Persistence of Alpine natural hazard protection

Meeting multiple demands by applying systems engineering and life cycle management principles in natural hazard protection systems in the perimeter of the Alpine Convention

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Preface – Maria Patek (PLANALP)

We are at a “cross-road” - in terms of whether it is necessary to set the priority for investing in new future protective infrastructure or “just” to try to keep the present state of functionality (or simply said: the present state) of protective structures throughout the perimeter of the Alpine Convention?

To me – as a representative of all torrent and avalanche-related protective policies, strategies and, - of course - structures in Austria – the answer is not easy (due to all political and citizens’ needs in our provinces or municipalities), but rational and practical: Priority has to be given definitely to maintenance. I clearly understand the upcoming years and decades as a demand / or challenge to further invest in the maintenance of the functionality of all protective infrastructures in place.

As many other Member States within the perimeter of the Alpine Convention, Austria has invested billions of EUR in protective systems against natural hazards and risk for centuries, and they are indeed effective. These systems require permanent monitoring and improving of their structural functionality and also the involvement of all organisations concerned and / or the beneficiaries of these structures. This, however, cannot be the task of the state’s administration or institutions responsible for disaster mitigation alone: this clearly needs the awareness, perception and acceptance of the public society, too.

This publication will contribute to a better understanding of the needs to invest in the maintenance / preservation of existing structural prevention facilities in place. It should be understood as a support, growing awareness or the use of all recommendations / good practices highlighted in the brochure. The close alliance of the countries located within the perimeter of the Alpine Convention – faced with similar challenges – calls for the exchange of transnational experience in order to reassure the increase of resilience of Alpine areas against natural hazards.

The common challenges have to be managed by each Member State individually – but cooperation, harmonisation and coordination will support their individual visions and efforts, too.

My sincere thanks go to all who have actively contributed to this notable publication.

Maria Patek

Maria Patek

President of the Platform of Natural Hazards of the Alpine Convention (PLANALP)

Preface – Markus Reiterer (Alpine Convention)

Even the early inhabitants of the Alps needed to protect themselves against natural hazards. So it is no surprise that the systems and infrastructures humans put in place for the purpose of protection have evolved considerably throughout history. Today we have a notable number of protection facilities throughout the Alps and we are constantly improving cooperation as a key factor to minimise and cope with natural hazards. One of the most striking advantages of the Alpine Convention and its PLANALP platform is this emphasis on cross-border cooperation and exchange of knowledge, data, expertise and support between the Alpine countries. This type of cooperation will enhance our ability to prevent, address and manage natural hazards and it will increase our resilience against them. Even though, each of the countries, though facing similar challenges, adopted their own policies, strategies and actions, they all work towards a common goal.

When we talk about long-term investments in protective infrastructures, we should not only consider its financial implications, but also address the knowledge and innovation that these installations require. Applying the methods of systems engineering to protective systems requires considering the entire life cycle starting with the conception, including planning, creation, operation and maintenance. Furthermore, these structures need ongoing monitoring and inspection in order to assess their status quo in terms of operability and functionality as well as any possible need of maintenance or replacement. Lastly, also the disposal or reconfiguration has to be planned.

Most importantly, it is necessary that protection systems meet the expectations and needs of the local inhabitants. These systems also have important functions as a backbone of social and economic prosperity of the Alpine region, since they provide structural and subjective safety to people, our societies as well as to economic investments.

With this brochure the Natural Hazard Platform intends to support national and regional authorities, policy makers as well as practitioners in their work concerning monitoring, inspection and maintenance of prevention facilities and to provide insights into the advantages of integrative methods. It is my sincere hope that the target audience will consider this publication and use it when planning their future activities.

I would like to sincerely thank the authors of this publication for the work done and to all the members of the Platform for their inputs. My special thanks go to the chair of the Natural Hazard Platform, Ms Maria Patek, for all her efforts and finally to all the partners in elaborating, disseminating and applying this publication.

Markus Reiterer

Secretary General of the Alpine Convention

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1. Executive summary

Protective infrastructures provide the basis for a smooth development of the regions and countries within the perimeter of the Alpine Convention in terms of economic and societal welfare. Over centuries, billions of euros have been invested by public and private institutions in protection systems within the respective Member States in order to significantly decrease the level of risk against natural hazards and to provide at least an acceptable level of safety.

Although most of these structures are designed and built for long usage (e.g. structures made by concrete or steel for about 80 years), there is always the risk of non-performance – or even failure. Permanent monitoring and maintenance to safeguard the performance of these structures is therefore a conditio sine qua non within the structures' life span and needs long-term planning and strategic decisions.

Based on the current high level of protection and safety standards against Alpine natural hazards in the Alpine Conventions' Member States, the preservation of protective facilities in the future is a great challenge which has direct consequences on life and economy in the Alpine area.

Although the related task of monitoring, inspection and maintenance of protection facilities are mostly regulated in detail by legal and technical standards. Furthermore some organisational structures and financing instruments are available. But in practice we note several deficits in the execution of these tasks. This gap has to be bridged by supporting all organisations concerned with prevention facilities (in whatever manner) with evidence-based, practically tested and future-oriented strategies and actions. By applying further aspects of Systems Engineering (SE) and life cycle management (LCM) principles in natural hazard protection systems a first step towards bridging this essential gap can be set.

Systems engineering is an interdisciplinary field of engineering that focuses on how to design and manage complex engineering systems over their life cycles. SE deals with work processes, optimisation methods and risk management tools in such projects/systems. SE ensures that all likely aspects of a project or system are considered – also in their time flow - and integrated. The approach requires rethinking from linear, one-dimensional to cybernetically orientated planning processes.

Introducing SE into natural hazard and risk management is relatively new and needs common cooperation, coordination and exchange of experiences made with the practical implementation of this complex approach throughout the perimeter of the Alpine Convention. By providing both – information in detail on the background and content of SE, its implementation as well as examples of good practice among the Member States – this brochure will support policy and decision makers, practitioners as well as the scientific community to commonly develop strategies for a foresighted maintenance of the functionality of the protection systems within the Alpine area.

2. Persistence of Alpine natural hazard protection – Introduction and challenges

For centuries, the Member States of the Alpine Convention have invested billions of euros in structural protection facilities against natural hazards in order to provide the basis for a smooth development in terms of economic and societal welfare. Long-lasting decisions of inhabitants (e.g. residence choice, building private wealth, social and familiar dispositions) as well as the economy (e.g. business location, investments, creation of new jobs) in the Alpine region are often based on the (subjective) perception of risk or safety. Public and private investments in protective infrastructure have to be therefore sustainable and include the maintenance and reconstruction of these facilities, too.

From the point of view of regional and local decision makers as well as the population concerned, investments in protection facilities have to contribute considerably to decrease the level of risk against natural hazards and to provide at least an acceptable level of safety. Losing this level of safety (e.g. by deterioration or decreased performance of protective structures) – which would lead to an enlargement of hazard zones – will not be politically or socially accepted.

At present, approximately **2 million structural protection facilities** related to Alpine natural hazards (torrent, avalanche, rockfall, landslide) have been counted in the Alpine parts of Austria, Germany, Italy, Liechtenstein, Slovenia and Switzerland, representing a **replacement value** of about **50 billion euros** (this figures are based on expert opinions, because there is the challenge to count exact figures because of different administrational responsibilities; these figures do not include estimations on structures held / owned by e.g. infrastructure authorities / companies (like railway, roadway etc.) nor do they include figures on protective infrastructure in the Alpine parts of France). Most of these structures are designed and built for long usage (e.g. structures made of concrete or steel for about 80 years). Decisions made during the design stage of such a structure or system are invariably fraught with significant uncertainties. In light of these uncertainties, there is risk of non-performance – or failure – of the structure during its life span (e.g. the loadings may vary significantly due to forces from unforeseen or even unexpected natural hazards). With respect to financial issues, there is a serious risk in underestimating the whole life cost of a given structure or mitigation system. Experience in practice with the holder (operator) or beneficiary of such structures or systems lead to the perception that only a few decision makers are aware of the whole life cost that include costs of development, operation, maintenance and repair, costs of failure, recycling, as well as indirect costs of non-performance or failure. A survey on typical maintenance costs among the Member States resulted in a share of about 1.5% per year of the building costs that has to be dedicated to regular operation and maintenance of prevention structures. This means in practice that over the life span of a given prevention structure refinancing of the original building costs will be necessary in order to provide the intended performance of the structure.

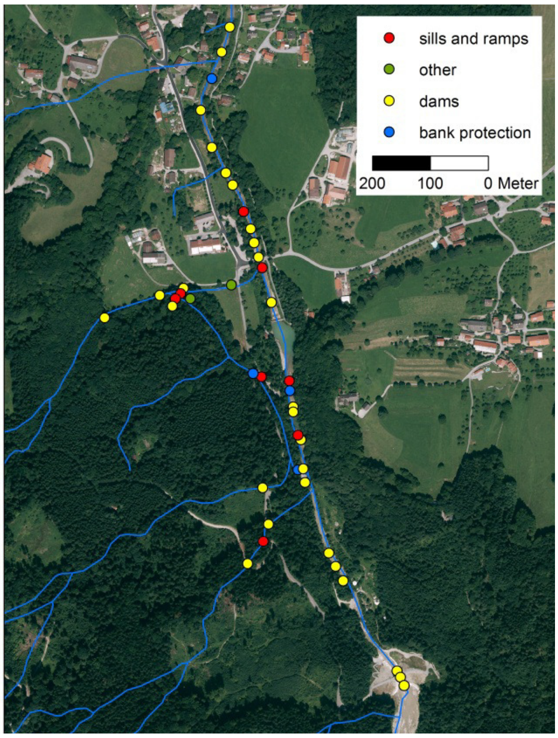

Fig. 1: Example for a high number of protection structures; Jenbach, Bavaria (LfU)

Given the impressive number of existing structural prevention facilities throughout the Alpine area (comp. example in fig. 1) and the capital stock they represent, there is the serious question on how to maintain the performance of these structures best, especially with the **challenges** of

a) *Advanced age* of a number of prevention facilities in the Alps resulting in call for immediate action
b) *Little knowledge on the condition* / performance levels of these structures
c) *Limitations on resources* (mainly financial, but also personal)

d) *Changes in legal frameworks* and implications (implications of EU Water Framework Directive, Flood Directive)
e) *New demands on existing systems, e.g. due to the development of new and sensitive infrastructures or social attitudes*
f) Demographic changes in Alpine regions and altered regional development potentials (also based on the development of transportation infrastructures) which lead to changes in the desired performance needs / functionality of these structures (comp. fig. 2)
g) Decreasing knowledge and awareness of holders (operators) or beneficiaries of such structures on the maintenance needs or life cycle-based interventions (with exception where the federal state / Länder are the holders, like Bavaria) including permanent monitoring
h) Question of responsibility and liability concerning these structures in countries where investment costs have to be shared among the public (administration) and the holder (operator) – especially in terms of non- (or minor) performance during a disaster event
i) *Quick development in the fields of risk management and high interactions, e.g. between structures and risk assessment*

Based on the current high level of protection and safety standards against Alpine natural hazards in the Alpine Conventions' Member States, the preservation of protective facilities is a great challenge in the future, which has direct consequences on life and economy in the Alpine area. Therefore, it should be on the top of the political agenda. Thereby, different impact levels with regard to protection facilities can be distinguished, where each level has its own view on the risk management topic:

- Single structure, where questions of stability, maintenance,… are vital
- Protection system / catchment area, where functionality or resilience are important topics
- Effect area, in which land-use questions, but also societal consequences gain importance
- State level, where mainly questions of funding and security are interesting
- European level, which gives some common basis for guidelines like the flood directive

Although the related task of monitoring, inspection and maintenance of protection facilities are regulated in detail by legal and technical standards and organisational structures and financing instruments are available in general, several deficits in the execution of these tasks exist in practice. This gap has to be bridged by supporting all those concerned with prevention facilities (in whatever manner) with evidence-based, practically tested and future-oriented strategies and actions. By applying systems engineering and life cycle management principles in natural hazard protection systems, the members of PLANALP want to contribute by this comprehensive brochure to a better understanding of the potential of systems engineering, especially in the frame of natural hazard and risk management and the promotion of its advantages.

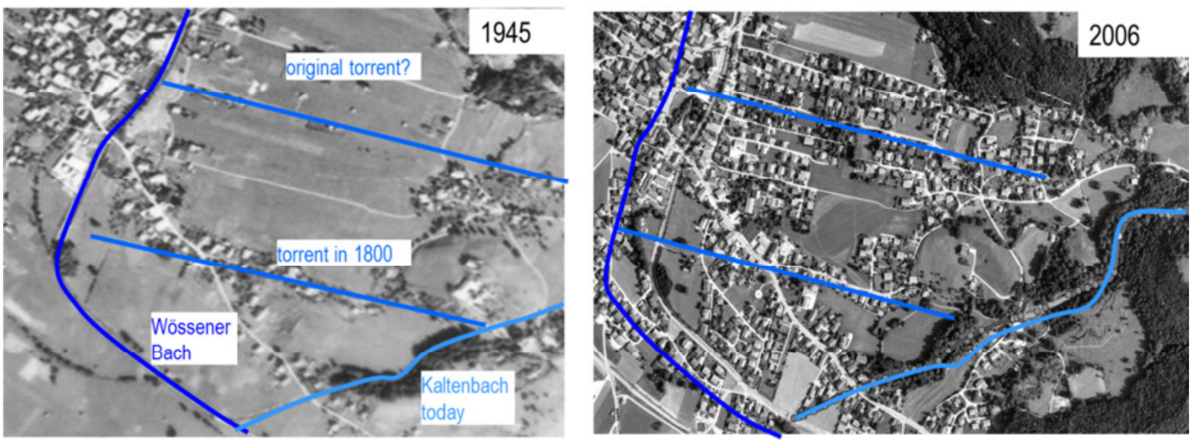

Fig. 2: Example for a change in Alpine regions – municipality of Unterwössen in Bavaria (LfU)

3. Systems engineering: holistic answer to multiple demands of integrated risk management

3.1 Overview

For a long time, the only possibility or strategy dealing with natural hazards was a kind of "hazard defence" determined to avoid hazards. This could be simplified as a "one-dimensional" strategy (compare green area in fig. 5).

A high number of structures were, however, realised over the time. So we have to deal with many single elements in different conditions and different age. While the function of the structures has to be ensured every time, the conditions of the single elements change and so the time perspective becomes more and more important. Especially questions like how to monitor the structures or what to do with elements reaching the end of their life time have to be answered. So in order to stay in the "dimension picture" a second dimension arises, where life cycle management approaches can help to face the challenges.

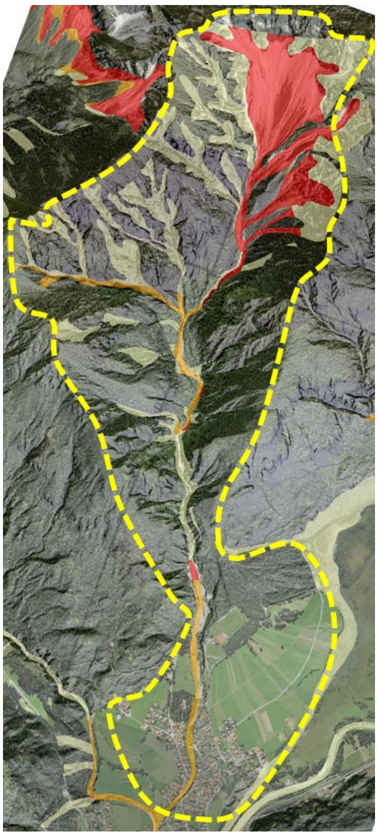

Fig. 3: For example, an Alpine catchment area is a complex system (LfU)

We learned, however, that dealing with natural hazards one obviously faces several complex systems: the catchment area with all the processes and interactions (fig. 3) and the social system which demands for example protection - just to mention two of them. That is the reason that nowadays we promote integral risk management (fig. 4) as best option to cope with natural hazards, which means that we try to live with natural hazards. So it is necessary to develop not only "one-dimensional" single-purpose structures and observe them over their life time (second dimension), but we have to realise complex and multipurpose protection systems consisting of many single elements, which could be regarded as third dimension. In this field systems engineering can provide interesting approaches to improve our protection systems engineering.

