Analysing changes in flood risks in an Alpine catchment

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Abstract

The project FloodTimeS aims at developing flood risk time series for the region of Reutte in Tyrol, Austria, in the catchment area of the river Lech. The flood risk time series are based on a model chain that consists of downscaling of GCM results, regional modelling of land-use and socio economic development, rainfall-runoff modelling, flood frequency analysis, determination of flooded areas and values at risk as well as loss estimation. In this paper, the methodological approach and first results for the 2005 flood event will be presented by applying a reduced model chain. A flood frequency analysis that includes historic flood records assigns a return period of 330 years to this event. An intersection of areas that were inundated in 2005 with different land-use scenarios illustrates that land-use policy can considerably influence the extent of flood-affected settlement areas.

Keywords: flood frequency, flood damage, land-use scenarios, flood in August 2005, Tyrol, Austria

1 Introduction

From 1980 to 2005, about two thirds of all economic losses due to natural hazards in the European Alps were caused by floods (OECD 2007). In the perspective of the catastrophic floods in 1999, 2002 and 2005, a considerable increase in flood risk has become apparent in the Alps (BMLFUW 2006; Stötter 2007). In Austria, the three floods caused damage of approximately € 35 Million, € 2,445 Million and € 515 Million, respectively.

In this context, flood risk is composed by the hazard, i. e. the physical and statistical aspects of the flood (e. g. return period of the discharge, extent and depth of inundation), and the vulnerability that determines the extent of flood damage (e. g. Merz & Thieken 2004). In risk analyses with a technical focus, vulnerability comprises two elements (Merz & Thieken 2004; Kron 2005: 1) the asset values at risk, i. e. the buildings, structures or people that are exposed to the inundation; and 2) the susceptibility (vulnerability) of the exposed elements to adverse effects of the floodwater. Thus flood risk can be defined as: Risk = Hazard x Values at Risk x Susceptibility. Changes in flood risks can hence be attributed to – but can also be mitigated by – changes in the flood hazard, elements at risk and their susceptibility.

Global climate change and socio-economic development have been identified as main risk drivers in many regions around the world (Bouwer et al. 2007; Feyen et al. 2009; Bouwer et al. 2010). The impact of climate change on the frequency and magnitude of floods differs spatially, and up to now there is no clear signal of trends in river floods (see e.g. Svensson et al. 2006 for discussion). In Europe, growing losses are mainly due to increasing population, wealth and inflation (Barredo 2009). Of particular importance is the ongoing settlement and economic development leading to a continuous increase in assets in flood-prone areas. Therefore, urban and spatial planning is seen as a key factor for the management of flood risk (Howe & White 2002; Petrow et al. 2006).

Up to now, there are only a few climate impact studies on floods that also include aspects on vulnerability and risk: For example, an investigation in England and Wales expects a 20-fold increase in the real economic flood risk by the year 2080, if present politics, practice and investments concerning flood management are not improved significantly (Hall et al. 2005). Te Linde et al. (2011) analysed the impact of climate and socio-economic change on flooding in the Rhine basin and concluded that the annual expected damage may increase between 54% and 230% by the year 2030. The two studies illustrate the urgent need to find adapted and sustainable risk management that reduce future losses to an acceptable level. As a consequence, the project FloodTimeS was launched in 2009 with the following master goals:

- to examine the impacts of climate change on frequencies and magnitudes of floods in the catchment area of the river Lech in Austria,
- to investigate and quantify shifts in the damage potential, particularly the development of settlement areas along the river, and
- to develop flood risk time series for the 21st century.

2 Methodological concept of FloodTimeS

The study is designed as a pilot project for flood risk analyses in the perspective of global climate change. As investigation area, the upper part of the catchment area of

