UNIVERSITY OF SOUTHERN QUEENSLAND

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Environmental economic aspects of river basins and their catchment

Identification and quantification of flood related land use externalities

A Dissertation submitted by

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Abstract

This thesis investigates a common problem of land use impacts on flood damage costs on a catchment scale. It does this through a particular case study, to quantify the technical upstream-downstream dependencies and highlights the externalities through hydroeconomic analysis of flood damages and mitigation costs. The substantive content of the project is cross disciplinary.

Peak and volume of river flows are functions of the catchment surface characteristics. This means that any impacts to the run-off regime (for example surface sealing or river training) could affect people and land users in the lower catchment. Thus, upstream activities can cause higher flood peaks, and also entail higher damages downstream. These damages are either borne by the affected parties or they are mitigated by state financed flood defence works or offset with financial compensation. These costs are usually not included in the economic considerations of the upstream land user who is partially causing them. In economic terms, these effects are referred to as unidirectional externalities. This means that a producer can export parts of his production costs to third parties and these are not included in the price of the product.

The Herzogbach is a small tributary of the Danube River in Lower Bavaria. It is located in a rural area, dominated by intensive farming practices. Two villages (Bachling and Buchhofen) in the headwaters and middle section of the catchment and one city (Osterhofen) in the lower catchment were analysed to determine the impact of upstream land use practices on the flood situation.

A combination of hydrological and hydraulic modelling provided the core data to allow the interpretation of economic data, using methods of cost damage estimation. A hydrological model of the catchment provided hydrograph simulations based on (a) a regionalisation approach, (b) hydrologic flood routing and (c) hydrologic reservoir routing. A two dimensional stream flow model was then used to convert the hydrographs into flood levels, to simulate the run-off in settled areas and determine the flood affected areas, flood levels and flow

velocities. Estimates for flood damages or mitigation costs resulting from different hydrological scenarios were compared. The scenarios are based on different land uses and allow economic externalities to be estimated.

It was found that intensive farming and river training increase the peaks, shape and volume of flood waves in comparison to extensive land use, grassland or forest. In the study area, especially river training reduced the detention effect of the river bed and the natural flood plain. These significant changes to the natural run-off regime directly affect land use in the lower catchment through flood damages and increased flood risk, and by reducing the effectiveness of planned or existing flood protection works.

The thesis concludes with linked technical and economic findings which indicate a rich potential new area for research - "hydroeconomics". The published literature shows few people have worked in this cross disciplinary area. The technical finding is that changes to land use, especially in agriculture, can increase the flood damages in downstream settlements or increase the cost of flood mitigation works significantly. From an economic point of view, this is a unidirectional externality which should be considered in catchment and flood management. Possible solutions could include the control of land use and instruments such as separate waste water fees for rainwater and sewage or run-off certificates.

Certification of dissertation

I certify that the ideas, experimental work, results, analyses, software and conclusions reported in this dissertation are entirely my own effort, except where otherwise acknowledged. I also certify that the work is original and has not been previously submitted for any other award, except where otherwise acknowledged.

08.06.2009

Signature of Candidate Date

ENDORSEMENT

Signature of Supervisor/s Date

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The study used data from the research and development project "River Basin Management

Plan for Small Size Catchments - Herzogbach, Angerbach, Lindenbach" (Dorner, Spachinger, Lenz & Metzka 2005*a*), which was managed and handled by the author of this study. The project was financed by the Free State of Bavaria as represented by the Water Management Office Deggendorf and the Government of Lower Bavaria together with the City Osterhofen, Municipalities Buchhofen, Künzing and Osterhofen.

Associated publications

Results of this study have been published in (Dorner 2005*a*), (Dorner 2005*b*), (Dorner, Spachinger, Metzka & Mitterreiter 2005), (Dorner, Spachinger & Metzka 2005), (Metzka, Dorner & Spachinger 2006). Other results are available in the unpublished River Basin Management plan for the Herzogbach catchment (Dorner, Spachinger, Lenz & Metzka 2005*b*) and the technical project report (Dorner, Spachinger, Lenz & Metzka 2005*a*). Maps are based on the ATKIS data set, aerial photos, land register map and historic land register map of the Bavarian Agency for Surveying and Geographic Information.

Parts of this thesis have already been published at conferences (Dorner, Spachinger & Metzka 2005) (Dorner 2005*a*), (Dorner, Spachinger & Metzka 2005), (Spachinger, Dorner & Metzka 2005), (Metzka et al. 2006), (Dorner, Porter, Eitel & Metzka 2006),(Dorner, Porter & Metzka 2007*a*), (Dorner, Porter & Metzka 2007*b*) and in national and international journals (Dorner, Spachinger, Metzka & Mitterreiter 2005), (Dorner 2005*b*), (Dorner, Porter & Metzka 2008). These publications refer to material especially in the Basics, Methodology and Analysis and Results. The material used from these publications is identified by citations at the appropriate locations in these chapters.

Glossary

Catchment: Area of a landscape that collects all water that flows towards a defined outlet.

Certificate/Certificate trading: Right/permission to emit a certain amount of a defined substance. Certification trading is the process of trading these emission rights between different groups of emitters in a defined market.

Externality: Is any impact, either positive or negative, on a party not involved in an economic transaction.

Flood Risk Management Directive: Directive of the European Parliament and of the Council on the assessment and management of flood risks.

Hydroeconomics: Field of environmental economics dealing with economic aspects of water under its special hydrological and hydrodynamic boundary conditions.

Internalisation: Is the process of integrating all externalities in the calculus of the causer.

Land consolidation: Legal and administrative instrument and management process to reorganise field structures and land property to improve the agricultural situation in an area.

Rivulet: Permanent water courses in a catchment smaller than $100km^2$.

Rural development: All instruments to improve the competitiveness and attractiveness of rural areas including e.g. land consolidation and the development or rural infrastructure.

Separate waste water fee: In contrast to regular waste water fees, calculating the fees for waste water based on the fresh water consumed by a household, the separate fee distinguishes between waste water (based on consumed fresh water) and storm water based on sealed areas connected to the storm water sewer.

Settlement: Group of houses and buildings.

Water Framework Directive: Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for the Community action in the field of water policy.

Preface

This thesis is cross disciplinary in nature. It stands on the border between engineering sciences and environmental economics and is written partly for both audiences. It aims to fill a gap in the understanding of hydrological processes from an economic perspective and, as an instrument of river basin management, develops a methodology of how to detect and handle land use externalities. A major emphasis is to draw on principles from both disciplines and use them together to enhance the effectiveness of this study. It is difficult to write a formal dissertation for both specialists at once. In this preface, I outline my approach to presenting the project to both groups. I hope that I have addressed the most interesting and relevant topics and have shown where future interaction and knowledge exchange between engineering sciences and economics must be fostered.

In order to provide understandable information for all readers, while also giving detailed information for the specialists in each field, this dissertation is structured as follows. The Introduction provides an overview of the study and its focus. It also describes the main objectives and the interdisciplinary focus. The Theoretical Background and Literature Review chapter then provides an overview of the interaction between land use and hydrological cycle, the necessary economic theory, especially concerning resource economics, and the externality problem applied to the special characteristics of water and water bodies. For readers with an engineering background, the principles of economics - especially the basic theory of markets - is described in more detail in the Appendix. For economists, the Appendix contains an extra chapter giving an introduction into the theory of hydrology.

Because of the breadth of subject matter, the Methodology includes a broad overview of the use, necessity and interaction of different evaluations and analysis techniques used in the dissertation. The chapter then describes how each individual discipline approach, such as hydrologic and hydraulic modelling and economic assessment, is used and how they can be combined to achieve the objective of identifying externalities.

The chapter Case Study gives an overview of the applied modelling approach. It presents the model results and the interpretation of hydrologic, hydraulic and economic data for each individual section of the catchment as well as the interpretation on a catchment scale. Detailed data and the graphic representation of model results are attached in the Appendix.

The Discussion and Conclusion Chapters suggest which instruments are suitable for internalising externalities. They also describe how the methodology can be used in the future for river basin management and as an instrument for flood mitigation.

Although the work described in this thesis is theory based, it responds to practical problems which inspired the study. In Germany, the administrative responsibilities for water bodies are shared between the state (major water bodies), the municipalities (smaller water bodies) and the districts. Often, two to ten municipalities share responsibility for one small catchment. Actions have to be coordinated and costs shared in projects within this catchment. This is often a problem in flood mitigation projects, because the most effective measures to protect an affected area downstream are often located in the next municipality upstream. At the moment, no regulations exist to enforce cross community projects. Even the argument that upstream land use increases flood problems in the downstream community is ignored or rejected.

The Bavarian government picked up this topic and assigned the University of Applied Sciences with a research project to prove and show the benefits of cooperative planning and action for a distinctive catchment. Dorner, Spachinger & Metzka (2005, p. 28) point out: "To improve the situation in the catchment a masterplan has been developed that integrates measures of flood protection and prevention, improvement of the water quality and the river morphology and combines them with measures of erosion reduction and sediment and nutrient retention in the area. The main strategy to implement all suggested measures is a combination of acquisition in areas of main interest along the river, fallow along rivulets and drains and measures of land clearance to improve the structure of fields and introduce retention structures like filter strips, grassed water ways and drains. [...] One aspect are also recommendations to change agricultural policies concerning subsidies and incentives to increase the size of extensive used agricultural areas and the implementation of sustainable agricultural techniques." This dissertation project amends the results of the research project with an economic assessment of the externalities of human actions in a catchment with respect to flood protection.

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Chapter 1

Introduction

1.1 Problem statement

Rivers and rivulets densely cover our landscape and link upstream areas to downstream ones. Rivers also connect different human groups and their activities from the head to the tailwaters of the catchment. Almost every quantitative or qualitative human impact to the river system is transported by the flow and may affect downstream stakeholders.

The project commences from the position that all human actions in a catchment and along a river system influence other parties - mostly downstream of the action. Conflicts of interest between these parties pre-exist because each user has potential demands of the system. The level of awareness of the conflict varies, but where negative impacts are recognised, some form of protest can arise against other users and even pre-existing uses. The problem of conflicting useage rights in river basins is bound to the nature of environmental services being public goods or common resources (Green 2003).

In most cases, nobody can be prevented from using the resource, nor can access be restricted. In some cases use restrictions have already, for example for water extraction and irrigation (Dinar & Subrahmanian 1997, Tsur & Dinar 1995), been established. However, unnoticed intensive usage of the resource can result in reduced availability, inefficiencies, conflicts and external impacts within the catchment (Bernauer 2002, Holden & Thobani 1996, Thurston, Goddard, Szlag & Lemberg 2003). Direct uses, such as waste water discharge and irrigation abstractions, already need licenses or are constrained by water fees (Johansson, Tsur, Roe, Doukkali & Dinar 2002, Kraemer, Pielen & Leipprand 2003). Other impacts, like increased run-off and flood development, are consequences of intensified land use or changes in land use. They, in turn, affect the flood risk to downstream users in a way that is not recognised from an economical point of view.

River systems that cross national boundaries pose extra concerns. Upstream countries and upstream users within the same country, tend to export their social costs. The problem that occurs when human economic actions affect other stakeholder groups without any form of compensation is referred to as an negative externality, hereafter called externality. Most environmental economic problems or externalities in river basins are caused by the upstream to downstream conflicts discussed above, and they represent a special form, called a unidirectional externality (Bernauer 2002). Bernauer (2002) lists water use, irrigation, agriculture (adding sediments and chemicals) and hydroelectric power production (creating additional peak flows and hindering navigation) as common upstream to downstream problems. Other types of common costs can also be considered as water-related externalities. They include for example the maintenance required for trained rivulets (small stream channels) in agricultural catchments following land clearance projects and the resulting responsibility of governments or city councils to conserve the existing river structures. Other types of land uses and their effects on the quantitative and qualitative availability and appearance of water would include:

- effects of land use, such as surface sealing in cities or intensive farming, on the peak and duration of floods
- river training and artificial channel structures, which increase the flow rate, reduce the detention capacity of the natural flood plain and increase the flood damages in settled areas.

These types of externalities can be negative and are worth analysing from an economic viewpoint for different reasons because:

- The environmental costs of human actions are not integrated into the economic equation of the producer, but assigned over time to other people.

