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The impact of late medieval deforestation and 20th century forest decline on extreme flood magnitudes in the Ore Mountains (Southeastern Germany)

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ABSTRACT

Vegetation is one of the main controlling factors in the system of flood runoff formation in headwater areas. Especially the absence or presence of forests has a substantial influence on the development of surface runoff and peak discharge as well as on the water balance at the catchment scale. In Germany there is a long history of wood consumption, deforestation and forest recovery. In the Ore Mountains the modern forest distribution is the result of two important developments. The most remarkable deforestation period began with the increase of mining activities after the early 12th century. In modern times, i.e. from the 1950s until the political turn in Eastern Germany at the end of the 1990s forests of the Ore Mountains suffered from industrial SO_2 emissions that caused a severe forest decline especially in headwater areas near the main ridge of the mountains. Since the Ore Mountains are one of the main flood generating regions in the Elbe basin the aim of the study is to reveal the influence of the deforestation history on the magnitude of extreme floods. The analysis is based on a rainfall-runoff modelling of the Upper Flöha River in the Ore Mountains (Free State of Saxony, South-eastern Germany) with the mainly physically-based modelling system WaSiM-ETH. Based on the assumption that the recent forest distribution is the result of all the historical developments an extreme flood event was simulated for land use conditions between 2000 and 2008 using statistical storm rainfall intensities with a return period of 100 years and a duration of 12 h (baseline scenario). Then two main scenarios with the forest distribution before the medieval deforestation in the 12th century and land cover before the onset of the SO_2-related forest decline in the second half of the 20th century were implemented in the model. The simulation reveals a significant impact of large-scale deforestation and forest decline on the magnitude of flood events. In the scenarios the peak discharge was between 16.4 and 21% lower than in the baseline scenario. This result is mainly influenced by a reduction of surface runoff with an increasing percentage of forests and by a decreasing antecedent soil moisture. The data show clearly, that forest conservancy and land use management are essential to maintain and increase the water retention function of forests.

1. Introduction

Land cover and vegetation have a distinct influence on the hydrology of landscapes and the water balance of river basins. This fact is generally accepted, but there are many interacting factors like regional climatic conditions, vegetation type, structure and health as well as the soil conditions that result in a high variability of the hydrological effects of the vegetation. In the case of storm events and the resulting extreme floods the system of controlling factors and interaction becomes even more complex.

Flood risk management strategies in Germany, Europe and other regions often include natural water retention in headwater areas and refer to the retention capacity of forests. This retention potential is primarily related to the water balance of forest soils whereas canopy storage can be neglected for large storm events (Eisenbies et al., 2007). Benecke and van der Ploeg, 1978) reported a canopy storage capacity for a 90 year old spruce stand in the German Solling region of 4.7 mm and 2.6 mm for a 120 year beech stand, which is very low compared with the storm rainfall in flood

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generating areas such as the Ore Mountains in Southeastern Germany (e.g. August 2002, rain gauge Zinnwald-Georgenfeld: 312 mm/d; May/June 2013, rain gauge Rechenberg-Bienenmühle: 108 mm/d; data provided by Deutscher Wetterdienst). By contrast water storage in forest soils is generally higher than in soils of other land cover types, which is caused by two main effects. The lower bulk density and higher hydraulic conductivity of forest soils and the high macroporosity increase infiltration (Wahren et al., 2009). In addition root uptake and subsequent transpiration of water via the stomata results especially during the vegetation period in a significantly lower soil moisture in forests compared to arable land or pastures. The lower antecedent soil moisture causes a higher storage potential (Wahren et al., 2007), but this effect depends on the antecedent rainfall conditions and may disappear when intense rainfall occurs in the days or weeks before a storm event. However surface runoff rarely occurs in forests and is limited to extreme rainfall or steep slopes (Schwarze, 2007) and infiltration, water storage and preferential flow dominate runoff formation (Eisenbies et al., 2007; Wahren et al., 2009; Hümann et al., 2011).

However the actual retention capacity of a specific forest system is controlled by many additional factors such as forest type (e.g. tree species composition, root structure, vegetation layers, litter layer), forest age and health, forestry management including usage of heavy machines (cf. Eisenbies et al., 2007), forest road density, soil (structure, impermeable layers, soil depth, hydraulic conductivity) and relief (slope). Water retention is also controlled by the meteorological conditions, e.g. high antecedent rainfall or – the other extreme – drought causing hydrophobicity (Gimbel et al., 2016) as well as the rainfall intensity and duration. Another important factor is the forest development, especially if arable land is reforested. Wahren et al. (2009) for instance discuss differences between afforestation and ancient natural forest in the Zellwald/Saxony and observed, that the retention capacity of old natural forests might even be lower than the retention of former arable land that was reforested because of soil structure related water logging in the old forest. Hümann et al. (2011) performed sprinkling experiments in the Hunsrück Mountains in southwestern Germany and identified a site, where the forest soil even 30 years after afforestation still showed an infiltration similar to arable land (influenced by a compacted soil layer near the surface). Soil characteristics of a typical forest soil may take several years to develop so that the site-specific cultivation history is an often underestimated element in the discussion of the water retention by forests. Because of all these factors the water retention capacity of forest can hardly be generalized.

