Abschlussbericht/Final report

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´Raum für den Fluss´und ´Wasserrückhalt in der Landschaft´. Modellierung der Landnutzungseinflüsse und Szenarioanalysen – Fallstudie Obere Iller

Efficiency of non-structural flood mitigation measures: "room for the river" and "retaining water in the landscape" Case Study Upper Iller

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1 Introduction

Floods are the costliest natural hazard in the world and account for 31% of economic losses resulting form natural catastrophes (Yalcin and Akyurek, 2004). The economic losses of the combined European countries from 1998 to 2003 amounted to more than US$ 60 billion (Plate, 2003). A review of the losses caused by floods events in the period of the last ten to fifteen years indicate that in Europe economic losses are dramatically increasing, mainly because there has been a marked increase in the number of people and economic assets located in flood hazard zones.

On one hand, it is clear that the flood hazard must be estimated with the maximum precision, as was pointed out by Francés (1998) and Jarrett and Tomlinson (2000), especially when the hazard is affecting urban areas. Flood hazard underestimation contributes to larger damages than expected, but unnecessary overestimation leads to costly overdesign of flood protection measures. On the other hand, an inappropriate flood risk management (or the absence of it) may lead to considerable losses of property and life.

Traditionally, flood hazard is estimated based on a design storm (without taking into account the actual spatial and temporal variability of extreme storms), transforming it in discharges using an aggregated rainfall-runoff model (not considering the spatial variability of the hydrological characteristics and loosing the possibility of analysing the effect of land cover changes within the basin) and computing the maximum water depth not using the most appropriate hydraulic model. I.e., the flood hazard uncertainty can be high if the new trends in flood hazard estimation are not used.

The difference between hazard and risk must be clear (Figure 1). The flood hazard in a given point of the flood prone area is the probability distribution function of the flood magnitude at this point. The magnitude is defined by different variables related with the flood damages, as maximum water depth, maximum velocity, flood duration, amount of sediments, etc., but in most cases the first one is the most representative. The flood risk (or impact to be clearer) is the mean annual damage per unit area. Damage in a wide sense: it can include economical, social and environmental losses. Potential damages are considered through the vulnerability of each element of the flood prone area. The vulnerability is a function of the flood magnitude, and it usually takes the form of a depth-damage curve (Grigg and Helweg, 1975). Therefore, flood impact is the probabilistic integral of the combination of flood hazard and land use vulnerability (Francés et al., 2001 and Plate, 2002):

$$D = \int_0^{\infty} V(h)\, f_H(h)\, dh$$

where V is the land use vulnerability, h is the flood magnitude and f_H is its probability density function.

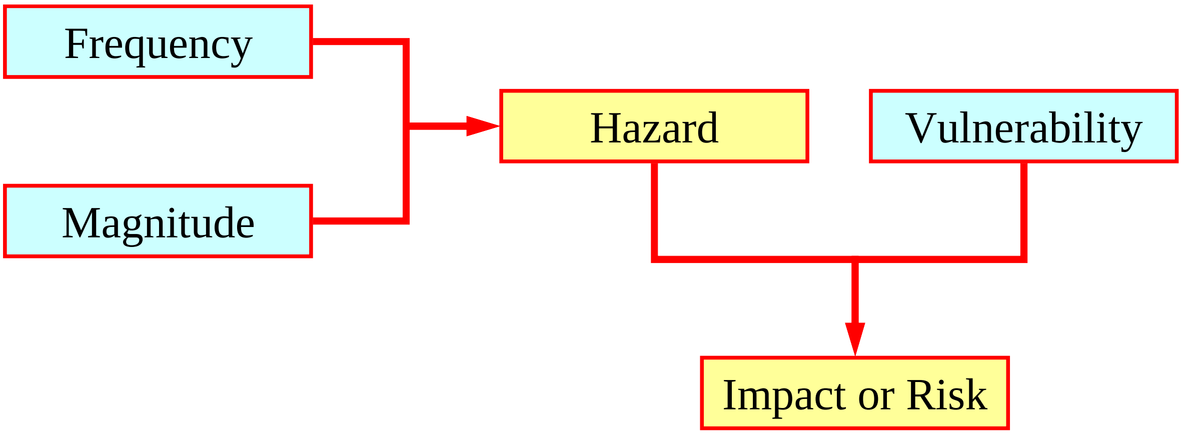


Figure 1-1. Basic definitions (computed concepts in yellow).

A detailed classification and description of flood protection measures was done by Yevjevich (1994), but the most common classification is to distinguish between structural and non-structural measures. Very often it is forgotten that the objective of the flood protection measures is to reduce the total flood impact, and not specifically the flood hazard. In fact, most of the non-structural measures don't change the hazard: they just reduce the flood impact by land use vulnerability changes. We will like to underline the worldwide experience has shown that in the long term and in most cases non-structural actions are the most effective ones (Natural Hazards Research and Applications Information Center, 1992; Smith and Ward, 1998).

We believe the flood impact (risk) analysis is needed in order to objectively compare different future scenarios that can affect either the flood hazard and/or the vulnerability in the flood prone area. These different scenarios arise mainly because land-uses changes in the basin and in the flood prone area and because the flood protection measures that can be adopted.

The project described in detail in this report is part of the ERA-NET-CRUE project:
Efficiency of non-structural flood mitigation measures: "room for the river" and "retaining water in the landscape". ERA-NET CRUE is funded by the ERA-NET Scheme under the 6th Framework Programme,General Directorate for Research in the European Commission.

This project has focused on a comparison of the efficiency of non-structural flood mitigation measures which include the non-structural flood risk mitigation concepts “retain water in the landscape” and “room for the river”. The study of three catchments located in Spain, Austria and Germany has permitted to cover a wide spectrum of flood processes that can be expected in Europe.

Main focus of the study described here is the Upper Iller Catchment in the Bavarian Alps, Germany.

2 Objectives

The aim of the overall project, including all three case studies (Iller, Kamp and Poyo) is to examine the relative effectiveness of two particular non-structural flood mitigation measures:

> “Retaining water in the landscape”: Land use changes and Local retention measures in the landscape
>
> “Room for the river”: flood retention along the main stream by providing additional inundation area

To do this, new scientific frameworks and technical tools integrating multidisciplinary approaches (meteorological, hydrological, hydraulics and socio-economical) on flood risk assessment have been used and tested in three different and, at the same time, complementary case study areas.

For the Upper Iller specifically, the main goal was to determine scenarios of forestation and small uncontrolled retention structures and to quantify their effectiveness with the help of the process based hydrological model Wasim-ETH. Results were compared to the the effectiness of large polders as well as to similar scenarios generated for the Kamp and the Poyo case studies.

3 Study area

The Iller river is situated in Southwestern Germany at the border to Austria (see Figure 3-1). It is one of the most important tributaries to the German part of the Danube. The upper reaches of the Iller upstream Kempten drain an area of 954 km2 (103 km² in Austria), the highest point of the catchment lies at 3000 m asl, the lowest (gauge Kempten / Iller) at 650 m asl. The Iller river starts at the junction of the Breitach (catchment area 117 km²), Stillach (82 km²) and Trettach (76 km²) rivers near Oberstdorf. The main other tributaries are the Ostrach (127 km²), Gunzesrieder Ach (47 km2), Konstanzer Ach (66 km²) and Rottach (31 km²).
The flow regime of the Iller can be characterized as alpine and sub-alpine with low flow in winter, high discharge during spring snowmelt and medium flow in summer. The mean annual flow at gauge Kempten is 47 m³/s. Due to the alpine setting, the soil cover is, except for highly permeable gravel deposits in the floodplains, mainly shallow. The area is predominantly covered by coniferous forest and meadows, the urban areas cover less than 3 percent of the catchment. The main flood season is summer, where heavy rainfall events of about 24 to 48 hours duration, usually orographically enhanced, can cause disastrous floods: The two highest recorded floods in over 100 years of observation took place in May 1999 (peak discharge at gauge Kempten: 850 m³/s) and August 2005 (peak discharge 900 m³/s) which means a return period of approximately 300-400 years.
After the disastrous flood in 1999, a 100 Mio € flood protection project was launched, ranging from the reinforcement of existing dikes, widening of the riverbed for increased transport capacity, structural measures like new flood protection walls in the cities of Sonthofen and Kempten and the construction of a 6 Mio m³ Polder near the city of Immenstadt. Thanks to the measures completed until August 2005 (just before the 2005 summer flood), the damage during 2005 was substantially smaller than in 1999, despite the higher discharge in 2005. Both extreme floods and some other smaller ones will be analyzed in this study.

The catchment is well equipped with rainfall gauging stations and several discharge gauges. These data are available at the Kempten water authorities (WWA Kempten) and have been provided to the project.

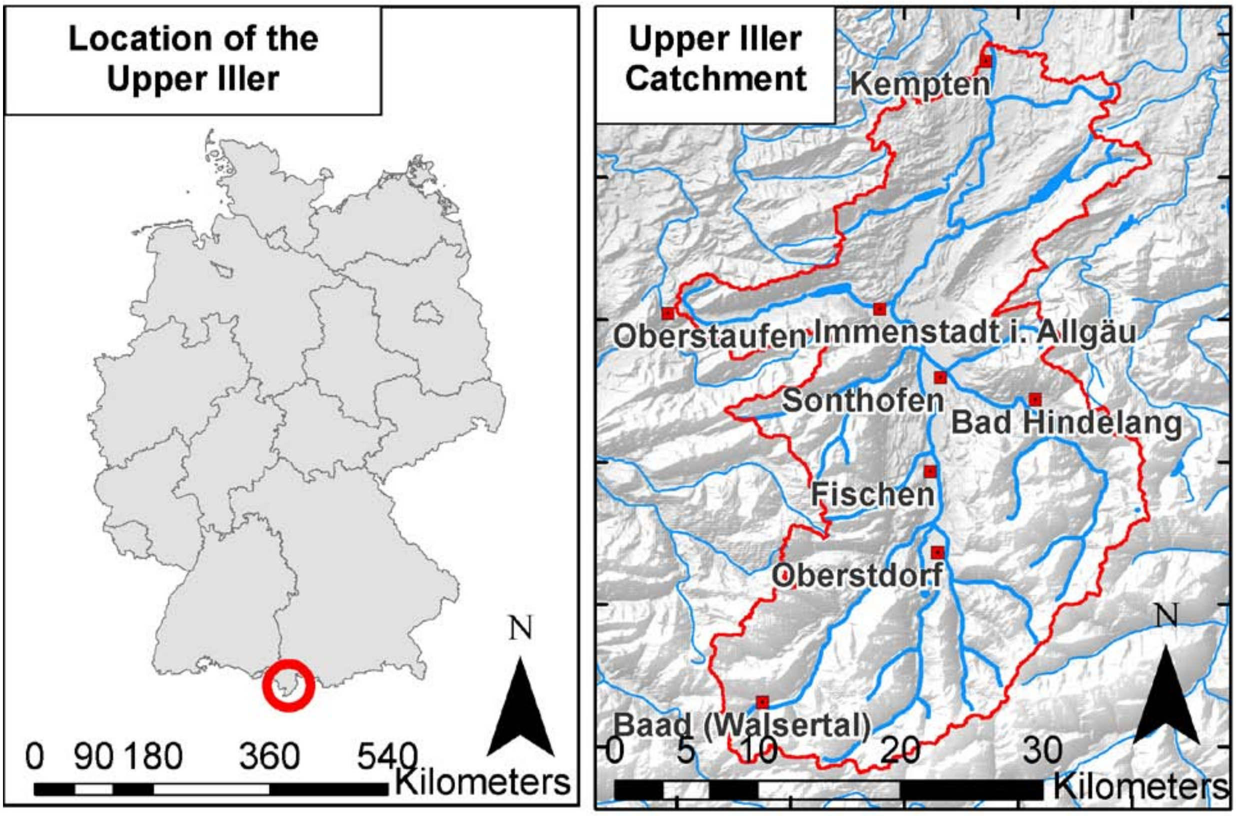


Figure 3-1 . Location of the Upper Iller Catchment

4 Work packages of the ERA-NET CRUE Project Efficiency of non-structural flood mitigation measures: "room for the river" and "retaining water in the landscape"

The work packages including the work done for the three different case studies are listed below. Not all methods described in this section have been used for each of the study areas, as the methodology was adapted towards local necessities, data availability and expertise of the project partners.

Taking into account the project objectives and the problems to be solved at each case study, this section describes the work packages of the project. The project is divided in 4 work packages, closely related as it is shown in Figure 4.1. For the sack of clarity, the proposed mathematical models to be used will be described below.

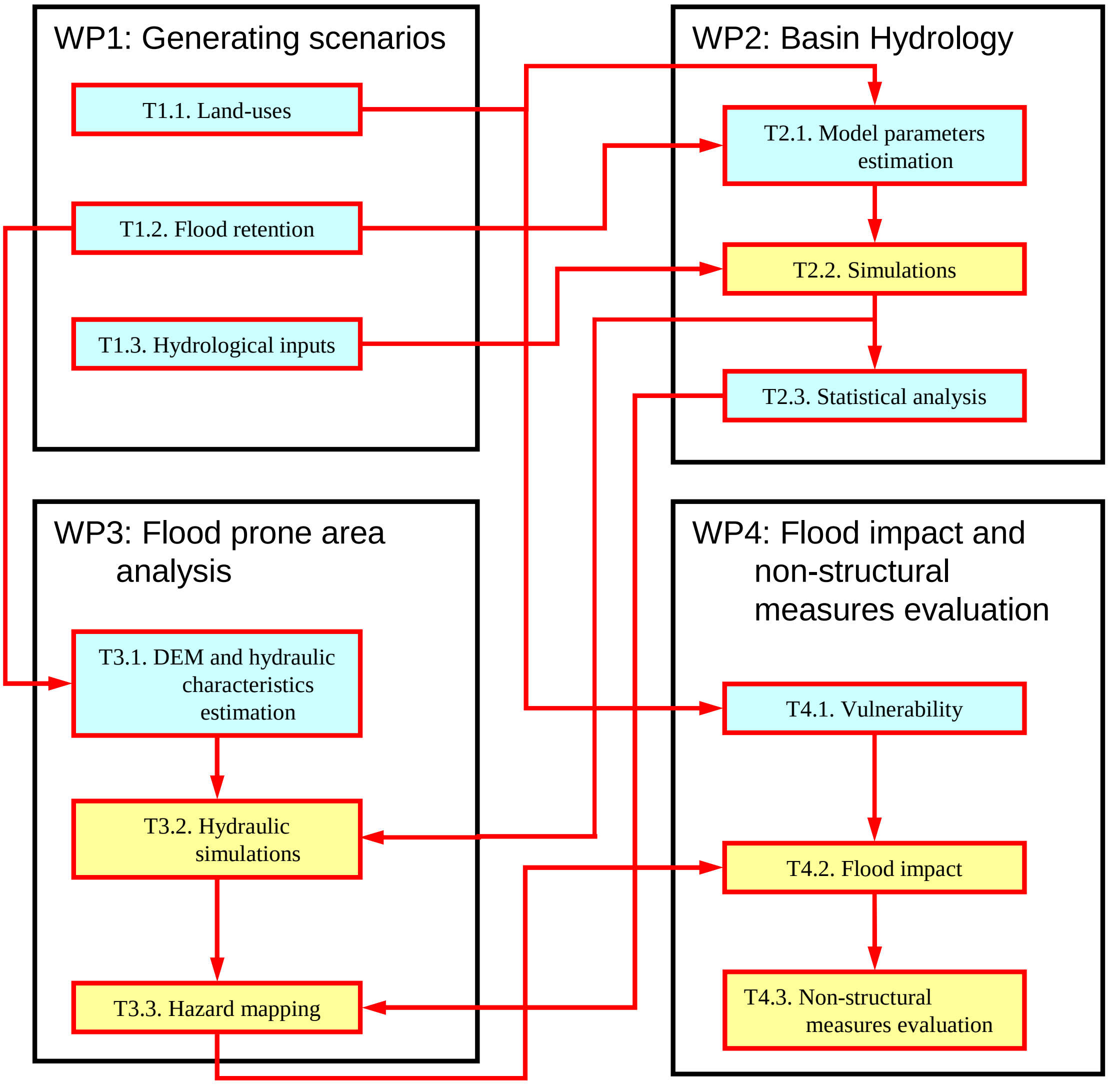


Figure 4-1. Linkages between work packages and tasks (output tasks in yellow)

4.1.1 WP1. Generating scenarios

Comparison of scenarios is one of the major tools that can help the decision makers. In this stage, the aim is both to describe the current status and to generate different scenarios (i.e. different "pictures" of future development) concerning the conditions of land-uses in the catchment and flood-prone areas, potential flood protection measures and storm and initial condition scenarios. These scenarios will serve as an input to the hydrological and hydraulic models, representing both the nowadays situation and possible future conditions.

- *Task 1.1: Land-uses scenarios*

The hydrological effects of land-use (and land-cover) changes have been studied by several authors, but thoroughly described by Calder (1993) and Ward and Robinson (1990). The major changes in land use that affect hydrology are afforestation and deforestation, the intensification of agriculture, the drainage of wetlands, road construction and urbanization. These changes located within the whole basin area will affect the flood hazard. But also changes in the land-use of the flood prone area can change significantly the total flood impact, by changing the flood vulnerability.

- *Task 1.2: Flood retention scenarios*

With these scenarios it is planned to analyse, compare and evaluate the efficiency of two potential non-structural measures:

Local retention measures based on the "retain the water in the landscape" concept, changing the flood propagation characteristics within the basin.
Flood retention in the main stream by providing inundation area based on the "room for the river" concept, increasing the flood routing in the flood prone area or close to it.

- *Task 1.3: Hydrological input scenarios*

Two main hydrological inputs need to be analysed: extreme precipitation and initial conditions:

Extreme precipitation input for the hydrological models will need a large sample of extreme storms, with a good description of its temporal and spatial characteristics. It is important that different types of storms/floods will be analysed that represent typical conditions in the study catchments. In the case of the Kamp catchments storm types to be identified include frontal events, rain on snow events and convective events. Similar storm types will be identified for the Iller catchment. In the case of Poyo catchment, high temporal resolutions rain gauge data are scarce. Because of this, in addition to a small number of historic events, rainstorm will be generated using the model RAINGEN.
The initial soil moisture condition can have a strong influence in the runoff production. For this reason, long term daily simulations will be done in order to asses the probability distribution of the initial situation before the extreme flood events. It is also expected that changes in evaporation (by changes in the basin land-cover) will impact on the soil moisture state.

4.1.2 WP2. Basin hydrology

Four rainfall-runoff distributed models have been used: TETIS model in Rambla del Poyo, Kampus model in the Kamp catchment and WASIM-ETH model in the Upper Iller catchment. The main objective of this work package is to obtain the input hydrographs to the hydraulic models for the different scenarios.

- *Task 2.1: Models parameters estimation*

The first step is the estimation by an expert of the hydrological characteristics maps for each cell, giving values close to areal mean point scale estimations. Depending on the available environmental information, there will be a different degree of approximation in the estimation of all cell parameters. Geological, soil, land-cover, ... maps will be used in this process with a GIS data management.

In the three case studies some recorded floods can be used for parameter calibration and verification. It is difficult to calibrate spatially distributed runoff model against runoff data (Grayson and Blöschl, 2000). Traditionally, systematic manual methods have been used for the calibration of complex hydrologic models. However, in order to obtain reliable results this type of calibration needs for the user to be an expert and usually it is a long time consuming process. Different calibration methodologies will be applied depending on the hydrological model, as described below.

Parameterisation of the effects of land use and land use management on runoff production is a difficult task. The main problem is that the effects on infiltration that are measured in the laboratory due not necessarily apply to the catchment scale because of heterogeneity and feed back effects. To address this scale issue (Blöschl and Sivapalan, 1995), in this project the model parameters and their changes will be gleaned from experimental analyses of the effects of land use change on floods directly at the catchment scale. Analyses of this type include Robinson et al. (2003), Brown et al. (2005), Anreassian (2004) and Bronstert et al. (2002).

- *Task 2.2: Hydrological simulations*

For all combinations of basin scenarios, precipitation inputs and initial conditions, the hydrological simulations will be done in order to obtain the input hydrographs to the hydraulic models.

- *Task 2.3: Discharge statistical analysis*

For the hazard estimation it is needed a frequency analysis of the random variable of interest. When a flow gauge station is available near the flood prone area, this frequency analysis is done directly to the recorded annual maximum peak discharges. This is the case of Kamp and Upper Iller case studies.
For ungauged basins or with short flow records, the frequency analysis must be done with the annual maximum daily precipitation, which is the case of Rambla del Poyo. To obtain the non-exceedence probability of the peak discharges obtained from the synthetic storms, conditional expectation to the maximum storm 24 h precipitation will be used (Francés and Madriñán, 2004):

$$F_X(x) = \int_{-\infty}^{\infty} F_{X|r}(x|r).f_R(r).dr$$

where: X= random variable of interest (peak discharge), R= annual maximum daily precipitation, fR(r)= pdf of R, FX/r(x/r)= conditional cdf of X given r obtained from simulations.
For the design storms estimation, the IDF curves also will be computed at each case study.

4.1.3 WP3. Flood prone area analysis

Different hydraulic models will be used for the flood prone area analysis, depending on the problem and the experience of the users. The main objective of this work package is flood hazard estimation for the different scenarios.

- *Task 3.1: DEM and hydraulic characteristics estimation*

The hydraulic models need as inputs the hydrographs (obtained in WP3), a DEM of the flood prone area and terrain hydraulic characteristics. The DEM must be of the maximum precision. In all cases there is already a DEM and in the case of Rambla del Poyo it was obtained using Lidar (Light Detection And Ranging) technology.
The hydraulic characteristic for the terrain is mainly the surface roughness, but also all special structures within the simulation area need to be characterized.
Using stage data, in the Kamp catchment case study some calibration and validation will be done.

- *Task 3.2: Hydraulic simulations*

For all combinations of flood prone area scenarios and input hydrographs, in Rambla del Poyo and in Kamp catchment hydraulic simulations will be done in order to obtain the magnitude (mainly maximum water depth) for each case. The described below hydraulic models will be used. In the Upper Iller, its flooding situations has recently already been analysed by detailed hydraulic modelling. This is why we do not need to apply a specific hydraulic model for this case study. The WWA Kempten will provide the model results, in particular inundation maps for different flood discharges and for different flood retention measures to be operated along the river.
To exploit the detailed DEM, a sensitivity analysis to grid size will be done in Rambla del Poyo.

- *Task 3.3: Flood hazard mapping*

After the hydraulic simulations, the flood hazard maps for the different scenarios can be obtained. GIS software will be used to help in this task. The flood hazard maps are the representation of the cumulative probability distribution function of the flood magnitude (mainly maximum water depth) at each cell, including high return period quantiles.

4.1.4 WP4. Flood impact estimation and measures evaluation

By a proper combination of the hazard and the vulnerability in the flood prone area, the total flood impact will be computed. The main objectives of this work package are to compute the flood impacts. With these impacts for each scenario and to analyse specifically the non-structural flood protection scenarios.

Task 4.1: Flood prone area vulnerability
A generic methodology will be established and adapted to the particular contexts related to each case study. The proposed methodology is based on:

Determination of the vulnerability of the elements at risk through the step-damage-functions, i.e. the degree of loss (0% to 100%) resulting from a potentially damaging event.
Estimation of financial, economic and social damages using defined estimation procedures.

An assessment of vulnerability is affected by data availability. Detailed analyses require an extensive amount of data which often are not available in data poor environments. Also, even if much spatial detail is included, most vulnerability analyses focus on the direct impacts and do not consider indirect or induced effects arising from a catastrophic event. For example, the flooding of a major roadway may affect the transportation of goods and the supply and distribution chain of several manufacturing companies. Given that the main focus if the project is on the relative efficiency of the mitigation measures, an aggregated vulnerability analysis, as consistent with the scale and the duration of the project, will be performed. The results of the INTERREG IIIB MEDOCC projects DAMAGE and QUATER (García Miralles, 2004 and 2005), Hazus FEMA project (http://www.fema.gov/hazus) and FLOODsite (if available) will be used.

Task 4.2: Flood impact estimation
The flood impact was defined previously as the probability integral between flood magnitude and land-use vulnerability. Obviously this integral must be solved in discrete form and using a GIS to deal with the two basic layers of hazard (task 3.3) and vulnerability (task 4.1).

Task 4.3: Non-structural measures evaluation
Finally, the information concerning the flood impact at each scenario will be used to compare and evaluate the effects of all investigated non-structural measures by assessing the different damage potentials (due to different non-structural measures) and performing a meso-scale risk-analysis.

Practical general conclusions will be obtained. For example, a ranking of the various flood mitigation measures will allow drawing inferences on the relative efficiencies of the measures. It is anticipated that the relative efficiency will depend, among other things, on the flood magnitude and flood types. It is expected that the infiltration related measures will be most efficient for floods of small and medium magnitudes, but it will be possible that in terms of total impact the efficiency would be higher. The retention related measures will be most efficient for short floods, i.e. floods with relatively small volumes relative to peak flows.

