Bavarian Environment Agency

Final report

Study of physical natural hazard models

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Study of physical natural hazard models

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Abstract

Extreme events and natural hazards have always been part of the reality of life for people in the Alpine region. In recent years, flood events and increasing amounts of heavy precipitation in particular have had a negative impact on human health and property. Even though public risk management measures are intended to prevent events up to flood levels used for design purposes and at least to mitigate the effects of extreme events beyond that point, the involvement of the population in taking their own precautions is crucially important. However, both successful implementation of individual protection measures and effective action during the extreme event itself will require greater awareness of and sensitisation to the issue of natural hazards in the future.

Interactive physical models of natural hazards are considered an essential training and communication tool for raising awareness, and they are already used in some Alpine countries in schools and at public events. The present study provides a survey of existing models mainly from the Alpine region. Based on an assessment of questionnaires, it was possible to evaluate 26 natural hazard models. Roughly equal proportions of these fall into the categories of purely presentation models, haptic-interactive models and models in the area of educational games, digital models and virtual reality. The majority of the models used are designed for a high degree of interactivity, encouraging direct involvement of children and young people but also of adults. A variety of uses at schools, action days and trade fairs requires a strong, mobile design. The focus is on natural fluvial events (floods, torrents, flash floods). However, the technical protection measures tend to concentrate on public measures and only rarely include issues surrounding self-protection.

Evaluation of the models studied made it possible to identify best designs, practices and methodological approaches. In combination with the specifications for the project, it was possible to arrive at clear conclusions for creating a new model prototype. The general scenarios examined included frequent flooding, the flooding level used for design purposes and an extreme flood on the one hand, and a torrent and heavy rain event on the other. Certain core messages underpin communication in the intended topic areas. An interactive physical natural hazard model was designed for implementation. The model represents a fictitious pre-Alpine landscape through which an Alpine river flows. Within a village, a torrent flows into this river from a mountain region. Thank to the large degree of freedom and mobility of the elements, the user of the model can carry out the educational tasks set by working out how to mitigate the events in a tactile, interactive way in a small group. In this context, technical protection concepts such as dykes, flood protection walls, dams and driftwood rakes can be individually constructed and their effect evaluated. Various designs of houses and other parts of the infrastructure can be used to depict the damage there and the resulting dangers from water ingress. The issues surrounding self-protection can thus be dealt with at the level of the individual house or the locality.

The creation of the model prototype was documented in detail. The model comes with a construction plan, a material list and photo documentation. This allows duplication and modification of this prototype for successful application in the Alpine region and beyond.

Introduction

Problem, background and motivation

In recent years, the impact of extreme events caused by Alpine natural hazards has made the news repeatedly in the regional and national press. Some familiar examples include

- the debris flows in summer 2015 in Bavaria (Oberstdorf) and Tyrol (Sellrain and Paznaun);
- the heavy precipitation with extreme flood discharges in small catchment areas in Lower Bavaria (e.g. Simbach am Inn) and Baden-Württemberg (Braunsbach 2016);
- the periodic debris flows on the Illgraben in Switzerland;
- the cascade event caused by rockfall on Piz Cengalo in August 2017 with subsequent mobilisation of areas of ice and sediment in the glacier area, followed by initiation of a debris flow with deposition in the valley town of Bondo;
- the extreme rainfall and flooding in northern Italy in autumn 2018.

Even though protective measures against the effects of natural hazards have been implemented on a large scale in the Alpine region by the relevant countries, there is always a residual risk of personal injury and property damage due to extreme events in the regions affected. In addition, the Alpine region is subject to growing settlement pressure, increased economic activity (Schneiderbauer et al., 2018b) and rising tourism. This is accompanied by a growing demand for land and also increased settlement in exposed regions. Pressure from human use and the expansion of infrastructure are increasing the potential for damage to the Alps more and more.

The fact that people and their goods in mountain regions are at risk from natural geological, hydrological and meteorological hazards, in particular river floods, torrent hazards, rockfalls, avalanches and landslides, is not a new insight. However, there is growing evidence of the causal links between climatic and anthropogenic factors in the mountain environment, the increased occurrence of extreme events and the negative impacts in the form of property damage, damage to human health, loss of biodiversity and other ecosystem functions (including protective forests, floodplain retention).

Schneiderbauer et al. (2018b) describe that dealing with natural hazards has a long tradition in Alpine countries. Specifically this means that those who have grown up in areas affected by natural hazards, or at least have settled there for a long time, are usually aware of both the generation mechanisms and the impact of natural hazards. Even before protective measures against natural hazards began to be taken, people often avoided the areas affected by natural hazards and in individual cases operated a certain degree of property protection. Only by knowing where, why and to what extent natural hazards occur was it subsequently possible to devise effective strategies for protecting the population and infrastructure from the effects of these hazards. Initially, until the second half of the 20th century, these were mainly structural and engineering measures such as dams, concrete structures, wooden barriers and protective nets (Schneiderbauer et al., 2018b). However, as these structural measures were designed for a certain event size (design event) and annual recurrence, overload cases beyond this could only be mitigated or prevented to a limited extent. At the end of the 20th century, it was recognised that preventative, non-structural and organisational measures offered certain advantages within the framework of integrated risk management. Thus, a lot of attention was paid to space and land use planning, emergency planning, training and communication. It was increasingly recognised that effective protection can go hand in hand with ecologically sound, sustainable measures. However, it also became clearer that, whatever measures are taken, there will always be a residual risk and acceptance and discussion of the potential overload cases is essential. The main goal can only be to reduce the risk to an acceptable level.

The following definitions will be used in this study:

Residual risk: *The risk remaining after all (basic) protective measures have been implemented.*

Overload case: *Flood event that exceeds the flood for which the flood protection facilities are designed and thus leads to their overload. In the case of dykes, this means that they overflow and, in the worst case, can even break. Since the location of the overflow and of any structural failure cannot be predicted, major damage can occur.*

As experience in other Alpine countries shows, physical, interactive models of natural hazards can contribute to raising awareness among the population. Especially for flood events that can cause serious damage to those affected and the infrastructure involved, successful flood protection through effective interaction of public measures and the actions of stakeholders, such as municipalities and citizens, is required. The public's awareness of flood risks must therefore first be raised. By integrating physical, interactive models of natural hazards into flood risk management, risk awareness can be raised and active participation and self-protection can be promoted.

In order both to examine the usefulness and impact of natural hazard models in increasing risk awareness and to discuss experiences of risk communication, an exhibition on natural hazard models and risk communication tools was held on 25 April 2019 in Heimschuh (Austria) as part of a workshop organised by EUSALP Action Group 8[1] and the Alpine Convention Working Group PLANALP[2]. Here, different Alpine regions presented existing physical natural hazard models and accompanying materials for risk communication. The focus was particularly on target audience-orientated risk communication and knowledge transfer in relation to successful examples of natural hazard risk reduction and adaptation to climate change at the local level. In order to gain a more detailed overview of existing models, the EUSALP Action Group 8 decided to conduct a study of existing models following on from the workshop. The subsequent intention was to design a prototype for a physical interactive natural hazard model and commission its creation as part of the AlpGov2 project.

This is the starting point for the current project, for which the Bavarian State Ministry for the Environment and Consumer Protection awarded the contract on 04.09.2020 using procedure *2020WLE000007 - Physical natural hazard models*, on the basis of a bid submitted by the contractor on 20.08.2020.

[1] https://www.alpine-region.eu/action-group-8
[2] https://www.alpconv.org/de/startseite/organisation/thematische-arbeitsgremien/

The first step in the study is the survey of existing natural hazard models presented below and an assessment of those models with regard to their educational suitability. Subsequently, the existing models are evaluated in terms of their suitability and applicability to the issue at hand, and recommendations for a new model are derived from this. In the second step, which builds on step 1, a prototype of a natural hazard model is created. For this purpose, the construction plan is presented and the educational content is explained. An essential point of the research was the analysis of the target audiences addressed by the existing models. Also important was the experience with the existing models in terms of mobility and the effort required for set-up and installation on site (e.g. electricity connection, water requirements). The results of the study had to provide conclusions about the elements required for the new model and its application. This relates both to the model's own technology (structure, pump, pipes) and also the technical process elements of the problem depicted (river, dyke, retention areas, houses, road, ...) and the educational approach of the model.

The study, the planning and construction of the prototype and the development of the associated pedagogical concept were co-financed by the European Union within the framework of the AlpGov 2 project.

Classification of the study in the risk governance approach

The concept of the risk governance approach involves the successful involvement of all stakeholders and decision-makers in jointly managing certain natural hazards. The core idea is that a common risk agenda can be achieved through the different protection options and their implementation on the part of stakeholders. In the context of the risk governance approach, preventative, active and sustainable public relations work is considered to be an essential pillar of effective damage reduction during extreme events. The particular priority here is to communicate the way in which the awareness of the citizens concerned is raised. However, this must be done within the municipality by providing concrete information adapted to the local conditions with explanation of the changes to behaviour and construction measures. Among other things information media, e.g. flood information sheets, are issued for this purpose (German Federal Ministry of the Interior, Building and Community, 2018).

According to EUSALP (Schindelegger, 2019), in order to improve risk governance, it is essential to consider the following points:

1. There is no standardised and universally applicable scheme for integrating risk governance mechanisms into society's approach to natural hazards. Risk cultures and institutional frameworks differ not only nationally, but also regionally and locally. The degree of acceptable risk varies.
   Conclusion: A physical interactive model can therefore only represent a part of reality. The model is therefore designed to be representative of the conditions in Bavaria in particular and it can be applied to other Alpine regions if similar circumstances obtain there.

2. The risk governance approach can achieve its greatest impact if it succeeds in connecting stakeholders from planning, disaster management and natural hazard management through platforms, joint consultations and frameworks.
   Conclusion: The model should reflect the work of different stakeholders.

3. Development and implementation of effective prevention measures is often only possible if interrelationships and interactions at the local and regional level are taken into account. Conclusion: If feasible, a model should represent both the determining factors and the countermeasures at regional and local level.

4. Development of hazard prevention measures requires the active participation of the population in implementing them in the framework of self-protection. Raising of awareness and training of risk perception on this issue must therefore be taken into account in advance. Models and workshops are a very good approach for this (Sermet et al., 2018b, Bogdan et al., 2021).
Conclusion: The model should be highly interactive to maximise learning.

5. The risk governance approach cannot be taken further through theoretical discussions alone. Concrete solutions must be developed and optimised locally in the affected region. However, this can only succeed if the people concerned are involved through funded initiatives. Conclusion: Those who interact with the model should find the reality of their lives reflected in it. Ideally, they will be able to identify with the depiction of the locality, landscape and nature.

Natural hazards in the Alpine region

This study and the resulting interactive physical model follow the recommendations on how to improve risk governance related to natural hazards in terms of residual risk and overload (Schneiderbauer et al., 2018b). The aim of creating a risk culture in which a society is aware of the residual risk should be emphasised. This includes targeted, audience-specific and careful risk communication. Important aspects in this context include:

- educating children, adolescents and young adults at an early stage about natural hazards, their damaging effects and the associated risks by including schools, action days and further training courses;
- informing and educating the public about the residual risks of natural hazards without creating an atmosphere of fear;
- using multimodal risk communication so that the information provided can be absorbed through different channels;
- using communication techniques such as storytelling in a targeted way to demonstrate how to deal with natural hazards based on society's experience.

Effective risk communication for the Alpine region is complicated by the fact that in general a multitude of natural hazards can occur, sometimes simultaneously or in interaction, and they can also vary locally. These include:

- River flooding as the overflow of flowing water from the river bed because the water level is significantly above the mean water level, triggered by large-scale rainfall over an extended period (continuous rain) or locally limited precipitation events with high amounts of precipitation in just a few minutes or hours (heavy rain)

- Floods in torrents with a relatively steep slope at the bottom, with significant changes in water flow and rapid attainment of the discharge peak and temporarily high bedload transport and in some cases significant driftwood accumulation, triggered by mostly heavy precipitation during summer thunderstorms in relatively small catchment areas close to settlements
- Debris flows in steep torrents as a descending mixture of water, coarse and fine debris or mud and driftwood with a solid content of usually at least 30%
- Debris flows as a slope movement, in which the debris masses flow downhill in a very elongated, narrow form, usually very slowly (creeping)
- Landslides due to sliding of the soil or rock, either slowly or quickly
- Rockfall and rock avalanches as sudden break-off or sliding of rock faces without warning, triggered by erosion, weathering, recession of permafrost soil and often intensified by a lack of protective forest, with the mass of falling rock simultaneously reaching a high velocity, resulting in a large release of energy at the impact site.
- Avalanches as rapid snow movements over a length of more than 50 metres, triggered by large amounts of snow sliding down mountain slopes
- Other relevant hazards, such as forest fires, glacial lake outbursts, hail, lightning or storms

Since it is not possible to represent all natural hazards equally in a physically interactive model, the focus in this project is on floods, torrents, heavy rain and debris flows, and less on other gravitational mass movements such as landslides or snow avalanches. At the same time, all natural hazard models have been considered in the research into existing models in order to identify best practices.

In the new model, the concept of risk as a key term in risk governance and the related concepts of hazard, vulnerability and exposure should also be represented and communicated. The viewers or users of the model should understand that their personal risk in respect of an extreme event is composed of the interaction between the probability of occurrence and the potential loss. The message here should be that everyone has a certain vulnerability (susceptibility) to a hazard and that the people, material assets and systems at risk in the hazard area may be damaged if they are exposed to a hazard process. Even if viewers perceive a very low risk overall due to the unlikelihood of occurrence, they should realise that a residual risk still exists despite preventative measures.

Risk perception and sensitisation

The perception of risk and the actual danger in the event of a disaster are important factors in affecting how an individual behaves during and after the damaging event. On the one hand, risk perception is based on a strongly subjective, individual assessment and evaluation of the likelihood of a hazard occurring and the associated consequences. On the other hand, risk is partly perceived purely intuitively or the responses to it result from limited sources of information (including hearsay, media reports, social media). Rarely is the population's perception of risk based on knowledge of objective risk factors (Shin et al., 2019). In the context of risk management, it has therefore become particularly important to evaluate and ultimately increase the public perception of risk (Ge et al., 2021).

Recent studies (Ruin et al., 2007, Miceli et al., 2008, MingChou et al., 2008, Wachinger et al., 2013, Choon et al., 2019, Ge et al., 2021) show that perceptions and experience of feelings of risk are strongly related to (1) risk exposures, (2) one's own experience/survival of extreme events and indirect reports (family, friends, media) of such events, (3) public trust in government actions, and (4) initiation of practical individual countermeasures. Risk perception has a significant influence on the acceptance of preventative protective measures and the implementation of one's own precautionary measures (self-protection). An individual's response to a threat in the risk area depends on the existing precautionary measures (government, municipal, private), the general (official) risk communication and information and the countermeasures that have actually been implemented successfully in the specific disaster (e.g. evacuation, rescue, building protection) (Stancu et al., 2020).

The sense of local belonging plays a big role in this. Research suggests that people who identify with or feel attached to a place tend to underestimate the potential vulnerability of that place to risk (Bonaiuto et al., 1996, Gifford et al., 2009). Intensity of local affiliation also weakens the relationship between perception of risk and preventative behaviour to deal with flood events (Dominicis et al., 2015). The results of Stancu et al. (2020) show that people with a strong sense of belonging to a place with a high risk of natural hazards (e.g. Alpine region) are more likely to feel anxious and less able to develop effective coping strategies (freeze response) when the risk of an extreme event is subjectively perceived as high. If this risk is also objectively high, the development of effective coping strategies is more likely among such people with a strong local attachment.

However, if the risk of natural hazards in a place is low (e.g. non-Alpine region), people who feel a less strong attachment to that place are more likely to develop coping strategies if they subjectively perceive the risk towards an extreme event as high (fight/face response). But if the risk here actually is high, those people develop less effective coping strategies (freeze/flight reaction). The attachment to a place or a region can therefore contribute significantly to how people behave in the presence of risk, how high the acceptance of protective measures is and how reflectively damage is dealt with after an extreme event. The effects could presumably be strengthened if it is possible to adjust the subjective perception of risk to the objective risk that actually exists in the region. This requires effective and truthful risk communication and information, as well as raising awareness of natural hazards. An interactive physical model can make a significant contribution to this.

In addition to public protective measures, however, it is essential that the population takes its own steps to minimise the residual risk. Implementation and installation of such "private protective measures" in the context of self-protection is often associated with controversy, however, not least

because they have to be self-financed, their effectiveness is questioned
or the different types of technical measures are completely unfamiliar. Pagliacci et al. (2020) conducted a study in the Veneto region of Italy, which is at risk from heavy rainfall. The results (Fig. 1) show that more than two thirds of the population do not take countermeasures because they do not feel threatened by an extreme event, even though there is objectively a high risk of flooding from heavy rainfall in the region. Seven percent of respondents report a lack of knowledge about the available protection measures and their benefits. For Pagliacci et al. (2020), it is precisely this point of view that constitutes the greatest barrier to successful mitigation of flooding of private property due to heavy rainfall. In general, however, both points of view could be changed through an increase in public relations work and education. Among other things, government information brochures and handouts – on the topic of floods, for example – help in this connection (Upper Austria Regional Government, 2016, Bavarian Environment Agency, 2018). An interactive physical model can also provide support here.

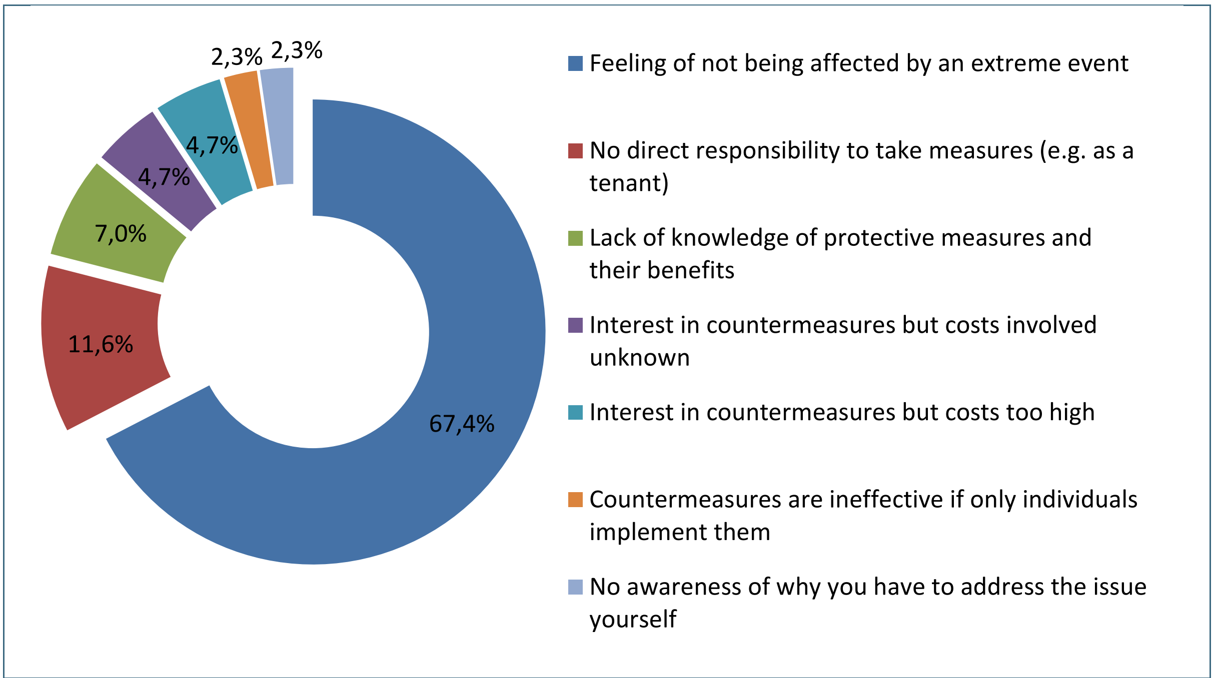

Fig. 1: Reasons for unwillingness to implement appropriate measures against flooding caused by heavy rainfall events in one’s own home: the data come from the study by Pagliacci et al. (2020) for the Italian region of Veneto, which is at risk from heavy rainfall.