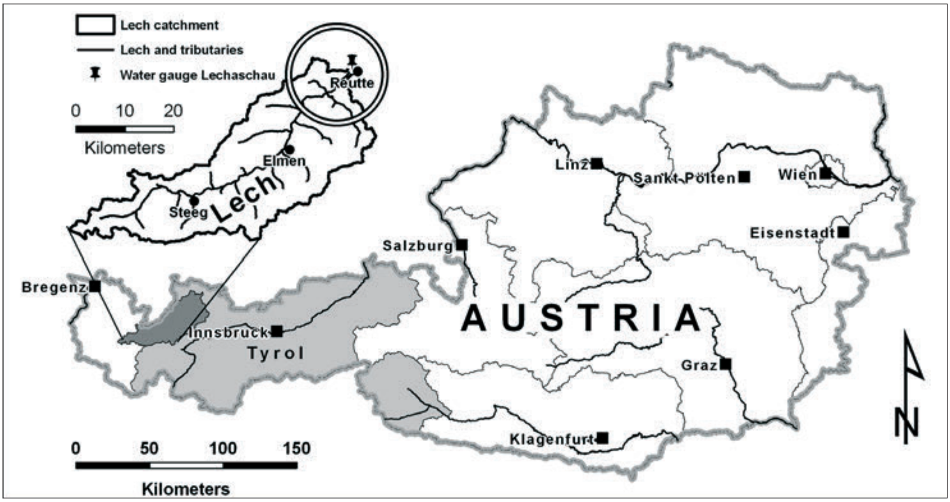

Figure 1: Investigation area of the FloodTimeS-Project: The catchment of the river Lech and the region of Reutte.

the river Lech with particular emphasis on the area around Reutte in Tyrol, Austria, was chosen (see Figure 1).

Following the definition of risk that was given above, meteorological, hydrological and hydraulic investigations to quantify the flood hazard as well as estimations of flood impacts to characterise vulnerability are necessary. As illustrated in Figure 2, hazard and vulnerability assessments are initially performed separately, but will finally be combined to risk estimates.

2.1 Flood hazard analysis

Two General Circulation Models (GCMs), i.e. the ECHAM5 model of the Max Planck Institute of Meteorology, Hamburg, Germany, and the HadGEM2 model of the Met Office's Hadley Centre for Climate Prediction, UK, were used to derive current and future climate in the study area. The coarse output of these models was statistically downscaled by applying the Expanded Downscaling technique (EDS; Bürger 1996). EDS belongs to the group of statistical downscaling with a particular focus on extremes. It is an advancement of a multiple linear regression. Initially, EDS is calibrated by establishing a statistical relationship between observed atmospheric fields – taken from the NCEP/NCAR (National Centers for Environmental

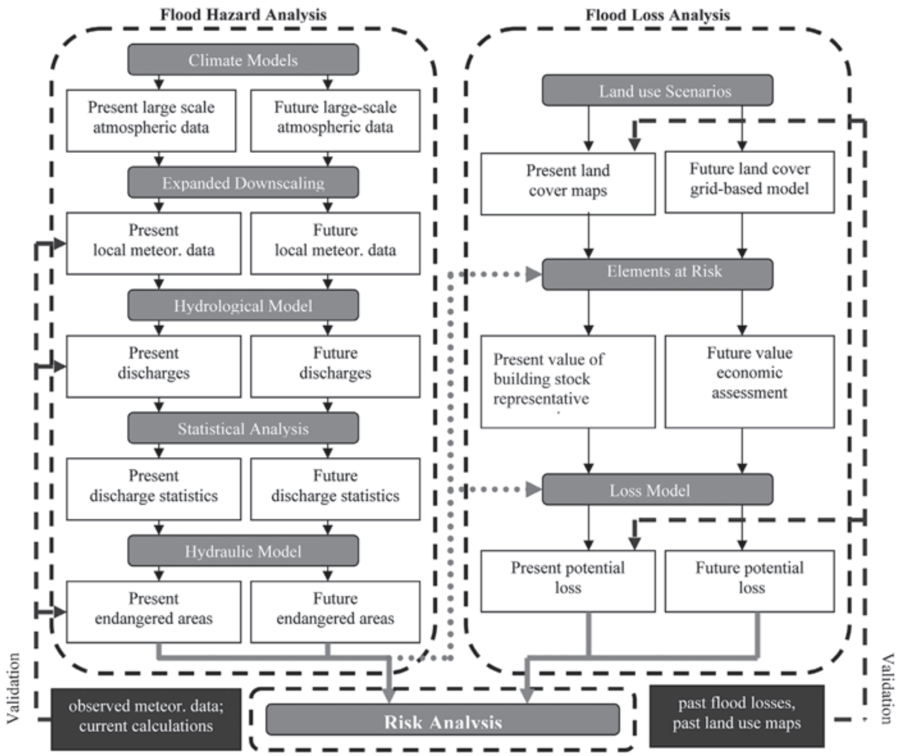

Figure 2: Methodological elements for assessing future flood risks.