4.2 Mathematical models

Several models have been used in this project for different purposes. Next, it is attached a short description of each of them. It is important to underline that all the models and the GIS software are already available to partners and can be used for the purposes of the project. The partners have substantial experience with hydrological and hydraulic modelling at each cases study.

4.2.1 Hydrological models

TETIS is a conceptually based hydrological model, it simulates all the main components of the Hydrological Cycle and it is distributed in space using a regular grid. This model has been developed by the UPVLC Research Group during the last ten years, with good results in different climatic and catchment size scenarios and for floods and continuous simulation related problems (Vélez, 2001; Francés et al., 2002; Vélez et al., 2002a, 2002b and 2002c, Vaskova et al., 2004). It can be downloaded from http://lluvia.dihma.upv.es/. The TETIS conceptualization for runoff *production at each cell consists of 5 vertical tanks, each one representing the different water storages in an "extended soil column". These tanks are called static, surface, gravitational, aquifer and, in case of snow, an additional tank is activated to represent the snow cover. The vertical connections between tanks describe the precipitation (rainfall or snow), snow melting, evapotranspiration, infiltration and percolation processes. The horizontal connections describe the overland flow, interflow and base flow. Therefore, the three main components of the observed hydrograph at the catchment outlet can be simulated with the minimum number of tanks. The propagation to the outlet of the overland, interflow and base flow collected by the river channel network is done using a kinematic wave approach.*

Within TETIS model, using the Split Parameter Structure (Vélez, 2001), it is possible to obtain an automatic calibration of a distributed model maintaining the parameters spatial variability, i.e., different values at each cell. The optimization algorithm for the automatic calibration used by TETIS is the so called SCE-UA method, proposed by Duan et al. (1992) with the modifications introduced by Sorooshian et al. (1993).

The Kampus model is a spatially distributed, raster based model that represents detailed hydrological processes at small scales, including surface runoff, subsurface stormflow and groundwater processes. The model has 20 parameters that need to be specified for each grid cell. To reduce the number of parameters to be specified a number of zones of uniform model parameters are delineated for subcatchments. This procedure is guided (in decreasing importance) by the understanding of runoff processes from field surveys, geologic maps, soil maps and sensitivity analyses. It is important to note that these zones differ from traditional hydrologic response units in that in assigning each pixel to one of the eight zones the relative role of runoff processes is carefully assessed by expert judgement. One of the zones, for example, is a groundwater recharge area which is identified by analysing the dynamics of piezometric heads in the area.

For calibration, the strategy proposed by Reszler et al. (2006) is adopted for the Kamp catchment. The strategy is a method for identifying the parameters and the structure of a pixel based spatially distributed runoff models for a particular catchment using patterns of process information. The aim is to accurately represent the runoff processes in every single pixel to maximise the accuracy of the flood forecasts for a range of hydrological situations. The proposed method consists of five steps: (1) setting a priori parameter values; (2) fine tuning the spatial patterns by spectral unmixing; (3) parameter calibration (fine tuning); (4) fine tuning of the model structure; (5) plausibility check of the simulated spatial patterns. The method provides a more reliable model structure and parameters than traditional calibration based on runoff data.

The German case study has used the WASIM-ETH model (Schulla 1997), which has been used extensively in previous studies and was already modified specifically for land-use change impact simulations. This is a "process based" continuous hydrological model, which uses a grid discretization scheme of usually between 50m and 250m grid length (Nieheoff et al., 2002). We will apply this model for detailed analysis of the efficiency of the potential for water retention in the landscape and for the effects of land use changes (e.g. afforestation, conservational agricultural practices, extension of urban areas) on runoff generation during heavy rainfall periods.

4.2.2 Hydraulic models

For the Rambla del Poyo case study it has been used the grid computing version of Sobek 1D2D. Sobek 1D2D is a non-steady state hydraulic model, developed by Delft Hydraulics, which can deal simultaneously the 2D simulation with the 1D simulation in the main water ways. In both cases it is possible to have subcritical and supercritical flows and the program solves satisfactorily the problem of filling and draining. It is foreseen the use of a grid computing beta version, because the

high computational cost using a large sample of synthetic storms. Delf Hydraulics will help in the installation and first runs of the program
In the Austrian case, the hydraulic model to be used is a non-steady state model suited for representing flood inundation processes on the flood plains. Depending on the reach to be modelled either a 1-D non-steady state model (such as HEC-RAS) will be selected or a 2-D non-steady state model (such as Hydro_AS-2D). The latter will be important for complex channel-flood plain interactions.

No new hydraulic simulations have been done in the Upper Iller case study, because there have been already comprehensive hydraulic investigations, lead by WWA Kempten. These results will be made directly available to the project partner to enable the evaluation of flood risk impacts of the before mentioned land-use change effects.

5 The Upper Iller catchment

5.1 Land use, soil types and topography

The hydrological model WASIM-ETH requires an extensive database of vegetation, soil and meteorological data. The Upper Iller catchment has a size of 954 km² and is predominantly covered by forest and meadows, the urban areas cover less than 3 percent of the catchment (Figure 5-1). The highest mountain tops are without vegetation cover. While most of the area is dominated by loam type soils, the upper mountain areas are often characterized by little developed soils (Figure 5-2). Elevations in this catchment range from 650 to nearly 2650 m above sea level (Figure 5-3). The land use data stems from the CORINE 2000 dataset and the soil map is obtained from the BÜK 1:1Mio.
All the above mentioned data sets are incorporated in the model as grids of 50m resolution.

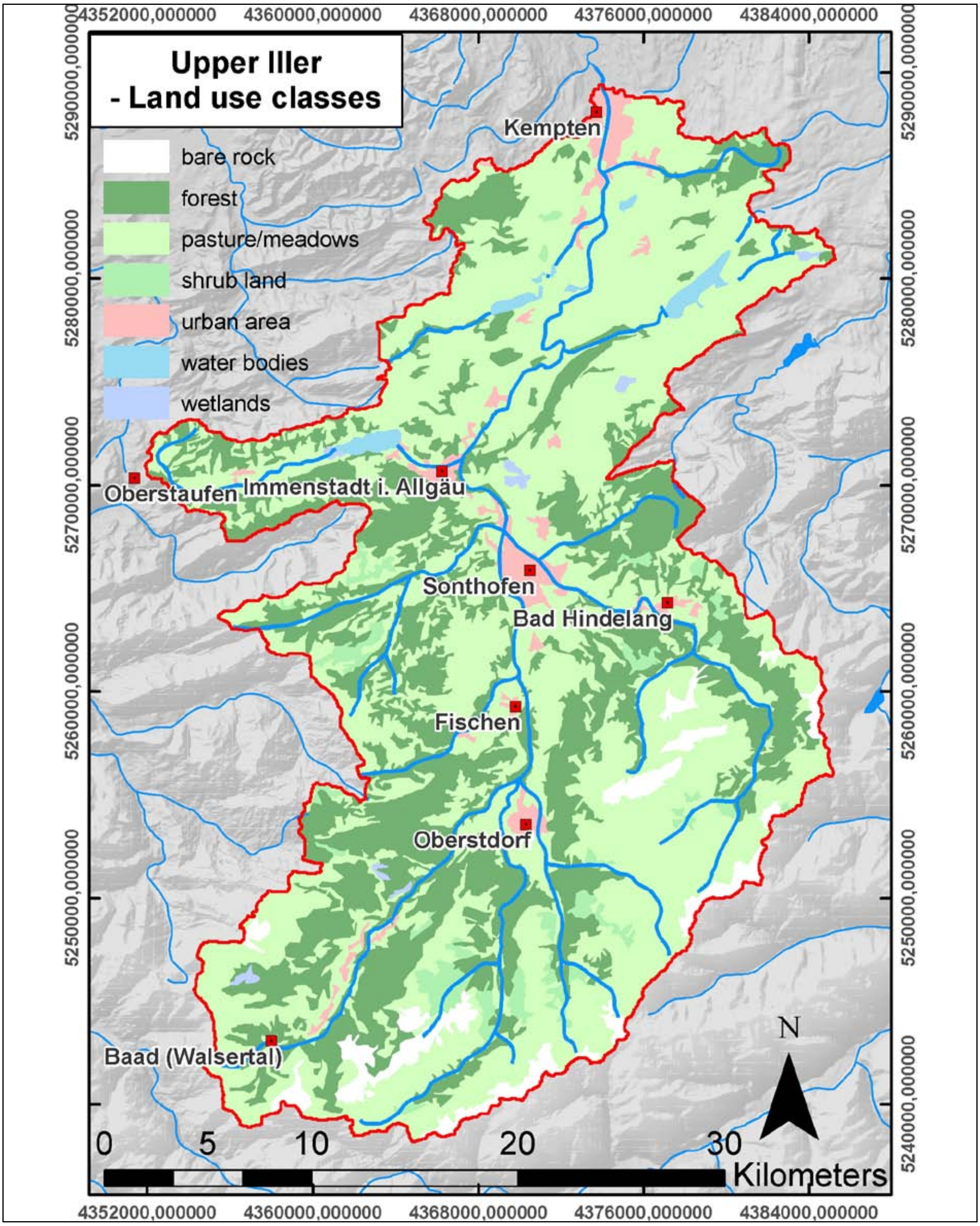


Figure 5-1 . Land use classes in the Upper Iller Catchment

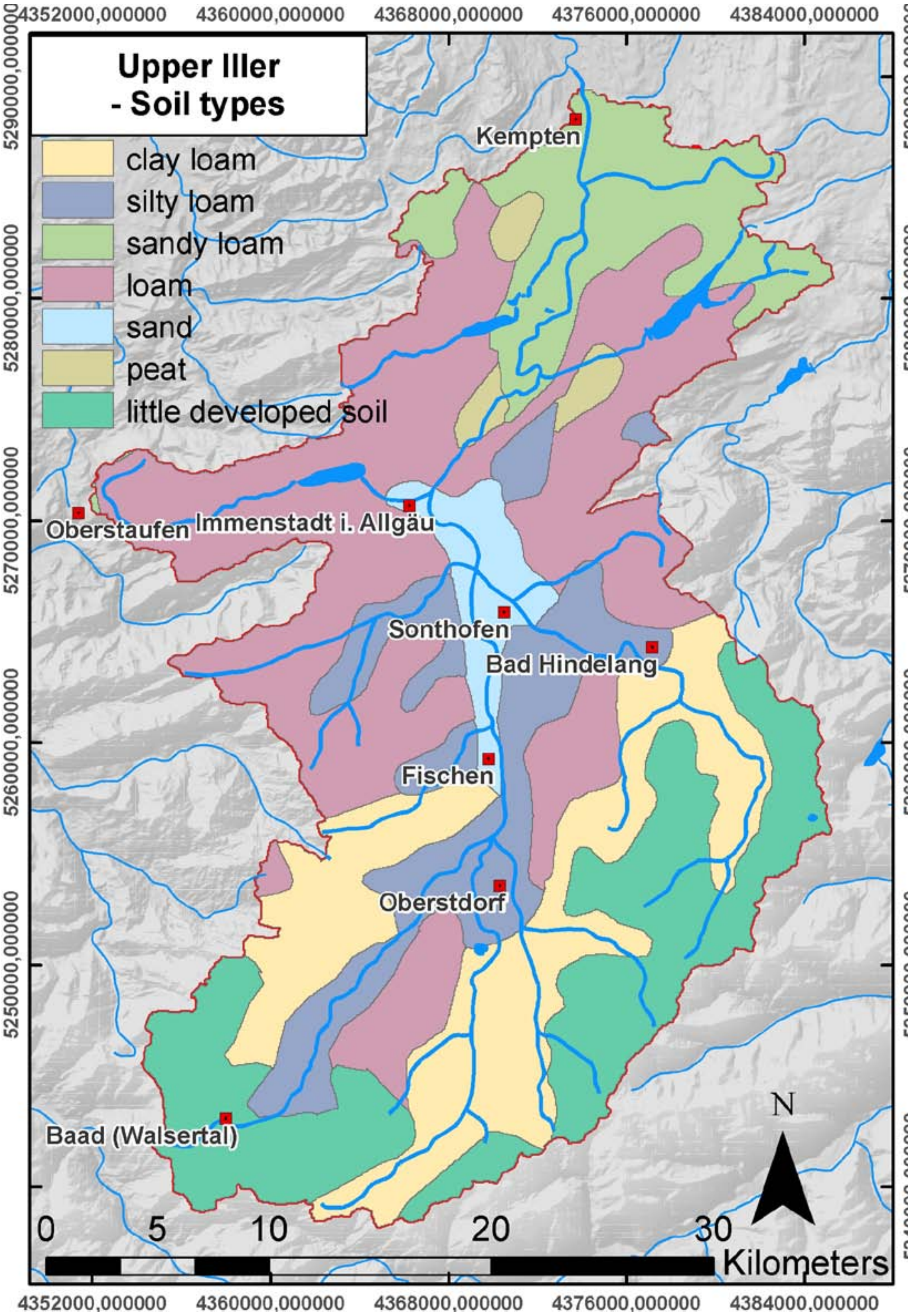


Figure 5-2 . Soil coverage in the Upper Iller Catchment

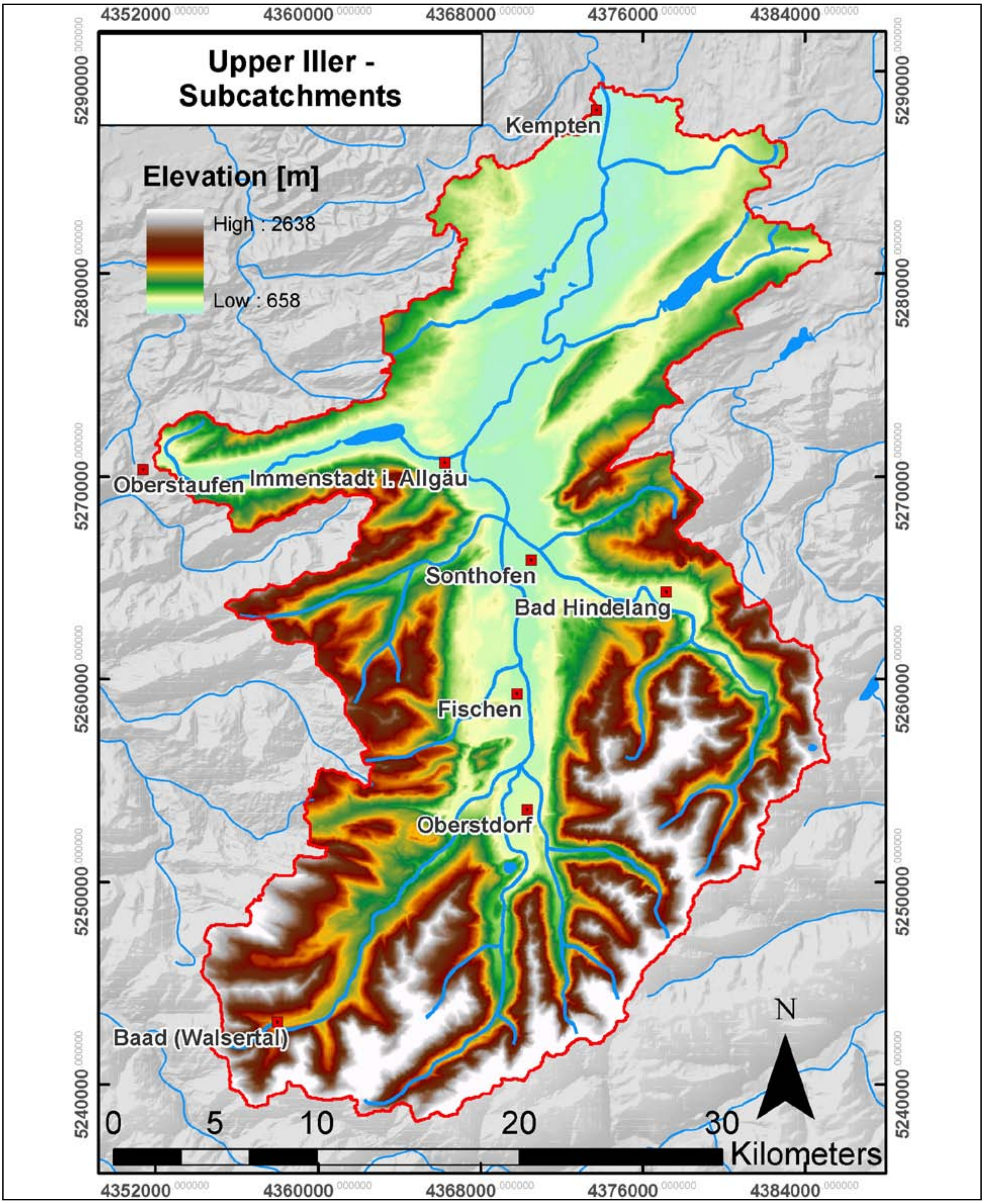


Figure 5-3 . Topography of the Upper Iller Catchment

5.2 Hydrometeorological data

The specific challenges for this alpine case study include the strong gradient of temperature and precipitation with altitude, which can often not be captured by the available climate station data. Especially high-altitude stations are underrepresented. However, both parameters, temperature and precipitation, are strongly influencing runoff generation and thus it becomes necessary to overcome this lack of data.

Spatial rainfall variability in the Iller Catchment is high. For example during the flood in August 2005 (300 year flood at Kempten) rainfall return periods at different raingauges were found to range between just above 2 years and nearly 30 years (corresponding to 65-210 mm) (see Figure 5-4 – green circles).

Availability of climate data for all stations in the research area is shown in Figure 5-5. While data availability has increased since 2004 it is clearly low in earlier years.

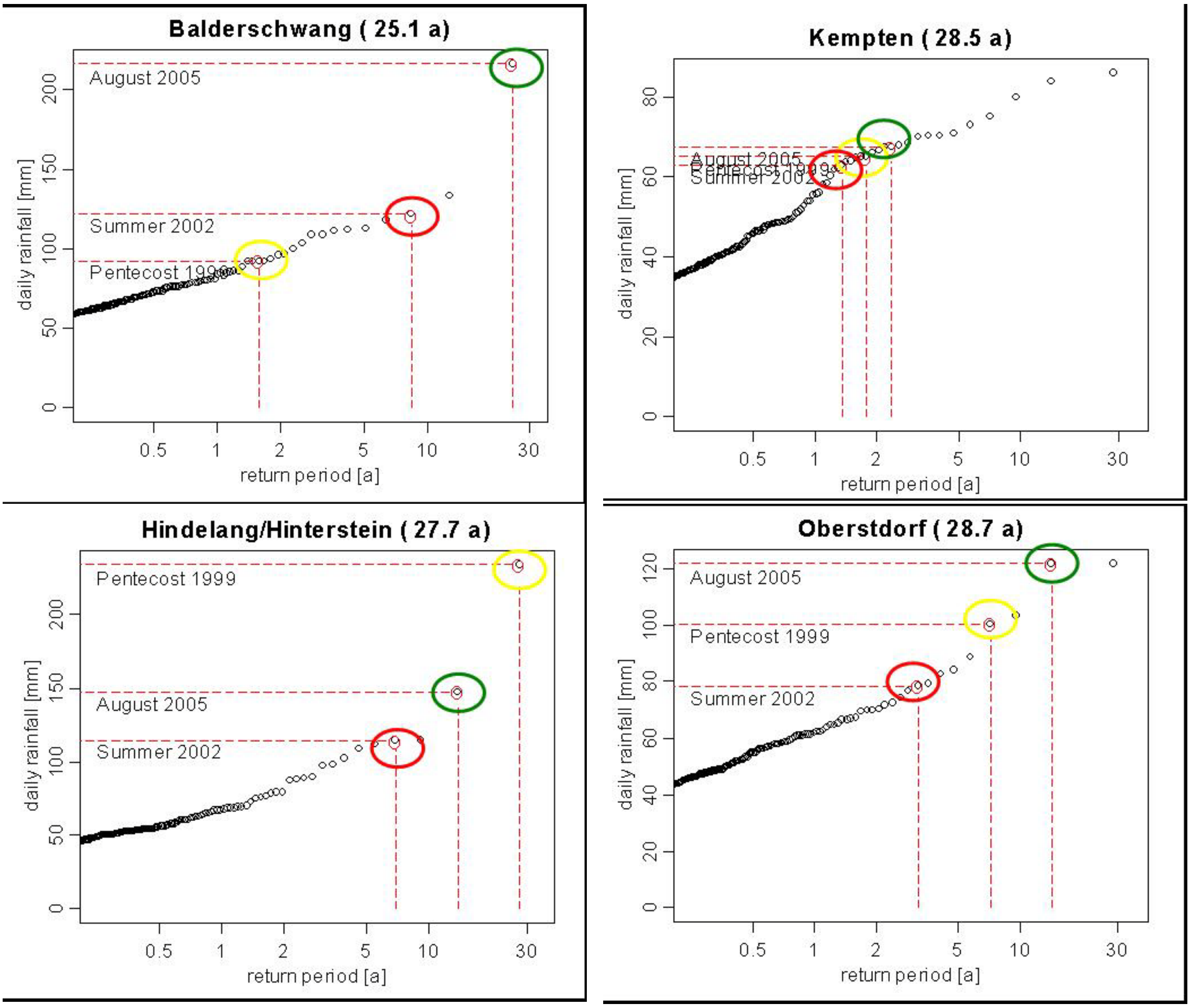


Figure 5-4 . High spatial variability of rainfall

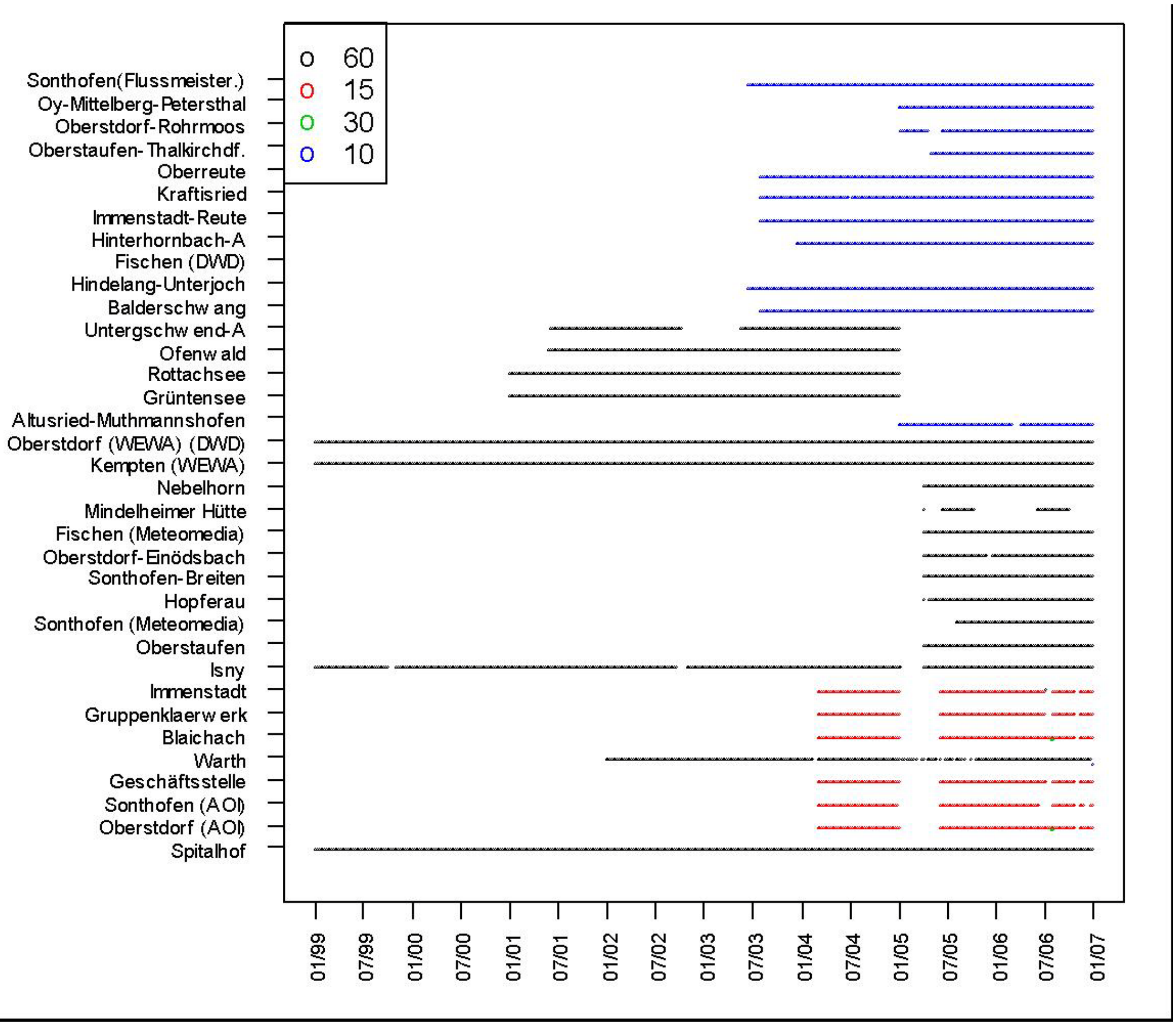


Figure 5-5 . Data availability

This high spatial variability of rainfall results in an urgent need for sufficiently high numbers of rain gauges in order to reproduce the discharge dynamics with a hydrological model.

