Flood water retention by riverine and terrestrial forests

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Abstract

This paper addresses flood retention by floodplain forests and the reduction of runoff by forested watersheds as a function of their management. The results from completed projects and the scheme of an ongoing project are presented.

In 2001 reforestation measures were conducted to increase the retention potential of the floodplain of the lower River Blies in Germany. Due to the short project duration of about two years, which included planning and realisation of the measures, reforestation had to be restricted to sites that were initially owned by the project members. Thus only 2 % of the floodplain could be included. This resulted in a simulated flood peak reduction of less than 1 % at extreme flood events. Despite the relatively small mitigation effect in this particular case the project led to valuable findings. This refers for instance to the utilisation of floodplain afforestation as an ecological and flood control compensation measure, which might substitute lost retention volumes due to leeves or other structures in the floodplain. Another flood control project showed by simulation, that there is a potential for flood peak attenuation of up to 15 % by reforestation of the total flood plain.

Since 2003 investigations have been conducted into the runoff reduction effects of sustainable forestation and of decentralized retention facilities in woodlands. In two forested watersheds of 4.4 and 8.4 km^2 flood mitigation effects of such measures have been monitored and simulated.

Introduction

The flood retention effect of riverine forests originates from their higher hydraulic roughness compared to floodplains without or with scant vegetation. This results in higher water levels (for a given discharge) which generate additional retention volumes and thus peak reductions of flood hydrographs.

These measures also delay the flood flow and thus in many cases cause an advantageous superimposition of main river and tributary flood hydrographs (timely separation of the hydrographs).

Runoff reduction in terrestrial forests is generated mainly from interception and transpiration losses (McCulloch & Robinson, 1993). With very few exceptions the hydraulic roughness inhibits overland flows (DVWK, 1999a). Ecologically sound management practices support these advantages by avoiding clear cuts, monocultures or ground compaction. An additional effect may have decentralized technical retention, e.g. by flow controlled culverts in logging road dams.

Investigations into flood retention of riverine forests

Project description. Within the EU flood control programme "IRMA - INTERREG Rhine-Meuse Activities" (see www.irma-programme.org) reforestation measures (Kautenburger *et al*, 2002) were conducted in 2001 to increase the retention potential of the floodplain of two sections of the lower River Blies in southwestern Germany (see Figure 1).