In Germany there is a long history of deforestation, silviculture and forest recovery. From the Late Roman to the early medieval period in the 7th century AD land use in Germany was still dominated by forests, which covered about 90% of the land area (Bork et al., 1998; Bork and Lang, 2003). Until the end of 13th century the percentage of forests had decreased dramatically to about 20% as a result of the growing population and increasing agriculture. In the 14th century a sharp decrease of the population density in Germany occurred, which is attributed to famines in combination with epidemic plagues (pestilence, e.g. 1347–1353 AD) and a series of extreme rainfall and flood events such as Magdalena flood in 1342. With the decreasing population forests recovered slightly and reached a percentage of more than 40% around 1450. Until the beginning of the Thirty Year War in 1618 anthropogenic activities and wood demand increased again resulting in a decrease of forest cover to 30% of the total area of Germany and remained on a similar level until modern times (Bork et al., 1998; Bork and Lang, 2003; Dreibrodt and Bork, 2006). Although this information is based on the study of numerous sites in Germany regional differences have to be considered. So it can be expected that mountain areas in Germany have been less affected by deforestation because of the limited suitability for agriculture. However mining activities have led to a large wood demand, so although the timing might be different from lowlands mountain areas were not excluded from deforestation.

The retention potential of forests in combination with the long history of forest decline and recovery leads to the question, how the anthropogenically induced deforestation has influenced the magnitude of extreme flood events in mesoscale river basins of the German mountain areas. The study presented here is based on a rainfall-runoff model and focusses on the Ore Mountains in Southeastern Germany. Among other mountain regions in the Czech Republic the Ore Mountains are one of the main flood generating regions in the Upper and Middle Elbe basin. During the flood events of 2013 and the extreme event of 2002 the Ore Mountains contributed much of the devastative flood discharge, so the region is in the spotlight of flood research (e.g. Schmidt et al., 2008; Petrow et al., 2007; Wahren et al., 2007, 2009; Reinhardt et al., 2011; Schädler et al., 2012; Bölscher et al., 2013; Reinhardt and Schulte, 2013).

2. Study area

2.1. Overview

For the investigation the watershed of the Upper Flöha was selected, which extends across the border region between the German state Saxony and the Czech Republic and in the transition zone between the Central and Eastern Ore Mountains. The Flöha drains the areas north of the main ridge of the Ore Mountains and ends in the Zschopau River (Fig. 1), which in turn drains via Freiberger Mulde and Mulde into the Elbe. The investigations focus on the river reach between the Rauschenbach reservoir (59.9 km upstream of the mouth) and the gauging station Pockau 1/Flöha (32.3 km upstream of the mouth) with a total drainage area of 315 km^2 and an elevation range of 398–921 m a.s.l. The area upstream the Rauschenbach dam is excluded because the reservoir provides a flood retention capacity of 4 million m^3 and water release during the peak phase of a 100-year flood is reduced to zero (data provided by the State Reservoir Administration of Saxony).

The climate in the study area can be characterised as warm-temperate with a strong variation of temperature and rainfall with altitude. The nearest weather station with a long-term record is operated by the German Weather Service (DWD) and located in Marienberg about 15 km west of the centre of the study area in an elevation of 639 m a.s.l. The mean monthly temperature of the period 1981–2010 ranges from −1,7 °C in January to 15.9 °C in July (mean annual temperature: 6.8 °C). All months are humid with a maximum monthly rainfall of 108 mm in August and a minimum of 51 mm in February (mean annual rainfall: 865 mm). With increasing elevation rainfall increases. At the DWD station Zinnwald-Georgenfeld located about 30 km east of the study area in an elevation of 877 m a.s.l. a mean annual rainfall of 1005 mm was measured in the period 1981–2010.

The geology of the Upper Flöha watershed is characterised by Palaeozoic and Precambrian metamorphic rocks covered with up to a few metres thick periglacial slope deposits (Heller and Kleber, 2016; Moldenhauer et al., 2013; Semmel and Terhorst, 2010). The main soil types are of podzols and cambisols on the cover beds as well as fluvisols and gleysols on alluvial deposits in the river valleys. Soil textures in the top soil are dominated by loam and silt.

The point of reference for the investigation is the town Olbernhau located in the centre of the study area at the Flöha River. However at the gauging station Olbernhau 2/Flöha (drainage area between gauging station and reservoir: 228 km^2; Fig. 1) only very

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