Natural hazard models as demonstration models

Demonstration models (demonstration experiments) are used to observe or study a problem in an eye-catching way, without the model necessarily following precise physical laws. Certain processes are represented in a very simplified way, other effects can be exaggerated to make a point. The focus is on visualisation of the problem, communication of the core messages and the comprehensibility of the system processes. At best, these models should encourage active interaction. The challenge in conceptualising them lies in selecting the content of the model and the methodological processes. On the one hand, the model must remain clear and be as intuitively understandable as possible for the layperson. On the other hand, sometimes complex system processes have to be explained in an understandable way. Unlike models in hydraulic engineering testing, however, demonstration models are not necessarily created according to laws of similarity, as the geometric scaling is usually far too large. As a result, runoffs, flow velocities, water depths and forces are not to scale. No measuring instruments are usually needed either, unless they are required to control the model or are part of the teaching process. Nevertheless, a demonstration model should present the essential effects of the natural processes. Ideally, those who see the model will find the reality of their lives represented in it.

A distinction is made between three types of demonstration model below, and the models in this study have been classified accordingly.

Presentation models	Presentation models are used for purely visual or acoustic representation of processes. The model viewers experience little or no haptic feedback. There is usually no interaction with the model or the processes taking place. The processes in the model are initiated, modified and stopped by the demonstrator. However, the observed processes can be worked through, discussed and investigated further in the teaching presentation and discussions, which must be moderated by the demonstrator. Mostly such models are used when the model construction is very fragile, reacts sensitively or may sustain damage if not operated properly. This can occur especially with young model viewers (children, adolescents). Even when used with large groups of viewers (trade fairs, exhibitions, school classes), a purely presentational model can be useful if the group is too large for simultaneous interaction.

Haptic-interactive models	In these models, the model viewers can experience the processes in the model both via the sense of touch (passive perception) or haptically by means of active contact (active perception) in addition to the visual and acoustic experiences. The potential spectrum of haptics is quite wide. As a minimum, viewers can simply feel or touch surfaces or materials that are built into the model or water that flows through the model, for example. A more advanced level is a model that is designed to be interactive. The model viewers are given as much freedom to shape what is going on as possible. Once the model has been set up, instruction has been given on how to use it and any tasks have been explained, the viewers are intended to work out the processes for themselves. Such models usually allow topographical reshaping of the model landscape (morphodynamic models), positioning, movement and removal of model components (houses, cars, people) or control and regulation of natural and technical processes (e.g. flow, precipitation, dyke construction). This pedagogical approach has many advantages in the field of natural hazard models and reinforces the learning effect. Model viewers can create their own protection concept for a location, for example, then trigger the event, observe the consequences of their own measures and adjust them as necessary. However, haptic and interactive models can only be used by a small group of viewers at any one time to avoid them interfering with one another. At the same time, they provide the opportunity to coordinate certain tasks within a group operating together. Interactive group work can be organised in this way.

Educational games, digital models, virtual reality	Educational games offer an effective way to promote learning through play, especially for children and school students. Educational play uses the natural play instinct of children to impart knowledge about certain subject areas. The more intense the emotions experienced during a game, the more of them remain in the memory, which serves as a basis for further learning. The pedagogical impact is reinforced when the focus is on the fun of playing and the didactic content remains hidden. With the increasing power of today’s computer technology, creating digital educational games is increasingly an option. This appeals especially to young people who enjoy computer games. The use of virtual reality (VR) can make content even more tangible.

Approach and analysis of the study

Research into existing models

The research into existing natural hazard models was mainly carried out by means of a questionnaire (Appendix 7.1). This was sent to the members of the Alpine countries via the EUSALP AG8 email distribution list and was also made available as a browser-based electronic form. The format of this questionnaire was deliberately kept relatively open in order to give the opportunity to answer the questions on the very different models quite freely. This was considered appropriate in view of the heterogeneity of the models. Answering the questionnaire took about 10 minutes.

First, in a section of general questions, information about the country, region and type of organisation (national, regional, municipal, international, research institution, private company, other) was collected in order to localise the respective model. This was followed by questions about the type of model (physical interactive model, physical model for presentation / demonstration, digital model, interactive game), the mobility of the model (stationary or mobile) and the processes depicted in the model. Information was then gathered about why the model was created, what its aims were and which target audience/age group it addressed. It was also possible to specify the occasions on which the model had already been used (schools, fairs, experience centres, public relations) and who is required to operate the model (number of people, qualifications). This was followed by queries about the general structure and design of the model, its spatial (geometric) scale, the visualisation of the process elements and the methodological approach. In a further section, respondents were able to provide a critical evaluation of the model. This was particularly helpful with regard to identifying best practice. First, respondents were asked whether they rated the complexity of the processes presented as very high, medium or low. They were also asked to assess which details had proved successful in implementing the model and using it in public relations.

The intention was to restrict the research primarily to the Alpine region. Nevertheless, a literature review was initiated to identify other natural hazard models, including those outside the Alpine region. This allowed additional information on best practices to be filtered out, which provided significant added value to the study. It should also be noted that the acquisition of information about other models is partly the result of recommendations from external partners.

Analysis and evaluation

At the end of the research, 31 models had been identified from questionnaires, references in the literature and other research. Of these, 26 models were included in the study. Two models from Switzerland were not included in the study because they are purely scientific, hydraulic engineering test models. One model is still only in the planning stage (*Climate Change Adaptation Model Region “KLAR! Zukunftsregion Ennstal”, Styria, Austria*) and there was no feedback on one other model from the Heimschuh workshop (*Models of different types of barriers for torrent and avalanche control - (Austria)*). A digital model of the Austrian BFW (*Flow-py*) was also left out of the study, as it is a purely scientific simulation tool without any application in public relations.

Localisation, organisational affiliation and model type

Fig. 2 shows a map of the Alpine region in which the responses to the questionnaire that were considered have been marked. The majority of the available models are from German-speaking countries: Germany (6), Austria (5), Switzerland (3). 4 models were reported from Italy, with a regional concentration in South Tyrol. There was one response each from France and Slovenia. Not marked in Fig. 2 are the examples from the literature research. These come from the UK (1), Turkey (1), the USA (3) and the United Nations (1).

Fig. 2: Map of the questionnaire feedback included for the Alpine region. The countries represented are Germany (6), Austria (5), Switzerland (3), Italy (4), Slovenia (1) and France (1).

An evaluation of the organisational affiliation (Fig. 3) shows that about one third of the models are regionally based and represent the conditions there. This is especially true for regions such as South Tyrol and Bavaria. About a quarter of the models are positioned at national level, for example in Austria, where the models are created and made available from the capital Vienna. Natural hazard models are also kept at research institutions (19%), some of which result from completed hydraulic engineering experiments, while others are used for teaching purposes. Some private companies (15%) distribute commercial natural hazard models, but these tend to relate to areas outside the Alpine region. Models belonging to municipal bodies (4%) and international organisations (4%) are clearly in the minority.

If we evaluate the models according to type (Fig. 4), we see a relatively equal distribution of presentation models (35%), haptic-interactive models (38%) and educational games, digital models and virtual reality (27%). The evaluation of the questionnaires and the literature research suggest that digital models and the use of virtual reality in particular have increased in the last four years. It can be assumed that this trend will continue and that the proportion of this type of natural hazard model will grow due to the increasingly effective methods of computer and IT technology.

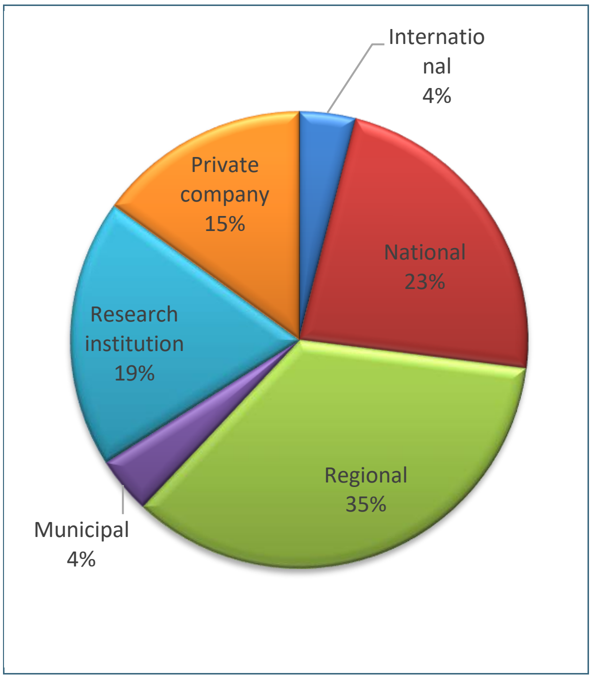

Fig. 3: Percentage breakdown of organisational level to which the models belong.

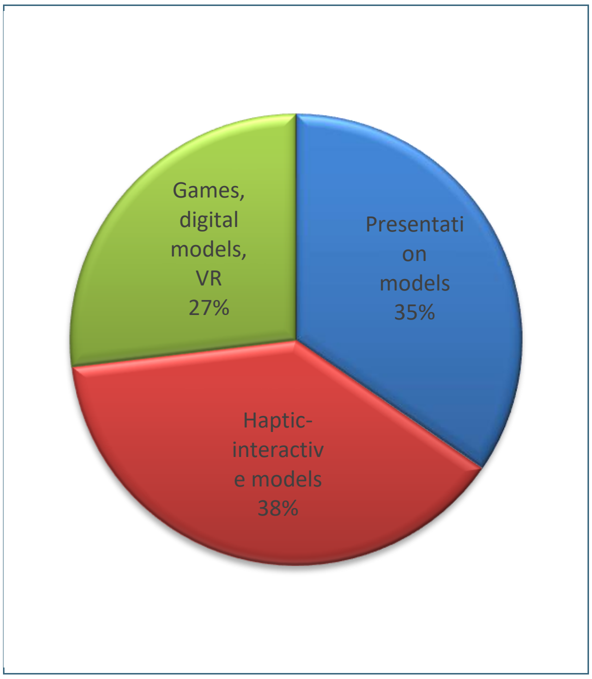

Fig. 4: Classification according to model type

Categorisation according to ease of use and interactivity

The questionnaire also asked about ease of use (Fig. 5) and respondents were requested to assess the degree of interactivity (Fig. 6). The majority of the models can be moved. These models are usually of a size that can be transported in a car or van. About a quarter of the models are stationary and cannot be transported. These are essentially very large, extensive models, some of which have emerged from hydraulic engineering experiments. Purely digital models (browser-based games, virtual reality) account for 19% of the models.

Half of the respondents to the questionnaire rated their model as highly interactive (Fig. 6). These models are usually haptic-interactive models or educational games, digital models or virtual reality. The other half is almost evenly distributed between medium and low levels of interactivity and tends to include the presentation models.

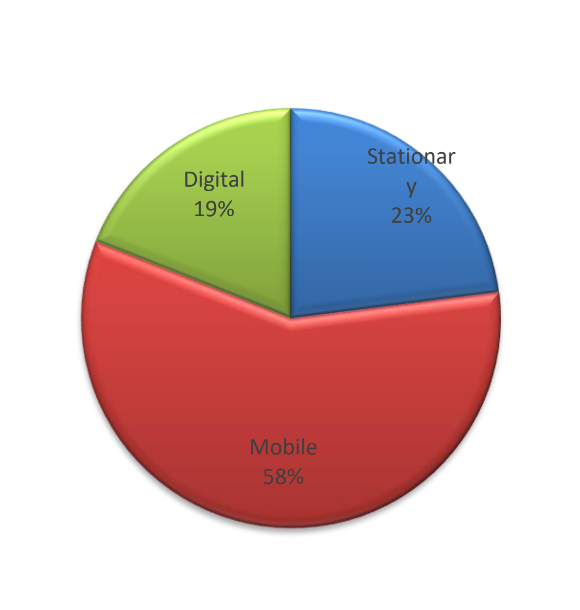

Fig. 5: Ease of use of the model

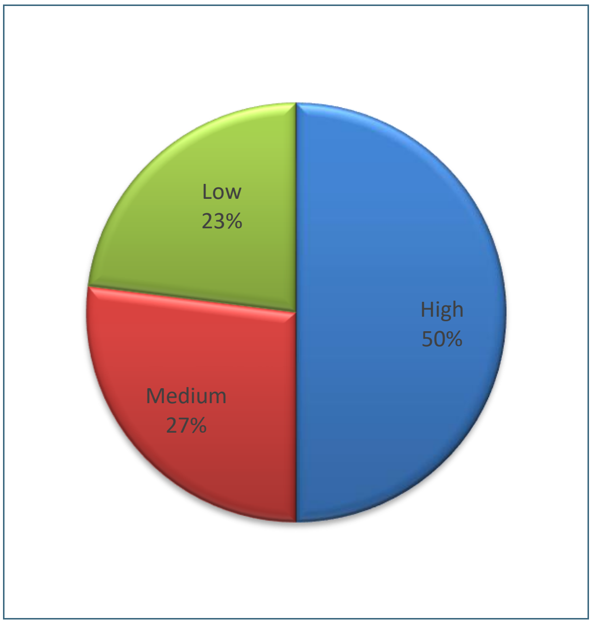

Fig. 6: Model owners' assessment of the degree of interactivity of their models.

Classification according to objectives, target audience and locations of use

Evaluation of the target audience showed that the clear majority of the models were originally designed primarily for children, young people and school students (Fig. 7). However, many respondents also indicated that the model could be used equally well with adult laypeople by making the scenario shown in the model less playful and adjusting the language level. A relatively small percentage of the models were designed for a topic-specific audience or for professionals.

The majority of the models were already in use in general public relations (Fig. 8). But the models were also used at schools and on action days to provide information about natural hazards, especially with the target audience of school students, children and young people. A small number of models are shown in exhibitions and museums.

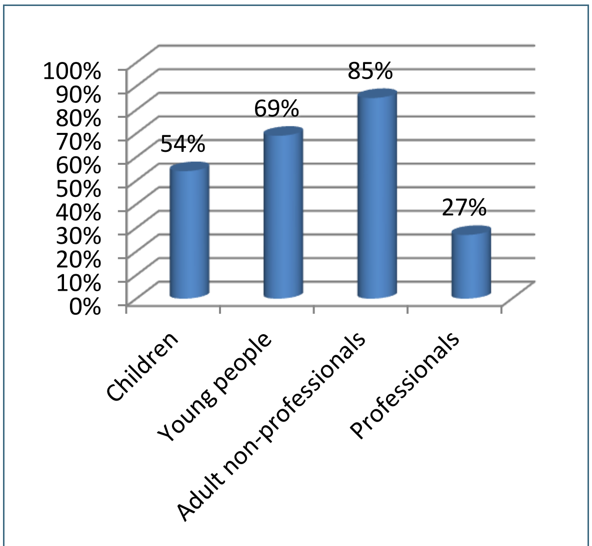

Fig. 7: Target audience at which the model is aimed

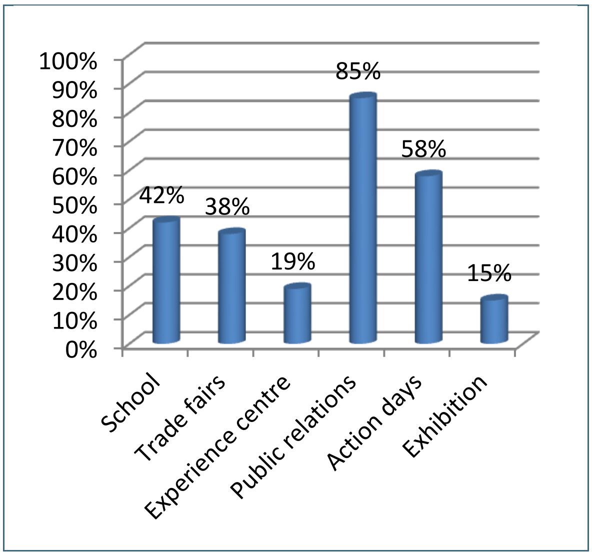

Fig. 8: Locations where the model is used (multiple an-

(multiple answers possible)

swers possible)

Creating, transporting and operating the model always involves a certain amount of effort, which – it is assumed – is perceived extremely subjectively (Fig. 9). About one third of respondents considered this to be high; about one third considered it to be low. Moderate effort was reported for 42% of the models. As a rule, the effort for the haptic-interactive models is very high, as the interaction requires guidance, supervision and subsequent evaluation and discussion. Digital models and simulations with virtual reality are particularly time-consuming to create. But once they have been distributed, the effort is significantly reduced.

54% of the models required a supply of water or a water connection for operation; 46% also required a power connection (Fig. 10). 27% of the models were completely self-sufficient, a group which mainly includes the educational games and browser-based digital models.

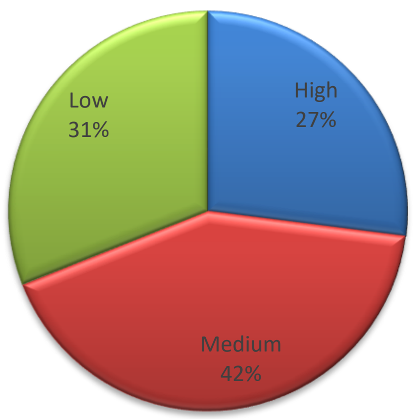

Fig. 9: assessment of effort involved in creating and running the model.

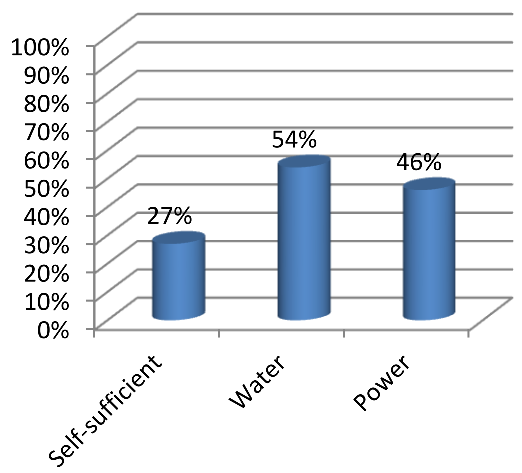

Fig. 10: Responses regarding the infrastructure required to operate the model (multiple answers possible)

Evaluation of the processes and process elements under consideration

An important element of the study was to survey the processes already examined in the existing models. This was intended to provide information about which processes have been covered most often in the models so far and which play a more subordinate role (Fig. 11). The vast majority of the models include the topic of flooding in connection with the processes in torrents, including the transport of debris and driftwood. In recent years, the issues of uncontrolled runoff and sudden flooding after heavy rainfall events (flash floods) have also increasingly become the focus of models. Approximately 23% of the models also include topics relating to damage to homes or look at the issues surrounding self-protection. Relatively few models deal with snow avalanches, rockfalls or landslides. It can be assumed that the last three categories play a subordinate role in terms of damage potential and that the population as a whole comes into less contact with them or is less affected by the damage. Furthermore, the topic of self-protection plays a decisive role in the area of floods, torrent hazards, uncontrolled runoff water, flash floods and heavy rainfall in particular, as those at risk can take effective countermeasures themselves in the event of an overload in these areas.