- Externalities may have inter-temporal effects. The negative effects can be delayed and occur as economic costs to future generations.
- Minor externalities of different individual polluters or causers can accumulate over time and on a catchment scale.

In some cases, especially in areas where water scarcity determines the efficiency of the economy, we already know how externalities can be handled (Green 2003, Qdaisa & Al Nassayl 2001, Tsur & Dinar 1995). Johansson et al. (2002) list several instruments and approaches such as certificate markets for water abstraction, water fees and regulations. The lack of clean water represents a special form of scarcity and is therefore linked to externality problems too. The request of the European Water Framework Directive (European Parliament & Council of the European Union 2000) to use "cost effective" measures to establish the good status of river systems, is an official task to take into account water related costs.

We know that human action in the catchment and along the river system affect flood development and consequently the peak, volume and duration of a flood. Maniak (1993, p. 10) states "Beim Ausbau oberirdischer Gewässer wurden vielfach die natürlichen Rückhalteräume in der Talaue verkleinert, um die Landwirtschaft gegen Sommerhochwasser und die Siedlungsgebiete gegen noch größere Hochwasser zu schützen. Dies führt zu Abflussverschärfungen mit größeren Hochwasserspitzen in den unterliegenden Gebieten." [As the river systems were developed, the natural detention storage was often reduced in the flood plain. Measures were required in order to protect agriculture from summer floods and the settlement areas against increased floods. There has been an increase in flood water levels and peaks in the lower catchment areas.].

Especially in small scale catchments, these quantitative relations between land use and water in the literature have been proven (Bormann, Diekkrüger & Hauschild 1999, Koehler 2005). But linkages between land use, river training and flood development can be shown for larger catchments as well (Lammersen, Engel, van de Langemheen & Buitveld 2002, de Roo, Odijk, Schmuck, Koster & Lucier 2001). Dyck (1995, p. 433) describes the enormous losses in flood capacity along the Elbe in Germany over the past 800 years and refers to the inadequate or token attempts to construct flood detention works to compensate these losses within the past

100 years. He states “Infolge Flußregelung und Deichbau haben sich die Retentiosflächen vieler Flüsse verringert. Dies konnte auch durch Rückhaltebecken und HW-Schutzräume in Talsperren meist nicht kompensiert werden. [In-stream works and levee construction have reduced the flood capacities of many river systems. It was not possible to balance this by detention reservoirs or flood storage in dams.]” (Dyck 1995, p. 433).

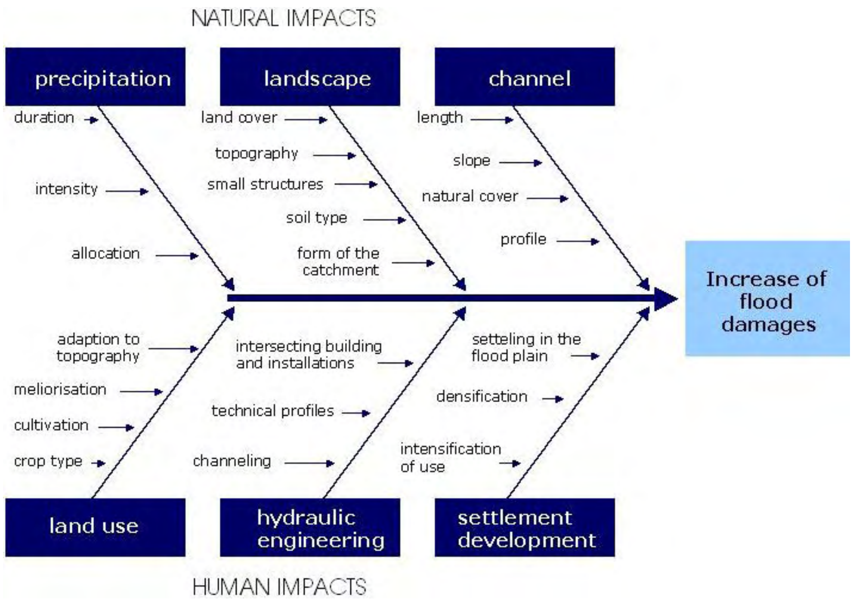


Figure 1.1: Cause and effect relations between anthropogenic impacts and flood development

The hydrological cycle as a physical process links detention in the catchment and in the river valley to flood development and resulting flood damages. The economic hypothesis would be: the extent of flood damages is influenced by land use in the upstream areas. Therefore, flood damages are a function of hydrological parameters, e.g. surface characteristics, catchment, river structure, land use and other anthropogenic impacts (Fig. 1.1). The main questions that follow are:

1. Can externalities, for example flood damages, be directly linked to land use and human-induced changes to hydrology and river morphology, and so quantified using hydrological models?

2. Can externalities be assigned to identified causers or polluters, or at least alternatively to specified user groups?

3. Can natural effects of flood development be split from anthropogenic ones?

4. Will the costs of the internalisation process not exceed the benefit?

To answer these questions for individual catchments, a lot of physical and environmental processes would have to be examined before an economic investigation could be started. The relevant circumstances determining the interaction between human impact, flood development and resulting damages must be identified and the human-induced run-off must be separated from natural effects.

1.2 Thesis scope

Widespread efforts have been made in recent years, especially in arid countries, to establish markets to trade water and avoid externalities (Johansson et al. 2002, Dinar & Subrahmanian 1997). Also, water quality is increasingly mentioned in the context of externalities and internalisation strategies (Kraemer et al. 2003). These trends form the context for this dissertation project and highlight the need to include flood development and protection in an economic framework. Costs for flood defence work have increased in recent years as have flood damages (European Commission 2006*a*, MunichRE 2003). Political, legal and market mechanisms have consistently failed to establish preventive measures and reduce flood impacts as well as related damages, because the hydrological development of floods has never been linked to the economic consequences on a catchment scale.

Umweltbundesamt (2007, p. 5) pointed out: "Die Umweltpolitik muss sich heute mehr als in früheren Zeiten dem ökonomischen Kalkül stellen. Die ökonomische Bewertung von Umweltschäden ermöglicht es, den ökonomischen Nutzen umweltpolitischer Maßnahmen zu schätzen, denn Umweltpolitik heute vermeidet Umweltschäden morgen. [Environmental politics must have a greater rationale now than in previous times of the economic calculus. The economic assessment of environmental damages allows the benefit resulting from environmental political measures to be estimated, because environmental politics today avoids environmental damages tomorrow.] " This must also be applied to land use management. Lord & Israel (1996) nominated the major problems in water resource management as:

1. the externality problem,
2. the open access problem,
3. the public good problem and
4. the scarcity problem.

They suggested the implementation of economic methods as providing a possible means to solve these problems.

The open access problem and the public good character of water and river systems are the main reasons for the development of externalities. If the use of a resource can not be restricted automatically, an open access situation arises in most cases, and results in an externality.

This raises the question as to whether the oft mentioned scarcity problem (Bella, Duckstein & Szidarovszky 1996, Johansson et al. 2002, Holden & Thobani 1996), is the only relevant aspect of water resources that can be linked to economic issues. It would seem that land use as well as river training and their effects on the development of floods should be recognised as serious upstream-downstream problems resulting in (negative) externalities. In literature, the quantitative and physical aspects of land use and river training were often mentioned (Niehoff, Fritsch & Bronstert 2002, Lammersen et al. 2002, Croke, Merritt & Jakeman 2004, Scheidleder, Winkler, Grath & Vogel 1996). Agthe, Billings & Ince (2000), Green (2003) and Thurston et al. (2003) also linked land use to the externality problem, but no framework or methodology existed on how to quantify the extent of the externality problem as a physical basis for an internalisation strategy.

This project is based on the hydrologic behaviour of the catchment. Water-related processes in the landscape, such as evapotranspiration, infiltration and surface run-off and the genesis and development of floods, will be first quantified. A broad variety of computer models are available to describe and simulate different subprocesses of the hydrology of a catchment. They can be used to calculate the volume and peak of design floods as well as for flood forecasting and the control of detention structures, such as lakes and reservoirs. In a lot of cases, they have shown that the development and extent of flood waves can be simulated accurately (Plate 2002).

When combined with a hydrodynamic model, the extent, depth and velocity of floods in settlements and a relation between land use and flood affected areas in a catchment can be established. A comparison of the situation in the catchment before human land use with the status quo can then be used to split off the human-induced effects from the natural run-off. Hence, it should be possible to connect human impact and the resulting changes of the natural system to the economic consequences for flood affected citizens. These analytical linkages would establish flood-damage functions for defined design floods under these scenarios and help to identify and quantify externalities.

The hypothesis addressed in this project is that land use in the upper catchment can have significant negative impacts in the lower catchment, which must be seen as negative externalities of land use. The key question to be answered is how these externalities can be quantified and which parameters describing land use in the hydrological systems can be used to draw conclusions about the economic effects of changes to this system.

Two economic concepts are applied in this thesis and must be distinguished:

1. the estimation of damage costs or costs for flood mitigation,
2. the evaluation of transfer of costs (externalities) and the potential for internalisation or regulation.

Both concepts will be connected in this thesis to identify whether damage and mitigation costs can be used to identify externalities of land use with regard to surface run-off and floods.

The project will investigate how human land use affects third parties on a river system regarding floods, and how these impacts can be modelled with regards to the externality problem.

This will be done in a two step approach:

1. A methodology will be suggested to estimate the physical aspects of the externality problem.
2. The methodology will be tested in a sample catchment using a combination of hydrological, hydraulic and economic methods and models.

The dissertation will concentrate on the aspects of land use that affect run-off and flood development. It will provide a methodology to model land use changes, like intensive agriculture, urban sealing and also river training, and their impact on the hydrological cycle as the basis for an assessment of the externality character of these activities. A combination of hydrologic and hydrodynamic stream flow models will be used in combination with flood damage estimations to link negative effects on flood development with costs and damages and show how costs are transferred in the catchment. The case study of the Herzogbach catchment will show how a combination of technical and environmental models can be linked with economic calculation to provide the basis for future internalisation strategies.

Due to the restrictions of modelling hydrologic processes on a meso and macro scale (Debene 2006, O'Connell, Beven, Carney, Clements, Ewen, Fowler, Harris, Hollis, Morris, O'Donnell, Packman, Parkin, Quinn & Rose 2006) and the related consequences for hydrodynamic modelling and damage assessment, no precise result can be expected. The proposed approach can only deliver evidence that in a catchment, land use altered run-off and therefore causes externalities. It can provide a rough estimate of the amount of the externality. Results of the case study can not be directly transferred to other river basins nor be scaled up to larger units.

1.3 Aim

A lot of international organisations call for the use of economic instruments to control the use of water. In a recent publication, the WWF (2006, p. 5) asks to "properly value water and the natural features and services offered by catchments, streams, aquifers, floodplains and wetlands."

The Kyoto Protocol has shown that a global approach to establish environmental economic methods is possible and desired by many people and nations. Similar strategies for local, regional and international river basins can be built on this cooperative approach to establish economically based methods for supporting the sustainable use of water and related resources. The objective of this project is to investigate the impacts and reactions between humans and nature in a river catchment. It aims to identify parameters that environmental economics and policy instruments can be based on, that they can successfully internalise and allocate these interactions in the case of flood development and flood damages. The proposed model structure and approach should help to apply environmental economic methods as an instrument of flood management. Other political objectives of river basin management can be supported as well, including:

- Use of agrarian subsidies to encourage best practices for improving sustainable land use and reduce diffuse pollution,
- development of insurance strategies to avoid or reduce settlement along river banks,
- providing a basis for new development strategies on a catchment scale.

The thesis will show how hydrological, hydrodynamic and economic models can be combined and used as a basis for the development of policies for flood prevention control. The following aspects are of importance for further political steps or the development of transnational or supra-regional water management policies. The thesis will provide guidance for the following questions regarding floods:

- What are the causes of external effects and misallocations and which developments in land use did result in flood problems?
- What are the economic costs of external effects or misallocation of rights in river systems and how can they be derived from technical and environmental data?
- On which environmental parameters, e.g. run-off coefficients for land cover, detention volume or flood peak, can internalisation strategies be based on to define or measure impacts and results of environmental policies?

