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ARTICLE

Effective and Sustainable Flood and Landslide Risk Reduction Measures: An Investigation of Two Assessment Frameworks

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Abstract Natural events such as floods and landslides can have severe consequences. The risks are expected to increase, both as a consequence of climate change and due to increased vulnerabilities, especially in urban areas. Although preventive measures are often cost-effective, some measures are beneficial to certain values, while some may have negative impacts on other values. The aim of the study presented here was to investigate two frameworks used for assessing the effectiveness and sustainability of physical and nonphysical flood and landslide risk reduction measures. The study is based on literature, available information from authorities and municipalities, expert knowledge and experience, and stakeholder views and values. The results indicate that the risks for suboptimization or maladaptation are reduced if many aspects are included and a broad spectrum of stakeholders are involved. The sustainability assessment tools applied here can contribute to a more transparent and sustainable risk management process by assessing strategies and interventions with respect to both short- and long-term perspectives, including local impacts and wider environmental impacts caused by climate change, for example. The tools can also cover social and economic aspects. The assessment tools provide checklists that can support decision processes, thus allowing for more transparent decisions.

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1 Introduction

Floods and landslides can have severe and even disastrous consequences with fatalities, diseases, construction and infrastructure failures, and can damage or completely destroy land (Dai et al. 2002; Srivastava and Laurian 2006; Holcombe and Anderson 2010; Singh 2010). The risks related to a flood or landslide can be described as the potential for loss, damage, or destruction of an asset as the result of a hazard exposing a vulnerability related to the event. The risk is a function of the probability, magnitude, and other characteristics of an event and the consequences of the event. The consequences depend on the exposure and the vulnerability characteristics of the elements at risk (humans, landscape and ecosystems, buildings and constructions, the social structure, and other values in the area at risk). The vulnerability is a function of the susceptibility (the likelihood of being exposed) and the adaptive and coping capacity. Both the probability and the consequences of floods and landslides are expected to increase in the coming decades, as a result of climate change and increased vulnerabilities, especially in urban areas (Poussin et al. 2012; IPCC 2013). The consequences may be damages caused directly or indirectly by a flood or landslide. An example of an indirect consequence is delays due to road or railroad damages (Holcombe and Anderson 2010; Suh et al. 2011). Strategies can be developed to reduce either the probability of an event or the consequences, or both (Dai et al. 2002; Brooks 2003; Sarewitz et al. 2003). Both physical and nonphysical measures can be implemented to reduce risks. The measures can be decided and implemented at different levels, from an individual level to national and international political and management levels.

At the national and international levels, measures to reduce risks can be enforced by policies, directives, legislation, frameworks, and other guidelines, and by economic incentives such as taxes and subsidies. International directives and agreements such as the EU Flood Directive (Directive 2007/60/EC), the EU Inspire Directive (European Directive 2007/2/EC), the EU Seveso Directive (Directive 2012/18/EU)), the Hyogo Framework for Action 2005–2015 (UNISDR 2005), and the Sendai Framework for Disaster Risk Reduction 2015–2030 (UNISDR 2015)—influence the development of national strategies and legislation. National measures also include information campaigns and education (Bormann et al. 2015) and programs such as the Room for the River program in the Netherlands.[1] National hazard and risk mapping, as well as governmental investigations and inquiries, are also important nonphysical, national-level measures to reduce risks (Schuster and Highland 2007). Physical and nonphysical risk reducing measures can also be applied at local and catchment levels, for example.

Examples of physical measures are classic flood risk reducing methods such as barriers, dikes, embankments, walls, and dams (Goltermann and Marengwa 2012). Landslides can be prevented by soil reinforcements and erosion-prevention measures in the most landslide-prone areas. Physical measures can be implemented from a catchment perspective, or from a political regional perspective, but can also be taken to a local and estate or household level. Regardless of the level at which the risk reduction strategy is implemented, it may result in consequences that involve two or more provinces and even countries.

Some of the more important nonphysical measures are education, information campaigns, communication with landowners, subsidies, increased preparedness, and the establishment of risk management networks (Glaas et al. 2010; Glavovic et al. 2010; Holcombe and Anderson 2010; Andersson-Sköld et al. 2013; Bormann et al. 2015). Other measures can be recommendations and restrictions in master plans and in detailed spatial planning (Srivastava and Laurian 2006; Holcombe and Anderson 2010).

An appropriate and sustainable risk reduction strategy needs to be defined, not only for the current risk but also for the protection requirements and the effectiveness of the risk reduction measures (Dai et al. 2002; Holcombe and Anderson 2010; Singh 2010). Risk reduction requirements can be defined on the basis of risk acceptance, for example, protection of a city in relation to certain flood levels. They can also be based on an analysis of the costs of risk reduction activities in relation to the consequences in the case of an event, preferably taking into account environmental and social aspects (Roberts et al. 2009; Anderson et al. 2010; Zeng et al. 2012). Developing the most sustainable risk reduction strategy requires assessing different alternative measures (or combinations of measures) in the context of short- and long-term perspectives. Previous studies have shown that the more open and transparent the decision-making process is, the more effective the risk reduction can be expected to be (Sharma et al. 2012).

1.1 Monetary Cost-Benefit Assessments in Risk Management

Monetary assessments can be powerful tools within risk management. A study of socioeconomic impacts and risk reduction strategies in urban landslide-prone areas in the United States showed that improved planning codes and professional practice reduced the monetary losses from landslides by more than 90% (Schuster and Highland 2007). The actions taken ranged from nonphysical measures, such as restrictions against new developments, implementation of construction codes, installation of warning systems, and the possibility to insure private property, to physical measures, such as excavation, grading, and other physical measures for existing buildings (Schuster and Highland 2007).

Poussin et al. (2012) examined the cost-effectiveness of different adaptation strategies at a local/regional level to reduce future flood damage in the Meuse river basin, including changes in land use and climate between 2000 and 2030. The assessment included calculated risk reduction in monetary terms of houses and inhabitants impacted by floods (water depth, flow velocity, and duration). The impact assessment was done by applying exposure, sensitivity, and adaptive capacity functions as described by Ernst et al. (2010). The strategies examined were dry-proofing (for example, sandbags, cofferdams, panels on doors and windows), wet-proofing (all semistructural and nonstructural measures that can be implemented to adapt the exterior and interior of a house), and a combination of both (Poussin et al. 2012). The results of the study showed that land use planning played a more important role than the impacts of climate change for the increasing flood risks in the Meuse river system.

However, many ecological and social factors such as disturbed ecosystem functions, social unrest, or psychological stress are difficult to evaluate in quantitative or monetary terms (Ismail-Zadeh and Takeuchi 2007). Another limitation of a cost-benefit approach is related to

[1] Room for the River program in cooperation with UNESCO-IHE 2013. https://www.unesco-ihe.org/sites/default/files/13270-rvdr-brochure-governance-engels_def-pdf-a.pdf.

impacts and potential maladaptation due to differing spatial and temporal scales. Patterson and Doyle (2009), for example, found that county-based planning and monitoring may result in unwanted and costly impacts elsewhere in a catchment area. Taking all those aspects into account in the cost-benefit analysis requires broader evaluation methods.

1.2 Integrated Assessments in Risk Management

An alternative to cost-benefit analysis is analysis that integrates monetary and nonmonetary assessments and valuations. Multi-criteria models, or multi-criteria analyses (MCA), are being developed as tools for illustrating potential conflicts of interest and unwanted outcomes of planning strategies. To achieve wanted and positive, and to avoid unwanted and negative, impacts of interventions, short- and long-term as well as wider consequences need to be assessed and valued (Barnett and O'Neill 2010; Nyberg et al. 2014).

Multi-criteria analyses (MCA) are frequently used for integrated assessments. Their foci and purposes vary, but costs are often valued in relation to technical performance and/or impacts on the environment (Renn 2005; Volchko et al. 2014). In general, the methodology also encourages an integrative role of stakeholders. The outcome of applying such models could be that stakeholders with differing experiences, needs, views, and interests find that they interpret the risk differently (Renn 2005; Bormann et al. 2015). A study by Gamper and Turcanu (2009) showed that a broad participation in the MCA process can improve the risk reduction and decision-making process by increasing common understanding, serving as a means of conflict resolution, creating a win–win solution, and acting as a complementing instrument in land use planning and risk management. Two MCA methods have recently been developed for assessing flood and landslide risk management strategies—the benefit value tree (BVT) by Bana e Costa et al. (2004), and the matrix-based decision support tool (MDST) by Andersson-Sköld et al. (2014a).

From the perspective of sustainable development, the functionality of measures (level of protection, time and cost for construction, and maintenance), their impacts on the environment (local-scale effects as well as use of resources and contribution to climate change), and social and socioeconomic aspects need to be taken into account, both from a short- and a long-term perspective (Barnett and O'Neill 2010; Nyberg et al. 2014; Andersson-Sköld et al. 2015). The short-term perspective applies mainly to the implementation phase of a measure, while the long-term perspective applies when a measure is in use, as well as to a post-use phase.

1.3 Aim of the Study

The aim of this study was to investigate the potential for assessing the effectiveness of risk-reducing measures based on a sustainability perspective. The following two methods were used:

(1) the benefit value tree (BVT) by Bana e Costa et al. (2004), where the costs (in monetary terms) are weighed against a selection of environmental and social benefits or negative impacts; and
(2) the matrix-based decision support tool (MDST) by Andersson-Sköld et al. (2014a), where monetary cost is one aspect among others.

