OPTIMAL FLOOD RISK MANAGEMENT – DECISION PROCESS IN PRACTICE

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ABSTRACT

The flood risk management policy for mountain torrents in Bavaria is currently updated. This paper discusses the basis for these works and presents an initial proposal of a decision framework. Existing approaches for decision and planning of flood mitigation strategies are reviewed, starting from an ad-hoc approach where the measures are designed as a reaction on an experienced flood event, to risk-based approaches that try to find an optimal balance between costs of the protection measures and the residual risk. Four methods for the evaluation of protection strategies are discussed: Cost-minimization analysis (CMA), cost-benefit analysis (CBA), cost-effectiveness analysis (CEA) and multi-criteria analysis (MCA). Finally, the proposed decision framework for Bavarian Alpine catchments is presented, which should allow an optimization of the existing flood protection systems.

INTRODUCTION

In flood risk management, as in other safety and risk engineering applications, one aims at identifying an optimal risk protection strategy. Typically, an optimal solution is selected among a countable number of considered potential strategies. In flood risk protection, strategies correspond to different combinations of protection measures (dykes, retention areas, mobile flood barriers etc.), warning systems, emergency response, and land use patterns. The strategies can be associated with different costs and different protection levels (leading to different residual risk). The optimal strategy should be identified based on economic efficiency and social and environmental requirements.

This study describes the basis for a modernization of the methodology for planning flood risk measures in Bavarian Alps. The future methodology should establish a unifying decision framework for all catchments and support the optimization of the existing protection systems in terms of maintenance effort, financial and personal efforts, resilience, residual risk and more. It should have a long-term perspective and favor flexible and adaptable solutions that allow facing the future changes of boundary conditions, including climate change, socio-economic developments in the flood plain and a change of priorities. It should also incorporate the state of the art of flood risk management in other Alpine countries into the Bavarian standards.

This paper reviews the approaches for planning of flood mitigation strategies that are typically used in flood risk management practice and it is discusses how these can be incorporated into the legal and organizational setting encountered. Four methods for the evaluation of the protection strategies are considered: Cost-minimization analysis (CMA), cost-benefit analysis (CBA), cost-effectiveness analysis (CEA) and multi-criteria analysis (MCA). Furthermore, the paper describes the context and challenges for the development and application of such a decision framework in Bavaria given by legal and organizational issues. Finally, the decision framework proposed for the updated guidelines for flood risk management in Bavarian Alps is presented. It is based on the findings of (Špačková et al., 2013), which discussed the optimization of the risk protection level from the economic perspective using CBA. In the present paper, the findings of this previous study are put into a broader perspective and their use in practical decisions is shown.

OVERVIEW OF DECISION SUPPORT APPROACHES AND METHODS

Planning of flood protection is a complex task, where many decisions must be taken about the protection concept, type of protection measures, design parameters, location, time of implementation etc. These decisions then determine the protection level and the associated residual risk, as well as the costs of the measures and potential other effects (environmental, social etc.).

The approach to planning and evaluation of flood protection measures has evolved from a (more or less) ad hoc approach that consisted in implementing mitigation measures as a reaction to the occurrence of an event, towards risk-based approaches that aim at finding an optimum protection level by comparing the benefits, costs and possible other consequences associated with the implementing of flood protection. Table 1 gives an overview of the different approaches and of the aspects that are taken into account in these approaches (marked with crosses). The aspects are: (a) the probability of the hazard, (b) consequences of the hazard and the risk, which is defined as the expected consequences (i.e. it combines both the hazard probability and the consequences) and (c) the costs of implementing the protection measures.

Table 1. Overview of approaches to planning of flood mitigation measures.

	Considered aspects		
	Hazard Probability	Consequences (Risk)	Costs of measures
I. Ad hoc reaction	-	-	-
II. Return-period	x	-	-
III. Return-period with zoning	x	x	-
IV. Risk acceptance criteria	x	x	-
V. Risk-based optimization	x	x	x

In the Ad hoc approach (I), the selection and design of the protection measures is based on experienced events, for example, a dyke against the maximum observed discharge during the events with some reserve. The protection level is determined by the magnitude of the experienced events and by choices made by the designers or decision makers. The probability of the event and the consequences are not explicitly evaluated. The cost of measures can be considered, but only implicitly; they do not influence the selection of the protection level.