The study is compatible with current developments in the European Union, where two Directives aim to establish new ways of water management. The so-called Water Framework Directive (WFD), "DIRECTIVE 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy" (European Parliament & Council of the European Union 2000), is an approach to harmonise the process of river basin management in Europe and establish coordinated management plans for national and international river basins. The main objective is to achieve a good status of all water bodies as the consequence of coordinated planning, management and action. The directive claims that member states should "take account of the principle of recovery of the costs of water services, including environmental and resource costs" (European Parliament & Council of the European Union 2000, Art. 9). In addition, a Flood Directive (European Commission 2006*b*) was published in 2007 to support and enforce the development of flood risk management plans on a catchment scale.

At the moment, the cause-effect linkages between human impacts, resulting changes in flood behaviour and costs are not part of the political discussion regarding flood risk management. The new political developments, resulting in new integrated and transnational management action, in combination with an increased flood awareness and the costs for developing and maintaining flood protection should result in a discussion about the aspects of externalities of land use in the catchment and the flood plain.

The challenge for policy-making regarding floods is to identify the impact of land use on floods and relate it to the externality problem. From an environmental point of view, emissions can be defined as the discharge of substances into the environment, with regard to economic activities, as a by-product of the production of goods or services (Wikipedia 2008). Land cover and soil condition are the relevant factors that influence detention and, as a consequence, excess run-off. From this point of view, the additional run-off as a result of land use can be compared to emissions. In the case of flood development and flood damages, the cause-effect relations with regard to externalities are, at the moment, not well understood or have not sufficiently been quantified. This makes it difficult for policy makers to establish new systems to promote greater environmental, but also economic efficiency. The thesis aims to identify the key parameters of flood development in river basins as a physical basis to allow the internalisation of human activities related to flood development.

In the future the developed methodology to physically quantify externalities can be combined with economic models, e.g. to develop internalisation strategies or combined with other methods predict the reaction of participants in the market to these internalisation strategies.

Chapter 2

Theoretical Background & Literature Review

The economic aspects of water are often discussed in the scientific literature with regard to ecological economics, environmental economics or ecosystem services (Green 2003, Ward & Pulido-Velazquez n.d., Brouwer & Hofkes 2008). The discussion about water scarcity (Johansson et al. 2002) or pollution (Kraemer et al. 2003, Cason, Gangadharan & Duke 2003) shows the economic importance of water. Studies addressing the social, economic and ecological aspects of water are now mainly performed for arid climates. Especially irrigation and its impacts, dependencies, chances and risks have been covered in literature (Dinar 2000). Wallacher (1999, p. 3) describes a new approach for defining a sustainable management and general use of water resources. He takes ethical, religious, sociological and political aspects of water management into account together with natural sciences, engineering and economics. Wallacher derives an interesting model for the interaction between these disciplines: While hydrology provides necessary data on the temporal and spatial availability of water, economics and socioeconomics can provide the information about current and future demand. Ecology is then seen to influence the supply side and to define the limits for sustainable water consumption. These limits provide a basis for water management planning and the analysis of hydrologic impacts. The need for water often conflicts with the scarcity of available supplies. This conflict includes an ethical dimension and not only an economic one, which must be dealt with. Therefore, it is necessary to establish ethical rules for the just distribution of water and for the proper allocation of usage rights.

A main reason for missing experiences in the resource allocation can be the complex interaction of hydrological cycle and human activities as well as a deficient economic understanding of the resource water. The following paragraphs give an overview of the ecological backgrounds of the resource water, as well as the relevant economic theory. More general information about the principles of hydrology and economics can be found in the Appendix.

2.1 Impacts of land use and river structure on run-off

Human actions have affected the catchment and along the river reaches over several centuries. They have altered different hydrological sub-processes, such as evaporation, infiltration and surface run-off, and affected hydraulic conditions of flows in water courses.

The European Environmental Agency (Scheidleder et al. 1996) conducted a metastudy to detect the effects of human interventions on the hydrologic cycle in the Biogeographic Regions (Boreal, Atlantic, Continental, Alpine, Mediterranean, Macronesian) in Europe. Several member states, including Denmark, France and Austria, participated in this survey. State administrations were asked to answer questions about the extent of interventions, their measured impacts on the hydrological cycle and the reason for the occurrence of these interventions. Three types of interventions were identified in the study:

- river, lake and estuary regulation,
- water abstraction,
- activities in the catchment.

Human actions like land use and river training have influenced different sub-processes within the hydrological cycle over the last decades. Examples include land clearance, farming and urban development which changed the surface characteristics, infiltration capacity, small run-off relevant structures like depressions and drains as well as run-off paths in the landscape. The Umweltbundesamt (2001) performed a study to identify the impacts of land use on run-off and flood development. Three sub-catchments were assessed: Lein 115 km^2, agricultural and flat to hilly, Körsch 127 km^2 as a mainly settled area and, Lenne 455 km^2 with a hilly catchment and mainly forestry. The main objective of the study was to detect the effect of different land use types on run-off development and floods. Different future land use scenarios were forecast using a model that combined prediction of the quantitative change and spatial analysis for the local areal development. A trend of increased urbanisation and the use of more intensive agricultural techniques were predicted. Hydrological model results showed that, depending on the type of precipitation, a 50% increase of settled areas can increase flood peaks by 30%. A historical scenario for land use (1.3% settled areas in 1836 in contrast to 25% today) showed that a real flood event from 1992 would have had a greatly reduced peak in 1836.

Auerswald (2002) measured the impacts of different farming practices on surface run-off. He compared traditional techniques with new systems like intermediate cropping. In parallel to a reduction of soil erosion, he detected a decrease of surface run-off from the new system. Scheidleder et al. (1996, p. 4) summarise the outcomes of the European study: “Land sealing by urbanisation and land drainage for cultivation occur in each of the proposed regions and, where it occurs, seem to be most important activities in the catchment.”. Changes of surface and subsurface structures influenced detention and run-off in addition to the type of surface.

Unfortunately it is still problematic to make statements about the general reaction of a catchment to human actions due to the differing geological, geometric and climatic situations. Scheidleder et al. (1996, p. 3) stated as an outlook, that “there is a need to define precisely human interventions and agree a methodology for quantifying their effects on water resources, water and ecological quality of the water and riparian areas [...] Human interventions can have profound effects on water resources, water quality and aquatic and riparian ecology. There is a need to quantify both their extent and importance, and to quantify the nature and significance of the effects they have.”

O’Connell et al. (2006) critically analysed the outcomes of available international studies. The analysis of studies from Great Britain, continental Europe and the US gave significant evidence that there are strong relations between land use patterns, field structures and drainage on local run-off. On a catchment scale, this study saw potential evidence that surface run-off and land use are linked with respect to surface water networks. Unfortunately, it failed to address and compare the effects for different catchments scales. Therefore, the study states, that "there is very little direct evidence that changes in surface run-off associated with changes in land management are transferred to the surface water network and propagate downstream." (O'Connell et al. 2006, p. 65). An analysis of sources used in this study, e.g. (Fiener & Auerswald 2003) or (Umweltbundesamt 2001) showed that for small catchments ($\leq 200km^2$), reactions of catchments to land use can be shown and have been quantified in several research projects.

To summarise, land use influences the run-off on a local scale, but also in small catchments. Effects of other human interventions in the surface water network, such as river training, damming or the control of floodplain vegetation, can have an impact on discharge and flood development. In general, the results can not be transferred from one catchment to another, because hydrological processes rely on a range of factors like geology, geomorphology, hydrological regime and climate, and must be assessed for each catchment individually.

2.2 Negative externalities and responses

2.2.1 Negative externalities

In a market based economy, most goods are allocated via markets. Prices are indicators for demand and scarcity of these goods. In a perfect market the price causes the optimal allocation of a good or resource and an optimal welfare of all market participants. The theoretical assumption of a perfect market includes the idea that all market actions only affect participants in this market. In reality, other people are often affected by market actions as shown by the case of pollution. The situation where the assumption of an optimal market differs from the real world situation and causes misallocation is called market failure. The market fails to maximise the total welfare and to allocate resources efficiently. The special case of misallocation of costs to third parties not involved in the market is called negative externality. The name indicates that a person outside the market has to bear the costs of market activities.

> "Sofern die Akteure die mit der Nutzung der Umwelt einhergehenden Wirkun-

> gen nicht - oder nicht ausreichend - in ihr ökonomisches Entscheidungskalkül einbeziehen, spricht man von externen Effekten. Die mit diesen Effekten monetär bewerteten negativen Wirkungen bezeichnet man als externe Kosten. Charakteristisch für externe Kosten ist die Tatsache, dass nicht die Verursacher diese Kosten tragen, sondern Individuen (oder auch die Gesellschaft als Ganzes), die in keiner direkten oder indirekten Marktbeziehung zu den Verursachern stehen. Im Ergebnis stellt sich eine Situation ein, in der die Umwelt über ein ökonomisch optimales Maß hinaus beansprucht wird. [In case stakeholders do not - or do not sufficiently - include the outcomes of the use of the environment in their economic determinants, outcomes can be called externalities. Effects valued in monetary terms are called external costs. Characteristic of external costs is the fact that the causer does not bear the costs, but individuals (or societies as a whole) who are not in a direct or indirect market relation with the causer. The result is a situation, where the environment is used beyond an optimal level.]" (Umweltbundesamt 2007)

There are different circumstances, bound to the characteristics of goods and resources, that must be met for them to be marketable. For goods to be bought and sold, two criteria must be met:

1. The good must be excludable, which means that people can be prevented from using it; and
2. it must be sought by rival users, which means that the potential users of the good will compete for its acquisition.

Therefore, four different types of goods (Table 2.1) can be identified (Mankiw 2003, p. 224):

1. Private goods, which are rivalrous and excludable,
2. public goods, which are neither rivalrous nor excludable,
3. common resources, which are not excludable but rivalrous, and
4. natural monopolies, which are not rivalrous but excludable.

Use	Access	
	open	excludable
rival	Common resources	Private goods
non-rival	Public goods	Natural monopolies

Table 2.1: Characters of goods

Public goods and common resources can result in allocation problems in most systems. Public goods are not excludable, so no one can make a profit from their use. There is no motivation to provide them. If they are provided for a fee, there is a risk that free riders not willing to pay for the provided good will use the good because it is not excludable. For this reason, public goods are normally provided by governments for all possible users (Mankiw 2003, p. 226). The problem with common resources is often explained by the parable of the "Tragedy of the common" (Hardin 1968) or "Almende".

In this parable, raising sheep for wool sales is the major business of a small town. The necessary land for grazing is owned by the community. To gain more profit, all sheep holders will attempt to produce more sheep. However, the limited grazing capacity of the available land is then exceeded by the total number of sheep, resulting in insufficient nutrition and hence reduced wool production for all farmers. Air, wildlife and water are often cited as the most important or known common resources (Mankiw 2003). Problems occur because economic markets cannot effectively handle the resource allocation of common or public goods. Generally, the cost of the use of the resource is not carried by the user. This unearned cost is called a negative externality. "An externality arises when a person engages in an activity that influences the well-being of a bystander and yet neither pays nor receives any compensation for that effect" (Mankiw 2003, p. 204). Two types of externalities are possible, depending on whether the effect on the bystander is positive or negative. Negative externalities represent market failures, because equilibrium in market forces is not possible. "The equilibrium fails to maximise the total benefit to society as a whole" (Mankiw 2003, p. 204). "Externalities cause markets to allocate resources inefficiently" (Mankiw 2003, p. 205).

Externalities do not only occur between individuals or groups of actors, they exist in the form of spatial externalities and inter-temporal externalities. Most actions take place in one area, but the effects are transferred to another area. Typical samples are air emissions or waste water discharge into river systems (Kraemer et al. 2003). But externalities can also have a temporal effect if the consequence or costs are transferred to other generations. Global warming and the effect of carbon dioxide emissions on the atmosphere or nitrate pollution of the groundwater are samples of temporal externalities.

2.2.2 Regulation and internalisation

Although the development of an internalisation strategy is not a main objective of the presented approach, the understanding of how externalities could be controlled, regulated or internalised is of importance for the comprehension of the economic concept behind this special part of welfare economics. In the following section, the main ideas of internalisation as well as command and control strategies and other political concepts, are presented and shortly discussed.

