PUBLIZIERBARER ENDBERICHT

A) Project data

Kurztitel:	RIMES
Langtitel:	Climate Change and Natural Hazard Risk Management in Energy Systems
Programm:	ACRP, 1st call for proposals
Dauer:	36 month
KoordinatorIn/ ProjekteinreicherIn:	Federal Research and Training Centre for Forests, Natural Hazards and Landscape (BFW)
Kontaktperson Name:	Antonia Zeidler
Kontaktperson Adresse:	Rennweg 1, 6020 Innsbruck
Kontaktperson Telefon:	0043-512-573933-5108
Kontaktperson E-Mail:	Antonia.zeidler@uibk.ac.at
Projekt- und KooperationspartnerIn (inkl. Bundesland):	Verbund – Austrian Hydro Power AG
Schlagwörter:	Climate change, avalanche, debris flow, permafrost, uncertainty
Projektgesamtkosten:	300.380 €
Fördersumme:	254.900 €
Klimafonds-Nr:	A963726
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B) Project Overview

1 Executive Summary

The main objective of the project has been the development of a standardised method for the assessment of the vulnerability of energy systems to natural hazards. In particular the possible effects of climate change have been considered and recommendations on how to integrate this information into risk management procedures have been formulated.

In Austria, one sector vulnerable to natural hazards is the energy sector. A sustainable energy supply relies on a functioning grid system. Considering the entire energy system, from the power generation to the end-user, natural hazard events can cause damages at several sensitive spots along the supply chain. In addition to direct damages to humans and the infrastructure, consequential losses due to disruption have to be considered. Current practice for risk-assessment for objects of the energy infrastructure mostly employs cost-benefit analyses without particular integration of detailed natural hazard risk-assessment procedures. The development and application of a standardized method would allow for the comparison of different possible protection measures on a long term basis, thus providing means for a sensible allocation of financial resources. As an additional benefit, such a method could provide tools for an assessment of potential impacts of future climate change on the natural hazard processes.

Primary focus of the project RIMES has been the development of such a standardized methodical risk-assessment procedure for objects of the energy system in an alpine environment. Based on investigations carried out in the study area Kaprunertal (Salzburg, Austria) a sequence of actions for hazard- and subsequently risk assessment for energy infrastructure objects (pylons, power lines, water inlets) exposed to natural hazard processes (avalanches, debris-flows) has been worked out. In the course of the project the current and projected future state of permafrost areas and glaciers in the study areas has been investigated. These developments in the currently glaciated and periglacial environment are of special interest for the development of sediment supply and transport processes in the investigated alpine systems.

To evaluate the general applicability of the developed risk-assessment framework to different geographical settings the method has subsequently been applied, albeit to a lesser extent, in the second project area Zillertal (Tirol, Austria). In order to assess the influence of natural hazards on the contemplated segments of the energy system the problem has been approached at object-level. In a first step for every object the relevance of the considered hazard processes has been evaluated based on a pre-assessment employing GIS-based analysis and preliminary estimation of the hazard situation on site. For potentially endangered objects further analysis steps have been performed. With respect to overall data-availability and cost-benefit considerations different hazard-analysis approaches have been pursued. The uncertainties inherent in the methods applied and data-sources used within the hazard-analysis procedure have been considered in the subsequent risk analysis by means of a probabilistic approach towards risk calculation.

Results indicate, that for the study area Kaprunertal the occurrence-rate of wet snow avalanches as compared to dry snow avalanches will rise at lower and middle altitude levels. Based on the projected temperature development also considerable permafrost degradation and glacier retreat has to be expected in the study areas. In the Kaprunertal this is expected to lead to a rising susceptibility towards debris-flows and alike processes in alpine altitude levels (>2400m). Predictions about the development of precipitation intensities and general precipitation patterns are associated with notable uncertainties. However, a general shift towards dryer summers/autumns and wetter winters/springs is expected. Based on these developments a shift of mainly precipitation influenced processes (e.g. debris-flows) towards spring is hypothesized.

2 Background and objectives of the project

In Austria, one sector vulnerable to natural hazards is the energy sector. Looking at an entire energy chain, from the power generation to the end-user, damages caused by natural hazard events can occur at many sensitive spots in the system. In addition to direct damages to humans and infrastructure, also indirect damages have to be considered. Also uncertainties related to climate change, occurrence of natural hazards or exposure and vulnerability of objects should be handled in the procedure. Decisions are most often based on hard facts and therefore considering uncertainties is difficult to implement in daily working procedures. Some frameworks have been suggested, however, these are often difficult to implement in existing working procedures and therefore not accepted by the decision makers. Especially in regard to climate change there is resistance by stakeholders as they do consider the uncertainties too high to react on. Therefore good communication practices are promoted, but are not yet a standard component in natural hazard risk management.

The aim of RIMES was to develop a decision support tool for hydropower facilities to assess the risk due to natural hazards for today and for the future also considering climate change. By stating, visualizing and communicating uncertainties (e.g. as ranges in the outcome or probabilities) sustainable decisions for the effective and efficient allocation of financial resources in mitigation measures shall be supported. This includes the presentation of the outcome in value ranges, instead of deterministic numbers, which reflect the possible range of outcome. In the project a participatory approach was pursued. Responsible decision makers of a hydropower facility were involved in the project to create a goal oriented research environment. Due to time and manpower constraints the following boundary conditions were agreed on:

1. **Geographical:** determination of risk for single hydropower generation facilities. The sum of risk of single objects leads to the collective risk of the facility.
2. **Conditional:** climate and climate change and the subsequent determination of hazard scenarios are based on precipitation and temperature for a planning horizon of 40 years; the natural hazard processes are avalanches, debris flows and sedimentation processes due to melting of permafrost.
3. **Contextual:** economic damages: direct (damages on infrastructure of hydropower facility) and indirect (losses due to the disruption of the energy production); costs are based on today's values.

Keeping to the frame conditions we acknowledge that important aspects such as ecological and social damages, other natural hazard processes, changes in vegetation, land use changes and a possible higher capacity of the production facility are neglected.

In order to meet the aim of the project, to develop a standardised method to assess the vulnerability of an energy system to natural hazard the proposed study comprised five objectives:

- **Objective 1** Identification of the most relevant climate change factors and assessment of their impacts on natural hazards, including uncertainty analysis
- **Objective 2** Performing a system vulnerability analysis for sub-systems of the energy grid in Austria, including uncertainty analysis
- **Objective 3** Development of a concept for an integrated risk management procedure (scientific, economic, social, cultural aspects) in the energy sector
- **Objective 4** Carrying out an integrated risk analysis (climate change, multiple hazards, damage potential scenarios) for a hydropower system following the concept developed under Objective 3
- **Objective 5** Development of a standardised method to assess the vulnerability of an energy system to natural hazards and to estimate the damage potential in regard to the uncertainties

3 Project content and results

Uncertainties across all Work packages

Uncertainties are associated to different steps in the risk management cycle. Hug (2012) developed an uncertainty matrix (Table 1) in RIMES. Based on this matrix the uncertainties for each working step were identified and subsequently, based on a SWOT analysis, the most appropriate technique to deal with the identified uncertainties was chosen. Uncertainties in the context of RIMES were described as follows:

1. **Climate change:** scenario analysis (baseline and worst case)
2. **Meteorological data:** extreme value statistics (confidence interval) for different climate change scenarios
3. **Process analysis:** descriptive statistics, sensitivity analysis (different release heights), scenario analysis (different return periods), probability distributions
4. **Damage potential:** simulation models, scenario analysis (different release heights), probability distribution techniques, Monte Carlo simulation
5. **Risk calculations:** Monte Carlo simulations for risk calculations, scenario analysis

Table 1: Uncertainty matrix for uncertainty classification in natural hazard risk management (Hug for RIMES, after Walker et al. 2003 and Pang 2008).

Location				Level		Nature
Step	Source					
Data acquisition	Method u.	Dataset uncertainty		Statistical uncertainty	Measurement uncertainty	Epistemic u. / Aleatory u.
					Sampling error	
Data analysis	Method u.	Context and framing		Statistical uncertainty	Measurement uncertainty	Epistemic u. / Aleatory u.
		Input uncertainty	Uncertainty about the external driving forces			
			Uncertainty about the systemdata		Sampling error	
		Parameter uncertainty	Exact parameters		Recognised ignorance	
			Fixed parameters		Total ignorance	
			A priori chosen parameters	Scenario uncertainty	Recognised ignorance	
			Calibrated parameters			
		Model uncertainty	Uncertainty inherent the model		Total ignorance	
			Uncertainty in model outcome			
Result communication	Method u.	Input uncertainty		Statistical uncertainty	Measurement uncertainty	Epistemic u. / Aleatory u.
					Sampling error	
		Communication uncertainty		Scenario uncertainty	Recognised ignorance	
					Total ignorance	

Climate change impact on natural hazards in Kaprunertal

On the basis of data from three meteorological stations: Sonnblick (3105 m asl), Mooserboden (2036 m asl) and Zell am See (766 m asl) the past changes in the climate (1949-2008) have been investigated at different altitudes. The key findings of the analysis include:

- Temperature levels show a significant rising trend at all stations. The increase is more pronounced in the minimum temperatures than in the maximum and mean temperatures.
- There is not a clear trend for precipitation. For the annual maxima of the one- and three-day precipitation the variance is much greater than the calculated trends. The trend of the average one- and three-day precipitation at the stations Mooserboden and Zell am See is stagnant, at the station Sonnblick a significant increase is notable.
- The trend of the snow parameters, days with snow depth ≥ 5 cm and maximum snow depth, are not representative, because the annual variance is higher than the long-time changes. The maximum one- and three-day new snow heights at the stations Mooserboden and Sonnblick are constant, but increasing at the station Zell am See.