The BVT and the MDST allow the inclusion of both quantitative and qualitative information in the assessment. The two methods were applied in two Swedish case studies to evaluate the risk reduction and sustainability of flood and landslide risk reduction measures by using available case information, literature, and stakeholder views, experiences, and perceptions.

2 Benefit Value Tree (BVT) and Matrix-Based Decision Support Tool (MDST): Two Methods to Assess Effectiveness and Sustainability of Risk Reduction Measures

In this study the BVT and the MDST are applied on two case studies. Both models are stepwise processes to assess and value the impacts of risk reduction measures. The assessments can be done using qualitative, quantitative, or semiquantitative ratings, and the valuation can be done in different ways. The main difference between the two approaches focused on here is the sustainability aspects considered in the assessment of impacts caused by the risk reduction measures.

2.1 The Benefit Value Tree (BVT)

The BVT for the evaluation of flood control measures was developed by Bana e Costa et al. (2004). It is a stepwise method initiated by an analysis of the problem context, followed by identification of options, assessment, and analysis of the options' impacts, and finally sensitivity and value analysis (Bana e Costa et al. 2004).

In the assessment, the costs of one or more alternative flood-control measures are compared to the risk reduction effectiveness as well as other impacts of the risk reduction measures under investigation. The BVT is based on expert views and consists of three main non-economic components (key benefit dimensions)—environmental impacts, social impacts, and technical effectiveness—that are analyzed in relation to the costs of the flood-control measure being assessed. In total, 16 non-economic ("benefit") components (Bana e Costa et al. 2004) are compared to the costs of the measure:

Environmental impacts

– Water
  - Time of inundation of the riverine zone.
  - Risk of discharge obstruction due to sedimentation.
  - Quality of surface water after a flood event.
  - Piezometric level of aquifer.
  - Quality of groundwater.
– Soil
  - Area of agricultural soil.
  - Soil contamination.
– Fauna and flora
  - Nature conservation interest.
– Landscape
  - Urban integration.
  - Enhancement of landscape.

Social impacts

- Perception (concern/anxiety) of flood (landslide) risk.
- Effects on the social fabric.
- Effects on public health.

Technical effectiveness

- Technical complexity of the intervention.
- Complexity of maintenance.
- Level of protection.

The impact assessment and analysis of the potential risk reduction measures can be done through qualitative descriptions combined with simple ranking, such as pros and cons. This can also be followed by, or done by, a more advanced and detailed information and assessment procedure, for example through the MACBETH impact assessment and weighting procedure as described in Bana e Costa et al. (2003, 2012). For a subsequent sensitivity analysis the VISA model can be used, for example, to calculate the aggregated benefit scores and perform the sensitivity analysis of the potential different flood risk reduction measures (Bana e Costa et al. 2004). Finally, the total cost (investment and other initial costs) versus overall benefit analysis is done taking into account the estimated variations in weights and uncertainties (Bana e Costa et al. (2004).

In this study, we use a semiquantitative scale. The scale ranges from -2 (very negative impact on the "benefit" component, that is, significantly more negative than -1) to $+2$ (very positive impact on the component, that is, significantly more positive than $+1$), where 0 implies no, or no significant, impact. The main reason for choosing this scale is that the study focuses on the 16 benefit dimensions in relation to the aspects regarded in the MDST described below. The study does not aim to make a detailed assessment but rather an aggregated assessment, since the uncertainties in the different assessments are so numerous that fine assessments are not relevant.

2.2 The Matrix-Based Decision Support Tool (MDST)

The MDST is a generically applicable tool (Andersson-Sköld et al. 2014a). It consists of a stepwise approach for analyzing the possible effects of different measures, for example, measures to reduce the consequences of natural hazards such as floods, climate change adaptation measures, as well as the consequences of strategies for contaminated land and general land use planning. A matrix-based, multi-criteria approach first defines the problem, then suggests possible risk reduction measures, and finally identifies and assesses their current and future social, economic, and environmental local and global impacts. The tool involves impact identification and assessment as part of the procedure. The impact categories considered cover health and environment, use of resources, social and economic aspects such as investment costs, and well-being and perceived welfare. Flexibility is also added as an individual impact category to be assessed. In total, 11 aspects are assessed regarding suggested measures or land use strategies:

Environment

- Global warming—emissions of greenhouse gases, carbon sequestration.
- Air—emissions of toxic gases, emissions of particles, airborne bio-accumulative substances, emissions that contribute to eutrophication, acidification, oxidants, and formation of ground layer ozone.
- Water—ecosystem status and drinking water quality, including biodiversity, fisheries, marine and limnological properties of high conservation value, eutrophication through leaching.
- Soil—terrestrial impacts, such as soil quality and soil pollution load, impacts on terrestrial biodiversity, ecosystems, and properties of high conservation value.

Resources

- Energy—energy consumption.
- Raw material—raw material acquisition.
- Landscape and land resources.

Social and economic aspects

- Well-being/perceived welfare—perception such as concern or anxiety about flood risk/landslide risk, perception of other aspects of doing nothing or the intervention such as aesthetics, attachment, perceived disturbances by construction, intervention, maintenance, and so on.
- Socioeconomic costs and revenues—infrastructure, cultural environment/heritage, accessibility, business activity, jobs, recreation and health (other than covered under environment due to global warming, air, water, and soil impacts), and so on.
- Direct costs/revenues—investment, maintenance, potential revenues (in the short- and long-terms), and so on.

Flexibility

- High flexibility implies no-regret solutions, and reversibility of the system.

The assessment should also comprise both short- and long-term impacts. The tool should be applied early in a decision-making process and the process benefits from iterative use. The tool has been applied in practical cases, for example, brown-field site developments in Gothenburg, Sweden (Andersson-Sköld et al. 2015). The tool encourages discussion, and the systematic view of sustainability increases awareness of the holistic perspective (Jonsson et al. 2012; Andersson-Sköld et al. 2015). The discussion when applying the tool draws attention to institutional adaptation measures as a complement to pure physical measures.

The analysis can be done at different levels of specification (qualitative description, semiquantitative, or based on quantitative estimates). It can, as in this study, be used for assessing the impacts, and the process can further be continued by including weighting, which can be done through different standard methods. The results should also undergo a sensitivity analysis, for which different methods can be applied. In this study the result of the assessment is presented through applying a scale ranging from -2 to $+2$. No weighting system was applied.

3 Methodology

The study was performed by applying two different MCA methods—the BVT (Bana e Costa et al. 2004) and the MDST (Andersson-Sköld et al. 2014a)—for the assessment of two different risk-reducing measures. The material is based on literature, available information from authorities and municipalities, expert knowledge and experience, and stakeholder workshops. In order to have a common basis for the stakeholders' views and values, a case study area approach was applied. The study aims to test the two assessment methods, as well as to describe the effectiveness of different risk reduction measures based on the available information.

3.1 Case Study Areas

A case study approach offers a common basis for understanding and interpreting the aspects studied. It provides opportunities to build an in-depth understanding of complex social, environmental, and economic interactions (Jonsson et al. 2012) and to realize stakeholder-oriented research that may have practical implications in the case (Johansson 2013). Two case study areas in Sweden were included in the investigation: the flood-prone Ljusnan–Voxnan river system and the landslide-prone municipality Lerum (Fig. 1).

Municipalities have large responsibilities in the Swedish risk management system (Jonsson et al. 2005). In Sweden, as in many other modern societies, different health, safety, and security matters are normally handled separately and in parallel planning and management processes by different sectors in the municipal administration (Johansson 2008, 2013; Norén 2016). Under the Planning and Building Act, the municipalities are responsible for the master plans and detailed spatial plans in the municipality (Johansson

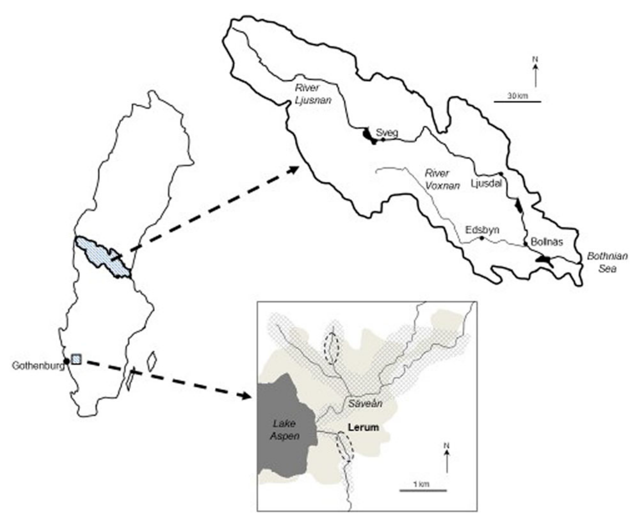

Fig. 1 Location of the two case study areas in Sweden: the Ljusnan–Voxnan River (*top*) and the municipality of Lerum (*bottom*). Edsbyn is the seat of Ovanåker Municipality. In the map of Lerum the *light grey areas* represent densely populated areas, and the *hatched areas* represent landslide-prone clay areas. The two areas where preventive measures were undertaken are marked by *dashed lines*

et al. 2006; Johansson 2013; Norén 2016). The municipality is responsible for planning and coordinating crisis management involving national agencies and authorities, nongovernmental organizations (NGOs), industry, and other organizations within the geographical area of the municipality.[2]

Currently there are hardly any systematic, and no common, approaches applied among Swedish municipalities for risk management, following the full chain from risk identification to assessing measures for flood risk reduction (Norén 2016). Municipalities often have some type of flood risk maps, but there is no systematic analysis of risk reduction measures or integrated assessments of pros and cons of potential measures (Norén 2016).