Public and private solutions can be used to avoid market failures from externalities or to reduce their effects. These solutions involve a process called internalisation, which means that political, social or economic instruments are used to include the external costs in the economic model. Private solutions can be based on moral or social codes like charities or contracts (Mankiw 2003).

Over the past years, different types of strategies and instruments have or are still being developed to avoid, reduce or compensate external costs. They can be subdivided into different categories (Table 2.2).

Beside market oriented solutions, command and control is also used to regulate markets, establish emission levels or ban practices. Hawkins (2000, p. 382) points out that "Command and control policies suit the bureaucratic instinct to regulate matters rather than help markets operate more efficiently within an appropriate, even-handedly, transparently enforced legal framework. It is harmful to pile law upon law without regard to the cumulative effect of measures which individually may be laudable."

In contrast to market based solutions, command and control strategies are criticised for different reasons:

CHARGE SYSTEMS	MARKET CREATION
Road Tolls	Tradable Emission Permits
Access Fees	Tradable Catch Quotas
Pollution Charges	Tradable Development Quotas
User Charges	Tradable Water Shares
Betterment Charges	Tradable Resource Shares
Impact Fees	Tradable Land Permits
Administrative Charges	Tradable Offsets/Credits
FINANCIAL INSTRUMENTS	**BONDS AND DEPOSIT REFUND SYSTEMS**
Eco Funds/Environmental Funds	Environmental Accident Bonds
Financial Subsidies	Environmental Performance Bonds
Soft Loans	Land Reclamation Bonds
Grants	Waste Delivery Bonds
Location/Relocation Incentives	Deposit Refund System
Subsidised Interest	Deposit Refund Shares
Hard Currency at below Equilibrium Exchange Rate	
Revolving Funds	
Sectoral Funds	
FISCAL INSTRUMENTS	**LIABILITY SYSTEMS**
Pollution Taxes (on Emissions or Effluents	Legal Liability
Product Taxes	Non-Compliance Charges
Input Taxes	Joint and Several Liabilities
Export Taxes	Natural Resource Damage Liability
Import Tariffs	Liability Insurance
Tax Differentiation	Enforcement Incentives
Royalties and Resource Taxes	
Land Use Taxes	
Investment Tax Credits	
Accelerated Depreciation Subsidies	
	PROPERTY RIGHTS
	Ownership Rights (Land, Water, Mining)
	User Rights

Table 2.2: Political, legal and economic instruments for environmental protection and natural resources management after Hawkins (2000, p. 385)

- They provide little incentive for technical developments to reduce emissions or impacts.
- Because of fixed emission levels, industries with low possibilities of reducing emissions are penalised in contrast to those with readily available technologies. (Hawkins 2000, p. 383)

Different economic theories and system types, as described below, are the basis for most internalisation strategies or approaches to control and regulate externalities. They either describe how internalisation strategies can be set up (Coase Theorem), or how the market is influenced to compensate externalities (liability, insurance systems, Pigouvian tax) or reduce them to a defined level (Pigouvian tax, charge systems, tradable permits). In the following the most important concepts will be presented. In the following chapters only regulations, subsidies and tradable permits will be discussed with regard to the technical and scientific findings of the study. The development of an internalisation strategy or the detailed comparison of different instruments would require a comprehensive economic analysis as well as as an evaluation of the political and organisational framing conditions.

Regulations

Regulations tend to work by setting a special limit (e.g. in the case of emissions). They require a good knowledge of affected industries and technologies (Mankiw 2004). The major advantage is that if all emitting activities are known, a maximum total emission level can be defined as the sum of all allowed emissions (Cansier 1996, p. 205). Regulations can be a quick instrument to achieve results. But they are also criticized for disregarding market mechanisms (Hawkins 2000, p. 382).

Pigouvian Tax

Public solutions for the problem of external effects are known as "command-and-control policies" or "market based policies" (Mankiw 2004, p. 212). The use of taxes to allocate resources goes back to the 19th century and the economist Pigou (1932). Taxes or subsidies are used to provide incentives for economic parties to change their behaviour. Problematic is that a maximum level of emission can not be established because the reaction of the parties involved can only be estimated. Taxes and subsidies are more market based mechanisms, because they allow economic actors to decide how and how much they change their behaviour or are willing to pay (Mankiw 2004, p. 213). Their decisions will be based on cost-benefit analysis and will lead to the development of more cost-efficient technologies and economic processes as they look for cheap and effective technologies to reduce their tax-payments or optimise the emission reduction (Mankiw 2004). Pigou's (1932) concept was critisised (Baumol 1972) for several reasons such as its inefficiency to handle externalities under monopoly or oligolopoly. Baumol (1972) presents a concept extending Pigou's approach and combines it with the setting of technical emission levels.

Charge systems

"Charge systems have been typically applied for the protection of resources from waste emissions and discharges." (Hawkins 2000, p. 384). Typical charging systems can be found in the water sector for the regulation of waste water discharge to water bodies. Also, charging systems set an incentive for polluters to recalculate their behaviour. The amount of the emission fee can influence the behaviour of the emitter to rethink his emission level and include the costs into his economic calculus. In comparison to tradable permits charge systems define a fixed price for the emission. Charge systems can be seen as a special form of the Pigouvian Tax.

Subsidies

Hawkins (2000) sums up all forms of financial instruments like reduced credits and subsidies. "These involve the direct use of subsidies or investments to accelerate the development of environmentally benign technologies. Sometimes they can be seen as negating the polluter pays principle" (Hawkins 2000, p. 386). Subsidies should be an incentive for polluters to rethink and calculate their behaviour. Assuming a logic and benefit oriented behaviour of actors, they would reduce their emission level or avoid emissions if the amount of the subsidy compensates or exceeds the costs for a mitigation strategy.

Subsidies can also serve other purposes, for example to compensate market failures and set an incentive for profitless businesses. The European agricultural subsidy system was mainly developed to compensate the high cost of national agricultural production compared to foreign products. To set additional incentives to take into account environmental aspects, subsidies are bound to so-called “cross compliance” conditions (Heißenhuber 2005). This means that agricultural subsidies are only paid to farmers if they respect certain defined farming practices including environmental objectives. So subsidies aimed to solve problems other than environmental can be used to set an incentive for environmental tasks.

Coasean Bargains

One of the best known theories about private internalisation solutions is the Coase theorem (Coase 1960), which states “if private parties can bargain without cost over the allocation of resources, then private market will always solve the problem of externalities and allocate resources efficiently” (Mankiw 2004, p. 210). The bargaining process will include compensation for the parties that give up their rights to a good (Endres 2000, p.34). Fundamental to this approach is the allocation of the property right to one of the parties by the state or government. The allocation of the right to the polluter is called the “laissez-faire” principle. The affected party in the market will start the bargaining process and try to make the holder of the right pay for any externality. Allocating rights to the affected party is called the polluter pays principle, because the polluter, or user of the resource, has to try to buy the right to emit or pollute as part of their activity (Endres 2000, p.34). The initial allocation of rights determines who will benefit from the outcomes (Coase 1960, Cansier 1996). Potential problems with the Coase theorem include the possibility that bargaining can fail, that the transaction costs are higher than the benefit obtained by the process, or that the number of participants is too big to co-ordinate the process (Mankiw 2004, p. 212). The results of the process can also be inefficient if the legal, economic or public position of one of the parties or its level of access to information affects the bargaining process (Endres 2000, p.47).

Tradable permits

Tradable permits are an instrument that allows a public program to be more like a market based system. Different forms of systems can be distinguished based on whether permissions are handed out or auctioned, unrestricted or time limited. The basic idea behind permits or emission certificates is that each emitter or polluter needs permission certiciates equal to his pollution level. Costs of permissions or the benefit of selling them will influence his decision. The company with the lowest potential for economic return will sell its permits to other users with higher potential returns. From the economic point of view, this is even more efficient than the use of taxes, because price equilibrium will develop in the permit market. Decisions to buy or sell permits are based on the relative costs of reducing emissions. An individual activity's emission can be reduced to a required level, established by the number of permits initially allocated by the government (Mankiw 2004, p. 215). Tradable permits are well known from the Kyoto protocol, which aims to establish a market to trade carbon dioxide emissions and establish a fixed emission level based on the amount of emitted permits.

Liability

From an economic point of view, liability law can also be used for the internalisation of external effects. It is a legal implementation of the polluter pays principle. The body responsible for damage can be required by the law to pay compensation to the injured party. The extent of the payment should reflect the costs incurred by the injured party. The existence of the law will affect the actions of the parties using the resource. They may calculate possible damages to be paid and, depending on this calculation, act or refrain from action because of their legal liability.

The liability law has a more preventive aspect than do other methods. The two main principles required to make liability law effective as an environmental economic instrument are that all parties understand its provisions and that they have the ability to estimate the damage costs that they will incur in monetary terms (Endres 2000, pp. 67). Liability systems are also problematic if the externality has an inter-temporal character, or is caused by a bigger group of actors, so that an individual liability is difficult to assess.

Insurances

Risk insurance can be seen as a consequence of liability. Insurance payments are based on risk estimation, likelihood and expected cost of payments to the insurance company (Endres 2000, p. 88). "Indeed, insurance itself is one of the best working examples of an economic instrument. It involves the quantification of environmental risk and an explicit financial discouragement to high risk activities. Pollution insurance can be seen as part of a broader universe of economic instruments which act as direct financial incentives away from polluting processes." (Hawkins 2000, p. 381)

Insurance systems are also established for natural hazards like floods. German insurance companies established their own zoning system to allocate property to different risk zones. Flood insurances have, in contrast to other flood mitigation and protection measures, a steering function. Because of the rising costs for insurance in flood affected areas, land owners and buyers will also include flood related costs in the form of fees in their investment assessment.

2.3 The economy of water

From the economic point of view, water is an interesting resource. Its economic importance is often pointed out in technical literature.

> "Wasser ist eine sich erneuernde natürliche Ressource. Es ist der am meisten genutzte Naturstoff. Wasserressourcen sind Wasservorkommen (Wasserdargebot), die für ein bestimmtes Gebiet und einen bestimmten Zeitraum (Raum- und Zeitbezug) für eine gesellschaftliche Nutzung prognostiziert, ermittelt, erkundet oder erschlossen wurden, gekennzeichnet durch ihre hydrologische und ökologische Verfügbarkeit sowie die technisch/technologischeen und ökonomischen Bedingungen. [Water is a renewable natural resource. It is one of the most used natural materials. Water resources are water sources (water supplies), forecasted, estimated, explored and made available for a special area and restricted period of time (temporal and spatial connection), depending on hydrological and ecological availability and the technical/technological and economic circumstances]" (Dyck 1995, p. 80)

Water is not only a basis for human life, but also a major factor for economic development through food, industrial and energy production. Rivers, lakes and the sea support major transport infrastructure. Together with groundwater streams and artificial reservoirs, they provide the necessary water supply for agricultural and industrial production. Its kinetic energy is used for hydro power and its thermal abilities for coal, gas and atomic power stations. Wallacher (1999, p. 17) points out that industry, agriculture and food production are major consumers of water. The production of one litre of beer requires an average 60 litres of water, one kilogram of sugar 120 liters, and a single car 20,000 liters.

It is not only of importance to look at the use of water itself, but also the functions water bodies provide. Technical intervention and human actions in general do not only use the resource water, but lead to severe damages and irreversible changes in our environment. "Wasser wird heute zumeist als eine unter vielen Ressourcen angesehen, die für die wirtschaftliche Entwicklung eines Landes notwendig ist und die sich für diese Zwecke nach Belieben aufstauen, umleiten und vermehren läßt. [Today water is seen as one of many resources necessary for the economic development of a country and that can be detained, redirected and increased for this purpose.]" (Wallacher 1999, p. 165)

But the relation between water and society depends not only on economic development or the ecologic value, but also population growth and land use. Increased population needs more space for settlements and agricultural production, industrialisation for infrastructure and production sites. These aspects have severe feedback on the hydrological cycle, because they increase water consumption, reduce the infiltration capacity of soils and enforce the development of anthropogenic structures in the fertile and flat flood plains of rivers.