Future climate in Kaprunertal – Climate change scenarios

Based on the results of the project reclip:more (Loibl et al., 2007) in RIMES the following two climate change scenarios for the period 2041-2070 are derived:

1) a baseline scenario representing a probable development of the climate
2) a worst case scenario representing the maximum expected changing rates.

The conclusions on climate change refer to the differences between the two climate periods 1981-2010 and 2041-2070. Table 2 shows the climate change signals for the parameters temperature and precipitation based on the climate scenarios and the data of the representative weather stations in the study area. Based on the projected trends a daily weather series has been compiled for the time frame 2041-2070 for all investigated meteorological stations.

Table 2: Predicted mean annual changes between the period 1981-1990 and the period 2041-2050 and the calculated changes per decade until 2050 for each season. The indices BS (baseline scenario) and WCS (worst-case scenario) indicates a probabilistic and a worst-case development of the climate.

	ΔT_{BS}	ΔT_{WCS}	ΔPRE_{BS}	ΔPRE_{WCS}
Kaprunertal				
winter	+1,8 / +0,3	+2,3 / +0,38	+5 / +0,8	+12,5 / +2,1
spring	+2,7 / +0,45	+3,3 / +0,55	+5 / +0,8	+12,5 / +2,1
summer	+2,4 / +0,4	+3,0 / +0,50	-5 / -0,8	-12,5 / -2,1
autumn	+2,7 / +0,45	+3,3 / +0,55	-5 / -0,8	-12,5 / -2,1

The key findings regarding the projected climate change in Kaprunertal (Mooserboden) include:

- The temperatures are projected to rise. The total number of summer-days (maximum temperature ≥ 25°C) will increase, whereas the total number of frost-days (minimum temperature < 0°C) and ice-days (maximum temperature < 0°C) will decrease especially in spring and autumn. Heat days (maximum temperature ≥ 30°C) are uncommon and the projected climate change does not indicate that temperatures ≥ 30°C will be increasing for the considered time frame.
- Precipitation is projected to increase in winter and spring and decrease in summer and autumn (Figure 1). The average number of days exceeding a given threshold remains more or less the same or changes by a maximum of one day for selected months.
- Even though precipitation is increasing in winter and spring, due to the temperature increase the values of

the calculated new snow depths are decreasing at all stations. In contrast to the precipitation projections, the predictions for the number of days exceeding a given threshold of new snow amount will decrease.

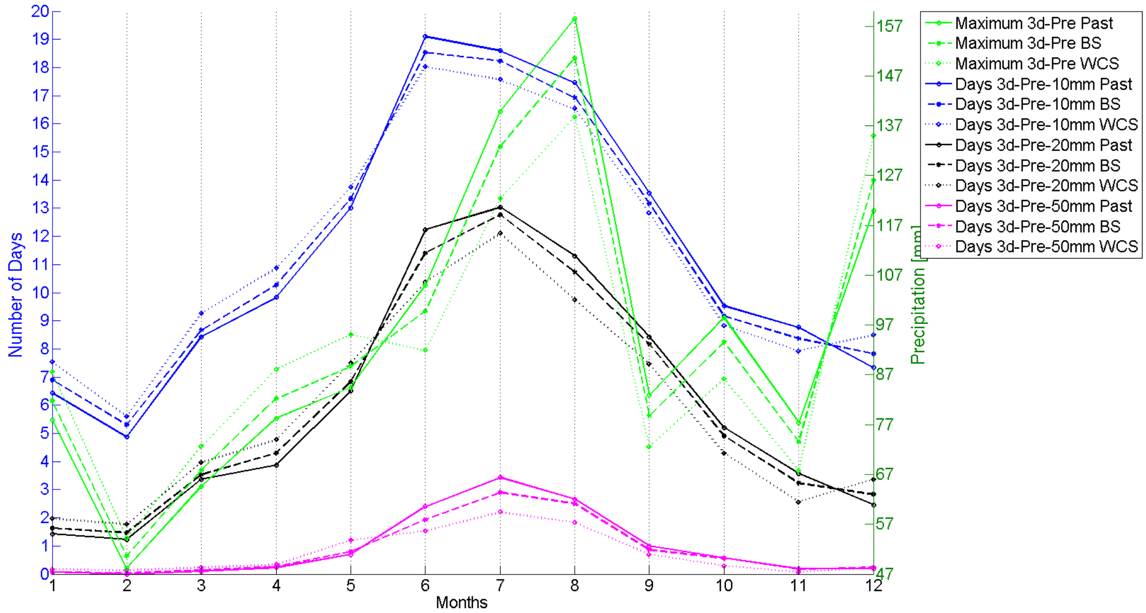

Figure 1: Precipitation parameters (Mooserboden) for the period 1981-2008 (solid lines), for the baseline scenario (2041-2068, dashed lines) and the worst-case scenario (2041-2068, dotted lines). Shown are for the particular months the maximum 3-day-precipitation (green), the number of days with 3-day-precipitation ≥ 10 mm (blue), the number of days with 3-day-precipitation ≥ 20mm (black) and the number of days with 3-day-precipitation ≥ 50mm (magenta).

Statistical analysis of relevant meteorological variables influencing natural hazards

In order to assess the impact of changing meteorological variables on natural hazard processes precipitation (amount, duration, type and intensity) and temperature (minimum, maximum, mean, frost days) have been analysed.

Extreme value analysis

Both, avalanches and debris flows, are related to heavy precipitation and therefore extreme events are important to consider. Additionally return periods of natural hazard events are often linked to the recurrence time of certain meteorological parameters. For avalanches e.g. the three-day-difference of the snowpack height is often selected to represent the release height of an avalanche.

The methods used to calculate the extreme values were the method of block maxima, the maximum likelihood estimation (MLE) and the generalized extreme value (GEV) distribution (e.g. Coles 2004, Beirlant 2005). In this study an extreme precipitation event is characterized by a value exceeding the fourfold standard deviation of this parameter.

The results can be summarized as follows:

- The number of extreme one-day- and three-day-precipitation events show an increasing trend in the summer months. However, this trend can mainly be attributed to the year 2002 with exceptional number of extreme events.
- The one-day- and three-day new-snow-heights do not show a significant trend in the number of extreme events at the station Mooserboden (see Figure 2 for 3d-NSH)
- The number of extreme new snow events will slightly decline or stay constant for low lying areas, no significant trend could be deducted for middle altitude areas. For high altitude areas the data shows a clear increasing trend in the number of extreme new snow events. The changes in the extreme values of

the one-day-and the three-day-precipitation correspond very well with the changing rates of the climate change scenarios. Hence, the extreme values based on the baseline scenario decrease on average by about 5 % and those based on the worst case scenario on average by about 13 %.

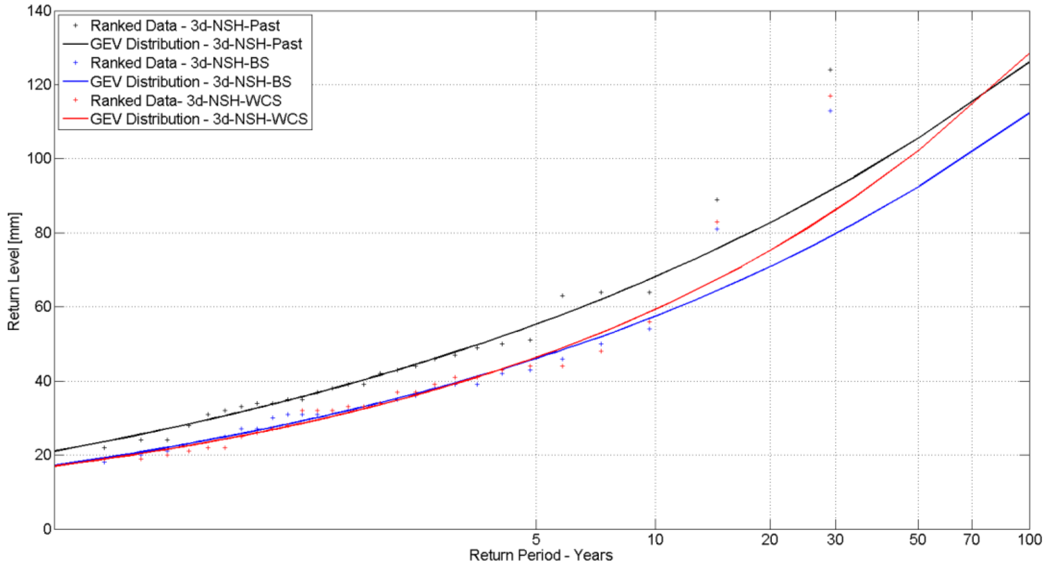

Figure 2: Extreme values for the 3-day-new-snow-height of the station Mooserboden on the basis of the measured data (1981-2008, black) and for the baseline scenario (2041-2068, blue) and the worst-case scenario (2041-2068, red). Shown are the extrapolated extreme values of the Generalized Extreme Value (GEV) distribution.