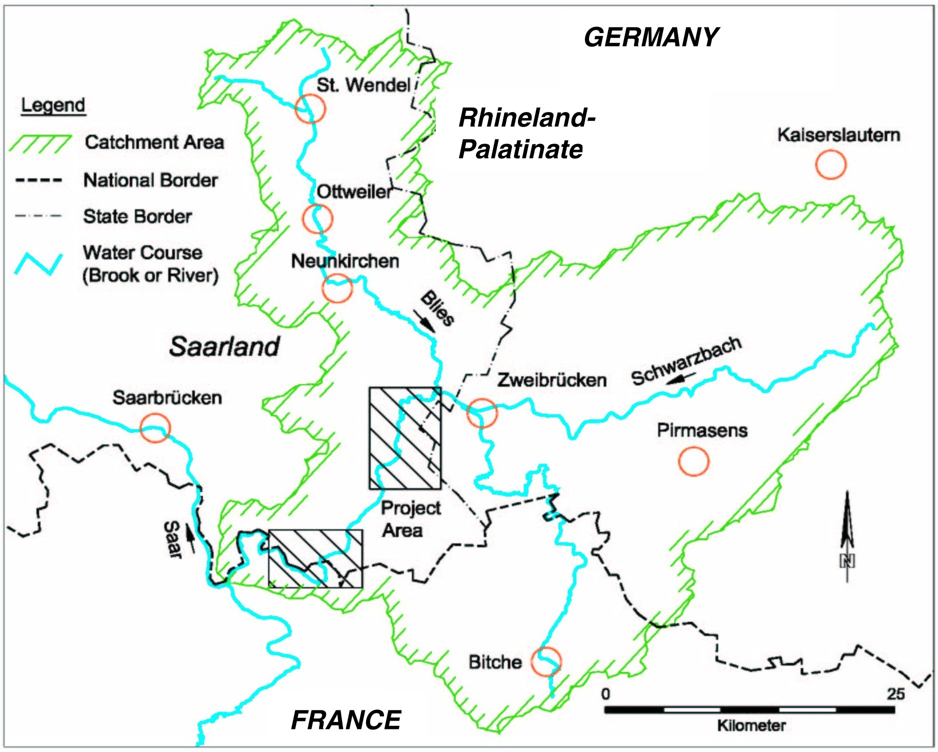

Figure 1. Location of project areas and watershed

Project location and selection. The northern section is located near the town of Blieskastel (see Figure 2) and is about 15.5 km long. The southern section extends over 13 km. The discontinuity between the sections is about 6.5 km.