2.3.1 Classification of water use

Water use or the use of water bodies can be subdivided into direct and indirect use. Direct use includes all types of use where water becomes directly part of the product or is used in the process of production. Indirect use sums up all effects where water is influenced as a side effect of the production; where the water "use" has no direct impact on the success or failure of the production process and the resulting product. Examples of direct uses are hydropower, farming in connection with irrigation or washing water for vegetables. A typical form of indirect use is erosion on agricultural sites and surface run-off. Excessive rainfall does not play a role for the success of agriculture. During such events most rain water is lost, because of low infiltration and fast surface run-off. But through erosive processes because of agriculture and the transport of sediments, nutrients and pesticides the farming process influences the water bodies.

Water can be used physically and chemically. A typical form of physical use of water is hydropower. The elevation energy of water is transformed into motion energy in a turbine, which is transformed to electricity. In sewer systems, the transport capacity is used to remove sewage and waste. In power stations, water is used to cool the system or transfer heat energy via steam to drive turbines. Classical chemical uses are the ability of water to serve as a solvent, either for other chemical substances (colouring, nutrition,...) or for detergents to remove dirt.

A discussion about the use of water should evaluate two different forms of use:

1. Consumptive use, for example irrigation or thermal power station cooling
2. modifying uses such as discharge of waste water

Dyck (1995, p. 82) names the main functions of water bodies as:

- self-purification,
- biological potential yield,
- ecologic potential,
- transport of material (solids or solved materials),
- potential energy (kinetic energy, heat capacity),
- recreational use and
- flood routing.

We can use a scientific classification scheme for the use of water, water bodies and ecosystems:

- Physical use, like gravitational energy, flow energy, transport capacity for suspended and solid substances and temperature.

- Chemical conditions like solvents for substances and fluids.
- Biological conditions, like self-cleaning capacity.

Anthropogenic uses can be said to be:

- drinking,
- basis for food production e.g. for irrigation and fisheries,
- energy production e.g. hydro power or process water for other types of power plants,
- transport function and cleaning of sewage and waste,
- transport of goods e.g. shipping or timber,
- industrial production,
- recreation and tourism.

This listing of different economic views on the resource water already shows the difficulty of classifying water in environmental economic terms. As a result, no general statement can be made about the rivalry of water. Each combination of scientific use types must be assessed individually. We know, for example, that the influx of water used for cooling purposes in industry changes the habitat conditions. It also may increase the biomass production as a benefit for fisheries, but also may increase algae growth and decrease the recreation factor.

Besides the direct uses described above, indirect uses or better side effects can be discussed. For example, run-off increases as a consequence of land sealing or the diffuse pollution with agricultural fertilizers as a result of surface run-off and erosion. Both can cause externalities. While direct uses are mostly regulated, indirect uses or side effects are often overlooked or not analysed from an economic point of view.

2.3.2 Economically relevant characteristics of water

"Watersheds differ from air sheds, however, in such key aspects as confinement to a channel, nonuniform mixing, and downstream accumulation" (Thurston et al. 2003, p. 410).

Therefore the can be more easily privatized or turned into a private good. For an economic classification and valuation, a lot of information about the regional situation, but also in general the hydrologic system interrelation is necessary: How much water is necessary for human and natural use? How much water can be expected for an area and a specific period? What quality will the available water have? What is the most efficient way to use the resource? What must we do to protect the resource? Who will be allowed to use the resource, and in which way?

Its regional and temporal varying availability, the problem of ownership (often referred to as water being a public good) and its allocation, make it difficult to evaluate water in economic terms. Especially its importance for human survival opens the door for discussion about the possibility and ethical dimension of fiscalising water or restricting the use of water. Water also became an important political issue, influencing local developments and international relations, for example, in the Jordan valley, the Euphrates and Tigris areas (Wallacher 1999, Sadoff & Grey 2002, Green 2003, Bernauer 2002).

To economically evaluate the resource water, we must distinguish between the different stations of water in the hydrologic cycle, the conditions of the catchment, the different functions water, water bodies and water ecosystems provide, and water related services. In parallel, we have to take into account the question of access and rivalry of use types.

Access to water depends on the station within the hydrological cycle. Water as rain is an open accessible good and mainly depends on its spatial and temporal availability. Except impacts of local and global climate change, precipitation is of theoretical relevance for the evaluation of externalities. Land use, land ownership and its impacts on surface run-off and infiltration are more important. Precipitation can be collected, stored and drained so the access to surface or ground-water can be restricted (but also increased, referring to floods). With smaller permanent and temporal water bodies like drains, ponds and rivulets, storage capacity and ecosystems can be accessed by neighbouring land owners - therefore the access is restricted. Bigger systems like rivers, lakes and seas are open to more potential users, but can not be called openly accessible. In transnational river basins or lake catchments the access is or can be restricted and depends on the upstream-downstream situation.

From the perspective of rivalry of use, we have to distinguish between the different functions that water, water bodies and water ecosystems provide. Water provides a range of functions, like food, transport fluid and solvent, energy transporter and energy control (e.g. temperature/climate), like we have seen above.

The environmental and physical aspects of water bodies cause a lot of problems in the economic evaluation of water resources. Any limitation on the evaluation on individual river basins will also restrict the dependencies in cause-effect chains, and of the impact of individuals. In contrast to climatic processes, where a global perspective is necessary in a catchment, only local factors and uses must be taken into account. But because of the upstream-downstream situation in a river basin, an upstream user will only marginally be affected by their own actions, while downstream users have to deal with the full effect of upstream activities. This shows that a technical and economic evaluation is strongly affected by the evaluation scale used (Bergström & Graham 1998, Brouwer & Hofkes 2008). While an upstream use of water by an individual would normally not affect the individual himself, it could affect other individual users within the same region or state. Therefore, a transnational and international dimension exists in addition to local or regional scales (Bernauer 2002). While national regulations and actions have a national economic consequence, they can strongly affect the political situation between two states.

Each person upstream influences, or can influence, the quantitative and qualitative availability and the temporal and spatial distribution of water available for a downstream user. Acting and affected persons can thereby be individuals in small catchments, regions in medium size catchments or even countries in the catchments of big streams (e.g. in the catchment of the Danube, 19 countries are spatially involved).

Water users can be separated into three different groups as upstream users, downstream users and riparian users. While an upstream-downstream situation causes mainly uni-directional externalities, the riparian situation can cause bi- or multidirectional externalities. Typical forms of unidirectional externalities are sewage and waste disposal or water extractions in river systems (Green 2003). Bi-directional externalities are, for example, one-sided flood protection measures causing higher water levels at the opposite bank of the river system (Agthe et al. 2000). Downstream-upstream relations are not so common because of the physics of discharge. Only backwater effects provide one example on a local or regional scale. Physical aspects of water-related externalities are not well described in literature.

2.3.3 Water related externalities and internalisation strategies

“Die natürlichen Ressourcen sind unter ökonomischer Rücksicht zwar knappe Güter, werden in der Praxis jedoch nicht als solche bewertet.” [Indeed, natural resources are, from an economic perspective, scarce resources. In practice, they are not valued as such.] (Wallacher 1999, p. 165). The characteristics of water being a scarce resource and a public or common good leads to misuse of water and water bodies. Water and water bodies are used as production factors without taking into account potential alternative uses. This causes misallocations and damages. While the products are part of the economic system and allocated as private goods, the resource is available for free. Direct consumptive use of water is of relevance. Other forms of impacts on the resource water can lead to inefficiencies and externalities as well. Only particular direct uses of water or water bodies have been regulated to this date. Economic and market-oriented solutions are scarce, and mainly concern trading of water extraction rights (tradable permits) (Dinar & Subrahmanian 1997, Holden & Thobani 1996) or fees for emissions such as waste water fees (Kraemer et al. 2003, Sieker & Klein 1998).

Water scarcity and fresh water consumption

Most papers and theories in environmental economics discuss aspects of internalisation and allocation of fresh water as a scarce resource. They either address the efficiency of water use as potable water, or in irrigation systems or deal with rival uses.

The literature describes three rival types of water use:

1. Potable water as a scarce resource,
2. irrigation water and its efficient distribution, and
3. the rivalry between different use types such as the need for potable and irrigation water.

Qdaisa & Al Nassayl (2001) describe a fresh water pricing policy in Abu Dhabi and its effects on water use. Citizens of Abu Dhabi were charged a flat rate of 13.5 USD/month for water up until 1997. Campaigns to make users aware of the costs of water production using desalination and the value of the resource were not able to significantly reduce usage. A change to a metered system with a corresponding 290% increase in the price of water (calculated as a proportion of the average use of 650 $l/cap * d$ and the flat rate) resulted in a percentage reduction in consumption of 28.8%. It was concluded that only realistic pricing can lead to a responsible use of water.

Irrigation is a major focal topic of the World Bank. Johansson et al. (2002) describe different theories and samples of the allocation of irrigation water in different countries. The conclusion is that "efficient allocations will help meet increasing water demands". Water use for irrigation has many impacts on other sectors. It has to respect these users' uses. "There are too few theoretical or empirical GE studies that consider the broader, economy-wide implications of changes in the allocation of irrigation water" (Johansson et al. 2002).

Another aspect of the problem is the rivalry of different users. One major example (Holden & Thobani 1996) is the Aral Sea case in Kazakhstan, where most of the water from the two supplying rivers is now used to irrigate cotton. Once the fourth largest inland sea in the world, it is now running dry. Salinity and pesticide storms are destroying the ecological system, as well as the local fishing industry, which was previously the primary source of income and food supply in the region.

Different instruments were developed to deal with the problem of water scarcity and water allocation. An interesting example is given by the change in pricing policy in Abu Dhabi (Qdaisa, Al Nassay 2001) as described above, where most fresh water is produced by desalination plants. A new pricing system based on volumetric charges more than double the charge for an average user and caused a reduction in use of 28%. This experience is repeated in the World Bank Paper by Dinar & Subrahmanian (1997), who compared the water pricing systems of 22 different countries. They point out that policy makers often have different reasons for charging, including "cost recovery, redistribution of income, improvement of water allocation, and water conservation"(Dinar & Subrahmanian 1997). This shows that pricing systems interconnect with other political aims. For this reason, not all pricing and allocation instruments provide equality of access or efficient results. Holden & Thobani (1996) compared examples of centrally administered systems with tradable rights systems and concluded that a central administration leads to inefficient outcomes, unsustainable use and poorly operated public infrastructure. Systems for pricing irrigation water have a very old tradition in some areas of the world. Tsur & Dinar (1995) describe different systems of pricing irrigation water in developing and developed countries. They distinguished eight different systems ranging from volumetric charges "per unit area" to water markets. They conclude that "Pricing schemes that do not involve quantity quotas cannot be used in policies aimed at affecting income" (Tsur & Dinar 1995).

Water quality and pollution

In the year 2000, the European Water Framework Directive (European Parliament & Council of the European Union 2000) was published as a legal framework for river basin management and the protection and improvement of water bodies and water quality in the member states of the European Union. Its approach is to harmonise national actions in the water sector and implement principles of trans-national river basin management for all European rivers. Article 5 asks for an economic analysis of water use and Article 9 for the recovery of costs for water services. These requests are formulated more precisely in Annex VI Part B, which suggests a list of measures to adopt parts of the program including legislative instruments, administrative instruments, economic or fiscal instruments, negotiated environmental agreements, emission controls, codes of good practice and abstraction controls.

In its Water Framework Directive, the European Union takes into account the economic impacts of water use and pollution. The Directive claims that member states should "take account of the principle of recovery of the costs of water services, including environmental and resource costs" (European Parliament & Council of the European Union 2000, Art. 9). According to the Guidance Documents (European Communities 2003, p.32) for the implementation of the Water Framework Directive, the economic analysis should contain an economic analysis of water use, an assessment and forecast for key economic drivers to influence pressures, the assessment of the actual status of cost recovery of water services and an analysis of the cost-effectiveness of measures to achieve the goal of the good status for all water bodies. The cost recovery should not only include direct costs of services, but also environmental and resource costs.

