionality of an existing protection system; and (3) a recently produced hazard map delineating frequency and magnitude of a specific hazard processes which once overlain with a map of elements at risk exposed provides a valuable indication of the areas at risk. Furthermore, as a result of (4) post event documentation which represents an indispensable knowledge base for any intervention aiming at effectively reducing risk, systems life-cycles may be used to design the appropriate mitigation project.

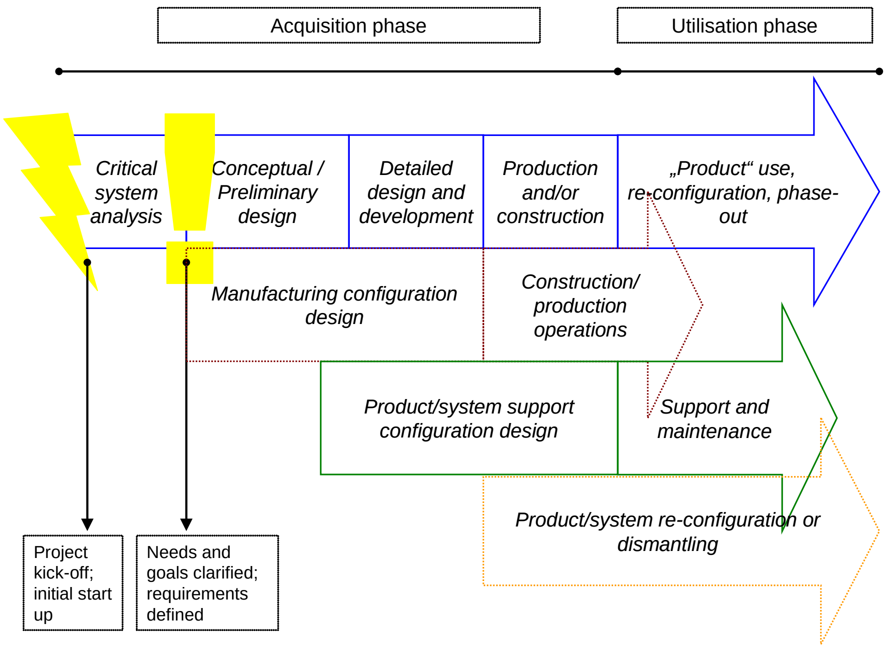

Fig. 1 System life cycle (adapted from Blanchard and Fabrycky, 2006:29)

There is a strong need for a critical system analysis within any engineering efforts, above all with respect to possible design alternatives and formalised procedures. Such efforts will initiate conceptual design to meet defined requirements, and is therefore suitable to reduce institutional vulnerability considerably. Moreover, necessary maintenance activities and related logistic support will become detectable, which results in an enhanced system reliability for the entire protection system. If necessary, the components of the system can be re-configured accordingly (e.g., if insufficient protection performance is proven, a sediment retention system can be converted into a sediment dosing system).

Designing by means of the system life cycle approach is different from conventional designing, but provides some benefits which are described subsequently. Furthermore, the structured concept is – apart from operational targets expressed in terms of system reliability – simultaneously responsive to explicit protection targets and risk mitigation needs (e.g., to requirements expressed in functional terms such as the aim to enhance the sediment dosing capacity of a measure), as well as to life cycle assessments (e.g., reduced clearing costs of retention basins that may be alternatively invested in raising flood awareness). In Fig. 2, these benefits are summarised with respect to methodological issues in the systems acquisition phase.

Firstly, efforts have to be undertaken to progressively dissect the initial problem definition with the objective to re-formulate and define consistently the problem under consideration (critical system analysis). As a result, the requirement baseline representing the overall strategy in terms of the first milestone is achieved. Secondly, during the step of conceptual design, the requirements to be met by future (protection) system entities, and the Ideal Final Result (IFR) have to be defined (Altschuller, 1984). Thereby, existing conceptual solutions have to be adjusted to the IFR, resulting in the functional baseline (milestone 2).