3.1.1 The Ljusnan–Voxnan River System

The Ljusnan–Voxnan river system (Fig. 1) is a flood-prone area that includes five municipalities of more than 10,000 inhabitants (Härjedalen 10,200; Bollnäs 26,900; Ljusdal 19,000; Ovanåker 11,600; and Söderhamn 25,800), five larger towns/municipality centers of 2500–13,000 inhabitants (Sveg 2500; Ljusdal 6200; Bollnäs 12,800; Edsbyn 4000; and Söderhamn 11,800), and around ten smaller towns/villages of 200–2200 inhabitants (Färila 1300; Järvsö 1400; Vallsta 300; Arbrå 2200; Segersta 300; Kilafors 1100; Marmaverken 400; Ljusne 1900; Ovanåker 200; Alfta 2200). Weather-related flooding events with costly consequences have occurred repeatedly. Examples of preventive physical measures undertaken are the establishment of dikes and new pumping stations, dredging, and the removal of a river neck (T. Wannqvist, Head of the Rescue Services Department, personal communication, 2013). In this study the effectiveness of previous preventive measures were investigated through focus group discussions. The clearing of a river grove was further assessed by applying the BVT and MDST.

3.1.2 Lerum Municipality

Lerum Municipality (about 40,000 inhabitants, whereof 17,000 in the city), is located in western Sweden, just east of Gothenburg (Fig. 1). The river Säveån runs through Lerum Municipality and the town (with the same name). The name Lerum means clay (ler) village (um) and describes the geological conditions in this landslide-prone area dominated by sensitive quick clayey soils. Recently measures to prevent landslides have been implemented and at the time of this study new measures were planned. Examples of previous preventive measures are culverting of streams and ditches, excavation and filling, tree removals, erosion control, road reinforcements, and slope reinforcements (U. Lundgren, co-ordinator of landslides, flooding, and geotechnical issues, Lerum municipality, personal communication, 2013). The effectiveness of previous measures was discussed in focus groups. In addition, the effectiveness of soil reinforcements and erosion reduction in one part of the stream was assessed by applying the BVT and MDST.

3.2 Focus Groups

Three focus groups were recruited, representing different networks and organizations involved in the preventive and/or operational risk management in the two case study areas. Two stakeholder groups represented the local level, one for Lerum Municipality (6 participants), one for Bollnäs and Ovanåker Municipalities (9 participants), and one group represented the stakeholders of the Ljusnan–Voxnan river system (14 participants). The groups were composed of civil servants with expertise in different sectors including technical experts on the built environment, geological information, physical planning and infrastructure, technical services, as well as experts on environment, health, social services and administration, education, child care, and rescue services. In two of the focus groups (Lerum and the Ljusnan–Voxnan river system) representatives of the county administrative boards participated. In the Ljusnan–Voxnan focus group energy producers and water regulators also participated. All three groups had taken initiatives regarding risk analyses, planning, and implementation of risk-reducing measures, and internal and external networking and communication. Their expectations were dominated by a view that their groups had made important interventions to reduce risks, and had played important roles in the risk management system.

During the focus group meetings the impacts of the different risk-reducing interventions were discussed based on the impacts included in the two methods. The discussions were based on available information on taken or planned measures in the case study areas. The information varied from well described as a basis for national co-funding (Lerum) to rather little information provided due to lack of documentation. During the focus group discussions questions on the measures' effectiveness, investment and maintenance costs, pros and cons regarding environmental impacts (local to global scale), and social and socioeconomic aspects were discussed aiming to achieve information that could be applicable in the assessments. The assessments are not based on averages of individual gradings or scaling but on the experiences and expectations of

[2] Swedish law act 2006:544. Law (2006:544) of municipalities and County Council actions before and during extraordinary events in peacetime and preparedness (in Swedish), Swedish Code of statutes 2006:544.

Table 1 Results from the BVT assessment based on expert judgments in the focus group discussions—clearing of a 10–15 km river grove (Ljusnan–Voxnan river system), and landslide prevention by soil reinforcements and erosion reduction along a stream stretch (Lerum)

Aspects considered in addition to costs in the BVT	Clearing of 10–15 km river grove. Reduces water level, and thereby the inundation zone		Landslide prevention. Soil reinforcements and erosion reduction along a stream stretch. Aims to completely reduce the landslide risk at the site (negligible hazard probability)	
Environmental	Effect of intervention	Value	Effect of intervention	Value
Water				
Time of inundation of the riverine zone	Aims to completely reduce the inundations, but not designed for specific protection level. Therefore, estimated high impacts (+1)	1	Not directly relevant	0
Risk of discharge obstruction due to sedimentation	The intervention may result in sedimentation elsewhere in the river system (−1)	−1	The intervention per se may result in sedimentation elsewhere in the river system during a very short time	0
Quality of surface water after a flood event	Low agricultural activities (no significant leaching of nutrients), that is the intervention has no/low impact on water quality. The intervention itself causes short time re-suspension. Erosion in river not significantly impacted by intervention	0	Low agricultural activities (no significant leaching of nutrients), that is the intervention has no/low impact on water quality. The intervention itself causes short time re-suspension. Erosion in river not significantly impacted by intervention	0
Piezometric level of aquifer	Very low/no significant impact on aquifer	0	Not directly relevant	0
Quality of groundwater	Large inundation areas in case of no intervention. The river water status: high levels of nutrients, some ongoing activities and some previously contaminated sites (reduced accumulation due to fewer flood events and less time)	1	No impact on groundwater quality	0
Soil				
Area of agricultural soil	Large areas of agricultural land that will be less impacted by flood events	1	No impact on agriculture	0
Soil contamination	See quality of groundwater	1	No impact on soil contamination	0
Fauna and flora				
Nature conservation interest	The intervention per se has an impact on the natural environment (its geology and habitat) due to the reduced riverine area and the dredging	−2	The intervention per se has an impact on the natural environment, but only for a limited stretch	−1
Landscape				
Urban integration	No/very low impact	0	No/very low impact	0
Enhancement of landscape	No known impacts and no focus group responses	0	The focus group respondents were in general slightly positive, but did not provide any strong positive or negative response. Two of the participants did, however, provide information that one of the landowners finds that the intervention has a high negative impact on aesthetics	−1
Social				
Perception (concern/anxiety) of flood risk	The focus group found that the intervention has contributed to reducing the flood risk (+1)	1	The focus group highly values the risk reduction in a long-term perspective (+2), but not all stakeholders agree (−2)	0
Effects on the social fabric	No known impacts	0	No known impacts (0) apart from that the interventions will result in costs that one landowner finds not acceptable (it is perceived to have impact on the owners' well-being and may cause conflicts)	−1
Effects on public health	No known health effects before or after intervention	0	No known health effects before or after intervention	0

Table 1 continued

Aspects considered in addition to costs in the BVT	Clearing of 10–15 km river grove. Reduces water level, and thereby the inundation zone		Landslide prevention. Soil reinforcements and erosion reduction along a stream stretch. Aims to completely reduce the landslide risk at the site (negligible hazard probability)	
Environmental	Effect of intervention	Value	Effect of intervention	Value
Technical				
Technical complexity of the intervention	Excavation/dredging, relatively low technical complexity (+1)	1	Excavation and slope reinforcement, relatively low technical complexity	1
Complexity of maintenance	Dredging, low complexity, relatively low frequency (+1)	1	No or low complexity and frequency	2
Level of protection	Some level of protection (+2)	1	High-hazard probability reduction	2
Total		+5		+2

Valuing/ranking scale: −2 very negative/not wanted, −1 negative/not wanted, 0 no (significant) impact, +1 positive/wanted, +2 very positive/wanted

the expert respondents. The grading presented in the result tables (Tables 1, 2) was determined by the authors based on the qualitative impacts and their relative magnitudes described in the focus group discussions. The reason for the semiquantitative and the discussion-based approach is the lack of relevant information, and especially in-depth and quantitative information, due to lack of structured processes and documentation already in the decision and follow-up processes, which has also been found as a general obstacle in the Swedish risk management (Andersson-Sköld et al. 2013).

4 Results

The results of the assessments of costs and benefits from a monetary perspective as well as the wider cost and benefit analyses (BVT and MDST) based on the experiences and expectations of the expert respondents are presented in Sect. 4.1, and an analysis and synthesis of the results is presented in Sect. 4.2.

4.1 Costs and Benefits of Physical Measures and Land Use Planning

The perception among all the focus group participants was that flood risk preventive measures can be cost-effective. In the focus group discussions related to the Ljusnan–Voxnan river system, the measures undertaken in the river system up-to-date were regarded as both relevant and cost-effective by the participants. There was one exception: the clearing of the river grove in the Ljusnan–Voxnan system, which, most likely, would not have been implemented today due to conflicting ecological aspects, mainly related to regulations according to the EU Water Framework Directive.