In a lot of countries, waste water discharge is already regulated. Sets of instruments such as emission rights, the determination of emission levels and charge systems are established

(Green 2003, Kraemer et al. 2003). "It is necessary to differentiate between faecel waste and other streams for wastewater. It is also necessary to distinguish between the problems of removing waste streams and the treatment of that waste once removed. Removal typically enables the producer to externalise the costs of that waste by depositing that waste on other people or in the environment" (Green 2003, p. 259). Diffuse pollution is another type of emission that must be taken into account. Bismuth, Buschhardt, Diewitz, Dittmann, Eichler, Garber, Gerten, Gregor, Haase, Junker, Kremser, Locher, Möller, Nantke, Rechenberg, Rechenberg, Schablitzki, Schmitz, Schulz, Solms, Terytze, Voigt, Werner & Wiemann (1998) show the connection between human land use, floods and, as a consequence, the effects on the transport of loads and suspended solids. Although the main reason for these effects is not the removal of substances, they contribute to water quality problems as a side effect of agricultural production.

Länderarbeitsgemeinschaft Wasser (2002) points out in its common report of the "Federal Working Group on Water Problems" and the "Federal Working Group on Agrarian Problems" the negative effects of agricultural land use. About 70% to 80% of N and P discharge into German rivers originates from non-point sources and especially from agricultural areas. The paper points out that political and economical instruments used in other sectors can negatively affect the water sector.

Floods

From the economic point of view the problem of floods is not in the first point their existence, extent or severity, because floods are natural phenomena. From an economic perspective it is of prior interest whether or not floods conflict with human activities such as land use infrastructure or other values. If floods conflicts with human interests, this can result in significant damages and economic costs. It can be distinguished between four types of costs: direct and indirect as well as tangible and intangible damages (Merz 2006). Direct damages, such as damages to buildings, furniture or infrastructure, are caused by the impact of water to these structures and goods. Indirect damages can also occur in areas outside or far away of the flood plain. The interruption of infrastructure or transportation and the resulting consequences for energy supply, communication or logistics in other areas are typical samples. In contrast to tangible damages, such as damages to infrastructure, intangible damages are difficult or impossible to assess from an economic perspective. Examples are loss of life, injuries or diseases. In the following case study the focus will be on direct tangible damages. They represent the majority of costs in small rural catchments, provide an accurate basis for the assessment of flood costs and can be seen as a conservative but robust approach.

The Munich RE (2002) quantifies the overall damage caused by the 2002 summer floods in Europe at over 18.5 billion Euros. This level of damage indicates that flood insurance could play a regulative role in any new policies. The fees and the risk of incurring additional costs from smaller events, which do not attract governmental help or insurance money, provide an incentive for users to think about land use patterns and the flood hazard in residential areas (MunichRE 2002, p. 21). The authors point out that the high costs of floods during previous years were due to three factors:

1. settlement and agricultural land use in flood endangered areas close to rivers,
2. a lack of understanding by the public of the functionality and protection afforded by technical flood protection works and
3. human influences in the catchments that increased the severity and characteristics of a flood.

After these severe floods in Central Europe, the anthropogenic impacts on the river systems, especially the effects of land use and modifications to river channels, were debated. Bismuth et al. (1998) showed a correlation between human actions and floods in his study for the German Federal Environmental Agency. Especially in larger areas with a high density of population like the Rhine basin, interactions between the severity of floods and the sealing of areas and land use are now proven. As a consequence, international regulations and a change in environmental politics are necessary.

Maniak (1993, p. 10) and Dyck (1995, p. 433) address the effects of anthropogenic influences. Dyck (1995, p. 433) describes the enormous losses of detention along the Elbe river during the last 800 years. He points out that the efforts to compensate for these lost volumes through technical detention measures are insignificant. These human activities result in economic consequences for downstream riparian users. “Construction of a levee can channelize a river so that during flood stage the flow of water is swifter and sent downstream where it does more damage than if the upstream levee were not constructed. Thus, the decision of community X to construct a levee may impose an external cost on downstream community Y through greater flood damage, higher levee construction costs, or both." (Agthe et al. 2000, p. 253). The same idea can be applied to river training.

Most papers dealing with the problems of floods - particularly the economic damages caused by floods and the anthropogenic impacts on flood development - fail to account explicitly for the link between externalities and resulting economic damages. "The effects of land use like agriculture or settlement can also be externalities if they influence others e.g. increase floods or pollute rivers. Rivers and their catchment show an upstream-downstream dependency. Land use and increased run-off in the upstream area cause floods in the regions downstream. Flood damages can therefore be seen as externalities." (Dorner, Spachinger & Metzka 2005, p. 29)

"It has to be mentioned that also the development in settled areas increased the potential damage of floods. This makes it more difficult to separate land use induced changes in the flood regime and the consequences for potential damages." (Dorner, Spachinger & Metzka 2005, p. 29). The concept of internalising these costs or of splitting off the "external costs" from regular flood damage due to misuse of the flood plain were not found in the literature. The same situation can be found in the area of water protection and waste water discharge, where from an economic point of view, only point sources are in the focus of public interest. The relations between agricultural land use, erosion, sediment delivery and water quality are well known from a technical point of view. Although the major influences on water quality are diffuse sources, a link to the economic consequences of this type of externality is yet to be developed.

Some authors have referred to the externality problem of land use and surface run-off. Thurston et al. (2003, p. 409) distinguishes between four land use types; namely residential, commercial, industrial and agricultural. He suggests the use of tradable run-off permits to reduce storm water run-off in impervious areas to reduce excess storm water flow. Problems caused by impervious areas include reduced infiltration and consequently less water available for groundwater recharge and reduced base flow (especially during dry periods) and the transport of chemicals."A market-based tradable allowance mechanism for trading runoff reductions will be a practical and cost-effective method by which to assign dispersed runoff control throughout urbanized areas."(Thurston et al. 2003, p. 410). The authors see two kinds of benefits resulting from such a market mechanism:

1. to stimulate the most efficient technology to hold surface run-off,

2. to provide an incentive to operate the technology efficiently.

A similar approach (Umweltbundesamt 2001, p. 50) is used in German cities. Municipalities charge households for waste water discharge. In most cases, the fee is based on the fresh water consumption. Some cities recognised that the increasing amount of impervious areas leads to increased renovation and extension investments for mixed and split sewer systems. The city of Munich was one of the first communities to implement a split waste water fee. The first part of the fee is still based on the fresh water consumption of a household. The second part of the fee is calculated per squaremeter of sealed area. Especially the second part of the fee was intended to set an incentive for newly built areas to reduce impervious areas and for unsealing existing areas.

Agthe et al. (2000, p. 250) discuss the economic aspects of flood protection systems. "The demand for flood control is similar to that for other commodities except that the buyers and sellers are usually, but not always, public bodies." (Agthe et al. 2000, p. 248). The authors especially see misallocation effects due to flood protection works as a major problem. "Forcing developers to pay for levees would discourage development in flood prone areas and make the economic costs and benefits of choosing such a location more realistic and better reflect market forces." (Agthe et al. 2000, p. 252). They argue that flood control is only a public good under two conditions:

1. Costs and benefits can not be directly assigned to an individual and cause free rider effects.

2. The liability for the failure of structures will retard private investors and the good "flood protection" will not be produced.

Chapter 3

Methodology

Different approaches are used to estimate and quantify externalities. The calculation of damage costs, substitutes or costs for protection are established approaches (Umweltbundesamt 2007). In contrast to other forms of externalities, the assessment of floods regarding externalities of land use from the upper catchment provides an additional problem: floods are, in general, a natural phenomenon. Although floods increase continously on a spatial basis the related damage function increases in steps. The affectedness of a building, e.g. the basement or first floor, is prior a question of whether or not the building is touched by the flood. The basement can get filled or floors, walls and furniture of the first floor will be damaged independent of the water level. Later flood damages per building increase depending on water level. Therefore flood damages can either be

1. the result of a flood as a natural phenomenon, if the flood is not altered by any human impacts,
2. "pre-existing" flood damages can be increased through human alterations, if these alterations increase for the example the peak of flood, or
3. flood damages can be the sole result of anthropogenic impacts in the upper catchment, if human values would not have been affected by a "natural´´ flood.

The first case can appear if an object at risk is situated in the natural flood plain and the increase of the flood due to human land use is not significant. Case two will appear if an object is situated in the natural flood plain, but a flood is significantly amplified by land use. If alterations in land use extremely influence the hydrology of the catchment, buildings outside the natural floodplain can also be affected - like in case three.

This means that the effects of anthropogenic alterations must be split from the natural flood. This already shows a second problem. The intensity of a flood event is not only dependent on the hydrological reaction of the catchment, but also on the probability of the storm event. It must be assessed how run-off, discharge and related costs will change under similar precipitation and initial hydrological conditions, but with altered land use and landscape structures. Therefore, a comparison of design storm events is necessary to derive the costs of the status quo of land use as well as those of a pristine catchment. The difference of these costs would represent the externality of land use, the costs tranferred from land users in the head water to downstream riparians. Statistical and measured data are not suitable tools and do not offer sufficient spatial and temporal distributed data to perform such an analysis. Hence, a combination of computer models will be necessary to apply the methodology to a catchment.

In flood risk management, the combination of hydrological, hydraulic and economic methods is widely applied (Brouwer & Hofkes 2008, Correia, Rego, Saraiva & Ramos 1998, Molner, Burlando & Ruf 2002, Zerger & Wealands 2004). Models have also been applied to estimate the effects of land use changes on run-off (Auerswald 2002, Bismuth et al. 1998, Bormann et al. 1999, Debene 2006, Lammersen et al. 2002, Niehoff et al. 2002, Scheidleder et al. 1996). A combination of both approaches to simulate the effects of land use changes on flood risk and to draw conclusions regarding externalities has not yet been applied. The coupling of hydrological, hydraulic and economic models and methods can provide evidence for the existence of land use related externalities. Using sensitivity analysis and scenario analysis, effects can be traced back to distinct model parameters representing different types of land use and landscape structure as causes. The accuracy of results underlies several constraints and restrictions. In particular, these are type and approach of the chosen models and their combination as well as the parametrisation of input data and handing over of data between the models, as well as calibration.

In the following sections, several individual categories of models and modelling approaches are presented which could be used to assess the externalities of land use from the perspective of quantitative hydrology. In the chapter "Case Study", a distinct modelling approach is selected, presented in detail and applied to a test catchment.

3.1 Background

The Umweltbundesamt (2007, p. 53) describes a standardised approach for the analysis and evaluation of externalities in Germany. The authors propose a methodology in seven steps:

1. definition of objectives
2. specification of the subject of analysis and the boundaries of the system
3. description of impacts
4. description of cause-effect relations
5. allocation of economic benefit and cost categories
6. economic interpretation of resulting changes in benefits
7. interpretation and comparison of damages with internalised costs

In this particular case, the objective is to identify and quantify the effects of land use on flood behaviour and related costs for downstream land owners and land users - which can be referred to as externalities. The boundaries of the system are defined by the natural border of the catchment. For meso scale catchments, it will be assumed that human impacts did not significantly modify these boundaries.

To show the effect of land use changes on discharge and to identify the related externality, it is necessary to link activities in the catchment with the effects downstream quantified in monetary terms. These hydrological processes in the wider catchment must be linked to discharge in the river channel and the development of floods in the floodplain. The impacts of these floods have to be estimated in monetary terms to quantify the amount of the externality.

In principle, two different approaches could be used to provide the necessary data:

- Comparison of measured and mapped data and
- computer-based modelling of hydrologic and hydrodynamic processes and economic effects.

For this purpose, measured data is insufficient. Intensive land use developed over the past 50 to 100 years. Although hydrological and measured data would be available for this space of time, it would be difficult to find sufficient flood data like water levels, extent of flood plains or flow velocities. Even from a hydrologic and statistical perspective, this short period would be insufficient to provide evidence for the effects of land use change on frequent, rare and extreme flood events.

Especially in smaller catchments where the impact of land use on discharge and flood development seems to be more significant, measured data and longer time series are often not available. Hence, no statistical analysis of hydrological and flood data can be performed for the pre- and post-land-use change period.

The idea to identify and quantify unidirectional externalities in river basins makes it necessary to solve interdisciplinary problems. This study connects hydrology and environmental sciences with engineering methods and economic analysis. In the first step, different answers to environmental questions must be found. The first hypothesis of this study (that upstream land use increases flood waves) can not be proven using statistical data. Changes in land use and landscape structures happened in central Europe over the last 2000 years. Only the status quo of climate, land use and run-off can be evaluated using statistical and topographic data sets from the last 50 to 200 years. For small river basins, no detailed recordings about discharge and precipitation pattern are available. The analysis of historic maps and recordings, but also paleontologic studies, gives us a very detailed idea how the landscape looked. This allows assumptions to be made about land distribution, agricultural techniques, typical vegetation and natural river structures. This data can be input for different types of computer models.