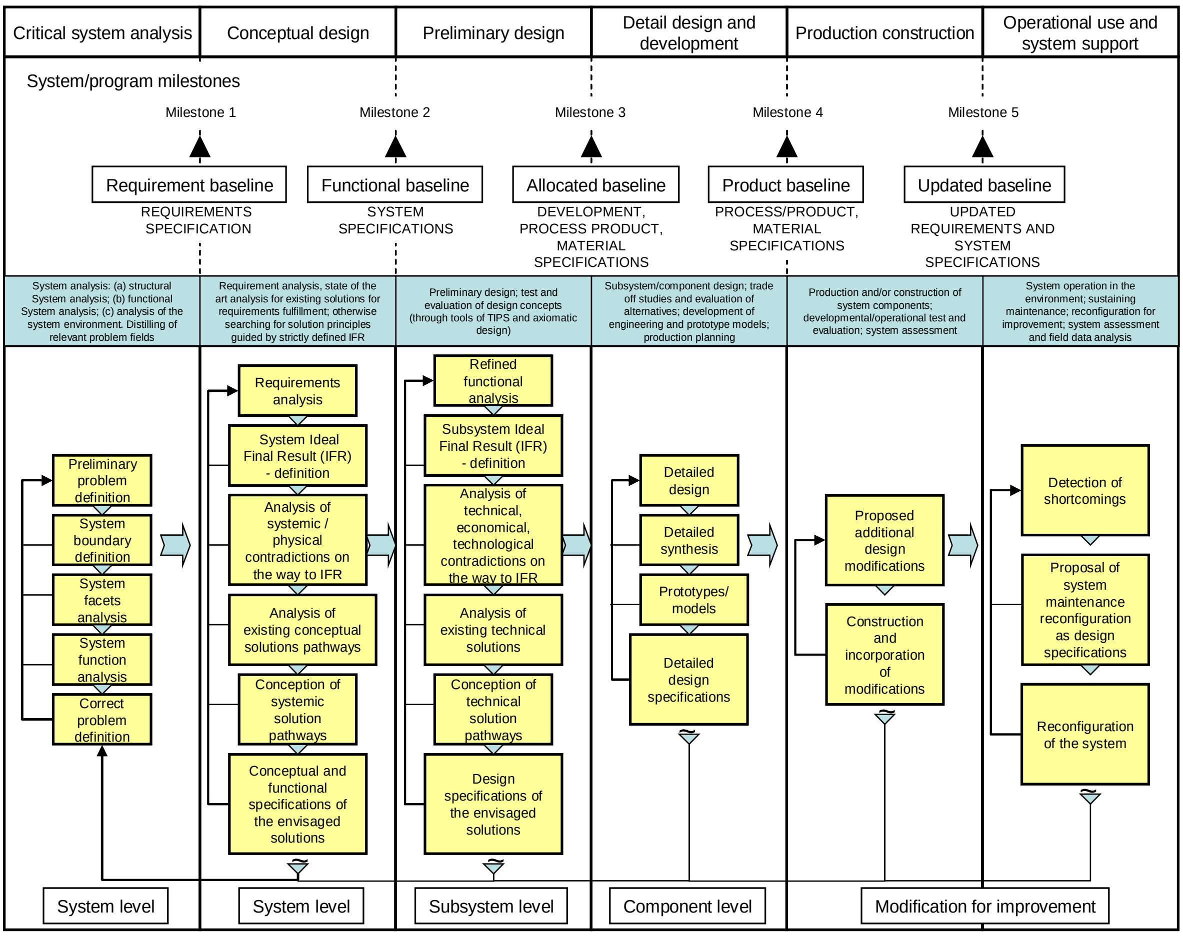

Fig. 2 System acquisition phase activities and interactions over the life-cycle for natural hazard risk mitigation (adapted from Blanchard and Fabrycky, 2006)