The cost-effectiveness of flood risk reduction measures, however, was found difficult to estimate in quantitative terms, and to evaluate, because of the rarity of events and the fact that measures may have both wanted and unwanted, and often unexpected, impacts on the river system. Due to the lack of recent events, the current vulnerability was also hard to predict.

The focus group discussions made clear that preventive measures were perceived as cost-effective also in the landslide-prone municipality Lerum. This is in agreement with monetary estimates for recent and planned preventive measures. One example is a recently conducted preventive landslide risk reduction measure, including culverting, excavation and filling, tree removal, and erosion control, in a residential area called Torpadal in Lerum (5 houses accommodating 13 people). The preventive measures added up to a cost of 700,000 Euros. The expected costs in the case of an event were estimated at 5 million Euros, based on road and house damages, fatalities and injuries, and a maximum of one casualty based on an expected average exposure and sensitivity (Andersson-Sköld et al. 2014b). The expected loss of life, which also was valued in monetary terms, was based on 24 h averages and would be expected to be much higher in the case of a nighttime event without warning.

Another investigated, but not yet implemented, measure in Lerum refers to a residential area with private properties where preventive measures included slope reinforcement (drainage, embankment, and excavation). The expected costs in the case of a small landslide event ($p = 0.5\ a^{-1}$) due to reconstructions and renovations are up to 100,000 Euros. A larger landslide ($p = 0.1\ a^{-1}$) would

Table 2 Results from the MDST assessment based on expert judgments in the focus group discussions—clearing of a 10–15 km river grove (Ljusnan–Voxnan river system), and landslide prevention by soil reinforcements and erosion reduction along a stream stretch (Lerum)

MDST		Clearing of 10–15 km river grove. Reduces water level, and thereby the inundation zone		Landslide prevention. Soil reinforcements and erosion reduction along a stream stretch. Aims to completely reduce the landslide risk at the site (negligible hazard probability)	
Health and environment		Effect of intervention	Impact value	Effect of intervention	Impact value
Global warming	Emissions of greenhouse gases, carbon sequestration	The intervention demands machineries and transportation of the dredged sediment and excavated masses, which will contribute to emissions of greenhouse gases. The activity is, however, only temporary and the contribution to GHG emissions is therefore limited over time (−1). No impacts on sequestration expected due to the activity	Short-term −1 Long-term 0	The intervention demands machineries and transportation of the excavated masses, which will contribute to emissions of greenhouse gases. The activity is, however, only temporary and the contribution to GHG emissions is therefore limited over time (-1). No impacts on sequestration expected due to the activity	Short-term −1 Long-term 0
Air quality	Emissions of toxic gases, emissions of particles, airborne bio-accumulative substances, emissions that contribute to eutrophication, acidification, oxidants, and ground layer ozone formation	The intervention demands machineries and transportation of the masses, which will contribute to emissions. The impact is, however, only temporary, and will not last over a long time	Short-term −1 Long-term 0	The intervention demands machineries and transportation, which will contribute to emissions. The impact is, however, only temporary, and will not last over a long time	Short-term −1 Long-term 0
Water	Ecosystem status and drinking water quality, including biodiversity, fisheries, marine and limnological properties of high conservation value, eutrophication through leaching	The intervention may result in sedimentation elsewhere in the river system, which may have impacts on the biodiversity and ecosystems (−1). The intervention itself causes short-term re-suspension, but erosion not significantly affected (0). Very low/no significant impact on aquifer (0). Large inundation areas in case of no intervention. The river water status: high levels of nutrients, some ongoing activities and some previous (contaminated sites) result in reduced accumulation of contaminants in groundwater due to fewer flood events and shorter duration (+1)	Short-term −1 Long-term 1	The intervention itself causes short-term re-suspension and possibly minor erosion (−1) in the stream, but long-term erosion will be reduced at the site (+1). The intervention may impact fish in the stream, but if done according to regulations, the impacts will be low or negligible (0). Very low/no significant impact on aquifer (0)	Short-term −1 Long-term 1
Soil	Terrestrial impacts, such as soil quality and soil pollution load, impacts on terrestrial biodiversity, ecosystems, and objects of high conservation value	Large areas of agricultural land that will be less impacted by flood events in a long-term perspective (+1) and over a long period, reduced accumulation of contaminants in soil (+1). The intervention per se has an impact on the natural environment (its geology and habitat) due to the reduced riverine area and the dredging (focus group response) long- and short-term response (−2)	Short-term −2 Long-term 0	The intervention per se has an impact on the natural terrestrial environment (its geology and habitat) due to excavation and reinforcements but the area affected is very limited (−1)	Short-term −1 Long-term −1
Resources					

Table 2 continued

MDST		Clearing of 10–15 km river grove. Reduces water level, and thereby the inundation zone		Landslide prevention. Soil reinforcements and erosion reduction along a stream stretch. Aims to completely reduce the landslide risk at the site (negligible hazard probability)	
Health and environment		Effect of intervention	Impact value	Effect of intervention	Impact value
Landscape and land resources	Use of land, housing, enhancement of landscape	No known impacts and no focus group responses	Short-term 0 Long-term 0	In addition to the impacts mentioned under environment (that is, minor changes of landscape). No known impacts and no focus group responses	Short-term 0 Long-term 0
Energy	Energy consumption	The intervention demands machineries and transportation of the masses, which will use energy. The activity is, however, only temporary and the use of energy is therefore limited over time (−1). The intervention has no impact on the hydropower dam system (0)	Short-term −1 Long-term 0	The intervention demands machineries and transportation of the masses, which will use energy. The impact is, however, only temporary, and will not last over a long time (−1)	Short-term −1 Long-term 0
Raw material	Raw material acquisition	The raw material acquisition depends on the energy source in use	Short-term −1 Long-term 0	The raw material acquisition is mainly the energy source in use	Short-term −1 Long-term 0
Social					
Well-being/perceived welfare	Perception (concern/anxiety) of flood risk, aesthetics	The focus group found that the intervention has contributed to reducing the flood risk and will do so even in future (+1). No negative impacts mentioned by the focus group participants (0)	Short-term 1 Long-term 1	The impact value depends on the respondent. The focus group highly values the risk reduction in a long-term perspective (+2), while one of the landowners finds that the intervention has a high negative impact on the aesthetics and will result in high costs impacting the landowners' well-being (−2)	Short-term −2 Long-term 2
Direct costs	Investment, maintenance, revenues, and so on	The intervention cost was €17,000, fairly high for small municipalities despite low complexity (−1). No or very low maintenance costs (0)	Short-term −1 Long-term 0	The intervention cost is estimated at €700,000, fairly high for small municipalities and landowners despite low complexity (−2). No or very low maintenance costs (0)	Short-term −2 Long-term 0
Socioeconomic costs	Infrastructure, cultural, accessibility, business activity, jobs, recreation, and health	The aim is to completely reduce the inundations, but the intervention is not designed for a specific protection level, therefore estimated to have high impact on reducing socioeconomic impacts over the long term (+1), providing minor jobs in the short-term (+1). No known effects on the social fabric (0)	Short-term 1 Long-term 1	Aims to completely reduce the landslide probability for several houses and inhabitants, therefore estimated to have very high impact on reducing socioeconomic impacts over the long term (+2). No known effects on the social fabric (0)	Short-term 0 Long-term 2

Table 2 continued

MDST		Clearing of 10–15 km river grove. Reduces water level, and thereby the inundation zone		Landslide prevention. Soil reinforcements and erosion reduction along a stream stretch. Aims to completely reduce the landslide risk at the site (negligible hazard probability)	
Health and environment		Effect of intervention	Impact value	Effect of intervention	Impact value
Flexibility	High flexibility implies no-regret solutions, reversibility of the system, and high resilience	The focus group mentioned that the intervention would not have been implemented today, since the ecosystem was affected too much by long-term impacts (−1)	Short-term −1 Long-term −1	The intervention will alter a very small stretch of a stream, but otherwise no significant positive or negative impacts on flexibility. No other nearby interventions expected (0)	Short-term 0 Long-term 0
Total—short term			−7		−9
Total—long term			+2		+4
Total			−5		−5

Valuing/ranking scale: −2 very negative/not wanted, −1 negative/not wanted, 0 no (significant) impact, +1 positive/wanted, +2 very positive/wanted

result in costs of up to 0.5–1 million Euros. The costs include road damages and related reconstruction, damages on houses and infrastructure (water, sewage, IT, and so on), personal injuries, and loss of life (Andersson-Sköld et al. 2014b). In the case of either a small or large landslide, salmon living in the Säveån River (smolt)[3] may be affected depending on the time of year of the event. The preventive measures planned were slope reinforcement (drainage, embankment, and excavation), and the budget was less than 450,000 Euros. The expected loss of life again was based on daytime averages and would be expected to be much higher in the case of a nighttime event without warning.

A cost-benefit analysis that only includes aspects such as degree of protection and the cost of investment and maintenance will, however, not reveal if some aspects are in conflict with the measure. Conflicts of interest, such as aesthetic aspects, were also mentioned with regard to landslide preventive measures. In general, budget issues were found to restrict preventive measures. In addition, unequal benefits and the fact that those financing the measures may not be the ones benefit the most were seen as conflicts of interest. An example is interventions upstream, at least partly financed by and having an impact on landowners not under flood risk themselves, that significantly may reduce the impacts downstream. Otherwise the costs for the ones at risk may be significantly higher despite that the cause is to be found upstream in the catchment area.