Combining different types of scientific and engineering models provides a general approach to identifying changes and developments in the natural and built environment. Molner et al. (2002) describe a framework for an integrated, physically-based catchment modelling system. It consists of hydrological, hydrodynamic, morphological and ecological models. They assess the long term effects of changes in the catchment of the river. Their aims are to identify which consequences in the river are man-made, what the interactions of different factors like quality and quantity are and how human impacts can be avoided. The core of their assessment is to be done through simulation with computer models. They mention the definition of important parameters that must be assessed and the need to combine different models at differing temporal and spatial scales as special problems.

Hydrological models deliver quantitative data about the development of flood waves. They allow different land use scenarios and river structures to be simulated in a computer model. Results indicate how changes in the landscape influenced run-off processes and affected the peak, shape and volume of flood waves. On a catchment scale, but also for subsections of the catchment, they show how a flood wave is fed by surface run-off and other sources, how the catchment structure influences run-off processes and how waves from different reaches superimpose or follow each other. They do not allow conclusions about the spatial distribution and the extent of a flood in the flood plain e.g. in a settled area.

Hydrodynamic models can use these data sets of flood waves as input to simulate the distribution of flood waves in spatial structures. The landscape is represented as a digital elevation model including the river channel, surface structures and buildings. The model can calculate the extent of a flood, water levels and flow velocities for this digitized landscape.

These data can then be used for the first step of economic evaluation. The knowledge of affected structures like buildings or infrastructure in combination with the corresponding water levels offers the possibility to derive the related damages for each scenario. A comparison of the different land usage and run-off scenarios is now possible from an economic stand point. This shows how a practical interaction of models can be used on a large scale.

Only a few combinations of scientific and economic models of river basin management are described in the literature. For the design of flood protection works, combinations of hydrologic, hydrodynamic models and cost-comparison method are used. In flood risk management, such combinations are applied for risk assessment and risk mapping (Büchele, Kreibich, Kron, Thieken, Ihringer, Oberle, Merz & Nestmann 2006, Hall, Meadowcroft, Sayers & Bramley 2003, Thieken, Müller, Kleist, Seifert, Borst & Werner 2006, Zerger & Wealands 2004). Insurance and reinsurance companies also combine simplified engineering methodologies and economic assessment tools on a large scale to identify potentially flooded areas and associated risks.

Studies of SwissRE (1998) and MunichRE (2004) draw an interesting picture of the aspects of floods. Except for the loss of human life or the deposition of toxic substances, floods are mainly viewed from an economic perspective. German insurance companies have developed a system of risk zoning for their own purposes. It categorises settled areas along 55.000 km of river systems in Germany into three different zones, based on flooding probability (average recurrence interval). Annual fees for flood insurance policies are based on this risk-zone estimation, in combination with insured value and exposure to floods.

The concept of combining different types of models was tested on the Herzogbach catchment. The models, described later on in detail, were developed to simulate different situations of land use in the test catchment. Responsible human impacts in the catchment, like land use and river training, were identified for the study site. As a main approach, different scenarios of land uses and river structures were used to detect the effect of land use practices and other influences on the earth bound part of the hydrologic cycle. The focus in the upstream part and middle section of the catchment was on the changes in agriculture, which influenced the hydrological characteristics. Downstream, the development of urban settlements was investigated to estimate the flood damages and mitigation costs. The scenarios simulated compared the status quo to a number of different alternatives, including a pristine catchment or river without any human influences, as it existed before humans started to act in the region.

The impacts of conflicts in usage were worked out and technical parameters identified as measures of causes and impacts. External costs were calculated, for example, by estimating the average costs of flood damage. Direct tangible costs, which can be calculated and estimated easily, were the basis of the calculation of external costs. But also some approaches to integrate intangible and indirect costs could be evaluated. In the last step, different instruments of internalisation are proposed. The comparison of different land use scenarios will make it possible to split human induced and the regular costs of purely natural events.

The models adopted for this project interacted by exchanging data with each other. The hydrological model calculated the main run-off data in the river at specified nodes, depending on land use scenarios, river bed structure and precipitation. The hydraulic model used the run-off at the nodes to calculate the flood situation in settled areas. Outputs were the exact size of the flood plain, flow velocity and flow depth for all points of the flood plain. Empirical formulas for costs and damages were used with floods of different recurrence intervals to establish average costs per year. The parameters, structures and mathematical and physical formulas behind the models are described in detail in the Chapter Case study. The general approaches and available disciplinary concepts of modelling and analysis are described in the following sections.

Two types of hydroeconomic modelling approaches can be distinguished (Brouwer & Hofkes 2008):

- the integrated approach and
- the modular approach.

Economic assessment, as well as hydrological and hydraulic modelling, can take place at different levels: micro, meso and macro level. Based on the chosen problem area, different methodologies and approaches are available. With regards to integrated economic and environmental assessment one problem is the different perspectives. While hydrological problems are mostly modelled on a catchment scale regarding the geographic characteristics of a region, economic data is available for administrative regions, and mostly at a different scale (Brouwer & Hofkes 2008).

3.2 Hydrological Modelling

The main intention of this study is to identify the impact of land use and river development in the headwater on people and property in the lower reaches of the catchment. Because of the long history of land clearance and agricultural development, there is insufficient statistical hydrological data available for a statistically-based analysis of the historical development of land use in small catchments and its impacts in the lower reaches.

Hydrological models simulate the run-off development in a catchment based on statistical or real time precipitation values. Input data include the duration and intensity of precipitation and the state of all surfaces in the catchment as defined by slope, surface roughness and soil conditions. For areas that lack recorded water levels, such models provide the design data to develop flood mitigation systems, in particular the volume and temporal information needed for the design of retention basins.

> "Hydrologische Erscheinungen, wie der Ablauf von Hochwasserwellen, können nach Methoden der Systemanalyse untersucht werden. [...] Es [das hydrolg. System] kann bestimmte Eingaben z.B. Niederschläge aufnehmen, sie transformieren und als Ausgaben z.B. Hochwasserwellen, ausgeben. Das Ergebnis (output) wird von der Eingabe (input) oder Belastung sowie von den Übertragungseigenschaften des Systems beeinflußt, welche mit Hilfe von mathematisch-deterministischen Modellen simuliert werden können." [Hydrologic events, like the development of a flood wave, can be assessed using methods of System Analysis. ... It (Annotation: The hydrological system) can use special input data like precipitation, transform it and display results like the flood wave. The result (output) is influenced by the input or load, as well as the transmission function of the system, which can be simulated using mathematical deterministic models.](Maniak 1993, p. 263)

Two concepts of hydrological modelling can be distinguished (Chiew, Stewardson & McMahon 1993):

- Black box models,
- process models.

While black box models use empirical equations, process-oriented approaches describe several physical processes through the relevant differential equations (Chiew et al. 1993).

By the spatial resolution of parameters, two types of hydrological models can be differentiated (Correia et al. 1998):

- distributed, where parameters are spatially distributed within the observation area;

- lumped, spatially independent representation of input parameters for the modelled observation area.

Beven (1989) sees several problems to use physically-based hydrological models. He mistrusts especially the application of these models for prediction and modelling of larger river basins. "We know that the descriptive equations that underly these models are good descriptors of processes occurring in well defined, spatially homogeneous, structurally stationary model catchments and hillslopes in the laboratory. We can feel less assured that those equations may describe the complex three-dimensional spatially heterogeneous and time varying system that is a real catchment." (Beven 1989). He sees problems in the use of physically-based models for predictions.

Chiew et al. (1993) compared different types of modelling approaches regarding their efficiency. In comparison to simple polynomial, time-series and process equations, conceptual modelling approaches gave the best results. They suggest using simple polynomial and time series equations for the estimations of monthly and annual flows. Conceptual models have been shown to provide better results for daily flows - especially under wetter conditions.

Bergström & Graham (1998) discuss the scale problem in hydrological modelling. Due to the problem of gathering detailed data and the heterogeneity of larger catchments they suggest using conceptual modelling approaches. They point out that conceptual models are quite insensitive to scale problems.

A special approach in conceptual models is regionalisation. "Regionalisierung ist die regionale Übertragung oder flächenmäßige Verallgemeinerung (Generalisierung) einer Größe oder einer Funktion (dieses Modells) bzw. der Parameter dieser Funktion (dieses Modells)." [Regionalisation is the regional transfer or spatial generalization of a dimension or function (of the model) or the parameters of this function (of the model).] (Dyck 1995, p. 74). It is necessary to first split off the effective precipitation, relevant for surface run-off, from the total rainfall and subtract losses from evapotranspiration and infiltration. If experiences with parametrisation and a sufficient amount of measured data are available, regionalisation as a conceptual lumped approach provides a suitable tool to build up catchment models for small, ungauged river basins (Plate, Ihringer & Lutz 1988).

Besides the simulation of the status quo, it is necessary to derive several alternative scenarios and especially the simulation of a pristine catchment without any or a reduced amount of anthropogenic alterations. Scenarios could include the following modifications to the status quo:

- Land cover,
- landscape structures such as hedges, ditches or boundary ridges,
- length of the river channel,
- profile of the river including shape of the flood plain.

For a sensitivity analysis it is necessary to have a model which distinguishes between surface run-off and channel run-off (flood routing) and offers the possibility to model reservoirs. So the different types of alterations regarding land cover, surface structures, channel structure and flood plain as well as technical detention as a substitute for natural detention could be evaluated individually.

A feasible approach would be to subdivide the catchment into sub-catchments and apply the regionalisation approach to these sub-catchments. Subunits are connected via river channels modelled with a flood routing approach. Existing and planned reservoirs can be integrated to simulate the effect and efficiency of technical detention and to compare it with lost natural detention volumes. As input data statistical design storm events can be used.

3.3 Hydrodynamic modelling - identification of the flood plains

To evaluate the spatial impact of floods it is necessary to have a distinct knowledge of the flood and its parameters, such as extent in the floodplain, water depth and flow velocity. Although different earth observation services (EOS) and technologies provide data about inundation and extent of floods (Horritt & Bates 2002, Horritt & Bates 2001), this data is not sufficient:

- Hydrological design events are not covered,

- resolution of earth observation data is not sufficient (Horritt & Bates 2001),
- the number of events covered and time span are insufficient,
- scenarios calculated using hydrological modelling approaches as design events are not represented by EOS data.

Hence, modelling approaches are necessary to estimate the spatial distribution of discharges of flood events calculated by the hydrological models. Four types or concepts of hydraulic and hydrodynamic modelling can be distinguished to get this spatial information:

- Raster based approaches,
- 1D hydraulic models,
- 2D hydrodynamic models,
- 3D hydrodynamic models.

For integrated flood risk modelling, several combinations of raster based, 1D and 2D approaches with hydrological approaches and methods of risk assessment can be found in literature (Bradbrook, Waller & Morris 2005, Correia et al. 1998, Hall et al. 2003, Zerger & Wealands 2004)

Also, simple GIS and raster based methods are described in literature, which are used to describe the filling of landscape structures by flooding using digital elevation models (Krüger & Meinel n.d.). Because they can not represent the hydrodynamic situation at intersecting buildings and do not reflect the effect of land cover on water flow and height, they have not been taken into account.

Hydraulic computer modelling numerically solves complex stream flow equations to calculate the water level and direction of the stream flow for a defined terrain and flow. Outputs can be presented as tables of water level, direction and velocity, but also as maps of flooded areas showing water depths in different colours. Hydraulic models help to identify flood endangered areas and allow the assessment of protection mechanisms like levees, dams or bypasses to be checked.

Horritt & Bates (2001) compared raster based approaches and 2D hydrodynamic models. They showed that raster based and finite element approaches can both represent the situation in the flood plain well. But raster based approaches are restricted in their ability to solve more complex hydraulic situations in the river channel itself. Horritt & Bates (2002) compared 1D and 2D modelling approaches. They conclude that both types of models can be used to model flood extent as well as flood wave travel times. They see 1D models equal to 2D models, if water surfaces are extrapolated against a high resolution digital elevation model. Results can not generally be transferred to other situations because the case study was only applied to one river with a quite narrow river valley and a small flood plain. The authors assume that in wider floodplains, 2D models may prove more effective.