Thirdly, based on the Theory of Inventive Problem Solving (TRIZ-TIPS), inherent contradictions originating from systemic or physical constraints between possible solutions have to be assessed, e.g., the search for a system that equally maximises sediment retention volumes during extreme events but minimises downstream sediment deficits during more frequent events. As a result, the conceptual and functional specifications of both feasible and technically effective solution pathways will be formulated (milestone 3). Fourthly, in the phase of detailed design and development, specifications will be formulated to obtain an optimised performance of each individual system component (milestone 4). Fifthly, the production construction phase follows, in which the realisation of the envisaged system is optimised and the preliminary design simultaneously improved (milestone 5). Finally, during the phase of operational use and system support, the system behaviour can be continuously improved in order to immediate intervention and re-configuration targeting at an improved performance of the designed system.

THE THEORY OF INVENTIVE PROBLEM SOLVING (TRIZ-TIPS)

The theory of TRIZ-TIPS, first described by Altschuller (1984) and further developed by Terninko *et al.* (1998), Zobel (2006) as well as Zobel and Hartmann (2009), provides the backbone within the design process following the system life-cycle assessment. The effectiveness of TRIZ-TIPS elements in the field of natural hazard risk management has recently been shown by Mazzorana (2008) as well as Mazzorana *et al.* (2008). Moreover, principles of TRIZ-TIPS can also be detected in the studies of Egli (1996) and Holub & Hübl (2008) with respect to local structural protection, and related to the practical implementation of mitigation strategies, such as described by Willi (2009) with respect to risk reduction for a settlement in Switzerland by controlled dyke failure in the lower catchment of the Engelberger Aa river. According to these experiences, a flood impact reduction concept for the city of Vipiteno, Italy, was proposed by Scherer and Mazzorana (2005, 2007). The overall principle in all of these case studies was to allow a quasi-controlled occurrence of losses in areas with lower economic value such as agricultural areas and the simultaneous protection of areas with higher values at risk exposed, such as settlement areas. Elements of TRIZ-TIPS are regularly implemented in stage 2 and 3 of the system acquisition phase (cf. Fig. 2), above all in the phases of conceptual design and preliminary design. These elements will gear functionally efficient mitigation measures that are able to provide a higher degree of risk reduction than conventional mitigation strategies by including possible alternatives already in the early planning stages. When applying this suggested workflow, a high-quality spectrum of conceptual solutions for the safety problem recognised in the hydrological system under consideration will be the primary result. The detailed structural mitigation concepts will be converted into application only in a subsequent step. A series of specific heuristics that were identified from successful risk mitigation projects implemented in the past will support the conceptual planning process. By feedback-loops the optimisation of mitigation measures and the minimisation of risk in the considered system will be continuously balanced. As a result, the bundle of possible mitigation strategies will be as varied as they are complex, and will enhance the level of protection achieved compared to the conventional planning procedure during the planning process. Therefore, in the following section these possibilities are extensively described with respect to planning and decision tasks in natural hazard risk management. The overall aim is to factually support the strategic decision making and the priorisation of risk reduction measures through a guided stepwise procedure based on axioms and principles of TRIZ-TIPS.

THE IMPLEMENTATION OF TRIZ-TIPS

The following issues will be addressed step-by-step during the implementation of TRIZ-TIPS within the management of mountain hazard risk. According to Fig. 2, these steps have to be undertaken iteratively within the critical system analysis in order to achieve the goals of milestone 1 and to set the basis for the operational elaboration of IFR.

Preliminary definition of the problem

By outlining the project, preliminary goals have to be described in order to gain insights in the subsequent workflow which has to be compiled, including possible motivations of all stakeholders involved. Thereby, the focus is on flexible strategies in order to allow for innovative solutions and necessary adjustments.

System boundary conditions

The technical and methodological boundary conditions of the study site have to be described in order to appropriately delineate the system geographically, with regards to content, and with respect to validity. Particular attention has to be given to process clusters and patterns that appeared to be present within the system configuration, as well as to process nodes and possible morphological progression such as sediment input, intermediate storage, and deposition. Therefore, a recently developed procedure for scenario determination may be used in order to derive consistent (and therefore relevant) hazard patterns (Mazzorana *et al.*, 2009), as exemplarily shown in Fig. 3 for debris flow-type hazards. As a result, qualitative as well as quantitative statements will be possible with respect to the expected process characteristics within the system, including knowledge on relevant effects, event documentation, and ad hoc investigations as well as an abstracted river system representation (Projektteam ETAlp, 2003).