Climate change and its impact on avalanches

In recent years some studies have addressed the influence of climate change on avalanche activity (e.g. Glazovskaya 1998, Martin et al. 2001, Laternser and Schneebeli 2002, Eckert et al. 2010a,b). However, most studies focused on the number of avalanches or the run-out distance without detailed analysis of the snowpack conditions. Other studies have analyzed the snow cover duration and snowpack height, but not in regard to avalanche activity. A well accepted assumption is that climate change will have an impact on the predominant avalanche type, especially at lower elevations. In Figure 3 the ratio of wet to dry snow avalanches is shown for an elevation of 1800-2300m a.s.l., including the mean for the observation period. On average 38% of the reported avalanches were moist.

In the Kaprunertal historical data on avalanche activity is available from the winter 1943 until 2012. In total 2973 events are registered of which 2676 are related to a specific avalanche path. On 297 days more than one avalanche was observed, however no local reference was made in the cadastre. The database contains 42 avalanche paths for which a minimum of 10 avalanches were recorded over the observation time. The maximum of avalanches recorded in one path are 166 events. Out of the 2676 avalanches 1611 were classified as wet snow and 1003 as dry snow avalanches; for 12 events the type was not specified.

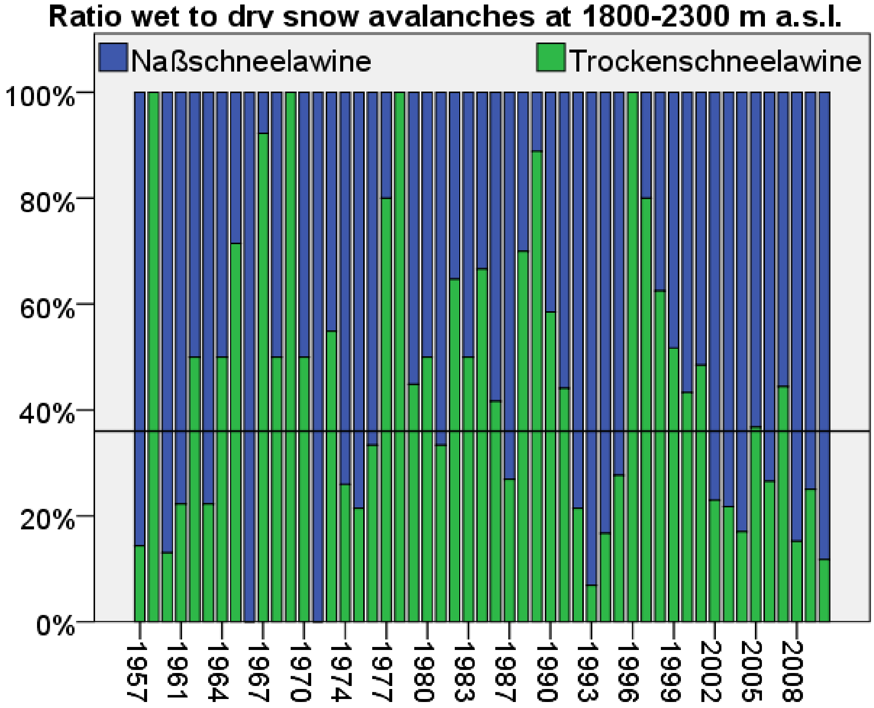

Figure 3: Ratio of wet to dry snow avalanches at an elevation of 1800-2300 m a.s.l.

A reliable quantification of the trend of the ratio of wet to dry snow avalanches is not possible as the dataset is subject to great uncertainties, which are due to:

- The quality of recordings
- Bias towards larger events that were relevant to the hydro power company
- Time lag in recordings e.g. due to visibility, none recordings, when no damages occurred, ignorance of events, inexactness of observation or poor accessibility
- Unexpected data gaps, e.g., although the winters 1951/52 and 1953/54 were pronounced avalanche winters in the Alps, no avalanches were recorded
- The reliability or the completeness
- The type of avalanches is subject to subjective opinions

Therefore we chose a more descriptive approach to understand the impact of climate change on avalanche activity.

Based on the climate change scenarios and the analysis of past data the following preliminary statements can be made:

- In winter the number of days were the precipitation type is snow has a decreasing trend
  Mooserboden (see Figure 4)
- There is an increasing trend in temperature for the month from January to May, whereas in November and December no trend is obvious (see Figure 5)
- At the station Mooserboden the snowpack height seems less variable in more recent years. While no obvious trend is recognized for November, December and January, in February the mean is increasing slightly and in March and April more pronounced. A decreasing trend can be seen for May.
- The percentage of wet snow avalanches will increase at lower and middle altitudes
- Even though there is an increase in the number of days with calculated extreme values of accumulated new snow, a higher avalanche activity cannot be verified

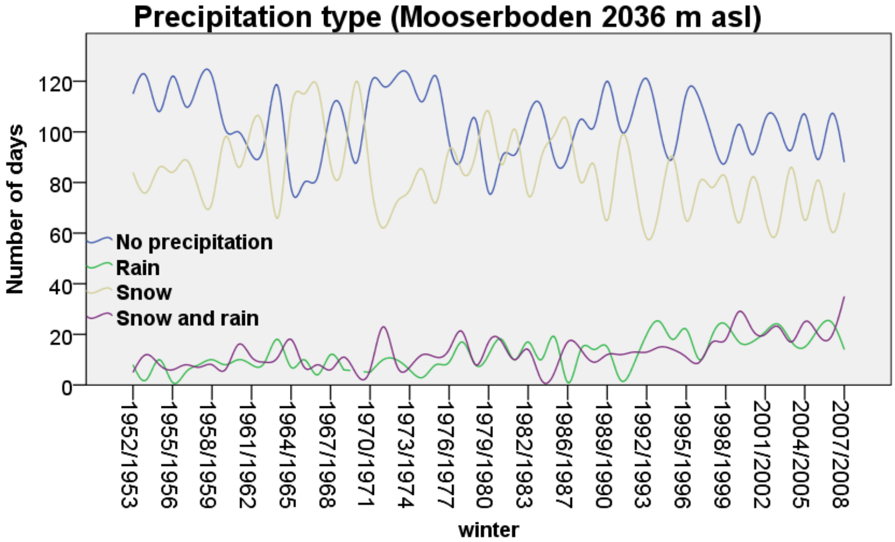

Figure 4: Number of days with the precipitation type rain, snow or snow and rain.

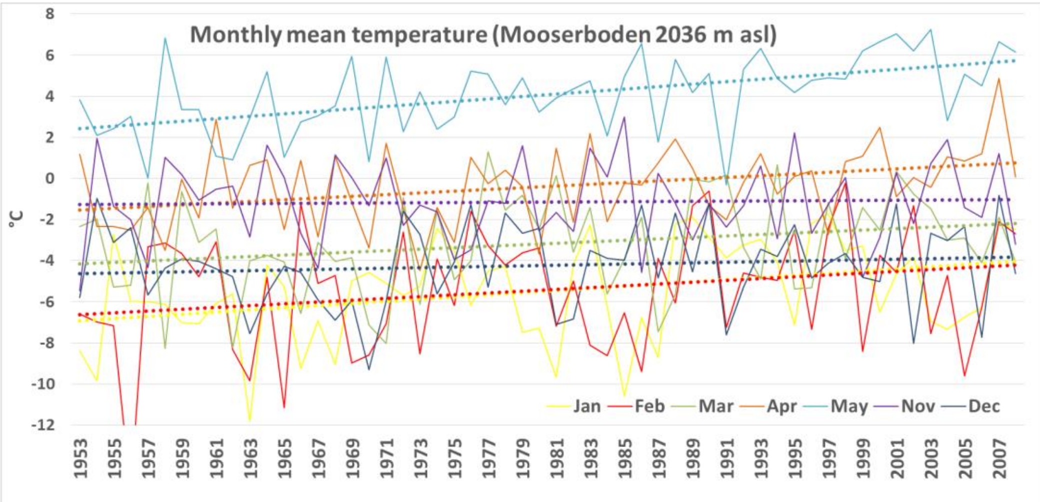

Figure 5: Time series of monthly mean temperature at station Mooserboden 2036 m a.s.l.

Climate change and its impact on debris flow activity, permafrost and glacier development

Over recent years different studies have investigated possible links between recent climate change and the frequency of debris-flow occurrence in the Alps (e.g. Zimmermann et al., 1997, Rebetez et al., 1997,Jomelli et al., 2004,2007, 2009; Stoffel et al., 2005). While no univocal trend regarding the possible development of future debris-flow activity becomes apparent, the studies emphasize a link between debris-flow activity and changes in temperature or precipitation patterns (Jomelli et al., 2009). According to a conceptual approach presented in Zimmermann et al. (1997) debris-flow activity in a catchment is mainly influenced by the catchments basic disposition, the variable disposition and the occurrence of a triggering event. While the disposition of a catchment mainly includes the presence of a certain amount of potentially mobilizable loose material and additional conditions like antecedent soil moisture content, the triggering event is characterized by the release of an additional source of water/moisture large enough to initiate a debris-flow.