Temperature, on the other hand, is very important for hydrological simulation as it is the basis for modelling snow accumulation and snow melt (which has a strong effect on the hydrograph, especially in alpine catchments). As temperature is clearly dependent on altitude (Figure 5-6) a simple inverse-distance interpolation of station data was not satisfactory. This type of interpolation results in an overestimation of temperatures at higher altitudes (Figure 5-7) and as a result also in an underestimation of snow storage. As high elevation station data is missing for the time period before 2005 a simple elevation based regression for temperature was difficult to achieve. To solve this problem, three synthetic stations were produced at the same locations as the later installed high altitude stations Warth, Mindelheimer Hütte, and Nebelhorn. With the data measured during 2004-2007 a linear statistical model was established to predict precipitation and temperature at these locations. This linear statistical model was applied for the time period 2001-2002 and thus "synthetic time series" for these high elevation stations were produced.

With sufficient stations also for higher elevation a regression based method can be used, correlating rainfall or temperature with elevation. This was successfully carried out for the temperature data (Figure 5-7). However, this proves to be more complicated for rainfall data: while there is usually a clear correlation with altitude on a monthly or annual basis this is type of relationship is difficult to establish for hourly intervals. As the runoff coefficients shown in

Table **5-1** *clearly show that measured and interpolated rainfall amounts are clearly unrealistic as we obtain runoff coefficients of more than 90% or even 100%. For the here described study we therefore chose a simple subcatchment specific correction of precipitation.*

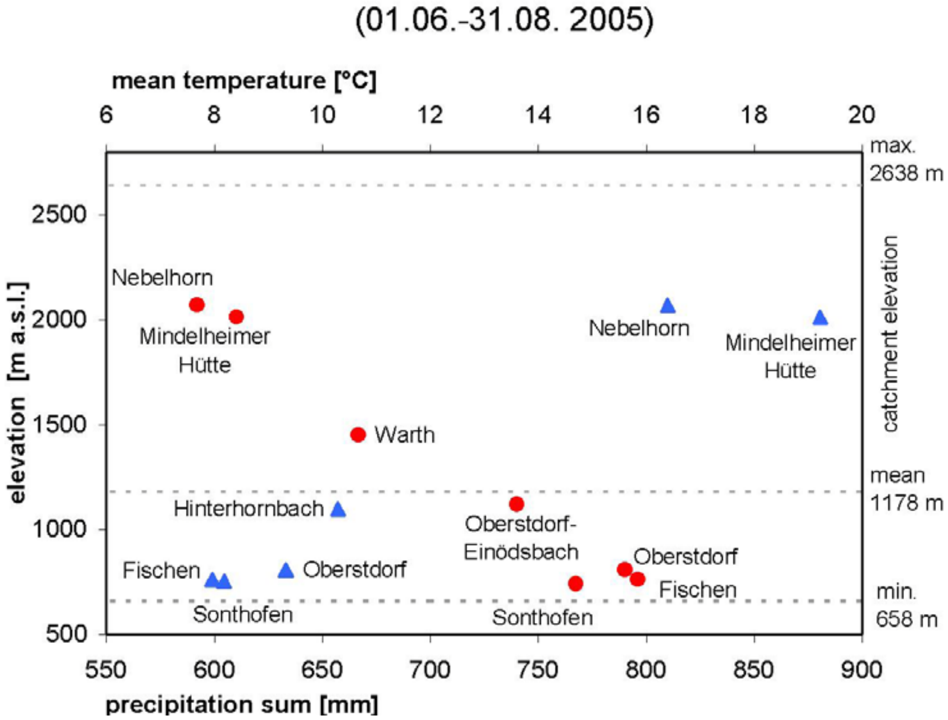


Figure 5-6 . Meteorological data vs. elevation

Table 5-1*. Rainfall amounts and resulting runoff coefficients on subcatchment basis.*

subcatchment [gauge]	***mean altitude [m]***	***mean annual rainfall (interpolated) [mm/a]***	***runoff coefficient from interpolated rainfall [-]***
Kempten	*827*	*1595*	*0.73*
Durach	*841*	*1341*	*0.65*
Greifenmuehle	*909*	*1484*	*0.75*
Immenstadt	*999*	*1764*	*0.91*
Gunzesried	*1277*	*1907*	*1.11*
Sonthofen	*1064*	*1984*	*0.94*
Winkel	*1180*	*1822*	*0.84*
Reckenberg	*1431*	*1939*	*1.15*
Gschwend	*913*	*1328*	*0.93*
Thalkirchdorf	*946*	*1771*	*0.88*
Breitachklamm	*1521*	*2243*	*0.99*
Oberstdorf_Stillach	*1474*	*2242*	*0.62*
Oberstdorf_Trettach	*1540*	*2040*	*0.96*

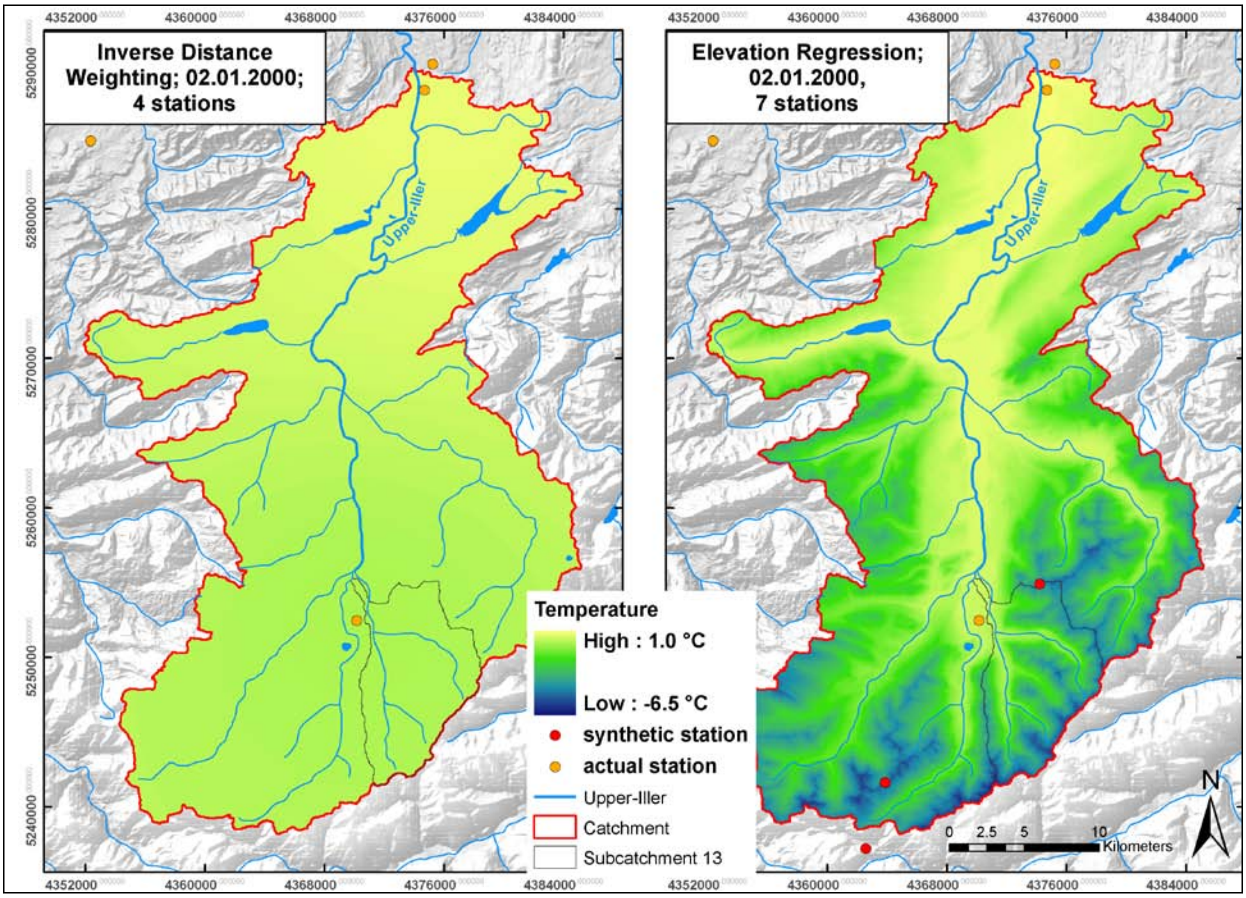


Figure 5-7 . Interpolation of temperature data – 2 possible methods

The climate stations used for the simulation period 2001-2002 as well as the types of meteorological data provided by these stations are shown in Figure 5-8. The locations of the higher elevation stations with the time series produced by the linear statistical model (the so called "synthetic time series") are also given in this map.

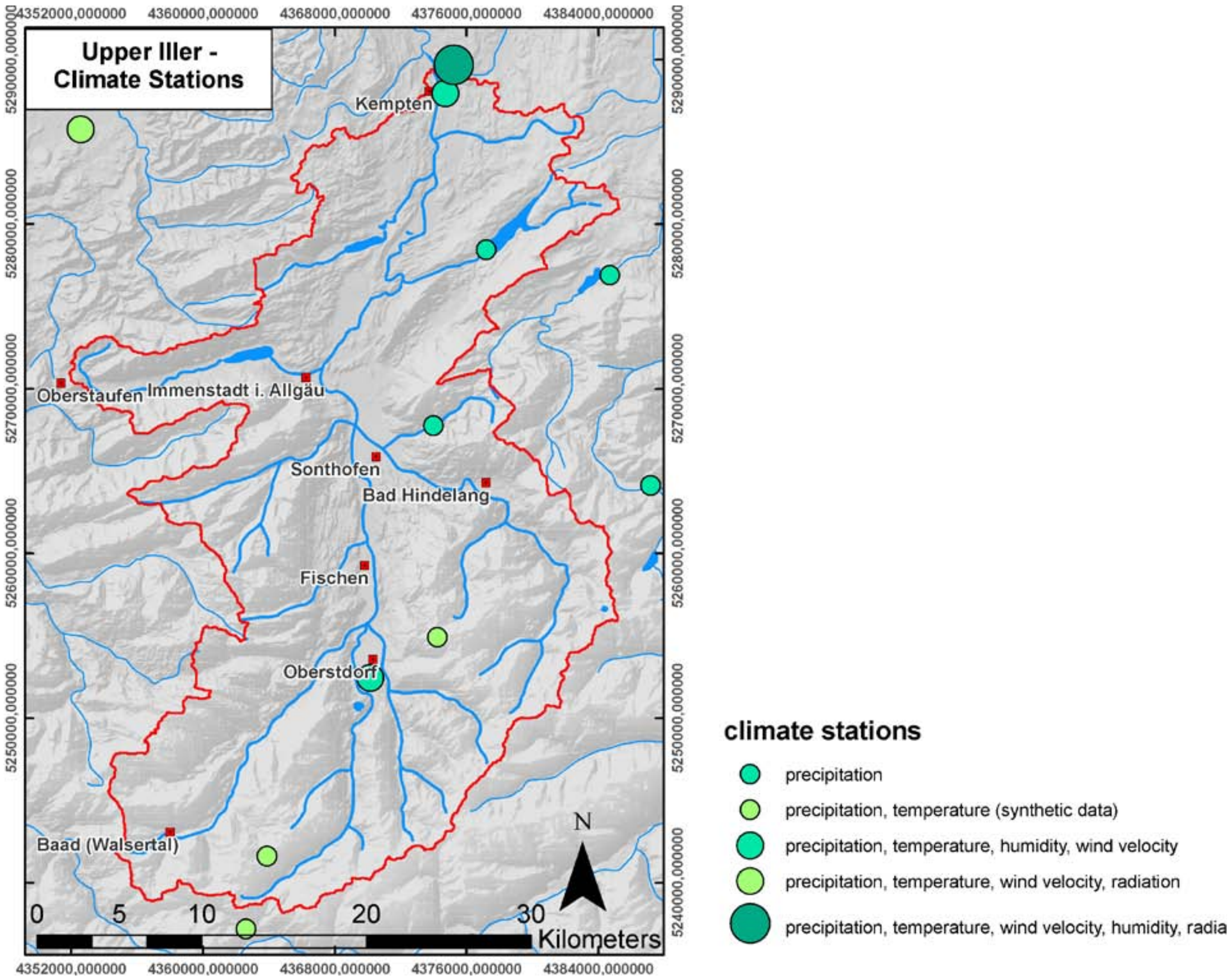


Figure 5-8 . Climate stations and data used for simulation

6 The hydrological model WASIM-ETH

The Topmodel-based Wasim-ETH (Schulla, 1997; Schulla & Jasper, 1999) is a deterministic and distributed model for the simulation of catchment water balance. It was originally developed for the investigation of climate change effects on water balance. It was has been extended to include macropore flow, siltation and water retention in the landscape as well as an improved representation of urban areas (Niehoff et. al 2002). It is grid based in the calculation of evapotranspiration, interception, snow melt and snow storage, infiltration and vertical soil water movement. For a summary of the model structure see Figure 6-1. Direct flow, interflow and baseflow are simulated as linear storages; the first two are calculated per grid cell while baseflow is calculated on the basis of the entire subcatchment. For the routing of streamflow the kinematic wave approach is used (Niehoff et. al 2002). For the simulation of evapotranspiration the Penman-Monteith equation is implemented. Infiltration is modelled with the Green and Ampt approach, deviding the incident rainfall into infiltration excess water and infiltrating water which is routed to the soil model. The soil model does not model soil water movement but uses a system of storages centering around the saturation deficit. The calculation of the saturation deficit is based on the Topmodel approach of the topographic index. The/most parameters of the different storages need to be calibrated (Niehoff et. al 2002). Wasim-ETH is a process oriented model, as it models flow components such as infiltration/saturation excess, direct runoff, interflow and baseflow and some of the soil storage characteristics can be connected to soil physical parameters.

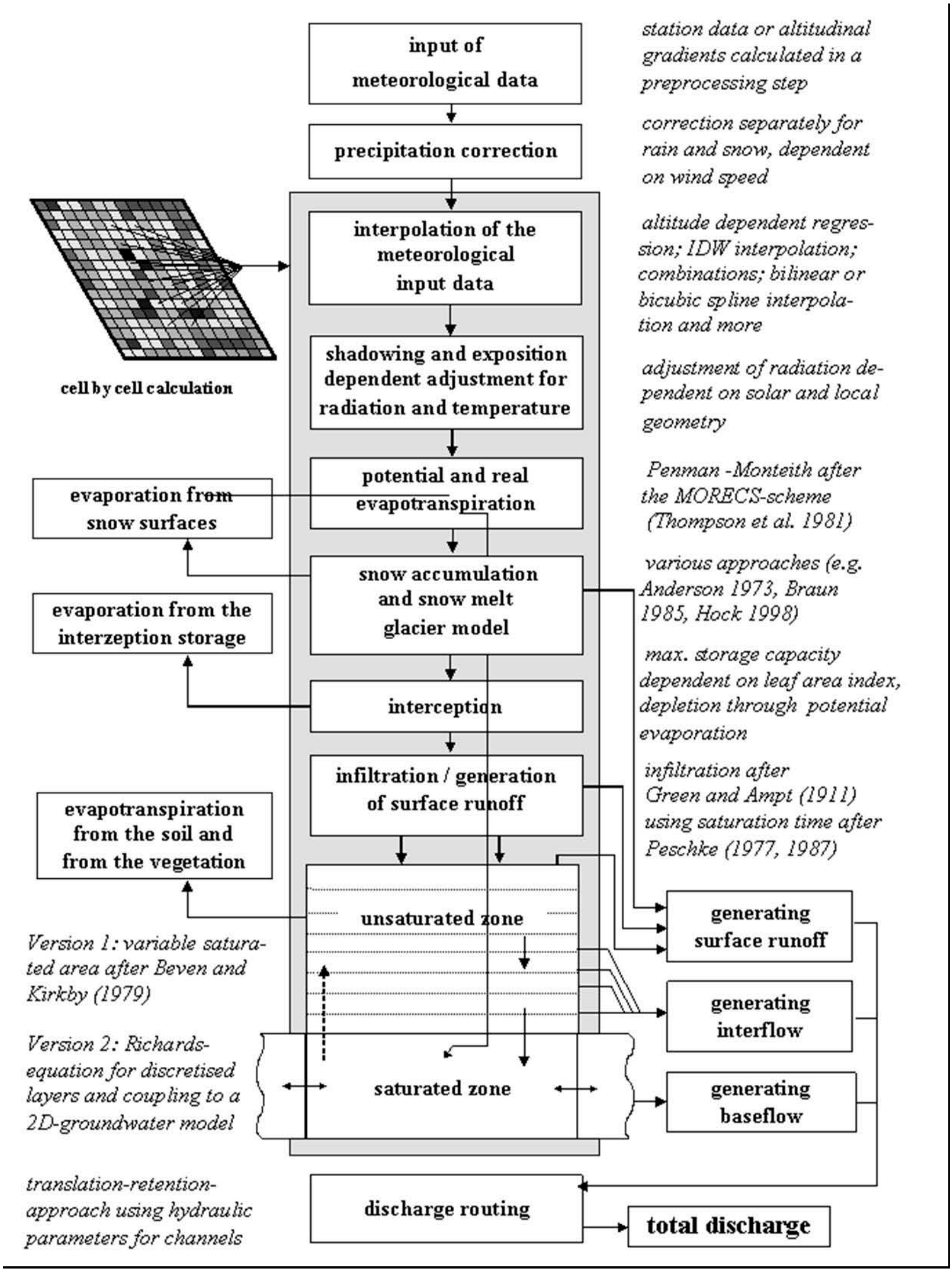


Figure 6-1 . Model structure of WASIM-ETH

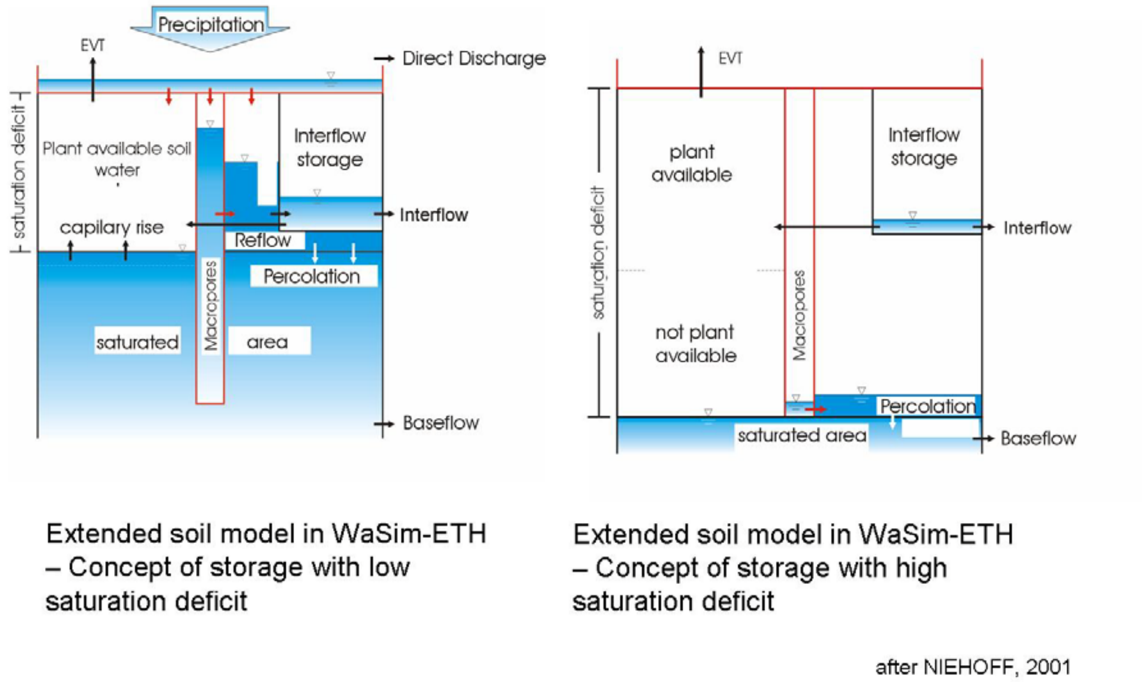


Figure 6-2 . Soil model of WASIM-ETH

Necessary input grids are landuse (Figure 5-1), soils (Figure 5-2) and a number of topographical grids determined from a digital elevation mode (Figure 5-3)l. Landuse and soil tables contain a high level of physically based information. For examples of the input data necessary for these tables see Figure 6-3. The spatial resolution chosen for this study were 50 m grid cells, and one hour time steps were used for the simulation.

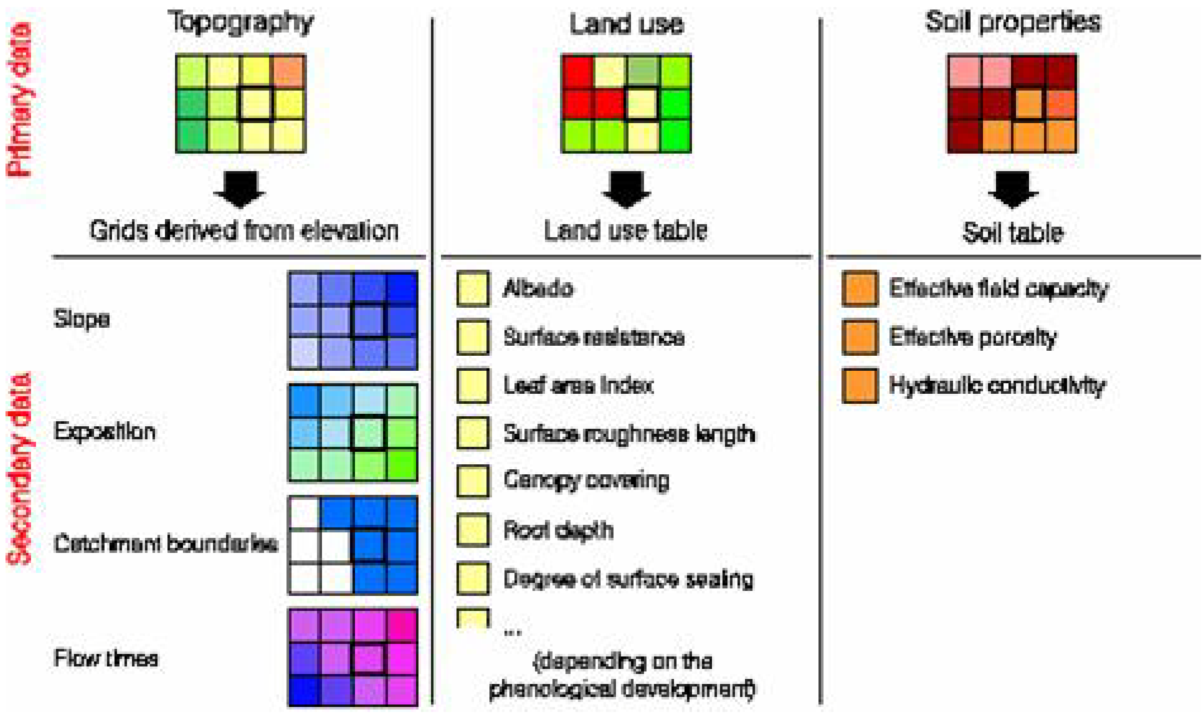


Figure 6-3 . Data requirements of WASIM-ETH

6.1 Model calibration (WASIM-ETH)

*Six soil parameters and 4 snow parameters had to be calibrated (*Table 6-2*). As the Upper Iller catchment is highly heterogeneous it was devided into 8 subcatchments (Figure 6-4). The 3 shaded subcatchments on Figure 6-4 were not simulated. Instead, for these subcatchments measured discharge time series were used as input for the simulation of subcatchment 1 and the entire basin. Calibration was carried out for each subcatchments seperately. During the calibration phase subcatchment 3 receives measured discharge time series for the subcatchments 6, 7, and 8 as upstream input and subcatchment 1 from subcatchments 2, 3, 4 and 5 (Figure 6-4). This ascertains that model errors from upstream catchments are not compensated for by the parameters determined for the lower catchments. Catchment characteristics can be found in* Table 6-1*.*