Prediction, National Center for Atmospheric Research) reanalysed data set – and local temperature and precipitation data. In a next step, the statistical relations can be used to derive local time series of temperature and precipitation from the large-scale GCM output (see Menzel & Bürger 2002). The downscaled local climate data are further used as input for the hydrological model HQsim (Kleindienst 1996) that generates runoff time series for present and future climate conditions. HQsim is a semi-distributed hydrological model, which was especially designed for simulating flow peaks in meso-scale alpine catchments. For a daily discharge simulation, only data on temperature and precipitation as well as regional characteristics such as soil, land-use and orography (slope, aspect, altitude) are required. In a third step, flood frequency analysis for the runoff series of the baseline and the future scenario are carried out for the water gauge in Lechaschau near Reutte. Series of annual maximum floods are extracted and the Generalized Extreme Value (GEV) distribution is fitted to the data as a first approach.

2.2 Flood loss analysis

The flood risk analysis for the next decades requires not only the assessment of the flood hazard, but also the estimation of future settlements and associated asset values at risk. Therefore, land-use scenarios were developed by means of the regional land-use model CLUE-S (Verburg et al. 2004), which accounts for a number of topographic, social and economic drivers. The future demand for different land-use types were derived from the spatial planning scenarios for Austria, published by the Austrian Conference on Spatial Planning (ÖROK, Hiess et al. 2009). Based on the generated land-use patterns, future settlement areas can be identified. For the land-use simulation area, zoning plans as well as nature reserves (Natura 2000) were incorporated in order to define areas where particular land-use developments are preferred or restricted. In a next step, asset values of the current settlement areas will be derived from the (object-specific) building asset database of Huttenlau & Stötter (2008). For future land use scenarios, asset values will be related to the development of GDP that is included in the ÖROK scenarios. Population and building asset values will be regionalised and assigned to distinct settlement areas by means of the dasymetric mapping approach of Gallego (2001) as shown in Thieken et al. (2006). The final flood loss estimate is obtained by intersecting the inundation scenarios from the hydraulic modelling (see below) with the generated settlement areas (including their asset values) and an adapted version of the multi-factorial flood loss estimation model FLEMOps (Thieken et al. 2008). This model includes several parameters that determine the amount of loss, e.g. water depth, building type and quality, but also precaution and contamination. With the adapted and validated model chain, flood loss and risk analysis can be performed for the next decades.

2.3 Linking hazard and vulnerability by hydraulic modelling

Flood hazard and loss analyses will be linked by hydraulic modelling that creates inundation scenarios for different flood discharges in the target area around Reutte (see Figure 1). Hydraulic modelling is conducted with the 2D Flow model HYDRO_AS-2D. Observed flood events, e.g. the flood in 2005, will be used for model calibration. Flood discharges with particular return intervals will be selected from the flood frequency curves and will be used as input for the hydraulic modelling. Inundation scenarios will then serve as input for the flood loss estimation model. In a final step, a flood risk curve will be constructed on the basis of the exceedance probabilities of the selected flood discharges and the associated estimated losses.

3 First results and discussion

In this paper, the results of a first reduced model chain are presented by taking the flood event of August 2005 as an example. In this reduced model chain the flood hazard analysis is restricted to a flood frequency analysis. The vulnerability assessment consists of an exposure analysis with different land-use scenarios.

3.1 Frequency analysis of the flood in 2005

Estimating the frequency of extreme floods is a key element, but also a major challenge in flood risk analysis. A robust estimation of extreme events requires long flood records in order to reliably extrapolate long return periods (e.g. Merz & Thieken 2009). However, in Alpine catchments long-term measurements are often missing. This hampers the application of flood frequency analysis when observed runoff data has to be used as input.

When fitting the Generalized Extreme Value (GEV) distribution to the annual maximum discharge series of two different time slices of the water gauge in Lechaschau near Reutte (see Figure 1) – 1971 to 1998 and 1971 to 2008, respectively –, a wide range of uncertainty is obtained (see Figure 3). The occurrence of several severe floods from 1999 to 2008 decisively changes the distribution function.