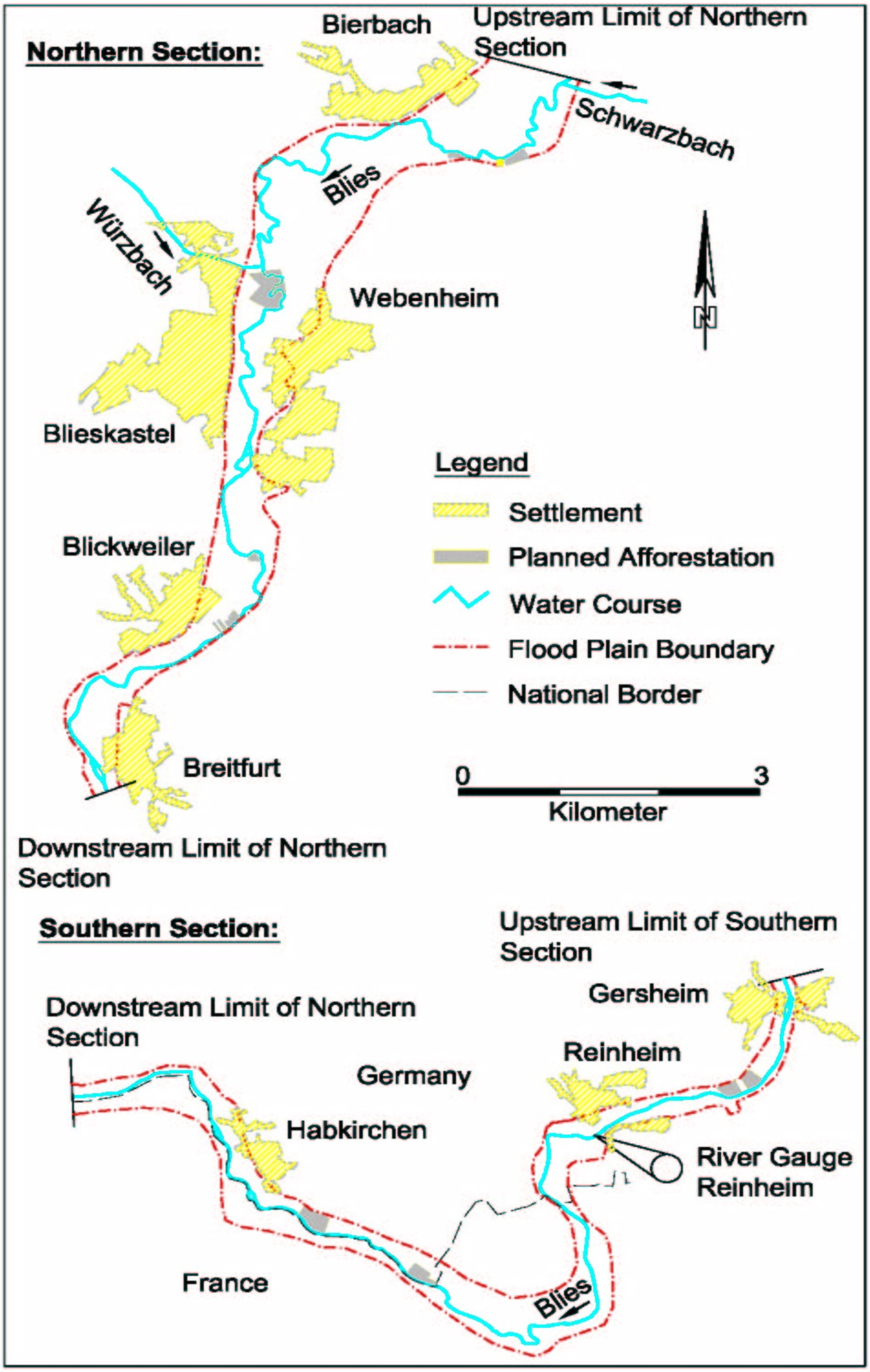

Figure 2. Project sections in detail

Beside afforested areas floodplain usage is mostly pasture with partially fallow land, woodland and a small portion of arable land. The catchment area of the project sections increases from A_E = 1,640 km^2 to 1,850 km^2 and covers the federal German state of Saarland (37 % of the total catchment area), the federal state of Rhineland-Palatinate (46 %) and France (17 %).

Due to the short project duration of about two years, which included planning and realisation of the measures, afforestation had to be restricted to sites that were initially owned by the project members. Thus only 23 ha (2.2 %) of the about 1,060 ha of the floodplain could be included, resulting also in a scattered distribution of forests (see Figure 2). For the same reason no optimization by hydrological criteria was possible, i.e. in respect to timely separation of hydrographs a more upriver reforestation would have been desirable.

General approach to determine the project effects. The water resources management component of the project was separated into

- the hydrological portion, which had to determine the flood peak reduction and into
- the hydraulic portion, which required calculation of the (steady) water profile levels for the before and after conditions with respect to upriver settlements.

There were intensive interactions between both portions. The hydrologists delivered the peak discharges for water profile calculations. By these the additional flood retention due to the increased water levels was determined, which in return resulted in reduced flow hydrographs and peaks. For this iterative process the following approaches were elected:

- hydrological storm-runoff model (Sartor, 1996)
- steady water profile computation according to the German Standard Code of practice (DVWK, 1991) for cross sections containing tree trunks
- discharge-volume-relationship method according to (DVWK, 1999b) for improved hydrological flood routing
- simplified method of *Hager & Droux* and *Haider* (ETH, 1999) to check results.

It was clear from the beginning of the project that all appropriate calculation approaches would result in peak attenuation close to the error boundaries of the method since only 2 % of the flood plain was reforested.

Storm runoff model. For the watershed upstream of the river gauge Reinheim (A = 1,798 km^2), an existing model could be extended to the mouth of the river (A = 1,890 km^2) and modified to suit the problem. A total of 56 river sections, 54 rural and 31 urban subcatchments were simulated. Model calibration was achieved with data from 33 rain gauges and 16 river gauges with up to 5 flood events each between 1993 and 1998 (see Figure 3). Validation was performed by comparing the flood statistics generated by the model with official values.