4.1.1 Application of the Benefit Value Tree (BVT)

The BVT method (Bana e Costa et al. 2004) was developed specifically to enable a more transparent and systematic assessment of the costs and benefits of flood risk reduction measures. Here, the method was applied to assess the clearing of a river grove in the Ljusnan–Voxnan river system and landslide prevention through soil reinforcement and erosion control. The selection of the river grove was made because this intervention was the most highlighted and discussed in general in the catchment area, and therefore the current knowledge and awareness of its pros and cons were most reliable. It caused also most discussions among the experts and focus group participants.

The application of the BVT to assess the clearing of a river grove in the Ljusnan–Voxnan system provided a summary of how the flood risk reduction measure will impact the inundation time, water and soil quality aspects, the fauna and flora, and landscape, as well as social and technical aspects (Table 1). The measure will shorten the time of inundation, contribute to improve the water quality

[3] Salmon in the stage of its first migration to the sea.

and result in less negatively impacted agriculture and reduced flood risk-related concerns among citizens. The measure is also regarded as not being complex in either the construction phase or with regard to maintenance, and it is perceived to provide protection (Table 1). The intervention is, however, also expected to result in unwanted, possibly severe, impacts on the geology, and the intervention will have negative impacts on the ecosystem and habitat due to the reduced river area and the dredging (Table 1). In total, the result is slightly positive (+2) if all environmental and social values are summarized and even higher (+5) taking into account the level of protection and the low technical complexity of the intervention. There is, however, a potential serious impact on the ecosystem that needs further analysis with regard to the value of impacts and/or regarding potential alternatives.

The BVT was also tested with the landslide preventive measure, that is, soil reinforcements and erosion reduction along a short stream stretch in Lerum. Despite being developed for flood risk reduction measures, many of the aspects considered were also relevant with regard to landslides. The aspects "time of inundation of the riverine zone" and "piezometric level of aquifer" were neglected as not directly related to landslides (Table 1). These two aspects are indirectly relevant, since a landslide may cause flooding and piezometric change, if occurring along water courses. In particular, landslides in quick clay areas may cause severe flooding, large waves, and even new meandering, as well as direct consequences not included in the BVT. The landslide impacts are more site-specific and less generically quantifiable compared to the time of inundation and the piezometric level of aquifer. The suggestion is to differentiate between "direct impacts" and "indirect impacts" of a landslide, and the values of the impacts need to be assessed and estimated based on the site-specific context and its potential consequences.

The other aspects included in the BVT are all relevant for landslides. In a short-term perspective, landslide risk reduction measures may result in increased suspension and sedimentation in the system and changes in water quality (surface and groundwater) as well as soil quality. For example, the risk of contaminant spreading may be reduced due to reduced risks of erosion and landslides. But under some conditions, for example, due to excavation of contaminated sites, the risks during the construction phase may increase. The aspects are therefore relevant to and applicable to landslides. In the same way, aspects related to fauna, flora, and landscape are also applicable to landslides. The impact depends on the method, design, and scale of the intervention and where the intervention is done. The social aspect "perception" was interpreted as concern or anxiety of flood risk. All technical and social aspects are also relevant and applicable to landslides.

Applying the BVT in this way on the landslide risk reduction measure resulted in a slightly positive outcome (+2) (Table 1). All the technical aspects, including level of protection, were positive (+2 or +1), and if there had not been a conflict of interest regarding aesthetic landscape values among civil servants and one of the landowners (−2) the result would have been even more positive. The interventions will impact the fauna and flora, but only to a limited extent (−1) (Table 1).

Applying the BVT method compiles and illustrates the pros and cons in a transparent way. It helps to illustrate the impacts of a measure, and whether there is a need for alternative strategies, a need for a more in-depth analysis, or a need for assessing the acceptance of the risk and the impacts of the intervention.

4.1.2 *Application of the Matrix-Based Decision Support Tool (MDST)*

The MDST also provides a summary of the impacts of the interventions (Table 2). The results differ as MDST was developed to assess the sustainability aspects of land use planning strategies as well as risk reduction measures. The rating is provided in relation to the situation if no changes are made. The method differs from the BVT in that the economic aspects are included among the other aspects. In addition, the economic aspects are divided into both direct costs and revenues, and socioeconomic impacts. The method further includes both short- and long-term impacts, impacts of relevance to the global, regional, and local scales, as well as other environmental aspects that are local/site-related. The flexibility related to the measure is considered (Table 2).

When applying the MDST, both interventions (clearing of the river grove and landslide prevention) have a high negative sustainability impact (−5). The impact varies, however, depending on which time perspective is considered. In a short-term perspective, there is a large negative impact (−7 and −9) for the clearing of the river grove and the landslide prevention respectively. The reason is that both interventions contribute to the emissions of greenhouse gases and other air pollutants, to affecting the water quality negatively initially, to the use of energy and resources, and to disturbing the ecosystems.

In a long-term perspective, however, both measures will contribute to improved water quality and will have positive impacts on well-being and socioeconomic aspects (Table 2). The results show a positive impact of both measures (+2 and +4) for the clearing of the river grove and the landslide prevention respectively.

The results show that neither of the interventions can be regarded as acceptable in comparison to the current situation if both short- and long-term perspectives are taken into account and valued equally. It is important that the impacted stakeholders or representatives evaluate long-term versus short-term impacts separately. Also, the importance of the different aspects considered by the MDST has to be valued by a weighting procedure and alternative solutions should be considered.

4.2 Analysis and Synthesis

Although both methods include aspects of the three sustainability dimensions (social, economic, and environment), the two methods consider different aspects and different temporal and spatial scale perspectives. Therefore, the two methods yield different and even opposite results. Both interventions yield positive (+5) or slightly positive (+2) results when applying the BVT, while both interventions are negative (−5) when applying the MDST.

Previous studies show that broader environmental aspects are rarely taken into account in daily decision making (Johansson 2008; Andersson-Sköld et al. 2014a, 2015). The MDST offers a structured and transparent method for such analyses. For analyzing the pros and cons of flood and landslide preventive measures, the MDST lacks some of the local/site-specific detailed analyses provided by the BVT. Therefore, regarding decisions to contribute to sustainable development, we suggest that the two methods be merged.

As the measures' effectiveness is essential we suggest this to be the starting point of the analysis. The functionality, how well-functioning the flood risk reduction measure is, in a short- and long-term perspective can be related to the technical benefit aspects in BVT. In order to cover both the local and global scales of environmental, landscape, and social impacts we suggest to merge those as a combination of impacts from the two models. The direct costs can be divided into short-term investments and longer-term maintenance costs. As there are large uncertainties related to flooding and landslides, both due to the socioeconomic developments and climate change impacts, flexibility in a long-term perspective should also be considered. The resulting combination based on the two models includes the following aspects (in a short- and long-term perspective) for assessing measures to reduce risks related to flooding and landslides:

Functionality

- Level of protection with regard to
  - direct impacts of both landslides and flooding: consequences for life and personal injuries, buildings, and infrastructure,
  - indirect consequences of landslides, for example, potential flooding/energetic waves, meandering, and the related consequences for life, buildings, and infrastructure.
- Technical complexity of the intervention (short-term), and complexity of maintenance (long-term)

Environmental aspects

- Global warming—impacts on emissions of greenhouse gases and carbon sequestration.
- Air—emissions of toxic gases, emissions of particles, airborne bio-accumulative substances, emissions that contribute to eutrophication, acidification, oxidants, and formation of ground layer ozone.
- Water quality, including quality of surface and groundwater (during construction in the short-term, and due to flood or landslide events in a long-term perspective)Soil quality and terrestrial impacts, such as potential discharge of nutrients or contaminants from agricultural soil.
- Ecosystem functions—fauna and flora (biodiversity, impacts on ecosystem functions and services such as fisheries, terrestrial, marine and limnological properties of high conservation value).
- Flooding—time of inundation, piezometric level of aquifer.

Resources and landscape

- Energy consumption and raw material acquisition.
- Urban integration.
- Enhancement of landscape.

Social

- Perception, such as concern or anxiety of flood risk/landslide risk, perception of other aspects of doing nothing or the intervention, such as aesthetics, attachment, perceived disturbances of construction, intervention, maintenance, and so on.
- Socioeconomic aspects (not considered under direct and indirect impacts) such as effects on the social fabric, jobs, business activity.
- Health and recreation.

Costs

- Investments short-term.
- Maintenance long-term.

Flexibility

- High flexibility implies no-regret solutions, and reversibility of the system.