The evaluation of the processes considered makes it clear that in future model prototypes, the topics of uncontrolled runoff, flash floods, heavy rainfall and especially self-protection should prove particularly important. These topics are therefore likely to have greater emphasis in the communication of natural hazards. A process that cannot be depicted in the prototype is a snow avalanche. However, the interaction between a flood in a watercourse and an incoming torrent within a locality would be an extremely valuable scenario. This could also cover the issue of bedload transport and the hazards from driftwood accumulation.

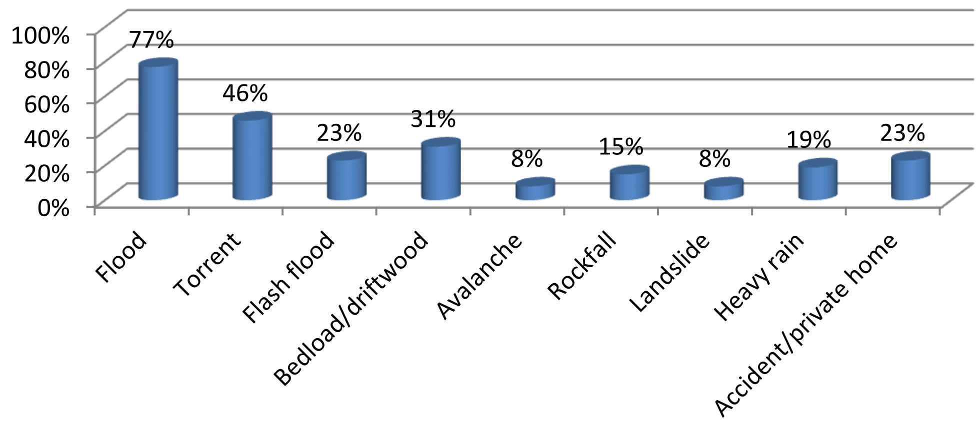

Fig. 11: Processes dealt with in existing models (multiple answers possible)

In the models researched, the river was a particularly important process element (Fig. 12). At 81%, a river is usually the main feature in the model. As a result, the protective measures associated with the watercourse (e.g. a dyke as a way of channelling water) and the infrastructure affected by the flood (houses, roads) are also often represented in existing models. However, none of the models researched include the principle of diversion (e.g. flood channel, flood ditch) and only two models address the principle of retention (dyke relocation, retention space, retention basin) to communicate public measures for flood protection.

In the models with a strong Alpine connection, a mountainous region or a slope is another central element. The topic areas of torrents, rockfalls, landslides and avalanches are depicted in this context in particular. As a process element, private property is represented only to a limited extent (19%). This in turn affects communication in the area of self-protection and individual countermeasures in the event of an overload.

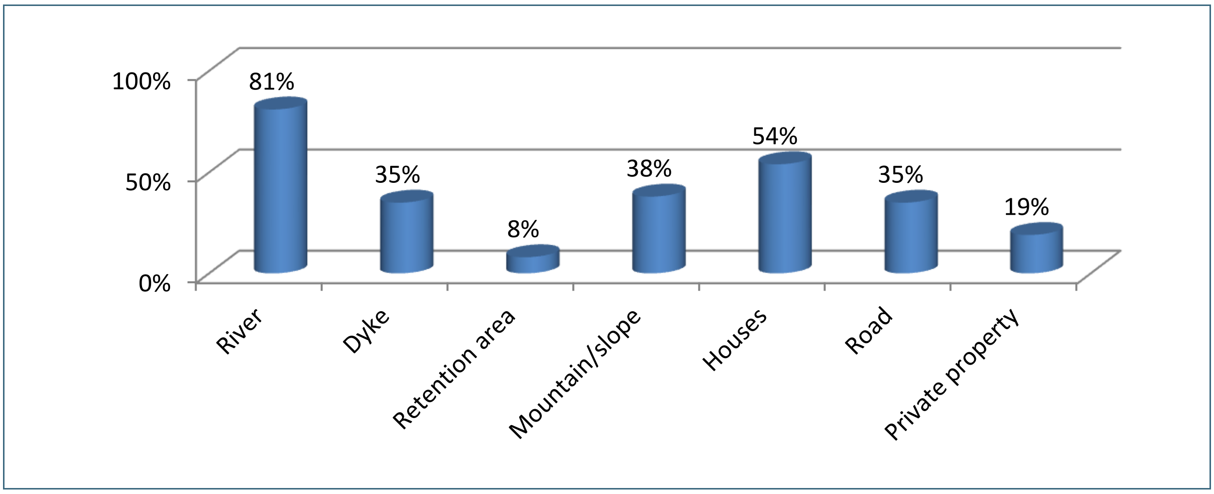

Fig. 12: Process elements dealt with in existing models (multiple answers possible)

Overall, it can be seen that 85% of the models address specific public protection measures (Fig. 13). 42% of the models show municipal protective measures such as forestry activities, early warning systems and organisational measures at the municipal level. Accounting for approx. 19%, measures relating to self-protection clearly play a less significant role. It is precisely in the latter area that the new physical model can create added value.

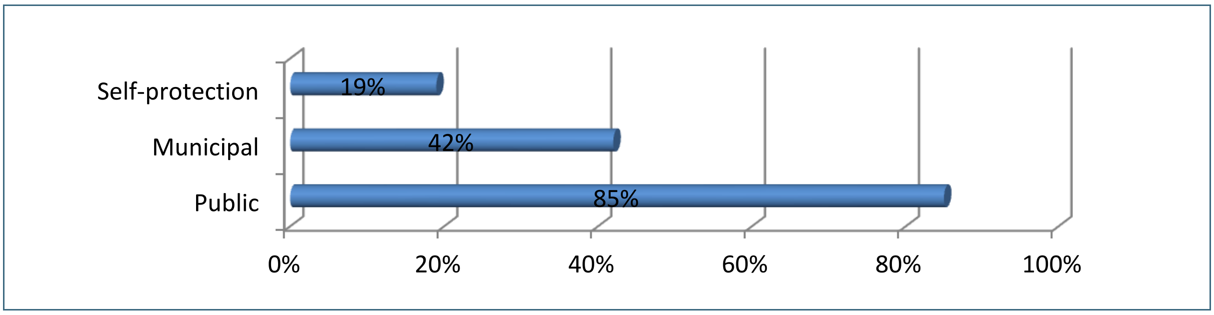

Fig. 13: Level of protective measures addressed in existing models (multiple answers possible)

Results

This section presents the individual existing models in detail, distinguishing between presentation models, haptic-interactive models and educational games, digital models and virtual reality. First, the model is described in general terms, together with its target audience and general purpose. This is followed by explanations of the processes dealt with and a description of the essential points of structural design and mode of operation, insofar as is useful for an assessment of the suitability of the respective model and derivation of recommendations for the prototype. This is followed by an evaluation of the respective model and a list of the particularly successful features, which are referred to as best practices. These are compiled at the end of this section and their transferability to the new physically interactive model (prototype) is evaluated. At the end of each subsection, selected photos and illustrations of the respective model are presented.

Presentation models

Flash flood model (Germany, UniBw Munich)

The flash flood model of the University of the German Federal Armed Forces Munich (Institute of Water Engineering) was originally designed and created on behalf of the Federal Office for Civil Protection and Disaster Assistance for public relations work at the BAU trade fair in 2013. This is a presentation model that shows the effects of floods and flash floods in terms of damage to a housing estate. The original target audience was a broad adult audience with no particular professional background. Having been presented at trade fairs, the model is still used at the UniBw Munich for teaching purposes and in public relations work (school classes, Girls' Day, Open Day). It also serves to raise awareness among visitor groups and school students, thus expanding the target group to a younger audience.

In the model, a flash flood scenario is represented on a fictitious housing estate. The model area is 2m long and 67cm wide and was designed with an approximate geometric scale of 1:50. The water is fed into the model from a 160 litre storage tank via a pump. The model can be disassembled so that the water tank and the rest of the technical equipment can be transported separately from the model area. The model can therefore to be considered mobile. The model shows two houses with a visible cellar and garage. One house has no basement waterproofing, and as a result its electrical system fails when the basement floods. This is visualised by the failure of the lighting in the house. There is also a floating oil tank in this house. The second house is protected from direct water damage by a black tank and raised light wells, among other things. However, the house experiences a lifting effect when neighbouring groundwater rises. Structural damage is considered as a possible consequence. The viewer's opportunity to interact consists of placing vehicles, people, dustbins, tool sheds, piles of firewood and also sandbags anywhere in the model. Objects in the village are caught in the flood wave, moved or carried away completely. A bridge crosses the road in the model and the course of the road has been lowered to accommodate this. This underpass fills up during flooding, so that cars parked there also fill up and/or float away. Parts of the road are lowered in relation to the adjacent terrain, so that the kerb height there offers a certain degree of protection against the water as it follows the road layout. The same protective effect can be achieved by appropriately placed sandbags. To illustrate this protective effect, some parts of the street are also edged with lowered kerbs, some without.

Even though the model shows many details of a housing estate, it is characterised by a high degree of abstraction. The main objective behind it was to address issues of self-protection rather than public protection measures. The physical processes of flash floods and floods are therefore extremely idealised.

Best practice:

- ✓ **The model can be split relatively easily into two transportable sections.**
- ✓ **The model depicts the effects of the flash flood in great detail (downward slopes into garages, basement flooding, etc.). The viewer recognises real life in the model and can compare their locality, house, street.**
- ✓ **Self-protection issues are addressed (oil tank floatation, raised light wells, duplex parking).**

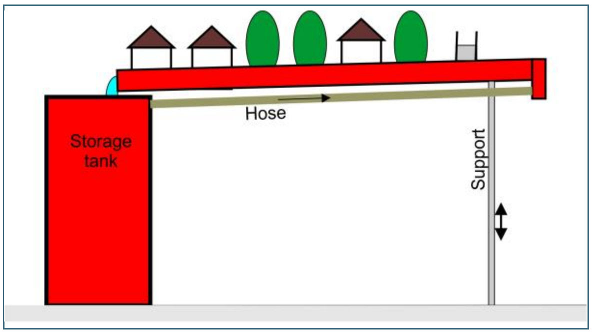

Fig. 14: Side view of the flash flood model as a schematic sketch

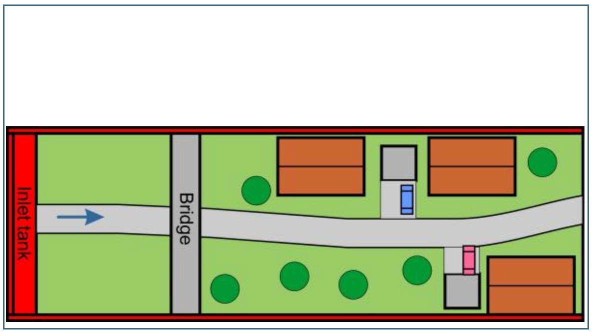

Fig. 15: Floor plan of the flash flood model as a schematic sketch

Fig. 16: Start of flash flood with cars and people caught up in it (direction of flow from bottom to top in image).

Fig. 17: The flash flood leaves the estate under water and carries away people and vehicles.

Biber Berti – torrent model (Austria, Vienna)

The "Biber Berti - Living with Natural Hazards" project is used very successfully by the Forest Engineering Service for Torrent and Avalanche Control of the Republic of Austria (WLV). The educational concept is aimed directly at a target audience of children and young people. Biber Berti (Berti the beaver) and his friends explain the origins of natural hazards and how to protect yourself from them in an age-appropriate way using various communication channels. In addition to information, games on the internet[3] and action days in nature, the hydrological processes in a torrent are demonstrated using a physical model.

The Biber Berti torrent model depicts a systematic process chain consisting of (1) precipitation and heavy rainfall, (2) runoff in the torrent and bedload, (3) technical measures to prevent flooding and (4) residual risk. For this purpose, the model includes a steep slope on which rainfall can be simulated. A retention basin and rockfall nets (scale approx. 1:100 - 1:1000, distorted) can be used on the slope. The precipitation collects at the foot of the slope and feeds a torrent, which then flows through a small village.

The demonstration starts with water only being channelled into the stream without a rain event occurring. With light rain, the stream is able to absorb the water volumes and it can drain away without damage. The intensity of the rain is then increased (heavy rain). Individual areas of the village are flooded. Pieces of wood that are introduced show the effect of alluvial wood in the torrent. In order to reduce the damage to the village, a barrier made of Plexiglas is installed at the top of the slope, creating a retention basin. This fills with water and bedload, illustrating the retention and protective effect of this public protection measure. Rockfall can also be simulated. To protect the houses in the village, rockfall nets can be placed on the slope.

The model is mounted on a trailer and can thus be used as a mobile unit for demonstrations at school events, for public relations work with children, at trade fairs and action days. Children and young people aged 6-20 were chosen as the target audience. One person is sufficient to operate the model and provide pedagogical support.

Overall, the complexity of the processes depicted is rated as medium. Nonetheless, the necessity of public protective structures and the way they work (retention basins, rockfall nets) are demonstrated to young people in a very vivid and easily understandable model. According to Torrent and Avalanche Control, the model could be extended to include other elements from the range of protective structures. A longer course of the river, a larger retention basin and the depiction of a forest area would contribute to an even better understanding of the natural processes.

Best practice:

- ✓ **The model is transportable on a trailer.**
- ✓ **The houses of the village can be moved in the valley or placed in the mountain area.**
- ✓ **The "Biber Berti" educational concept around the model is an excellent way to extend its impact.**

[3] http://www.biberberti.com/DE/index.php

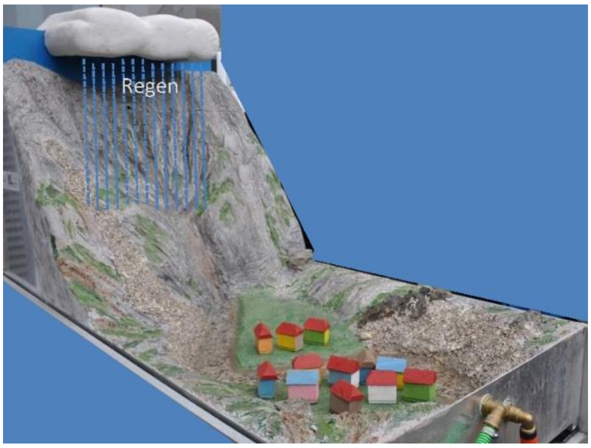

Fig. 18: The model depicts a slope region and a settlement in the area of the alluvial fan.

Fig. 19: Biber Berti in action at the workshop in Heimschuh 2019

Fig. 20: The position of the houses in the valley can be altered in the model.

Fig. 21: The model is mounted on a trailer, which enables mobile use.

Torrent model with dam structures (Austria, Vienna)

In the torrent model with dam structures, the focus is on the fluviatile process of a torrent, the bedload and driftwood carried by it and the effect of the dam structures. It is in use at the Torrent and Avalanche Control in Vienna. The model is 3 m long and 1 m wide and includes the course of a torrent, the dam structures there and a sample landscape on both sides of the torrent banks. A check dam is installed in the middle of the watercourse. This is to retain the debris and driftwood brought by the water from upstream. The flow in the model is initiated when water is added to the top of the watercourse using a watering can. The visitor can then observe the effect of the check dam. The model demonstrates only the effect of public protective measures. There is no interaction.

The whole model is mounted on four castors, which simplifies manoeuvring on site. The model is transported by van or on a trailer. A power connection and a few buckets of water are required to get the model up and running.

Best practice:

- ✓ **The structure and effect of the check dam are very well illustrated.**
- ✓ **The landscape is realistic.**
- ✓ **The model is framed with wooden panelling, which gives the model a natural character.**

Fig. 22: The torrent model is filled with water. A bedload check dam is installed in the watercourse.

Fig. 23: The model mounted on wheels during an action day.

Fig. 24: Front view of torrent model.

Fig. 25: The retention of debris and driftwood can be observed by the visitor.

Rockfall model with protective structures (Italy, South Tyrol)

The Office for Geology and Building Materials Testing of the Autonomous Province of Bolzano-South Tyrol uses a mobile model to demonstrate rockfall hazards and the passive protective structures required. In addition to providing background information, the aim is to illustrate the process of rockfall and the resulting dangers for a locality to both the layperson (young people and adults) and technicians. In addition, visitors are given the opportunity to position protective structures themselves and test their usefulness. The core objectives thus include understanding of the process of rockfall, understanding natural processes and raising awareness of protective measures.

The model is approx. 2 x 3 m in size and consists of a wood and steel structure. Two thirds of the model comprises a replica of a sloping hillside with rock faces, a rockfall course (ditch/valley, cutting) and forest. The rocks are released on the steep slope and roll, fall and/or jump into the valley, where a model village with buildings, roads and vehicles is damaged. Both the infrastructure of the village and the structures protecting against rockfall (rockfall barriers, rockfall protection dams) can be positioned anywhere in the model to try out different scenarios. The model is demonstrated in five steps

- Step 1: Positioning of the infrastructure of the locality
- Step 2: Selecting rocks
- Step 3: Dropping or tipping the rocks
- Step 4: Assessment of possible damage to the locality
- Step 5: Implementing countermeasures in the model (installing protective structures, relocating houses/roads)
- Step 5: Repeat of steps 2, 3 and 4

After the introduction, visitors can determine what happens in all the steps themselves. Any questions can be asked, explanations given and questions answered in the dialogue. The operator explains that different roughnesses and different degrees of hardness of the slope surface might have helped.

The model has already been used in public relations and at trade fairs. As a mobile model, however, it requires a van for transport and three people to set it up.

Best practice:

- ✓ **The topography has been worked out in great detail.**
- ✓ **The model explains in a simple and clear way the processes and measures that take place in a clearly defined scenario.**

Fig. 26: Rockfall model of the Office for Geology and Building Materials Testing of the Autonomous Province of Bolzano-South Tyrol at an exhibition

Flood model (Germany, WWA Traunstein)

A flood model was created by pupils for pupils as part of a school project. At the suggestion of the Bavarian State Ministry for the Environment and Consumer Protection, it was purchased by the Traunstein Water Authority and is located there in the River Master's office. It has already been used in schools, among other places, and is also to be presented at the State Garden Show in Ingolstadt in 2021. The mobile model with dimensions of approx. 2 m x 1.5 m consists of two parts.

Two river courses are used to illustrate the different runoff retardation, wave flattening and retention for a straight river course without vegetation in one part and for a meandering river course with bank vegetation in the other. The same flow is fed into both parts of the model at the same time and the amount of water leaving each river course at the downstream end and how quickly it does so are compared. The effort required to operate the model is considered low. However, the interaction in the model is limited to initiation of the flow.

Best practice:

- ✓ **By comparing the two river courses, the positive effect of renaturation processes and the return to a near-natural watercourse based on government requirements are visualised.**

Fig. 27:
In the flood model of the Traunstein Water Authority, the effect of watercourse morphology on runoff retardation is presented in the two parts of the model. The photo shows the straightened river course without vegetation on the left and the meandering river course and bank vegetation on the right.

Check dam model (Turkey, Trabzon Flood Museum)

The State Water Authority of Turkey maintains an interactive flood museum at the 22nd Regional Directorate in Trabzon district.[4] The aim of this facility is to increase the population's awareness of flooding scenarios and to raise awareness in order to reduce damage and losses. Various protective measures for homes are also presented and instruction is given about what to do in the event of a flood.

The range of topics in the museum is very large and is intended to cover a wide spectrum of age groups from primary school age to senior citizens. There are various models that cover, among other things, the development of flood events (mountain region, heavy rainfall models in urban areas, landslide models, urban flooding model, model showing the effect of mud flow on residential areas, model showing human interventions in rivers causing flooding, model of deforestation triggering landslides, floods model), flood events themselves (floods, torrent hazards, flash floods) and the effect of a wide variety of structures on flood and sediment retention.