Probably the most common approach is to design the mitigation measures for a certain design flood, which is characterized by its return period (approaches II-III in Table 1). For example, in Bavaria, the standard protection level is set to a 100-years event, while in the Netherlands, the protection standard goes up to a 10000-years event in some highly populated regions (Paudel et al., 2013). Design of flood protection for a return-period (approach II) is in principle not risk-based, because it does not explicitly take into account the potential consequences of the hazard. The risk can be considered by dividing the flood prone area into zones with different damage potential and by distinguishing the protection level for these zones (approach III). The flood protection is also often designed to fulfil some prescribed risk acceptance criteria (approach IV). The criteria can be given in terms of maximum acceptable risk to people (Jonkman et al., 2003), as a maximum annual material risk (i.e. maximum expected material damage per year) per object, or in other suitable units. In any of the approaches II, III and IV, the cost of the protection measures are not considered for determining the protection level; if the risk is ranked as unacceptable, measures must be taken regardless of their costs.

Finally, a fully risk-based optimization (approach V) can be performed. The aim of such optimization is finding an optimal balance between costs of the measures, the residual risk and potential other benefits and costs associated with implementing the flood mitigation. Such optimization can be additionally constrained by a budget constraint (i.e. maximal costs that can be invested to the protection measures), by safety constraints in the form of a maximum acceptable risk to people (approach IV), by a minimum protection level given by the return period of the flood event (approach II and III), or other constraints.

Methods for evaluation of the protection strategies

Because of the complex effects of protection measures it is necessary to consider different alternative solutions, like types of measures or combinations. Then the best alternative has to be identified. Different methods for the evaluation of the protection strategies are discussed in the following, they are illustrated in Figure 1.

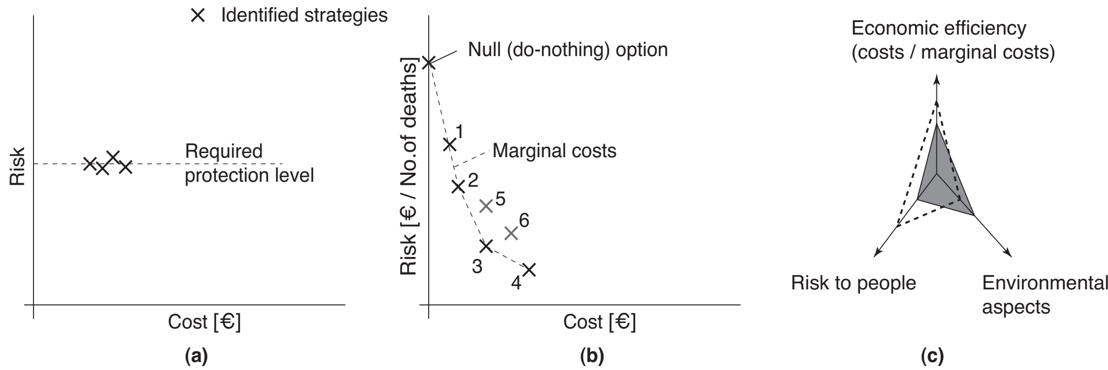

Figure 1. Illustration of methods for evaluation of risk protection strategies: (a) cost minimization; (b) cost-benefit analysis / cost-effectiveness analysis; (c) multi-criteria analysis.

The cost minimization analysis (CMA), illustrated in Figure 1a, intends to identify the most inexpensive option from a set of options that comply with the required target. The target can be defined, for example, as the required protection level determined by a return period of the event (approach II and III) or as a protection level found to be optimal within a fully risk-based optimization (approach V). As is evident from Figure 1a, when the protection level is given (e.g. set to a 100 years event), the residual risk of the evaluated strategies is similar. The small differences in the residual risk are due to variable reliability of the measures (i.e. in the different failure - probabilities for discharges higher than the 100 years event) or due to the different consequences in case of failure or overtopping of the measures (e.g. an overtopping of a dike can cause dynamic flood waves, whereas an overtopping of a concrete wall leads to a slow flooding).

Cost-benefit analysis (CBA), illustrated in Figure 1b, compares the monetized value of benefits with costs needed to achieve them. In planning of flood risk protection, the benefits correspond mainly to the risk reduction; other types of benefits are typically not considered within the flood risk management applications of CBA. The risk can include different types of expected damages: the tangible direct damages on property and infrastructure, monetized value of injuries and fatalities (Jonkman et al., 2003; Lentz, 2007) and other intangible damages. The quantification of the intangible damages and especially of the value of human life is, however, often subject to criticism and has only been accepted in some societies and types of application, including for example the planning of flood protection in Switzerland (Bründl et al., 2009).