In order to assess the potential influence of the prospected change in climate conditions in the study area on future debris-flow activity the development of the availability of mobilizable sediment (i.e. disposition) and possible changes in the occurrence pattern of triggering events (heavy precipitation, snow melt) have been investigated. With respect to the future availability of loose material especially the currently glaciated and periglacial areas are of interest. In these areas the degradation of permafrost and retreat of glaciers is hypothesized to produce additional sediment sources in the future.

The potential evolution of the permafrost distribution in the study area has been simulated after the PERMAKART approach (Keller, 1992; Schrott et al., 2012; Ott et a., 2013). Scenarios based on present and prospected future climate conditions have been modeled. The results of the simulations for the current and future weather/climate data were compared in order to obtain areas susceptible to permafrost degradation over the coming years. Regarding the development of glaciers in the study area data from the Austrian Glacier Inventory was used. From this dataset the glaciated areas for the reference years 1969 (Patzelt, 1978; Patzelt, 1980; Groß, 1987), 1998 (Lambrecht and Kuhn, 2007) and 2006 to 2009 (Abermann et al., 2009 and 2012; Stocker-Waldhuber et al., 2012) are available. The estimation of future glacier development has been based on the recent glacier retreat-rates.

With respect to the prospected change in the frequency and seasonal pattern of triggering events data from three representative meteorological stations were analyzed. It has been assumed that the station Zell am See (766 m asl) is representative for the climate/weather in the study area below 1000 m asl, the station Mooserboden (2036 m asl) for the range between 1000 and 2400 m asl and the station Sonnblick (3105 m asl) above 2400 m asl. Hence, each of the three altitude levels in the study area (low-, middle- and high-altitudes) is represented by one corresponding meteorological station and therefore by one climate change scenario. For debris-flows the lowest elevation level (<1000m) is not considered relevant, because the majority of the catchments under investigation do not have substantial areas in this altitude level.

The 0°C level in the Kaprun region under present day conditions is located at approximately 2310 m a.s.l. with an area of >60 % above this level. The assumed rise in air temperature will elevate the 0°C level by 470 m until 2050 (temperature gradient of 0.51/100m), which means that approximately 25 % of the catchment area will remain above this limit. This prospected trend is in alignment with an observed increase in summer precipitation in the form of rain as compared to summer precipitation in the form of snow for the station Mooserboden (2036 m asl) (see Figure 6). A similar trend can be observed at higher elevations (station Sonnblick, 3105 m asl), however snowfall in summer months is still more frequent at this elevation.

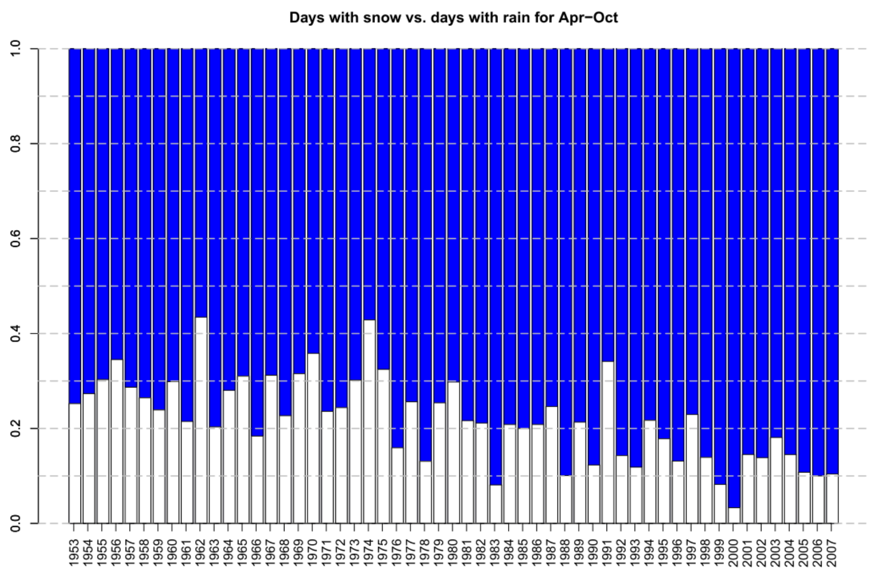

Figure 6: Days with snow (white) and days with rain (blue) in the summer months (Apr-Oct) for the station Mooserboden from 1953-2007.

In the Kaprun region in 8 out of 35 investigated catchments (with a total area of 18.3 km²) substantial (>10% of the total catchment area) permafrost and glacier areas are currently present. In these 8 catchments glaciers and permafrost cover an area of 4.8 and 7.1 km², which represent 26.3 and 39.1% of the total catchment area, respectively. Only one catchment (CM_18) is solely influenced by permafrost while no glaciation is observed. In the remaining 7 catchments the sum of permafrost and glaciated areas accounts for more than 50% of the total catchment area. In these catchments the projected increase in air temperature will reduce the glacier area in the whole catchments to 1.6 – 2.2 km², which corresponds to 8.8 – 12.3 % of the whole catchments. For the glaciers in the region this corresponds to a reduction in glacier area of 69 – 78 % as compared to the glacier extent in 1969. In two catchments (CM_19 and CM_20) glaciers are expected to vanish completely until 2050. Still, as the area of the catchments is rather small the absolute glacier retreat areas are mainly below 0.5 km². Only in CM_24 the retreat area is expected to be more than 1 km² (Figure 7). The cumulative area subject to deglaciation in the 7 catchments is expected between 2.5 – 3.6 km².

Also permafrost areas will almost vanish in most of the 8 catchments. The cumulative permafrost area will be reduced to 0.9 – 1.9 km², which corresponds to only 4.8 – 10.5 of the total catchment areas. In sum a reduction of present permafrost areas of 73 to 82 % can be expected. The cumulative sum of permafrost degradation areas in the 8 catchments influenced by glacial and periglacial dynamics is expected in the range of 3.9 to 5.2 km².

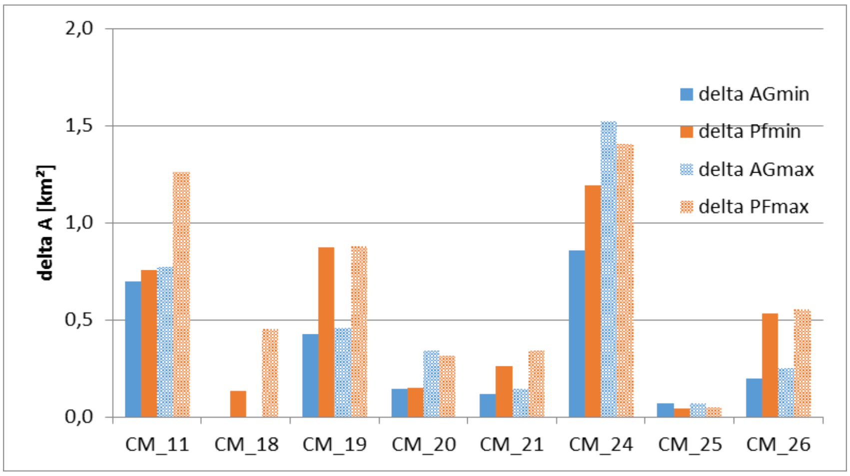

Figure 7: Predicted glacier retreat (AG) and permafrost degradation (Pf) areas (km²) for catchments in the Kaprunertal until the year 2050. The predicted changes are based on a 2.4°C inreace in mean air temperature until 2050. Min and max values refer to different approaches used for the calculation of retreat rates.

While it can be argued with reasonable certainty that in areas above approx. 2400 m asl the availability of erodible sediment will increase with the projected change in climate conditions, assumptions about future development of sediment availability in lower lying catchments and the evolution of frequency and seasonal patterns of triggering events are subject to higher uncertainties.

In summary, the projected change in climate variables is expected to lead to the following developments:

- The general disposition towards debris-flows and similar mass movement processes is expected to increase in areas located above 2400m. The release of additional loose material and destabilization of currently ice-covered and permanently frozen ground will lead to a higher susceptibility to debris-flows and alike processes in these areas. However, it is expected that in these areas debris-flow activity will still mainly be limited to summer months (Jun-Sept), where larger amounts of precipitation can be expected in form of rain and snow cover is largely absent.
- With respect to catchments largely located between 1000 and 2400 m the basic disposition against debris-flows should mainly remain unaltered with respect to availability of loose material. However, mainly due to the shift of precipitation patterns towards increased precipitation in winter/spring and decreased precipitation in summer/autumn, a shift in debris-flow activity towards spring is hypothesized. Along with the predicted general temperature increase snow-melt and combined snow-melt and precipitation events might become more important as potential triggering factors for debris-flows. Further the variable disposition against debris-flows is expected to increase in spring due to the predicted increasingly moist conditions (snow melt influencing antecedent soil moisture levels, increasing precipitation sums).

- Regarding the development of the frequency of high intensity precipitation events, which can be regarded as the most frequent trigger of debris-flow events, no distinct trend could be identified from analysis of past data. Developments in this respect are expected to stay within the limits of present day variability.