The centrepiece of the exhibition is the interactive **Open Check Dam Hydraulic Model**[5]. The stationary model is constructed in a similar way to a hydraulic engineering test model and uses a geometric scale of 1:25 on a model length of 14m with 80cm watercourse width. The model's relatively robust and solid design makes it extremely durable. In recent years, the model has mainly been used to test planned or newly developed boulder and bedload barriers with regard to their retention and protection effects. Even though the model was initially used primarily to answer technical engineering questions, its current integration into the Flood Museum also offers the opportunity to demonstrate the general benefits of such structural models of watercourses in public relations work. The public can see how retention of solids and reduction of flow velocity serves to reduce potential flood damage. In addition to the representation of a clear water runoff, bedload and driftwood can also be added to the model of the mountain stream. Simply adding these materials also allows for visitor interaction, albeit on a small scale. The structure cannot be altered by the visitor. An engineer or the museum staff are needed to operate the model. A clear water runoff is set up in the first stage. In the second stage, bedload and driftwood are added to generate an event typical of a torrent. The largest rocks and tree trunks are held back at a first bedload barrier. Further barriers arranged downstream (check dam, open dam) gradually filter out the finer components as well and only allow the turbid water to continue running.

The operator suggested addition of the sediment by conveyor belt as an optimisation of the model. As additional scenarios, landslides could be initiated and the effect of culverts could be explained.

Overall, the Open Check Dam Hydraulic Model is characterised by high transferability of the system processes observed. However, a certain level of expertise is required to fully understand the effect of the types of boulder barriers and their design gradations. Interaction by visitors to the museum is limited to the addition of sediment or driftwood.

[4] https://www.youtube.com/watch?v=Sckx4e4Yzag&feature=youtu.be
[5] https://www.youtube.com/watch?v=xHcGqRb4-ss&feature=youtu.be

Best practice:

- ✓ **Authentic reproduction of the course of the river and its flow dynamics.**
- ✓ **The design of public torrent barriers and the way they work in protecting against debris and driftwood are presented clearly and in detail.**

Fig. 28: Check dam model in the Turkish Flood Museum after construction

Fig. 29: Various types of boulder barriers have been tested and demonstrated in the model so far.

Fig. 30: Use of the check dam model in the Flood Museum for demonstration purposes

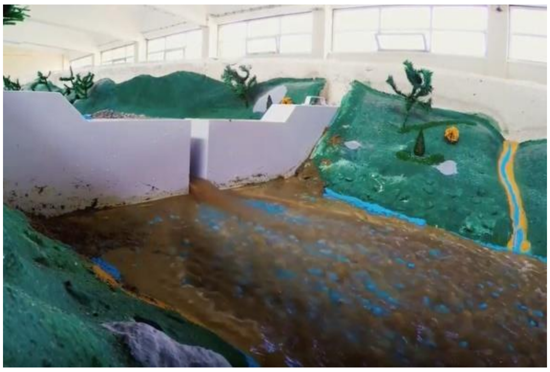

Fig. 31: Effect of a slotted dam in the model

Fig. 32: Effect of a check dam in the model with driftwood

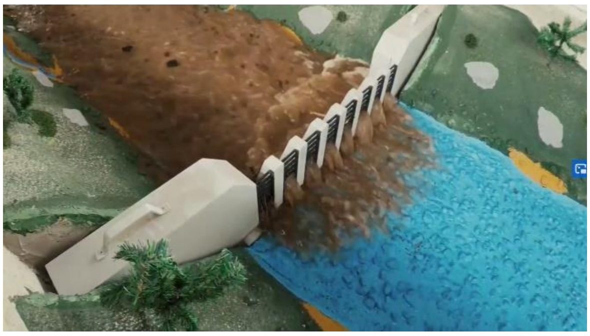

Fig. 33: Effect of another variant of the check dam on the model with driftwood

Models in Laboratorium3D (Switzerland, Ticino)

Laboratorium3D is a private company which carries out hydraulic engineering investigation of floods, torrent hazards, heavy rainfall, river morphology and hydraulic engineering protection structures. In terms of design and range of tasks, it equates to a private version of a university hydraulic engineering research institute. Currently, the laboratory has a 12 m and a 6 m experimental flume in which maximum gradients between 10% and 25% can be set. In addition to studying river and torrent processes as a basis for developing and optimising protective engineering measures, the Ticino-based laboratory wants to use the infrastructure for training and awareness-raising purposes.

For young people, an educational programme is currently being developed in cooperation with other organisations to awaken interest in nature and technology, understanding of natural processes and awareness of protective measures and natural hazards. In addition, the laboratory models are open to professionals in public administration and engineering companies. Given the work in which the laboratory is involved, it is not possible to explore the area of natural hazards on a specific model for demonstration purposes, but the topics presented are based on the company's current project experiments. Here, physical modelling in the laboratory makes it possible to demonstrate the effectiveness of a project in a concrete way and, at the same time, to make clear the effects of the river engineering work on the environment and landscape.

The visualisation of the hydraulic processes in the physical model thus contributes significantly to a more effective and productive dialogue between the different actors involved in the planning, design and implementation of the measures. This is in line with the principles of the risk governance approach.

Best practice:

- ✓ **Despite the complex morphodynamic issues, the effect of the protective structures can be explained with the existing experimental set-ups.**

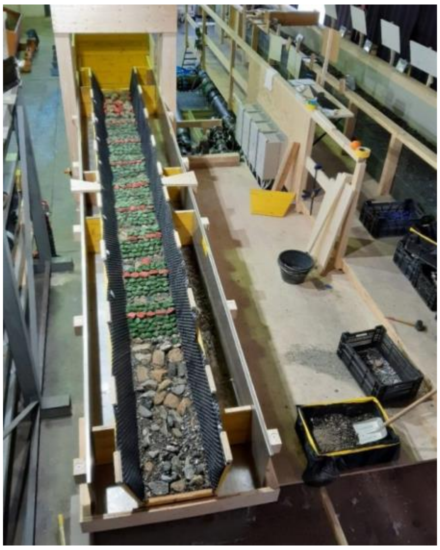

Fig. 34: Model for the river engineering measures on the Maira at Laboratorium3D

Fig. 35: Investigation of the stabilisation of the Maira riverbed at Promontogno by means of a stepped basin system

Model for dyke relocation, preliminary lowering of barrages and flood polders during a flood wave (Germany, Bavaria)

In the context of the discussion of the flood polders on the Danube, a model was created at the Technical University of Vienna which simulates the effect of a dyke relocation, preliminary lowering of a barrage and a flood polder on the course of a flood wave. The main aim is to produce film material in which the effects of the various flood protection measures are presented in a vivid and generally understandable way. The target audience was the general public, in particular the participants in the discussions about the floods (including municipalities, stakeholders, associations, interest groups).

The flow model was created in 2016 in a flow channel at the Technical University of Vienna. It consists of an approx. 12 m long upstream area, in which the technical measures are installed, and a downstream area, in which the effect of the measures on a settlement (houses with a church) is observed. Depending on the protective effect of the flood protection measure under examination, the river water overflows the banks of the settlement to a greater or lesser extent and spreads into the urban area. The terrain behind the dykes rises in a straight line in the model. The extent of the flooding is indicated by a tape measure, which serves as a level gauge, in the form of the flood width in centimetres.

In order to demonstrate the effects of the technical flood protection measures on the settlement during an ongoing flood wave, three different measures were considered:

Measure 1 - Dyke relocation: First, the protective effect of a dyked river course was examined as a reference point. High flow velocities occur in the watercourse. The straight and obstructed course of the river results in an increase in runoff. During floods, however, the water overflows the banks unhindered and floods the settlement. For comparison, the course of the river upstream from the settlement is then widened with the same flow rate. The dyke relocation depicted in this way creates a certain amount of retention space. Observers recognise that in the event of a flood, this retention space is filled up first. Once it is full, however, flooding of the settlement still occurs, albeit with a time delay and with slightly less severe consequences. This shows that small floods can be absorbed by dyke relocations and creating new flood plain areas. In the case of larger floods, the free retention area is already filled before the flood reaches its peak and is then no longer available for retention. In addition, this measure is intended to convey to observers that the dyke relocation and the creation of flood plain landscapes give the river more space for natural development. This not only helps flood protection by delaying runoff, but also brings about the formation of ecologically valuable habitats.

Measure 2 - Preliminary lowering of barrages: First, observers learn that larger rivers are regulated by barrages and chains of barrages linked together. It is then explained how, by deliberately lowering the level before a flood wave is expected, the reservoir space is made available as retention space. Particular emphasis is placed on the need to consider downstream residents when draining the reservoir. However, the model shows that preliminary lowering of the barrage has only a minimal effect on the flood wave and can only be applied as an additional measure, especially for small floods.

Measure 3 - Flood polders: A flood polder is presented as an effective way of reducing the flood peak. Following an explanation of the associated structural measures, observers are given an understanding of how a polder works. The intention is to make people aware that deliberate flooding of undeveloped areas, e.g. agricultural or forestry areas, is accepted in order to protect built-up areas and their inhabitants from the damage caused by floods. In the model, the water coming from upstream is diverted (in a highly simplified way) into a retention area to one side of the settlement. This protects the settlement from flooding in the model.

Overall, the model design corresponds to a scale model of the sort used in hydraulic engineering testing. The three public flood protection measures can be communicated to the observer in a comprehensible and appropriate way through the video clips, even if the effects of the flood are greatly simplified in the model.

Best practice:

- ✓ **The tape measure which functions as a level gauge provides the observer with a visual aid for comparing the water levels and thus the effectiveness of the flood protection measures.**
- ✓ **It is made clear that some measures may be required under certain circumstances, in particular preliminary lowering of barrages, which can lead to flooding and damage in the downstream area even before the actual flood wave arrives.**

Fig. 36: The river model in the hydraulic engineering laboratory of the Technical University of Vienna, with a view of the settlement in the downstream area

Fig. 37: During floods, the river overflows the banks of its obstructed course and floods the settlement

Fig. 38: Flooding in the settlement area is clearly depicted.

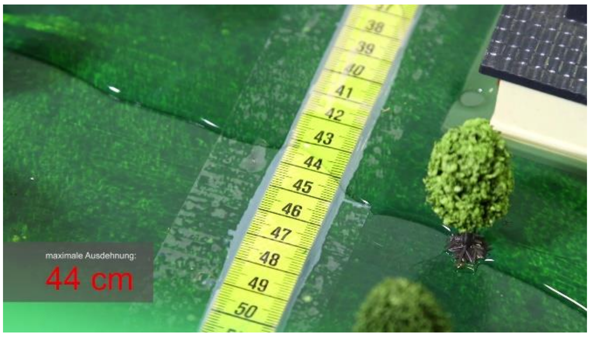

Fig. 39: A tape measure is used as a level gauge that enables the effect of flood protection measures to be assessed.

Participatory 3D Risk Mapping (France, PARN)

In the context of the Integrated Natural Risk Management territories (INRM - the French 'TAGIRN' network), new approaches to risk communication are being tested for the French Alpine regions. One of these is the creation of three-dimensional topographical risk maps with the participation of the local population. For a given area, the landscape is reproduced roughly using cork materials, and the actual land uses of the area (residential areas, houses, roads, ...) and the natural processes (course of a river, etc.) are mapped onto it. In addition, the danger zones are marked on the model. In this way, the inhabitants of the region can see their vulnerability in the model, which enables a discussion about the risks they face.

Best practice:

- ✓ **Creating the model in collaboration with the residents of the region helps with acceptance of the model and encourages discussion.**

Fig. 40: The model in the creation phase

Fig. 41: The landscape is modelled.

Fig. 42: The finished model with red markings of the risk areas

Fig. 43: Using the model with children

Haptic and interactive models

Interactive models for Alpine natural hazards (Slovenia, Ljubljana)

Hidrotehnik Water Management is a private service provider in the area of public water management in Slovenia. It monitors catchment areas and carries out planning, design and maintenance. In addition, it works in public relations, communicating the dangers and countermeasures to be taken in the event of natural hazards such as floods, torrents, flash floods, rockfalls, landslides and heavy rainfall, and dealing with issues of self-protection. Among other things, interactive models have been developed for young people to demonstrate the dangers posed by natural hazards and also by flood protection structures if they become overloaded, and to teach them what to do in an extreme case. This is particularly intended to raise awareness of correct behaviour during natural hazard events (events for short). In addition, the aim is to explain the capacity of natural structures (e.g. protective forests) to mitigate events. The benefits of the models are directly linked to the continuous risk governance approach, which promotes and provides training in self-protection and personal responsibility before, during and after a flood.

The model consists of four sections, each in a plastic box.

Protected forest section: In this part of the model, the effect of the forest on precipitation retention and erosion reduction is presented. The same amount of water is poured over two areas with the same slopes, one a forested area and the other, for comparison, an unvegetated area. In both cases, the characteristics of surface runoff are observed. The water flows more slowly out of the forest and the forest floor. By contrast, the water on the open area leads to rapid runoff, which also causes erosion of the soil. In a joint discussion, the young people work out why both healthy and extensive forest areas and fields that are cultivated or covered with vegetation all year round are important for flood protection.

Torrents and associated hazards section: This part of the model deals with sudden hazards after extreme precipitation in Alpine terrain and associated secondary hazards, e.g. run-off in torrents, landslides on roads, erosion of banks, rockfalls. This is done by spraying water onto sloping terrain covered with soil and observing the effect that erosion has. Some effects, such as landslides, also occur after the flood peak has passed. This is to convey the idea that secondary hazards can also arise after events. The intention is to teach young people to stay away from dangers until the area is opened up again.

Retention basin section: This section of the model is intended to explain the functioning of a retention basin, but also the inevitable residual risk. First, the young people are shown how a retention basin is constructed in principle and how it is used in the context of flood protection. If only a little water is added to this part of the model, the water remains in the body of water. At a critical level of runoff, the retention basin must be activated and it can be observed how this eases the flood situation in a settlement. However, if the runoff exceeds the next critical value, even the retention basin cannot provide complete protection. The settlement is damaged by the flood despite the protective structure. Young people are intended to see that such extreme cases are serious and threatening situations and it is important to follow the instructions of parents, teachers or the emergency services and move to a safe place.

Dyke damage section: This part of the model deals with the functioning of a flood protection dyke, in particular its limited effect in an extreme event and the resulting hazard patterns. The river is filled with water for this purpose and the effects on the other (air) side of the dyke are observed. Young people can observe how the turf or whole areas of the earth crack and bulge and how seepage water escapes through the dyke. In the worst case, slopes collapse, hydraulic heave occurs and eventually the dyke may collapse. Again, it should be understood that the dyke is a technical protective structure and not a playground. In particular, it must not be approached in the event of a flood, for example to observe the flood from there.

Best practice:

- ✓ **A good compromise is struck between simplicity of the model, cost and complexity of the processes**
- ✓ **Relatively simple structure, easy to transport and with well-created teaching and methodology**
- ✓ **The discussion-based concept is intended to stimulate reflection and further discussion at school and at home.**

Fig. 44: Section with protective forest during set-up

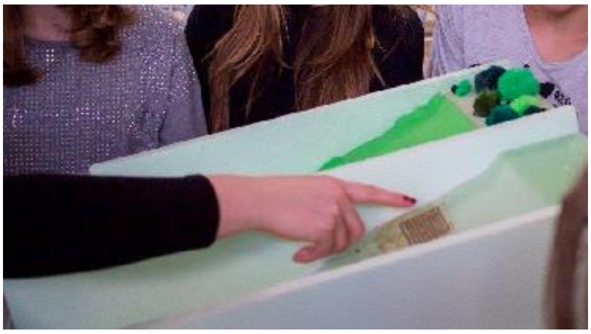

Fig. 45: The result for the area without protective forest is explained

Fig. 46: Section with torrent, showing erosion when water is sprayed on it

Fig. 47: Section with torrent and erosion: observation of the erosion process

Fig. 48: Section with the retention basin during filling

Fig. 49: Section showing dyke damage and failure

Flood protection torrents in Bayrischzell (Germany, UniBw)

The Rosenheim Water Authority commissioned a physical testing model for the confluence of two torrents in the municipality of Bayrischzell as part of the planning for expansion of the flood protection. This is the point at which the Larchbach flows into the Wendelsteinbach. In the existing planning, the Larchbach has been channelled through a covered rectangular channel with two bends running in opposite directions before the confluence. It was assumed that the resulting three-dimensional flow conditions would be very strong and restrict the amount of runoff. A bridge in the centre of the village represents another key point with regard to the freeboard required and the risk of obstruction with driftwood. At the University of the German Federal Armed Forces, both the runoff capacity of the two torrents and the sediment and driftwood transport were investigated in a hydraulic engineering model (scale 1:10) for the load cases HQ5, HQ10, HQ50 and HQ100 in 2019/2020.

Since the end of the project, the physical model has been available for university teaching purposes but also for public relations work. At events such as open days, the hazards of flooding, sediment transport and obstruction with driftwood are demonstrated to a wide audience. There is no specific target group. Visitors can regulate the flow of the two torrents and add any amount of sediment and driftwood to the water themselves. Demonstrations were also held for the local councillors of Bayrischzell and for pupils from Munich Technical College.

Best practice:

- ✓ **The interactions between runoff, sediment and driftwood can be experienced directly in the model.**
- ✓ **The model is well presented with trees, people and vehicles so that the observer has a sense of the scale of the processes occurring.**
- ✓ **The function of various protection measures, such as bank protection, flood protection walls, driftwood rakes and gravel traps are discussed.**

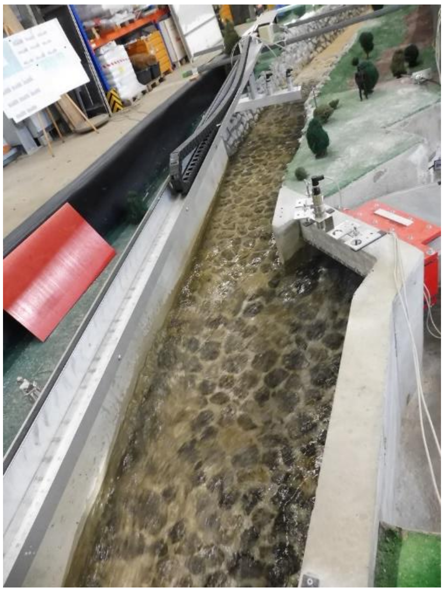

Fig. 50: Model of the confluence of the two torrents in the Bayrischzell area. The Wendelsteinbach flows from top to bottom and the Larchbach flows in from the right.

Fig. 51: In the case of HQ_{100} in the Wendelsteinbach, the village is protected by a wall of armourstone and a flood protection wall.

Fig. 52: The covered channel of the Larchbach becomes blocked with heavy influxes of alluvial wood.

Fig. 53: Accumulations of driftwood can also lead to blockages at the bridges in the village, which can block the upper course.

Rockfall model (Austria)

The Torrent and Avalanche Control, Vienna/Burgenland Section uses a rockfall model to illustrate the necessity of protective forests and the protection they offer against rockfall hazards. The process elements addressed are the mountains, the forest, the infrastructure and the living area.

The model consists of a wooden frame (sloping surface 1 x 0.7 m), which is set up on an incline on feet made of iron tubes. In the lower part of the model, a village is represented by a few houses. Above this, there is a wooded area on the slope. One half of the slope is covered with very few trees. On the other side, a dense protective forest has been set up. A flap at the top of the wooden structure can be used to throw stones down the slope, which are prevented from hitting the houses of the village either by the trees, the dense forest or by protective nets.

The viewers build an effective protective forest, test it with a rockfall event and then evaluate their own planning performance. The slope of the model has holes so that viewers can insert the trees individually and thus “plant” the protective forest themselves. In addition, rockfall protection nets (scale approx. 1:100) can be installed as a technical measure. The aim of the model is to recognise the effect of the protective forest with regard to rockfall hazards on the basis of the measures the participants take themselves.