The list of aspects now includes both local and large-scale impacts, as well as other aspects of relevance for sustainable development (social, environment, economy). An example of how to apply those merged aspects based on the results from Tables 1 and 2 is provided in Table 3. The corresponding result for the full list of aspects is a slightly positive (+3) impact for the flood risk reduction

Table 3 Examples of applying the merged BVT and MDST methods based on the results presented in Tables 1 and 2—clearing of a 10–15 km river grove (Ljusnan–Voxnan river system), and landslide prevention by soil reinforcements and erosion reduction along a stream stretch (Lerum)

Aspects considered	Clearing of a 10–15 km river grove. Reduces water surface level, and thereby the inundation zone		Landslide prevention. Soil reinforcements and erosion reduction along a stream stretch. Aims to completely reduce the landslide risk at the site (negligible hazard probability)	
Functionality	Effect of intervention	Impact value	Effect of intervention	Impact value
Technical complexity of the intervention and complexity of maintenance	Excavation/dredging relatively low technical complexity (short-term impacts). Dredging, low complexity, relatively low frequency (long-term impacts)	Short-term 1 Long-term 1	Excavation and slope reinforcement relatively low technical complexity (short-term impacts). No or low complexity and frequency (long-term impacts)	Short-term 1 Long-term 2
Environmental aspects				
Water quality, including quality of surface and groundwater (during construction in the short-term and due to flood or landslide events in a long-term perspective)	The intervention may result in unwanted (−1) sedimentation elsewhere in the river system. No significant leaching of nutrients (0). Reduced contaminant leaching and accumulation due to fewer flood events and less time (+1)	Short-term −1 Long-term 1	The intervention itself causes short-term re-suspension and possibly minor erosion (−1) in the stream, long-term erosion will be reduced at the site (+1)	Short-term −1 Long-term 1
Ecosystem functions—fauna and flora (biodiversity, impacts on ecosystem functions and services such as fisheries, terrestrial, marine, and limnological properties of high conservation value)	The intervention per se has an impact on the natural environment (its geology and habitat) due to the reduced riverine area and the dredging (focus group response) long- and short-term response (−2)	Short-term −2 Long-term −2	The intervention per se has an impact on the natural terrestrial environment (its geology and habitat) due to excavation and reinforcements but the area affected is very limited (−1)	Short-term −1 Long-term −1
Social				
Perception, such as concern or anxiety of flood risk/landslide risk, perception of other aspects of doing nothing or the intervention, such as aesthetics, attachment, perceived disturbances of construction, intervention, maintenance, and so on	The focus group found that the intervention has contributed to reducing the flood risk and will do so even in future (+1). No negative impacts mentioned by the focus group participants (0)	Short-term 1 Long-term 1	The impact value depends on the respondent. The focus group highly values the risk reduction in a long-term perspective (+2), while one of the landowners finds that the intervention has a high negative impact on the aesthetics and will result in high costs impacting the landowners' well-being (−2)	Short-term −2 Long-term 2

intervention and a neutral (0) impact for the landslide intervention. For both interventions, there was a negative result in a short-term perspective (−3 for the flood risk reduction and -8 for the landslide risk reduction intervention) due to disturbances during the construction and use of resources, and so on, and a positive result in a long-term perspective (+6 for the flood risk reduction and +8 for the landslide intervention) due to the increased protection level and related social aspects. Both interventions result in more positive total impacts compared to the MDST method. The neutral result for the landslide risk reduction measure when not taking into account any weighting indicates that the intervention may be relevant. If weights had been applied the result may have differed depending on the perceived importance of long- versus short-term impacts. The results indicate further that the short-term impacts on environment and resources are high and that a cautious approach needs to be taken—for example, less energy and material demanding methods need to be considered during the intervention work.

The results of the analysis of expert experience and knowledge are useful for illustrating the pros and cons. The results are especially useful for the comparison of potential alternative strategies and to identify which strategies provide the most benefits compared to negative impacts.

The results of any of the methods (BVT, MDST, merged method) do not take into account the stakeholders' and decision makers' valuation of the importance of considering different aspects. The perceived importance or value of the individual sustainability aspects may vary among

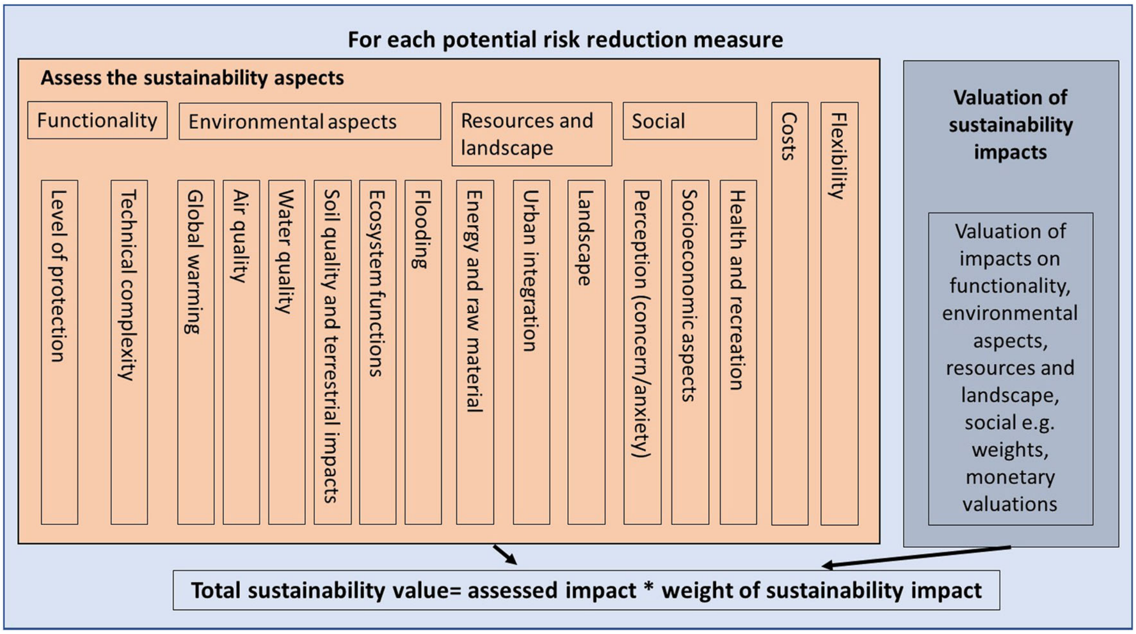

Fig. 2 Valuation of sustainability aspects, a function of assessed impact and -weight of the sustainability impact

different decision makers, experts, and stakeholders. Therefore, if the perceived value is expected to vary among the individual sustainability aspects, we suggest an additional step in which the value of the impact is included through a weighting procedure, for example, a ranking or more advanced methods such as monetary valuations. The value of each of the individual sustainability aspects will then equal the product of the assessment estimate and the weight of the impact (Fig. 2).

The result of the weighting is context-dependent and the perceived values may vary over time. Therefore, the weighting has to be done in a transparent and well-documented way. For successful risk management, the process needs to be continued by following up activities, decisions, and detailed planning (Fig. 3).

4.2.1 Expert and Stakeholder Involvement in the Assessment Process

To open the decision process up for additional potential solutions early on, the weighting process must not only include experts but also the decision makers and preferably also the general public. The risk analysis and management process should preferably also be a dialogue-driven iterative process where the valuation procedure includes relevant stakeholders. This increases the acceptance of the decision and contributes to the identification of new, even more sustainable measures, as well as increased knowledge and understanding among the involved participants.

The process of using a group of stakeholders and complementary experts for assessment and weighting provides not only increased awareness among the participants but also information on where there are disagreements and knowledge gaps that may need further in-depth analysis before a decision on the most favorable strategy is made. For example, the landslide risk reduction measure needs further analysis before a decision can be taken. One important aspect is that one of the landowners is neither willing to accept, nor contribute to the intervention. A next step in the process could be to include the landowners in discussions of the proposals as well as alternative solutions, their costs, negative impacts, and benefits to achieve a common understanding of the alternatives among the landowners and the civil servants.

The application of either method illustrates that there are some aspects that benefit from the interventions and others that do not. For example, both interventions will have negative and unwanted impacts on ecosystem functions and the environment, while they will reduce the risk, which is the main aim. Therefore, further analyses and communication are needed, in which the pros and cons are valued in relation to each other. The valuing can be done through workshops, questionnaires, or web-based activities, as well as through already existing networks.

4.2.2 Networks Offer Effective Stakeholder Involvement

One important aspect of the assessment methods applied here is how to reconcile the use of expert opinions with the need for participation and involvement of stakeholders and practitioners within and outside the responsible authorities. During the study of Ljusnan–Voxnan river system and the

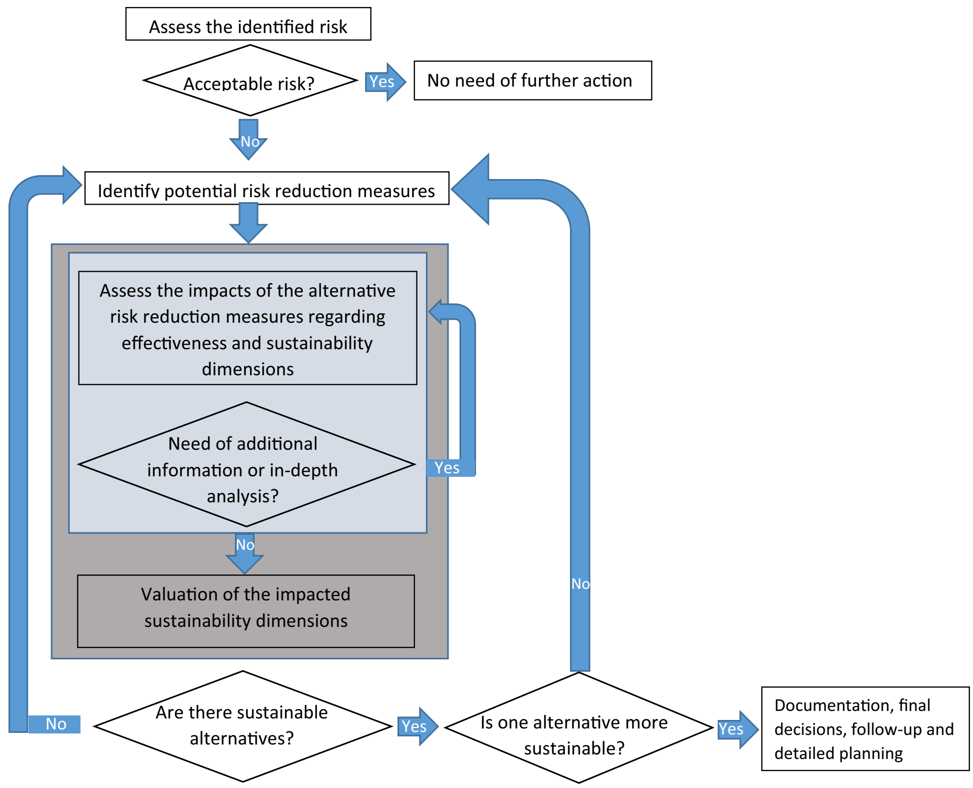

Fig. 3 Iterative risk analysis and management process

city of Lerum several of these aspects were raised in the focus group discussions.