Fig. 4: Principle of integrated risk management (ClimChAlp 2008)

3.2 Principles and definitions

The main purpose of technical protection systems and protective structures is the reduction of risks and other negative effects by natural hazards for the endangered zones to an acceptable (reasonable) level. In the evidence of the increasing complexity of protection systems the challenges for configuration, planning and design of these systems go far beyond classical construction engineering. Modern protection systems do not only embrace technical structures, but also measuring devices, regulation and control technology and even biological measures; furthermore, they often consist of various separated structures, functional units or structures in sequences/functional chains and closely interact with other planning, legal and organisational measures. Some examples of complex protection systems:

- Cascades of controlled flood retention reservoirs
- Avalanche protection systems embracing defence structures in the starting zone, artificial avalanche release systems and deflecting/retarding structures in the run-out zone
- Flood protection systems consisting of permanent control structures, mobile flood protection systems and flood alert systems

Hence complex protection systems represent assemblies of structural, mechanical, mechatronic and digital elements with unequal ruggedness, service life, maintenance requirements and risk of failure. Another characteristic of complex protection systems is the multidisciplinary competence to be planned, designed, constructed, operated and maintained as well as the multitude of responsibilities bringing about a high demand for coordination among planning engineers, approving authorities, operating institutions and beneficiaries of protection. The principle of integrated risk management is not only applicable to the protection function of these systems, but also to reduce risks concerning the stability, serviceability and durability of the protection system itself, mainly to prevent malfunction or even total failure (breakdown) after extreme events.

The management of complex technical systems in general requires approaches oriented at the sustainability, the life-cycle perspective and quality assurance. This principle also applies for natural hazard protection systems, pointing out the gaps of conventional planning procedures and paving the way for the implementation of "systems engineering". Systems engineering is by definition an interdisciplinary field of engineering that focuses on how to design and manage complex engineering systems over their life cycles. Issues such as reliability, logistics, coordination of different teams (requirements management), evaluation measurement and other disciplines become more difficult when dealing with large or complex projects. Systems engineering deals with work processes, optimisation methods, and risk management tools in such projects/systems. Systems engineering ensures that all likely aspects of a project or system are considered and integrated. The approach requires rethinking from linear, one-dimensional to cybernetically orientated planning processes.

Infobox systems engineering (SE):

SE is an interdisciplinary approach and aims at enabling the realisation of successful systems. It focuses on an early definition of customer needs and required functionality early in the development cycle, documenting requirements, and proceeding with design synthesis and system validation in relation to the entire problem.

(Definition by the International Council on Systems Engineering (INCOSE)

SE means: "Build the right system; build the system right." SE considers the whole problem, the whole system, and the whole system life cycle from concept to disposal.

(by UK Chapter of INCOSE)

Origin: 1940s in telecommunication; fundamental enhancements in space flight

Although at first sight the application of the "systems engineering" approach in natural hazard and risk appears to be highly theoretical and strongly limited by the capacity of engineering practice. Hereinafter it will be shown that a wide range of systems engineering elements are already standard in natural hazard engineering. Systems engineering as a comprehensive engineering concept, however, is a new approach and needs further characterisation and specification. In a conceptual sense, systems engineering may also be applied – with some simplifications – to the whole risk management cycle as the criteria of quality life cycle, reliability and service standards also apply to comprehensive protection and safety functions.

3.2 Elements (methods) of systems engineering and system life cycle

When the systems engineering concept is applied to protection systems, the whole life cycle starting with the conception, including planning, creation, operation and maintenance and ending with the decay, disposal or reconfiguration, is covered. One fundamental principle is the compliance of the functionality of the protection system with the "customer expectation", in particular the congruence of protection effects with the protection needs of the beneficiaries. In general, the fulfilment of protection goals is the most important benchmark for the quality of a protection system (structure).

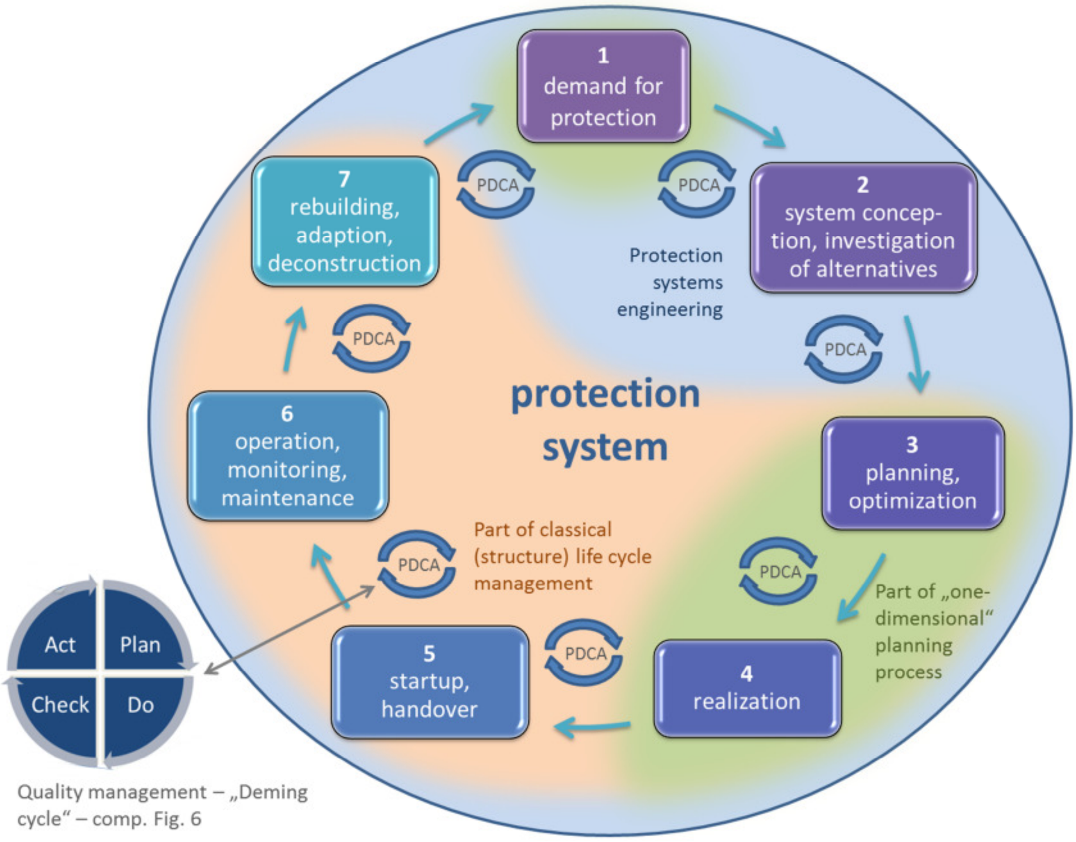

Fig. 5: Systems engineering for protection systems: 7 phases of the system life cycle, sustained by the cyclical reevaluation (feedback) displayed as PDCA cycle ("Deming cycle") of quality management

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There are **seven main phases of systems engineering** which can be displayed in the "system life cycle" (fig. 5) of natural hazard engineering:

1. **Demand for protection:** identification of protection needs and definition of protection objectives: hazard and risk assessment, analysis of vulnerability, determination of safety level (limit values), determination of system requirements.
2. **System conception and investigation of alternatives:** variant studies including assessment of management alternatives referring to the criteria efficiency, costs/benefits and risks; final target: conception of protection system regarding elements of the whole risk management cycle.
3. **Planning and optimisation:** optimization of protection effects: protection concept, design of measures, functionality assessment, study of the cost-effectiveness.
4. **Realisation:** creation (construction) of the protection system.
5. **Startup, handover:** putting into operation: quality check, functionality test, handover to the holder (operator) of the protection system.
6. **Operation, monitoring and maintenance** of the protection system: service, inspection, recurrent condition assessment, repair and restoration.
7. **Rebuilding, adaption or deconstruction:** what to do after reaching the end of life time - renewal, replacement, adaptation of new boundary conditions or needs, removal (disposal) or controlled decay.

The process in the system life cycle is supported by a constant (recurrent) feedback displayed in the form of the PDCA cycle ("Deming cycle") of quality management. The principles of this feedback are: Plan, Do, Check, Act (fig. 5 and 6).

Hereinafter several **methods (functions) of systems engineering** are presented that show the practical value of implementation of this approach in natural risk management:

- **Project management** is an essential function to steer complex and multi-layered planning, creation and operation processes of protection systems, including the coordination of a multitude of actors and stakeholders in the project.
- **Requirement analysis** and **systems design** aims at the design of solid,

efficient and less failure-prone protection systems and is achieved by definition of specific protection goals, variant study, minimum standards, functionality testing and application of approved technology. System design is oriented at relevant hazard scenarios and has to be carried out already at the start of the planning process. It focuses on the configuration (architecture) of the protection system, the functionality and the design of structures, taking into account effect interrelation and the serviceability of the protection system (structure). Additionally the protection needs, the technical, organisational and economic capacity and the legal requirements of the operators (beneficiaries) are considered.

- **Engineering change management** aims at current adaptation and reconfiguration of protection systems to changing framework conditions, primarily of environment (e.g. climate change), society, technology and societal risk acceptance. A most important function is the documentation and controlling of these changes as well as the current control and recurrent condition assessment. Protection objectives have to be cyclically adapted as well. (comp. e.g. good practice B5)
- **System integration** deals with the reconfiguration, enhancement or realignment of existing systems in the course of a restoration campaign at the end of the first life cycle or after severe damages caused by extreme events. New elements (e.g. protection structures, rakes and grills, measuring and control devices) are integrated into the existing protection system changing the functionality and/or the risk of failure. Hence system integration requires the revision of protection targets and security levels, further functionality testing and the adaptation of maintenance strategies. (comp. e.g. good practice B12 and 13)
- **Standardisation** is a key function of quality assurance in systems engineering and serves the continuous improvement process (CIP). Complex systems with a multitude of planners, performers, operators and responsibilities require strict and applicable regulations and standards (norms) in order to guarantee smooth and error-free planning processes, workflows and interface work. Standards support all phases in the PCDA cycle, while standards themselves recurrently have to be checked concerning their accuracy and applicability and have to be adapted if necessary. (fig. 6) Standardisation refers to all kinds of norms, including legal norms, common technical standards as well as specific standards, guidelines and operation regulation for a specific protection system (structure) and may cover design, dimensioning, steering, organisational as well as safety issues.

Infobox life cycle management (LCM):

(Product) LCM is a process of managing the entire lifecycle of a product from inception, engineering design and manufacturing to service and disposal of manufactured products. LCM integrates people, data, processes and business systems and provides a product information backbone for companies and their extended enterprise.

(Definition by WIKIPEDIA)

Origin: 1930s in product development; fundamental enhancements in regard to mainly the life cycle of industrial products

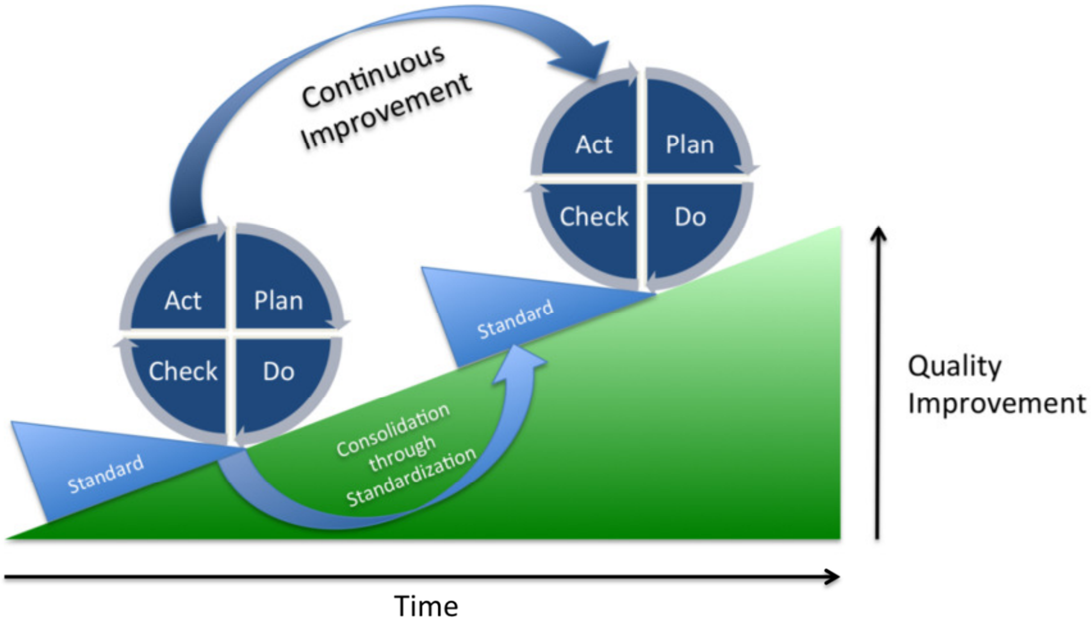

Fig. 6: Continuous improvement of protection systems by recurrent application of PDCA cycle, supported by standardisation.

- **Risk management for protection systems** is a tool to identify potential hazards and risks for the stability, serviceability and durability of the system (structures) early enough and prevent system failures or total breakdown by appropriate measures, safety reserves and redundancies for key elements in the system. Concerning protection systems for natural hazards risk management also has to take into account the impact of extreme (catastrophic) events and the consequences in case of overload. Protection systems that include complex decision support systems based on measuring, controlling or warning devices also need increased attention in regard to electronic (digital) system breakdown, interruption of power supply or simply human failures.

3.3 Legal, economic and organisational aspects of systems engineering

The more complex protection systems are, the more likely is the occurrence of malfunction, failures or total breakdown. Hence increasing complexity also raises the risk of liability for planners, operators or approving authorities. Planning, design, operation and maintenance of complex protection systems involve generally a multitude of actors and decision makers with different levels of expertise, competence, technical and economic capacities or even risk awareness. This unbalanced situation requires the creation of protection systems that are oriented at the capacity of the holders or beneficiaries (as a rule layperson) who are liable and who bear in case of failure or breakdown the risk of compensation of damages to third parties in case of failure or breakdown.

As a rule, legal norms and official approvals of protection systems presuppose the application of a "common state of the art" which hardly exists for protection systems (structures). Protection structures, control devices or warning systems have the characteristic of prototypes to a large extent rather than frequently approved technologies. Due to the rareness of real occurrence of design events few experiences concerning the functionality (serviceability) of protection structures under extreme impact exist. The sustainable serviceability of protection systems that need recurrent supervision, adjustment, inspection or maintenance by the operator (holder) presupposes standardised operation procedures, regular instruction and training. As protection works are rarely in function and responsible persons may vary very often, the documentation and transfer of knowledge are additional challenges for the operation of these systems.

Traditionally, the cost calculation for protection systems (structures) is limited to the planning and construction phase, while operating expenses or maintenance costs are not taken into account. Recent research clearly has proven that these costs may clearly exceed the costs of production over the lifetime (service life) of a protection system (structure) and exponentially increase with crowing complexity. A new approach in systems engineering is "**life cycle costing**" (fig. 7), a method of cost calculation that takes into account all phases of service life (planning, construction, operation, maintenance, disposal or renewal). An additional problem is that these costs occur at different times and parties (comp. e.g. good practice B3), while planning and construction costs are generally funded by governmental (public) institutions at the beginning of service life, the costs of operation and maintenance primarily concern holders or beneficiaries of protection measures in the operation phase. Life cycle costing guarantees the common truth about costs and supports awareness for all parties: it has to be defined who has to cover which costs in what phase during service life.

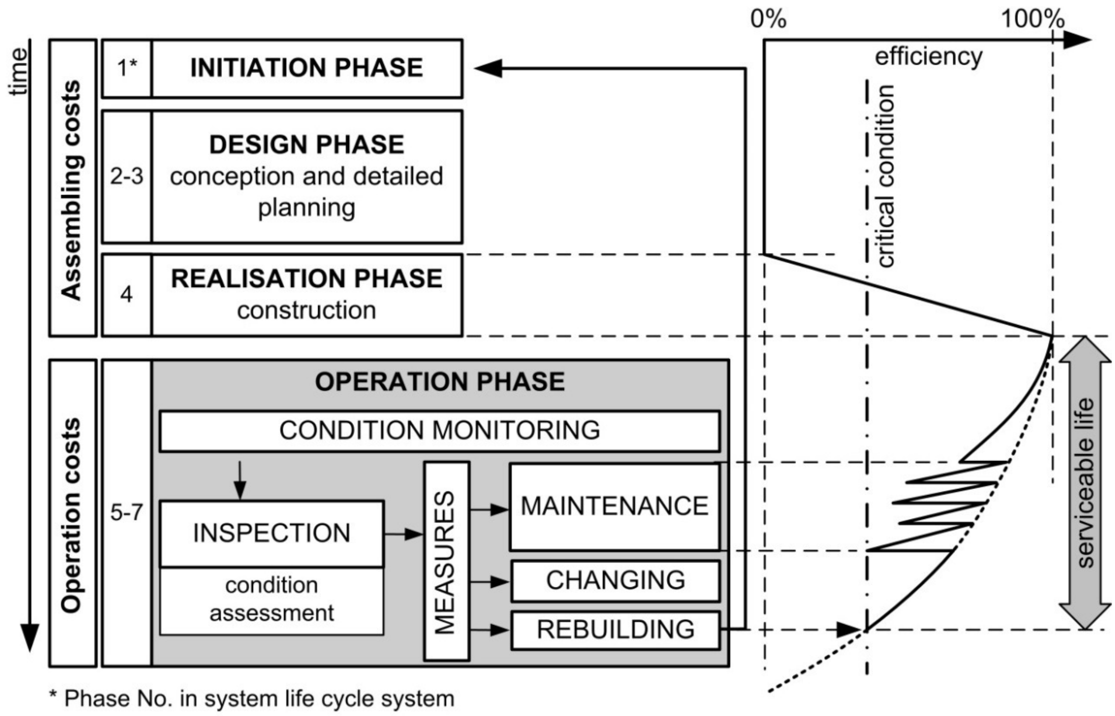

Fig. 7: Principle of life-cycle management of protection systems as basis for life-cycle costing.