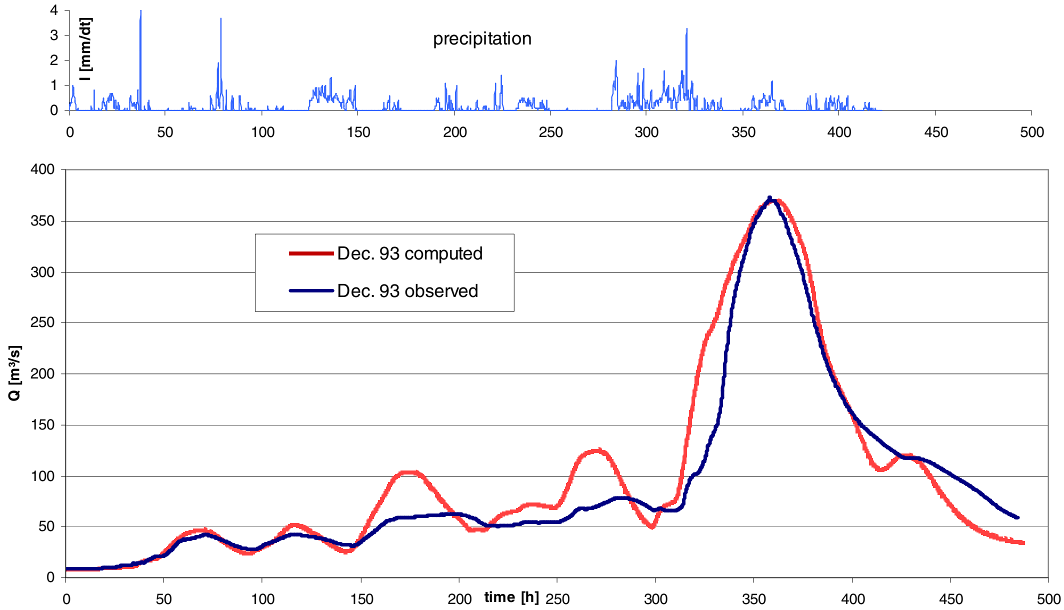

Figure 3. Flood hydrograph of December 1993 at river gauge Reinheim

Water profile calculations. These were executed through a 1-dimensional, steady hydraulic calculation by the approach of *Mertens* according to (DVWK, 1991). The data set of conditions before the project was calibrated by flood marks from the December 1993 event. Vegetation parameters were determined from representative sites, which were allocated to 8 classes (see Figure 4).

Figure 4. Representative site of vegetation class "trees and shrub, mixed, dense"

Surveying. This was performed by GPS or by analysis of aerial photographs. River cross sections were set up by terrestrial surveying. To generate maps of inundated areas a digital contour model was created and combined with calculated water levels. The parameter assumption of future vegetation was coordinated with ecologists, e.g. average trees are expected to be in a 2 m spaced grid with a trunk diameter of 0.3 m (for initial planting and succession).

Flood routing. The hydrological storm runoff model made use of the discharge-volume-relationship (see Figure 5) for the initial conditions and the predicted conditions after the project was implemented.

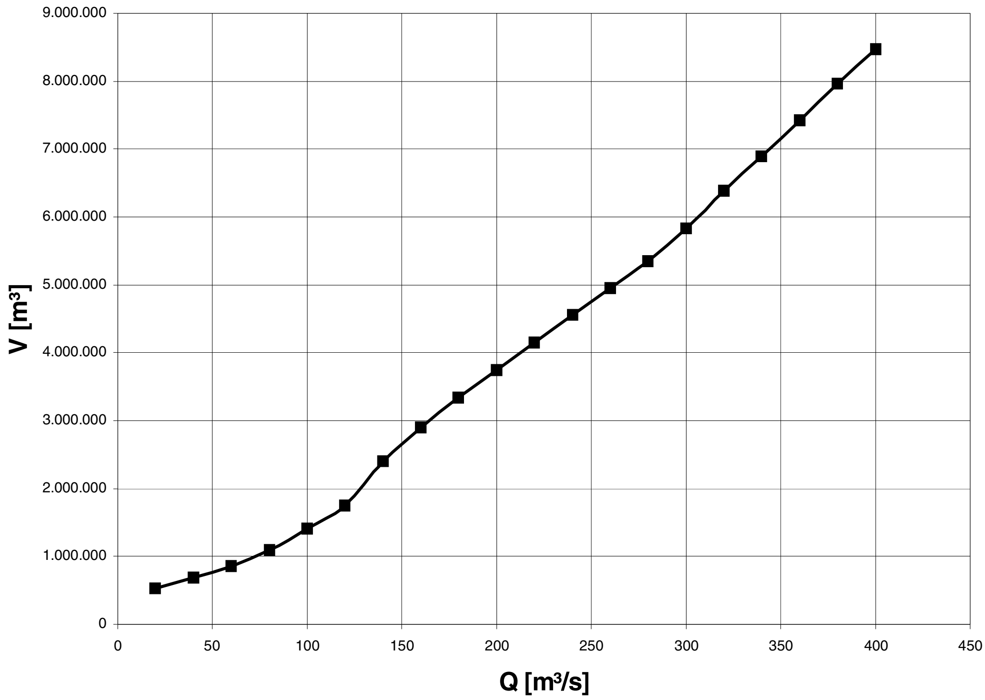

Figure 5. Discharge-volume-relationship for the section between river gauge Reinheim and the end of the project area.