The rockfall model can be disassembled and fits in the boot of a car. Thus, it can be used as a mobile model at schools, action days or trade fairs. Even indoor use in the classroom is possible. Only one person is required to supervise the model.

Overall, the model represents a single isolated process, namely rockfall, and the effect of the protective forest and of technical measures. This is conveyed in a very understandable, intuitive and interactive way. The complexity of the model is classified as medium. The cause of the rockfall and the damage it actually causes in the locality cannot be evaluated.

Best practice:

- ✓ **Trees and technical measures can be placed more or less anywhere in the model.**
- ✓ **Relatively simple to set up and easy to transport**
- ✓ **Message of the model: “Lots of trees - lots of protection” is very clear.**
- ✓ **The rocks rolling down makes a distinctive “noise”, which makes the visitors take notice. This acoustic effect underlines the danger of the event.**

Fig. 54: The rockfall model with the movable forest area on the left and the protective forest on the right. The village affected lies below. The rocks can be seen at the top.

Fig. 55: The rockfall model at the workshop in Heimschuh in 2019.

Fig. 56: Trees and protective walls are positioned to improve their effect, which enables interaction with the protective measures.

Fig. 57: Testing the protective measures with rocks by raising the flap.

Interactive model of a pumping station (Germany, WWA Deggendorf)

There is an interactive model of a pumping station in the information centre in the Shipmaster’s house at the Deggendorf Water Authority. As an integral part of the “Danube as a lifeline” exhibition, it explains the structure and function of a pumping station – one of the protective measures implemented by the authorities – to visitors as part of the public relations work. As far as the protective effect of the dyke is concerned, the intention is to convey the idea that inland drainage of the dyked areas into the Danube must be guaranteed during both normal runoff and flooding of the Danube.

The model is square with sides of 70 cm and is suitable for a target audience of primary school children and older. The way the pumping station works can be studied independently or under supervision using the information provided and through its intuitive operation. Visitors to the information centre are able to interact with the model. Three control wheels on the model can be used to control a slide gate of the pumping station, the output of the pumping station pump and the runoff in the Danube from the outside. It shows that at normal or slightly increased runoff into the Danube, the water from the hinterland can be fed into the Danube without the aid of the pumping station. In this situation, the pumping station is not yet in use. The water from the hinterland is only channelled into the Danube through the pumping station. In a flood situation, this can be used to illustrate what would happen if a dyke had been constructed without a pumping station. This is done by increasing the Danube runoff, leaving the slide gate open and the pump switched off. The water level in the Danube rises, flows through the pumping station and floods the hinterland. To mitigate the damage, the visitors then close the slide gate, preventing the Danube flood water from reaching the hinterland. But this means that runoff water from the hinterland builds up in front of the dyke and would flood it if the pumping capacity of the pumping station is not adjusted to the amount of water to be pumped from the hinterland into the Danube.

Overall, the interactive model of the pumping station illustrates the way this protective measure works in an extremely intuitive way and thus contributes to acceptance of government-managed flood protection. It is easy to use and understandable for everyone. Usually the model is used as part of a guided tour, but it can also be operated independently. The consequences of flooding in the hinterland cannot be represented by the model.

Best practice:

- ✓ **The model has been created very carefully and in high quality.**
- ✓ **The complex processes for operating the pumping station can be controlled intuitively from outside using just three control wheels.**

Fig. 58: Model of the pumping station without runoff in the Danube

Fig. 59: Model of the pumping station during a flood situation in the Danube

Uplift of houses (Austria, Upper Austria)

The Department of Water Management of the Upper Austria Regional Government deals with the processes of flooding, flash flooding, heavy rainfall and resulting recommendations for self-protection, among other things, using a model of the uplift of houses. There are two target audiences. On the one hand, the aim is to make homeowners aware of the dangers of flooding and rising groundwater with regard to uplift of their houses. On the other, the model is used in fire brigade training to point out the dangers in houses affected in this way when the emergency services are deployed to carry out a rescue or to pump out flooded cellars. The model is therefore mainly used in public relations and fire brigade training, but also in schools.

The mobile model is 80 x 40 x 40 cm in size and depicts the process elements of the home and the ground around it on a geometric scale of 1:50. Houses made of Perspex, glass balls to simulate the granular moving floor, stoppers, a pump to pump out a Perspex house and a bucket to fill up the model are used.

Before the model demonstration begins, the essential background information is discussed with the visitors. A hollow body and a solid rock are first lifted to explore the physical quantity of density. Then both are immersed in a water-filled bucket to observe the buoyancy effect. Then the volume of a common cellar is worked out together and the buoyancy is calculated for it. In addition, visitors estimate the counterweight of the house. For the subsequent model demonstration, a model of a house is placed in an aquarium. The remaining space in the aquarium is filled with glass marbles, which form the bottom. A bucket is used to pour water into the aquarium and into the house. The observers can now see how the groundwater level around the house is rising. As long as the water level in the house stays below a certain level, the house will remain stable in its position. As soon as the water outside the house has risen above the level of the terrain (above the level of the marbles), water is pumped out of the model house using a small hand pump. Attentive observers hear a rattling as glass marbles slip under the slowly rising, tilting model. The house lifts due to the hydrostatic uplift. By the end of the experiment, the house is leaning at an angle.

The model shows that with a leak-tight design (white tank), the house can float up in the presence of groundwater if the uplift force is greater than the total of all the building loads. It makes no difference whether it is groundwater, slope water or flood water. In the worst case, buildings can suffer severe structural damage or even break. Connection pipes can leak or break away. The visitors can then discuss how the resulting damage to the building can be avoided. This includes, among other things, allowing floodwater to enter through flood openings. It is even better to protect the property from uplift by flooding the basement with clean water at the right time. It is important for the fire brigade to understand from the model that before pumping out a basement, it is necessary to check whether the surrounding groundwater level has already subsided or the building is designed to be uplift-proof.

Even though the model looks at one isolated process, its effectiveness in raising awareness is impressive. Homeowners can identify with the problem directly and take precautions to protect their own homes.

Best practice:

- ✓ **Using marbles is suitable for children. They are already familiar as toys and children are therefore very aware of the sound the marbles make when they move and run under the house as it is lifting.**
- ✓ **The topic of self-protection is addressed, high value for homeowners.**

Fig. 60:
The uplift model for houses of the Department of Water Management of the Upper Austria Regional Government, here at the workshop in Heimschuh in 2019.

Tyrolean flood model (Austria, Tyrol)

At the Office of the Tyrolean Provincial Government, the Water Management Department has a flood model for demonstration at public events (e.g. open days). An exact target audience was not defined for the model. The mobile model (several people are needed to move it) has a size of approx. 2.5 m x 1.5 m and is intended to contribute to the understanding of natural processes and to explain the functioning of flood protection measures (linear and retention measures). For this purpose, a schematic river course made of plastic was created on a wooden substructure, which passes a schematically designed village with wooden buildings and then an undeveloped area. From a water tank, a pump delivers the water to the upper reaches of the river. As the key protective measure, a straight dyke is constructed, which can, however, be removed by means of screw fittings. By varying the bank protection (with or without a dyke), three scenarios are presented. Initially, no dykes are set up. Without the protective measures, flooding of both the built-up and the undeveloped area will occur. In the second scenario, the village is enclosed by a dyke and thus protected from flooding. However, the undeveloped areas (retention areas) are flooded, which leads to little or no aggravation of the flood situation downstream. In the third scenario, the course of the dyke runs around the village and the undeveloped area. This means that neither of the two areas is flooded. However, this also means that there is no retention area available to buffer a flood wave. This can lead to an aggravation of the flood situation downstream.

Even though the relatively detailed model idealises the complex natural processes and the scenarios remain highly schematic, the model structure can vividly illustrate the basic effect of the dykes and retention areas. However, interaction is only limited to positioning of the houses and the dykes. For the latter, however, there is only one installation variant. The operator mentions the simpler and faster option of replacing the flood protection measures as a potential optimisation of the model.

Best practice:

- ✓ **Protective measures with screw fittings allow the effect of the protective measures to be demonstrated.**

Fig. 61: View of the flood model at the Office of the Tyrolean Provincial Government from upstream

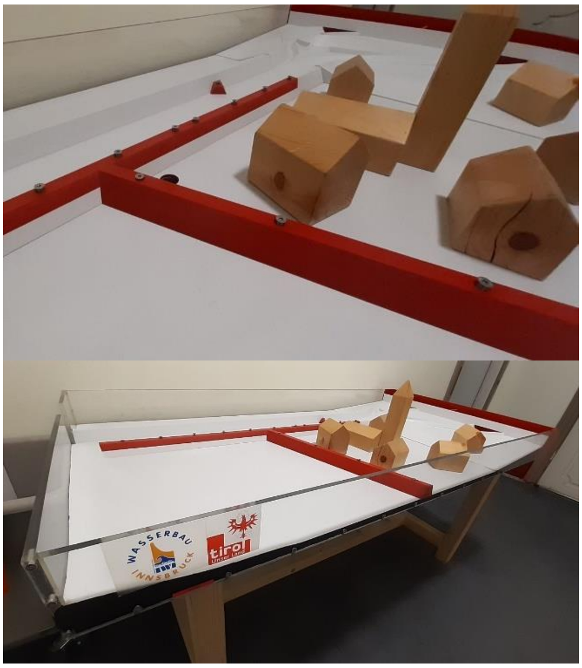

Fig. 62: The red dyke elements in the model can be removed with the screw fittings.

Ward’s Stormwater Floodplain Simulation System (USA, Rochester)

The Stormwater Floodplain Simulation System is a commercial product of the US company Ward’s Science[6]. The educational model was created in collaboration with the Michigan Stormwater-Floodplain Association. They can use the model to investigate how different factors in a catchment area affect the course of a flood wave. It demonstrates the critical role of floodplains and the anthropogenic impact on the environment, especially in terms of land sealing. Students also discover the benefits of retention areas and floodplain landscapes for delaying runoff. The participants can create their own dykes and test them in a flood situation. Conceptually, the model is designed for teamwork, so that a small group of students work out the best possible solution for a given scenario.

The model consists of an acrylic glass tank (1.17 m long, 0.46 m wide, 0.24 m high) in which a river landscape with a curved river course has been modelled. At the inflow edge, a sprinkler system enables simulation of two different precipitation intensities. The outflow is through a tube on the outflow edge.

As an introduction to the approach, water is sprayed onto a sealed car park area in the first scenario. The precipitation is applied to the surface by pouring water from a bucket into a perforated acrylic glass tray, from which it then rains down onto the parking area. The students observe that no water can penetrate the ground and that it goes directly into the river via the sealed surface. As a result, the flood wave quickly reaches a settlement near the course of the river and floods it. A measuring tape attached to the side allows the water level to be read and plotted over time. Afterwards, the students independently work out possible improvements to avoid the flooding. A dyke around the settlement can be modelled with plasticine, for example, and the effect of the protective measure can be tested with the same flow rate. However, it is also possible to evaluate how the dyke construction affects the water level course for downstream residents.

In a second step, a small retention basin is installed under the sealed car park. The precipitation thus first falls on the sealed surface, then runs into the retention basin and only reaches the course of the river after that has been filled. This models a partially permeable surface, such as that made possible by grass pavers in the parking area. Overall, the students recognise that the retention effect achieved in this way delays and mitigates the runoff of the flood wave into the watercourse.

As a third option, instead of the retention basin and the car park, the students set up an area with absorbent sponges that simulate the effect of a floodplain or forested area. The students apply the same precipitation intensity to the sponge area as before and compare the development of the water level in the river over time. The delay in runoff and the reduction of the flood peak are thus clearly visible.

Even though the model is only the size of a small table, various scenarios can be investigated. The basic educational idea is comprehensible and clearly defined. The methodological approach is very well thought out and allows the pupils to interact with the model intuitively and independently.

[6] https://www.wardsci.com/store/catalog/product.jsp?product_id=8889092

Best practice:

- ✓ **The issue of land sealing is addressed.**
- ✓ **With the help of the tape measure, the water level is recorded over time so that the retention effect of the areas on which the precipitation falls can be assessed.**

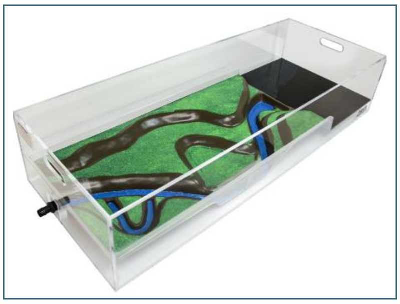

Fig. 63: Stormwater Floodplain Model with flow direction from right to left

Fig. 64: The model can be elevated at the inflow edge to achieve higher flow velocities.

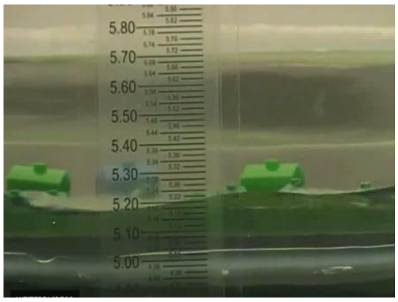

Fig. 65: The model users record the change in water level over time by means of a scale.

Fig. 66: Precipitation falling on a sealed car park area is simulated by adding water.

Fig. 67: An estate near the village is flooded.

Fig. 68: Users can protect the village by installing a simple dyke.

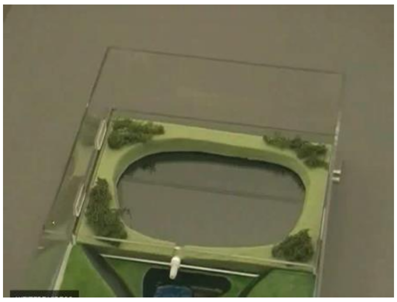

Fig. 69: A retention basin is created in the inlet to hold water.

Fig. 70: The car park is set up above the retention space.

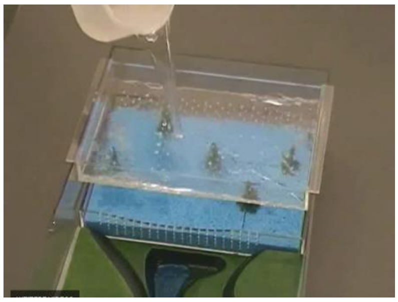

Fig. 71: Sponges simulate the retention effect of floodplains and forest areas.

Wetropolis Extreme Rainfall and Flood Demonstrator (UK, Leeds)

The Wetropolis model was mainly developed at the University of Leeds by Onne Bokhove and Wout Zweers (Bokhove et al., 2020). UK flood experts approached the researchers and requested a model for communicating the issues of flooding and heavy rainfall to the public, but in particular to explain the concept of recurrence intervals (annual recurrence). It had been recognised that, although statistical variables have to be used to explain structural protection concepts, the population has a very poor understanding of the statistics behind extreme events. The plan was to use a physical interactive model with a focus on a randomly generated flood event as an aid in future. The intention was also to explain how flood waves can be attenuated (surface roughness, storage effect of porous soils). A specific target audience for the model was not defined in advance.

Wetropolis is a conceptual physical model with a curved river course, floodplains, storage processes, porous surfaces (marshland) and an urban area affected by a randomly generated rain event. In terms of the scenario and bathymetric progression, Wetropolis is based on the Boxing Day floods of 2015 on the River Aire in and above Leeds. The actual model has dimensions of 1.2 m x 1.2 m x 1 m. In addition, there is a table-top structure with the control units (including Arduino controller, pumps, valves). The model surface was created from polystyrene and the river course and the flooding areas were then hydraulically roughened by applying fine sand. Three aquarium pumps with a maximum flow rate of 0.375 l/s convey the water from a tank of approx. 26 litres to the inflow edge of the watercourse. The precipitation in the marsh area is made possible by a perforated copper pipe. The marsh itself is represented by an acrylic glass box filled with expanded clay balls and open on one side to drain into the body of water. Gauze material prevents the expanded clay balls from being washed out of the marsh reservoir. The marsh represents a porous soil structure into which precipitation water can seep and then be released into the watercourse with a time delay. For interaction, the outlets from the reservoir are equipped with valves so that the model viewers can also store the rainwater or drain it into the watercourse by hand. The flooding of the urban area can be experienced through haptic feedback.

The recurrence interval for an extreme event is determined by a Galton board, through which a statistical distribution function is fed into the model in real time. Thus, both normal and extreme events occur, according to the intensity and duration of the precipitation in the model. A second Galton board is used to determine at random whether the precipitation falls (i) into the reservoir with immediate runoff into the watercourse, (ii) into the reservoir and the marsh, (iii) onto the marsh with subsequent re-formation of groundwater and delayed non-linear runoff into the watercourse, or (iv) no precipitation falls at all in the catchment area. For the general process of the model, a normal (non-critical) runoff is initiated in the model watercourse. Within a Wetropolis model day, a random rain event is generated every 10 seconds. Depending on how the balls fall in the Galton board, the rain event occurs in one of the four model areas with four different rain intensities. Two of the combination options lead to low or very high flood situations. However, it is not known during the demonstration when the extreme event will occur (about three times in 100 Wetropolis days, corresponding to about 1000s). The model viewer thus gains an understanding of what a rare event is.

The strength of the Wetropolis model is that it conveys the probability of an extreme event and its recurrence interval. In particular, the statistical probability of an extreme event is conveyed. The extreme event can be observed from the precipitation, through the rise in the groundwater level or the runoff into the watercourse, to the flooding of the affected areas. Overall, it is a conceptual model of medium complexity. The model focuses on showing how the processes come about and only addresses public countermeasures to a limited extent. Issues relating to self-protection are not covered at all. The effort required to create and operate the system is considered high. Overall, the model can be considered mobile. It was created so that it can be transported in a larger car with the rear seats folded down. The Wetropolis model has already been used at a wide variety of exhibitions, trade fairs and public relations events, but it has been particularly beneficial at workshops with flood victims.

Its creators point out that flooding of the urban area could be highlighted further to improve the model. For example, lights in the city could go out if short circuits occur during flooding. In addition, roughness of the watercourse should be illustrated by removable segments. In addition, more porous areas can be created and smaller bodies of water with additional buffer functions and variable, user-controllable storage could be installed.

Best practice:

- ✓ **Representation of probabilities in the model**
- ✓ **Porous material simulates the effect of infiltration for time-delayed runoff**

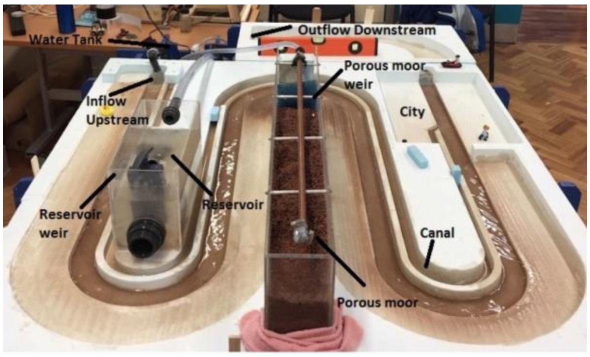

Fig. 72: Photo of the basic structure of the Wetropolis model in operation

Fig. 73: Photo of the Wetropolis model with view of the marsh reservoir

Fig. 74: Galton boards for controlling the duration, intensity and location of precipitation.