It has to be noted that at the present stage empirical evidence supporting these hypotheses is very limited. In this respect the prospected developments should be interpreted with care. This is especially true considering that stochastic natural events (e.g. heavy storms), which are presently not accounted for in the prediction of future developments, might have a more severe influence on the system state than the investigated climatologic variables.

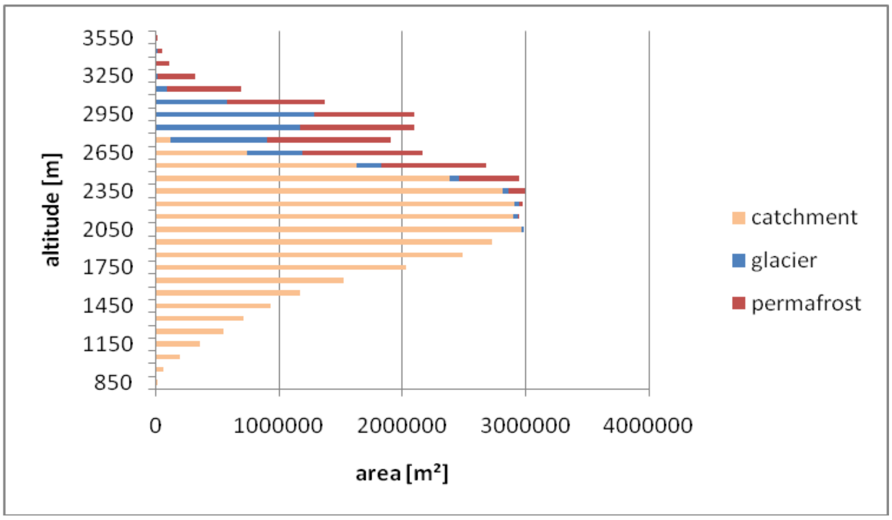

Figure 8: Areal distribution of the 35 investigated catchments in the study area Kapunertal for different altitude levels.

Exposure analysis

In close collaboration with the project partner the vulnerability of the energy system (hydropower generation) has been determined. Nine object classes (access roads and trails; water intake weirs and diversions; above ground powerlines, energy production buildings; outdoor substations; dams and reservoirs) have been selected. In the study area of Kaprun a total of 73 objects were considered, in Zillertal 62 (Figure 9).

Having identified all relevant objects at risk, for each of these objects likely hazard scenarios were determined as depicted in Figure 10 for an example of avalanche hazard on electricity towers. Four different scenarios (frequent, infrequent, rare, extreme event) have been defined for each object and according process (avalanche, debris-flow). The definition of scenarios is based on a pre-analysis of collected data within a GIS environment, field work and additional methods (empirical relations, local expertise). For each of these scenarios the process intensity and corresponding expected damage to the object has been assessed. The methods applied for the scenario definition and damage assessment have been varied (from expert based assessment in the field, to more elaborate simulation-based approaches) based on local conditions and availability of data sources. Figure 11 shows an example of the hazard assessment incorporating the application of different simulation-models, Figure 12 depicts the exposure analysis based on GIS analysis and field work.

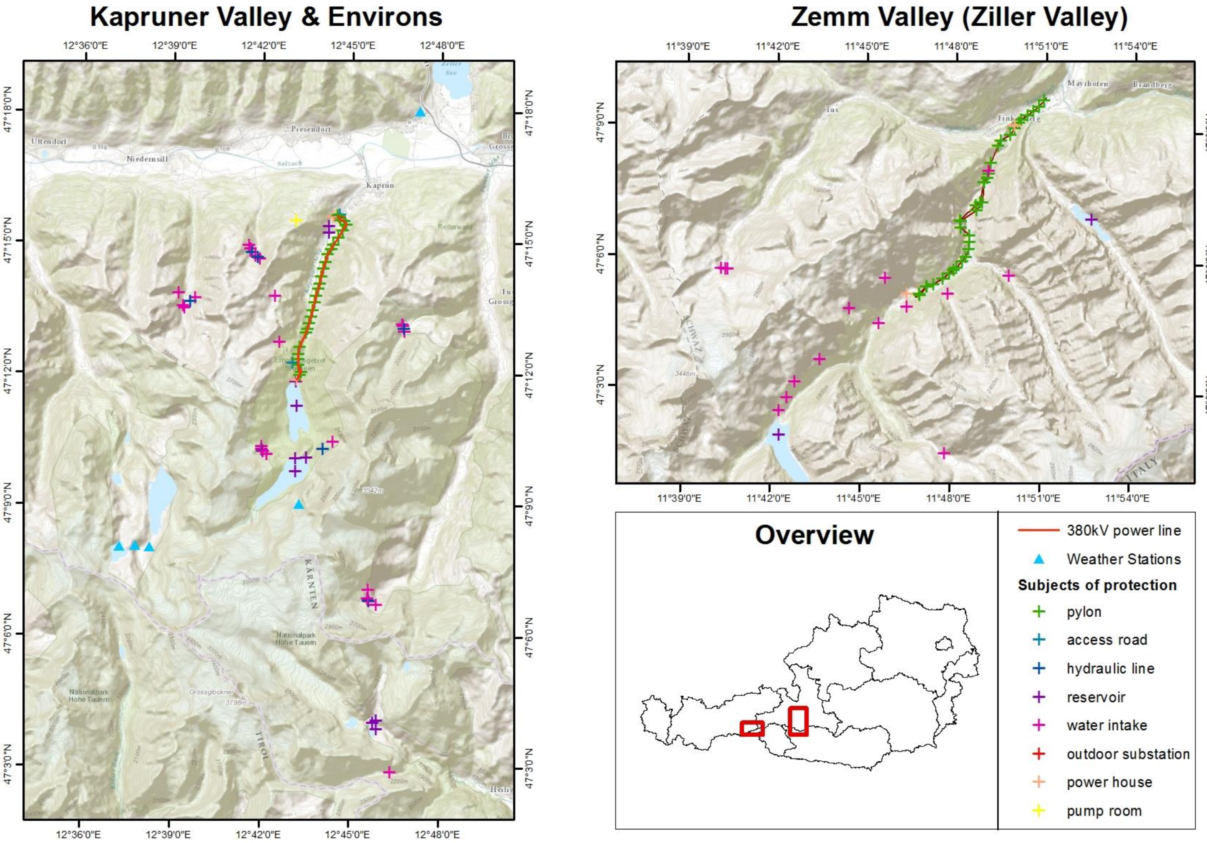

Figure 9: Overview of risk objects in Kaprunertal and Zillertal

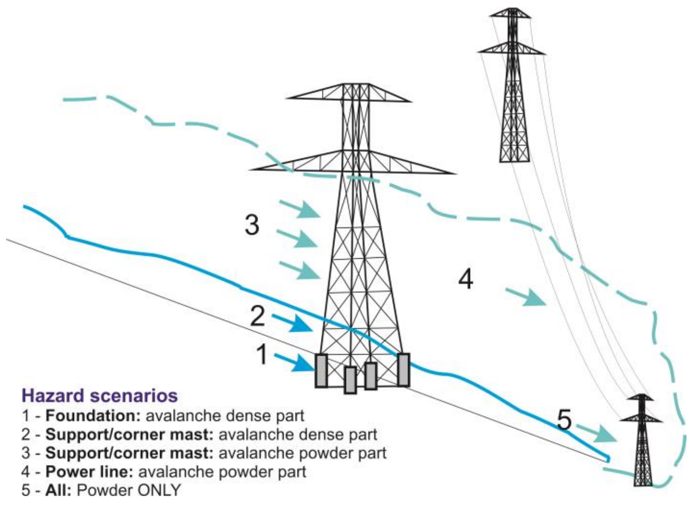

Figure 10: Avalanche hazard scenarios for electricity tower

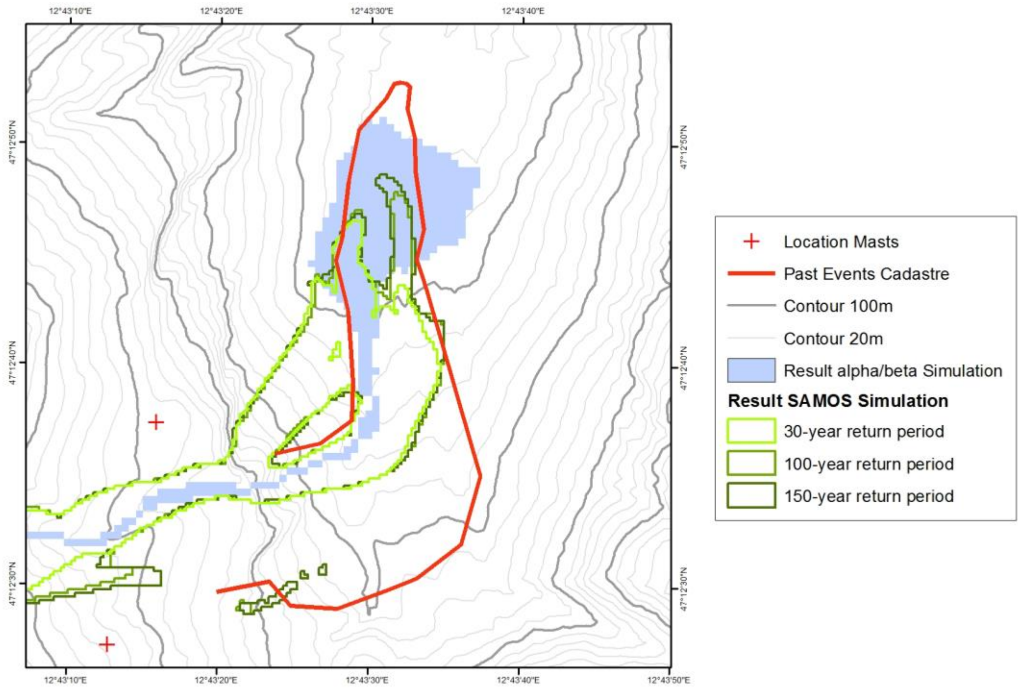

Figure 11: Comparison of results from a numerical simulation (SAMOS AT) (green lines - 1KPa dynamic peak pressure isoline), a statistical model (a/ß-model) (blue area) and the largest observed extent of the Schranbach avalanche (red lines) (sources: Digital Elevation Model - Land Salzburg; past events cadastre - Verbund AHP).