In the framework of CBA, the optimal protection level can be found by minimizing the sum of residual risk and costs (Špačková et al., 2013). The concept is illustrated in Figure 2. Identified strategies (shown as crosses) lead to varying protection levels and they are thus associated with varying residual risk (expected annual damage) and with varying costs. Two possible cases are illustrated: Figure 2a shows the unconstrained optimization, where strategy 4 has the smallest sum of risk and costs from all identified alternatives. Figure 2b shows an optimization constrained by a limited budget that sets a maximum cost C_{max} that can be invested into flood protection and by a safety constraint that requires ensuring a minimal protection level. In the constrained optimization in Figure 2b, the unconstraint optimum (strategy 4) lies in the infeasible region; strategy 3 has the smallest sum of risk and cost among the feasible alternatives.

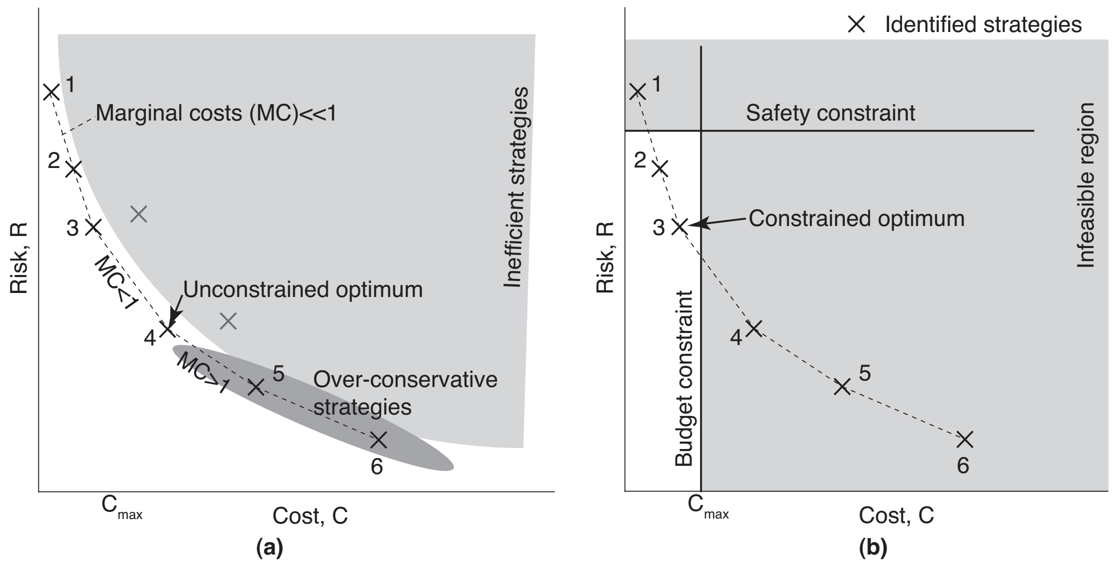

Figure 2. Identification of optimal flood protection level using the cost benefit analysis (CBA). Both risk and costs are expressed in monetary values. (a) Unconstrained optimization. (b) Constrained optimization.

Cost-effectiveness analysis (CEA), illustrated in Figure 1b, also evaluates the costs and benefits (risk reduction) of the identified strategies. However, unlike CBA, it does not monetize the value of the risk reduction (Ramsberg, 2000). In Figure 1b we illustrate the idea on the case of evaluating the risk protection strategies from the perspective of safety to people. Strategies ensuring different protection levels are associated with different risk to people (i.e. different expected number of fatalities per year) and with different costs. The optimal protection level can be found by quantifying the societal willingness to pay for ensuring the safety (Fischer et al., 2013). In this case, however, the benefits (risk reduction) are monetized, and CEA turns into CBA (Ramsberg, 2000).