Table 6-1.*Subcatchments, topographical characteristics and land use*

Subbasin	*ID*	*area [km²]*	*mean altitude [m]*	*min. altitude [m]*	*max. altitude [m]*	*slope %*	*drainage density [km/km²]*	*forest %*	*meadow/ pasture %*
Kempten	*1*	*245.55*	*826.86*	*658*	*1714*	*13.2*	*0.73*	*18.8*	*59.4*
Gunzesrieder Ach	*2*	*46.41*	*1276.64*	*875*	*1805*	*38.3*	*3.88*	*45.1*	*41.4*
Sonthofner Iller	*3*	*130.62*	*1062.23*	*729*	*2122*	*28.9*	*1.38*	*43.5*	*46.5*
Ostrach	*4*	*126.96*	*1431.99*	*764*	*2360*	*53.5*	*1.42*	*28.2*	*36.8*
Burgberger Starzlach	*5*	*19.85*	*1179.79*	*766*	*1715*	*37.4*	*9.07*	*78.1*	*20.5*
Stillach	*7*	*81.14*	*1473.28*	*784*	*2638*	*52.0*	*2.22*	*25.0*	*37.2*
Trettach	*8*	*74.35*	*1543.50*	*784*	*2606*	*66.7*	*2.42*	*16.8*	*40.7*

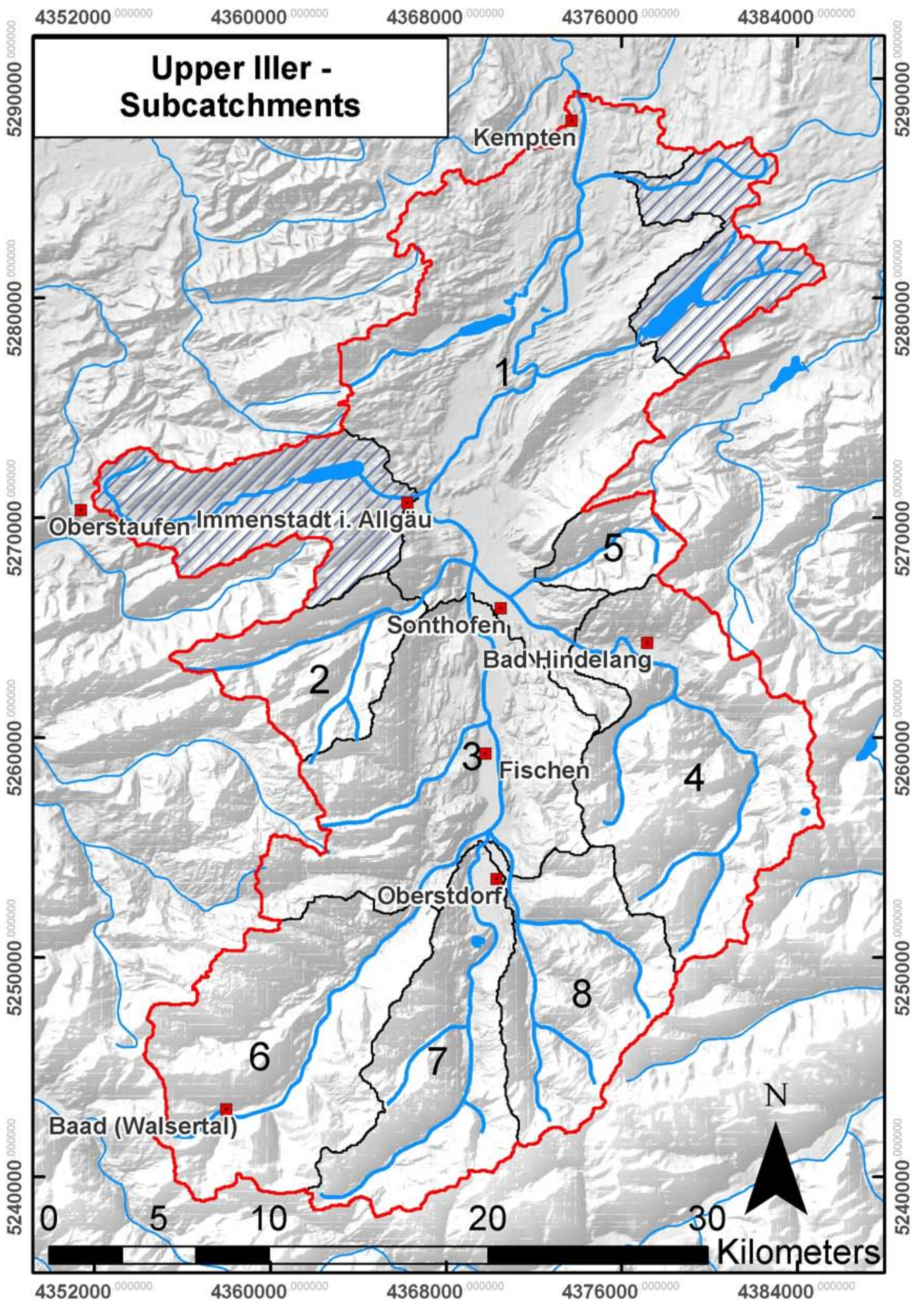


Figure 6-4 . Subcatchments used for model calibration.

Table 6-2. ***Soil and snow parameters of Wasim-ETH***

Parameter	description	unit
m	recession parameter for baseflow	m
Tcorr	correction factor for soil transmissivity	-
Kcorr	correction factor for vertical percolation	-
kD	single reservoir recession const.-surface runoff	h
Hmax	maximum storage capacity of interflow storage	mm
kH	single reservoir recession const.-interflow	h
t0r	temperature limit for rain	C
t0	temperature limit for snow melt	C
c0	degree-day-factor	mm/d/C
cmelt	fraction of snowmelt which is suface runoff	-

As some of the parameters in Table 6-2, especially m and Tkorr strongly define the system state it is not possible to use the same initial conditions for different parameter sets. For this reason it became necessary to produce initial conditions for each of the parameter sets tested during calibration. A stable state of the system was achieved by running the model repeatedly for the time period March 2001 – March 2002, each time using the final catchment state as initial condition for the next run until the size and filling level of the storages corresponding to the saturated and unsaturated zone became stable. To decrease computation time this procedure was carried out for a temporal resolution of days. Additional the number of possible pre-runs was limited to 100.
The calibration procedure involved two different methodologies. In a first step (procedure 1) the parameter space was scanned for parameter ranges with which is was possible to achieve sensible system states which are able to produce flow from the direct flow, interflow and base flow. This was done by using a long list of parameter sets (100-200) and varying each parameter in a predefined range. To allow for an efficient combination of as many parameter ranges as possible, each parameter was varied between its minimum and maximum with a different frequency. (If you would vary them all with the same frequency you would only allow for combinations for example of the lowest parameter values or the highest parameter values.) This variable frequency parameter variation is shown exemplarily for fictitious parameters in Figure 6-5. After determining best parameter sets as well as sensible parameter ranges with this method, calibration was carried out with PEST (a freely available software for non-linear parameter estimation using the Gauss-Marquardt-Levenberg algorithm) (Doherty 2004). A composite objective function was used to ensure the plausible reproduction of the different processes (total runoff, groundwater response, storage dynamics…).
However, as the response surface of the Wasim parameters often is not smooth but discontinuous and the numerical stability of the model is also influenced by the parameter combination PEST is often unable to determine a clear gradient towards a better parameter set. In this case the optimisation result was chosen as a new starting point for procedure 1. If a better parameter set was determined in this step PEST was started from this newly determined parameter set.

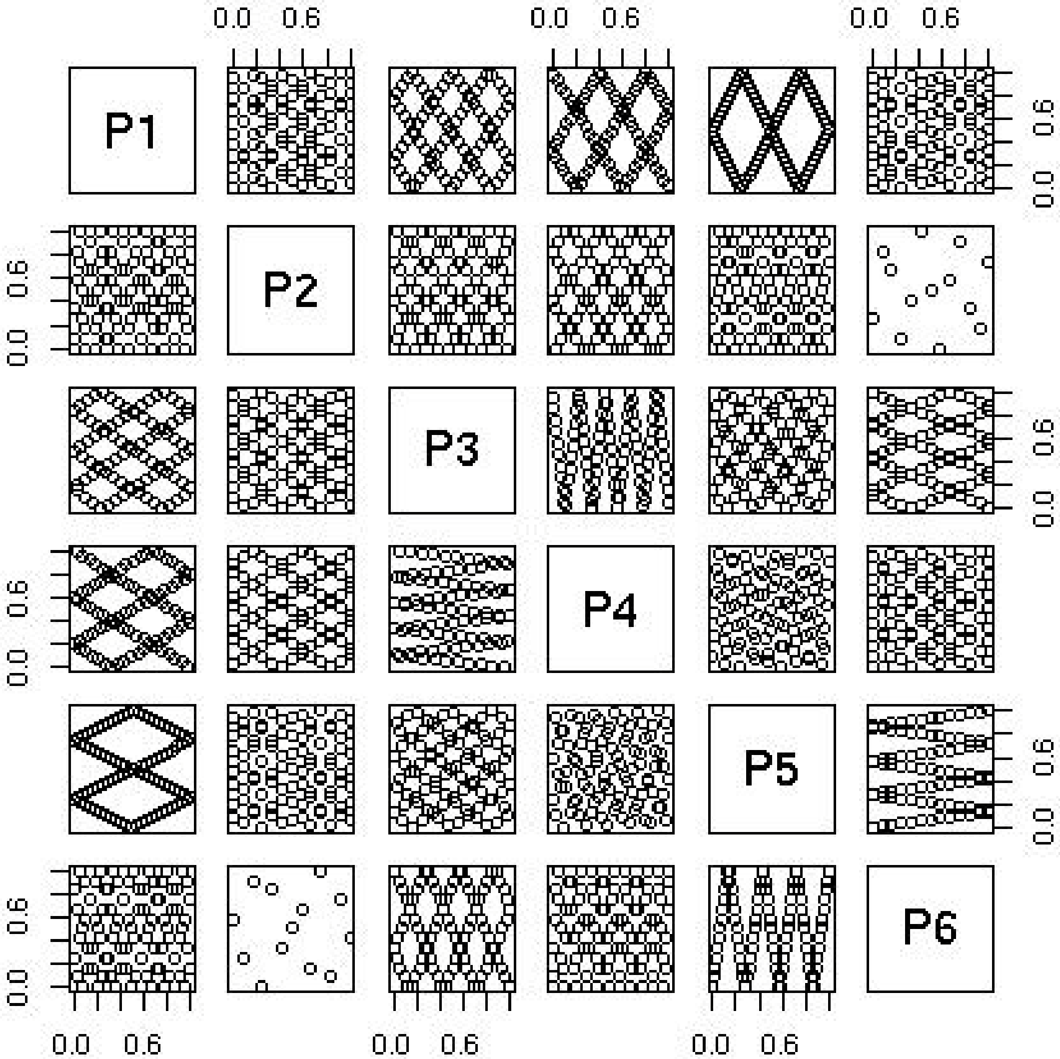


Figure 6-5 . Efficient parameter variation in the first step of calibration.

As mentioned above calibration was carried out for each of the subcatchments separately. The simulation results are shown in Figure 6-6 to Figure 6-13 and Table 6-3*.*
In Figure 6-6 to Figure 6-8 the results for the highly alpine headwater catchments are shown. In these catchments model calibration proved to be the most difficult. This can have a number of different reasons. As these three catchments have the highest mean altitudes as well as the highest range of altitudes they are especially influenced by all problems resulting from the topographic gradient. This can be the underestimation of precipitation in general and the misrepresentation of snow accumulation and snow melt as a result of faulty temperature interpolation. Furthermore, no snow data was available for these catchments and the snow model could only be calibrated to the extent and duration of the typical snow melt pattern in streamflow, i.e. diurnal variations. After personal communication with the local Water Authorities we also got the information that the stage-discharge relationship for subcatchments 7 and 8 is highly uncertain and prone to strong overestimation in one case and underestimation in the other case.

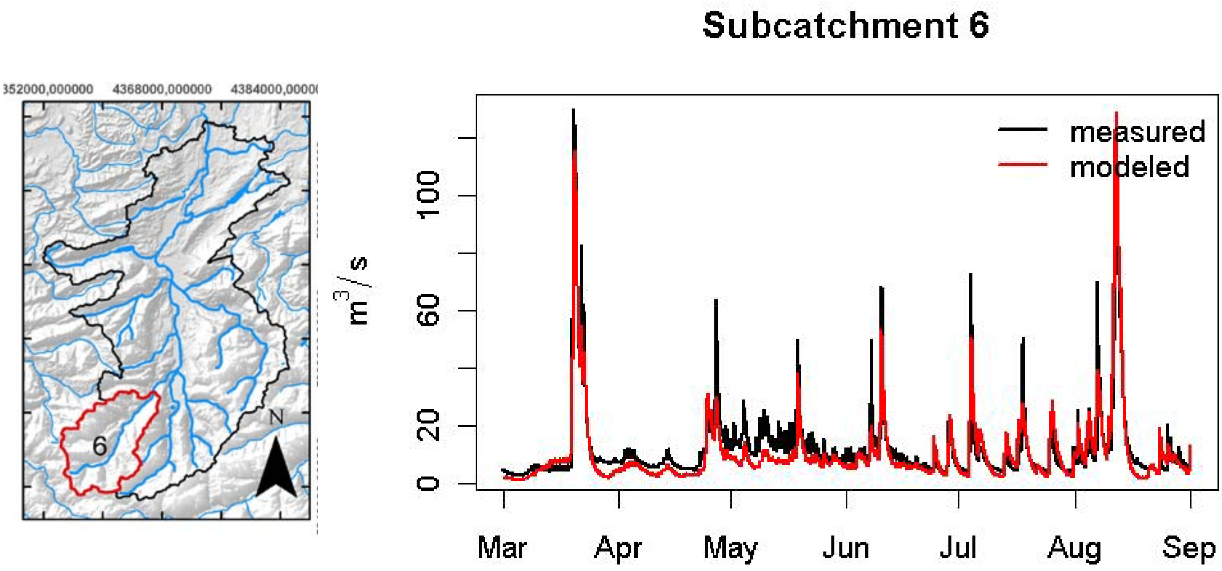


Figure 6-6 . Simulation results for subcatchment 6.

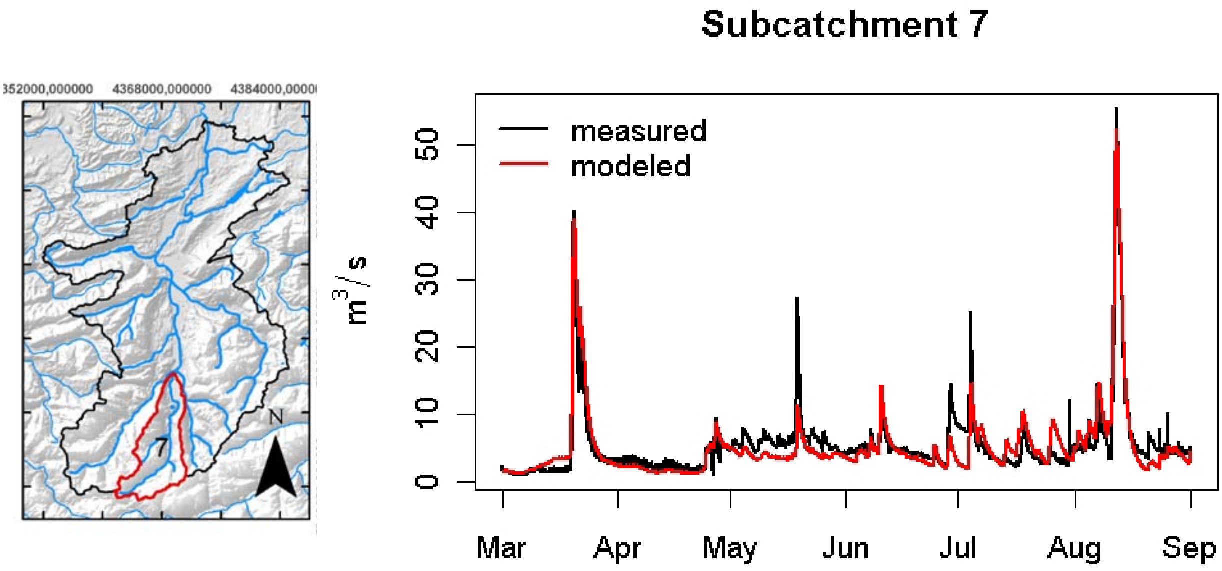


Figure 6-7 . Simulation results for subcatchment 7.

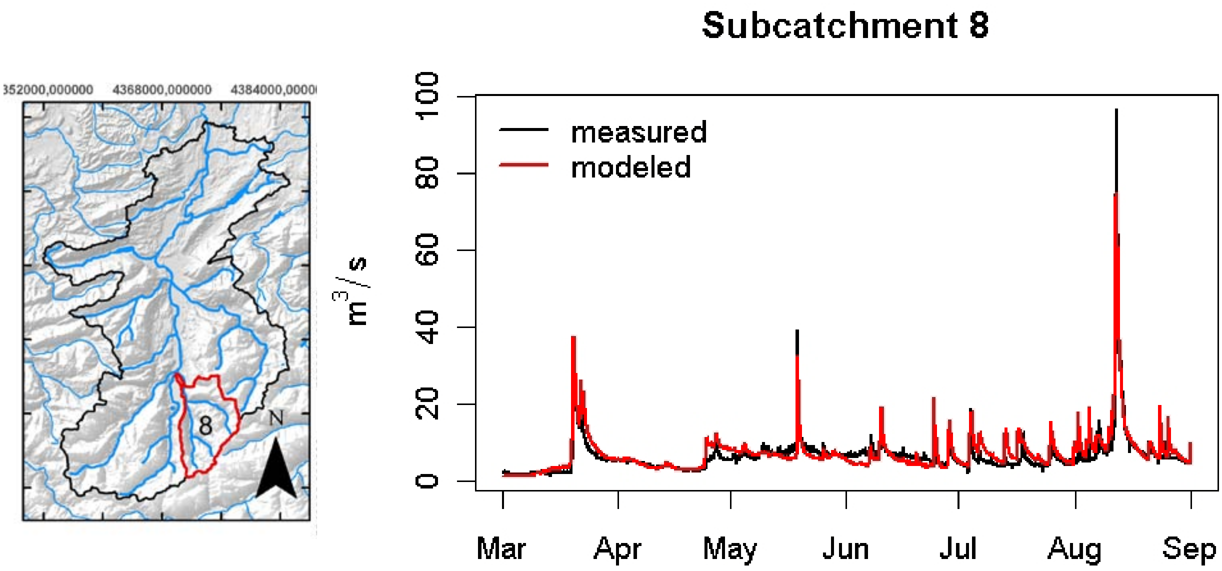


Figure 6-8 . Simulation results for subcatchment 8.

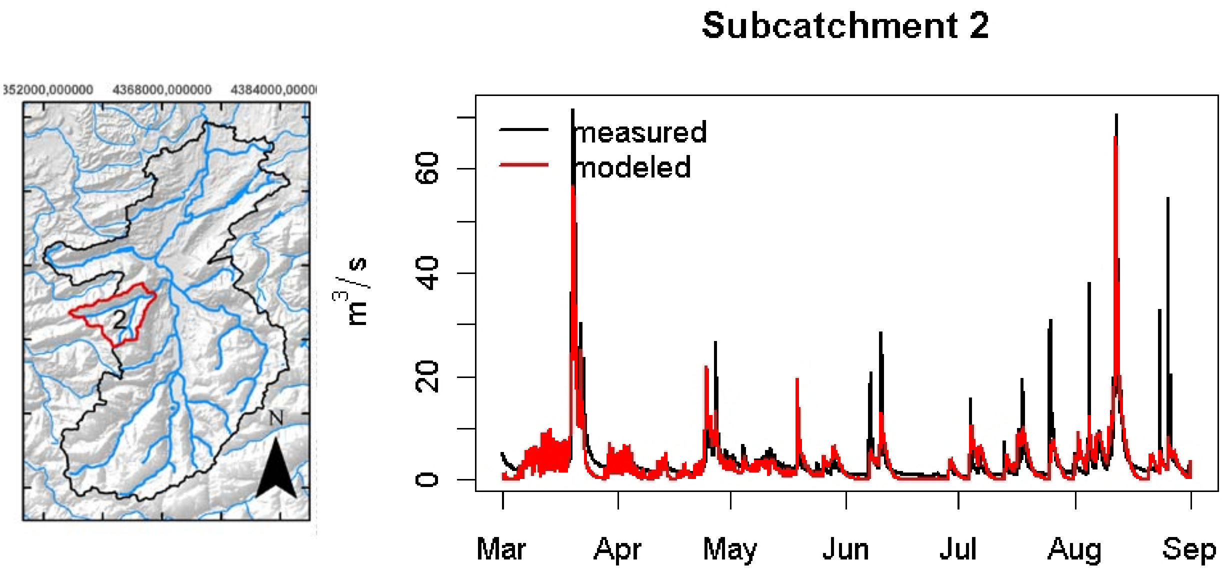


Figure 6-9 . Simulation results for subcatchment 2.

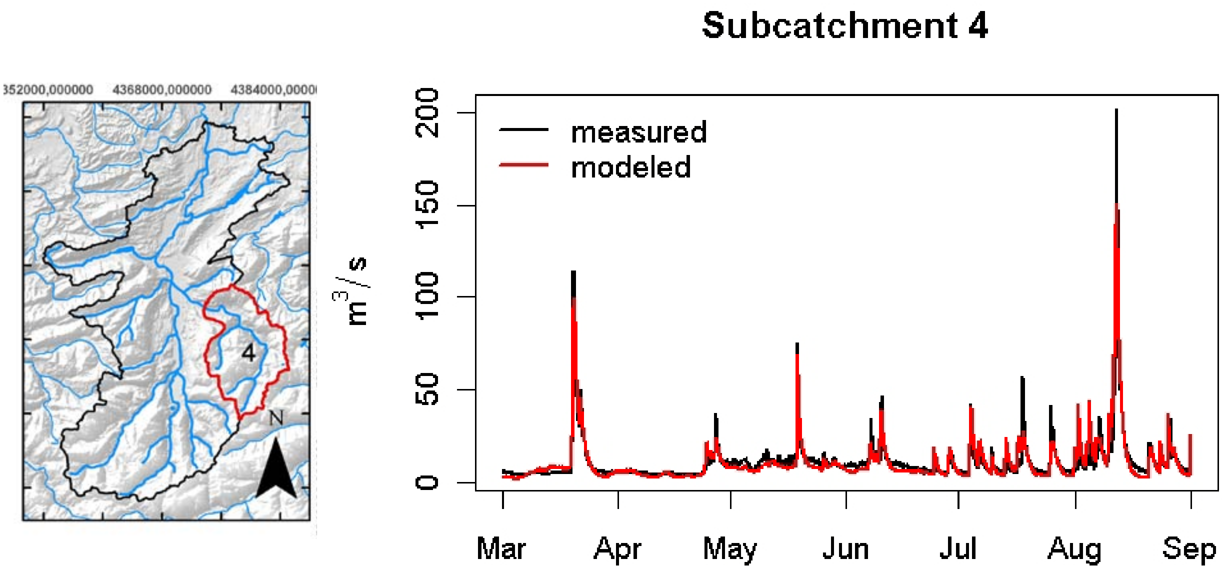


Figure 6-10 . Simulation results for subcatchment 4.

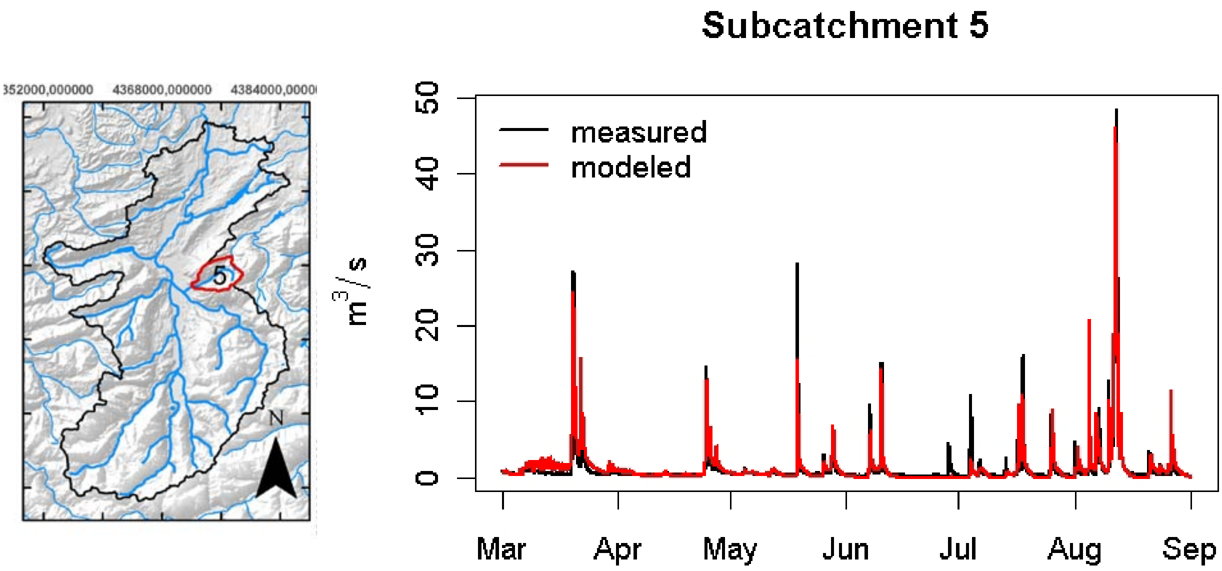


Figure 6-11 . Simulation results for subcatchment 5.