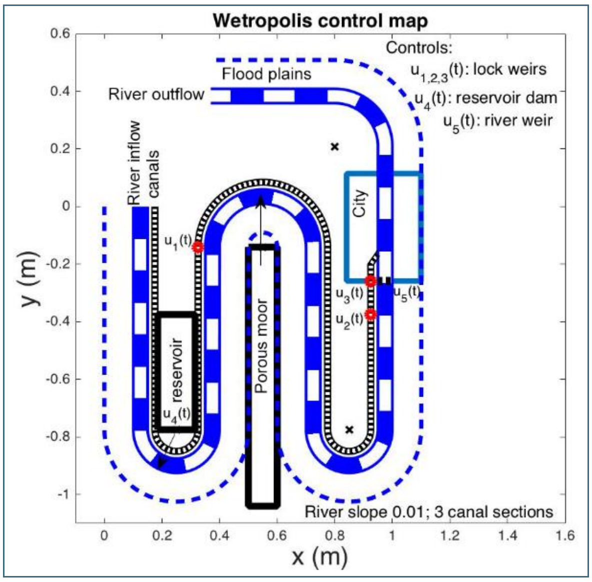

Fig. 75: Schematic illustration of the Wetropolis Models with model dimensions

Emriver Em2 (Italy, University of Bozen-Bolzano)

The Emriver Em2 model is a commercial product made by Little River Research & Design from Illinois, USA. It covers the topic of river flooding in connection with morphodynamics. Additional structures such as dykes, dams and bridges can be used to illustrate the interactions that occur (e.g. kolk formation). The model encourages interaction, and model users immediately want to try out the experiments to learn fundamental morphodynamic processes. This model is used at the University of Bozen-Bolzano for teaching on flood hazards and to study fluvial flow forces. In addition, the model has been presented to school and adult audiences at both fairs and exhibitions.

The model represents the complex and dynamic process of fluid flow and the stages of sediment transport from the start of the movement, erosion and sediment uptake, through transport, to deposition. The following scenarios can be studied:

Fluvial morphodynamics	Measurement of longitudinal profile and topography
Aquatic ecology	Interaction between habitat elements and morphodynamic processes, role of riparian vegetation with regard to flow cross-section and sedimentation
Forestry, management of riparian zones	Role of riparian vegetation and the watercourse margin with regard to bank erosion and progressive meandering, protective effect of the forest and floodplain in relation to retention and reduction of flow velocity in the event of overload, hydraulic interaction between channel and floodplain.
Issues in engineering and environmental sciences	River profile, meandering, erosion, accumulation, instream river training, flood protection, roughness, naturally stable channel cross-section

The entire structure (1.9 m x 0.8 m) can be disassembled for transport with a larger vehicle. A reinforced aluminium box forms the base for the model and is placed on two folding aluminium trestles. A flow of 1892 litres per hour is fed into the model by a submersible pump (12V supply) from a bucket-shaped reservoir with a capacity of 102 litres and a modular sediment filter on top. In the inflow area, an energy dissipater unit ensures a gentle inflow of water and prevents initial erosion at the beginning of the model. Adding blue and green colouring agents makes the flow visible. The heart of the model is the 68 kg of plastic sand, which is spread over the model surface. The sediment consists of different grain sizes, each coded with a different colour. This makes transport phenomena visible according to grain size.

2 or 3 people are needed to set up and operate the model. Once the flow has been set up, the model can be used relatively independently and intuitively by the user. The playful approach enables easy interaction even for non-professionals. The supervision work increases when a lot of people are working on the model at the same time, as they may interfere with each other in relation to the hydraulic and morphodynamic conditions.

A relatively shallow watercourse is examined in the model. As far as interaction with other natural Alpine hazards is concerned, the model could be extended to include more hilly regions to illustrate torrent processes and the resulting events when they flow into the main watercourse.

It should also be noted that the manufacturer Little River Research & Design offers two larger variants of the model, the Em3 and Em4. However, these are not yet in use in the Alpine region.

Best practice:

- ✓ **High degree of user motivation to interact.**
- ✓ **Sediment colour-coded by grain size allows easy visual differentiation in morphological processes**
- ✓ **Robust model**
- ✓ **Many different scenarios possible**
- ✓ **Role of riparian vegetation and the watercourse margin with regard to bank erosion, protective effect of the forest and floodplain in relation to retention and reduction of flow velocity in the event of overloading**

Fig. 76: Use of the Emriver Em2 model in Italy

Fig. 77: Emriver Em2 model in use with children

Fig. 78: Colour-coded sediments make transport phenomena visible according to grain size.

Fig. 79: The Emriver Em2 model encourages interaction.

Interactive model for visualisation of hydrostatic pressure (Germany, WWA Ansbach)

With this model, the effect of hydrostatic pressure and the resulting force on a river dyke can be both visualised and experienced haptically. The model is suitable for a wide audience and any age group and is located in the permanent exhibition on flood protection. The model essentially consists of two discs, between which a transparent plastic bag filled with about 10 litres of water is suspended. One of the two discs is anchored to the ground. The other disc is movable via a swivel joint at the upper edge. Users of the model can either push the movable disc by means of various handles or pull it from the other side, causing the water bag to be compressed. As a result, the water rises upwards, the hydrostatic pressure increases and requires the model users to apply an increasingly stronger force to push or pull the bag. The model can be extended to include a dynamometer or pulley. The model is mobile and requires a van for transport. The model can be set up on various surfaces by two people.

This model only reflects the physical effect of the hydrostatic pressure; due to its low complexity, it cannot represent the natural processes on the dyke in the event of a flood.

Best practice:

- ✓ **The physical effect of the hydrostatic pressure can be experienced directly.**

Fig. 80: Hydrostatic model in action (side view)

Fig. 81: Hydrostatic model in action (front view)

Educational games, digital models, virtual reality

Card-based games for natural hazards: Memory and puzzle (Italy, South Tyrol)

The Provincial Warning Centre in Bolzano / South Tyrol uses interactive memory and puzzle group games to learn about floods, torrents and avalanches through play. Children of primary school age learn about natural hazards, how to deal with them, possible countermeasures and protection strategies.

The memory game set comprises 20 - 30 pairs of cards, each measuring 25x25cm. Made of hard plastic, the cards have natural phenomena, natural hazards and protective measures printed on one side. At the beginning of the game, the memory cards are laid out upside down on the floor in the classroom, on the ground outside or on a large table. The children stand in a circle around the cards and turn them over in turn. They look for two identical cards and pick them up as they find them. When a card is turned over, the picture on the card is discussed in a playful and simple way, thus conveying the content. Repeatedly uncovering the cards means that the natural phenomena depicted become imprinted in the children's minds. The winner of the game is the player who has revealed and picked up the most pairs of cards at the end. The children identify with the picture on the cards they have won: "I have the avalanche, the driftwood rake and the mountain goat".

The puzzle is used to create an overall picture by putting the puzzle pieces together correctly. First, the relatively large image sections are scattered on the floor. The children then put the whole picture together. The completed picture can be discussed.

As the cards are so easy to use, both games can be used in classrooms and on action days. The choice of images can be extended or changed and includes the following process elements in relation to public structures, municipal activities and self-protection:

- Natural hazards
- Protective measures such as torrent barriers, avalanche nets, dams
- Damage to houses, cars, flooding
- River landscapes, watercourse widening, revitalisation

.

Best practice:

- ✓ **Repetition helps children to internalise natural phenomena.**
- ✓ **The game is easy to transport and assemble.**
- ✓ **A memory game could support the impact of an interactive physical model.**
- ✓ **The size of the puzzle picture means that the children are physically active in putting the pieces in the right place. This also provides mental stimulation.**

Fig. 82: Examples of memory cards: large, meaningful pictures are very appealing to children, e.g. big diggers or large-scale devastation.

Fig. 83: Memory game with pictures of natural hazards, protective measures and river landscapes.

Fig. 84: Starting point for group work on the puzzle

Fig. 85: The puzzle has been successfully assembled and the content of the picture can be discussed.

MurGame (Switzerland)

MurGame[7] is an interactive, server-based computer game developed on behalf of the Swiss Federal Office for the Environment. The development costs for the basic version amounted to CHF 140,000. The underlying software of this “serious game” is used for professional modelling of debris flows. In MurGame, three-dimensional visualisation of the flows has been embedded in a game engine. The aim of the interactive game is to communicate the possible measures available to reduce risk from debris flows in a locality. The game was created mainly to raise public awareness and to make an innovative contribution to the professional training based on sound scientific principles. The target audience is broad. The game is generally presented to an interested public audience, but can be used for (secondary) schoolchildren and students and for training professionals such as architects, local natural hazard advisors, etc.

[7] https://murgame.ch

The process of debris flow and its destructive power are visualised in the game. Raising awareness of natural hazards in general, and in particular the interplay of protective measures and their costs, is one of the main objectives. Players go through the entire cycle of integrated risk management. In addition to the general issue of hazards, the aspects of damage potential and risk are highlighted. Organisational, spatial planning and construction measures (to protect both areas and properties) can be taken to reduce the risk.

A fictitious landscape with a residential estate is presented for this purpose. A torrent flows through the estate and one of two scenarios comes into play: either a small or a large debris flow. The torrent flows into another body of water at the end of the estate. Players have the task of constructing an estate with various buildings (residential houses, a church, a shop, a farm) on the alluvial fan while taking account of certain specifications, and of protecting the estate from a damaging event by implementing measures (dams, bedload collectors, reinforced construction, warning siren). The mudslide and the flooded areas are visualised by means of a rapid mass movement simulation. Players receive immediate feedback on the success of their planning. A subsequent assessment in the form of a damage report assists in quantifying both human losses and financial losses and indicates the satisfaction of the population with the performance of the players. After optimising the measures, the debris flow can be simulated again. Ideally, the risk is reduced by proportionate measures to such an extent that an optimal cost-benefit result is achieved with simultaneous satisfaction of the population.

MurGame has already been used successfully in schools, at trade fairs and in general public relations work (professional training, further education courses, teaching, integration in websites). At trade fairs, supervised use has proven to be ideal in drawing the players’ attention to certain aspects depending on the objective. This also makes it possible to identify starting points for further discussions.

MurGame can be used for a relatively wide range of applications. In guided use, the moderator has the opportunity to steer the discussions towards specific aspects depending on interest (property protection, space planning/hazard maps, ...). Even if the 3D modelling of the debris flows does not come up to the standards of today’s online games from larger gaming companies in purely visual terms, players can address the subject matter interactively in quite a detailed way. The processes depicted are quite complex, but the game remains intuitive. It should be seen as a learning game, not simply an entertainment game. The software is currently under further development. Among other things, the range of measures is to be expanded and operation and various game elements optimised.

Best practice:

- ✓ **Exemplary topography for the future physical model: main watercourse into which a torrent flows.**
- ✓ **Public protection structures (e.g. dykes), municipal measures (e.g. warning services, forestry) and the population’s own precautions (oil tanks, elevated light wells) are dealt with.**
- ✓ **The software is eye-catching at trade fairs and appeals especially to a young target audience who like gaming.**

Fig. 86:
The starting point for the game is a village built on an alluvial fan with a torrent flowing through it. This then flows into another watercourse.

Fig. 87: In MurGame, an estate has been created to complete the task set by taking appropriate protective measures.

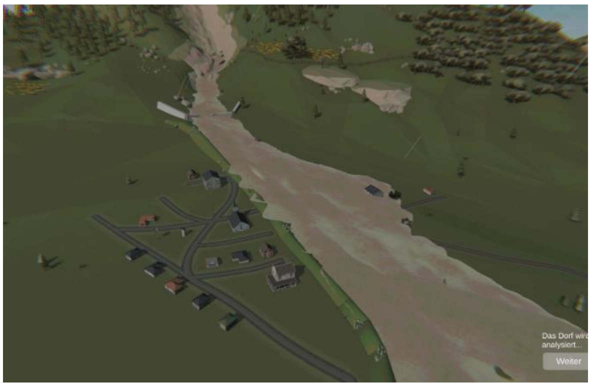

Fig. 88: In the computer-generated scenario, the locality is hit by an extreme event, revealing the effect of the planned protective measures.

Stop Disasters! (United Nations)

The UN Office for Disaster Risk Reduction (UNDRR) commissioned the company playerthree to develop the online serious game Stop Disasters![8] It deals with a total of five natural hazards (tsunami, hurricane, bush fires, earthquake, flood), each of which can be played by players at three difficulty levels. The primary goal of the game is to save lives.

For the flood scenario, a city in central Europe is depicted, in which a certain number of people live and which is characterised by agricultural and industrial areas. Located near a mountainous region, the city is repeatedly exposed to flooding. The player starts with a certain population size and is supposed to protect as many people, buildings and parts of the infrastructure as possible in preparation for an upcoming extreme event. In addition, various compulsory tasks must be completed when expanding the residential area, such as building a school or a hospital. The school must be particularly well protected, as it must be available as an emergency shelter in the event of a disaster. Players must also cover wells so that sources of drinking water are not contaminated during flooding. A fixed budget and a time limit until the extreme event occurs limit the players and require balanced decision-making. This leads to the realisation that not everything can be protected and people have to live with a degree of residual risk.

Best practice:

- ✓ **Players learn the concept of residual risk by playing the game.**
- ✓ **In addition to large-scale protection measures such as dykes and flood walls, measures at the local level and in the context of self-protection are also addressed (e.g. well protection, reinforcement of houses, secondary function of infrastructure).**

Fig. 89: Game interface of the Stop Disasters! online game, here in the flood scenario

[8] www.stopdisastersgame.org

Flood Action Virtual Reality (USA, Iowa City)

Sermet and Deminar (2018) present a virtual environment for disaster awareness and as a training tool for flood first responders. They point out that a realistic 3D game environment with real-time presentation offers great advantages. Their concept combines the technologies of virtual reality, artificial intelligence and high computing and graphics power. Users can orientate themselves in this representation of the real world, which has been digitised using geodata (DEM up to 1 m grid size). This allows the terrain and elevations of real places and landscapes to be mapped accurately enough to visualise floodplains in detail. ArcGIS can be used to add further environmental features, such as buildings, trees, roads, bridges, etc.
and traffic systems. Other environmental factors and weather events can be added. By specifying precipitation duration, intensity, humidity, wind speed, temperature and visibility precisely, historical flood events can also be reconstructed with regard to the catchment area, flood plain, water depths and recurrence interval.

Generally, a distinction is made between indoor and outdoor scenarios. The indoor scenario is particularly aimed at the general population. The players wake up in their bed at the beginning of the game and find themselves in a situation where water is entering the house and rising quickly. The task of the participants in virtual reality is to think about the measures required, prioritise them and finally carry them out themselves. This could be locating and rescuing other residents (multi-player mode), shutting off the building’s electrical system and gas supply, or finding an appropriate exit from the building to reach the emergency services. This scenario is intended to raise the awareness of the population regarding the dangers of flood events and the necessary countermeasures.

The outdoor scenario is particularly suitable for education, training and coaching of professional rescue workers. The players find themselves in a city where various mission objectives – some with time constraints – have to be completed. This can be done alone (single-player mode) or with other players (multi-player mode). It can involve escaping from the flooded area, supporting or rescuing survivors or supplying the population with emergency materials. Players can communicate fully with one another in the simulation. An integrated voice recognition system also enables the system to evaluate the stress level and psychological state of the rescuer from the pitch of the player’s voice.

The authors rate the usefulness of their virtual environment as very high, especially for a younger target group. Teenagers and young adults have a particular affinity for this technology because of the 3D gaming reality. Currently, however, the simulated area is limited to a circle with a radius of 1 km due to the limited computing and storage capacity. Further structural data (buildings, etc.) would have to be digitised in future to make the simulation environment feasible for other regions, too.

In addition to Flood Action Virtual Reality, Sermet and Demir use other applications of artificial intelligence to raise awareness among the population of flood events and the necessary measures to be taken. However, as these are not primarily models as defined by this study, they are simply listed here for the sake of completeness (Sermet and Deminar, 2018b, Sermet and Deminar, 2020, Sermet and Deminar, 2020b). A complete presentation and explanation of these methods can be found in the dissertation by Sermet (2020c).

Best practice:

- ✓ **There is a specific attempt to reach a young target audience.**
- ✓ **Issues of self-protection are dealt with (in single-player mode).**

Fig. 90: Screenshot of the Flood Action VR in the emergency supply scenario

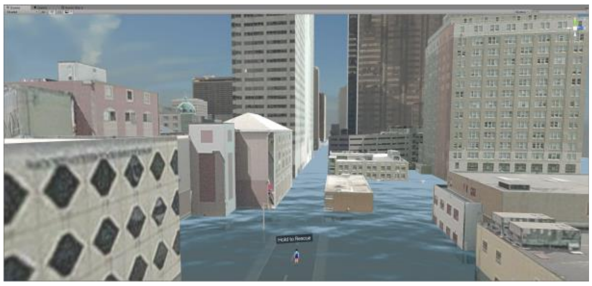

Fig. 91: Screenshot of the Flood Action VR in the scenario for rescuing the population

Virtual reality for danger zones (Italy, South Tyrol)

As part of the Interreg V-A Italy-Austria project RiKoST (Risk Communication Strategies), a virtual reality tool has been developed to communicate natural risks more effectively. The method of 3D animations with VR glasses developed and tested for the Regional Warning Centre in Bolzano has already been tested with the population in middle and high schools, as well as in public places. The aim of the development and its use with a broad target audience is to improve understanding of what natural hazards can do and what might constitute hazard zones. For this purpose, technical maps are transformed into 3D animations and 360° images of natural events. In addition to a better spatial idea of how processes work, this also allows general familiarisation with natural hazards and their effects.

The animation starts with a selection of the process to be considered:

- in the case of **hazard zones in general**, a 3D round trip is made of eight municipalities in South Tyrol, in which the yellow, blue and red hazard zones are shown in colour. At the same time, a voice explains the meaning of the colours and gives general information about natural hazards.
- The **avalanche** process is illustrated using the example of the 2018 Langtaufererertal avalanche event. A 360° panoramic view shows how the village and its buildings looked after the damage caused by the avalanche and how the village looks today.
- In the **flood** process, the cathedral square in the city of Brixen is visualised in the blue danger zone with and without flooding.
- In the village of Prags, the **debris flow** process is shown using the 2017 event, with a depiction of the village square with church before and after the event.
- For the **rockfall** process, a slope on the outskirts of Bolzano is visualised, with one half of the image showing part of an estate and its buildings with rockfall, the other without.

The selected 3D animation is then saved to VR goggles and can be controlled independently by hand using the command stick. Supervision is required at the same time to provide explanations. The animation can also be accessed by mobile phone using a QR code and viewed as a 2D animation.

Overall, the VR goggles are used to illustrate hazard zones and thus explain municipal hazard zone planning. The work involved in operating this tool is relatively little. It may be necessary to update the images and 3D animations after a certain time. The use of technology has proved particularly successful with young people, as they already have a high affinity for digital games.

Best practice:

- ✓ **VR goggles can be used almost anywhere (schools, public places, action days in halls).**
- ✓ **Interaction between supervisor and viewer enables additional explanations and information to be provided about danger zones and natural events.**

Fig. 92: VR goggles offer a view of danger zones in a three-dimensional environment.

Fig. 93: The 360° visualisations can be followed up in parallel on a 2D screen to provide additional explanations.

Projection model of the 1818 Giétro glacial lake outburst (Switzerland, Valais)

This model shows the origin, course and effects (flood, torrent, flash flood) of the glacial lake outburst in Giétro in 1818 (Ancey 2019). The dynamic course of events is projected onto a physical model surface (approx. 2.5 m x 1.25 m) in the form of a video film. The model and the associated video/projector installation were created by a joint project of local, regional and national authorities and with the technical support of research institutes (Federal School of Technology (EPFL) and the Technical School HES-SO, Sion).

The model is displayed in the local museum in Bagnes, where the consequences of the glacial lake outburst are commemorated. Its primary purpose is to demonstrate the events of the time to a broad public. However, aspects of risk assessment can also be mapped on the model at a scientific level. The model consists of eight assembled blocks on which the topography of the affected area (Bagnes valley) was directly milled on a scale of 1:25,000 using a CNC machine. A projector is installed above the landscape, which projects the events as a video onto the landscape. This requires complex calibration of the projector image with the physical base model in advance.