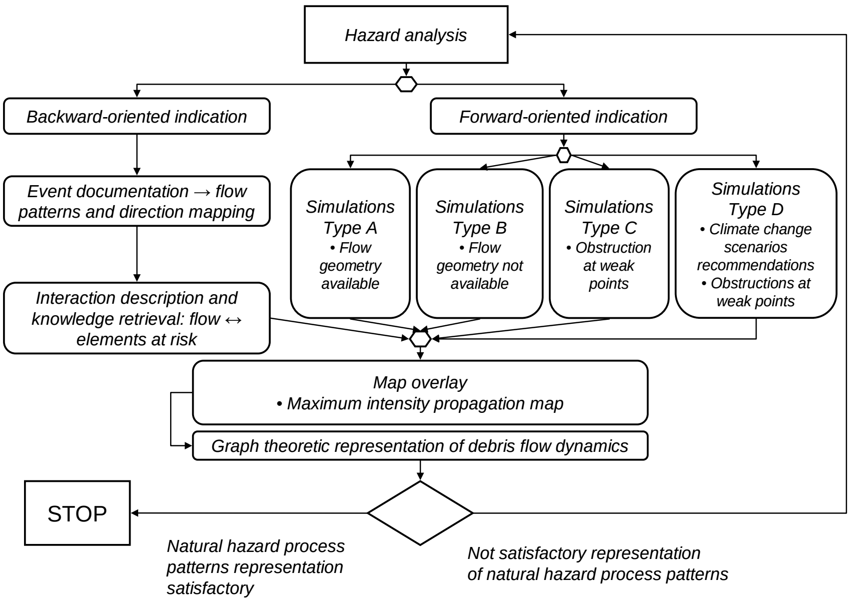

Fig. 3 Procedure adopted to analyse the hazard process patterns as part of the system boundary conditions

Similarly, the elements at risk under consideration have to be determined, and necessary steps for quantification have to be defined, including the possible assessment of physical and resulting economic vulnerability (Fuchs, 2009).

Mitigation measures

The overall condition of any existing mitigation measures within the system have to be analysed and assessed, including information on maintenance necessities and reliability. The overall aim is to evaluate whether or not the protection system has to be re-configured or maintained, or if additional efforts are necessary in order to improve the reliability of the measure.

Ecology and bio-potential

The assessment of the overall ecological and limnological conditions of the study site is a necessary prerequisite to figure out possible ecosystem enhancements, ranging from creating appropriate ecological niches for determined fish populations to providing connectivity along the stream reaches (e.g., removing insurmountable obstacles such as consolidation dams or alternatively create possibilities of bypass).

Possible system gaps and needs

By acknowledging the critical system analysis steps 4.1-4.4, a synopsis of identified inadequacies or failures has to be compiled, with a particular focus on resulting risk as well as on ecological issues as legally prescribed. As a second step, possible improvements necessary to overcome these constraints have to be shaped, and a draft with respect to practical implementation should be prepared. The overall aim is to formulate the general IFR (cf. Section 2).

Operational elaboration of IFR

Operationally, the IFR will be achieved by (1) a description of an IFR model which meets the requirements of economic efficiency, ecological sustainability, and systems reliability; and (2) an approximation of this idealised model given the practical constraints (either being of economic, ecologic, or feasibility restrictions). A major focus in this final step of TRIZ-TIPS should be devoted to physical, spatial, and temporal resources available, since an IFR is not target-oriented if e.g. the area available for the construction of mitigation alternatives is restricted. Hence, with respect to torrent processes, alternative solutions such as dosing of solids instead of consolidation and retention might be taken into account. Here, we propose a set of tailored principles to assess systemic or physical contradictions on a system level (cf. Fig. 2). These principles include approaches of separation, dynamisation, combination and redundancy.