Therefore, Merz & Blöschl (2008) suggested expanding this traditional concept by including temporal, spatial and causal information. In the following, the inclu-

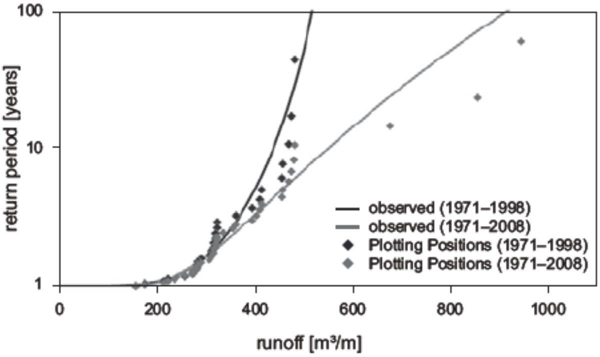

Figure 3: Flood frequency analysis for different time slices of the water gauge in Lechaschau.

Table 1: Estimation of return periods and floods at the water gauge in Lechaschau.

Used time series	Return period of the flood 2005 [years]
1971–1998	>> 1000
1971–2008	~ 110
1971–2008 with historic flood records	~ 330

sion of historical data in flood frequency analysis is tested. For this, runoff records downstream of Lechaschau/Reutte, i.e. at the water gauge in Füssen (Germany), were used. Here, data are available since 1901, since 1954 measurements are, however, influenced by backwater effects. Therefore, data were only used to identify severe historic flood events. The time series at Füssen revealed that a flood with similar intensity like the one in 1999 occurred in 1910. This historical event is also confirmed by Meier (2002) for the Upper Lech Valley. This event was thus included in the flood frequency analysis at the gauge Lechaschau by using the procedure of DVWK (1999), i.e. the data gap between the historical event in 1910 and the beginning of continuous measurements in 1971 are filled several times with observed flood discharges that fall below the historical event. This is based on the assumption that in the data gap the statistical characteristics of the observed time series are also valid (see DVWK 1999; Merz & Thieken 2009).

Table 1 summarises the estimates of the return period of the flood event of 2005 that had a peak discharge of 943 m^3/s at the gauge Lechaschau. It is assumed that the two curves shown in Figure 3 can be regarded as an envelope of the "real" flood frequency distribution at the gauge Lechaschau, since the series of the time period 1971 to 1998 contains comparatively low flood discharges, while the series from 1971 to 2008 contains three severe flood events. Considering this, Table 1 illustrates that the inclusion of historical information significantly improves the estimation of events with higher return periods.

Although the inclusion of historical data helps to improve flood estimations, questions concerning the stationarity of discharge data are still open. Merz & Thieken (2009) addressed this topic and stated that the benefits of enlarging the time series results in the drawback that the time series may not be representative for the present conditions. Further investigations will follow to reliably estimate higher return periods at the water gauge in Lechaschau based on the complete model chain that was introduced above.

3.2 Land-use and vulnerability

The land-use simulations for the region of Reutte were performed for all spatial planning scenarios for Austria, published by the Austrian Conference on Spatial Planning (ÖROK), starting in 2006 and ending in 2030. Thereby various parameter combinations were tested and comparisons were made when integrating the neighbourhood functions or zoning plans. Thus it was possible to compare the influence of spatial policies and the weight of the neighbourhood functions. As an example, two simulation results for the area of Reutte are shown in Figure 4, presenting the

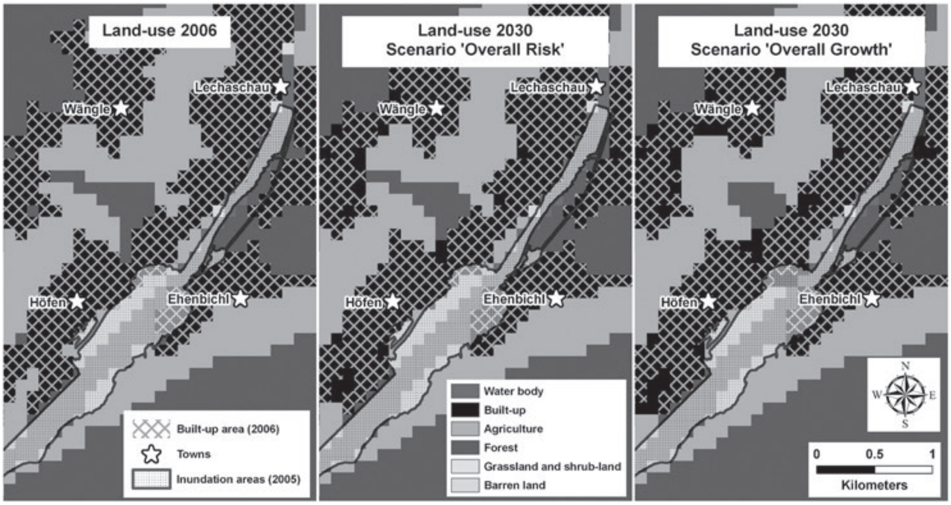

Figure 4: Land-use map of 2006 (left) and 2030 for the scenarios 'Overall Risk' (middle) and 'Overall Competition' (right) in the area of Reutte overlaid by the inundation area of August 2005.