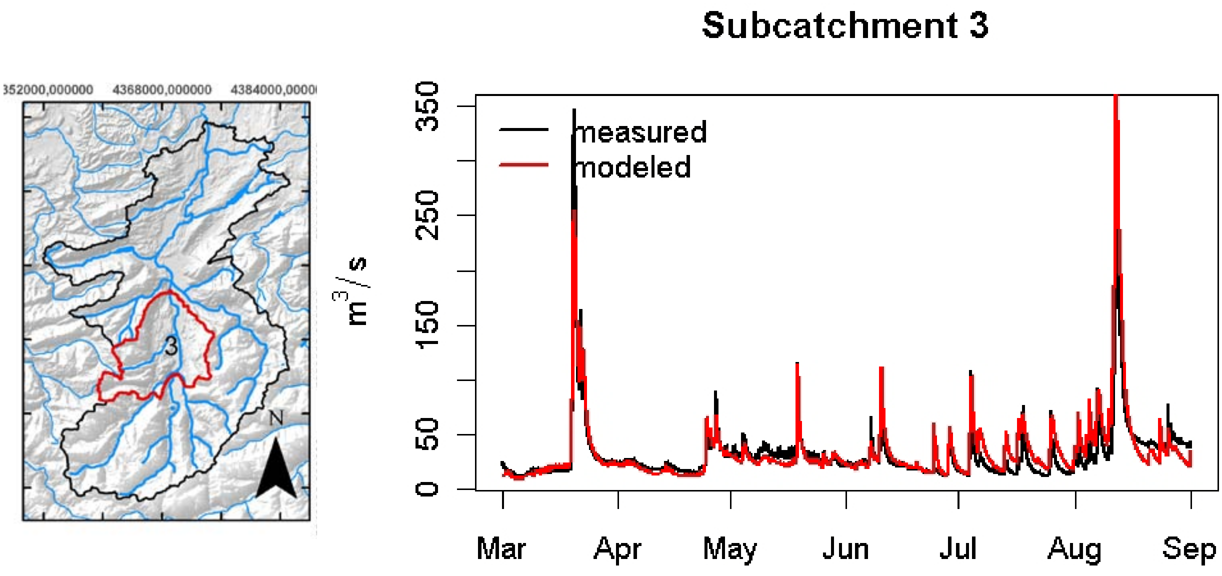


Figure 6-12 . Simulation results for subcatchment 3.

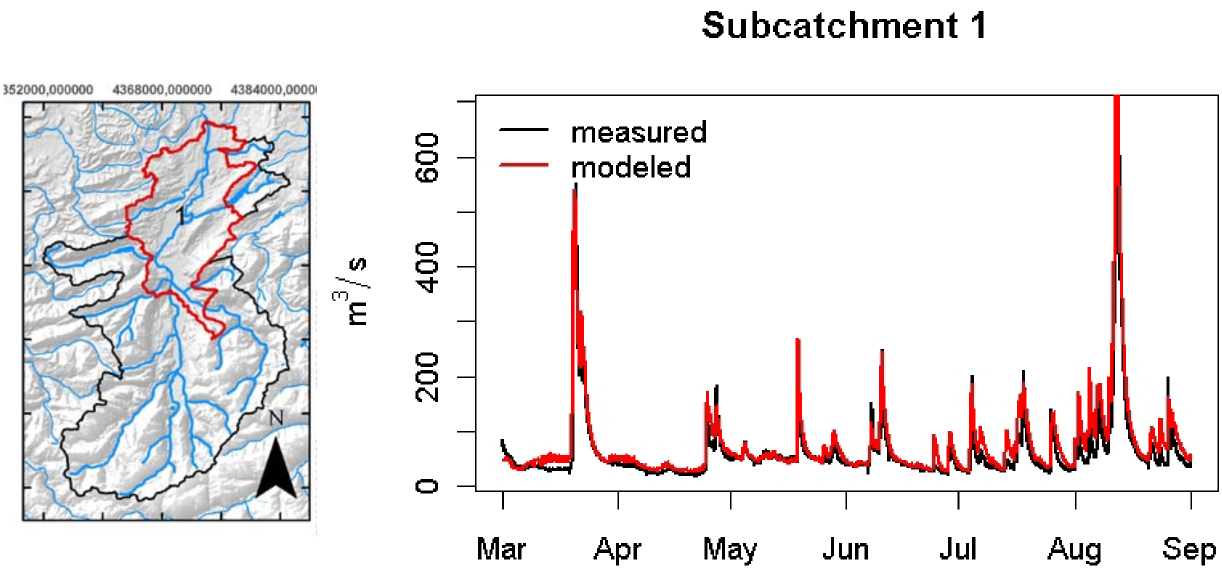


Figure 6-13 . Simulation results for subcatchment 1.

Subcatchments 2, 4 and 5 are headwater catchments located at slightly lower elevations than 6, 7 and 8, where subcatchment 2 proved to be the most difficult to calibrate.
Subcatchments 3 and 1 (Figure 6-12 and Figure 6-13) are not headwater catchments, thus receiving input from the upstream subcatchments. For the calibration measured discharges are

routed into these basins while for the here shown modelling results the simulated discharges from the upper catchments are used.

Table 6-3 *shows summarises the model performance for each of the subcatchments. Both, information on the water balance as well as the Nash-Sutcliffe model efficiency are given. The water balance is generally reproduced quite well over the entire simulation period (March-August 2002), with deviances of less than 10% in most cases. Runoff coefficients of > 1 are possible as a result of snow storage effects. Nash-Sutcliffe efficiencies lie between 0.78 and 0.86, which is quite high given the above described difficulties with the input data as well as streamflow data.*

Table 6-3*. Simulation results for WASIM-ETH for each of the subcatchments. Subcatchments 1 and 3 also include input from upstream catchment simulation.*

Subcatchment	***Runoff coeff. measured***	***Runoff coeff. modelled***	***Nash-Sutcliffe-Efficiency***
1	*0.61*	*0.75*	*0.81*
2	*0.97*	*0.90*	*0.79*
3	*0.70*	*0.76*	*0.78*
4	*1.00*	*0.96*	*0.87*
5	*0.68*	*0.76*	*0.86*
6	*0.70*	*0.76*	*0.86*
7	*0.98*	*0.94*	*0.81*
8	*0.97*	*1.08*	*0.80*

***Flow components**:*

As WASIM-ETH is a process-based model it allows you to look at the different components of flow, such as base flow, interflow, and direct flow. However the calibration process seems to enforce direct flow as the most important flow component, because this usually produces best values of RMSE and also of the Nash-Sutcliffe Efficiency. In these cases base flow is often 0 or almost 0 and shows no dynamics at all. As this is not satisfactorily according to our understanding of the processes in this catchment, we used a composite objective function putting emphasis on a plausible base flow production. This was successful in some cases, eg. subcatchments 7 (Figure 6-7), 3 (Figure 6-20) and 1 (Figure 6-21). However for all other subcatchments streamflow could only be reproduced reasonably well with quite low base flow as well as low base flow dynamics. The flow components over time are shown for each of the subcatchments in Figure 6-14 to Figure 6-21.

In most cases were base flow is only produced at a very low level, interflow takes over in providing stream flow during periods between rainfall events. Surprising is the case of subcatchment 2 (*Figure 6-17*), where most of the event dynamics are produced by interflow instead of direct flow. Only during the snow melt period as well as during larger rainfall events do we have a pronounced and strong response in direct flow.

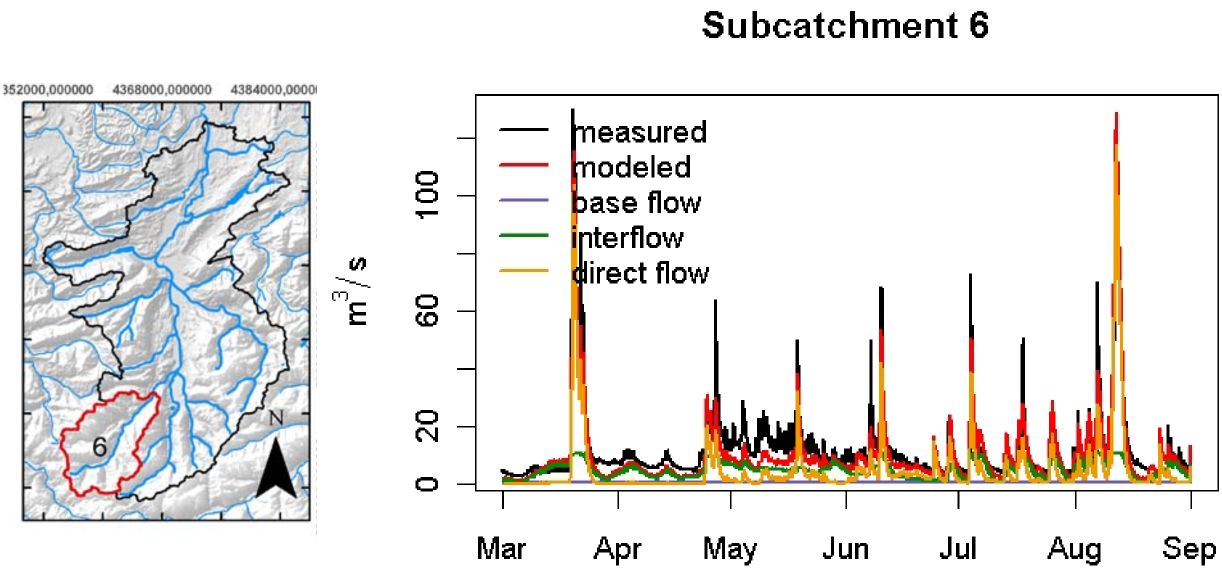


Figure 6-14 . Flow components for subcatchment 6.

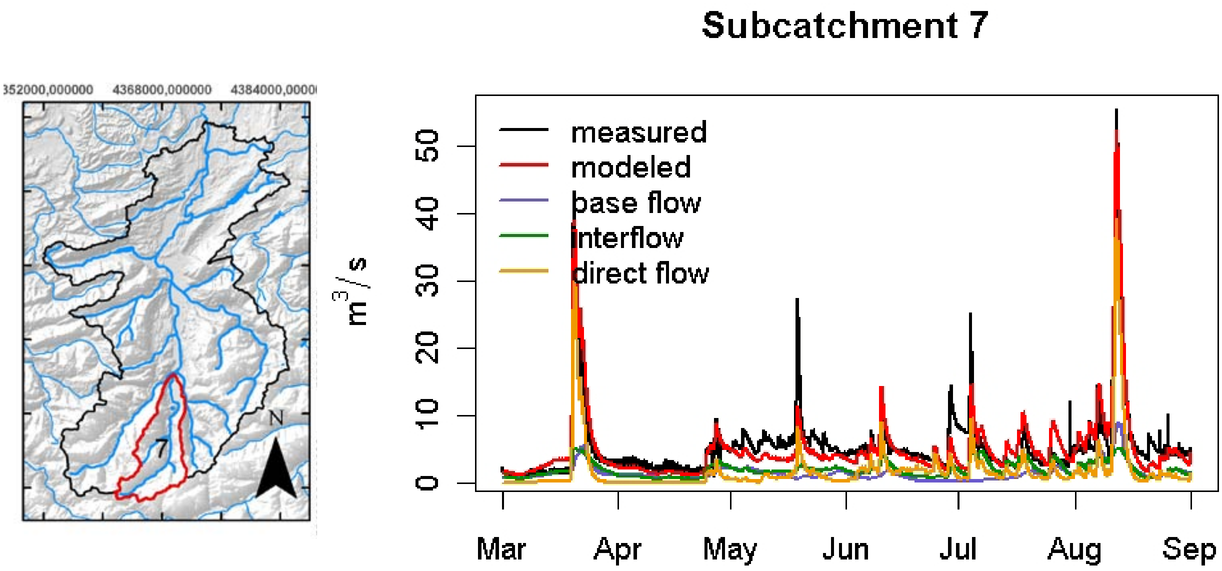


Figure 6-15 . Flow components for subcatchment 7.

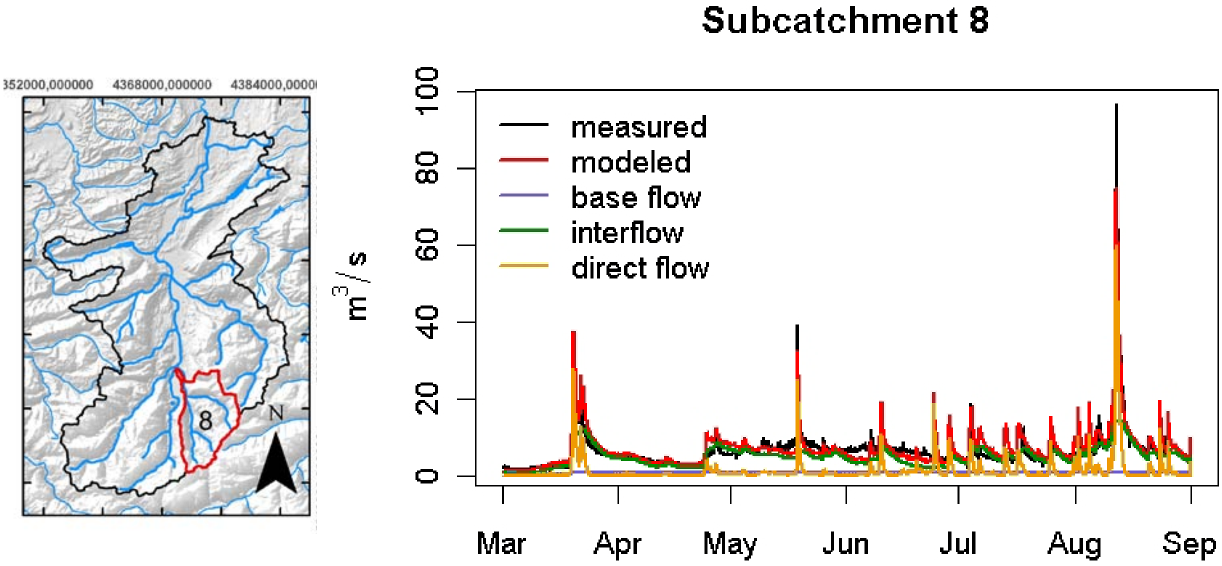


Figure 6-16 . Flow components for subcatchment 8.

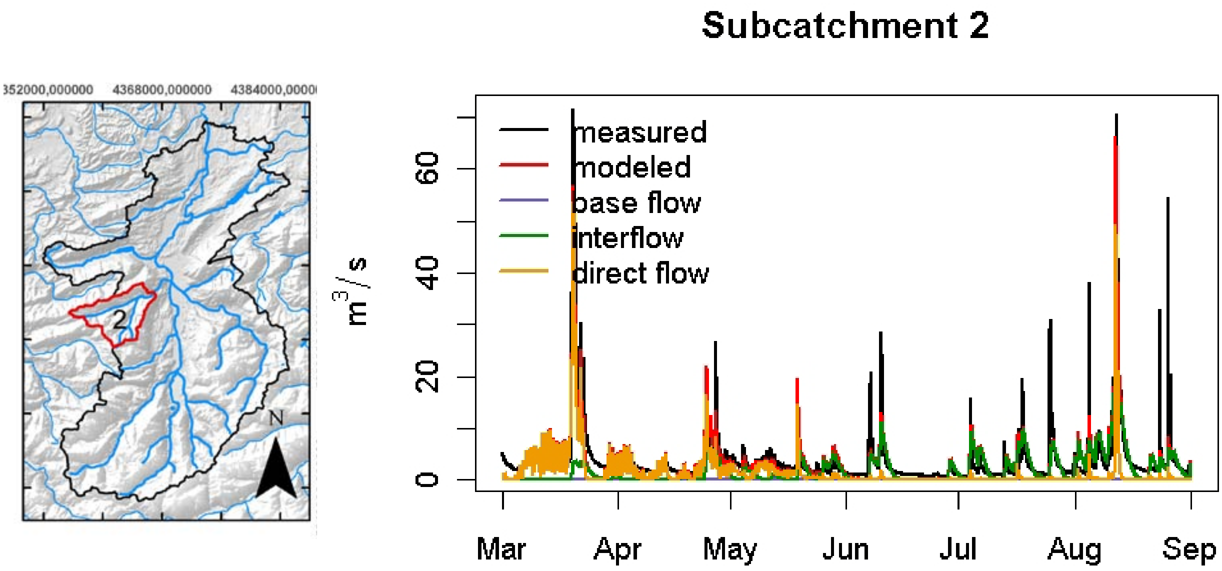


Figure 6-17 . Flow components for subcatchment 2.

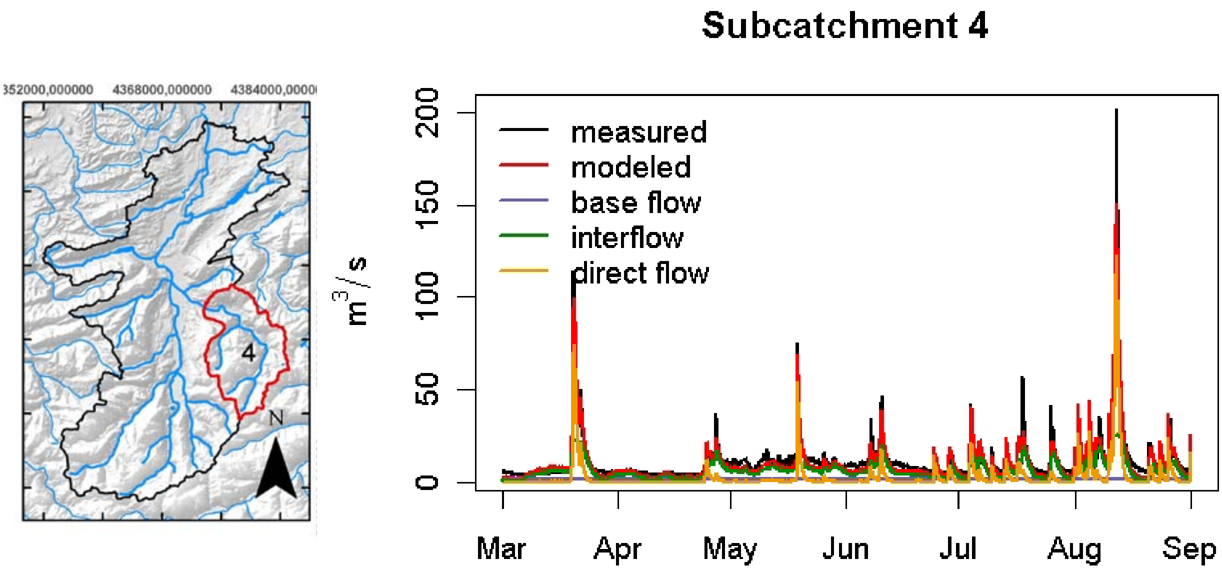


Figure 6-18 . Flow components for subcatchment 4.

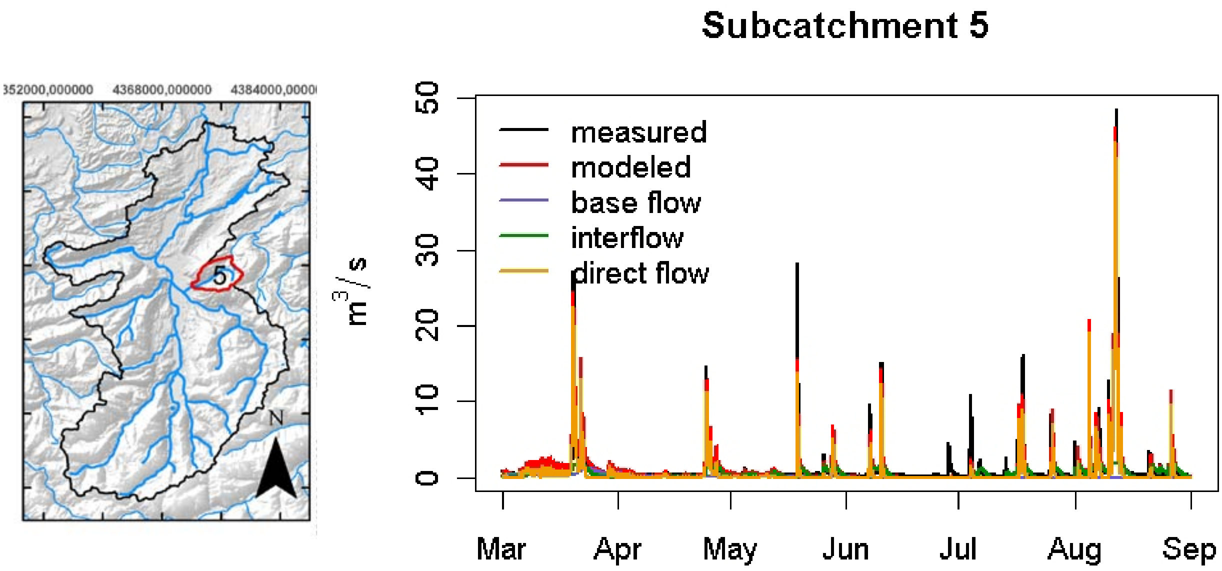


Figure 6-19 . Flow components for subcatchment 5.

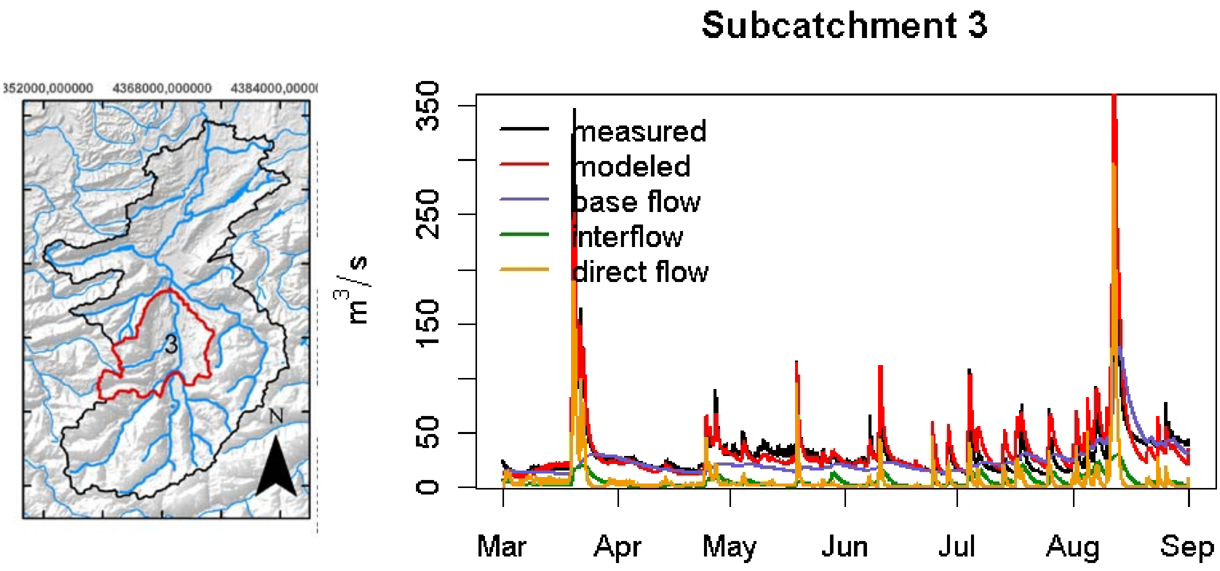


Figure 6-20 . Flow components for subcatchment 3.