(1) Separation principles

(a) Spatial separation: The overall aim is to separate areas of high process intensities from areas with a relevant accumulation of values at risk, or to concentrate adverse effects in low-vulnerable areas.

(b) Temporal separation: The overall aim is to separate intensity maxima of liquid discharge and sediment transport rates on the process side, and to separate elements at risk from areas highly affected during critical periods of extreme events (e.g., by evacuating people at risk).

(c) Separation by change of status: The aim is to reconfigure critical system configurations (e.g., narrow bridge passages in case of expected woody material transport).

(d) Separation within the system: It may be possible to create subsystems with a lower degree of susceptibility while the residual parts of the system remain unaffected (e.g., local structural protection for individual buildings).

(2) Dynamisation principles
    (a) Dynamisation of the sediment transport rates: The overall aim is to dose solids in order to decrease local peak discharges (particularly with respect to woody material transport).
    (b) Ecosystem dynamisation: The overall aim is to enhance ecosystem functionality.
    (c) Dynamisation of mitigation: The overall aim is to create a flexible modular mitigation concept taking into account the entire range of possible alternatives. This principle allows for adaptation if the parameterisation will change in the future.
(3) Combination principles
    (a) Combination of mitigation: The overall aim is to efficiently reduce effects with respect to hazard and vulnerability, and to increase the system reliability and maintainability.
    (b) Multi-purpose combination: The overall aim is to design parts of the mitigation concept with respect to alternative uses, e.g., modelling the landscape in order to achieve avalanche deflection without compromising the agricultural use of the area).
(4) Redundancy principles
    (a) In particular for a worst-case scenario, certain elements of the mitigation concepts should be redundant in order to avoid system failures.
    (b) Information as one important pillar of creating disaster resilience should be promoted to enable efficient intervention planning and civil protection.

DISCUSSION AND CONCLUSION

In natural hazards research, risk is defined as a functional relationship of (1) the probability of occurrence of a hazardous process, and (2) the assessment of the related extent of damage, defined by the damage potential and the vulnerability according to the intensity of the hazard process. Following this definition comprehensive mitigation concepts have to be elaborated in a structured manner aiming to fulfil the requirements of effectiveness and efficiency. In order to tailor the practical steps to this theoretical framework, and therefore achieve the optimal protection level against hazard processes, the planning process has to follow distinct guidelines that allow for a consistent management process. Thereby, the necessities of efficient risk reduction have to meet other requirements that are commensurate, such as the ecological sustainability of the mitigation concept, the technical reliability if structural mitigation is implemented, the functionality of the concept itself even under uncertain and changing process behaviour on the system loading side, as well as an adapted maintenance strategy. The method of TRIZ-TIPS, embedded in the concept of system life-cycle engineering, has shown to provide a higher degree of risk reduction than conventional mitigation strategies by including possible alternatives already in the early planning stages. Based on a set of specific heuristics, a high-quality spectrum of conceptual solutions for the safety problem recognised in the hydrological system under consideration will result.

In particular concerning the European Flood Risk Directive, but also with respect to the overall aim of building hazard-resilient communities, future studies should include the applicability of TRIZ-TIPS within flood risk management plans. Since such plans are of certain relevance in order to deal pro-actively and from an ex-ante perspective with flooding hazards including torrent processes, the applicability in the framework of flood risk management plans is obvious. A particular focus should be placed on the combination between participative effects such as Formative Scenario Analyses (Mazzorana *et al.* 2009) and conventional modelling approaches in order to better achieve the overall aim of managing natural hazard risk in a sustainable manner.

REFERENCES

Altschuller, G. (1984). *Erfinden: Wege zur Lösung technischer Probleme,* Verlag Technik, Berlin, pp. 272.

Armanini, A., and Larcher, M. (2001). “Rational criterion for designing opening of slit check dam”, *Journal of Hydraulic Engineering* 127(2): 94-104.