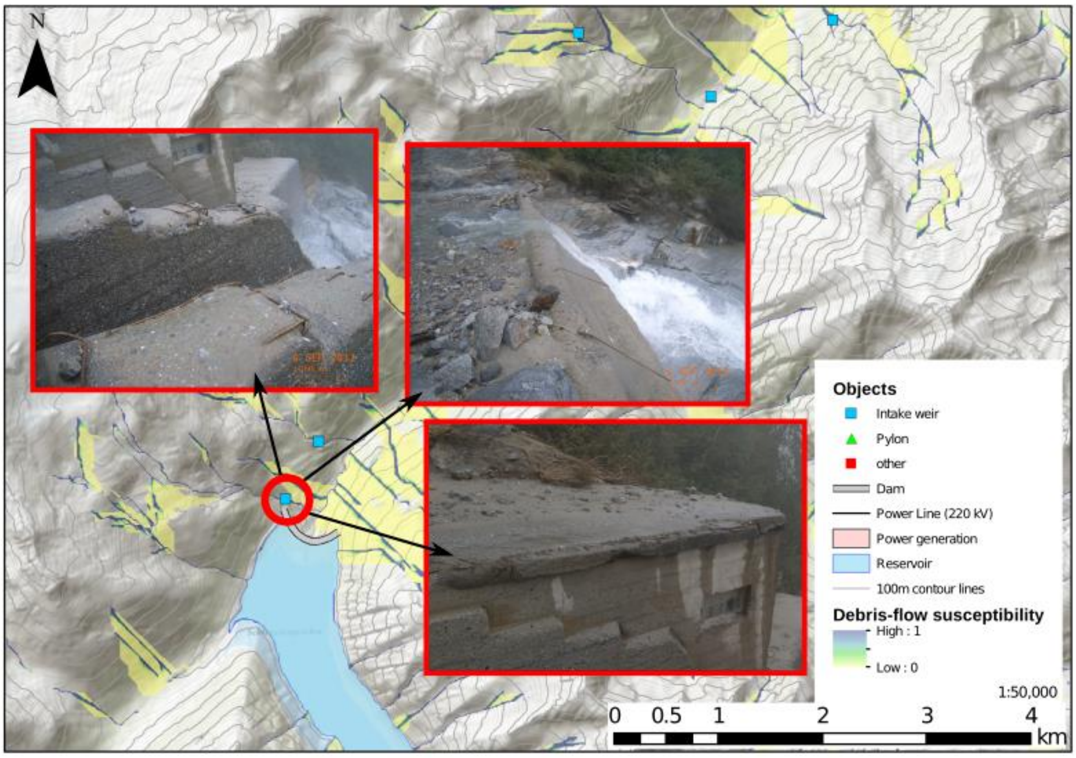

Figure 12: Example of the analysis of the exposure of objects to debris-flows.

Consequence analysis

Considering single objects at risk, the representatives of the hydropower facility stated that it would be interesting for their decision to group the damages into four classes in regard to their degree of damage to a specific object rather than to the total amount of costs. A damage is considered small, if the cost for repairing the object does not exceed 2% of the specific cost; a catastrophic damage occurs when at least 50% of the building costs arise.

Determining the damage potential

For any cost-benefit analysis and risk calculation it is important to reliably assess the damage potential for each object at risk. The consequences are the damages caused by natural hazard event impacts on objects of the hydropower facility. After Bründl et al. (2009) the damage can be calculated as:

$$D(O)_{i,j} = (1-\varepsilon_i) * V(O)_i * DS(O)_{i,j} \quad (1)$$

…where $D(O)_{i,j}$ is the potential damage (in €) to an object (O_i) caused by a scenario (S_j). ε_i is a factor accounting for structural mitigation measures. $V(O)_i$ is the value (in €) of the object at risk and $DS(O)_{i,j}$ reflects the damage susceptibility of the object (O_i) to the given scenario (S_j).

Consequently, the damage potential is a function of the value of an object, the damage susceptibility (*DS*) of an object in relation to the intensity of a process and a factor introduced to account for mitigation measures. The *DS* in Equation (1) is directly related to the limits of defined damage classes: 0-0.02 (small), 0.02-0.1 (medium), 0.1-0.5 (large) and 0,5-1 (catastrophic). This is different from other cost-benefit-calculations that are based on the hazard zones as delineated in the hazard zone maps. However, this distinction in four classes give the management higher planning flexibility (see Zeidler et al., 2012).

Uncertainties in these parameters arise from imperfect information, but the severity on decisions has to be assessed for each specific case. Often site-specific information is neglected (e.g. construction types, terrain factors), which may be reflected in too high or too low values of the *DS*. Additionally, there is not sufficient data to quantify the extent of the damage of individual objects depending on the impact pressure. The uncertainty is epistemic as it can be reduced in the case that more reliable information becomes available (see Hug, 2012). The concept for determining damage potential within the RIMES project and an exemplary application of this concept to a showcase are presented in Zeidler et all (2012).

The concept of risk is commonly described as a function of probability and consequences. Data and experience gathered from research conducted in the study area Kaprun were used in WP1-WP3 to establish a risk management concept. This concept has been applied to the study areas Kaprun and, albeit to a lesser extent, Zillertal. Figure 13 shows the results of the applied risk assessment procedure for a pylon of the 220kV-powerline in the Kaprunertal. The obtained distribution of yearly risk is based on a Monte-Carlo Simulation of expected damage classes (small, medium, large, catastrophic as defined above) for the four considered scenarios (frequent, infrequent, rare, extreme event). The processes snow-avalanche and debris-flow have been considered. The detailed information on the applied methodology will soon be published. Figure 14 depicts the location of the considered pylon and a debris-flow scenario.

The key output is the decision tree that will be published in the near future. This decision tree has been worked out in order to show the necessary steps to determine the risk of an energy system against natural hazard processes. The risk assessment within the RIMES project is separated for each object into the three natural hazard processes investigated, avalanches (sector A), debris flow (sector B) and sedimentation (sector C). For every object within the system each of the three sectors have to be processed. With the help of this tool the following questions can be addressed:

1. Where is the energy system vulnerable to natural hazards?
2. How much damage is potentially inflicted by an event (primary and secondary losses)?
3. Which different mitigation concepts can be applied?
4. What are the uncertainties about climate change, the impacts on natural hazards and the damages?