Special attention has to be given to the interests of landowners that are involved if protection structures are placed on private properties with beneficiaries other than the landowner himself. This situation requires solutions concerning the utilisation of private real estates and the compensation of economic detriments for the whole service life. This problem is subject to expropriation in the public interest or the granting of rights of utilisation based on contractual agreements.

Furthermore, an important aspect of inspection and maintenance of protection measures are legally determined maintenance obligations of catchments, water courses or water infrastructure. Other legal obligations concern the duty of sustainable management of protection forests, the clearing of torrents from drift wood or the preservation of a good status of water bodies according to the EU Water Framework Directive.

Consequent planning and design of protection systems has by all means take into account the life-cycle costs and the shared responsibility among planners, operators, holders and legally bound persons concerning inspection, operation, maintenance, risk management and public safety assurance. The handover of protection systems to operators (holders) after completion is therefore also a transfer of risks, liability and economic loads that have to be taken into account and to provide awareness for both parties (except for Bavaria). In simple terms: Systems engineering also requires guidelines for the use of protection systems (structures). As protection structures as a rule are created in the public interest and are public good, nobody may be excluded. Zhe instructions concerning functionality, maintenance requirements, operation rules and residual risks involve all beneficiaries (even the citizens of whole municipalities or road users). Hence, the instruction and documentation of operation rules is also part of the common risk communication on local level. In this sense, the life-cycle of public risk awareness and operational knowledge also has to be taken into account.

4. Life cycle management (LCM) for protection systems

4.1 Introduction

Following the comprehensive systems engineering approach, integral protection concepts have to be elaborated in a structured manner aiming at fulfilling the requirements of effectiveness and efficiency with respect to a broad spectrum of objectives (compare section 3.2).

The feasibility of the integral protection concepts has to be evaluated under changing system loadings as well as adapted maintenance strategies. Taking into consideration these aspects, the necessity to optimise the functional performance and the operational reliability over the entire life cycle of the envisaged protection system is mandatory. With such a long-term planning perspective (i.e. a planning horizon of 100 years) a suitable LCM approach is required.

The major principles of the LCM system as an integral part of the systems engineering approach are related to

(1) an improvement of methods to determine the system requirements in terms of functionality according to specific needs at an early stage of the design phase, i.e. the cost/benefits and reliable performance and implementation of mitigation strategies;

(2) an assessment of the entire system including all necessary elements;

(3) a consideration of the intrarelationship between individual system components and interrelationships between higher and subordinate levels within the system hierarchy;

(4) a flexible protection concept and monitoring strategy allowing for adaptations and adjustments throughout its life span; and all points above considered.

In fact, without the consideration of proper design principles and the implementation of suitable maintenance strategies, the effectiveness of protection systems is going to decline faster over the time. In parallel, on several debris cones and alluvial fans a clear increasing tendency of wealth moving into flood prone areas could be retraced over the last decades (compare also fig. 2). This leads to an exacerbation of the flood risk and should be taken into account in integrated risk management or better be avoided in the future. What is particularly worrying in this situation is that resulting flood risk patterns might remain largely concealed, since limited attention has been devoted to the assessment of both the damage susceptibility and the functional performance of protection measures over their entire life cycle in the past.

Structures forming the protection systems are of a dual nature because they are designed to mitigate natural hazards, but on the other hand they are prone to be damaged throughout their life cycle by the same processes they should mitigate, thus reducing their performance over the time. Furthermore, a normally not allowed, but in practice not totally avoidable sudden or unexpected collapse of check dams can result in increased hazards downstream due to the formation of dam-break surges and the release of large volumes of sediments.

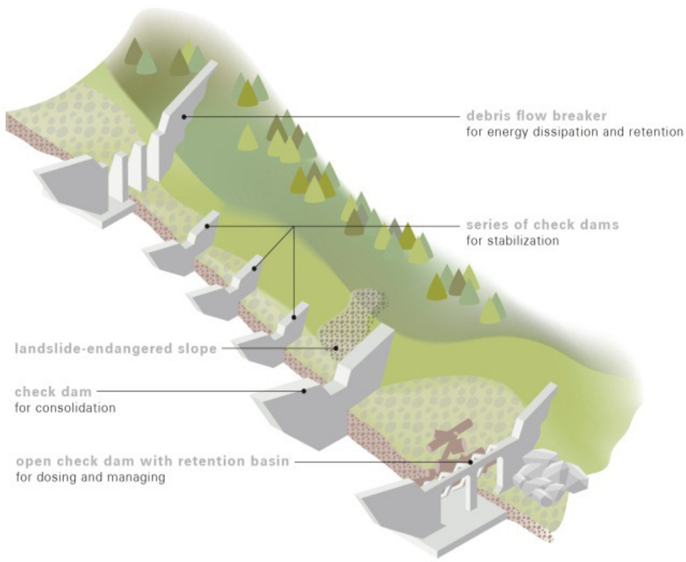

Fig. 8: Several structures form a “function chain”, where interactions have to be considered (LfU)

Following these premises the design of a protection system has to be based on

1. an ex-ante and technically sound verification of its functionality
2. structural reliability of the system including the case of overloading, when no sudden uncontrolled collapse of the structure and/or at least the system should occur

ad 1: That means the determination that the planned system interacts in the desired way with the analytically determined hazard process spectrum. The desired interaction has to be functional in order to the full and cost-efficient achievement of the risk mitigation goal and the defined ecological and hydro-morphological condition targets.

Technically speaking, the verification of the functionality of a particular system entails an ad-hoc definition of the verification concept, which might include, for example, the computation of hydraulic performance indicator values, the assessment of event-based and long-term sediment balances, peculiar performance indices for certain functional components (i.e. dosing efficiency of open check dams).

Ad 2: It includes that the structural reliability of the system has to be assured by taking into account that this concept is closely linked to the previous one (due to the above-mentioned dual nature of protection systems). Two different types of limit states are considered, namely the ultimate limit state and serviceability limit state. As stated in EN 1990, it has to be verified, based on the application of load models and structural models, that no limit state is exceeded when the design values for actions, material properties and geometrical data are used. Here (a) the Ultimate Limit States – **ULS** – and (b) the Serviceability Limit States – **SLS** – are briefly illustrated in their essential aspects.

(a) Ultimate Limit States – ULS: exceeding these limit states may result in a structural collapse or other forms of structural failures. They are related to the safety of people and/or the safety of the structure. **In this context EN 1990 prescribes the set of verifications listed in the box below**.

(b) Serviceability Limit States – SLS: The design situations to be considered in this case are **structural functions** of the entire structure or of a portion, the **comfort of people** and the **appearance** of the structure. These aspects are generally of limited relevance for typical protection systems in mountain streams. To assess these limit states the following criteria can be adopted: limitation of strain, deformations, crack widths and oscillations.

- **ECU:** Loss of static equilibrium of the entire structure or of specific parts, all considered as rigid bodies. In this case, small deviations of the value and the spatial distribution of the considered action type (e.g. dead weight of the structural parts) are relevant, whereas the strength of construction materials or the building ground are of no influence;
- **STR:** Failure or excessive deformation of the structure or its parts including the foundation piles. Here the bearing capacity and the strength of materials are relevant;
- **GEO:** Failure or excessive deformation of the building ground, whereas the bearing capacity of the soil (or rock) is decisive;
- **FAT:** Failure of the structure as a consequence of fatigue.

The reader may note that the verification approach with respect to structural reliability is of single structures anchored in various directives and norms, whereas the verification of functionality of single structures and even more the system is problem-specific and complementary to a rigorous cost-benefit analysis. Hence, from a LCM perspective, the proper design of highly functional systems is of highest priority.

The adoption of a solid verification concept is crucial to assure quality throughout the system life cycle and helps to clearly define both inspection and maintenance activities, which are very resource-intensive demanding both available finances and personnel.

4.2 Phases of LCM cycle

As shown in figure 7, the system life cycle encompasses different phases.

The whole cycle can be divided into an acquisition phase (fig. 5 parts 1 to 4) and an operation phase (utilisation phase, fig. 5 parts 5 to 7). This allows to distinguish between

a) actions necessary to develop the system and

b) 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 (compare gig. 5 and 7). The utilisation phase is characterised by the use of the product, reconfiguration and phase-out. System life cycle engineering includes concepts of the product life cycle, which is restricted to the manufacturing process, and concepts of maintenance and support capability as well as reconfiguration processes, which are of particular importance with respect to existing hazard mitigation strategies that have proven to be suboptimal and should therefore be enhanced. Possible starting points for such a system life cycle approach in integrated risk management may include

Fig. 9: Operation can also cause high efforts, for example retention basins have to be emptied from time to time

(1) an analysis conducted on a regional scale showing the need to increase the level of risk management against natural hazards (e.g. by further reduction of vulnerability or by higher protection level) 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;

(3) a recently produced hazard map delineating frequency and magnitude of specific hazard processes and 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.

4.2.1 Structuring the planning process

In this section we outline a conceptual planning approach to tackle planning problems in the field of protection systems engineering. It is flexible enough to face design situations where a completely new protection system has to be conceived as well as maintenance or restoration of existing protection systems. It was ideated as a step-by-step workflow to support practitioners in everyday planning activities:

1. Definition of **the system boundaries** of the considered study site focusing on the extent of the significant catchment and any relevant tributaries and deposition areas.

2. Definition of the **system characteristics** regarding protection system, natural hazard processes, damage potential and vulnerability.

3. **Problem identification** and description: definition of the problems (with the new and enhanced knowledge status) to be solved with a particular focus on risk mitigation and ecological functionality and explicit description of the systemic contradictions to be overcome.

4. **Formulation of the Ideal Final Result (IFR)** to be achieved by the description of a "model" to be approximated. The IRF has to be intended as a specification supporting the planner throughout the planning process. Since the IFR is formulated in an early planning phase, it is essential to explicitly refer to the previously identified system contradictions and to define a continuous target system. Expressed in another way, the targets to be attained are formulated in terms of maximisation (minimisation) objectives. An ideal protection system should have, among other things, the following characteristics (comp. e.g. good practice B5 and B7):

- long **durability** (high reliability), easy and cheap maintainability;
- high **functionality** (efficiency) with substantial mitigation effects for short return periods and just sufficient mitigation effects for long return period events;
- **low uncertainties** about protection system responses to extreme events, which lead to an easier integration and more effective implementation of early warning systems etc;
- a **resilient response** to extreme loadings (beyond design events), which especially requires solid and adaptable systems.

In special cases, like torrent control, further demands can occur, like

- high **sediment transport** regulation capacity with progressive reduction of the remaining sediment yield potential;
- **ecological requirements**, not only by Water Framework Directive, e.g. ecologically careful design of transverse structures prevent erosion and at the same time preserve essential characteristics of the natural water-flow and also allow best development of aquatic ecosystems (comp. good practice B9).

- **social function** of watercourses as important element of landscape- and townscape, recreation facility, water power, …

5. Analysis of all **possible physical, spatial, temporal and financial resources** for an optimal application of the IRF. In this phase the planner should go beyond the assessment of available space for hazard mitigation. For example, in torrent control apart from traditional consolidation and retention concepts also possibilities of dosing transported solid material (woody debris) or smoothing in space and time the peak flow intensity (e.g. diverting excessive loads towards damage-minimising sectors) should be explored. From an integrated risk management perspective it could be essential to identify objects to be "sacrificed" in case of a worst case scenario (i.e. damage-minimising sacrifice).

6. Elaboration of **solution concepts and/or variations** based on the IFR and following the principles shown in table 1.

7. **Evaluation** of the developed solution strategies.

8. **Selection of the optimal solution** concept based on cost/benefit criteria answering for each proposed solution the following questions (comp. e.g. good practice B6):

- what has been enhanced;
- what has worsened;
- what has been substituted and
- what has still to be done with reference to attain the IFR?

9. **Communication of the residual risk** to affected people.

Root Principles	**Derived Principles**
(i) Separation Principles	a) Spatial separation: The overall aim is to separate areas characterised by relevant process intensities from areas at risk, i.e. with a relevant accumulation of values at risk. Corollary: Concentration of adverse effect in low vulnerable areas. b) Temporal separation: The overall aim is to decouple the maximum intensity of liquid discharge and sediment transport on the process side in time and to displace movable objects at risk from endangered areas during the critical time frames within the extreme event duration (e.g. by evacuating people at risk). c) Separation by change of status: The aim is to achieve a reconfiguration of critical system configurations during the critical timeframes within the event duration (e.g. by avoiding bridge clogging). d) Separation within the system and its parts: 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).
(ii) Dynamisation Principles	a) Dynamisation of the sediment transport process: The overall aim is to control the sediment transport process (e.g. by dosing it through open check dams) and the wood transport process (e.g. by preventive trapping through retention structures). b) Ecosystem dynamisation: The overall aim is to enhance ecosystem functionality. c) Dynamisation of mitigation – modularisation of the protection system: 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.
(iii) 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) Multipurpose combination: The overall aim is to design parts of the mitigation concept with respect to alternative usage (e.g. modelling the landscape in order to achieve flow deflection without compromising the agricultural use of the area).
(iv) Redundancy Principles	Redundancy in intervention planning: In particular for a worst-case scenario, certain elements of the mitigation concept should be redundant in order to avoid system failures.

Table 1: Principles for the planning of effective flood risk mitigation strategies.

4.2.2 Realisation

The detailed design is the interface between the planning phase and the realisation phase in the course of the LCM cycle. In this stage the approved draft plans are edited and structural details are elaborated. It is still possible to wield influence on the operation phase of the structure even at this moment. The resulting design plans contain and display all information, which is required for the construction respectively realisation.

A detailed statement of work and a bill of quantities based on the design plans are necessary to find a suitable company carrying out the construction services. All required activities and materials are described in these documents. The bill of quantities can be put together out of single building blocks, which in most cases are available as patterns. To achieve an economical realisation of the measure, an invitation to tender should be implemented. The offered prices are the foundation of the final settlement.

Within the invitation to tender it can be practicable to allow variant solutions of the bidders. Alternative procedures, ways of construction or building materials can be suggested in this way. The assessment of innovations and newly developed solutions should consider the following lifecycle of the structure. Alternative solutions can influence the upcoming monitoring or maintenance of the structure in a positive or negative way. Even adaptions or changes of the building in the future can be affected.

After the placement the offered prices should be compared with the calculated costs. On the one hand, the financial framework has to be maintained. On the other hand, the offered prices can be used as calculation basis for prospective construction projects. Existing standard values can be adapted.

The execution of the construction work is symbolised by the ground-breaking ceremony. It is an important step in the structures life cycle. An accurate implementation of the planning is essential, so that the structure can fulfil its function for the whole life span. The predefined construction materials and quality standards have to be strictly monitored. Building materials like concrete can be sampled and examined for their stability or consistence in a laboratory.

An incorrect or sloppy realisation can cause an accelerated abrasion of the structure or deficiencies, which might be detected only after the end of the warranty period. Constructional faults within realisation require attendance and corrective maintenance works earlier in the life span and this leads to additional maintenance costs. A worst-case scenario as a result of deficiencies can be the failure of a whole structure in the calculated loading case.

Fig. 10: Realisation of a debris flow control structure in the torrent Zillenbach, municipality Hindelang, Oberallgäu (Picture: WWA Kempten)

In the course of realisation it has to be checked also whether the boundary conditions of planning – as for instance the condition of the building site – apply. If the parameters set in the planning phase do not correspond to reality, the stability of the structure can be endangered (e.g. base failure, soil erosion).

Therefore, it is important to manage and supervise the construction progress. Periodical site meetings of the builder-owner or his representative and the construction company lead to a higher quality of realisation and its result.

In certain circumstances it is required to digress from the design plans in the course of realisation. In these cases the changes have to be documented in the as-completed drawings, which are an important basis for adaptations or changes of the structure in the future. The as-built documents can also be a helpful tool to assess the condition of the structure in the context of monitoring. If these plans do not exist, the design plans have to be used instead. The uncertainty whether these plans were implemented one-to-one remains.

The actually performed services are the calculation base for the settlement. Service items, not mentioned in the invitation to tender or occurred during realisation, lead to additional costs. In these cases the approved financial framework has to be kept in mind.

The acceptance of the construction marks the end of the realisation phase and the structure is put into operation. Deficiencies, discovered prior to the handover, have to be documented. The remedy of defects has to be cleared with the construction company.