The results of the focus group discussions showed that well-functioning networks, the Ljusnan–Voxnan network,[4] for example, provide large benefits and a basis for effective communication. According to the respondents, well-functioning networks need a clear goal and aim, as well as continuity of concrete and relevant activities. Such activities can, for example, be to communicate with the public, politicians, and administrations.

The benefits of the Ljusnan–Voxnan network are that it has increased the knowledge and smoothness of contact routes in case of an event, increased the understanding among stakeholders, increased dialogue, exchange of experience, and knowledge transfer and thereby also competence among the stakeholders. The network has moved towards greater consensus despite the increase in number of perspectives, views, and new ideas, and a better understanding of values and valuing among the network members.

The network also resulted in increased ability to keep an overview and control (for example, on the runoff in the system), and increased preparedness and safety/security, including keeping flood risk on the agenda within the river system. Another benefit was increased cooperation and more preventive activities, including risk identification and prognoses and increased ability to achieve funding for preventive measures. The cost of maintaining the network was regarded as very small (a modest number of working days per year for each member, including 2–3 days travelling) compared to the identified benefits.

There were existing networks also in the case study municipalities. They were regarded as well-functioning but were informal and depended on the individuals involved. The internal organization and communication were deemed well-functioning within the networks, but the cooperation and communication between a larger group of stakeholders, the general public, as well as between the municipality departments, could be increased. To this end, the suggestion was to introduce and maintain routines. This would also increase the effectiveness of introducing new staff in the organizations.

5 Discussion

In agreement with previous research, this study found that physical landslide preventive measures are cost-effective in built-up areas with high risk (Plate 2007; Schuster and Highland 2007; Hinkel et al. 2010; Zeng et al. 2012; Andersson-Sköld et al. 2014b). Physical measures to reduce flood risk can be cost-effective as well.

[4] Further information about the existing river system networks in Sweden in general (in Swedish) can be found at https://www.msb.se/sv/Forebyggande/Naturolyckor/Oversvamning/Alvgrupper/ and http://www.uio.no/forskning/tverrfak/demokrati/aktuelt/arrangementer/konferanser/2012/papers/paper—norkom-olausson.pdf.

Physical preventive measures may, however, involve large-scale changes, and they can entail complex and costly investments that require a long-term perspective. They also demand a solid and broad knowledge base since such investments may increase the risk of maladaptation (Patterson and Doyle 2009). This can be a challenge, especially in areas where flood events are rare and the probability, exposure, and consequences with and without the measure may be difficult to assess.

In addition, physical measures use resources, impact the local environment, add emissions to air, soil, and water, and may alter the risks of nutrient and soil contaminant leaching. In this study, we developed the BVT and MDST methods into a merged method that provides a way to include these aspects. The BVT contributes to assessing the local-scale impacts of flooding and risk reduction, and the functionality and effectiveness (level) of the protection. The MDST contributes to a wider environmental assessment and also includes air quality in addition to the terrestrial and water focuses in BVT. In the merged version, as in both BVT and MDST, individual well-being, socioeconomic aspects, and the impacts of investment and maintenance are included. Such broad perspectives in the local planning process are of great importance in addressing urgent and serious challenges such as climate change. Otherwise we have to face a situation in which measures to reduce risks such as flooding will generate new problems as an unwanted effect and waste scarce resources.

The results of applying the MDST and the merged method indicate the importance of taking both short- and long-term perspectives into account. The time perspective illustrates not only the investment costs in relation to the monetary costs and benefits in a long-term perspective, but also the environmental and social impacts during the investment and construction phase as well as over the measure's in use time. The information is useful, not least in the weighting process as the short-term impacts may be valued as more important than the long-term perspectives. This is, for example, often the case when applying discount rates in cost-benefit analyses. Investment budgets may be restricted, and the short-term socioeconomic impacts may be severe (for example the impact on an area's attractiveness) and important at the time. In this study, we have developed a method designed to take short- and long-term perspectives into account.

Conflicts among different stakeholders could be decreased through increased transparent documentation and increased communication among different interests and stakeholders (Johansson et al. 2006; Andersson-Sköld et al. 2013). An important issue in the risk management process is to decide for whom the intervention should be effective and who should be responsible for funding. Some measures are beneficial to many and others only to an individual landowner. The municipality or landowner who may need to finance a risk reduction measure may benefit less than others in the river system or in a landslide-prone area, and for others the measure may even cause negative impacts. It is important to evaluate such impacts in the planning and risk reduction strategies.

The merged sustainability tool, based on the MDST and the BVT, should preferably be applied initially by experts as a basis for the communication and involvement of key stakeholders in the decision process. Further communication and discussions are needed to obtain stakeholders' values, needs, and views. The application of the merged method is accordingly recommended to be iterative, taking into account new options, views, and values.

The assessments in this study have been based on results from focus group discussions with experts. For more in-depth results more advanced methods such as catchment and hydraulic modelling, stakeholder and expert questionnaires, and/or in-depth interviews, as well as refined sensitivity- and weighting analyses can be applied. The merged method, as applied here, is however applicable as a structured first preliminary assessment, to reveal pros and cons. Not least the method can be applied as a checklist and a tool to increase the understanding, learning process, and the communication among different stakeholders. However, a deeper understanding and quantification of the consequences (in a short- and long-term perspective and regarding impacts on local to larger scales) would further improve the assessment. It would also contribute to better and more robust valuations of risk reduction alternatives. This would both need more thorough investigations and follow-up of previous events and ex ante studies and research.

The current level of assessment, applying the merged method developed here, is useful in the decision and planning process as decision makers can consider the different measures in an understandable and transparent way. It also offers a method to eliminate the usual problem of taking the broader environmental aspects into account in the local management processes. Based on the structured method (checklists) a wide range of stakeholders can be involved in the process of decision making.

Communication and stakeholder involvement are, however, challenging and can be time-consuming. Networks including relevant stakeholder representatives are effective in overcoming some of those barriers. The results of the focus group discussions showed that well-functioning networks (with clear goals and aims, continuity, and relevant activities) also provide a well-functioning base for communication, not only among its members but also with external stakeholders and the general public. The results of this study indicate that such networks or organizations can be relevant in leading or facilitating the communication process. In some cases, there may be certain additional

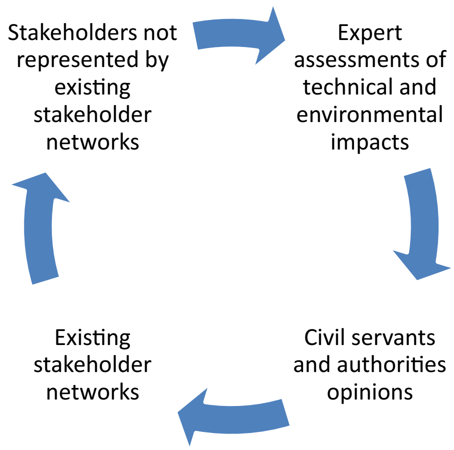

Fig. 4 Iterative processes including stakeholders, civil servants/authorities, and experts

stakeholders that need to be involved in the process such as impacted landowners. These need to be involved early in the iterative process (Fig. 4).

6 Conclusion

The effectiveness of a flood or landslide risk reduction measure should be viewed in a wide perspective. An important question is for whom the measure should be effective and who should be responsible for funding. The merged BVT and MDST method provides a comprehensive and integrated assessment of flood and landslide risk reduction strategies, including economic, social, and local aspects as well as global environmental impacts and use of resources in a short- and long-term (future generation) perspective. The methods are to be used as checklists for discussion and as frameworks for decisions to improve the possibility of more sustainable decisions. The results of this study show that the risks of sub-optimization and maladaptation can be reduced by including many aspects in short- and long-term perspectives and involving a broad spectrum of stakeholders.

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References

Anderson, M.G., E. Holcombe, M. Esquivel, J. Toro, and F. Ghesquiere. 2010. The efficacy of a programme of landslide risk reduction in areas of unplanned housing in the Eastern Caribbean. *Environmental Management* 45(4): 807–821.