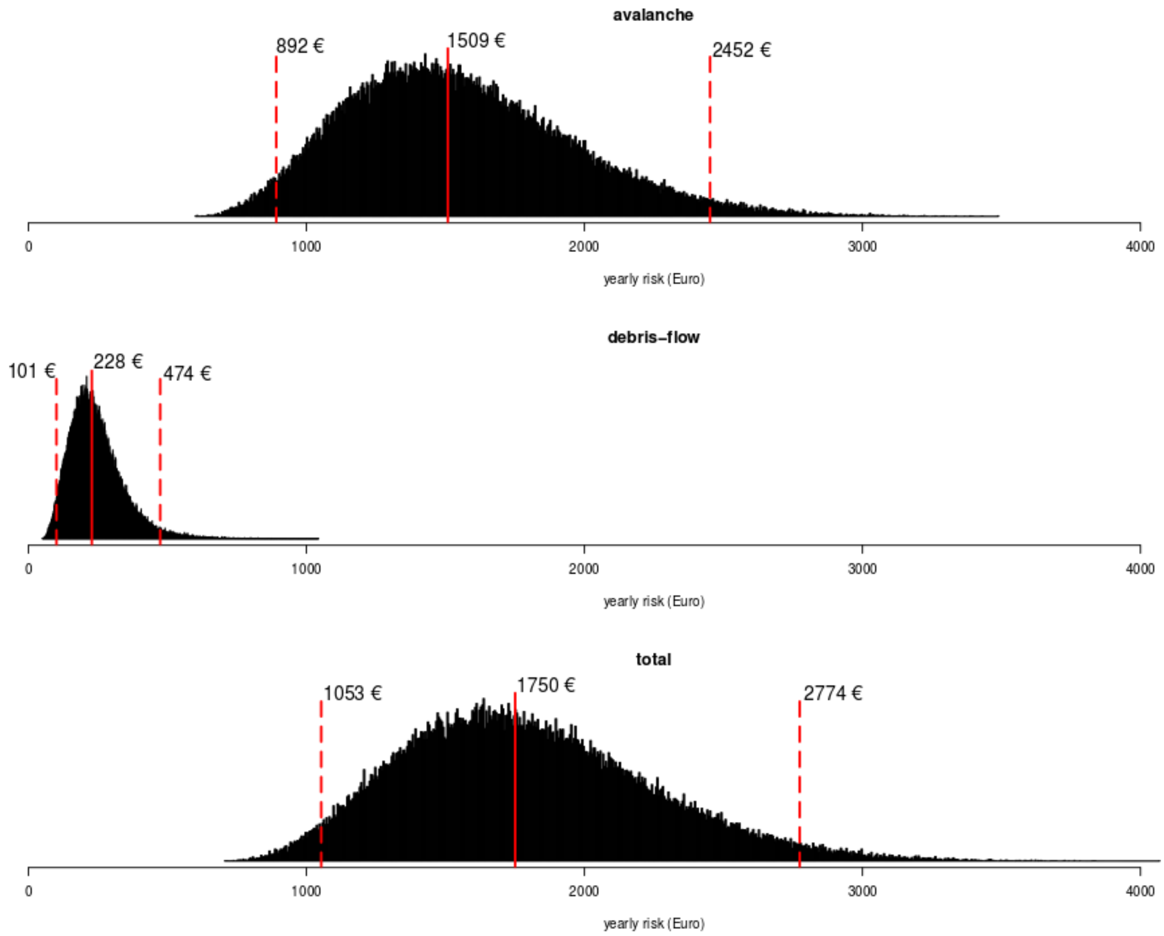

Figure 13: Result for the yearly risk arising from avalanches and debris-flows for a pylon of the 220kV-power line. The main portion of the yearly risk is expected to arise from avalanches, while debris-flows play a minor role for the considered object. Solid lines indicate the 0.5 quantile, dashed lines indicate the 0.025 and 0.975 quantile for the obtained distribution of yearly risk respectively.

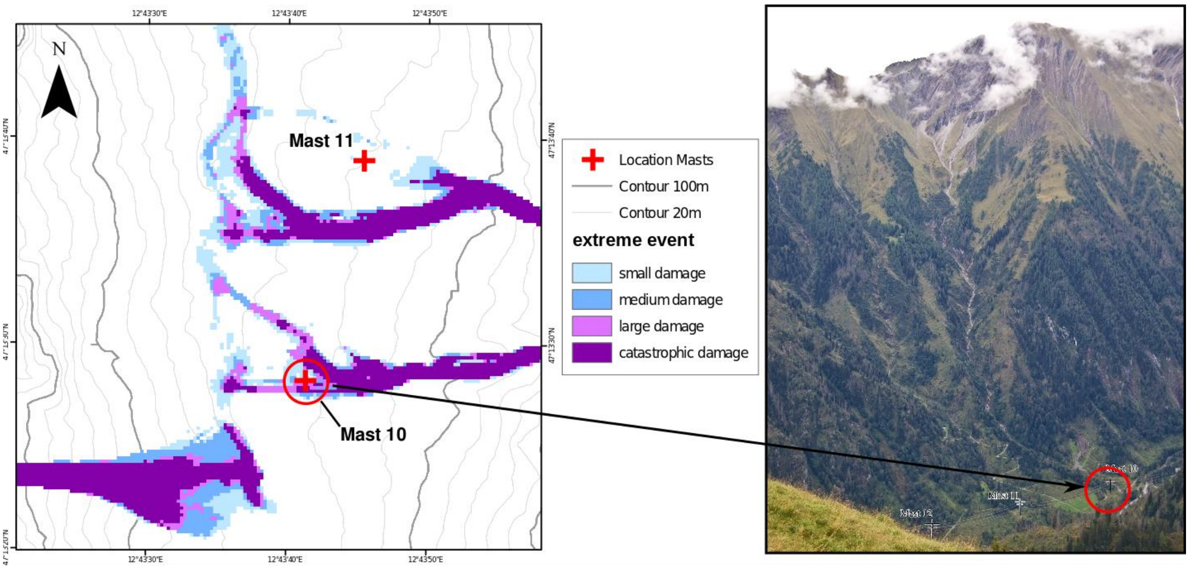

Figure 14: Location of the Pylon (Mast 10) in the study area. left: Damage classes assessed for an extreme event (low recurrence interval). right: Location of the pylon as seen from the opposite slope (facing east).

4 Conclusions and recommendations

The finding that have been derived from the project by the project team can be divided in different aspects. The main key findings can be seen in the process analysis, especially in regard to climate change. The other aspects are in conjunction with the uncertainty analysis (identification, calculation and communication), damage potential analysis and risk management procedures.

In the process analysis we have shown that the work with climate change scenarios is suitable to describe the impacts on natural hazard processes. Further it has been shown that it is often difficult to link climate change directly to observed events. Especially for debris flows it is difficult as the general process frequency is rather low and the availability of historic event records is very limited in many areas. For avalanche it is somewhat easier as more continuous data on past events has been available. However, there are still shortcomings in the analysis due to great uncertainties, but trends such as the increasing portion of wet snow avalanches can be observed in the past data.

Uncertainties due to climate change are difficult to implement in daily decision making and the importance is often neglected by stakeholders, even though they realize the need for longer planning horizons. In many cases the yearly variance in the observed processes are higher than the expected influence of climate change.

From a pure scientific point of view the quantification of uncertainties has a high significance, but for practical implementations of procedures the acceptance may not be as high and relevant to the decisions. However the highest importance is seen in the communication of sources of uncertainty in order to be aware when making a decision.

Integral risk management is applicable at different planning levels. A first assessment for e.g. a regional levels does not require a detailed analysis as is necessary at a local scale. Subsuming the results one can say that the importance of the procedure declining the higher the level of appraisal. Meaning that natural hazards are more important at object scale than on national scale.

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C) Project details

5 Methods

Uncertainties across all work packages

The main theoretical work on uncertainties in the scope of RIMES was covered in a Master thesis with the title "Uncertainties in natural hazard risk management" (Hug, 2012). The thesis focuses on the identification of suitable statistical techniques to be applied in the different steps of risk management. The results are based on a literature review of previous studies on uncertainties (sensitivity, scenario, Monte Carlo and Bayesian analysis as well as a hybrid approach, creedal networks, fuzzy sets theory and generalized likelihood estimations). The studies were evaluated based on a SWOT (Strength-Weakness-Opportunities-Threats) analysis and subsequently an uncertainty matrix was developed that was applied in the single working steps in RIMES.

Activities and methods

In order to investigate the hypothesis that the projected change in mean and extreme values of climatic variables might have various effects on natural hazards processes like avalanches, debris flow or the future development of permafrost and glacier areas the following activities have been performed within RIMES:

1) **Climate change in the study areas:**
   - Literature review on climate change in Austria and in the study areas
   - Definition of two climate change scenarios (baseline and worst-case) for the study areas based on reclip:more (Loibl et al., 2007)
   - Analysis of data from meteorological stations in the study area (Zell am See, Mooserboden, Sonnblick). Investigation of possible changes in the minimum, maximum, mean and extreme values of different climatologic parameters (temperature, precipitation).
2) **Hazard analysis for the study area** Kaprunertal **:**
   - Review of existing studies investigating the impact of climate change on natural hazards
   - Analysis of the avalanche cadastre (e.g. frequency, magnitude)
   - Field work: Mapping of avalanche paths, debris flows, sediment sources and permafrost in the study area.
   - GIS-based analysis for identification of areas potentially prone to hazard processes and estimation of process intensities
   - Application of simulation models (avalanche, debris flows) to quantify run-out length and intensity estimates.
   - Sensitivity analysis of input parameters (e.g. release height for avalanches) to account for climate change and quantify uncertainties
   - Comparison of model outputs (physical simulation model, statistical model) to show uncertainties due to the choice of different models
   - Permafrost modelling for the two defined climate change scenarios after PERMAKART (Schrott et al., 2012)
3) **Exposure analysis:**
   - Questionnaire to identify potentially endangered objects (risk elements)
   - Clustering of the objects into three categories according to their importance in the operational management of the hydro power production facility

- Expert discussion (workshop) on damages to be considered in RIMES
- GIS-visualisation of endangered objects and associated processes (hazard maps)

4) **Consequence analysis:**

- Definition of damage classes relevant to hydro power production (workshop)
- Assessment of the damage susceptibility based on selected hazard scenarios per object
- Definition of acceptable residual risks to identify relevant return periods of damages for different object classes (workshop)
- Calculation of damage potential based on commonly used formulas and Monte Carlo simulations