4.2.3 Operation and maintenance

Operation

In some cases, the operation of protection facilities causes noteworthy permanent efforts. Operation does not change the condition of the structure or facility, it just contains the effort during normal work or steady cost. These efforts can also add up to an important amount, which should be recognised already in the planning phase. Just to mention a few examples for operation costs: power costs for measuring devices, light or pumps; personnel costs for operation including stand-by duties; steady clearing works and (self-)monitoring.

Monitoring concept

A fundamental task to guarantee a reasonable safety level of the protection works is periodic monitoring concerning condition and effectiveness. This task is mainly the duty of the protection works holder (e.g. state, communities, beneficiaries, water cooperatives, or the holder of the protected traffic way (e. g. railway company) – also refer to the good practice examples B1, B3, and B11). The monitoring concept can be divided into two parts: the inspection and the measurement or intervention part (figure 12).

Fig. 11: Monitoring is essential to detect the necessity of maintenance and as a consequence to keep up functionality

The main target of the inspection part is to assess the condition in a comprehensive manner. This is guaranteed by the comparison of the actual state with a reference state. The aim of the inspection is to classify the structure in different condition levels, e.g. in a range from “new” or as “good as new” to “completely destroyed”. For classification of the condition at the actual state, the possible development of the condition in the future and the necessary moment for measures must be taken into account.

Inspection concepts should consider the importance of different structures. Barriers that represent a key structure in the protection system are subject to more frequent inspection and have to be maintained primarily. A key structure is characterised by massive damages in the protected area in the case of its failure.

The organisation of the inspection is regulated quite differently in the countries of the Alpine region. But in any case it is essential that the inspection is carried out by a qualified person and that the result of the inspection is well documented. In Italy, Austria and Germany for example the results are stored in databases for a further use (refer to annexe A – databases of structures).

It is important not only to monitor (and later on to maintain) structures, but also the watercourse, the banks and the waterside land. Those elements also fulfil functions in the whole system and therefore it can be, for example, necessary to remove deposited debris, excessive vegetation on the bank or woody debris. The interaction between watercourse, banks, slopes and structures have to be taken into account.

Every monitoring concept has of course to be flexible to changes and especially after events a separate monitoring is essential to prove the functionality of the system and to initiate necessary maintenance. To allow monitoring and maintenance a permanent access to the facility is necessary during the whole lifetime.

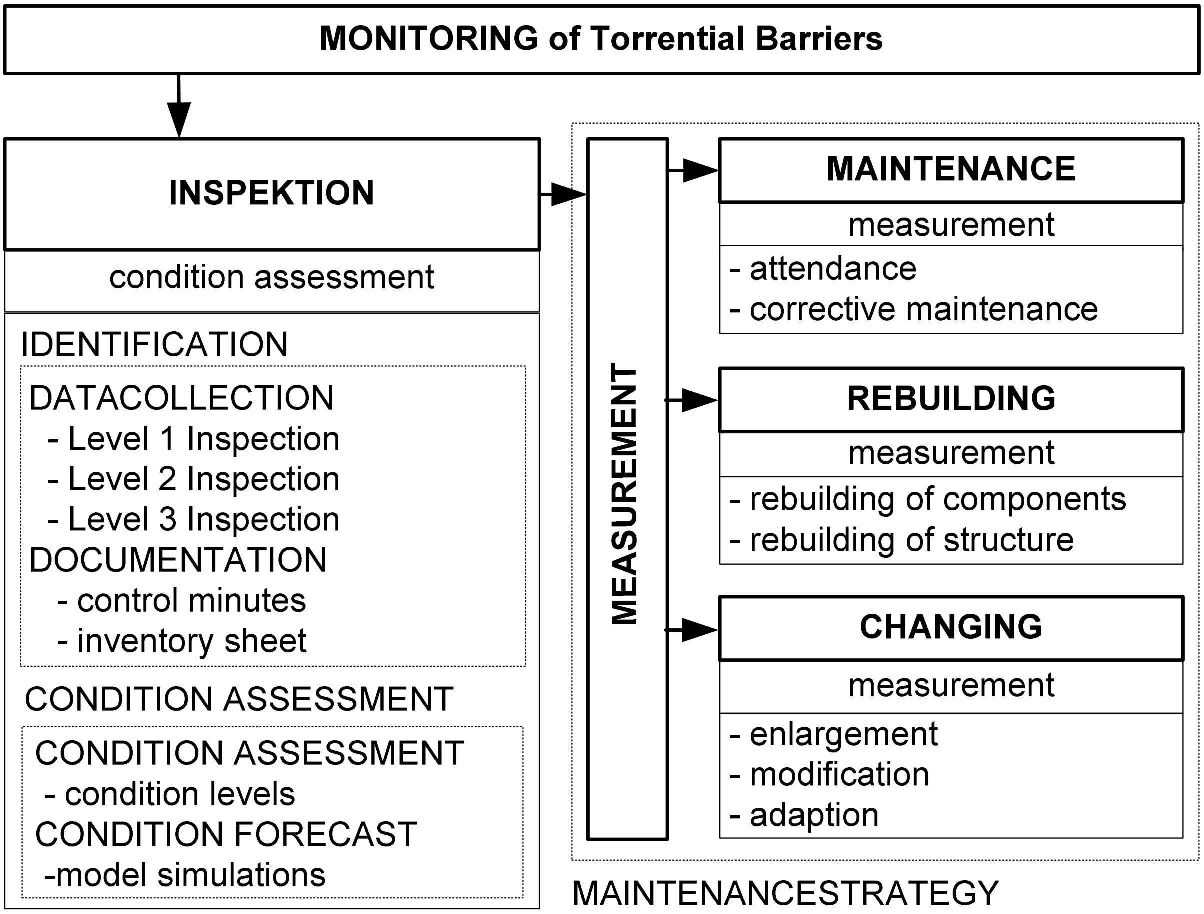

Fig. 12: Configuration of the maintenance concept for protection works

Instruments for inspection, documentation and assessment

To identify the actual condition and to ensure a consistent assessment, standardised instruments are useful (refer especially to good practice example B1). These instruments can be split into operational instruments, instruments of documentation and instruments of assessment.

Example for operational instrument for inspection (Austria)

Three different inspection levels consider economic limits. In level 1 all structures will be periodically inspected e.g. by lumbermen during the annual inspection of the torrents (e.g. task of the community due to the Forest Act). If damage on a structure is identified, a competent expert will do a level 2 inspection. If there is no chance of assessing the structures' actual condition, a level-3 inspection will be performed.

Level 1 and 2 are checked with visual inspection methods. For a level-3 inspection complex engineering methods are used, e.g. analyses of material samples, measuring systems, static and hydraulic simulations. Ideally this inspection level is carried out by an interdisciplinary expert team. These operational instruments are suitable to the RVS 13.03 standards.

A consistent and comparable description of the structures' damages is assured by well-developed control minutes. In Austria for example, a damage catalogue for torrent protection works was developed. This catalogue is based on the experience of practitioners and the theoretical background of researchers. The catalogue contains a classification of damages and detailed descriptions for several types of damages. The classification scheme divides the damage types in those with relations to the ultimate limit state, those with serviceability limit state to those with durability limit state (according to EN 1990). In addition, the classification considers the type of structure and the design material. A consistent and comparable description of the structures' damages can also be assured by well-developed instruments that enable effective decisions regarding type and timing of measures and control form sheets, which guide the inspector.

The collected data will be used for maintenance planning as well as further inspection planning to get a precise and efficient maintenance management. It enables effective decisions regarding type and timing of measures. A completed database could also be used as a base for simulations of further developments depending on different maintenance scenarios and in order to optimise life-cycle costs.

Maintenance

Regular maintenance of protection systems and structures is an important part of integrated natural hazard management. It provides the protection function, improves operation security and keeps structures in a good condition. Thereby no change in the protection function or the whole system is attained, which generally also means that no legal permission is needed. Main elements of maintenance are: reconditioning, repairs, (small) reconstructions.

The life span of a structure is affected by the maintenance strategy, especially the minimum triggering level respectively the frequency of maintenance actions. Regular attendance and corrective maintenance extend its life span. The more the structure approaches the critical condition (fig. 3), the more urgent measures have to be taken.

Maintenance should take into account several boundary conditions like ecological questions. For example, during certain times like spawning season of fish, major measures within the watercourse should be avoided.

Rebuilding or changing the system?

Every structure will reach the end of its life span sometime. In this case several possibilities are available:

- Rebuilding the structure(s) or its components
- Adaptation, modification or enlargement of the structure(s) because of changing boundary conditions (comp. e.g. good practice B 10)
- Controlled decay because no structure is necessary anymore
- Complete removal of the structure, because meanwhile it has a negative impact on the system
- Change of the whole system (e.g. one new large structure replacing several old ones)

For the assessment of the further course of action the whole system (catchment area) has to be observed by an integrated approach (refer e.g. to good practice example B2). This is the only way to identify the best strategy for a protection system that consists of many single structures, erected in different times and under different boundary conditions. An example for such an approach is given in the good practice example of Habichtgraben (B4, Germany), Gadria (B8, Italy) or the management of old avalanche protection structures (B12, B13 Switzerland).

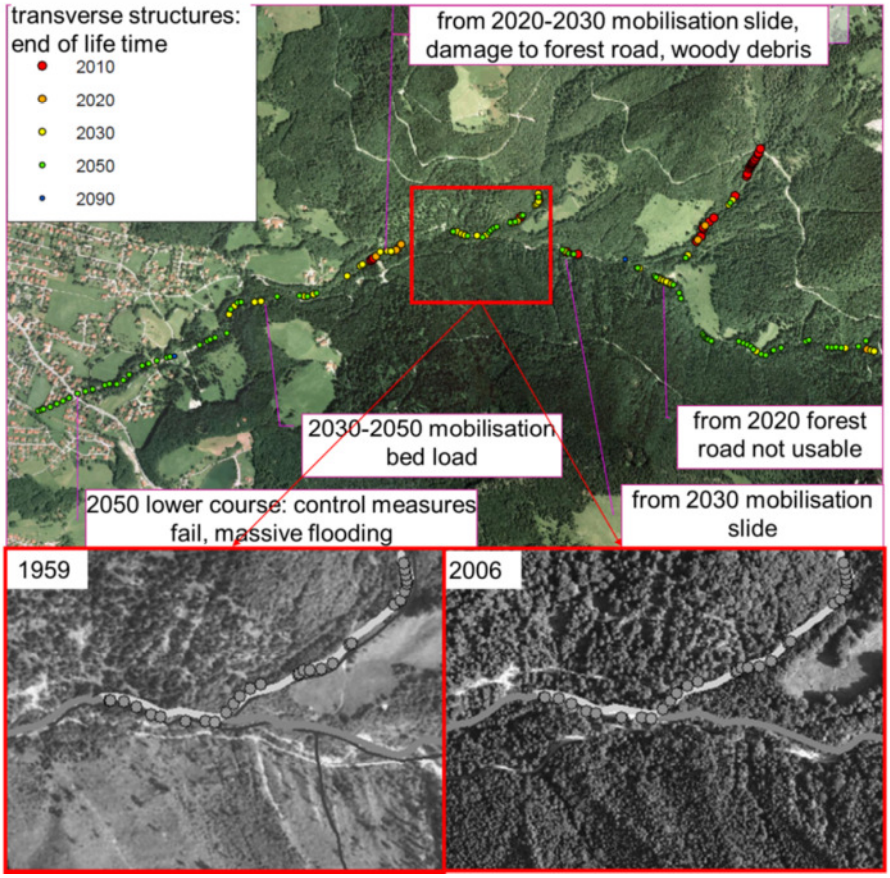

Fig. 13: Assessment of consequences after reaching the end of life time (Rimböck, A.; Asenkerschbaumer, M. (2012))

5. Implications and recommendations

CONCERNING THE DIFFERENT IMPACT LEVELS OF PROTECTION SYSTEMS, FIGURED OUT IN CHAPTER 2, WE WANT TO DISTINGUISH ALSO BETWEEN IMPLICATIONS AND RECOMMENDATIONS REGARDING THESE LEVELS.

5.1 Overall / general recommendations

Introduction of systems engineering in management of natural hazards: Systems engineering contains many valuable elements, which can promote an improved, sustainable and integrated approach in natural hazard management.

Innovative protection systems based on the cradle-to-cradle (former: cradle-to-grave) concept (life cycle management): with this perspective it is possible to make use of the intelligence of natural systems and to provide green care and green jobs for the future. Therefore it is sensible and necessary to enlarge the perspective from cradle-to-grave into a cradle-to-cradle perspective regarding the whole cycle and to optimise the consumption of resources.

Homogenisation of figures concerning capital stock / replacement value: as we realised, the database in the different countries regarding the number and value of the protection structures is heterogeneous. To gain better comparable figures for this important “security infrastructure” a standardisation for the value assessment and therefore a homogenisation of the database should occur.

Taking into account ecosystem services: By better understanding, enhancing and incorporating ecosystem services in protection systems investments become more sustainable. Therefore life time can be extended and cost of maintenance reduced. In some cases, even a full transfer of the protection function from structures to ecosystem services can take place.

5.2 Structural level

Observation and documentation system for protection facilities: all single protection elements of a system should be covered by an area-wide and well-adjusted system for careful inspection and documentation of all actions. This can assure a proper overview and therefore the system can be adequately handled, which allows an optimisation of operation and maintenance of the whole system.

Application of a life-cycle costing approach: during preparation and pre-planning aspects of functionality, stability, serviceability and durability have to be assessed in a well-adapted way. Such an early consideration of life cycle costing approaches facilitates the search of optimised solutions.

5.3 Catchment level

Analysis of development in the catchment area: only a careful consideration of all aspects in the whole catchment area can form a reliable basis for all planning phases. On this background specific scenarios can be derived which have to be considered in the planning process. With this approach and a periodic update it should be possible to react to future developments/changes and to gain adjustable and resilient protection systems.

Integrated approach to ensure sustainable and adjustable protection systems: only an integrated risk management in consideration of all protection elements - like protection forest, structural measures, planning measures - and with participation of all people concerned can lead to sustainable results and allow adjustable solutions.

5.4 Impact area level

Taking into account protection systems in spatial planning: only if risk assessment and protection systems with their consequences and constraints are systematically considered in spatial planning, functional and reliable overall solutions can be attained.

Balance of risks, chances and charges: the realisation of protection systems is a great effort. Not only the costs, but also the resulting chances and the residual risks have to be shared beyond the people concerned to allow best identification, acceptance and function.

5.5 National level

Reliable and continuous finance planning: only if finances are continuously available and the amount is based on an analysis of conditions of the existing structures and an assessment of the future needs (e.g. by means of a database, by capital stock calculation or other means) an adequate maintenance level can be ensured. This is vital for an unrestricted function of protection systems and for the reliability of the safety level.

Legal and technical minimum standards: to ensure a comparably high quality and reliable protection effects some standards should be elaborated and put into practice. This is even more important as many different interested parties work together in the elaboration of suitable protection systems. Furthermore, standards are a suitable instrument to share experiences and to facilitate quality management.

5.6 Alpine Space (resp. European level)

Consideration of protective infrastructure issues in specific funding programmes: many planning guidelines, protection systems and other elements of risk management are encouraged by national or European-based funds. If the functionality, reliability and long-term maintenance of the protective infrastructure are improved, the proper use of these financial instruments is optimised.

Cross-border approach in the Alpine Space: natural hazards are not subject to borders. Therefore, it is more than sensible to face this fact by a cross-border approach. Furthermore, there is always the problem between upstream and downstream riparian zones, which requires strengthening solidarity principles. A lively exchange of experience and information shall provide a comparable status of protection systems regarding systems engineering in the different countries.