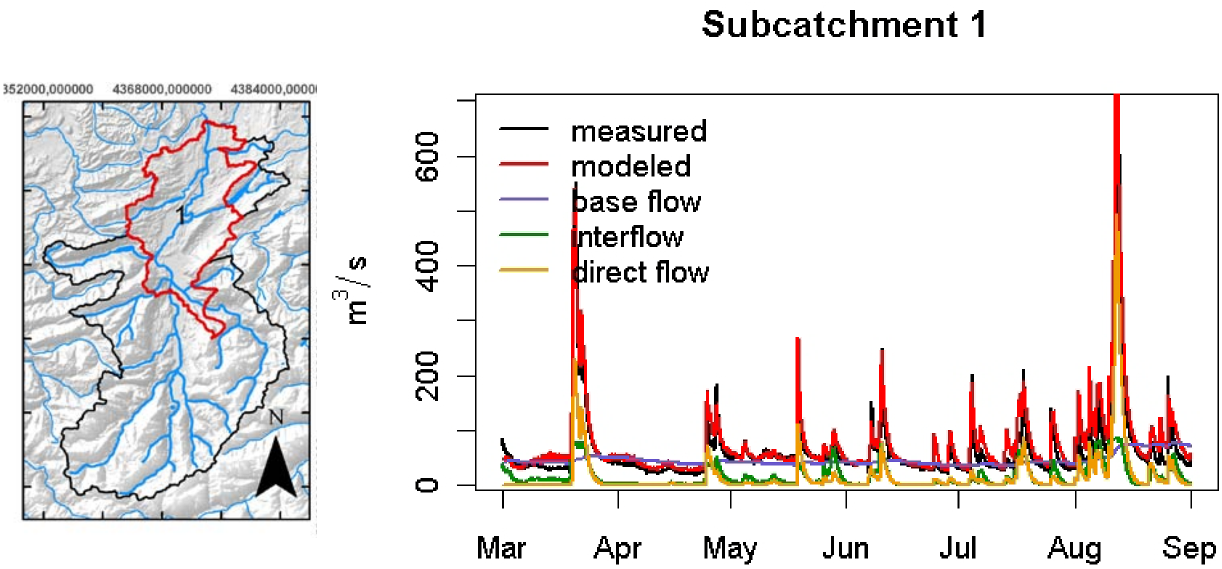


Figure 6-21 . Flow components for subcatchment 1.

6.2 Model validation (WASIM-ETH)

Model validation was carried out for the time period March-August 2005, with an initial pre-run phase from March 2004 to March 2005. As the discharge time series of most gauging stations have one or more gaps of at least several months, validation was only carried out exemplarily for one of the subcatchments, subcatchment 4. The simulated and measured time series are shown in Figure 5-30. The fit of simulated and measured time series for the validation period is surprisingly good, with a Nash-Sutcliffe efficiency of 0.86.

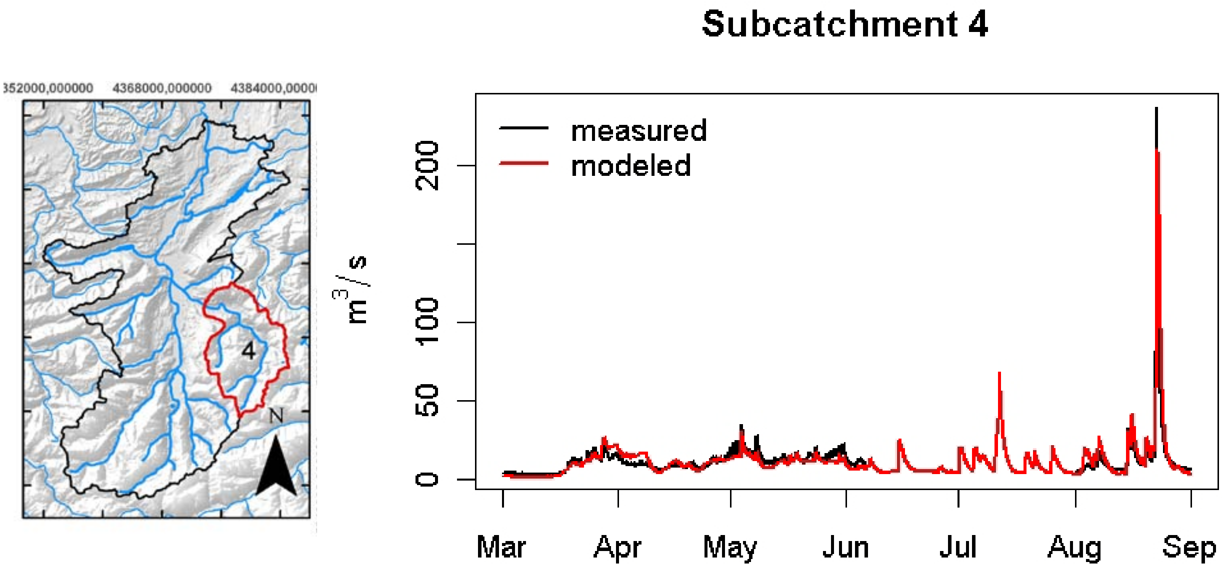


Figure 6-22 . Validation results for subcatchment 4.

7 Catchment scenario simulations

To analyse the efficiency of flood retention measures in the landscape a number of different scenario simulations were run for the Upper Iller catchment. These scenarios include both, scenarios of land use change as well as scenarios of small local retention measures (microponds and small retention reservoirs).

7.1 Forestation scenarios

The scenarios for the increase in forested area were generated in the following way:

1) *only pastures/meadows below the tree line were considered as potential areas for forestation*
2) *as the subcatchments of the Upper Iller are characterised by a steep topography and the more level pieces of land are the most valuable to the farmers, only pastures/meadows with a gradient of more than 5% were chosen as potential forestation areas*
3) *furthermore, only plots of at least 5000 m² were considered for forestation*

The resulting increase in forested area for each of the subcatchments is shown in Figure 7-1 and Table 7-1.

Table 7-1. *Forestation scenario: increase in forested area for each of the subcatchments.*

subcatchment	ID	area [km²]	mean elevation [m]	forested area [km²]	forested area [%]	scenario: forested area [km²]	scenario: forested area [%]	increase forested area [km²]	relative increase forest
Kempten	1	246	827	46.2	18.8%	136.1	55.3%	89.9	2.9
Gunzesrieder Ach	2	46	1277	20.9	45.1%	39.2	84.5%	18.3	1.9
Sonthofner Iller	3	131	1062	56.9	43.8%	102.4	78.9%	45.5	1.8
Ostrach	4	127	1432	35.9	28.3%	78.1	61.5%	42.2	2.2
Burgberger Starzlach	5	20	1180	15.5	78.0%	19.3	97.3%	3.8	1.2
Breitach	6	117	1521	54.0	46.2%	86.2	73.7%	32.2	1.6
Stillach	7	81	1473	20.3	25.0%	41.2	50.8%	20.9	2.0
Trettach	8	74	1543	12.5	16.8%	37.3	50.0%	24.8	3.0
entire catchment	/	954		304.7	31.9%	582.2	61.0%	277.6	1.9

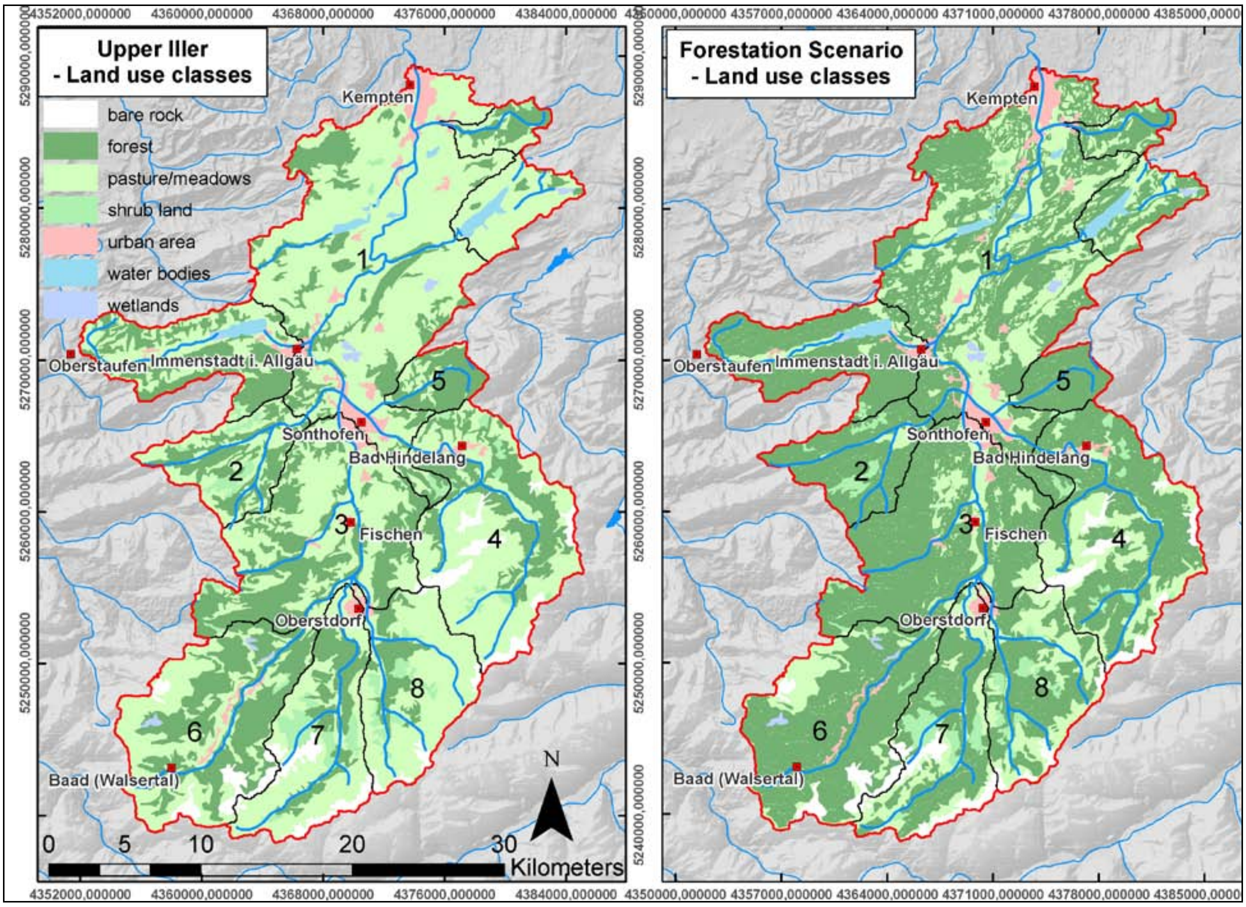


Figure 7-1 . Forestation scenario: increase in forested area for the Upper Iller catchment.

An increase in forested area directly effects interception, evaporation and transpiration via the plant parameters, LAI (leaf area index), root depth, canopy resistance to wind, and albedo. Furthermore, it is assumed that in the long term, a change in soil properties will also result forestation. This in incorporated in the simulation as an increase in soil storage capacity by 2 Vol. %. The value of 2 Vol. % was chosen in order to make the results of the Upper Iller case study comparable to those of the Kamp case study.

As a result two forestation scenarios were generated for each of the 8 subcatchment

1) *increase in forested area following the criteria described above*
2) *increase in soil storage capacity by 2 Vol.% for newly forested areas.*

7.2 Microponds

For purposes of comparison, a scenario using micropondes similar to those in the Kamp case study was generated: Small retention hollows (~10-100 m³) are proposed for keeping the water in the landscape. An average potential storage capacity of 1.2 mm is assumed (as has also been done in the Kamp study). This scenario is incorporated in the model as follows: the potential of the surface retention is increased by 1.2 mm. This storage can only be filled by infiltration or saturation excess. Once neither saturation excess nor infiltration access are generated any longer (e.g. after the rainfall event or at lesser rainfall intensities) the storage is emptied by infiltration. However, as these water filled hollows are likely to cause sedimentation of fines on the soil surface not the soil characteristic hydraulic conductivity is assumed for infiltration from these hollows but a strongly reduced conductivity, in our case $1*10^{-8}$ m/s.

7.3 Micro-reservoirs

In a next step a scenario of slightly more sophisticated micro-reservoirs is generated. The potential location and volume of these reservoirs has been determined in during a field campaign in May 2007.
These reservoirs are based on the local microtopography and are thought to be restricted by a small dam with a culvert. These micro-reservoirs are defined by their catchment size, a constant outflow and a fixed volume. Only a fraction of direct flow is routed into these reservoirs. This fraction is defined by the ratio of catchment size of the reservoir over the size of the subcatchment. The catchment of the reservoir is determined with the help of a GIS analysis of the digital elevation model given the location of the reservoir. If the so defined fraction of direct flow exceeds the value of constant outflow the reservoir starts to fill up. It will empty with the given outflow rate. If the reservoir is filled it will flow over and the outflow is the sum of the spillage and the constant outflow rate. Volume and location of the simulated micro-reservoirs is given in FIGURe. However, these micro-reservoirs are modelled on subcatchment basis, i.e. the volume of reservoirs over the subcatchment is accumulated and modelled as a single storage. Similarly the cumulated catchment size of all micro-reservoirs in a subcatchment is used to define the fraction of direct flow that is routed into the reservoir. Summed up over the entire catchment we obtain a retention volume of 452 000 m² and a cumulated reservoir catchment area of 90.3 km². This volume is small compared to the polder which was built north of Immenstadt with a volume of 6 800 000 m² (construction started 2001 and will be completed in 2009).

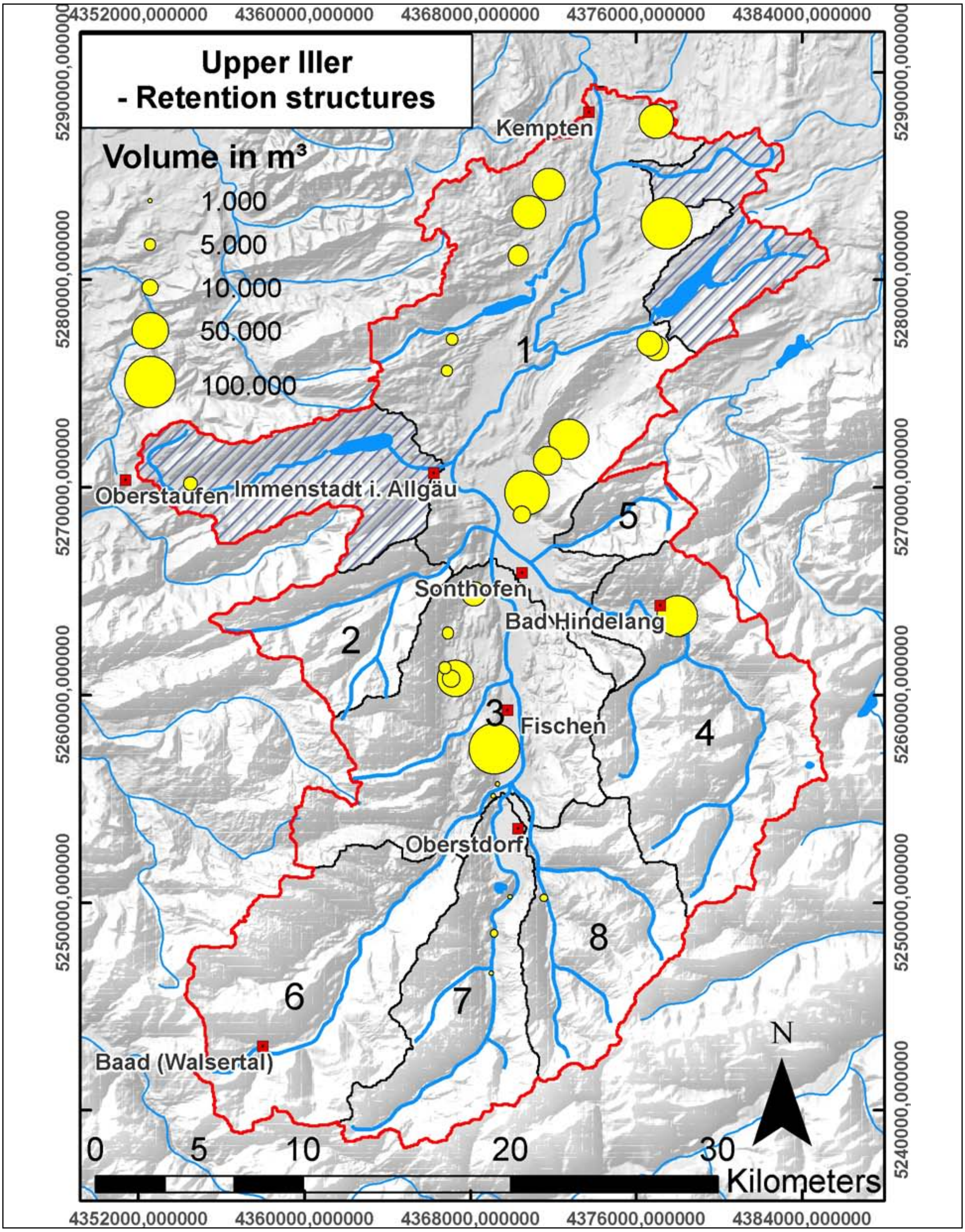


Figure 7-2 . Microreservoirs: scenario for the Upper Iller catchment (the two largest reservoirs in subcatchment 1 and 3 are already existing structures and are thus not incorporated into the modelled scenario).

8 Hydraulic Modelling

The „Institut für Hydrotechnik“ was commissioned by the local water authorities (Wasserwirtschaftsamt Kempten) to carry out hydraulic modelling study for the Upper Iller Catchment. In this study special emphasis was put on the simulation of the newly constructed polders north of Immenstadt with a retention volume of 6 800 000 m³ and other smaller retention measures as well as the construction of dams upstream. The basis for this simulation are profiles perpendicular to the river at 200 m intervals. For the simulation the hydraulic model FLOODSIM was used, which was developed at the "Universität der Bundeswehr", Munich. The model was calibrated with the flood event in May 1999.
For this study discharge reduction at gauging station Au (just downstream of Kempten) was determined and is shown in Table 9-3 *(from HWS-Konzept Iller Nord,2004, p.153). As the polder only is activated during extreme events, considerable peak reduction is only achieved for flows > HQ 100.*

9 Results

9.1 Scenario Simulations

The following scenarios were used for simulation in the Upper Iller catchment:

1) *forestation*
2) *forestation and resulting increased soil storage*
3) *microponds*
4) *a combination of forestation, increased soil storage and microponds*
5) *micro reservoirs*

The scenarios were simulated for the period March 2002 to August 2002.

Scenario results are shown exemplarily for one headwater catchment (subcatchment 4) and for the entire basin.

Scenario simulations for subcatchment 4:
It was found that while the scenarios had some effect for small and medium size events in subcatchment 4, there was very little effect for the largest event (Figure 9-1-Figure 9-3). This can also be seen in Table 9-1.

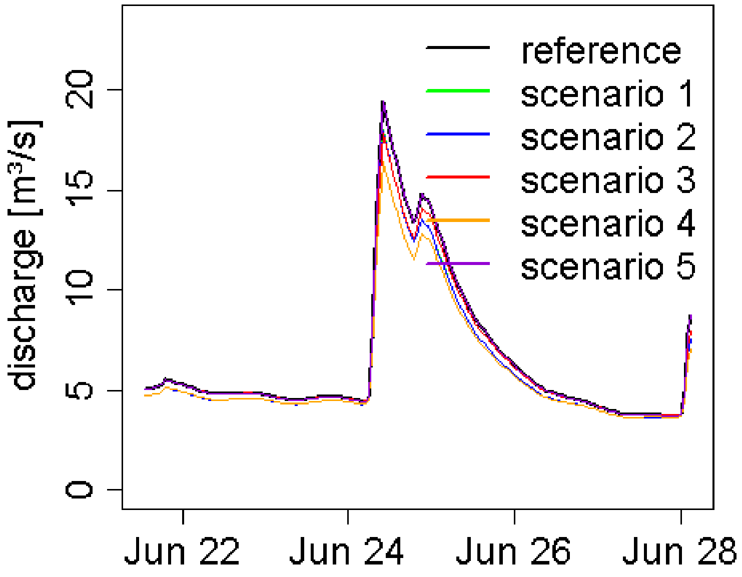


Figure 9-1 . Small event – Simulations runs for all scenarios – subcatchment 4.

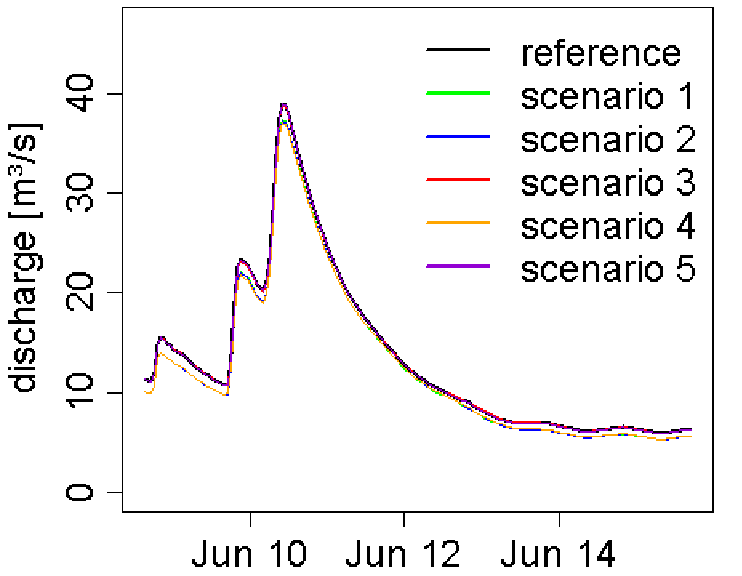


Figure 9-2 . Medium size event – Simulations runs for all scenarios – subcatchment 4.

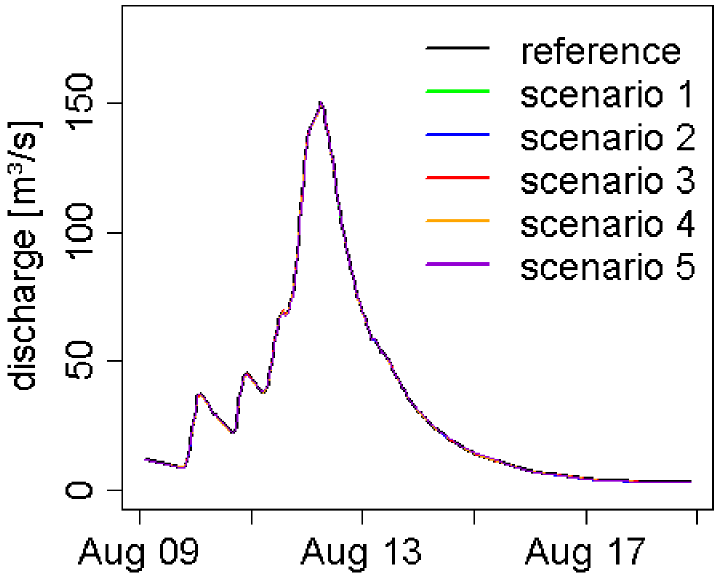


Figure 9-3 . Large event – Simulations runs for all scenarios – subcatchment 4.

Table 9-1. ***Simulation results for all scenarios for three selected events (subcatchment 4).***

Subcatchment 4 (Reckenberg-Ostrach)			
Area	*127.113*	*km²*	
	large event	*medium event*	*small event*
3 single events:	*11.08.2002*	*11.06.2002*	*24.06.2002*
antec.Precip (5days)	*120.85*	*64.2*	*10.9*
Precip	*217.4*	*49.4*	*53.4*
event volume			
ref	*216.44*	*64.79*	*29.43*
Scenario 1 (sum - mm)	*215.53*	*60.97*	*27.52*
Scenario 2 (sum - mm)	*215.57*	*60.96*	*27.51*
Scenario 3 (sum - mm)	*216.8*	*64.86*	*28.72*
Scenario 4 (sum - mm)	*215.9*	*60.98*	*26.8*
Scenario 5 (sum - mm)	*216.42*	*64.78*	*29.42*
ref (sum m³)	*2.75E+07*	*8.24E+06*	*3.74E+06*
Scenario 1 (sum m³)	*2.74E+07*	*7.75E+06*	*3.50E+06*
Scenario 2 (sum m³)	*2.74E+07*	*7.75E+06*	*3.50E+06*
Scenario 3 (sum m³)	*2.76E+07*	*8.24E+06*	*3.65E+06*
Scenario 4 (sum m³)	*2.74E+07*	*7.75E+06*	*3.41E+06*
Scenario 5 (sum m³)	*2.75E+07*	*8.24E+06*	*3.74E+06*
reduction in volume over entire event			
Scenario 1 (reduction-m³)	*1.16E+05*	*4.86E+05*	*2.43E+05*

Scenario 2 (reduction-m³)	*1.11E+05*	*4.87E+05*	*2.44E+05*
Scenario 3 (reduction-m³)	*-4.58E+04*	*-8.90E+03*	*9.03E+04*
Scenario 4 (reduction-m³)	*6.86E+04*	*4.84E+05*	*3.34E+05*
Scenario 5 (reduction-m³)	*2.48E+03*	*1.48E+03*	*1.00E+03*
reduction in volume over entire event (%)			
Scenario 1	*0.42%*	*5.90%*	*6.49%*
Scenario 2	*0.40%*	*6.28%*	*6.98%*
Scenario 3	*-0.17%*	*-0.11%*	*2.58%*
Scenario 4	*0.25%*	*5.87%*	*9.16%*
Scenario 5	*0.01%*	*0.02%*	*0.03%*
peak flow in mm/h			
ref	*4.253*	*1.102*	*0.551*
Scenario 1	*4.241*	*1.058*	*0.510*
Scenario 2	*4.243*	*1.054*	*0.509*
Scenario 3	*4.254*	*1.097*	*0.507*
Scenario 4	*4.244*	*1.048*	*0.465*
Scenario 5	*4.253*	*1.102*	*0.551*
peak reduction in percent			
Scenario 1	*0.27*	*4.02*	*7.42*
Scenario 2	*0.24*	*4.31*	*7.62*
Scenario 3	*-0.03*	*0.42*	*7.97*
Scenario 4	*0.20*	*4.84*	*15.63*
Scenario 5	*0.00*	*0.03*	*0.01*

In order to study the peak reduction a little more closely, the same three events were plotted with event discharge in black (left y-axis) and the discharge reduction in m^3/s for all scenarios on the right (blue) y-axis. It was found that the forestation scenarios (scenarios 1 and 2) already reduced flow before the start of the event, the micropond scenario only became effective with the onset of rainfall. In case of the small event the micro-reservoirs did not have any noticeable effect, as flow remained below the constant flow outflow of the reservoirs almost for the entire period (Figure 9-4). This was also the case for the medium size event (Figure 9-5). In this case you can also see the effect of delayed infiltration from the microponds as discharge reduction for this scenario (scenario 3) becomes negative and is thus increasing discharge at late times. For the large event (Figure 9-6), we can also see the effect of the micro-reservoirs, which are filled entirely before the peak of this event is reached and thus become ineffective for peak discharge. At late times we also see the discharge phase and the resulting negative flow reduction.