Barredo, J. (2007). “Major flood disasters in Europe: 1950-2005”, *Natural Hazards* 42(1): 125-148.

Barredo, J. (2009). “Normalised flood losses in Europe: 1970-2006”, *Natural Hazards and Earth System Sciences* 9(1): 91-104.

Blanchard, B., and Fabrycky, W. (2006), *Systems engineering and analysis*, Prentice Hall, Upper Saddle River, pp. 804.

Christensen, J., and Christensen, O. (2003). “Climate modelling: severe summertime flooding in Europe”, *Nature* 421(6925): 805-806.

Egli, T. (1996). *Hochwasserschutz und Raumplanung: Schutz vor Naturgefahren mit Instrumenten der Raumplanung – dargestellt am Beispiel von Hochwasser und Murgängen*, ETH Zürich, Zürich, pp. 166.

Fuchs, S., Bründl, M., Stötter, J. (2004). “Development of avalanche risk between 1950 and 2000 in the municipality of Davos, Switzerland”, *Natural Hazards and Earth System Sciences* 4(2): 263-275.

Fuchs, S., and Bründl, M. (2005). “Damage potential and losses resulting from snow avalanches in settlements of the canton of Grisons, Switzerland”, *Natural Hazards* 34(1): 53-69.

Fuchs, S., Thöni, M., McAlpin, M., Gruber, U., and Bründl, M. (2007). “Avalanche hazard mitigation strategies assessed by cost effectiveness analyses and cost benefit analyses – evidence from Davos, Switzerland”, *Natural Hazards* 41(1): 113-129.

Fuchs, S., and Keiler, M. (2008). “Variability of natural hazard risk in the European Alps: evidence from damage potential exposed to snow avalanches”, *Disaster management handbook*, edited by: Pinkowski, J., Taylor & Francis, London: 267-279.

Fuchs, S., Kaitna, R., Scheidl, C., and Hübl, J. (2008a): “The application of the risk concept to debris flow hazards”, *Geomechanics and Tunnelling*, 1(2): 120-129.

Fuchs, S., Keiler, M., and Zischg, A. (2008b). „Multi-temporale skalenabhängige Schadenpotenzialanalyse“, *Wildbach- und Lawinenverbau* 158: 146-156.

Fuchs, S. (2009). “Susceptibility versus resilience to mountain hazards in Austria – Paradigms of vulnerability revisited”, *Natural Hazards and Earth System Sciences* 9(2): 337-352.

Heinimann, H. (1995). “Naturgefahren aus forstlicher Sicht – Vergangenheit, Gegenwart, Zukunft”, *Schweizerische Zeitschrift für Forstwesen* 146(9): 675-686.

Holub, M., and Hübl, J. (2008). “Local protection against mountain hazards – State of the art and future needs”, *Natural Hazards and Earth System Sciences* 8(1): 81-99.

Keiler, M., Sailer, R., Jörg, P., Weber, C., Fuchs, S., Zischg, A., and Sauermoser, S. (2006). “Avalanche risk assessment – a multi-temporal approach, results from Galtür, Austria”, *Natural Hazards and Earth System Sciences* 6(4): 637-651.

Kienholz, H., Krummenacher, B., Kipfer, A., and Perret, S. (2004). “Aspects of integral risk management in practice”, *Österreichische Wasser- und Abfallwirtschaft* 56(3-4): 43-50.

Kundzewicz, Z., Ulbrich, U., Brücher, T., Graczyk, D., Krüger, A., Leckebusch, G., Menzel, L., Pińskwar, I., Radziejewski, M., and Szwed, M. (2005). “Summer floods in Central Europe – climate change track?”, *Natural Hazards* 36(1-2): 165-189.

Mazzorana, B. (2008). “Das EF30Forward Konzept – Ein Hinweisinstrument zur Ermittlung der Zuverlässigkeit und Funktionseffizienz von Wasserschutzbauten”, *Interpraevent*

2008, edited by: Mikoš, M., Hübl, J., and Koboltschnig, G., Internationale Forschungsgesellschaft Interpraevent, Klagenfurt, Vol. 1: 415-424.