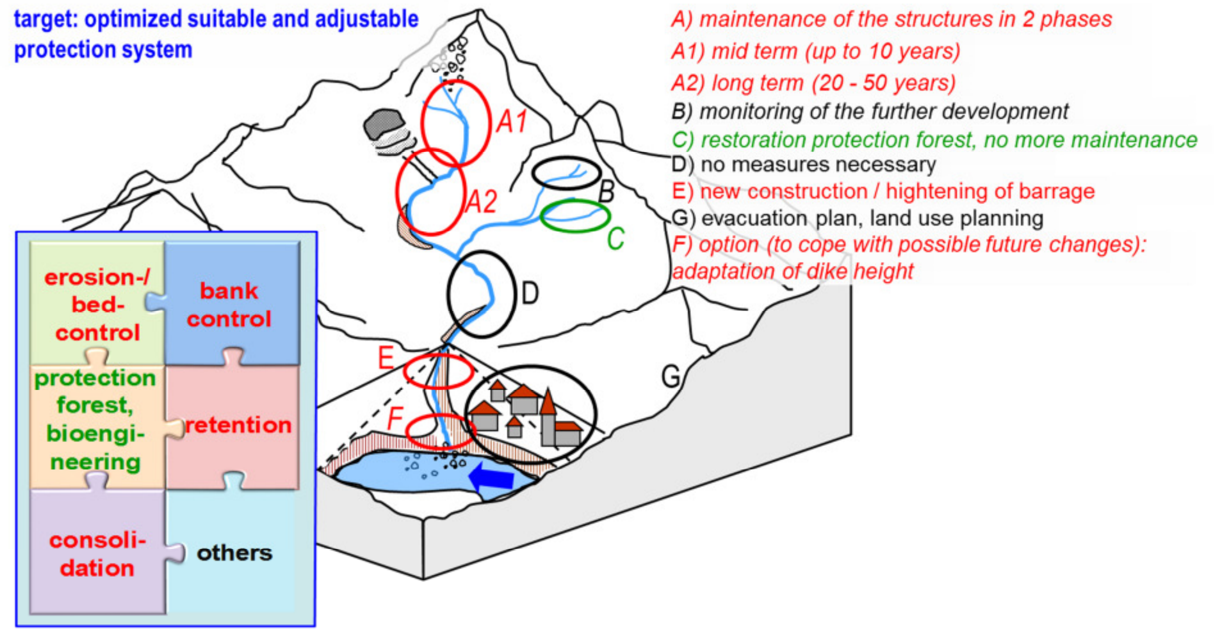

Fig. 14: Vision of maintenance and change management in a torrential catchment area (Rimböck et al (2012)

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ANNEXE

ANNEXE A - Country-related facts and figures regarding systems engineering in natural hazard management

ANNEXE B - Good practice examples from Member States

ANNEXE C – Good practice examples from Member States on construction details that support or prolong the lifetime / functionality of a protective infrastructure in place

ANNEXE A – Country-related facts and figures regarding systems engineering in natural hazard management

Duty of maintenance

Torrents

a) Monitoring and inspection
b) Attendance and corrective maintenance
c) Rebuilding and changing

Country (alphabetical order)	**Who is responsible**	**Who is financing**	**Who is operating**	**Legal basis**	**Costs (€/year)** incl. definition of the costs
Austria	a) In general: Water authority, torrent and avalanche control service; for specific protection work: holder (operator) (e.g. municipality, road administration, water cooperative)	a) Holder (operator) or beneficiaries of protection system: e.g. municipality, road administration, water cooperative	a) Holder (operator) of protection system: e.g. municipality, road administration, water cooperative or commissioned civil engineer	Water Act Forest Act Water Engineering Funding Act	Up to 15 % of annual investment costs: approx. 20 million euros
	b) Holder (operator) (e.g. municipality, road administration, water cooperative)	b) Beneficiary for recurrent measures; extraordinary maintenance: Public funding, shared among federal state, province and beneficiary) (e.g. municipality, road administration, water cooperative)	b) Holder (operator) of protection system: e.g. municipality, road administration, water cooperative; Extraordinary maintenance work by Austrian Torrent and Avalanche Control Service		
	c) Holder (operator) (e.g. municipality, road administration, water cooperative)	c) Public funding, shared among federal state, province and beneficiary) (e.g. municipality, road administration, water cooperative)	c) by Austrian Torrent and Avalanche Control Service or Provincial Flood Control Service		
Germany (Bavaria)	a) state (State Offices for Water Management)	a) state	a) state (State Offices for Water Management)	Bavarian Water Law	about 12 million
	b) state (State Offices for Water Management)	b) state	b) state (State Offices for Water Management)		
	c) state (State Offices for Water Management)	c) state	c) state (State Offices for Water Management)		

Italy	a, b, c) local authorities (provinces, regions, municipalities) for public safety and public infrastructures, institution in charge of the object to be protected (highways and railway companies, private firms)	a, b, c) local authorities (provinces, regions, municipalities) for public safety and public infrastructures, institution in charge of the object to be protected (highways and railway companies, private firms,)	a) owner or competent authorities b, c) private firms, public firms	National soil defence law (183/89) Regional soil defence laws	
Liechtenstein	a) Municipalities / Office for Civil Protection	a) state	a) Municipalities / Office for Civil Protection	Water management laws (Rüfeschutzbauten gesetze, Rheingesetz)	3.4 million (incl. new investments)
	b) Office for Civil Protection	b) state	b) Office for Civil Protection		
	c) Office for Civil Protection	c) state	c) Office for Civil Protection		
Slovenia	a) state (relevant Ministry for Water Management)	a) state	a) Slovenian Environment Agency & Concessionary services in Water Management	Slovenian Water Act and it's sub-legislations	about 7 million
	b) state (relevant Ministry for Water Management)	b) state or in some cases state with co-financing of local community	b) Slovenian Environment Agency & Concessionary services in Water Management		
	c) state (relevant Ministry for Water Management)	c) state or in some cases state with co-financing of local community	c) Relevant Ministry (Water Management or Infrastructure) with support of Slovenian Environment Agency & Concessionary services or Construction Contractor		
Switzerland	a) Cantons and local authorities	a) Federal state, cantons, local authorities	a) cantons or local authorities	Federal Forest Act Federal Water Engineering Act Corresponding cantonal acts	
	b) Cantons and local authorities	b) idem	b) cantons or local authorities		
	c) Cantons and local authorities	c) idem	c) cantons or local authorities		

* Maintenance of water and waterside land in Slovenia is carried out under the mandatory public utility services in the field of water management and also by selected concessionaires under a concession contract directed and managed by the Slovenian Environment Agency (body of Ministry for Water Management)

Duty of maintenance

a) Monitoring and inspection
b) Attendance and corrective maintenance
c) Rebuilding and changing

Avalanches

Country (alphabetical order)	**Who is responsible**	**Who is financing**	**Who is operating**	**Legal basis**	**Costs (€/year)** incl. definition of the costs
Austria	a) In general: Water authority, torrent and avalanche control service; for specific protection work: holder (operator) (e.g. municipality, road adminis-tration, water cooperative)	a) Holder (operator) or beneficiaries of protection system: e.g. municipality, road administration, water cooperative	a) Holder (operator) of protection system: e.g. municipality, road administration, water cooperative or commissioned civil engineer	Water Act Forest Act Water Engineering Funding Act	Up to 5 % of annual investment costs: approx. 2 million euros
	b) Holder (operator) (e.g. municipality, road administration, water cooperative); for protection forest: land owner	b) Beneficiary for recurrent measures; extraordinary maintenance: public funding, shared among federal state, province and beneficiary (e.g. municipality, road administration, water cooperative); for protection forest: land owner or public subsidies (Provincial Forest Service)	b) Holder (operator) of protection system: e.g. municipality, road administration, water cooperative; Extraordinary maintenance work by Austrian Torrent and Avalanche Control Service;); for protection forest: land owner or public subsidies (Provincial Forest Service)		
	c) Holder (operator) (e.g. municipality, road administration, water cooperative)	c) Public funding, shared among federal state, province and beneficiary (e.g. municipality, road administration, water cooperative)	c) by Austrian Torrent and Avalanche Control Service or Provincial Flood Control Service		
Germany (Bavaria)	a, b, c) object protection structures: institution in charge of the object to be protected (street building authorities, private firms) remediation of protection forest:	a, b, c) object protection structures: state, private firms remediation of protection forest: state	a, b, c) object protection structures: institution in charge of the object to be protected (street building authorities, privat) remediation of protection forest: state (Forest+Water Officies)	object protection structures: duty to implement safety precautions	remediation of protection forest: 0.5 – 1.0 million (only partially water)

	state (Forest+Water Offices)				
Italy	a, b, c) avalanche control structures: local authorities (provinces, regions) for public safety and public infrastructures. institution in charge of the object to be protected (highway and railway companies, private firms, ski resorts companies). forest management: local authorities (regions, provinces, municipalities)	a, b, c) avalanche control structures: local authorities (provinces, regions) for public safety and public infrastructures institution in charge of the object to be protected (highway and railway companies, private firms, ski resorts companies), forest management: local authorities (regions, provinces, municipalities)	a, b, c) avalanche control structures: private firms, public firms forest management: Private & public forestal firms	National soil defence law (183/89) Regional soil defence laws Regional forest laws	
Liechtenstein	a) Office for Civil Protection	a) state	a) Office for Civil Protection	Forest law	0.2 million (incl. new investments)
	b) Office for Civil Protection	b) state	b) Office for Civil Protection		
	c) Office for Civil Protection	c) state	c) Office for Civil Protection		
Slovenia	a, b, c) institution in charge of the object to be protected (e.g. road & railway management authorities, local communities)	a, b, c) state roads & railway management authorities, local communities, companies, private firms	a, b, c) institution in charge of the object to be protected (e.g. road & railway management authorities, local communities)	The Construction Act, duty to implement safety precautions	
Switzerland	a) cantons and local authorities	a) federal state, cantons, local authorities	a) cantons or local authorities	Federal Forest Act Corresponding cantonal act	
	b) cantons and local authorities	b) idem	b) cantons or local authorities		
	c) cantons and local authorities	c) idem	c) cantons or local authorities		

Rockfall

Duty of maintenance

a) Monitoring and inspection
b) Attendance and corrective maintenance
c) Rebuilding and changing

Country (alphabetical order)	**Who is responsible**	**Who is financing**	**Who is operating**	**Legal basis**	**Costs (€/year)** incl. definition of the costs
Austria	a) In general: Water authority, torrent and avalanche control service; for specific protection work: holder (operator) (e.g. municipality, road administration, water cooperative)	a) Holder (operator) or beneficiaries of protection system: e.g. municipality, road administration, water cooperative	a) Holder (operator) of protection system: e.g. municipality, road administration, water cooperative or commissioned civil engineer	Water Act Forest Act Water Engineering Funding Act	Up to 5 % of annual investment costs: approx. 1.0 million euros
	b) Holder (operator) (e.g. municipality, road administration, water cooperative); for protection forest: land owner	b) Beneficiary for recurrent measures; extraordinary maintenance: public funding, shared among federal state, province and beneficiary (e.g. municipality, road administration, water cooperative); for protection forest: land owner or public subsidies (Provincial Forest Service)	b) Holder (operator) of protection system: e.g. municipality, road administration, water cooperative; Extraordinary maintenance work by Austrian Torrent and Avalanche Control Service;); for protection forest: land owner or public subsidies (Provincial Forest Service)		
	c) Holder (operator) (e.g. municipality, road administration, water cooperative)	c) Public funding, shared among federal state, province and beneficiary (e.g. municipality, road administration, water cooperative)	c) by Austrian Torrent and Avalanche Control Service or Provincial Flood Control Service		
Germany (Bavaria)	a, b, c) institution in charge of the object to be protected (e.g. street building authorities, municipalities)	a, b, c) state, municipalities	a, b, c) institution in charge of the object to be protected (e.g. street building authorities, municipalities)	duty to implement safety precautions (Verkehrssicherungspflicht)	

Italy	a, b, c) local authorities (provinces, regions, municipalities) for public safety and public infrastructures institution in charge of the object to be protected (highway and railway companies, private firms),	a, b, c) local authorities (provinces, regions, municipalities) for public safety and public infrastructures institution in charge of the object to be protected (highway and railway companies, private firms)	a) owners or competent authorities b, c) private firms, public firms	National soil defence law (183/89) Regional soil defence laws	
Liechtenstein	a, b) Roads: Office for Building and Infrastructure; Rest Office for Civil Protection	a) state b) state	a, b) Roads: Office for Building and Infrastructure; Rest Office for Civil Protection	Forest Law (Waldgesetz)	0.2 million (incl. new investments)
	c) Office for Civil Protection	c) state	c) Office for Civil Protection		
Slovenia	a, b, c) institution in charge of the object to be protected (e.g. roads & railway management authorities, local communities)	a, b, c) state roads & railway management authorities, local communities, companies, private firms	a, b, c) institution in charge of the object to be protected (e.g. road & railway management authorities, local communities)	The Construction Act, duty to implement safety precautions	no data
Switzerland	a) cantons and local authorities	a) federal state, cantons, local authorities	a) cantons or local authorities	Federal Forest Act Corresponding cantonal acts	
	b) cantons and local authorities	b) idem	b) cantons or local authorities		
	c) cantons and local authorities	c)idem	c) cantons or local authorities		

Databases of structures

Country (alphabetical order)	Is there a structural protection measure-related database/register	Number of protection structures	Contents of the database						Interface to other databases
	(if yes: name of database if no: ---)	(in database)	Structure dimensions	Assessment of condition	Use for planning of monitoring	Documentation of monitoring and inspection	Documentation of attendance and corrective maintenance	Documentation of rebuilding and changing	
Austria	Austrian Torrent & Avalanche Cadastre: Protection measure data ; Structural data-base of road and railway operations	WLV: 150,000 (actual state of recording and assessment); ÖBB: ?	x	x	x	x	x	x	Export of data in *.xls or *.shp-file (GIS) possible; outline in interactive PDF-maps
Germany (Bavaria)	Torrents: InfoWibA	about 50,000	X	X	X	X	(x)	(x)	Export of data in *.xls or *.shp-file (GIS) possible
	Avalanches: --- (no nationwide consistent database)								
	Rockfall: --- (no nationwide consistent database)								

Italy	ReNDIS (Repertorio Nazionale degli Interventi per la Difesa del Suolo)								WebGIS and shapefile
	South Tyrol: BAUKAT (torrent control structures)	about 35,000	**x**	**x**	**x**	**x**			Shapefile
	South Tyrol: LAWBAUKAT (avalanche control structures – under construction)		**x**	**x**					Shapefile
	South Tyrol: VISO (rockfall protection structures – under construction)		**x**	**x**					ORACLE
	Autonomous Province of Trento: database of protection structures	About 18,000	**x**	**x**	**x**				
	Region Friuli Venezia Giulia – cadastre of protection structures								Shapefile
Liechten-stein	Schutzbautenkataster (SBK) Avalanches, Rockfall	1,000	**x**	**(x)**				**x**	Export of data in *.xls or *.shp-file (GIS) possible
	Torrents: --- (in development)								
Slovenia	Water infrastructure: "Vodni objekti"	about 14,000	**X**	**(x)**	**(x)**	**(x)**	**(x)**	**(x)**	Export of data in *.xls or *.shp-file (GIS) possible
	Avalanches: --- (no nationwide consistent database)								
	Rockfall: --- (no nationwide consistent database)								
Switzerland	ProtectMe								

ANNEXE B – Good practice examples from Member States

Note: The good practices collected with the support of the Member States are a non-exhaustive representation of the different complex situations existing in the Alpine area

INSTALLING A SYSTEM FOR A REGULAR, PERIODICAL INSPECTION OF THE CONSTRUCTIONS THROUGH PROFESSIONAL SKILLED EXPERTS AS A STEP TOWARDS BETTER MAINTENANCE AWARENESS

Presentation of the problem: During the operation of the retention basins it became evident that the operator of the construction – municipalities and water boards – neglected the maintenance of the construction and the inspection of important system parts. There has often been a lack of expertise.

Framework (responsibilities, law, organisation): The maintenance of retention basins is regulated in the Water Law Act 1959 (WRG 1959). Generally, the operator (mostly a community) is responsible for the maintenance work.

Solution / description: In 1993 all retention basins were inspected in regard to design or constructional shortcomings as well as in terms of weak points during the operation of the constructions. The results of this analysis and the shown shortcomings induced the responsible people in the regional government authority to install a system for a regular, periodical inspection of the constructions through professional skilled experts. Together with representatives of the Chamber of Engineers of Styria and Carinthia the scopes of work of the "retention basin supervisor" was worked out in 1994 (refer to fig. 6).

During the annual site inspection and control of the construction in regard to existing shortcomings in construction, design and statics also the functional capability of all plant components have to be checked. In addition to the annual control, the retention basins have to be inspected after every event respectively after every ponding of the basin. The inspection report is forwarded to the client, to the operator of the basin as well as to the Water Right Authority. Furthermore a caretaker, e.g. a municipal employee, is responsible for the maintenance of the construction which is documented in an operation diary. This system is financed by the federal ministry, the government of Styria and by the operator.

Tasks of the supervisor:

- Preparation of a retention basin book (technical and legal documents)
- Preparation of a handbook and work rules
- Annual inspection of the construction visually and functionally
- Report to the Water Right Authority, the Styrian Government Department 14, the operator, the district construction management and the torrent und avalanche control
- Training and education of the caretaker
- Inspection of possible reconstruction works
- Monitoring and checking of any refurbishment

Tasks of the caretaker:

- Keeping an operation diary
- Maintenance of the construction
- Status control of all plant components (4 times a year)
- Removal of log jams
- Informing the operator in case of emergency

Fig. 15: Organisation of the inspection system in Styria

FURTHER INFORMATION/LINKS:

The inspection of the retention basins in Styria via civil engineers has proved itself to be optimal. All constructions are in a proper condition. The sense of responsibility is increased due to the activities of the civil engineers and because of the common annual field inspection.

www.wasserwirtschaft.steiermark.at

B2 - Galina Torrent – Redevelopment of historic protection systems   Austria

Phase of LCM: planning

WITH RESPECT TO CHANGING ENVIRONMENTAL AND SOCIETAL CONDITIONS THE 100-YEAR OLD PROTECTION SYSTEM IN THE GALINA TORRENT (NENZING, VORARLBERG) – CREATED AS PART OF THE HISTORIC RHINE RECTIFICATION – REQUIRED A COMPLETE REDEFINITION OF PROTECTION TARGETS, REDEVELOPMENT OF THE PROTECTION CONCEPT AND ESTABLISHMENT OF A NEW CONSORTIUM OF BENEFICIARIES.