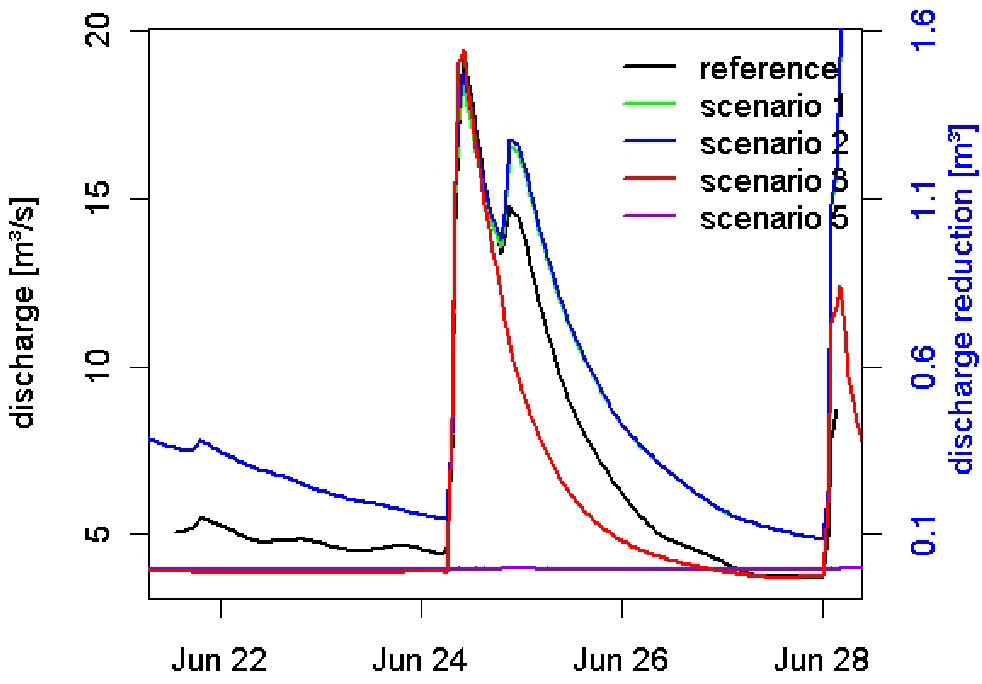


Figure 9-4 . Small event – discharge reduction for all scenarios – subcatchment 4.

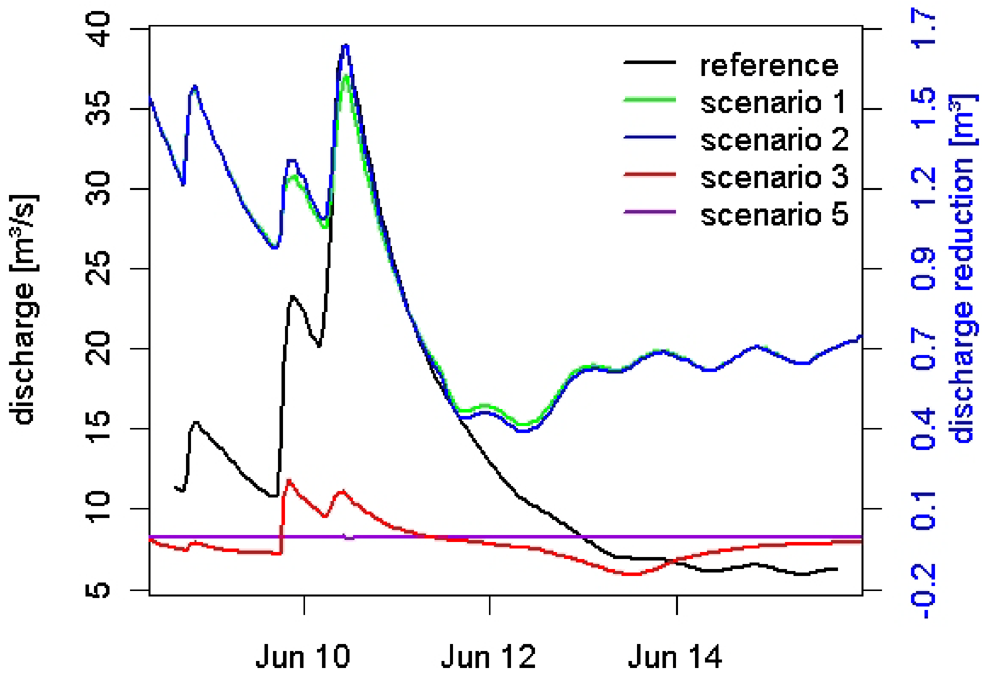


Figure 9-5 . Medium size event – discharge reduction for all scenarios – subcatchment 4.

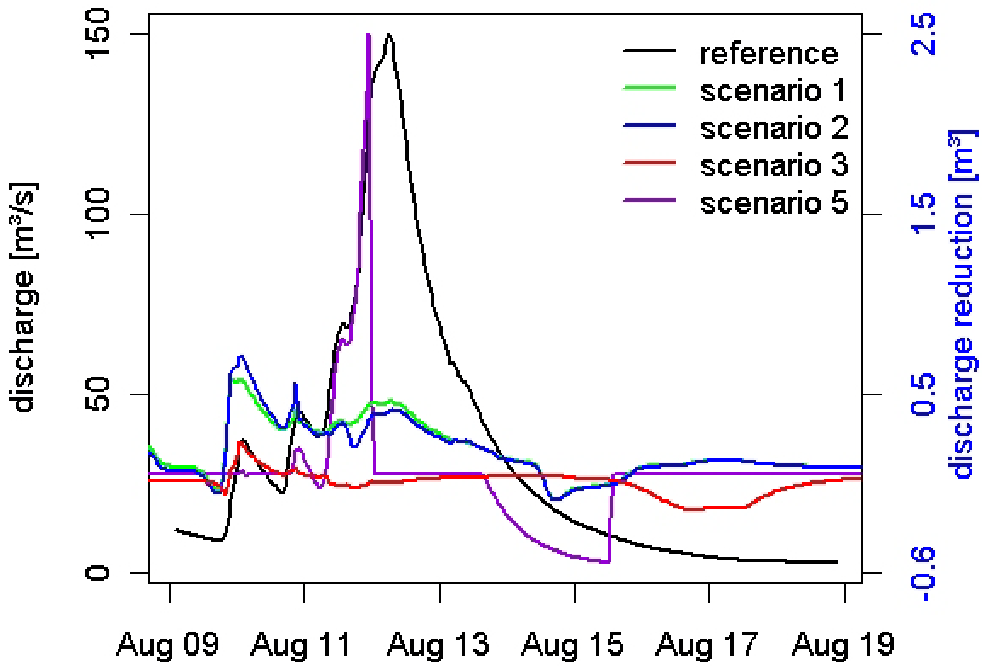


Figure 9-6 . Large event – discharge reduction for all scenarios – subcatchment 4.

Scenario simulations for the entire basin:
*Similar effects as in subcatchment 4, but on a larger scale were found for the entire basin of the Upper Iller. Again we see the largest relative reduction for the smallest event, which is also the event were the effect of the microponds is highest (Figure 9-7) However, microponds in his case have an effect on peak flow but not on peak volume (*Table 9-2*). Hardly any effect can be seen for the large event in August 2002 (Figure 9-9).*
Again, the micro-reservoirs only become active for the largest event (Figure 9-12). For this event you can also see quite nicely how the microponds become inefficient as they are already filled during the first small peak and then actually increase flow during the event (Figure 9-12 and Table 9-2*).*

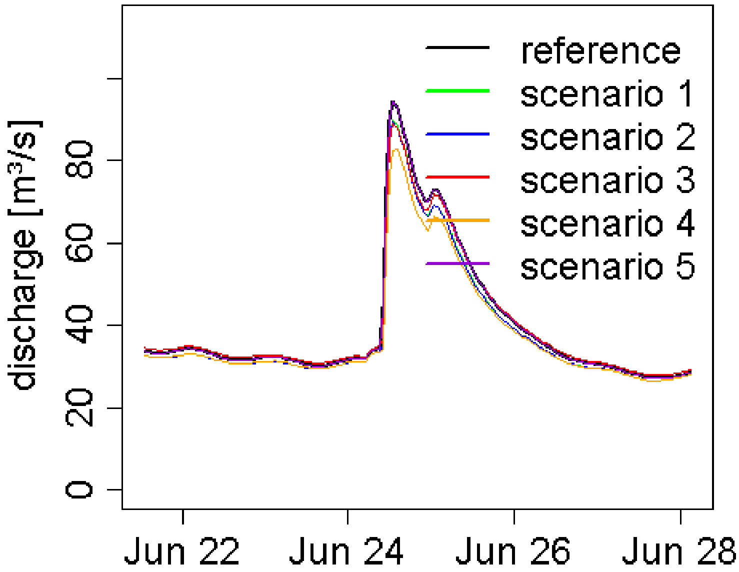


Figure 9-7 . Small event – Simulations runs for all scenarios for the entire basin.

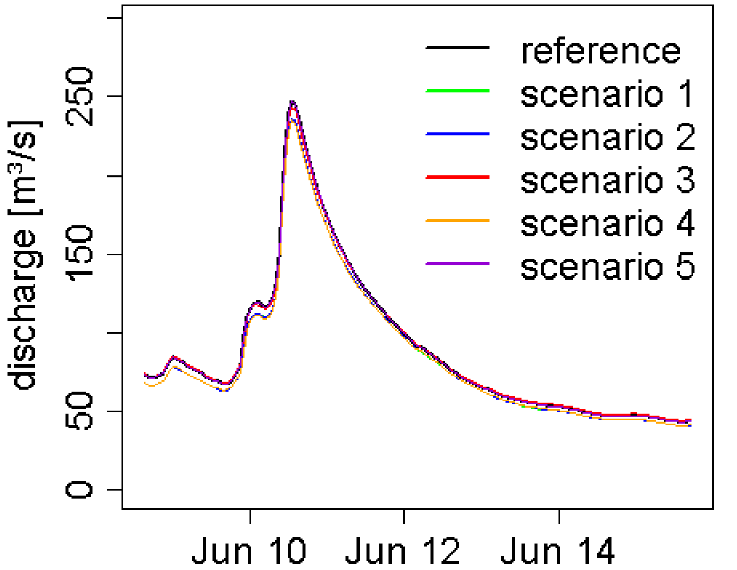


Figure 9-8 . Medium sized event – Simulations runs for all scenarios for the entire basin.

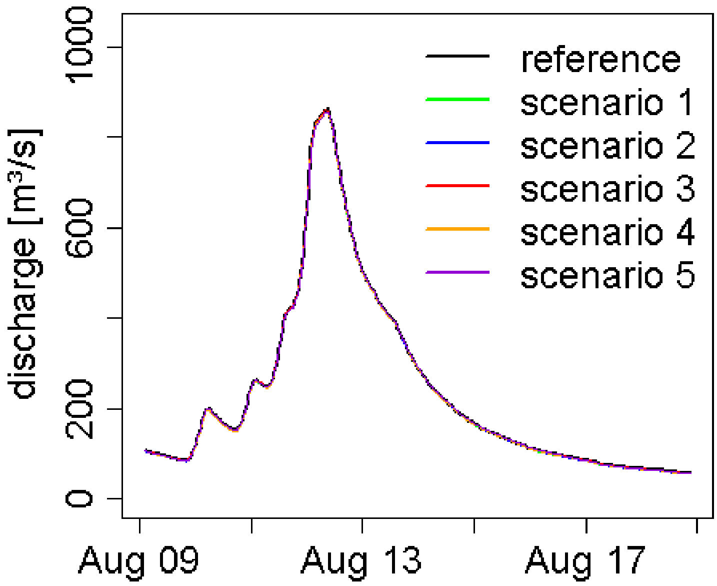


Figure 9-9 . Large event – Simulations runs for all scenarios for the entire basin.

Table 9-2. ***Simulation results for all scenarios for three selected events (entire catchment).***

Subcatchment 1 (Upper Iller - Kempten)			
Area	*954.31*	*km²*	
	large event	*medium event*	*small event*
3 single events:	*11.08.2002*	*11.06.2002*	*24.06.2002*
antec.Precip (5days)	*175.14*	*102.18*	*5.89*
Precip	*253.85*	*64.21*	*55.34*
event volume			
ref	*210.02*	*57.51*	*23.74*
Scenario 1 (sum - mm)	*208.22*	*54.90*	*22.86*
Scenario 2 (sum - mm)	*208.33*	*54.91*	*22.83*
Scenario 3 (sum - mm)	*210.29*	*57.71*	*23.78*
Scenario 4 (sum - mm)	*208.51*	*54.83*	*22.43*
Scenario 5 (sum - mm)	*210.02*	*57.51*	*23.74*
ref (sum m³)	*2.00E+08*	*5.49E+07*	*2.27E+07*
Scenario 1 (sum m³)	*1.99E+08*	*5.24E+07*	*2.18E+07*
Scenario 2 (sum m³)	*1.99E+08*	*5.24E+07*	*2.18E+07*
Scenario 3 (sum m³)	*2.01E+08*	*5.51E+07*	*2.27E+07*
Scenario 4 (sum m³)	*1.99E+08*	*5.23E+07*	*2.14E+07*

Scenario 5 (sum m³)	*2.00E+08*	*5.49E+07*	*2.27E+07*
reduction in volume over entire event			
Scenario 1 (reduction-m³)	*1.71E+06*	*2.48E+06*	*8.44E+05*
Scenario 2 (reduction-m³)	*1.60E+06*	*2.47E+06*	*8.76E+05*
Scenario 3 (reduction-m³)	*-2.59E+05*	*-1.94E+05*	*-3.57E+04*
Scenario 4 (reduction-m³)	*1.43E+06*	*2.55E+06*	*1.25E+06*
Scenario 5 (reduction-m³)	*-1.82E+03*	*3.91E+02*	*2.86E+02*
reduction in volume over entire event (%)			
Scenario 1	*0.85%*	*4.52%*	*3.72%*
Scenario 2	*0.81%*	*4.72%*	*4.02%*
Scenario 3	*-0.13%*	*-0.37%*	*-0.16%*
Scenario 4	*0.71%*	*4.63%*	*5.51%*
Scenario 5	*0.00%*	*0.00%*	*0.00%*
peak flow in mm/h			
ref	*3.239*	*0.931*	*0.356*
Scenario 1	*3.220*	*0.892*	*0.339*
Scenario 2	*3.221*	*0.892*	*0.337*
Scenario 3	*3.239*	*0.919*	*0.336*
Scenario 4	*3.220*	*0.886*	*0.313*
Scenario 5	*3.222*	*0.932*	*0.356*
peak reduction in percent			
Scenario 1	*0.59%*	*4.18%*	*4.64%*
Scenario 2	*0.55%*	*4.28%*	*5.14%*
Scenario 3	*0.00%*	*1.28%*	*5.62%*
Scenario 4	*0.58%*	*4.90%*	*12.13%*
Scenario 5	*0.52%*	*-0.06%*	*0.00%*

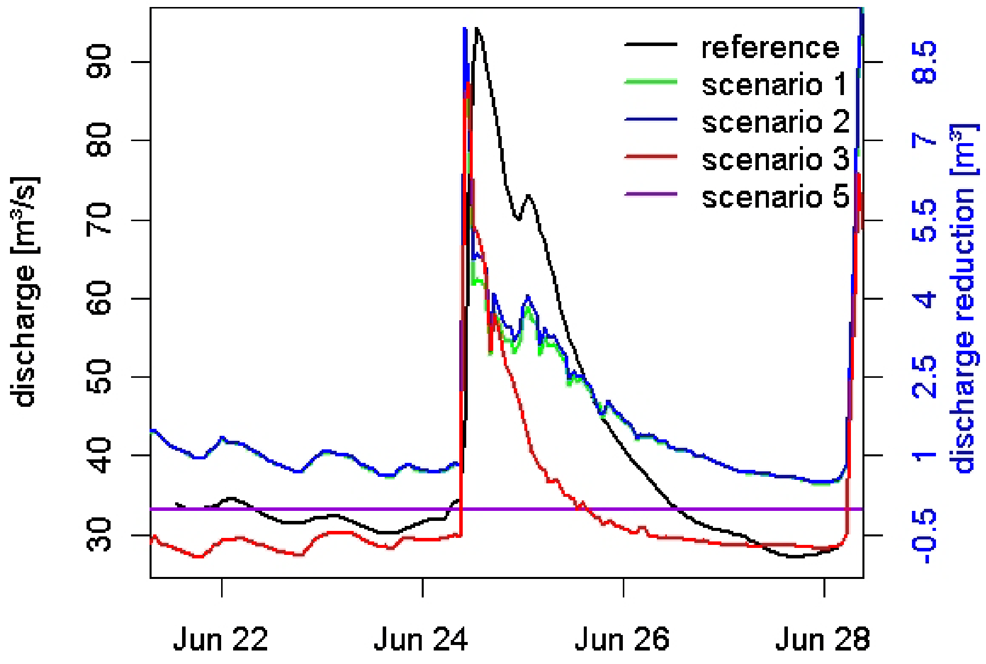


Figure 9-10 . Small event – discharge reduction for all scenarios – entire basin.

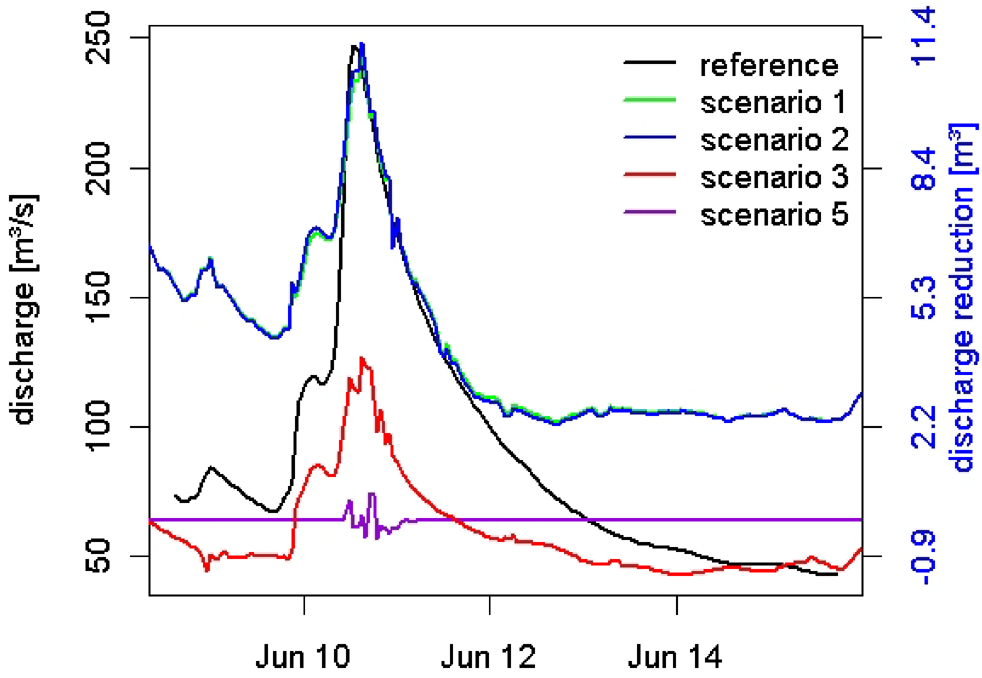


Figure 9-11 . Medium size event – discharge reduction for all scenarios – entire basin.

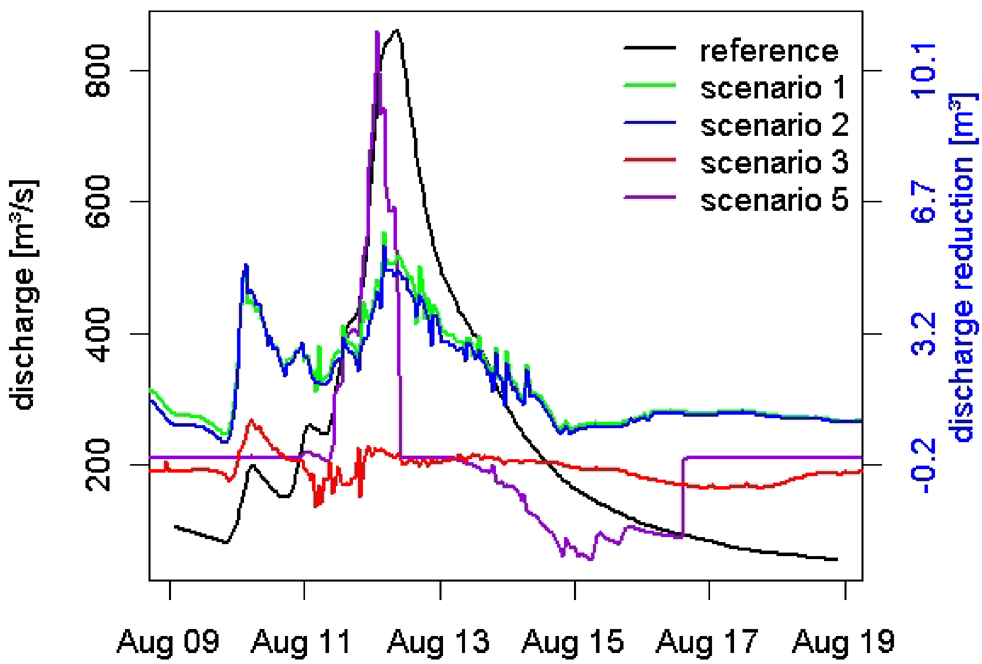
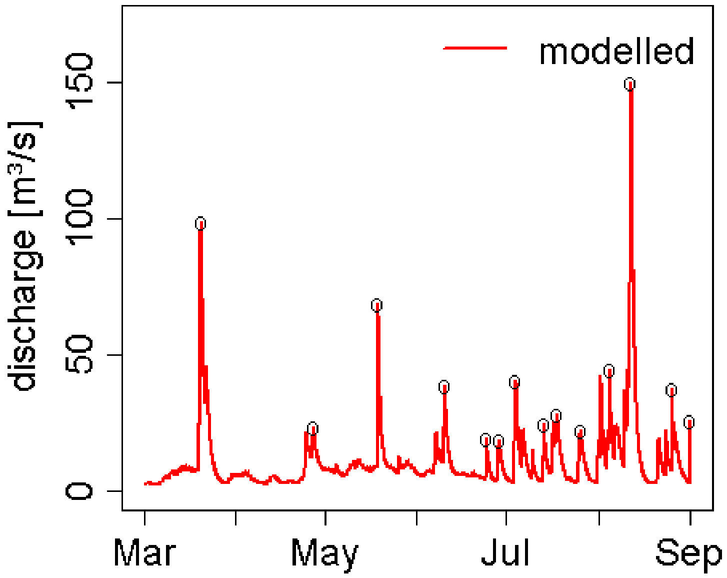


Figure 9-12 . Large event – discharge reduction for all scenarios – entire basin.