As mentioned earlier, it is often argued that the quantitative analysis based on CBA is not suitable for decision support, because many aspects such as the value of human life or environmental and social impacts of the proposed measures cannot be easily quantified or that it is unethical to assign monetary values to these attributes. To avoid a fully quantitative analysis, some researchers and practitioners suggest to provide the assessed risk, costs and other aspects of all identified strategies to the decision makers and to let them decide on the protection level (Woodward et al., 2013). To make the decision process more systematic, the multi-criteria analysis (MCA), which is illustrated in Figure 1c, is often used. MCA is a framework that allows the identification of the optimal solution based on multiple attributes: these include attributes that can be monetized, attributes that can be quantified but not monetized, as well as qualitative ones (Mysiak et al., 2005; ECA, 2009; Defra, 2009). Multiple versions of MCA have been used in the practice; examples include the analytical hierarchy process (AHP), multi-criteria utility analysis or fuzzy-set based methods (UK Dep. for Communities and Local Government, 2009). Fundamentally, all these methods rate the relative importance of each of the decision criteria and select the optimum based on this rating. It should be noted that the rating is prone to be dependent on the subjective view of the analysts and/or decision makers. The assumptions and priorities of each decision maker and analyst are different, and the schemes that are analysed by different people or even by the same people in different time are thus likely to be treated unequally. A standardization of the procedure and rating is thus needed to ensure objectivity and a fair evaluation of all projects. An example of a standardized scoring system used for evaluation flood risk mitigation projects in the UK is given for example in (Johnson et al., 2007).

CONTEXT AND CHALLENGES OF FLOOD RISK MANAGEMENT POLICY IN BAVARIAN ALPS

Today, the flood protection in the torrents of the Bavarian Alps is ensured by operation of almost 50.000 individual structures. It was decided to invest 2.3 billon Euro into flood risk management in the period of 2001-2020 in Bavaria (StMUGV, 2005), of which about 400 million Euro are for torrent control. Many of the existing torrential structures are up to 100 years old, some of them are highly worn down and they often do not fulfill the requirements to modern flood protection. The circumstances and objectives for flood control in mountain torrents have notably changed over the years, and the flood management policy has to be adapted to better meet the new requirements.

Following the German water resources law (WHG) and the Bavarian water law (BayWG), the Bavarian state, represented by the water authorities, has to provide a comparable safety level throughout the state and therefore to introduce new or to improve existing protection measures. The minimum required safety level is given by the design flood for the investigation of flood zones (BayWG) and the target of a protection against a 100 years flood (HQ_{100}) for settlement areas by the Bavarian development program (Landesentwicklungsprogramm – LEP). To achieve this safety level in the Bavarian Alps, over 200 new or upgraded protection systems are needed. The improvement of the protection level is mandatory but subject to the availability of financial resources. The local communities are expected to participate in financing the projects.

The situation in different torrential catchments is highly variable. In some catchments, relatively large settlements are regularly flooded, the risk is high and the costs for constructing protection measures are reasonable – it would therefore be beneficial to increase the current protection level. In contrast, catchments exist where the current protection level is high and maintenance is costly, even if the potential risk is low. Examples are catchments without larger settlement, where protection measures were built to protect agricultural land or facilities that have lost their importance today. The proposed decision framework should be applicable to all these types of catchments and it should ensure a fair distribution of resources amongst them.

The effort for implementing the decision framework in individual catchments must be reasonably low, in order to be applicable in practice. These efforts are dependent on:

a. The number of the analysed risk protection strategies: considering too many strategies leads to unacceptable engineering efforts, too few strategies (or wrongly selected ones) are likely to overlook the optimal one.
b. The level of detail in the analysis: The hazard analysis, damage modeling, planning of measures, evaluation of the effect of the measure on risk and assessment of their costs can be done at different levels of detailing. For some catchments, a rough estimation based on little information and preliminary engineering assessment can be sufficient, while other cases might justify a detailed analysis requiring extensive on site investigations, detailed hydrological and hydraulic modeling, detailed damage analysis and detailed planning of measures and modeling of their effects.

Finally, in most cases insufficient information is available about the actual state of the flood risk protection in the catchments, about the current risk and costs in each catchment and about potential other aspects that should be considered. A proper calibration of the decision framework at this point of time is therefore unfeasible and it must be progressively improved in the future based on the information obtained from individual catchments. One of the main goals of the proposed evaluation procedure is thus the unification of the outputs of the analyses made in different catchments so that they provide comprehensive and standardized information on the catchments.

The procedure of flood risk management planning in Bavaria has 3 phases:

1. Preliminary assessment (Basisstudie) of catchments where the existing protection level is lower than HQ_{100} to prioritize the necessary measures. This contains a rough estimation of the damage potential and of investment costs for increasing the protection level to HQ_{100}. This phase has been completed.
2. Preliminary design: Conceptual planning of flood protection measures and alternatives: identifying possible protection strategies for the catchments with high priority out of phase 1, choosing an optimal and feasible strategy in terms of protection level and type and dimensions of the protection structures.
3. Structural design: Detailed design of protection structures for the protection strategy proposed in phase 2

In this paper, we mainly focus on the procedure proposed for the phase 2, which is being developed in an ongoing research project of the Bavarian Environmental agency and Technische Universität München.