Andersson-Sköld, Y., R. Bergman, M. Johansson, E. Persson, and L. Nyberg. 2013. Landslide risk management—A brief overview and example from Sweden of current situation and climate change. *International Journal of Disaster Risk Reduction* 3: 44–61.

Andersson-Sköld, Y., P. Suer, R. Bergman, and H. Helgesson. 2014a. Sustainable decisions on the agenda—A decision support tool and its application on climate-change adaptation. *Local Environment* 21(1): 85–104.

Andersson-Sköld, Y., S. Falemo, M. Tremblay. 2014b. Development of methodology for quantitative landslide risk assessment—Example Göta river valley. *Natural Science* 6(3): 130–143.

Andersson-Sköld, Y., S. Thorsson, D. Rayner, F. Lindberg, S. Janhäll, A. Jonsson, U. Moback, R. Bergman, and M. Granberg. 2015. An integrated method for assessing climate-related risks and adaptation alternatives in urban areas. *Climate Risk Management* 7: 31–50.

Bana e Costa, C.A., J.-M. De Corte, and J.-C. Vansnick. 2003. *MACBETH. LSEOR* 03.56. London: Department of Operational Research, London School of Economics and Political Science.

Bana e Costa, C.A., J.-M. De Corte, and J.-C. Vansnick. 2012. MACBETH. *International Journal of Information Technology & Decision Making* 11(2): 359–387.

Bana e Costa, C.A., P.A. Da Silva, and F.N. Cirreia. 2004. Multicriteria evaluation of flood control measures: The case of Riberia do Livramento. *Water Resources Management* 18(3): 263–283.

Barnett, J., and S. O'Neill. 2010. Maladaptation. *Global Environmental Change* 20(2): 211–213.

Bormann, H., R. van der Krogt, L. Adriaanse, F. Ahlhorn, R. Akkermans, Y. Andersson-Sköld, C. Gerrard, N. Houtekamer, G. de Lange, A. Norrby, N. van Oostrom, and R. Sutter. 2015. Guiding regional climate adaptation in coastal areas. In *Handbook of climate change adaptation*, ed. W.L. Filho, 337–357. London: Springer.

Brooks, N. 2003. Vulnerability, risk and adaptation: A conceptual framework. Working paper 38. Norwich, UK: Tyndall Centre for Climate Change Research and Centre for Social and Economic Research on the Global Environment (CSERGE).

Dai, F.C., C.F. Lee, and Y.Y. Ngai. 2002. Landslide risk assessment and management: An overview. *Engineering Geology* 64(1): 65–87.

Ernst, J., B.J. Dewals, S. Detrembleur, P. Archambeau, S. Erpicum, and M. Pirotton. 2010. Micro-scale flood risk analysis based on detailed 2D hydraulic modelling and high resolution geographic data. *Natural Hazards* 55(2): 181–209.

Gamper, C.D., and C. Turcanu. 2009. Can public participation help managing risks from natural hazards? *Safety Science* 47(4): 522–528.

Glaas, E., A. Jonsson, M. Hjerpe, and Y. Andersson-Sköld. 2010. Managing climate change vulnerabilities: Formal institutions and knowledge use as determinants of adaptive capacity at the local level in Sweden. *Local Environment* 15(6): 525–539.

Glavovic, B.C., W.S.A. Saunders, and J.S. Becker. 2010. Land-use planning for natural hazards in New Zealand: The setting, barriers, 'burning issues' and priority actions. *Natural Hazards* 54(3): 679–706.

Goltermann, D., and J. Marengwa. 2012. SAWA Final Report summary, Hamburg. www.sawa-project.eu/uploads/documents/SAWA_Final_Report_Summary_%20draft25052012.pdf. Accessed 1 Oct 2016.

Hinkel, J., R.J. Nicholls, A.T. Vafeidis, R.S.J. Tol, and T. Avagianou. 2010. Assessing risk of and adaptation to sea-level rise in the European Union: An application of DIVA. *Mitigation and Adaptation Strategies for Global Change* 15(7): 703–719.

Holcombe, E., and M. Anderson. 2010. Tackling landslide risk: Helping land use policy to reflect unplanned housing realities in the Eastern Caribbean. *Land Use Policy* 27(3): 798–800.

IPCC (Intergovernmental Panel on Climate Change). 2013. *The physical science basis*. Cambridge: Cambridge University Press.

Ismail-Zadeh, A., and K. Takeuchi. 2007. Preventive disaster management of extreme natural events. *Natural Hazards* 42(3): 459–467.

Johansson, A. 2013. Societal risk and safety management—Policy diffusion, management structures and perspectives at the municipal level in Sweden. PhD thesis, Karlstad University, Sweden.

Johansson, A., I. Svedung, and R. Andersson. 2006. Management of risks in societal planning—An analysis of scope and variety of health, safety and security issues in municipality plan documents. *Safety Science* 44(8): 675–688.

Johansson, M. 2008. Barriers and bridges—Communicative conditions in the Swedish environmental objective performance. Ph.D. thesis No. 469, Linköping Studies in Arts and Science, Linköping University, Sweden.

Jonsson, A., I. Danielsson, and A. Jöborn. 2005. Designing a multipurpose methodology for strategic environmental research—The Rönneå catchment dialogues. *AMBIO* 34(7): 489–494.

Jonsson, A., M. Hjerpe, Y. Andersson-Sköld, E. Glaas, K. André, and L. Simonsson. 2012. Cities' capacity to manage climate vulnerability: Experiences from participatory vulnerability assessments in the lower Göta Älv catchment, Sweden. *Local Environment* 17(6–7): 735–750.

Norén, V. 2016. When water becomes a threat—Risk assessment and risk management plans for floods and drinking water in Swedish practice. Ph.D thesis 1416, Uppsala University, Sweden.

Nyberg, L., M. Evers, M. Dahlström, and A. Pettersson. 2014. Sustainability aspects of water regulation and flood risk reduction in Lake Vänern. *Aquatic Ecosystem Health and Management* 17(4): 331–340.

Patterson, L., and M.W. Doyle. 2009. Assessing effectiveness of flood policy application through spatiotemporal monitoring of socioeconomic exposure. *Journal of the American Water Resources Association* 45(2): 237–252.

Plate, E.J. 2007. Flood risk management for setting priorities in decision making. In *Extreme hydrological events: New concepts for security*, ed. O.F. Vasiliev, P.H.A.J.M. van Gelder, E.J. Plate, and M.V. Bolgov, 21–44. The Netherlands: Springer.

Poussin, J.K., P. Bubeck, J.C.-H. Aerts, and P.J. Ward. 2012. Potential of semi-structural and non-structural adaptation strategies to reduce future flood risk: case study for the Meuse. *Natural Hazards and Earth System Sciences* 12: 3455–3471.

Renn, O. 2005. *Risk governance: Towards an integrative approach*. Geneva: International Risk Governance Council.

Roberts, N.J., F. Nadim, and B. Kalsnes. 2009. Quantification of vulnerability to natural hazards. *Georisk: Assessment and Management of Risk for Engineered Systems and Geohazards* 3(3): 164–173.

Sarewitz, D., R. Pielke Jr., and M. Keykhah. 2003. Vulnerability and risk: Some thoughts from a political and policy perspective. *Risk Analysis* 23(4): 805–810.

Schuster, R.L., and L.M. Highland. 2007. The third Hans Cloos lecture. Urban landslides: Socioeconomic impacts and overview of mitigative strategies. *Bulletin of Engineering Geology and the Environment* 66(1): 1–27.

Sharma, U., A. Scolobig, and A. Patt. 2012. The effects of decentralization on the production and use of risk assessment: Insights from landslide management in India and Italy. *Natural Hazards* 64(2): 1357–1371.

Singh, A.K. 2010. Landslide management: Concept and philosophy. *Disaster Prevention and Management: An International Journal* 19(1): 119–134.

Srivastava, R., and L. Laurian. 2006. Natural hazard mitigation in local comprehensive plans: The case of flood, wildfire and drought planning in Arizona. *Disaster Prevention and Management: An International Journal* 15(3): 461–483.

Suh, J., Y. Choi, T.D. Roh, H.J. Lee, and H.D. Park. 2011. National-scale assessment of landslide susceptibility to rank the vulnerability to failure of rock-cut slopes along expressways in Korea. *Environmental Earth Sciences* 63(3): 619–632.

UNISDR (United Nations International Strategy for Disaster Reduction). 2005. *Hyogo framework for action 2005–2015: Building the resilience of nations and communities to disasters*. Geneva: UNISDR.

UNISDR (United Nations International Strategy for Disaster Reduction). 2015. *Sendai framework for disaster risk reduction 2015–2030*. Geneva: UNISDR.

Volchko, Y., J. Norrman, L. Rosén, M. Bergknut, T. Söderqvist, T. Norberg, S. Josefsson, K. Wiberg, and M. Tysklind. 2014. Using soil function evaluation in multi criteria decision analysis for sustainability appraisal of remediation alternatives. *Science of the Total Environment* 485–486: 785–791.

Zeng, J., Z.Y. Zhu, J.L. Zhang, T.P. Ouyang, S.F. Qiu, Y. Zou, and T. Zeng. 2012. Social vulnerability assessment of natural hazards on county-scale using high spatial resolution satellite imagery: A case study in the Luogang district of Guangzhou, South China. *Environmental Earth Sciences* 65(1): 173–182.