Presentation of the problem: After a service life of more than 100 years torrent control works and successfully reforested erosion scars in the Galina catchment have reached a critical stage concerning stability and serviceability and require cost-intensive restoration. The Galina torrent control works were originally built to retain enormous masses of loose rock and gravel from erosion in order to unburden the Rhine rectification from sedimentation and colmation. Although the catchment and huge debris cone are well afforested and do not have any major settlements, several important infrastructures (such as railroad, provincial load, power plant) were established in the former hazard zone of the Galina torrent, which is now exposed to increasing risks.

Framework (responsibilities, law, organisation): The torrent control works in the Galina catchment were created and financed in the framework of the bilateral treaty Austria-Switzerland for the rectification of the Rhine river with 100% funding by the state. Due to the historic origin of the protection works there are maladjusted responsibilities for maintenance and monitoring of the protection system, excluding the actual beneficial occupants of the protection effects and services. The critical condition of the protection structures is obvious, while a prognosis for the ongoing process of decay (protection works and forest stands) is debatable and depends on the development of disasters. As the actual hazard map shows a moderate risk (assuming full protection function), the beneficial occupants still needed to be convinced about their responsibility and financial involvement for maintenance and restoration.

Solution / description: The restoration of the protection system and reforestation in the Galina catchment requires a concept adapted to the new risk scenarios and changed protection needs of the actual beneficial occupants. As no legal basis exists anymore to justify a 100% financing by the federal state, a new model for financing urgent maintenance and restoration works and an appropriate legal basis in order to involve all beneficiaries to the extent of their benefits and averted losses was crucial. After hard and intensive negations concerning the relevant risk scenarios (potential amplification of hazard zones), the scope and priority of restoration measures and the cooperation of the beneficiaries in a new protection concept a new project with a total cost of € 2,8 million was elaborated and financially approved in 2014 including far-sighted restoration measures until 2035.

FURTHER INFORMATION/LINKS:

http://www.naturgefahren.at/projekte/galina.html

Fig. 16: Historic protection works and reforsted erosion scars in the Galina catchment (Vorarlberg)

B3 - The role of Water Cooperatives in collaborative risk governance Austria

Phase of LCM: planning and operation

LOCAL WATER COOPERATIVES – A LEGAL BODY COMPOSED OF INDIVIDUALS, MUNICIPALITIES, COMPANIES ETC. – IN THE FRAME OF NATURAL HAZARD MANAGEMENT AS A STRONG VEHICLE TO SHARE THE FINANCIAL BURDEN/RISK OF NATURAL HAZARD PREVENTION ALONG WITH A BROADER AUDIENCE.

Presentation of the problem: In order to strengthen the current efforts to boost resilience in Austria, there is also the question about more privatisation of risks. This requires stronger engagement of non-governmental actors, such as private households and businesses, to increase investments in self-protection and also to increase risk awareness and perception. Exploring the potential of collaborative financing mechanisms is one – but vital – step towards collaborative risk governance and therefore also to systems engineering.

Framework (responsibilities, law, organisation): As it is the case in Austria, in accordance with the Water Act of 1959, a water board or water cooperative is a legal body composed of individuals, municipalities, companies etc. with a variety of tasks, including sharing of (financial) risk associated with water-related hazards at a specific site – mainly valleys and regions as well as the maintenance of the structures. Each member contributes financially to a common fund, which is intended for use in the development of mitigation or prevention measures. The idea behind this is to share the financial burden, e.g. to develop protection measures in a torrent/river with all people/organisations that anticipate a given safety level in a valley/region – regardless of whether they are directly affected by natural hazards.

Solution / description: A number of water boards or water cooperatives currently exist in Austria (some of which are over 100 years old, e.g. the Schmittenbach, Zell am See, Salzburg water board), it is, however, not yet a common cooperative structure throughout the Austrian country. With regard to torrent and avalanche-related hazards, the highest number of water boards can be found in the province of Salzburg (approx. 260) and include approximately 230,000 households. The level of contributions made to the common fund by each member is formalised using a point-based system which reflects the degree of exposure of a given property and/or building. Due to this “direct” involvement of the members of a water board in natural hazard management, a high level of identification with the “products” of protection strategies can be observed and this, in turn, supports maintenance and further mitigation measures in the areas in question.

FURTHER INFORMATION/LINKS:

www.wg-schmittenbach.at (for example)

B4 - Habichtgraben - Change of system in a torrent Germany

Phase of LCM: operation

IN THE TORRENT "HABICHTGRABEN" ONE NEW LARGE BARRAGE WAS BUILT TO REPLACE SEVERAL OLD AND ALMOST DESTROYED SMALL BARRAGES IN THE UPSTREAM CATCHMENT AREA.

Presentation of the problem: The Habichtgraben is a torrent in the municipality of Eurasburg, which flows into the river Loisach 7 km south of Wolfratshausen. About 60 check dams (construction material: concrete, stone or wood) in the catchment area are meanwhile in a bad condition or have already been destroyed. The maintenance of these old barrages would be very costly.

During the last decades, as a side effect of the check dams, a dense forest has grown and stabilised the slopes in the upper area. The settlement area in the lower catchment, however, was still in danger. The positive ecological development allowed a change in the protection system.

Framework (responsibilities, law, organisation): For the old barrages the state as a builder of the structures was in charge of maintaining the torrent and its protection works also in the upper catchment, before the system change was realised. The local State Office for Water Management (Wasserwirtschaftsamt) Weilheim representing the state was also responsible for upkeeping the protection level for the settlement area. A legal basis is the Bavarian Water Law.

Solution / description: An integrated approach was the basis for the planning phase. The whole catchment area was observed in this process. Finally, the planners came to the decision that a single new sediment control dam in short distance upstream of the settlement area could fulfil the purpose of the existing old check dams and could therefore replace them.

Lower building and maintenance costs were only one advantage of this solution. Because the Habichtgraben passes through a nature-protected area according to the Flora-Fauna-Habitats Directive (FFH), the preferred solution caused a smaller intervention in this territory.

The structures in the upper catchment area are no longer maintained after the finalisation of the new protection works. A removal is, however, not intended. As a legal consequence, the obligation for maintenance of the upper torrent (upstream the new protection works) itself switched from the state to the municipality of Eurasburg. This shift of responsibility was finalised by an onsite inspection, where the details were arranged and written down in a protocol.

The measure was legally approved by the local administrative district office and has already been realised. Because the protection level remained the same, the municipality did not participate in the building costs of the new barrage.

FURTHER INFORMATION/LINKS:

State Office for Water Management Weilheim
www.wwa-wm.bayern.de

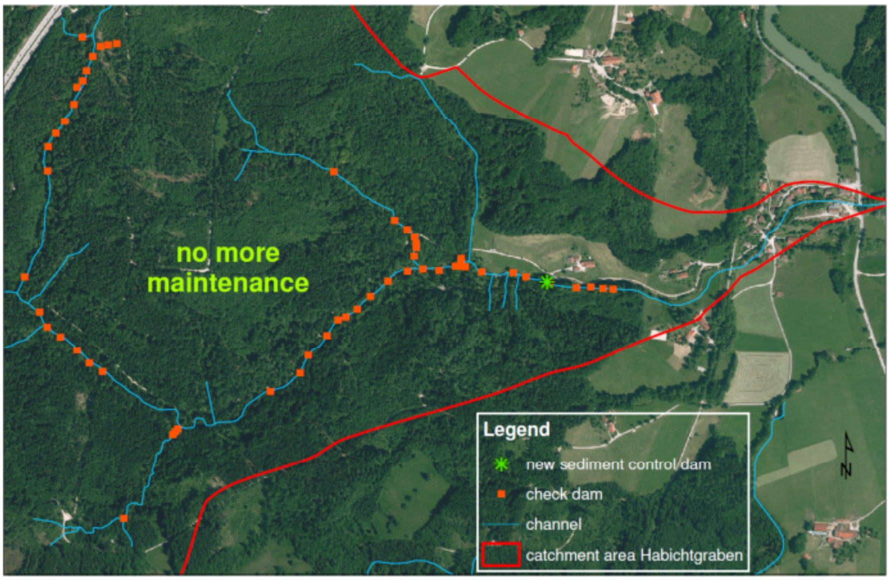


Fig. 17: Building of the new sediment control dam (Picture: WWA Weilheim)

Phase of LCM: operation

THE MOUNTAIN FOREST INITIATIVE AS A CONTRIBUTION TO ADJUSTABLE LONG-TERM STABLE CONCEPTS REGARDING CHANGING INTERESTS.

Presentation of the problem: Measures in the catchment basins of torrents are able to support technical protection structures or even replace them. A mountain forest in good condition, for example can reduce the peak discharge in the channel and stabilises the slopes. An integrated approach in torrent catchments enables to achieve adaptable protective systems and thus to react on changing boundary conditions in the future (e.g. climate change). The ability of mountain forests to protect residential areas and infrastructure against abiotic natural hazards has to be maintained or restored by pointedly protection forest management.

Framework (responsibilities, law, organisation): In 2007, Bavaria launched the “Climatic Programme Bavaria 2020” which includes different measures for the reduction of greenhouse gas emissions, adaptation to climate change and the intensification of research and development.

Solution / description: A special set of measures known as the “Mountain Forest Initiative” (Bergwaldoffensive, BWO), focuses on the adaptation of the Alpine forests in Bavaria to climate change.The central aim of the BWO is to stabilise and sustainably adapt the Alpine mountain forests to climate change. For this purpose, 30 projects were identified in areas with special climatic risks. Integrated master plans were developed for these projects, which include different silvicultural measures like thinning, planting and natural regeneration, the construction of forest roads, and hunting and pasture management for the reduction of browsing damage.A large number of owners are usually affected by the projects. Thus, the pilot measures are planned and initiated in agreement with the land owners and local stakeholders. This strong focus on participation renders the process transparent – a crucial factor for the success of the projects.

Other important elements of the BWO include improving the supply of suitable tree seeds for the Alpine region in Bavaria, strengthening applied research and generating new basic information for the management of Alpine forests. For example, a digital map of forest soils in the northern Alps was generated as a basis for restoration and forecasts by the WINALP project (Waldinformationssystem Nordalpen) in cooperation with partners from Austria (Tyrol, Salzburg).

FURTHER INFORMATION/LINKS:

www.forst.bayern.de
www.hswt.de
http://arcgisserver.hswt.de/Winalp

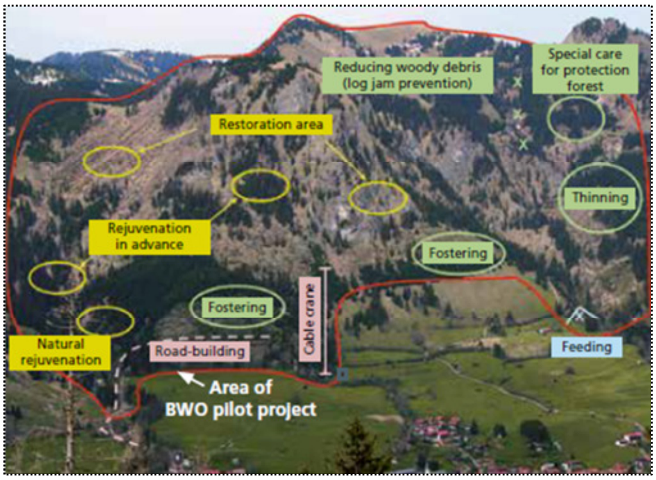


Fig. 18: Example of measure combination within a Mountain Forest Initiative Area. (Bavarian State Institute of Forestry)

Phase of LCM: planning

IDEA FOR (FINANCIAL) EVALUATION OF ALTERNATIVES REGARDING DIFFERENT CONSEQUENCES IN CASE OF OVERLOAD RESP. DIFFERENT RESIDUAL RISK.

Presentation of the problem: Alternatives might safeguard the same protection level (e.g. 100-year flood), but have different residual risk due to “silent reserves”, different failure process (suddenly, stepwise etc.) or other effects. At the moment, there is no common approach to observe such effects on residual risk resp. behaviour in the case of overload.

Framework (responsibilities, law, organisation): the responsibility for observing the case of overload resp. the residual risk is associated with the responsibility for planning the protection measures - for measures with respect to medium and large rivers as well as for torrent control in Bavaria it is the state, for measures concerning small streams and rivers it is the municipality.

Solution / description: At the moment the comparison between different alternatives for protection measures focuses on the building costs. This is based on the assumption that all alternatives safeguard the same protection level. In terms of risk assessment this means, that both the protected and the residual damage potentials are the same for the alternatives and can thus be neglected.

In reality there are differences regarding the residual risk for several alternatives. So we started to think about considering these differences in the selection process for the favoured alternative. This could be done by elaborating more detailed damage functions, and also considering some more rare events compared to the design event. Calculating the average damage on this basis should show differences in the residual risk (see fig. below). Therefore, it is vital what supporting points for the calculations are chosen. But we are still at the beginning and need more investigations on this before introducing it as standard.

FURTHER INFORMATION/LINKS:

Spackova, O.; Rimböck, A.; Straub, D.; (2014): Risk Management in Bavarian Alpine Torrents: a Framework for Flood Risk Quantification Accounting for Subscenarios; IAEG XII Congress - Torino, September 15-19, 2014

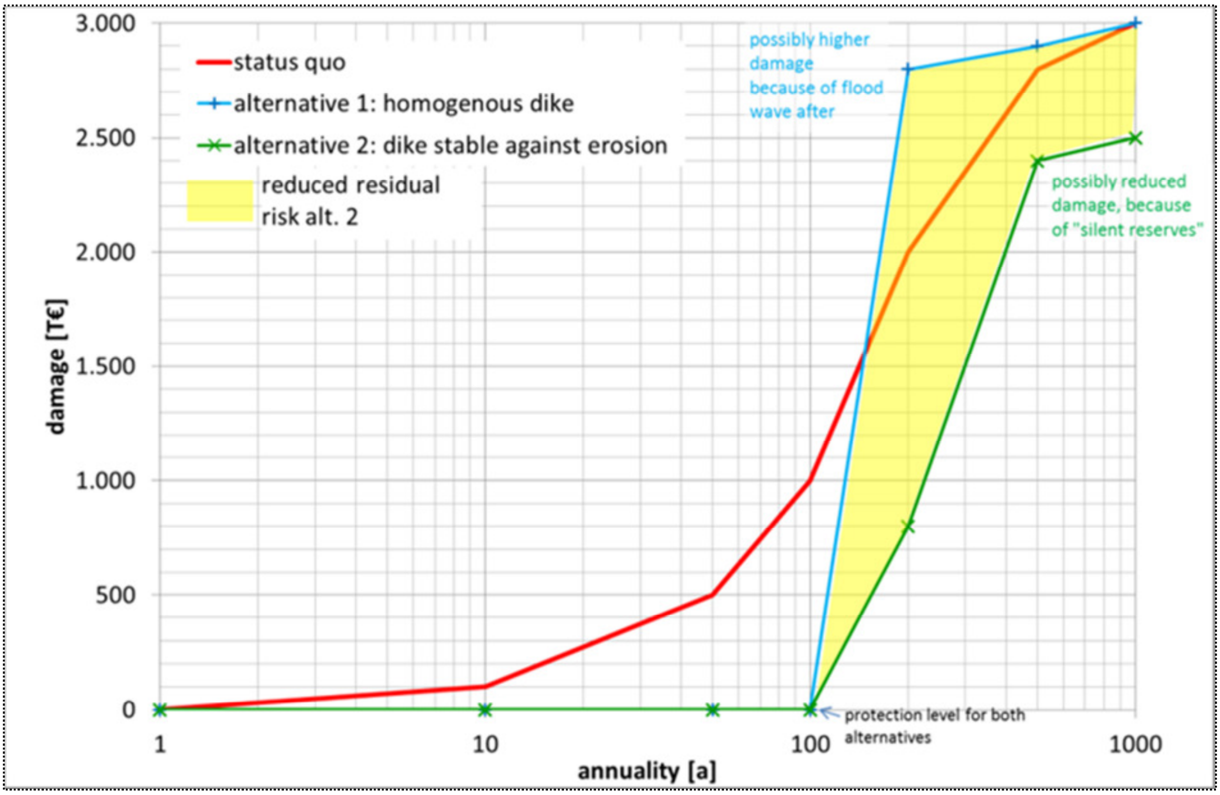


Fig. 19: Suggestion for the calculation of different residual risk concerning protection alternatives

B7 - Guiding and evaluating river corridor developments through a structured target system

Italy

Phase of LCM: planning

EFFECTIVENESS IN RIVER CORRIDOR MANAGEMENT REQUIRES CLEAR AND MEASURABLE TARGETS

Presentation of the problem: River managers are increasingly aware that land development within river corridors may bring about persistent, wicked or unstructured problems. Thus, river corridor management processes are particularly challenging due to their inherent complexities, uncertainties and the variety of actors with different perspectives involved at various levels. The potential lack of transparency and consistency of the decision making processes in a participatory environment minimizes the benefits for the concerned societies.