DECISION FRAMEWORK FOR FLOOD RISK MANAGEMENT PLANNING IN BAVARIAN ALPS

The scheme of the proposed adaptive procedure is displayed in Figure 3. The information available from the preliminary assessment (Phase 1) and from other sources available to the administrative bodies serves for prioritization of the necessary protection systems in the catchments. The measures with the highest priority will be investigated following phases 2 and 3.

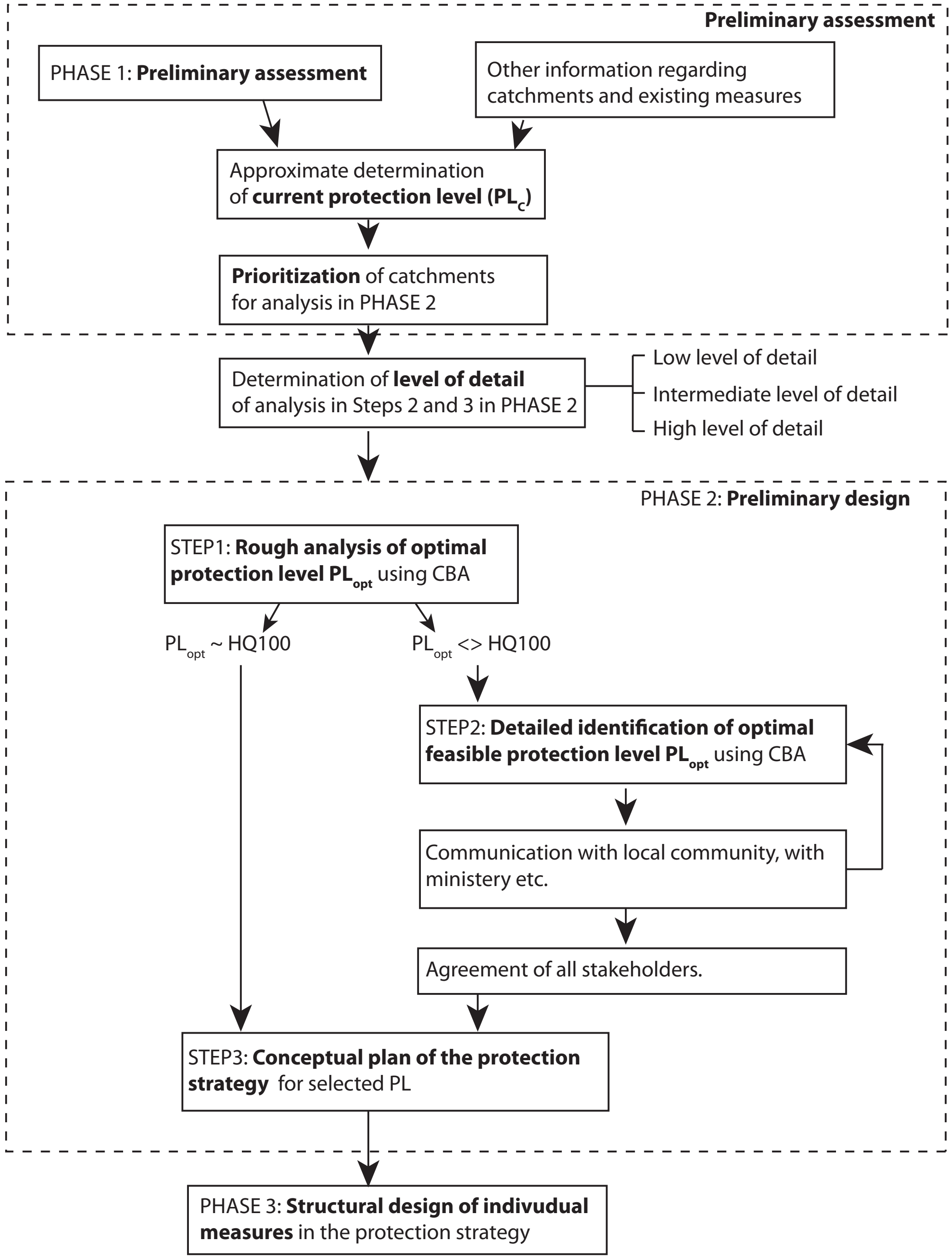

Figure 3. Scheme of the proposed adaptive decision framework.