Starting with the failure of the glacier, the visitor can observe the effects of the resulting fluvial processes in the model. The emerging glacial lake and the flood wave are projected onto the model. For detailed observations, visitors can choose the following sequences:

- the flood after the 1818 outbreak
- the development of the landscape in the forest and the city on the topographical map
- the influence of climate on the glacier since the Little Ice Age

Overall, the model reproduces the complex processes of the 1818 Giétro glacial lake outburst in great detail. The effort required to create and operate the model is rated as medium. Only the installation of the projector and calibration of the projection with the physical base model require a certain amount of effort.

Best practice:

- ✓ **The digital model shows the extreme event as a whole, from the trigger to the fluvial processes and the effects in the inhabited areas.**

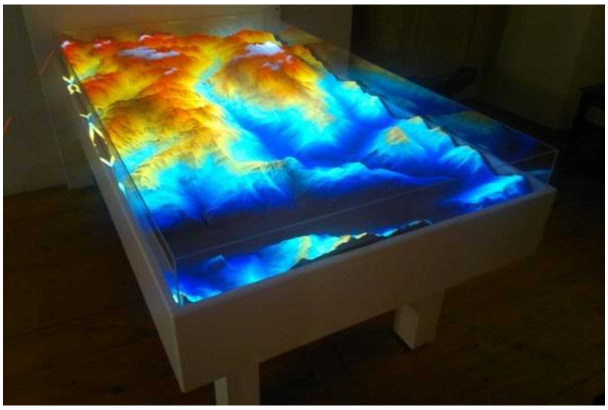

Fig. 94:
The model of the 1818 Giétro glacial lake outburst: the lighting and the colour scheme make the topography clearly visible.

Augmented Reality Sandbox – (USA, Davis)

The Augmented Reality Sandbox combines a haptic sand model with 3D visualisation.[9] The concept was developed as part of a US National Science Foundation-funded project entitled "Informal science education for freshwater lake and watershed science" by UC Davis' W.M. Keck Center for Active Visualization in the Earth Sciences (KeckCAVES) in collaboration with the UC Davis Tahoe Environmental Research Center, Lawrence Hall of Science and ECHO Lake Aquarium and Science Center.

Model users can use their fingers and hands to model a landscape in a box filled with sand. A Microsoft Kinect 3D camera and a video projector are installed above the model. These capture the current topography in the sandbox and project a topographical map with colour graded contour and elevation lines onto the sand. This gives you a spatial idea of the sand landscape that has been created. In addition, rain can be simulated in the model by holding up your hand. The rain then runs down the slopes of the projected landscape and may collect in the reservoirs created.

Through the haptic changeability of the landscape in the sandbox and the immediate reaction of the video projection, topics such as catchment areas, reservoirs, runoff behaviour and dams can be worked out in an entertaining way. The model is primarily aimed at a young target audience. It is also intended to help assess the natural processes to expect in real terrain or when looking at a standard 2D map. In the Alpine region, Augmented Reality Sandboxes are in use in Germany, Austria, Switzerland, Italy and Slovenia.

Best practice:

- ✓ **Combination of haptic and digital components**
- ✓ **Direct feedback for haptic modelling**

Fig. 95: In the Augmented Reality Sandbox, sand can be positioned in a landscape which is projected onto it as a topographical map. Here it is in use at the workshop in Heimschuh in 2019.

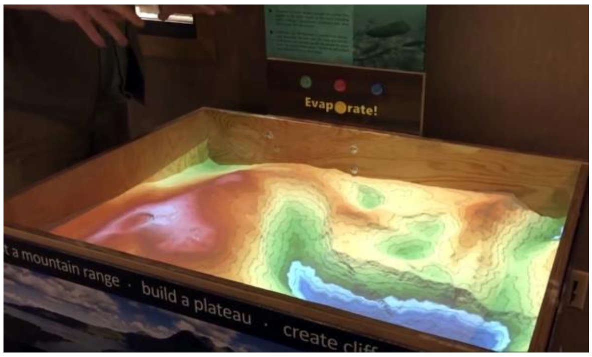

Fig. 96: After creating the topography, rain can be simulated, which then flows as it would in the real landscape.

[9] https://arsandbox.ucdavis.edu/

Child-friendly interactive learning by independent model construction (Italy, South Tyrol)

In schools and on action days, a high educational impact can be achieved by getting children to build a model representing a specific issue independently. This is especially useful for children of primary and middle school age, as cross-curricular learning can take place during construction. Games with VR goggles are more popular with slightly older pupils (after primary school).

Fig. 97: Model of a stream made by children

Fig. 98: Children built this model to represent a rockfall and mudslide

Fig. 99:
This model was created by children and includes a wide variety of natural hazards

Derivation of recommendations

Evaluation of the models

The results of the study reveal a wide range of existing models. In the Alpine countries, but also beyond them, there is a wide variety of presentation models, haptic-interactive models, educational games, digital models and virtual reality applications that are used to communicate information about natural hazards. The topics dealt with in the models often reflect the natural hazards that predominate in the region in which they are used. As a rule, the target audience and/or the planned place of use of the model is clearly defined. Overall, it can be said that the effort required to create, operate and maintain the models is relatively high.

Most models also address the issue of natural hazards in terms of the impact on infrastructure and human health. The models include a wide variety of countermeasures, ranging from natural protective measures to government-initiated technical protective measures and self-protection. However, a clear separation of tasks between public protective measures and self-protection is not presented in full. Due to the complexity of natural hazards in the Alpine region, most models can only represent one or two events at a time without the model overloading the viewer. Nevertheless, most models do contribute to increasing risk awareness with regard to natural hazards. The issue of remaining risk (residual risk) is addressed relatively little. As far as the educational approach is concerned, however, the degree of interactivity plays a major role. In general, operators consider a high degree of interactivity in the model to be of educational value.

After evaluating all available models, it can be concluded that a demonstration model representing river floods and torrent hazards in the Alpine region with a strong interactive orientation and group dynamic effect can offer the greatest advantages. Below is a list of the features of the models in the study that are proven to be effective, followed by an explanation of the design of the model prototype.

Extraction of effective features (best practices)

As many models are highly mobile, high loads usually occur during loading, transport, assembly and operation in changing environments. Especially in terms of the longevity of the model, robust designs have proven their worth. It is also advisable to use materials, components and equipment that can be obtained easily. This simplifies cost-effective replacement during maintenance and repair. The outer skin of the model can be made with a natural wood covering, which creates an ecological point of reference and can have a strong appeal for visitors. Those models that include digital elements in addition to haptic-interactive elements are particularly well received by younger target audiences.

Many operators of the models have reported that a twin-track orientation of the model makes sense as far as target audiences are concerned. Where possible, the model should be designed in such a way that it can be used to teach young people and to reach an adult audience. Only the language level and the topics covered then require adaptation. Especially in the latter case, issues surrounding self-protection can be addressed. Overall, however, a model is particularly effective when the viewers see an identifiable reality in it and can compare their town, their house or their street with the processes it shows. This explains why interactivity in the model was particularly successful when houses, cars and people were provided as relocatable elements. Where qualitative measuring devices (e.g. measuring tapes) were used in the model, operators were also able check the effectiveness of the countermeasures they take. In order to demonstrate the effect of natural retention and the function of the protective forest, use of porous materials to illustrate infiltration and storage capacity has proven effective. This shows that it is not only technical protective measures that can be illustrated effectively in the models, but also that representation of natural restraint systems is also an integral part of them.

The majority of the models researched have already been used at large events (trade fairs, action days, schools). Many operators said in retrospect that the group should be no larger than five people to ensure problem-free, coordinated operation of the model. This number falls to 3 or 4 people if a high level of interactivity is required and the group is expected to work together on a task on the model.

The prototype for a new natural hazard model

Conclusions and recommendations from the study

Various conclusions for the prototype of the physically interactive natural hazard model can be drawn from the specifications and framework conditions of the project, the research into existing models and the identification of examples of best practice. Even though an attempt should be made to represent as broad a spectrum of reality as possible in the model, the prototype will only be able to illustrate a partial reality, in terms of space, topography and scenario. Since the model is initially intended to represent the conditions in Bavaria in particular, but should also be applicable to other Alpine regions, a topography that is as universal as possible and scenarios for typical natural Alpine hazards should be selected. It makes sense to depict a larger watercourse (similar to the Isar, Loisach or Iller) into which a torrent flows. In the area of the confluence, there should be a village that is protected both by various public technical flood protection measures and by a certain amount of (self-)protection planning. This enables thematic examination of river floods and torrent hazards, in conjunction with bedload and driftwood transport. In addition, the issue of heavy precipitation on slopes and individual aspects of municipal planning (forestry, protective forest, land use) can be covered in this context. As a result, the model also represents different stakeholders at the official, municipal, voluntary and private levels.

The remit of the study itself specifies a high degree of interactivity for the prototype. The benefit of this in terms of educational impact has also been underlined by the study. The model should therefore have a high degree of haptic freedom. This means that the processes to be observed depend heavily on the actions of the model users. It should be possible to adjust both hydrological and hydraulic intensities according to the scenario and to adapt protective measures. The principle of annual recurrence or probability should play a part in the model, which is possible through the representation of different flood states ($HQ_{Frequent}$, HQ_{100}, $HQ_{Extreme}$). Flooding of areas can be compared by including flood hazard maps. The role of certain (critical) elements of the infrastructure should be communicated, for example schools or gymnasiums as reception centres and maintenance of important parts of the infrastructure for aid and rescue services. It should be possible to position individual elements in the model as freely as possible (houses, garages, people, cars). The positioning of other elements, such as driftwood rakes, dykes and protective forest should be limited to predefined locations. Variable use and control of protective measures will be particularly important. The following approaches are helpful in this regard:

- Modelling dyke courses with building blocks (e.g. Lego) (height, length, position can be changed)
- Building up flood protection walls step by step with building blocks
- Setting the bars of driftwood rakes to any shape
- Installing or removing torrent dams
- Setting up a protective forest on a slope
- Using self-protection materials (sandbags, mobile flood protection wall, ...).

Overall, however, it seems appropriate to embed the messages to be communicated regarding natural hazards in an overarching framework scenario. Setting up a limited number of educationally and methodologically defined scenarios, including specification of a goal for the model user, prevents undirected use which can have little educational value.

Scenarios and key messages

For an overarching framework and clear definition of the messages to be communicated, four scenarios including their core messages have been developed. These are in line with the specifications of the project, include some of the best practice examples from the study and reflect feasible options. The scenarios, their core messages, the general educational thrust and the methodological elements are presented below. Detailed scripts for the scenarios are enclosed with the subsequent model in the form of handouts.

Scenario 1: Public protection measures up to the flooding level used for design purposes

Key messages

1. The technical options for dealing with floods follow the principles: feed through, divert and retain.
2. As far as is possible and justifiable, efforts are made to encourage the natural retention of the watercourse and to use it for flood retention. The effect of river widening or river renaturation, including alluvial reforestation, often still applies in the case of an $HQ_{Frequent}$. During larger flood events, a locally limited reduction in the water level is achieved, but this has little if any effect on the runoff further downstream.
3. Technical measures (dykes, flood protection walls, flood depressions, retention areas) are designed to withstand floods up to the event design level (Bavaria: HQ_{100} with 15% climate supplement as appropriate). Each building has a certain life span which events can change. Design values for events should therefore be understood as dynamic values that are adapted to the respective situation. If necessary, a climate supplement is taken into account (currently 15% in Bavaria).
4. Smaller events ($HQ_{Frequent}$) are handled without damage. However, this does not mean that the water body does not pose any dangers during these events (no bathing, boating etc., flooding of agricultural land).
5. The flood hazard maps (HWGK) provide information on the areas in which floods are to be expected at $HQ_{frequent}$ and HQ_{100}.

Methodology and educational impact of the model

1. To begin with, a medium runoff is initiated in the watercourse. The torrent also discharges a medium runoff.
2. Initially, no technical protection measures (dyke, flood protection wall) are installed. The task for the group will be to protect the village from a river flood by means of technical protection measures.
3. By looking at a flood hazard map, the model viewers work out the expected extent of the flood (flood areas) if no technical measures are implemented. Which areas of the model will be affected and what action does that dictate?

4. As an input, the principles of feed through, diversion and retention are explained. Available materials are presented.
5. The runoff in the river is increased to $HQ_{Frequent}$. After an explanation of what “frequent” means, water levels are read from level gauges and the flow velocity is assessed qualitatively. Various alarm levels must be triggered depending on the water level.
6. Certain areas of the locality are now flooded. Some of the water runs into the houses, cellars and garages, causing short circuits and floating oil tanks. The model users are now intended to protect the village from flooding with the help of dyke elements and flood protection walls. This can be done by placing Lego bricks in prepared positions.
7. The effect of the measures is considered and the application of the “feed through” principle is discussed.
8. The idea that the public authorities are responsible for protecting citizens up to a design level event is then addressed. Once again, the flood hazard map shows which areas will be flooded during HQ_{100}. Participants must realise that the $HQ_{Frequent}$ measures are not sufficient in this context.
9. The conditions in the model are then increased to the design level event (Bavaria: HQ_{100}). The corresponding alarm levels should be triggered again. This time, other stakeholders (the fire brigade, etc.) are activated and a warning app is triggered to warn the residents of the locality. The organisational measures taken are discussed in terms of their effect in the context of risk management.
10. Once again, the model user’s role is to protect the locality from the river flood, this time for the design level scenario. The dyke elements and flood protection walls are ready for this purpose once again. The methods of diversion, which have already been explained, can also be used, in the form of a flood channel. Task: What measures can be taken to survive the design level event without damage?
11. The measures introduced are discussed in terms of their impact. How would the flood hazard map change now?

Scenario 2: Public protection measures and self-protection in the event of extreme flooding

Key messages

1. Public technical protection measures (dyke, flood protection wall, retention area) are designed to withstand floods up to the design level event (Bavaria: HQ_{100} with 15% climate supplement as appropriate).
2. Rare (extreme) events (Bavaria: $HQ_{Extreme}$) can generally be mitigated in their effect by public measures (in the case of resilient systems), but still lead to overloading of the protective structures. In a resilient protection system, however, this does not lead to structural failure.
3. The flood hazard maps (HWGK) provide information on which areas are expected to flood in the event of extreme flooding.
4. In order to limit individual damage, the population must take their own precautions. This includes both obligatory preventative measures, such as flood-proof adjustments to oil heating

systems, and optional measures, such as insurance, technical building protection and taking the right steps during the extreme event (do not enter cellars, do not enter the current of water...).

Methodology and educational impact of the model

1. This builds on scenario 1: the locality is protected up to the design level event by the technical measures already taken (Bavaria: HQ_{100} with 15% climate supplement as appropriate).
2. The extreme event is discussed in terms of probability (annual recurrence) and expected impacts.
3. In the model, the runoff is increased to the extreme event level $HQ_{Extreme}$. It becomes clear that the public protection measures can no longer provide complete protection. The dykes partially overflow, and the hazards this can cause (seepage, dyke failure) and the necessity for prepared sealed overflows are discussed. The flood protection walls in the village overflow (slightly). If a flood channel is in use, there is no more freeboard. Damage occurs again in the village (water in houses, cellars and garages). The torrent is held back by a dam and also overflows its banks.
4. The required warning levels must now be triggered again, stakeholders (fire brigade, etc.) activated and messages sent to the population via the warning app.
5. No other public technical measures can be used. Self-protection measures must now be initiated in the village and in individual houses. Sandbags and mobile flood protection walls are available for this purpose. Oil tanks can also be secured.
6. Additional aspects of self-protection are covered here, namely the following three areas:
   a. Avoidance: do not build in the risk area, build at a higher level, do without a cellar.
   b. Resistance: basement waterproofing, waterproof concrete (white tank), backwater protection, mobile barrier systems, sealed light wells, raised light wells
   c. Adaptation: secure heating tanks etc. to prevent them from lifting, do not install utilities equipment in basements, flood basements proactively if necessary, adapt use (lower-value, clearable use of floors at risk)
7. The water is now not only standing in fields and in the village, but is also making roads impassable. A discussion is held with the users about what each individual should do now if freedom of movement is severely restricted and there is a high risk of flooding, e.g. staying at home, protecting the house, helping others, turning on the radio, avoiding hindrance to relief workers, getting people to shelters as necessary (schools, gymnasiums), getting people to safety, remembering that material possessions are secondary, not making your own rescue attempts, being aware of the risk of drowning / electrocution in basements, underground car parks and riverbank areas, following the instructions of emergency services, following the emergency plan, not starting cars
8. Finally, the level in the model is slowly reduced to a moderate runoff. The dangers to life and limb and to material possessions and environmental hazards (heating oil in the cellar, ...) that are still present after the flood or can occur subsequently are then discussed.

Scenario 3: Torrent hazards

Key messages

1. Torrents transport not only very fast-flowing water but also sediment and driftwood and can thus generate a powerful destructive force.
2. Public measures (e.g. erosion protection on mountains, driftwood rakes, barriers, guidance through local areas) should provide protection against torrent events ≤ HQ_{100} including characteristics typical of torrents such as bedload and alluvial flow.
3. Due to short build-up times, early warning is usually not possible. However, technical and biological measures can be taken to affect the supply and displacement of solids and the tendency to run off, which then influence the course of the event.
4. Healthy nature (including protective forest, soil capable of absorbing water, year-round vegetation in fields) contributes significantly to reducing damage. In addition, technical measures are often required to protect the residential area. Through proactive planning of space and emphasis on individual responsibility, the risk can also be reduced beyond the government development target. The individual behaviour of each person plays a major role (e.g. not building on alluvial fans if possible, protection of property).

Methodology and educational impact of the model

1. The main watercourse remains at medium runoff.
2. Initially, a non-critical rainfall event in the catchment area of the torrent / in the mountainous region is initiated by sprinklers, which generates only a slight (non-critical) increase in water level and flow velocity in addition to the normal runoff in the torrent. Sediment and driftwood do not move.
3. The rainfall intensity in the catchment area of the torrent is increased. The precipitation flows down the slopes and collects in the torrent.
4. One slope of the catchment area is an unwooded area that has been cleared by deforestation. The precipitation runs off quickly, cannot infiltrate and takes sediment and wood with it, which ends up in the torrent and is carried into the village. As a result, obstructions and flooding occur.
5. The other slope in the catchment area is in a natural state. Due to the effect of the protective forest, the flow velocity is reduced, the precipitation seeps away either completely or at least partially into the spongy soil material and enters the torrent at the foot of the slope. Little or no sediment is washed out or driftwood picked up.
6. The flowing water in the torrent transports sediment and driftwood. The driftwood obstructs bridges and narrow sections, which restricts the cross-section of flow and causes the water to overflow into the village. Flooding in the torrent and the sediment load brought in causes the main watercourse to back up, which can lead to overloading of the protective structures.
7. Effective countermeasures are discussed with the model users. To reduce the significant erosion effect in the catchment area, trees can be planted to create a protective forest there.
8. Further technical countermeasures can be set up in the torrent and their effect tested. Bedload barriers can be created from Lego bricks for this purpose, although it must be ensured that there is a bottom outlet. Individual bar elements can also be combined to form a driftwood rake that holds back the driftwood.

9. Aim: to protect the locality from the effects of flooding in the torrent. Which measures have which effect? Clearance of the washed up sediment and driftwood accumulation needs to be addressed after the event.