5) **Risk calculation:**

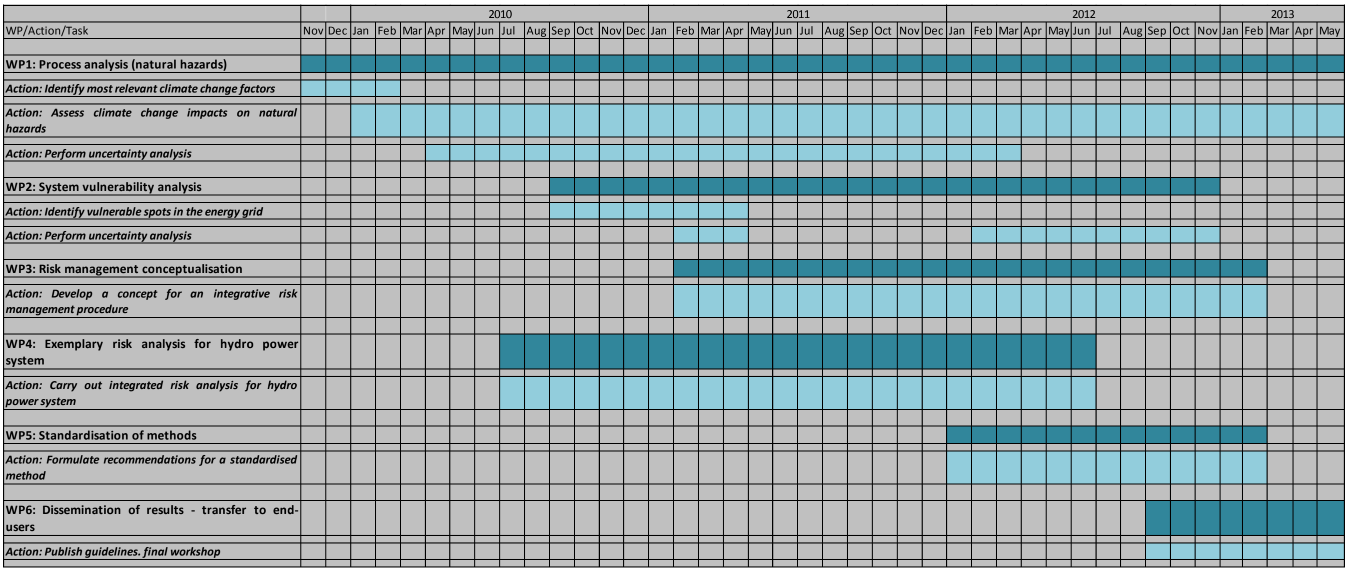
- Calculation of the risk for different object classes
- Development of an @risk interface to perform Monte Carlo simulations to calculate risk

6) **Conceptualisation of the risk management procedure:**

- Review state-of-the-art (literature review)
- Adaptation of existing procedures to the requirement of RIMES
- Subsequent evaluation and incorporation of results from WP1 and WP2 to formulate a general risk management procedure uncoupled from the study areas
- Suggestions on how to incorporate uncertainty results in risk management
- Definition of acceptable risks (workshop and expert discussions)
- A decision tree has been worked out in order to show the necessary steps for determining the hazard potential, the vulnerability and consequently the risk of an energy system for the investigated natural hazard processes.
- Basic recommendations for a standardised method have been formulated. The recommendations should serve as a reference for the consideration of uncertainties in risk management practice.

Since parts of the project were aimed at the development of a practicable risk management tool to support the management of hydro-power facilities, a close cooperation with these project partners was fostered. Preliminary results and applied methodologies were discussed at workshops during the project run time. In addition, the results of the work packages have been and will in the future be presented at national and international conferences and disseminated through different channels, including publication in peer-reviewed journals.

6 Work plan


2010
2011
2012
2013
WP/Action/Task
Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Jan Feb Mar Apr May
WP1: Process analysis (natural hazards)
Action: Identify most relevant climate change factors
Action: Assess climate change impacts on natural hazards
Action: Perform uncertainty analysis
WP2: System vulnerability analysis
Action: Identify vulnerable spots in the energy grid
Action: Perform uncertainty analysis
WP3: Risk management conceptualisation
Action: Develop a concept for an integrative risk management procedure
WP4: Exemplary risk analysis for hydro power system
Action: Carry out integrated risk analysis for hydro power system
WP5: Standardisation of methods
Action: Formulate recommendations for a standardised method
WP6: Dissemination of results - transfer to end-users
Action: Publish guidelines. final workshop

7 Publications and Dissemination

Master theses

Hug, Daniel (2012): Uncertainty analysis in natural hazard risk management. Julius-Maximilians-Universität Würzburg.

Rosner, Marie-Louise (2012). Empirisch-statistische Modellierung der aktuellen und zukÃ¼nftigen Verbreitung von Hochgebirgs-Permafrost (Kapruner Tal, Österreich). Master Thesis. Universität Salzburg

Bouda, Michael (2012). Geomorphologische Kartierung im Bereich der Ebmatten-Bäche (Hohe Tauern, Österreich). Master Thesis. Universität Salzburg

Elena Stoll (voraussichtlich Februar 2014): Zeitreihenanalyse von lawinenrelevanten meteorologischen Daten. Meteorologisches Institut der Universität Innsbruck.

Proceedings

- Conference presentation (poster): "The principle concept on how to determine the impacts of a changing climate on natural hazards" was presented on the International Conference 'Mountain Risks: Bringing Science to Society', which was held in Firenze on 24-26th November 2010. The poster and the proceedings article are attached in the appendix.
- Zeidler, A. and P. Dobesberger (2012): Considering climate change in natural hazard Risk Management in energy systems. A practical approach. Extended abstract. 12th Congress INTERPRAEVENT 2012. Grenoble.
- Zeidler, A., Huber, A., Hug, D. and P. Dobesberger (2012): Decision uncertainties in natural hazard risk management: damage potential. Reviewed Proceedings. Conference Risk Analysis 2012, Croatia.
- Stoll, E., Zeidler, A. and R. Fromm (accepted): Assessing long term trends in winter conditions. Proceedings of the ISSW 2013 in Grenoble.
- Zeidler, A. and P. Dobesberger (accepted): Basic findings of the project RIMES. Proceedings of the ISSW 2013 in Grenoble.

Peer reviewed papers

- Zeidler, A., Stoll, E., Huber, A., Dobesberger, P. (2013): Assessing climate change and its impact on avalanche activity in Kaprunertal /Austria. To be submitted to: Cold Regions Science and Technology Special ISSW 2013 issue.
- Dobesberger, P., Huber, A. and A. Zeidler (…): Integrating climate change in natural hazard risk management. Not yet submitted.
- Dobesberger, P., Huber, A., Juen, I. and A. Zeidler (…): Application of an integral risk management concept in Kaprunertal. Not yet submitted.
- Zeidler, A., Huber, A. and D. Hug (…): Uncertainty considerations in risk management. Not yet submitted.

Presentations at external events

2010

- Dobesberger, Paul (2010): "The principle concept on how to determine the impacts of a changing climate on natural hazards". Poster. International Conference 'Mountain Risks: Bringing Science to Society', Firenze, 24-26th November 2010.

2011

- Zeidler, A. and P. Dobesberger (2011): "Vulnerability assessment of climate change impact on natural hazards in energy systems". Talk. European Geosciences Union General Assembly 2011.
- Dobesberger, P. (2011): "Calibration and Comparison of three SVAT (Surface-Vegetation-Atmosphere Transfer) models". Poster. European Geosciences Union General Assembly 2011, Vienna.
- Zeidler, A. and P. Dobesberger (2011): "Climate Change and Natural Hazard Risk Management in Energy Systems". Talk. "Informationsveranstaltung Klima- und Energiefond", Vienna, 17.-18.5.2011.

2012

- Zeidler, A. (2012): Climate Change and Natural Hazards. Vortrag im Rahmen des Meeting: WCRP-IASC-SCAR Climate and Cryosphere Project. Scientific Steering Group, Eighth Session. Innsbruck 12-15 March 2012.
- Dobesberger, P., Huber, A. and A. Zeidler (2012): Determining the impact of a changing climate on avalanche hazard potential. Talk. European Geosciences Union General Assembly 2012, Vienna.
- Zeidler, A., Dobesberger, P., Huber, A. and G. Lochmann (2012): Natural Hazard Risk Management in Energy Systems. Considering Climate Change. Poster. 12th Congress INTERPRAEVENT 2012. Grenoble.
- Zeidler, A., Huber, A., Hug, D. and P. Dobesberger (2012): Decision uncertainties in natural hazard risk management: damage potential. Talk. Conference Risk Analysis 2012, Croatia.
- Dobesberger, P., Huber, A. and A. Zeidler (2012): Bestimmung des Gefahrenpotentials von Infrastruktur im Alpinen Raum unter Berücksichtigung des Klimawandels. Vortrag im Rahmen des PARAmount Postgraduate Kurses am 25.10.2012, Innsbruck.

2013

- Stoll, E., Zeidler, A. and R. Fromm (2013): Assessing long term trends in winter conditions. Poster. ISSW 2013, Grenoble. Accepted.
- Zeidler, A. and P. Dobesberger (2013): Basic findings of the project RIMES. Poster. ISSW 2013, Grenoble. Accepted.
- Adams, M., Huber, A., Reimer, T. and A. Zeidler (2013): Identifikation möglicher Lawinen-Hotspots entlang alpiner Energieinfrastruktur auf regionaler Ebene – Anwendung eines automatisierten GIS-basierten Ansatzes im Kapruner Tal (Österreich). Poster. AGIT 2013, Salzburg.