Framework (responsibilities, law, organisation): River corridor management ultimately seeks to find alternatives and prospects that represent different syntheses amongst: i) what society desires, ii) what complies with the natural evolution patterns, and iii) what is allowed by the existing legal framework. In other words, the objective is to identify the decision space in terms of intersections among the following dimensions: (i) desiderata or space of desirability (i.e. the value system and the preference structure of the concerned society); (ii) the developmental possibilities (i.e. river corridor evolution trajectories, assessed ecosystem resilience and natural hazard risks, forecast developmental trends and economic scenarios) and (iii) the constraints (i.e. legal and institutional settings, budget limitations, conjunctive and disjunctive restrictions, modus operandi etc.). Making the desiderata of the concerned society and stakeholders (or of a smaller representative steering panel) explicit is the first milestone in the holistic river corridor management approach we propose. The elucidation of the developmental possibility space is achieved through a multidisciplinary approach, aiming at integrating river corridor-related environmental science and socioeconomic science. Every river corridor development attempt is embedded in peculiar legal and institutional settings imposing constraints on the management process.

The operational target system: The conceptual scheme of an operational target system is shown in figure 10. With respect to the objectives to be considered in river corridor management we elaborated the following categorisation for the Drava River (from Nardini and Pavan, 2012): risk (R) (in different forms: flooding, fluvial dynamics, debris flow/landsliding; residual); costs (C) (investment and management); disturbance (D) to existing activities, particularly because of: land-use change, change of property, delocalisation, modification of hydropower generation; "nature value" (N), namely the ecological status of the river ecosystem; Externalities (E), particularly the impacts that the considered subbasin may export to the rest of the river. In the green boxes we list indicators that are commonly assessed in objective terms, whereas in the orange boxes we report decision-relevant knowledge to be elicited from experts, stakeholders and decision makers.

FURTHER INFORMATION/LINKS:

For details: email: wasserschutzbauten@provinz.bz.it

References:
Nardini A., Pavan S., River restoration: not only for the sake of nature but also for saving money while addressing flood risk: a decision-making framework applied to the Chiese River (Po basin, Italy). Journal of Flood Risk Management 2012; 5:111–133.

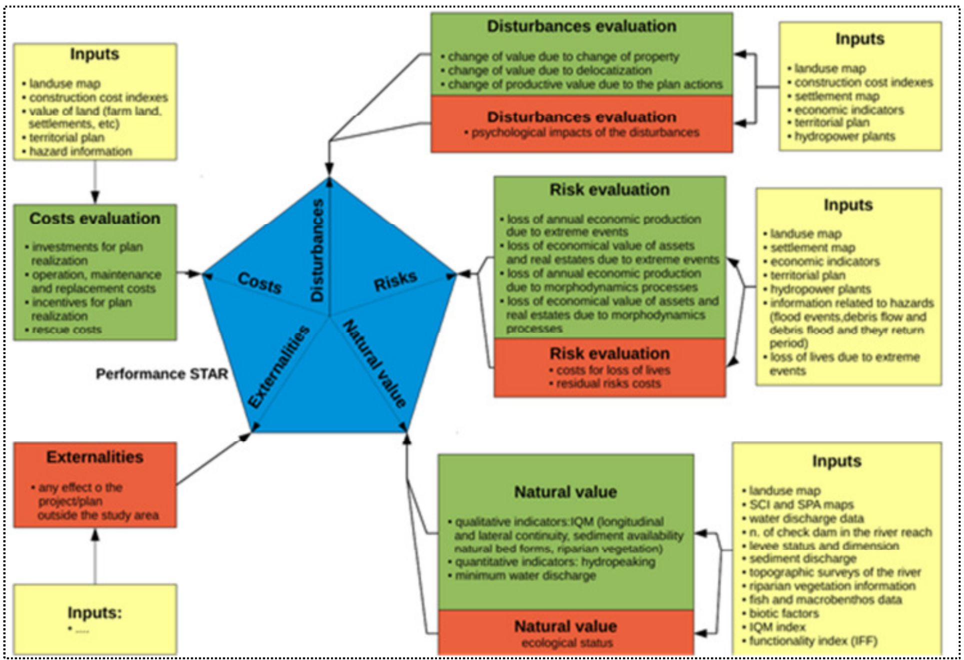


Fig. 20: Operational target system

B8 - Towards a protection system reconfiguration on the Gadria stream Italy

Phase of LCM: planning

A BALANCED PLANNING APPROACH

Presentation of the problem: The Gadria catchment (South Tyrol, Italy) with a drainage area of 6 km² presents one of the largest fans in the Alps (10.9 km²) with frequent debris flow rates (1-2 per year). The average precipitation in the main valley is quite low (about 500 mm) compared to similar debris flow basins in the Alps. Thunderstorms are responsible for most of debris flow occurrences. Since the middle age 39 events have been documented. The main tributary, the Strimmbach, has recently shown debris flow activities and erosion processes in the lower part of the stream. In the current unfavourable configuration the Gadria and the Strimmbach frequently deliver considerable sediment volumes to a single retention basin. This, in the long run, entails unsustainable clearing costs for public administration. Moreover, despite the presence of the deposition basin, the alluvial fan is prone to hazard impacts. Simulations showed that for events with a return period > 30-yr. outburst of the channel boundaries is possible. For events with larger return periods, clogging of the bridge in the village of Allitz is to be expected, which would induce hazard propagation on larger portions of the cone area.

Planning objectives

The risks for the endangered objects on the debris cone should be reduced significantly. This entails a reduction of the specific risks for residential buildings and infrastructure (mainly roads) and commensurately for the agricultural areas. Simultaneously, the functionality of the protection system should be enhanced. This means essentially to design a sediment-dosing system capable of buffering the peaks of the involved hazard processes without additional maintenance costs (clearing up the costs for deposited debris flow volumes). The ideal solution would be a self-functioning dosing system.

Planning approach

Since the performance of the envisaged system will crucially depend on its dosing functionality, a balanced planning approach elaborated by Simoni et al. (2014) involving backward-oriented indication, numerical simulation and physical scale modelling (Hübl et al., 2012) was adopted (compare figure 1).

Possible solutions

The adopted investigation strategy clearly indicates that modifying the existing check dam by widening its opening could significantly contribute to increase the functionality of the system and thereby to reduce the life-cycle costs to a significant extent. Possible flood risk exacerbations for the endangered settlement areas could be avoided by established techniques (e.g. local object protection, local deflection walls and a modification of a wood bridge). On a conceptual level also more radical interventions have been hypothesized (compare Stecher et al. 2012) entailing a complete removal of the retention check dam to reestablish the sediment continuum. Provided that integrative local protection measures will be realised, this solution will contribute significantly to a complete solution of the acute counterproductive debris flow material deposition problem.

FURTHER INFORMATION/LINKS:

For details: email: wasserschutzbauten@provinz.bz.it

Hübl, J., Fleisch, M., Chiari, M., Kaitna, R. (2012): Physikalische Modellversuche zur Optimierung der Geschieberückhaltesperre am Gadriabach (Vinschgau,Südtirol); IAN Report 144, Institut für Alpine Naturgefahren, Universität für Bodenkultur - Wien (unpublished)

Simoni, S., Vigoli, G., Zambon, F. (2014): Assessment of mutual interactions between control structures, torrential and river sediments, and large wood. SEDALP Project (unpublished)

Stecher, M., Mazzrana, B., Hübl, J. (2012): Proposal of risk mitigation strategies based on a conceptual planning approach. 12th Congress INTERPRAEVENT 2012 – Grenoble / France - Conference Proceedings.

Fig. 21: Gadria creek: Details of the clogging mechanisms (i.e. through driftwood and solid material) of the check dam openings and the consequent full aggradation of the disposition basin.

Phase of LCM: planning

RECONCILING FLOOD PROTECTION AND ECOLOGY

Presentation of the problem: Until recently the planning approach of river engineering works was mainly targeted at mitigating hazards, designing hydraulically suitable and stable river cross sections. As a consequence of such river regulation interventions, areas located in the valley bottom could be made available for various developmental interests. Conversely and inevitably aquatic habitats have shrunk over the time. An increasing social concern about the loss of ecosystem integrity and functionality induced rethinking of the traditionally planning paradigms: multifunctional solutions by mitigating risks and commensurately enhancing the ecological value as well as meeting the recreational demand are now largely preferred.

Framework (responsibilities, law, organisation): Within the EU-funded Interreg IIIB Project River Basin Agenda, the Department of Hydraulic Engineering of the Autonomous Province of Bolzano elaborated a restoration project for the Mareta River.

Solution / description:
The Mareta River flows through the Ridanna Valley in South Tyrol and joins the Isarco River near the city of Vipiteno. Its watershed has an area of 209 km² and its elevation ranges from 935 to 3470 m asl. The reference flood discharges are 90 m³/s for a recurrence interval of 10 years and 230 m³/s for a recurrence interval of 100 years.
In the second half of the last century the Mareta River was subject to intense gravel extraction activities and afterwards, during the 80es, river engineering works in form of a series of grade control structures to consolidate the stream bed were implemented converting its river typology from braided to monocursal with a substantial interruption of the sediment continuum.
To reestablish the conditions for river dynamics substantial ecological enhancement was made in a first development stage which removed 16 check dams in order to reestablish the river continuum. The stream consolidation was achieved by posing huge boulders with a minimum weight of 2 tons.
A monitoring programme was initiated to verify the quality of this river restoration project in the long run. Morphological changes were detected by topographically assessing cross-sectional variations. The ecological status is monitored by ad-hoc vegetation and habitat survey.
A major aim is to foster a better human-river relationship. Flood protection works realised in the last century exacerbated the perception of fear with respect to water-related hazards. Now in the new setting the river is accessible and attractive for recreational purposes. The "new" Mareta River is a good practice example for both recreating a human-river symbiosis and providing the necessary protection function for the exposed elements at risk.

FURTHER INFORMATION/LINKS:
For details: e-mail:
wasserschutzbauten@provinz.bz.it

Fig. 22: Mareta river before and after human-river symbiosis improvement

Phase of LCM: operation – conversion of structures

Presentation of the problem: The last decades have shown that mainly in terms of discharge peaks it is not possible to completely control flooding processes with just check dams. Therefore, the focus of structural measures has moved to the enlargement of sediment traps and flood retention basins.

Framework (responsibilities, law, organisation): Knowledge of natural hazards prone areas due to hazard maps, consideration of overload cases and application of cost-benefit analyses for protection concepts.

Solution / description: The natural hazard maps showed that hazards associated with rare and very rare events as well as the overload cases can rarely be solved in the catchment area itself. The more the financial resources are limited and by using cost-benefit analyses it is obvious that the solution can mostly not be found just in building barriers along the channel. Therefore, new concepts have to be found or existing ones have to be changed.

Runoff modelling showed that in long-lasting heavy precipitation compared to the years 1999 and 2000 it is not possible to bring the collected runoff through the outfall into the Rhine. Since in thunderstorm events, the debris flow and sediment deposits are an additional problem the idea arose that sediment traps used for this purpose could also provide additional retention. The enlargement of the sediment traps itself provided the opportunity to question the existing structural measures like check dams and to minimise them wherever possible.

Of course, such system adjustments are only possible if the space for retention measures is available and the geological conditions allow those kinds of solutions. It shows, however, that additional knowledge or changing circumstances require a review of the used structural measures. The change of existing structure systems is always hard to communicate, but the consideration of overload cases and the cost-benefit analysis allow for it.

An example of an adapted system is the enlargement of the retention basin in Balzers. Before increasing the maximum retention of all basins up to 100,000 m^3 already a HQ20 caused problems. Now a one-hundred-year event can be managed without causing any damage to the village. In addition, the enlargement of the sediment traps leads to a later and less frequent use of the retention basin. As for the retention, the use of agricultural land is needed, and compensation payments could be reduced by this measure. Due to the enlargement of the sediment trap the cross-border road connecting Liechtenstein and Switzerland is now protected from debris flows without having built any barriers along the channel.

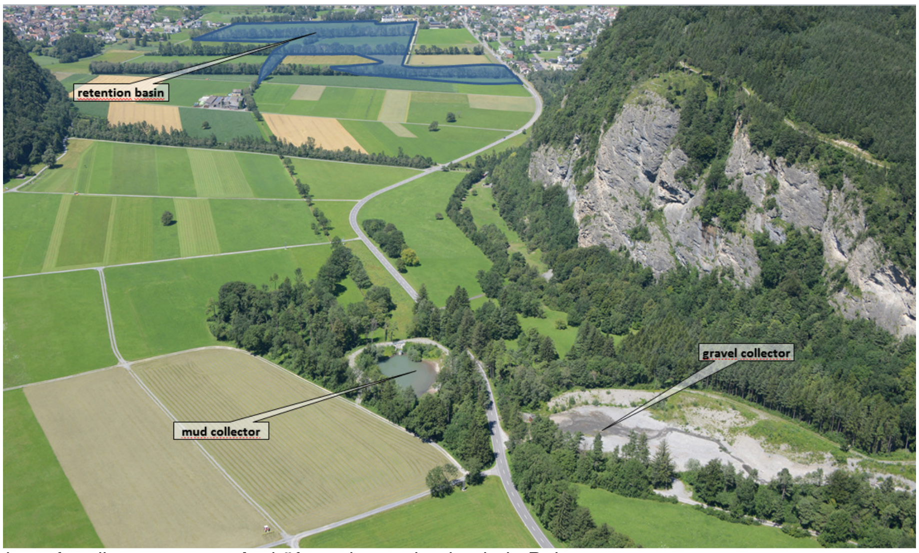


Fig. 23: Overview of sediment traps at Andrüfe and retention basin in Balzers

Phase of LCM: monitoring, analysing and planning

Presentation of the problem: Scarce public awareness of the dangers which could be posed by dams, and the lack of the information necessary for the emergency preparedness to perform evacuation in case of failure of a dam, incited the Administration for Civil Protection and Disaster Relief at the Ministry of Defence of the Republic of Slovenia (ACPDR) to conduct a complex review of documentation and state of Slovenian dams and reservoirs for water management purposes (in 2012).

Framework (responsibilities, law, organisation): Four partner organisations: the Faculty of Civil and Geodetic Engineering, University of Ljubljana, Hidrotehnik, d.d., IBE, d.d., and the Slovenian National Building and Civil Engineering Institute participated in the elaboration of the review. As a result of the review, the consortium prepared recommendations for improving the safety of the dams and for raising public awareness.

Solution / description: The care for safe use and exploitation of dams and reservoirs in the world has made considerable progress in recent decades. Due to the intensive use of space and the increasing need of building dams closer to populated areas, more and more attention is given to the integration of such facilities into space and to the fulfilment of higher demands imposed by standards to ensure safe operation and exploitation of dams. A more detailed analysis in the research and development project "State of dams for water management purpose in Slovenia" (VODPREG) covered water dams and reservoirs in public use (the owner being the state or local communities), while a concession was awarded to qualified operators, holders of public water management services (final selection, 45 dams and weirs). With regard to the national regulations, structural behaviour of large dams (with a structural height of over 15 m) has to be monitored regularly. In the scope of the project the established monitoring systems for 42 earth dams were reviewed (8 of them higher than 15 m).

The work was divided into three sections. In the first one, a survey of all relevant archive documentation on the structures was made, while in the second one, field investigations were performed within the following scope: (1) visual examination of structures, (2) inspection of mechanical and electrical equipment, (3) underwater diving inspection. Within the third section, a synthesis report was prepared with relevant findings of the inspections carried out; based on the identified state, an assessment of an individual structure hazard level for the environment was made.

After the above-mentioned tasks were accomplished, it relatively soon turned out that the measures were necessary in practically all dams. The final analysis result combines a review of estimated costs needed for rehabilitation of individual dams and an assessment of the total duration of remedial interventions. The overall financial scope of the proposed rehabilitation measures amounts to approximately 13.6 million €. The investment structure is as follows: out of the total amount 12% are needed for arrangement of expert and technical bases, 1% for arrangement of documentation, 9% for creation or rehabilitation of monitoring systems, 54% for interventions in dam bodies, 10% for interventions in concrete and masonry structures and 14% for interventions in storage reservoirs and in the downstream areas.