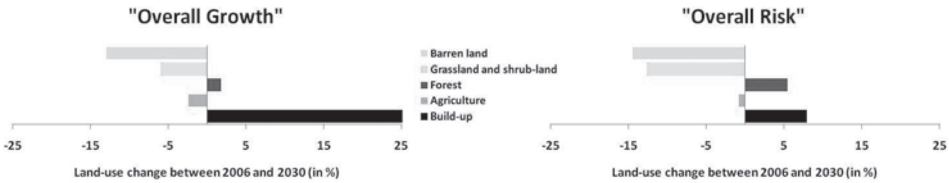

Figure 5: Land-use change (in %) between 2006 and 2030 for the scenarios 'Overall Growth' (left) and 'Overall Risk' (right) for the whole study area.

weakest scenario 'Overall Risk' (Figure 4, middle) and the most extreme scenario 'Overall Growth' (Figure 4, right side).

In both examples the nature reserves 'Natura 2000' and the area zoning plans were considered. Thus built-up areas could only grow in the backcountry (westside of the Lech river) and hardly along the river reach. In the scenario 'Overall Risk' a slight increase of 8% of the built-up area (Figure 5) is expected in the whole study area whereas in the scenario 'Overall Growth' this area expands by 26% (Figure 5).

For a first indication of flood loss, the land-use scenarios were intersected with the inundated areas observed during the flood in 2005. The intersection of the land-use map of 2006 and the inundated areas of August 2005 (Figure 4, left side) shows that at this event only small parts of the westside of the Lech river were affected, i. e. the community of Höfen. By contrast, the eastern part i. e. the community of Ehenbichl, in the south of Reutte, was hit stronger. Altogether, 16 ha of the settlement area were inundated by the event in 2005 (Table 2).

Assuming an event similar to the flood in August 2005 and the land-use scenarios that are shown in Figure 4, an indication of the future flood affectedness can be given. In case of a weak settlement expansion like in the scenario 'Overall risk'

Table 2: Changes of flood endangered areas in case of a flood event like in August 2005.

Land-use scenario	Affected settlement area (in ha)	Increase in inundated settlement area in comparison to 2005/2006
Land-use 2006	16	–
Land-use 2030, scenario 'Overall Risk'	17	6.2 %
Land-use 2030, scenario 'Overall Growth'	21	31.2 %

only a slight increase ~6% (Table 2) of flood-prone areas would occur. In detail, the newly developed and affected settlements in the area inundated by the event of 2005 are located in the south-western part of Ehenbichl. In the stronger scenario 'Overall Growth' an additional settlement area in the centre of Höfen would be affected, which results in a total increase of ~31% (Table 2) of the affected area in comparison to the actual land-use situation in 2005.

This example demonstrates that only slight changes in risk are to be expected if no intensive settlement expansion and no larger flood event than in 2005 are assumed. However, an extreme settlement increase like in the scenario 'Overall Growth' in connection with a more severe flood event than in 2005 would affect large areas in the study area. In this context it has to be mentioned that in this paper only the river reach up to Reutte was investigated. The area in the north of Reutte, the community of Pflach, where high flood losses occurred in 2005, has not been investigated yet, due to lacking data. This area will be included in future work.

4 Conclusions

The project FloodTimeS aims at quantifying changes in flood risk in the area of Reutte, which is located on the River Lech in Tyrol, Austria. For this purpose, a complex model chain has been set up. In this paper, changes in the flood risk are indicated for a flood event that occurred in 2005 by applying a reduced model chain. A flood frequency analysis that includes historic flood records assigns a return period of 330 years to this flood discharge. An intersection of the areas that were inundated in 2005 with different future land-use scenarios further revealed that different land-use policies can considerably influence the extent of flood-affected settlement areas. For this severe flood event, a land-use scenario based on the ÖROK-scenario "Overall Risk" limits the expansion of settlement areas more effectively than the ÖROK-scenario "Overall Growth", in which an increase in inundated settlement areas of about 30% occurred in the study area. In order to mitigate future flood losses, land use policies should be adapted accordingly.

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