Peak discharge versus peak reduction:
Analysis of peak discharges was carried out for 10 automatically identified events for the entire basin and for 14 events for subcatchment 4 (Figure 9-13). Peak discharge versus peak reduction was plotted for both the entire basin and subcatchment 4 in Figure 9-14. Again we find the larger the event, the smaller the effect of the scenarios. We also find a slightly higher effect of scenarios 1, 2, 4 and 5 in the entire basin than in subcatchment 4 for maximum peak discharges. While the forestation scenarios are clearly more efficient than both, microponds and micro-reservoirs for smaller events, this differences diminishes at higher flows.

Peak reduction and antecedent conditions:
The 14/10 events analysed for the peak reduction study were separated into events with wet antecedent conditions (more than 40 mm of rainfall in the 5 days prior to the event) and events with dry antecedent conditions (less than 40 mm of rainfall in the 5 days prior to the event). This separation made it possible to study the effect of antecedent conditions on peak reduction (Figure 9-15 and Figure 9-16). For subcatchment 8 we clearly see that microponds are most effective for dry antecedent conditions. For all other scenarios there is no clear pattern for the headwater catchment. The micro-reservoirs seem to work best for medium sized events and dry antecedent conditions, however this result might also be caused by the small sample size.
For the entire catchment there is a clear pattern for scenarios 1-4: peak reductions are highest for smaller events with dry antecedent conditions. The separation that only smaller events are classified as dryer antecedent conditions for the entire basin is a bit unfortunate as this causes a mixing of effects: event size and antecedent conditions.



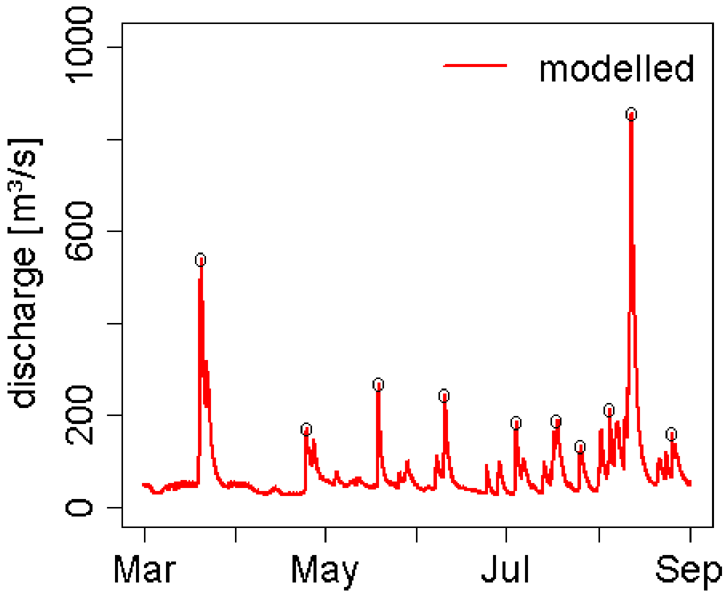


Figure 9-13 . Selected events for subcatchment 4 (upper graph) and the entire basin (lower graph).

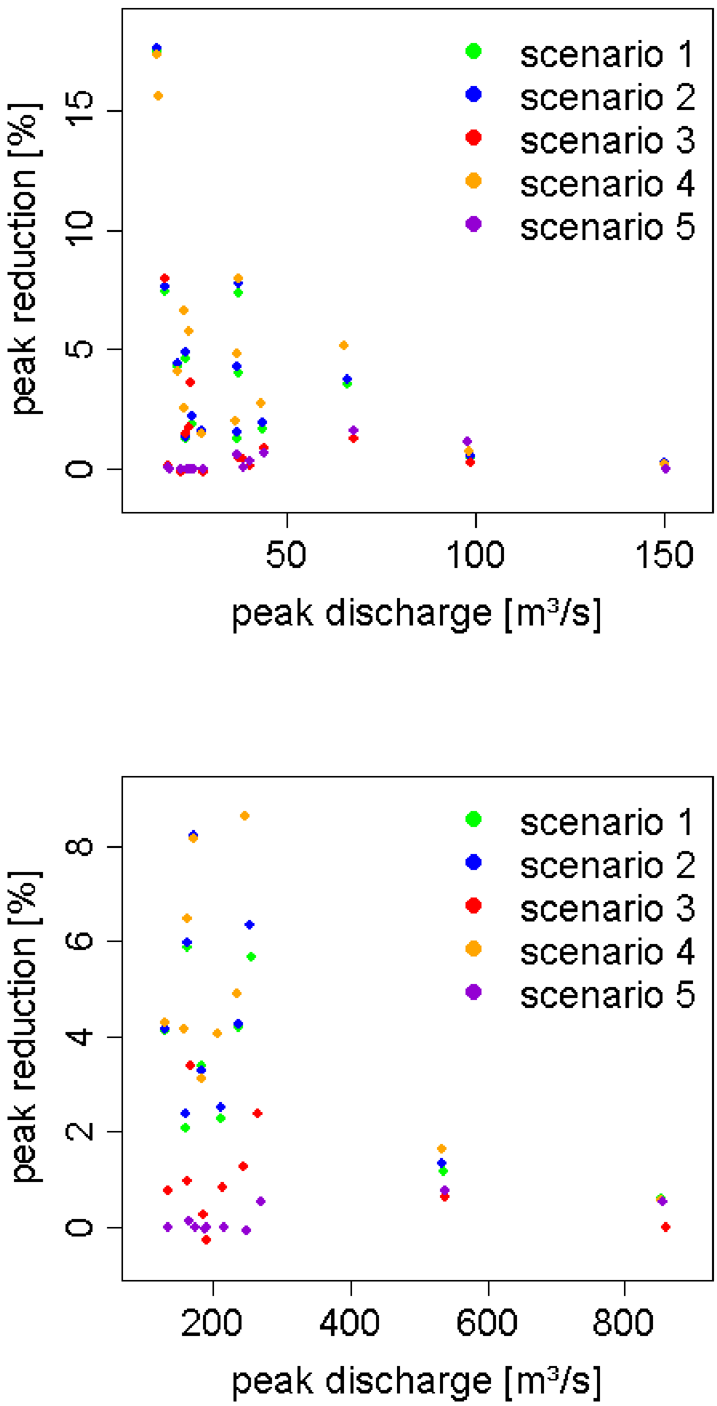


Figure 9-14 . Peak discharge vs peak reduction for subcatchment 4 (upper graph) and the entire basin (lower graph).

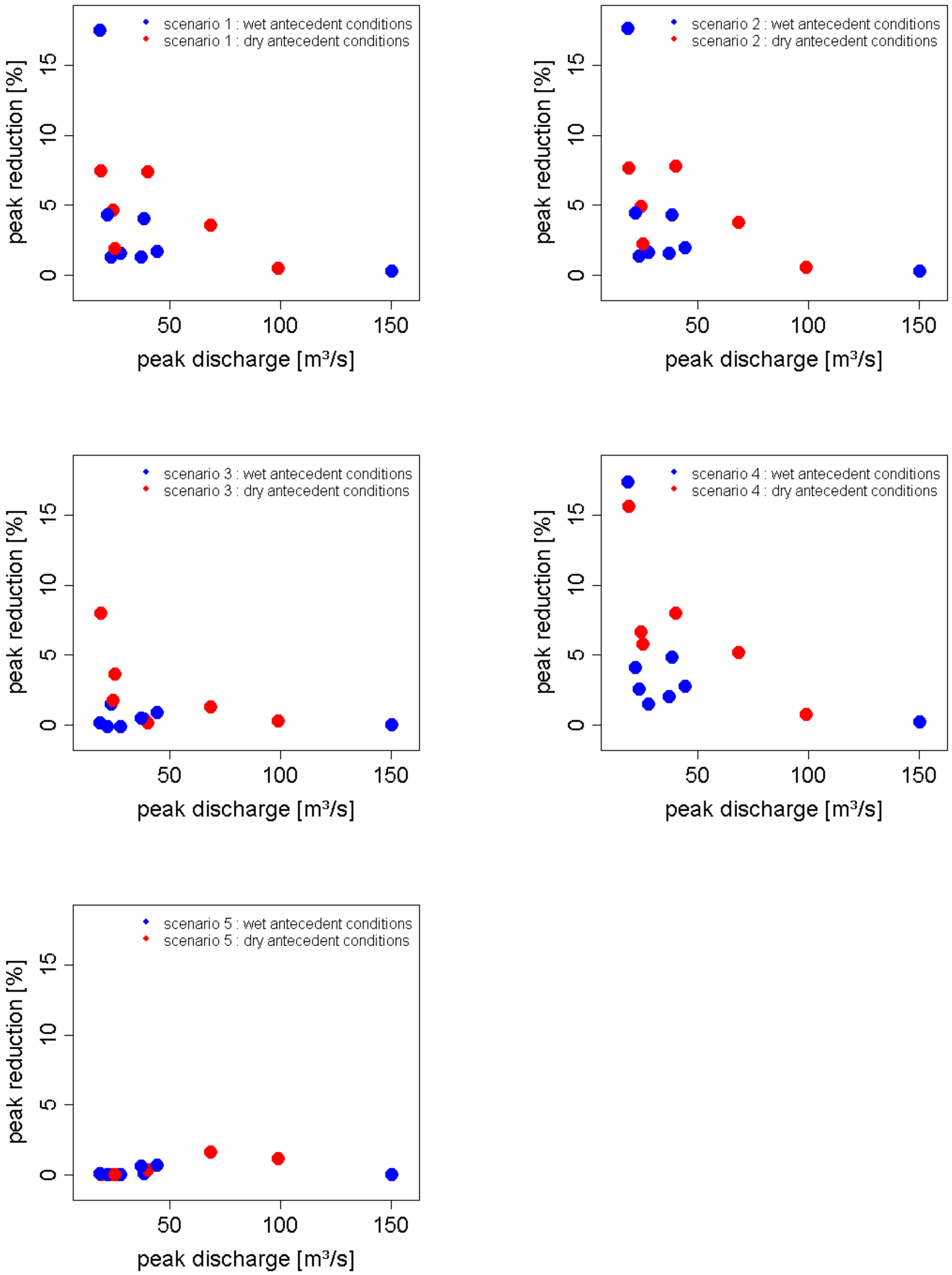


Figure 9-15 . Peak discharge vs peak reduction for subcatchment 4 for all 5 scenarios. Blue dots signify wet antecedent conditions (more than 40 mm of rainfall in the 5 days prior to the event).

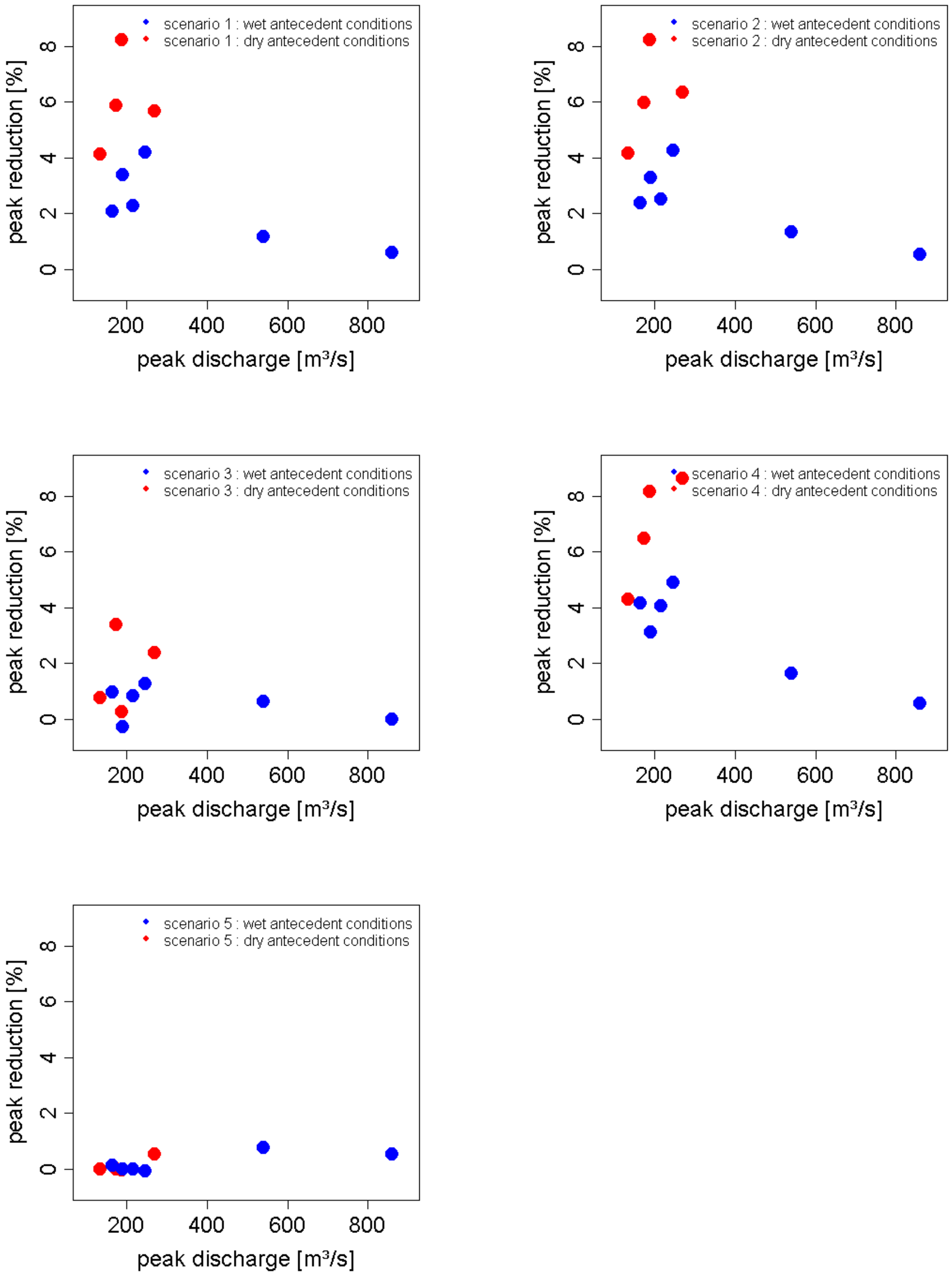


Figure 9-16 . Peak discharge vs peak reduction for the entire basin for all 5 scenarios. Blue dots signify wet antecedent conditions (more than 40 mm of rainfall in the 5 days prior to the event).

Comparison with the hydrodynamic simulation of a large polder:
For HQ 100, which is about the size of the large event modelled with Wasim-ETH for the simulation period in 2002, peaks are not decreased but increased. This is the result of a disadvantageous superposition of hydrographs as a result of flood retention measures upstream. Comparing this figure with maximum retention with our flood retention scenarios (0.59% peak reduction with forestation scenario 1) we find that the forestation scenario achieved a peak reduction of 5 m³/s at peak flow, while the polder simulation resulted in an increase of 14 m³/s. At HQ 300 on the other hand the polder simulation achieved a peak reduction of 103 m³/s, while the peak reduction from forestation for such extreme events is likely to be close to zero.

Flooded area for the area of the city Kempten at HQ 100 is shown in Figure 9-17 (from HWS-Konzept Iller Nord,2004). A similar picture is to be expected for the forestation scenario generated in the here presented study.

Table 9-3*. Peak reduction – results from the hydrodynamic simulation of the new polder and additional smaller retention measures and dams (entire catchment) (from HWS-Konzept Iller Nord,2004).*

	HQ5	*HQ10*	*HQ20*	*HQ50*	*HQ100*	*HQ300*	*HQ500*	*HQ1000*
Q [m³] (without new retention measures)	*309*	*352*	*459*	*525*	*594*	*919*	*1005*	*1108*
Q[m³] (with new retention measures)	*302*	*345*	*461*	*532*	*608*	*816*	*894*	*991*

Figure 9-17 . Flooded area in Kempten at HQ 100 (from HWS-Konzept Iller Nord,2004).

9.2 Comparison to the Kamp and the Rambla del Poyo Catchments

In the Spanish catchment of the Rambla del Poyo four landscape retention scenarios were compared: present, afforestation, 184 small reservoirs and a single dam equivalent in volume. It was found that the afforestation scenario is the most effective with an increase of area covered with pine trees from 0.5% to 55% resulting in mean runoff reduction of 38% under dry conditions and 15% under wet conditions.

In the Kamp catchment, the afforestation scenario (increase in forested area from 47% to 86%) resulted in a peak runoff reduction of 5% for a 200 year event and in a peak runoff reduction of 20-25% for smaller events. The micro ponds (7500 micro ponds with a volume of 100m³) only resulted in a peak runoff reduction of 2%, while 6 retention basins along the river achieved a reduction of 49% for the 200 year flood. (see final report: Francés, F. García-Bartual, R., Ortiz, E., Salazar, S., Miralles, JL., Blöschl, G., Komma, J., Bronstert, A., Blume, T., Francke, T. (2008): Efficiency of non-structural flood mitigation measures: "room for the river" and "retaining water in the landscape". CRUE Research Report No I-6. Valencia, Wien, Potsdam, 2008)

10 Summary and conclusions

Scenario simulations with a process based model were carried out for the Upper Iller catchment. Despite the challenging problems with the meteorological as well as the hydrological input data, a reasonable calibration was achieved with a Nash-Sutcliffe coefficient for the entire basin of 0.81.

The following scenarios of water retention in the landscape were generated and simulated for the Upper Iller catchment:

1) *forestation*
2) *forestation and resulting increased soil storage*
3) *microponds*
4) *a combination of forestation, increased soil storage and microponds*
5) *micro reservoirs*

It was found that overall the effect of the forestation scenarios as well as the microponds was largest for smaller events. The micro-reservoirs only start operating at higher discharges and are thus more efficient for larger events. However, due to their limited size and catchment area, they often tend to either overfill in some cases or they only receive a small fraction of the generated direct flow in other cases.
It was also found that microponds are only efficient for drier antecedent conditions and smaller events. In the case of the large event the effect of delayed infiltration from the microponds leads to an increase in discharge at late times. For the large event we can also see the effect of the micro-reservoirs, which are filled entirely before the peak of this event is reached and thus become ineffective for peak discharge. At late times these reservoirs then also cause an increase in flow.
Peak discharge reductions of 2-8% were achieved for peak flows of about 40 m³/s in subcatchment 4. For these flows a drier antecedent condition led to a stronger reduction for scenarios 1-4.
For the entire basin, the forestation scenarios resulted in peak reductions between 2 and 8 % for flows of approximately 200 m³. For similar flows the microponds only achieved a peak reduction of ca. 0-3%.

The peak reductions achieved with the different scenarios of water retention in the landscape were compared to the results obtained by the hydrodynamic simulation carried out by the "Institut für Hydrotechnik". In this study the large polder upstream of Immenstadt with a volume of 6.8 Mil was simulated as well as other smaller flood protection measures.
For an event of similar size as the large event in August 2002 not a reduction but an increase of 14m³/s resulted from these flood protection measures, due to disadvantageous overlapping of hydrographs. (The large polder was not activated for this event.) The forestation scenario on the other hand resulted in a small decrease of 5m³/s.
However, thanks to the polder a reduction of more than 100m³/s could be achieved for a HQ 300, while landscape water retention scenarios are likely to have very little effect on flows of this magnitude.

The selection of the proper flood protection measures (or combination of measures) should be based on a local analysis of their effectiveness and efficiency. The following general findings, however, have been obtained from this project:

1.- Given that the changes in the flood magnitude are a delicate balance of the various controls, it is important for the data to be of the best quality and the models to be carefully parameterised.

2.- Volume matters. Overall, the effect of the reduction in flood risk depends on the retention volume compared to the magnitude of the flood. The simulations indicated that in all three *catchments the additional retention volume obtained by afforestation is likely small. Also, the effect of retaining the water in the landscape in micro-ponds is relatively small as, in most landscapes, it is difficult to accommodate large retention volumes. However, it may be useful to combine the above measures with other positive effects (not considered in this project) such as soil conservation, sediment transport reduction and environment protection.*

3.- Allowing for "room for the river" provides large retention volumes more easily. Such measures may hence be socially more acceptable than "retaining water in the landscape", given the spatial coincidence of environmental impact and risk reduction in the floodplain and the relatively limited effect of the latter. The room for the river concept has the additional advantage of being able to design the mitigation measure in a way that the maximum flood reduction can be achieved for a chosen magnitude (eg. 200 yr flood) while afforestation and micro ponds mainly reduce the small floods and their storage may be exhausted for medium and large floods.

4.- If the present flooding frequency is high, small reductions in the flood hazard can produce significant reduction in the flood risk.

5. While the effects of polders and additional flood plains along the main stream can be estimated reliably by simulation models, it is much more difficult to estimate the changes in the infiltration capacity with afforestation or deforestation within the catchment. The changes in the soil characteristics are likely to occur over decades and it is hence strongly recommended to perform local infiltration experiments to complement the model based assessment of the effects of land use change on flooding.

11 Acknowledgements

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13 Project Summary

Joint project title	**Flood risk management strategies in European Member States (FLOOD-ERA) - A methodology to evaluate the effectiveness and efficiency of mitigation measures with regard to different risk perceptions**
CRUE Project No.:	**I-6: Efficiency of non-structural flood mitigation measures: "room for the river" and "retaining water in the landscape"**
Project partner #1 (Co-ordinator):	**Félix Francés**
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Email:	axelbron@rz.uni-potsdam.de
Project website:	http://www.iiama.upv.es/roomfortheriver
Objectives	**This project has been focused on a comparison of the *effectiveness* of non-structural flood mitigation measures. In particular measures which realise the non-structural flood risk mitigation concepts “retain the water in the catchment” and “room for the river”.**
Background	**The methodology used to estimate the hazard and the risk is applied to the highest technological level.**
Research	**Generation of synthetic convective storms in a basin with poverty data for historical storms.** **Estimation of the non-excedence probability of the peak discharges obtained from the synthetic storms.** **Parameterization and distributed hydrological modelling of land use changes: Afforestation and deforestation.** **Comparison of the *effectiveness* of non-structural flood mitigation measures**
Findings	• Given that the changes in the flood magnitude are a delicate balance of the various controls, it is important for the **data to be of the best quality** and the models to be carefully parameterised. • The main hydrological processes have been reasonably represented by the **distributed hydrological model** specific for each case study, covering a wide range of flood generation mechanisms. • The **antecedent soil moisture** is conditioning the retention effects of the landscape measures, depending on its location (slope or channel) and hydro-meteorological conditions. • **Volume matters**: the results show that the potential of the landscape retention

	measures depends highly on the ratio between the retention increment and the flood magnitude. - **Afforestation:** gives significantly higher reductions compared with local retention measures but with a maximum retention limitation. - In the **"room for the river"** measures **large polders or retention basins** are needed to produce significant reductions in the flood risk in the three case studies, with some local differences. - Another advantage of **"room for the river"** actions compared with "retaining water in the landscape" is that the former are placed in the floodplain, where the benefits (flood risk reduction) are also located.
Implications (Outcome)	Decision would have to be based on an **integrated flood management plan** that balances the various options of flood mitigation and management and their actual costs i.e. efficiency analysis.
Publications related to the project	**1. F. Francés, G. Blöschl, A. Bronstert, (2007). Efficiency of non-structural flood mitigation measures: "room for the river" and "retaining water in the landscape".** In Flood Risk Management Research From extreme events to citizens involvement. Proceedings of the European Symposium on Flood Risk Management Research (EFRM 2007), Dresden, Germany, 6th -7th February, 2007. Jochen Schanze (Ed). ISBN 978-3-933053-5 **2. F. Francés, G. Blöschl, A. Bronstert, (2007). Efficiency of non-structural flood mitigation measures: "room for the river" and "retaining water in the landscape".** Proceedings of the Mid-term Seminar, Lyon, France, 17th October, 2007 **3. S. Salazar y F. Francés, (2008). Comparación de la eficiencia de medidas de mitigación de las inundaciones mediante retención en el territorio.** Proceeding of the XXIII Congreso Latinoamericano de Hidráulica, Cartagena de Indias, Colombia. September, 2008. **4. S. Salazar, F. Francés, J. Komma, G. Blöschl, T. Blume, T. Francke and A. Bronstert, (2008). Efficiency of non-structural flood mitigation measures: "room for the river" and "retaining water in the landscape".** In Flood Risk Management: Research and Practice. Proceedings of the European Conference on Flood Risk Management Reasearch into Practice (FLOODRISK 2008), Oxford, UK, 30 september-2 october 2008. P. Samuels, S Huntington, W. Allsop and J. Harrop Editors. CRC Press/Balkema. ISBN:978-0-415-48507-4. **5. A. Bronstert, T. Blume, T. Francke, D. Niehoff** : **Möglichkeiten des Hochwasserrückhalts im Einzugsgebiet:Ergebnisse aus dem Rhein- und Illergebiet,** Workshop, Laufen, Germany, 2008. **6. Blume T., Francke T., Günther K., Bronstert A.: Possible flood retention in an alpine landscape: A case study from the Upper Iller, Germany.** Geophysical Research Abstracts, Vol. 10, EGU2008-A-04172, 2008.