Mazzorana, B., Scherer, C., and Marangoni, N., (2008). “Additional torrent control strategies on debris flow alluvial fans with extremely high vulnerable settlements”, *International Environmental Modelling and Software Society Proceedings iEMSs 2008*, edited by: Sànchez-Marrè, M., Béjar, J., Comas, J., Rizzoli, A., and Guariso, G., International Environmental Modelling and Software Society, Barcelona, 1492-1499.

Mazzorana, B., Hübl, J., and Fuchs, S. (2009). “Improving risk assessment by defining consistent and reliable system scenarios”, *Natural Hazards and Earth System Sciences* 9(1): 145-159.

Mileti, D. (1999). *Disasters by design*, Joseph Henry Press, Washington, pp. 351.

Mitchell, J. (2003). “European river floods in a changing world”, *Risk Analysis* 23(3): 567-574.

Nationalrat [Swiss National Council] (2000). “Motion Ständerat ((Danioth) Inderkum). Interdisziplinäre alpine Forschung”. Bericht der Kommission für Umwelt, Raumplanung und Energie vom 17. April 2000 zur Motion Nr. 99.3483 s.

Oberndorfer, S., Fuchs, S., Rickenmann, D., and Andrecs, P. (2007). “Vulnerabilitätsanalyse und monetäre Schadensbewertung von Wildbachereignissen in Österreich”, *BfW Berichte* 139: 1-55.

PLANAT [Nationale Plattform Naturgefahren] (2004). *Strategie Naturgefahren Schweiz. Synthesebericht in Erfüllung des Auftrages des Bundesrates vom 20. August 2003*, PLANAT, Biel, pp. 81.

Projektteam ETAlp (2003). ETALP: Erosion, Transport in Alpinen Einzugsgebieten – “Stummer Zeugen Katalog”, BMLFUW, Wien, pp. 49.

Ruchti, B., and Litotov, P. (2001), “TRIZ-based innovation principles and a process for problem solving in business and management”, *TRIZ-Journal* 6(12): online available at www.triz-journal.com.

Scherer, C., and Mazzorana, B. (2005). *Schutzwasserbau für den Oberen Eisack. Bericht zur Hydrologie*, unpublished report, Interreg IIIB project Alpine Space “River Basin Agenda”, Bolzano, pp. 117.

Scherer, C., and Mazzorana, B. (2007). *Gefahrenszenarien im Einzugsgebiet des Mareiter Baches*, unpublished report, Interreg IIIB project Alpine Space “ClimChAlp – Climate change, impacts and adaptation strategies in the alpine space”, Bolzano, pp. 129.

Terninko, J., Zusmann, A., and Zlotin, B. (1998), *TRIZ: Der Weg zum konkurrenzlosen Erfolgsprodukt*, Verlag Moderne Industrie, Landsberg a. Lech, pp. 288.

Üblagger, G. (1973). “Retendieren, dosieren und sortieren”, *Mitteilungen der forstlichen Bundesversuchsanstalt Wien* 102: 335-372.

Weck-Hannemann, H. (2006). “Efficiency of protection measures”, *Risk21 – Coping with risks due to natural hazards in the 21st century*, edited by: Ammann, W., Dannenmann, S., and Vulliet, L., Taylor & Francis, London: 147-154.

Willi, H. (2009). “Integrales Risikomanagement am Beispiel Engelberger Aa“ *Geomatik Schweiz* 5/2009: 193-196.

Zobel, D. (2006). *Systematisches Erfinden: Methoden und Beispiele für den Praktiker*, Expert-Verlag, Renningen, pp. 422.

Zobel, D., and Hartmann, R. (2009). *Erfindungsmuster: TRIZ: Prinzipien, Analogien, Ordnungskriterien, Beispiele*, Expert-Verlag, Renningen, pp. 218.