Further information/links:
ACPDR: www.sos112.si (Project Report) and SLOvenian COmission on Large Dams (SLOCOLD): www.slocold.si

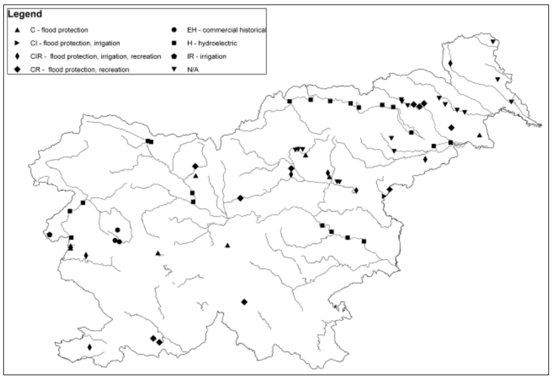


Fig. 24: Project VODPREG - 68 dams classified in categories were identified for the task (Kryžanowski et al., 2013)

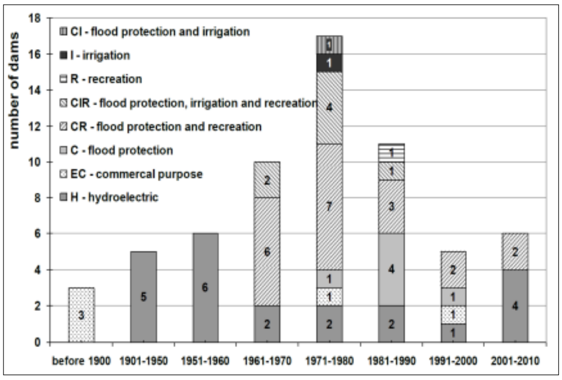


Fig. 25: Dynamics of dam construction according to their intention of use

B12 - Management of old avalanche protection structures Switzerland

Phase of LCM: operation

Presentation of the problem: Old avalanche control structures in Switzerland often consist of stonewalls and masonry terraces. Due to their long duration of use, the walls and terraces in many locations are in poor condition. Because their effect in preventing avalanche release no longer meets the current technical requirements, the question arises as to whether such structures should be repaired or whether it would be better to dismantle them and replace them with modern control structures. The Federal Office for the Environment edited a manual to help in the evaluation of conservation strategies to be adopted in individual cases and in identifying the measures to be carried out on avalanche control structures consisting of stonewalls and masonry terraces. The manual is addressed to cantonal authorities and the owners of such structures.

Framework (responsibilities, law, organisation): the maintenance of protective works is under the responsibility (commune, canton, railway company) of the entity that has constructed them and owns them. The federal state can subsidise their reconstruction under the Forest Act.
The owner is liable for any damage that a deficient protective work can cause to a third party.

Solution / description: There are about 1,000 kilometres of stonewalls and masonry terraces for protection against avalanches. These structures were built from 1890 until 1940, when these techniques were replaced by metallic snow bridge or snow net.
Stonewalls and masonry terraces stayed in service over many decades. They were exposed to the harsh conditions of high mountain climate and were sometimes reconstructed when some parts were destroyed (see figure 26). A more general approach to their maintenance was necessary, as they have reached the end of their lifetime.
A six steps approach was defined for the systematic evaluation of the structures and the definition of the measures to be taken:

1. Data acquisition: localisation of the structures, type
2. Summary assessment: shape of the structure, identification of values to be protected
3. Effect assessment: protective effects of the structures, hazards due to the shape of the structure
4. Definition of possible measures: deconstruction, reparation, replacement, no action
5. Global assessment of the measures: efficiency, cost effectiveness, sustainability
6. Implementation of the chosen measure

For step 1, an inventory of protective works can help to get an overview and to fix priorities at a regional level.
In step 5, not only technical arguments from hazard prevention are taken into account, but also more general criteria like protection of the cultural heritage and of the landscape. An economic model completes the evaluation of the measures.
The approach has been applied in different cantons and has led to a significant progress in the systematic management of old protective works against avalanches.

FURTHER INFORMATION/LINKS:

Margreth S., Blum M. 2011: Gestion des ouvrages paravalanches en murs de pierres et terrasses en maçonnerie. Guide pratique. Office fédéral de l'environnement, Berne. Connaissance de l'environnement n° 1109: 80 p.

http://www.bafu.admin.ch/publikationen/publikation/01610/index.html?lang=fr

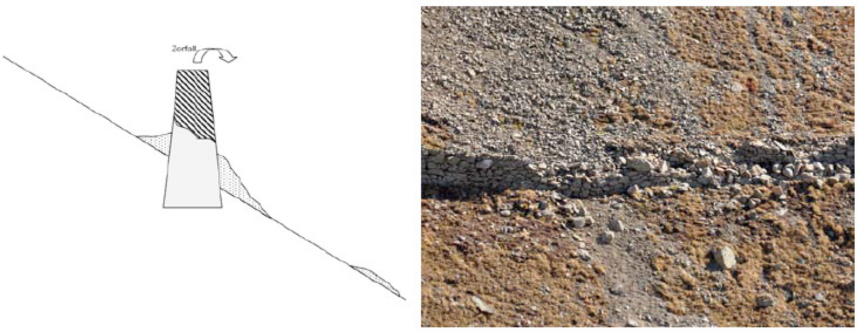


Fig. 26: Dismantled stonewall against avalanche

Phase of LCM: planning (rehabilitation and alternatives)

AFTER AN OLD ARRAY OF CHECKDAMS HAS BEEN DESTROYED DURING TWO DEBRIS FLOW EVENTS IN THE GUPPENRUNSE TORRENT, A CHANGE IN PROTECTION SYSTEM IN A NARROWER SENSE OF INTEGRATED RISK MANAGEMENT IS PLANNED FOR REHABILITATION.

Presentation of the problem: In 2010/2011, two debris flow events destroyed and damaged the over 100-year old and 1 km long array of check dams in the catchment area of Guppenrunse torrent and parts of the underlying canal. This heightened strongly the risks caused by debris flows for the settlements lying on the two debris fans of the torrent. Authorities had to decide whether the old array of check dams should be reconstructed or another strategy of protection could be more adequate.

Framework (responsibilities, law, organisation): The communal corporation is in charge of the rehabilitation of protection measures. The project will be realised on credit of the federal state, the canton and the municipality.

Solution / description: A detailed analysis with a debris flow model in consideration of different scenarios (full reconstruction, partly reconstruction, no reconstruction of the check dams) was carried out with the following result: The retention effect of the check dams on the sediment transfer at the debris fans amounts practically to zero, because the topographic situation would provoke a huge sediment deposition at the fan apex anyway.

On the basis of this analysis, a new variant with another protection strategy was worked out. It includes the construction of three fixing check dams, two new retention basins at the fan apex and the reconstruction of the canal. The system can completely hold back the expected sediment volume.

The new variant „retention at the fan apex" shows several advantages in comparison with the variant „reconstruction of the array of check dams":

- better security in case of „over load events"
- higher robustness in connection with natural variety during the process and uncertainties in hazard assessment (general and with climate change)
- combined protection against debris flows and avalanches
- better cost-effectiveness (in spite of higher costs for maintenance, construction costs and total costs are very much lower. Moreover, it leads to a higher risk reduction for the settlement)

As a disadvantage of the new variant, an alternative drinking water supply for the settlement Schwändi on the debris fan must be built up, since the new retention basins are located in the protection zone of the only source of drinking water.

In general, in comparison with the old system the new variant represents an appropriate change from active cost intensive measures in the catchment area to a new protection system in a narrower sense of modern integrated risk management.

Further information/links:
Tiefbauamt of Canton Glarus, Switzerland
http://www.marty-ing.ch/referenzen.html?1085

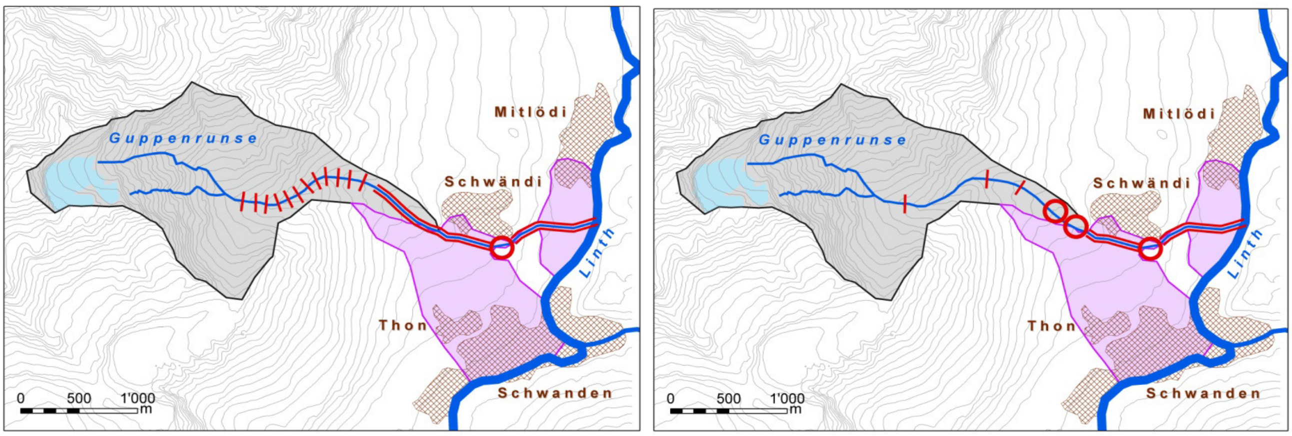


Fig. 27: Left: schematic map of the old protection system with destroyed array of check dams
Right: schematic map of the new protection system with retention at the fan apex

ANNEXE C – Good practice examples from Member States on construction details that support or prolong the lifetime / functionality of a protective infrastructure in place

C1 - Reuse of old construction parts

The old rock dam was not stable enough. Instead of its total replacement, it was reinforced by back-anchored concrete columns. Example Maigraben, Landkreis Rosenheim, Bavaria

C2 - Adjustable rake columns

The steel columns of this woody debris entrapment rake can easily be fixed in different distances to each other. So this construction can be adapted to further experience without having to rebuild it. Example Maigraben, Lkr. Rosenheim, Bavaria

C3 - Steel cover of the spillway section of gabion dams

Gabions would quickly get destroyed due to abrasion especially in the spillway section. Therefore, “easy to replace” steel plates cover the endangered part of the dam construction. Example Talgraben, Lkr. Bad Tölz-Wolfratshausen, Bavaria

C4 - Adjustable beams in dam construction

The vertical distance of the steel beams in this retention dam can easily be changed. So this construction can be adapted to further experience without having to rebuild it. Example Maigraben, Lkr. Rosenheim, Bavaria

C5 - Mobile unit for quality control of building materials

Mobile unit for quality control of building materials during the early contraction phases - a contribution to a prolonged durability and an increased reliability of protection structures (Autonomous Province of Bolzano)

C6 - Reconstruction of old concrete dam

One of the solutions to maintain the design functionality of decrepit old dams is the reinforcement of building massive supporting stone constructions in front of old structure, anchored and connected with the existing one and actually working like one object (two examples from the torrents Mačkov graben and Prošca, photo: Hidrotehnik, Slovenia)

C7 - Upgrading and adapting of old stone dams

New boundary conditions demand upgrading of functionality of existing protection structures – a common measure is raising protection dams. On the photo there is such an example from the torrent Lučno, with additional adapting of structure with manageable passage (closed with removable wooden trunks) for local owners who have to occasionally gather the woods from the forested headwaters (photo: Hidrotehnik, Slovenia)

C8 - Rehabilitation of an existing array of checkdams in Steinibach Hergiswil, NW

The array of check dams was built as block dams lying on a rock-filled log crib in the year 1956. After the log cribs were exposed by scouring and erosion, the stability of the array of check dams could not be ensured anymore. Rehabilitation measures were taken in the years 2012 and 2013 consisting of pre-concreting of the check dams, construction of subsidiary dams, scouring protection and rehabilitation of training structures.

Situation before rehabilitation
Source: canton of NW

Situation after rehabilitation
Source: BAFU

Pre-concreting

Source: canton of NW

Finished pre-concreting and coverage with log

Source: canton of NW

Construction of a subsidiary dam

Source: Schubiger AG

Pre-concreting and training structures

Source: Schubiger AG

C9 - Modification of the bedload retention basin Grosstanne, Steinibach, Hergiswil, NW due to change in scenarios (landslides)

Since the retention volume of the three bedload retention basins Grosstanne (construction year 1979) was too small and the system was constructed without consideration of woody debris, it was modified in the years 2013 and 2014. The three arch dams were elevated to create more retention volume. The structure was improved by stiffening the dam toes with slices of concrete and enlarging the dam body. The lowest retention basin was functionally converted into a retention basin for woody debris. Before the rehabilitation measures were carried out, they had been simulated in physical model tests.

Arch dams 1 and 2 before modification Source: canton of NW

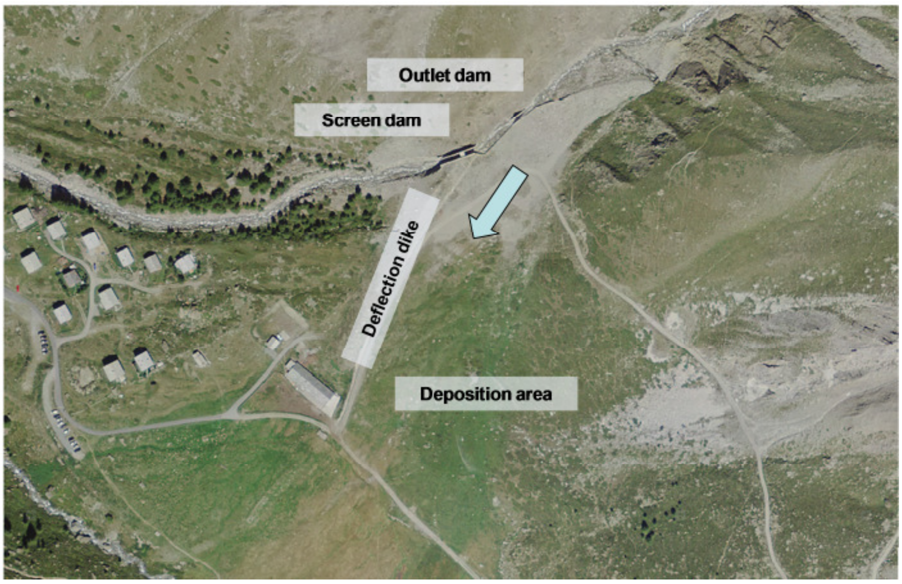
Arch dams 1 and 2 after modification Source: canton of NW

Modification of arch dam 3 for retention of woody debris Source: canton of NW

View over the finished construction Source: Schubiger AG

C10 - Bedload retention with outlet structure and deflection dike Ottawan, Täsch, VS due to new sce-narios (climate change)

Because of melting permafrost, landslide processes and a potential outbreak of a glacier lake, the sediment potential in the catchment area of Rotbach and the following Täschbach is practically infinite. The protection of the settlement Täsch could not be ensured by the existing retention basin at the fan apex, because the retention volume was several times too small. A flexible and solid protection system was needed to deal with these high and uncertain design values. In 2006, a protection system was built up in the 700 m higher lying valley Täschalp, consisting of the following elements: an outlet structure and a deflection dike lead bedload in a large unsettled area for deposition in case of medium and extreme events. Runoff and small events flow through a screen dam…..l-



Overview Source: BAFU

Outlet dam (right), screen dam (left of outlet dam) and deflection dike with deposition area (left)

Source: BAFU

C11 - Modification of the bedload retention basin Humligentobel, Wolfenschiessen, NW due to man-agement of over load case

The settlement of Wolfenschiessen lying on the left side underneath the retention basin was endangered by potential debris flow overload events from an activated rockfall area in Humligentobel. To ensure a controlled overflow out of the basin to the right side, the outlet dam of the existing retention basin was modified in 2004. In August 2005 the construction was successfully "tested" during an extreme debris flow event. It flowed over the outlet dam on the right side in a forest and in agriculturally used grassland without leading to higher damages.

Retention basin before modification Source: BAFU

Retention basin after modification Source: BAFU

C12 - Modification of bedload retention basin at Betelriedgraben, Blankenburg, BE due to new order/law

Due to the new Federal Act on dams and reservoirs, which has been valid from 1/1/2013, certain retention basins for flood protection must fulfil advanced structural standards. The arch dam of the retention basin of Betelriedgraben does not comply with these requirements. A modification is planned for the years 2016 and 2017 within a flood protection project. The planned structural enhancement consists of an elevation of the dam crest, a brace support of the instable outlet dam and measures to avoid scouring underneath the outlet dam.

Existing arch dam, retention basin of Betelriedgraben Source: BAFU

Modification measures planned in the flood protection project   Source: Theiler Ingenieure AG

C13 - Protective infrastructure in torrents influenced by lateral mountain pressure

Control works at torrents within the influence of sagging of mountain slopes is a notable challenge. Most of all the lateral mountain pressures lead to negative impacts and sometimes to a rapid destruction of conventional check dams. Good experience has been gained in Austria with a construction type, where the wing of the check dam can move (to a certain degree) against a stable overflow section.

Check dam with a slidable wing to balance lateral mountain pressure, Source: die.wildbach (Salzburg)

Persistence of Alpine natural hazard protection

Meeting multiple demands by applying systems engineering and life cycle management principles in natural hazard protection systems in the perimeter of the Alpine Convention

PLANALP Brochure 2014