Phase 2 is divided to three steps: In Step 1, the optimal protection level is identified based on a rough analysis making use of the limited amount of data available from Phase 1 and other sources. The concept of CBA is used. At least 3 different strategies with different protection levels PL (e.g. current protection level $PL<HQ_{100}$, $PL\sim HQ_{100}$ and $PL>HQ_{100}$) will be considered. For each strategy, the risk and costs are roughly assessed, with a significant contribution of engineering judgment, and the optimal protection is identified as shown in Figure 4a.

If the optimal strategy found in Step 1 corresponds to the protection against HQ_{100}, which is required by law, a detailed conceptual plan of the protection strategy (Step 3) can be prepared. However, if the optimal strategy found in Step 1 does not correspond to the protection against HQ_{100}, a more detailed analysis identifying the optimal protection level is to be carried out (Step 2). In this detailed analysis, more strategies with different protection levels should be evaluated (in total c. 4-5) and the estimation of risk and costs for each strategy must be supported by a more detailed study including hydrologic and hydraulic model of the torrent, damage assessment, detailed analysis of the influence of the proposed protection measures etc. The optimal protection level can be identified following Figure 4b. The findings of the study must be communicated to and discussed with the affected community, with the relevant ministry and possible other stakeholders. Additional aspects such as environmental and social or the possibility to adapt the proposed protection level in the future should be taken into account. Based on these considerations, a decision for another protection level than HQ_{100} may be reached.

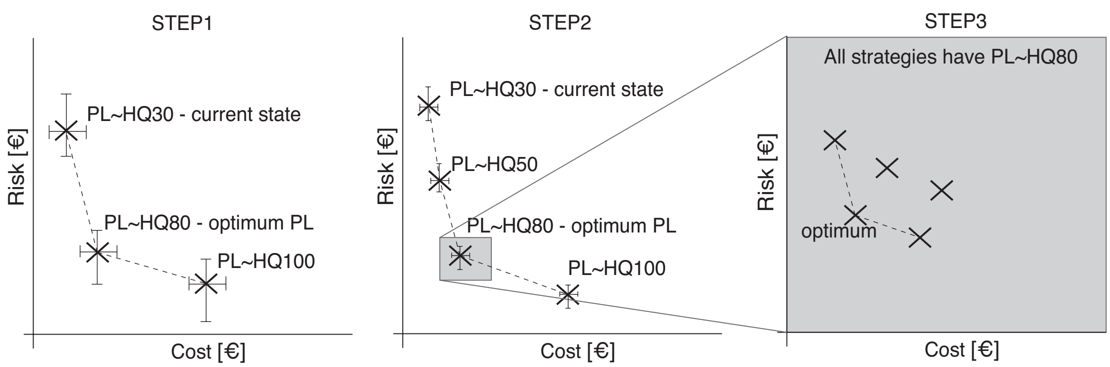

Figure 4. Identification of optimal protection level (PL_{opt}) in Step 1 and 2 and identification of optimal strategy ensuring PL_{opt} in Step 3.

In the conceptual planning of the protection strategy (Step 3), several strategies fulfilling the selected protection level are analyzed (see Figure 4c). The residual risk and costs for each of them is assessed at a more detailed level; these estimates are compared to the estimates of risk and costs made in the previous steps to validate the assumptions made in these previous steps. The optimum is again identified using CBA, but other aspects are taken into account as well.
Finally as shown in Figure 3, a detailed design of individual measures for the strategy selected in Step 3 of Phase 2 is carried out in Phase 3.

CONCLUDING REMARKS

A proposed decision framework for planning of flood risk mitigation strategies in Bavarian torrents was described in this paper. The framework employs the cost benefit analysis (CBA) concept for identification of the optimal protection strategy based on assessing their residual risk and costs. Criteria such as social and environmental impacts, adaptability of the proposed strategies to future changes and risk to people are only considered qualitatively in the proposed framework. Development of an objective (semi-)quantitative methodology for evaluation of these criteria seems not possible at this stage, because an insufficient amount of information about the whole system is available. It is anticipated that the proposed decision framework will be improved in the future based on the results and experiences from the analyses of a first set of catchments.

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