Results. The following results refer to the flood event from December 1993 (see Figure 3) which had a return period of approx. 75 years. For peak attenuation a difference between predicted and current status was determined to be less than 1 %. The simplified methods of *Hager & Droux* and *Haider* led to a result of the same magnitude. This result is not very surprising, because

- only 2 % of the flood plain was afforested
- there was no timely separation of the hydrographs
- the reference flood was an extreme event.

The generated retention volume by the measures was also calculated to be less than 1 % of the volume of the 1993 flood. But interestingly this is more than the volume lost through a newly designed levee in Blieskastel. The predicted rise of water levels is up to 3 cm with the exception of the special case Blieskastel. Thus critical degradation to upriver settlements is not traceable.

An ongoing investigation (Aatz & Musong, 2005) mainly confirms all the achieved results by a dynamic 2-dimensional hydraulic simulation. However the limitation of this study is the simple determination of the hydraulic roughness by the approach of *Manning*.

Another flood control project at the River Lahn (Lang & Tönsmann, 1999) showed by simulation, that there is a potential for flood peak attenuation of about 15 % by reforestation of the total flood plain (see Figure 6).

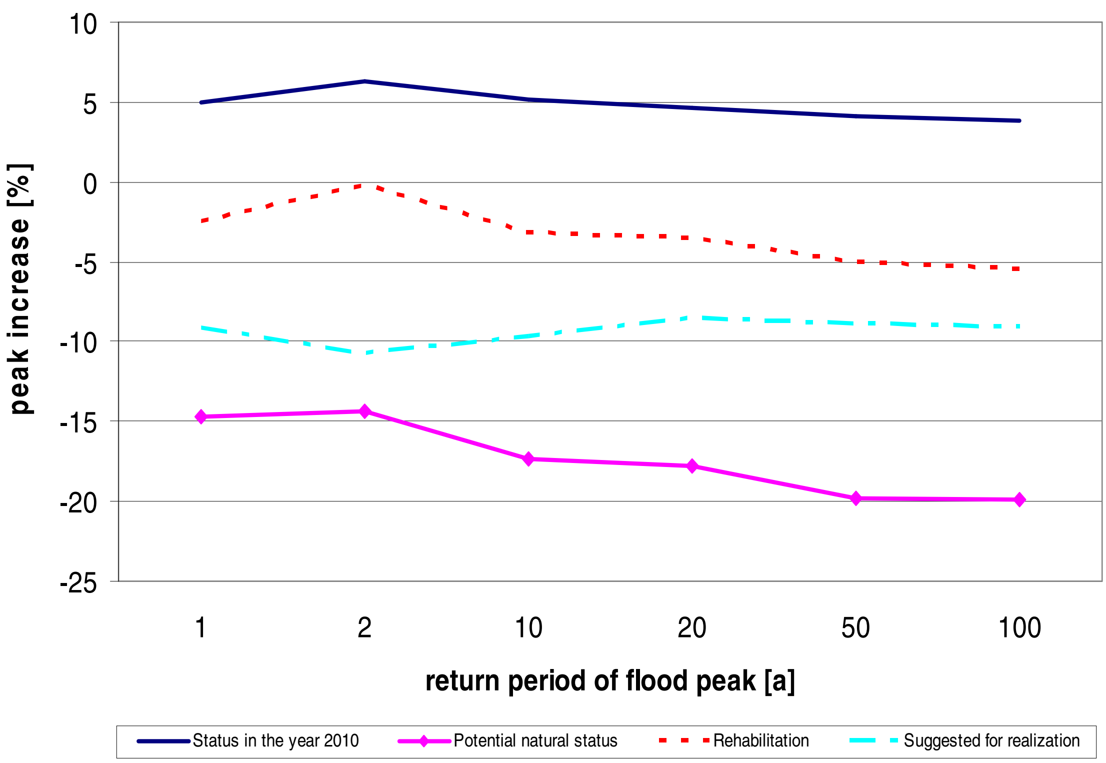

Figure 6. Peak attenuation at the River Lahn for different scenarios.