Scenario 4: Dangers due to heavy rain and wild water runoff

Key messages

1. Due to heavy rainfall events and uncontrolled runoff water, regions, inhabitants and parts of the infrastructure may have to cope with flooding, even if they are located outside the actual flood-plains of watercourses.
2. Heavy rains are precipitation events that occur in very specific locations and cause large amounts of precipitation in a short time. However, a reliable meteorological forecast of the location and intensity of these events is only possible shortly before they occur.
3. If the precipitation cannot be completely absorbed by the soil (due to heavy compaction or sealing), it runs off over the surface (uncontrolled runoff water).
4. The uncontrolled runoff water can reach considerable proportions even before it reaches a watercourse and thus cause considerable damage. These events, known as flash floods, are usually characterised by heavy surface runoff, rapidly rising water levels and powerful runoff waves.
5. Heavy rain can also fall in hilly areas and run off over the mountain slopes and fields, so that uncontrolled water runoff and associated damage can also be expected there. The slope of the terrain often accelerates the water masses, which can give rise to significant forces that lead to soil erosion, damage to infrastructure, danger to people and even carry away heavy objects (silo bales, stored timber, cars, for example).
6. Risk and danger can be reduced by proactive spatial planning and strengthening individual responsibility.

Methodology and educational impact of the model

1. The main watercourse remains at medium runoff.
2. The sprinklers in the mountain region are taken from the catchment area of the torrent and positioned in the neighbouring valley and over the slopes there. In the torrent, there is still a normal runoff including a normal rain event as an offshoot of the heavy rain.
3. In the neighbouring valley, the sprinkler output is increased significantly. The precipitation flows down the slopes, reaches the village from the mountain side and flows through the village towards the main watercourse.
4. Parts of the infrastructure that are not usually exposed to danger from watercourses are now also affected by flooding.
5. In addition, the uncontrolled runoff from the slope undermines a shallow soil body in the mountain region, which fails and slides away. Boulders also come loose and develop into a rockfall. The soil body and rocks block a road. Model users can mitigate or prevent this by using trees and protective nets.
6. A discussion is held with the model users about how flooding and its effects (even in protected areas) must also be expected in this scenario and how general precautionary measures (alignment of buildings, basement drains, walls) are both essential and effective. This links the themes of self-protection, insurance and the principle of resistance.

1.1 Construction plan of the model prototype

Extensive mobile use of the natural hazard model will be made in future. The demonstrations are to take place in schools, on action days, at trade fairs and in public relations work in general. To facilitate transport, the model is installed in a box trailer (Fig. 100). The trailer has inside dimensions of 2.6 m (length) by 1.6 m (width) and can be opened upwards on three sides by means of flaps (Fig. 101). A particularly low loading height of 60cm and inside wheels allow even small children to access the model. The trailer can be towed directly to the demonstration locations. The trailer provides a direct platform for the model and it does not necessarily have to be lifted out. When not in use, the model will be kept at the Inn Museum of the Rosenheim Water Authority. However, the box trailer cannot be positioned in the exhibition space there. The model is therefore designed so that it can also be lifted out of the box trailer and transported and displayed separately on supports with wheels. The general plan for the design of the model is described below. A detailed list of the materials and equipment required and an assembly plan are supplied with the finished model prototype.

Fig. 100: Box trailer as the basic carrier for the model

Fig. 101: The trailer can be opened on three sides and the low loading height allows children to access the model.

General design layout

The model consists of three levels. At the lowest level (under the model), all of the fittings required to load and anchor the model in the box trailer can be found. The slots for the supports with wheels are also located there. The installation lines, electrical cables and water lines (inlet and outlet) run through the middle level (intermediate level). The water circuit is designed in such a way that all water flows back into a reservoir by gravity. In addition, the intermediate level serves as an inspection space for carrying out maintenance work relatively easily without having to disassemble the model itself. The water tank (reservoir) and the pumps inside it are carried separately from the model in a tow-bar box on the rear wall of the model. Installing these components in the model itself makes inspection and cleaning more difficult. The water tank should also be positioned under the model so that there is free drainage from the model into the tank. Before putting the model into operation, the water circuit equipment (tank, pump, hoses) is removed from the tow-bar box and connected to the model via connections and couplings. The top level of the model comprises the actual terrain that represents the natural hazard.

Model landscape, infrastructure and installations presented

The topography and bathymetry of the model landscape were inspired by the landscape of Mur-Game and are based on conditions in the Upper Bavarian village of Eschenlohe (Fig. 102). The general layout and elements included are presented below. A detailed description of the model is given in the documentation for the finished model.

The model focuses on a pre-Alpine river that flows through the landscape in a winding course diagonally from south-west to north-east. There are two gauge stations in the river, which take the form of measuring sticks. They enable water levels to be read and thus serve as an indicator for triggering the alarm stages in the event of flooding. There is a village on both sides of the river.

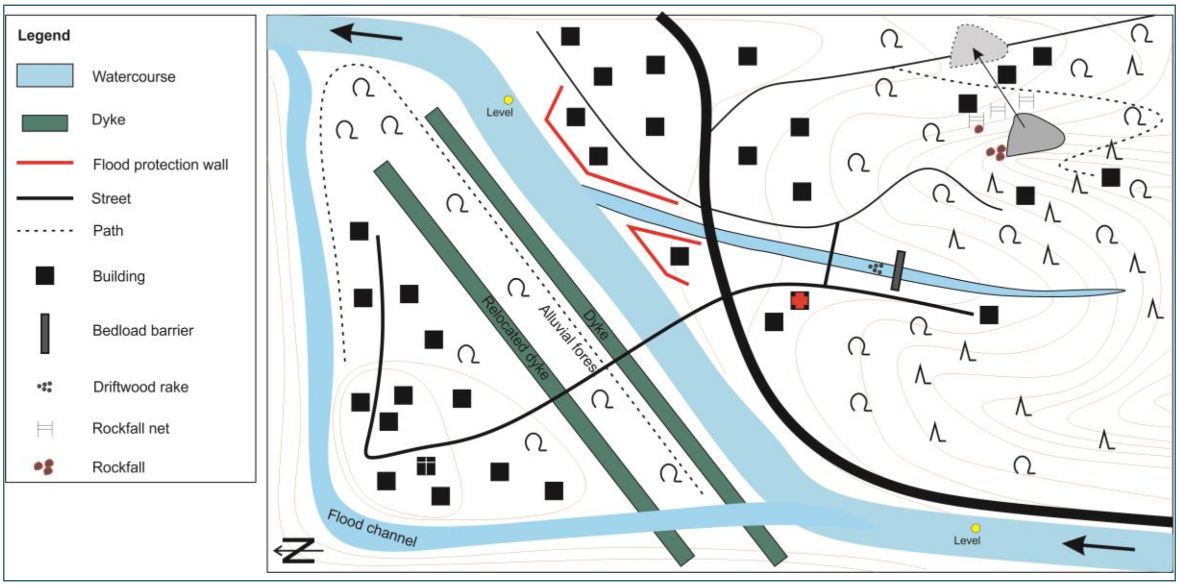

Fig. 102: General plan (top view) of the model, without scale. The south-north orientation is from right to left in the picture.

Low terrain is represented on the orographic left of the model. This was originally a natural floodplain (floodplain forest), but is now used as a settlement area (houses on the northern edge of the model). The original centre of the village is located on a slightly elevated area (houses to the northwest). This keeps it protected from the effects of river floods. However, this does not apply to the estate in the floodplain forest area. In scenario 1, these houses are flooded if no technical protection measures are taken. Two dyke courses are therefore available in the model to protect this settlement. The first (southern) dyke lies directly on the river and allows the floodplain forest behind it to be used as a residential estate and cultivation area, although this provides little natural retention space. The dyke located further back protects the settlement equally well, but leaves the forest area as a floodplain. For scenarios 1 and 2, a flood channel is available in the northern area of the model. This begins at either dyke in the east of the model, goes around the centre of the village and opens out into the river at the north-eastern corner of the model.

To the orographic right of the river is the second residential area of the village, partly built into the slopes of a mountainous region. For the houses located on the main river, flood protection must be provided by flood protection walls (red line). The centre of the south-eastern part of the model is a mountain region with the catchment area of a torrent in the middle (southern edge). Sprinklers are installed above the southern area of the model, both aligned above the catchment area and extending into the foothills of the slopes as far as the residential area. The torrent rises in a spring in the catchment area and flows from the south to the north towards the settlement, where it runs into the river in the village. The eastern slopes of the catchment area are densely forested and provide good erosion protection during precipitation. The western slopes, on the other hand, are only sparsely forested. Bedload and driftwood can be moved from there and thus enter the torrent. In order to protect the village from torrent hazards, a bedload barrier or driftwood rake can be installed above the village. If neither of these elements is used in scenario 3, bedload and driftwood can obstruct the narrows and bridges further downstream.

For scenario 4, the sprinklers in the eastern and south-eastern part of the model are activated. The precipitation then does not fall in the catchment area, but forms uncontrolled runoff water, which reaches the foothills of the estate via the eastern slopes. In addition, precipitation in the southeast leads to undercutting of the surface of a slope, which falls away towards the east and blocks a road. This can also endanger individual houses. It can be prevented in the model by setting rockfall nets. As an optional element, individual large stones can also be used in this scenario to represent a rockfall.

The main elements of the infrastructure are built from Lego bricks to enable a high degree of interactivity and to visualise the impact of the floods and self-protection measures. Some houses cannot be changed, however, as they have electronics installed in them that make it possible to represent a power failure in the event of flooding. Most of the houses can be moved in the model and their structure can be changed. Some houses have basements which can be provided with a certain degree of flood protection by raising the basement windows, etc. The function of some buildings relevant to flooding is marked (hospital, fire station, etc.). The dykes, the flood protection walls and the technical protection measures in the torrent are also made of Lego. The trees and the rockfall nets can be positioned in the holes provided. Materials for self-protection of individual houses (e.g. mobile protective walls) are provided and can be positioned in the model.

Summary and outlook

The main objective of this study was to draw up an inventory of demonstration models for the communication of Alpine natural hazards, on the basis of which a new model prototype could be designed. The fact that such models can contribute to communicating government implementation of risk management and the essential measures of self-protection and that this results in an increase in the population's awareness of natural hazards is shown by the existing models in other Alpine countries. However, the literature review at the beginning of this study also reveals that subjective perception of risk needs to be more closely aligned with the objective risk (that actually exists) to avoid ineffective behaviour of the population before, during and after a natural event. In order to improve the development of successful strategies to cope with an incident, the main aim of this project should be to promote an understanding of self-protection and the correct course of action in those circumstances.

For the research into natural hazard models already in use in the Alpine region, a questionnaire was sent out to potential operators of such natural hazard models. In addition, it was possible to evaluate current academic literature to identify other models outside the Alpine region. Finally, 26 responses were included in the evaluation, roughly equal proportions of which were purely presentation models, haptic-interactive models and models from the area of educational games, digital models and virtual reality. The range of models evaluated is quite large, at least in terms of their spectrum of use, their structure and the processes they represent. This is mainly due to the communication aim of providing information about the individual natural hazards that prevail locally. Nonetheless, certain underlying recommendations regarding proven designs, practices and methodological implementations could be identified in almost all models. These were integrated directly into the conception of a new model prototype.

A model landscape was created in a frame structure, in which a torrent flows into a larger watercourse within a village. In order to provide information about flood and torrent hazards, it was possible to draw up four general scenarios that address the topics of frequent flooding, design-level floods, extreme floods, torrent hazards and heavy rainfall events with uncontrolled runoff. A high degree of haptic freedom enables users to interact freely and play around with the model. Both public technical protective measures and areas of self-protection are covered in equal measure. The creation of the model prototype is documented in detail. The future model will be accompanied by a construction plan, a material list, photo documentation and an assembly plan. This allows duplication and modification of this prototype for successful application in the Alpine region and beyond.

In general, further interactive models of this sort covering individual topic areas are conceivable. Important topics in the Alpine region such as rockfall, landslides, avalanches and heavy rainfall in urban areas could be communicated in a way that addresses specific target audiences, especially in the context of climate change. Particularly with regard to the issue of heavy rainfall, the possible preventative countermeasures connected with self-protection (green or grey stormwater infrastructures) could then be dealt with in more detail.

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Appendix

Questionnaire for the survey of existing natural hazard models in Alpine countries

General questions

1. Please tell us which country and region you come from (e.g. Austria, Tyrol).

2. What kind of organisation do you belong to? Please tick as appropriate.

   ☐ National organisation

   ☐ Regional organisation

   ☐ Municipal / urban organisation

   ☐ International organisation

   ☐ Research institution

   ☐ Private company

   ☐ Other organisation:______________________________

3. Could you please provide us with your contact details (name, address, telephone number, email address) so that we can get in touch with you if we have any queries?

Questions about the model

4. How would you categorise your model? Please tick as appropriate.

   ☐ Physical interactive model

   ☐ Physical model for demonstration

   ☐ Digital model

   ☐ Interactive game

5. Which processes are covered in the model? Please tick as appropriate. Multiple answers allowed.

   ☐ Flood

   ☐ Torrent

   ☐ Flash flood

   ☐ Avalanche

   ☐ Rockfall

   ☐ Landslide

   ☐ Heavy rain

   ☐ Accidents, damage to private infrastructure

   ☐ Other:______________________________

6. Why was the model created?

7. What is the aim of your model? (e.g. understanding processes, understanding natural processes, raising awareness of protective measures, function of structures, self-protection...)?

8. For which target audience and age group was the model designed?

9. Where was/is the model used? Please tick as appropriate. Multiple answers allowed.

☐ Schools

☐ Trade fairs

☐ Experience centres

☐ Public relations work

☐ Action days

☐ Other:______________________________

10. Please describe your model and its characteristics in general terms (size, structural design, mode of operation, material, equipment, technology). You are welcome to send us pictures, photos, technical drawings, etc. for this purpose.

11. Which processes are examined in the model? What is the approximate spatial/geometric scale?

12. Which process elements are represented? (rivers, dykes, polders, houses, roads, ...)

13. What is the methodological process behind the model? Please explain briefly what happens stage by stage (e.g. 1st step: Allow only clear water to flow down the torrent, 2nd step: Increase water volume and show flood wave, 3. Children add driftwood and the bridges are blocked, ...)

14. What is your assessment of the complexity of the processes presented? Please tick as appropriate.

☐ Very high:	complex and highly dynamic natural processes are presented which influence one another.
☐ Medium:	individual natural processes are presented which, although they do not illustrate the complexity of natural conditions to the full, still give a good impression of the dynamic character of natural hazards.
☐ Low:	a single isolated process or only a few interrelated processes are represented in a highly idealised model.

15. Which of the following measures are covered in the model? Please tick as appropriate. Multiple answers allowed.

☐ Public protective structures (e.g. dykes, polders)

☐ Municipal measures (e.g. warning services, forestry)

☐ Self-protection by the population (oil tanks, elevated light wells)

16. How easy is the model to use? Is the model fixed or mobile?

17. By whom and how is the model operated? Is there an opportunity for the target audience to interact with the model or is it limited simply to viewing a process or information? If interaction does take place, how does it work?

18. What is your assessment of the effort required to create and operate the model (e.g. in terms of personnel and material requirements)?

☐ High:

☐ Medium:

☐ Low:

Experience

19. Why has the model proven/not proven to be successful in terms of education and raising awareness of natural hazards in your opinion?

20. Which feature of your model has worked particularly well? Are there an eye-catching elements?

21. If you were to create the model again, how would you improve it?

22. What is your experience of the model in terms of the chosen objectives, target audience, age groups, place of use and ease of use?

23. What would an “ideal” natural hazard model look like for you?

24. Could you send us pictures of the model or make them available for download?

25. Is it possible to view the model?

26. Do you have any further recommendations regarding the creation of a physical natural hazard model?

27. Are you aware of any other examples of good practice or other types of natural hazard models?

Model documents

The following separate files are supplied with the prototype model.

- Construction plans, drawings, digital terrain model
- Material/equipment list and assembly plan
- Educational approach
- Operating instructions for the model
- Scenario handouts

Photo credits

We would like to thank the participants in the study, especially for the photographs that they have approved and provided for publication, which are credited below.

Figure	Name or description	Location	Country
Fig. 1,Fig. 2,Fig. 3, Fig. 4,Fig. 5,Fig. 6, Fig. 7,Fig. 8,Fig. 9, Fig. 10,Fig. 11,Fig. 12, Fig. 13,Fig. 14,Fig. 15, Fig. 16,Fig. 17, Fig. 50, Fig. 51,Fig. 52,Fig. 53, Fig. 100,Fig. 101,Fig. 102	Ivo Baselt	Neubiberg	Germany
Fig. 18, Fig. 20, Fig. 21	Kilian Heil	Vienna	Austria
Fig. 19,Fig. 24,Fig. 25, Fig. 55,Fig. 60,Fig. 83, Fig. 95	Environmental Education Centre (UBZ)	Styria	Austria
Fig. 22,Fig. 23	die.wildbach	Vienna	Austria
Fig. 26	Office for Geology and Building Materials Testing	Autonomous Province of Bolzano – South Tyrol	Italy
Fig. 27	Traunstein Water Authority	Traunstein	Germany
Fig. 28,Fig. 29,Fig. 30, Fig. 31,Fig. 32,Fig. 33	Emre Akcali	Trabzon	Turkey
Fig. 34,Fig. 35	Laboratorium3D GmbH	Biasca	Switzerland
Fig. 36,Fig. 37,Fig. 38, Fig. 39	Bavarian Environment Agency	Augsburg	Germany
Fig. 40,Fig. 41,Fig. 42, Fig. 43	Benjamin Einhorn	Grenoble	France
Fig. 44,Fig. 45,Fig. 46, Fig. 47, Fig. 48,Fig. 49	Joze Papez	Ljubljana	Slovenia
Fig. 54, Fig. 56,Fig. 57	Kilian Heil	Vienna	Austria
Fig. 58,Fig. 59	Deggendorf Water Authority	Deggendorf	Germany
Fig. 61,Fig. 62	Region of Tyrol	Tyrol	Austria
Fig. 63,Fig. 64,Fig. 65 Fig. 66,Fig. 67,Fig. 68 Fig. 69,Fig. 70,Fig. 71	Ward's Science	West Henrietta	USA
Fig. 72	Onno Bokhove, Photo compilation: Luke Barber	Leeds	UK
Fig. 73,Fig. 74, Fig. 75	Onno Bokhove	Leeds	UK
Fig. 76	Andrea Andreoli	Bolzano	Italy
Fig. 77,Fig. 78,Fig. 79	Emriver geomodels	Carbondale, IL	USA
Fig. 80,Fig. 81	Ole Werner	Ansbach	Germany
Fig. 82,Fig. 84,Fig. 85, Fig. 92,Fig. 93, Fig. 97, Fig. 98,Fig. 99	Civil Protection Agency	Autonomous Province of Bolzano - South Tyrol/Italy	Italy
Fig. 86,Fig. 87,Fig. 88	MurGame (www.murgame.ch); Developer: geo7 AG, Koboldgames GmbH, WSL Institute for Snow and Avalanche Research SLF; funded by: Prevention Foundation of the Cantonal Building Insurers, die Mobiliar, Federal Office for the Environment BAFU.		
Fig. 89	UN Office for Disaster Risk Reduction	New York	USA
Fig. 90,Fig. 91	Muhammed Yusuf Sermet, Ibrahim Demir, University of Iowa, Hydroscience & Engineering: Sermet, Y., & Demir, I. (2018). Flood Action VR: A Virtual Reality Framework for Disaster Awareness and Emergency Response Training. In Proceedings of the International Conference on Modelling, Simulation and Visualization Methods (MSV) (pp. 65-68). Sermet, Y., & Demir, I. (2020). Virtual and augmented reality applications for environmental science education and training. New Perspectives on Virtual and Augmented Reality: Finding New Ways to Teach in a Transformed Learning Environment, 261-275.		
Fig. 94	Eric Bardou (EPFL)	Nax	France
Fig. 96	The Augmented Reality Sandbox - an interactive exhibit at Dickinson Museum Center, Dickinson ND: Author: Df9465, 22 March 2018		License: Creative Commons Attribution-Share Alike 4.0 International