Conclusions and outlook. Despite the relatively small mitigation effect in this particular case the IRMA project led to valuable findings. This refers to the utilization of floodplain reforestation as an ecological and flood control compensation measure, e.g. for lost retention volume by levees or other structures in the floodplain.

The compensation may refer exclusively to the additional steady volume due to reforestation, which could be determined by hydraulic methods using the roughness parameters developed interdisciplinary in the IRMA project. Thus the complicated hydrological determination of peak attenuation would not be required. This approach is in accordance with a new state directive in Rhineland-Palatinate, which requires that lost retention volume has to be compensated, even if the influence (of an individual measure) on the flood peak is not traceable. The Saarland state water authorities even claim to substitute lost volumes by new retention volume of 1.5-times in magnitude. In Germany reforestation is officially rated as an ecological compensation measure. Its planning and realization for riverine floodplains was proved by the IRMA model project.

The approach is meanwhile being applied to a real case. In the town of Neunkirchen (upriver from the project area, see Figure 1) approx. 25,000 m^3 of natural retention volume will be lost by a projected construction of a hotel complex in the floodplain of the River Blies. Current investigations are conducted to compensate this lost volume by excavation of manmade embankments and by redevelopment of riverine woods.

Runoff reduction by forested watersheds

Since 2003 the Trier University of Applied Sciences has participated in the EU co-funded flood control project "Water Retention by Landuse" (see www.warela.de) as part of INTEREG III B NWE programme. The project component discussed includes investigations into runoff reduction effects of sustainable forestation and into decentralized retention facilities in woodlands. In two forested catchments (located close to the above mentioned IRMA project areas) these measures will be introduced and their flood mitigation effects monitored and simulated.

For the nearly complete forested catchment "Holzbach" of 4.4 km^2 a hydrological long-term monitoring programme was initiated in 2004. Phase I is scheduled to calibrate a storm runoff model for the current status of the watershed, which is mainly managed by economical aspects. Phase II will start in about two years time by implementing measures like blocking of artificial drainage and introducing sustainable forestation (without clearcuts, monocultures, soil compaction etc.).

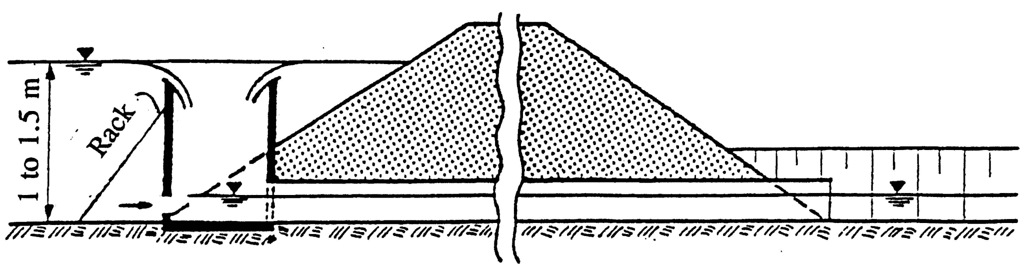

Figure 7. Flood retention by a logging road dam with flow control structure

The second watershed "Upper Blies" (headwater catchment) of 8.4 km^2 is partially forested and has been monitored by a river gauge for decades. Here more technical measures such as decentralized retention facilities will be conducted and their effects simulated and monitored. Five small reservoirs with retention volumes between 200 m^3 to 40,000 m^3 will be created by using former fishing ponds and by flow control of existing culverts in logging roads (see Figure7).

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