1D models are simple to use, but neglect the spatial character of flood hydraulics (Horritt & Bates 2001). Especially complex situations of the river channel itself (bend, intersecting buildings), and of varying land cover in the wider flood plain, are difficult to model.

The selection of models to detect flood prone areas is a difficult task because the type of model (2D or combined 1D and 2D models), the area (topography, multiple flow paths) and the type of run-off (waves or bores) have to be recognised. Especially in settled areas where different flow paths are possible, simplified models can lead to large errors (Leopardi, Oliveri & Greco 2002). 2D models provide better results in small channel structures and under complex discharge situations, like built-up areas in the foreland and structures in the main river channel. Horritt & Bates (2002) use friction parameters to calibrate the model against a real event. They see advantages in 2D models because of better distributed friction parametrisation.

3.4 Estimation of flood damages

3.4.1 Categories of damages

Flood damages and types of damages rang from damages to objects through the interruption of transportation-systems to immaterial damages.

“Der Begriff Umweltschaden umfasst sowohl Schäden an Gesundheit und Eigentum (traditioneller Umweltschaden im juristischen Sprachgebrauch) als auch den erweiterten Umweltschaden (ökologischer Schaden, z.B. Schäden an der Artenvielfalt). Die Beantwortung der Frage, ob – und falls ja in welchem Ausmaß – ein Umweltschaden vorliegt, muss sich sowohl auf naturwissenschaftliche Erkenntnisse als auch auf gesellschaftliche Wertungen stützen. [The term environmental damage covers damages to health and environment (traditional environmental damages in a juristic usage) as well as extended environmental damages (ecological damages, e.g. to biodiversity). The answer to the question, whether - and if so, up to which extent - an environmental damage exists, has to be supported by scientific results as well as societal valuation.]" (Umweltbundesamt 2007, p. 7).

Kelman & Spence (2004) separate indirect flood damages like business interruption or changed spending patterns from direct damages caused by forces, pressure or chemical reactions to objects or persons.

> "Moreover, tangible damage is further divisible into two subtypes (i.e. direct and indirect damage). Direct damage is the damage caused to items (e.g. buildings and inventory items) by contact with or submersion in water. In contrast, indirect damage is the damage caused by the disruption to physical and economic linkages, and includes such things as the interruption of traffic flows, loss of personal income and business profit, as well as such consequences of flooding as, for instance, the cost of alleviating hardship. Direct damage can be calculated by using the damage curve, which describes the relationship between the two main flood characteristics (i.e. depth and duration) affecting the property and the damage suffered per establishment. In general, the same flood depth causes different flood damage to different types of land use." (Lekuthai & Vongvisessomjai 2001, pp. 345-346)

Flood damages are normally subdivided in four different categories (Merz 2006):

- Direct damages
  - Tangible damages (e.g. to buildings, furniture, cars)
  - Intangible damages (e.g. loss of life)
- Indirect damages

  - Tangible damages (e.g. interruption of transportation and communication systems)
  - Intangible damages (e.g. epidemics)

Indirect damages and especially indirect intangible damages are difficult to assess. Different methodologies have been derived to calculate or estimate indirect damages, for example as a percentage of direct damages:

> "indirect damage can be determined, as it is usually considered to amount to a fixed percentage of the direct damage." ... "values for indirect damage (formulated as a percentage of direct damage): 15% for residential land, 35% for commercial, 45% for industrial and 10% for agricultural." (Lekuthai & Vongvisessomjai 2001, p. 347)

The approach suggested by the German Federal Environmental Agency (Umweltbundesamt 2007, p. 41) for the assessment of externalities goes beyond the estimation of damages. It names and structures the potential costs resulting from externalities or their internalisation as:

1. Damage reduction costs
   - direct costs (Renovation and reconstitution)
   - indirect costs (adaptation or avoidance)
   - costs of prevention
2. Costs of uncompensated environmental and health damages
   - costs of additional measures to reduce damages
   - costs of uncompensatable damages

Also, compensation of damage reduction costs as a possible alternative or extension are included. The classical approach for the evaluation of efficiency of flood protection works differs from the assessment of externalities. In flood protection studies the cost-comparison or cost-benefit method (Schmidtke 1981) is used to assess the efficiency of a project or different scenarios against the status quo without flood protection. Flood damages and building costs are weighed against each other for a defined period (in Germany 100 years (Länderarbeitsgemeinschaft Wasser - LAWA 1998)). The scenario with the most efficient outcome will be chosen. If the building costs significantly exceed the prevented damages, the project would not proceed. The effects resulting or causing externalities are often ignored. Following Umweltbundesamt (2007) these additional types of costs could be found from an analysis of flood-related damages and costs related to flood risk management:

1. Damage reduction costs:
    - Costs for technical structures like levees, walls and dams,
    - resettlement of infrastructure or buildings,
    - implementation of flood resistant building standards,
    - declaration of flood plains and restriction for buildings.
2. Costs of uncompensated environmental and health damages:
    - Insurance costs,
    - effort for disaster control,
    - costs for residual damages.

Because floods also have a natural non-human component (floods as a natural phenomenon), the full damage costs can not be used for the estimation of externalities. The costs resulting from protection against or the damages of natural flood events must be subtracted from the costs of a flood event increased by human activities. Only the costs caused by human alterations in the upper catchment are transferred to stakeholders in the lower section. Other costs or damages are the result of a misallocation of land use in the lower reach or the risk or mitigation of natural disasters.

The list above shows that the structure of costs resulting from flood related land use externalities is very complex. It is difficult to estimate all types of indirect (tangible and intangible) and direct intangible damages, like business interruptions, loss of life and casualties. In literature, different approaches can be found for handling these cost categories.

But these approaches either refer to assessments on a larger scale or require comprehensive data from local surveys.

For the assessment of hydrological externalities of land use, three different methods could be applied:

- Damage costs: assessment of flood damages as a result of land use, using the difference between the costs from floods resulting from the status quo of land use minus those from a natural catchment.
- Substitutional approach: costs for technical flood detention to compensate the loss of natural detention
- Costs of avoidance: building costs for technical flood protection such as levees and walls

3.4.2 Relevant factors

The SwissRE (1998) uses six factors to estimate the possible losses in an area affected by floods:

1. Depth of water,
2. flow velocity,
3. surge effects,
4. transportation of debris,
5. speed of rise and
6. standing period.

Also, Kelman & Spence (2004, p. 297) mention a similar list with water depth, flow velocity, bed shear stress, dynamic forces (flow momentum, stream power, depth times speed), rate of flood rise, debris potential and flood duration as the main parameters of hazards:

"Flood actions may be energy transfers, forces, pressures, or the consequences of water or contaminant contact." (Kelman & Spence 2004, p. 297)

To assess the risk of natural disasters, the MunichRE (2003) developed a risk index and evaluated the situation of 50 global mega-cities. The components of this risk index are:

- Risk and its likelihood,
- the possible impacts of disasters, like types of buildings, protection measures, quality and density of infrastructure,
- the exposed values as a combination of domestic values, GDP and global importance.

3.4.3 Level of detail and data gathering

The methodologies to assess potential flood damages range from mapping of buildings including age, structure, material and furniture on a small scale (Büchele et al. 2006, Kelman & Spence 2004), to large-scale assessments using statistical and national accounting data (Kleist, Thieken, Köhler, Müller, Seifert, Borst & Werner 2006, Thieken et al. 2006). This study attempts to use meaningful economic data to restrict the complexity of the problem. The majority of buildings in the flood plain are detached houses or functional buildings or a combination of these as farm houses. Detached houses usually have a basement and the first floor is about 0.1 m above the natural surface. Functional buildings such as barns and garages are accessible and situated at ground level. These assumptions, based on German building standards and planning practice, were evaluated by field surveys.

3.4.4 Flood damage functions

Total flood damages of an object or a village over a certain period depend not only on affected buildings and discharge, but also on the probability of discharge.

> "The total damages caused by periods of recurrent flooding (flood return periods) are utilized to determine the probability-damage relationship [..] At the same time, this curve presents the flood damages incurred for different intervals of

> recurrent flooding (flood return periods). The expected annual flood damage can be determined from the above probability-damage curve. [..] the expected annual flood damage is the damage divided by its return period, or the damage multiplied by its exceedance probability." (Lekuthai & Vongvisessomjai 2001, p. 357)

The accumulative effects of low losses with a high probability can exceed the damages of a high loss and low probability event. For example, a five year flood event occurs statistically 20 times during 100 years, while a 100 year flood event occurs only once.

For the calculation of potential flood damages over a certain period, two functions are necessary (Schmidtke 1981):

1. The distribution function of the flood peaks as a result of the hydrological model or statistical analysis of stream gauging.
2. The flood damage function as a result of hydrodynamically simulated discharges and damage analysis.

The following function can be used to calculate the estimated flood damages over a certain time period (Schmidtke 1981):

$$S = \int_{Q_A}^{HHQ} S(Q) * h(Q) * dQ (Euro/a)$$

$S(Q)$: Damage function (Euro/flood event)

$h(Q)$: Density function of flood peaks $(NumberofEvents/a * m^3/s)$

Q_A : lower boundary of damage inducing flood events

HHQ : maximum flood event

A distribution function for flood peaks or for flood damages is not always available. Often, both functions are described as a set of data points for probability, discharge and flood damages. For example, as the results of the above described combination of hydrologic and hydrodynamic models with damage analysis. The function can be solved by approximation (Schmidtke 1981):

$$S \approx \sum_{i=1}^{n} \frac{s_i + s_{i+1}}{2} * \frac{h_i + h_{i+1}}{2} * \Delta Q$$

i : discharge interval

s_i : damages for interval i

h_i : number of events per year times discharge for interval i

Chapter 4

Case study

Because of the complexity of the analysis of processes in the catchment and the flood plain, this case study will concentrate especially on the items 1 - 4 of the Umweltbundesamt (2007) methodology mentioned above. This project applies this methodology to the situation in a test catchment.

For the choice of the test catchment, a number of criteria were defined:

- Significant human land as a percentage of catchment area.
- Different types and sizes of housing and urban estates.
- Availability of basic data for modelling, as well as measured data for model calibration.
- Availability of historical data and current data of land use and river system.
- Size of the catchment between 20 and 100 km^2 to be manageable from a modelling perspective.
- Easy to access and reach for data collection and surveying.
- Prototypic for a number or a class of catchments.

Each development of a computer model needs resources and input. For the presented approach, three different models and methods must be prepared and combined. Because of the complexity of modelling and the necessity to show first the significance of anthropogenic alterations, effort and expenditures have to be relatively efficient and must provide robust results. In the presented case study a methodology is applied that uses and alters only two parameters which can definitely be quantified and parameterised:

- Land use, represented by land cover by an approach similar to the CN values of the SCS modelling approach as part of a hydrological regionalisation approach,
- length of the river channel and slope of the river bed in the flood rooting approach.

These parameters can be measured or interpreted from current and historic maps. Other alterations and the pristine situation in the catchment, such as modifications to the terrain, historic river profiles or small scale structures in the landscape could only be guessed from historic data. Hence, the presented approach provides a conservative estimation of impacts of anthropogenic alterations to the hydrologic situation.

4.1 Herzogbach river basin

The Herzogbach basin was chosen after a first assessment because it seemed to fulfill most criteria such as availability of historical and current data, significant land use, accessibility as well as prototypic land use and land use pattern. It is difficult to find meso scale catchments between 10 and 100 km^2 catchment size where gauged data is available as a long time series. There are three reasons, why the Herzogbach catchment was the choice for this project:

1. The catchment is situated at the border between two landscapes representative for the Alpine Upland. While the upper part of the catchment is situated in the tertiary hilly landscape the lower part is located in the Gäuboden.
2. Both landscapes are intensively cultivated and have undergone significant changes of land use and landscape structures over the past 50 years.
3. Availability of significant flood marks as well as measured data of a one year time series.

The different aspects of the region and landscape are now described in detail with regard to the key parameters relevant for this study.

4.1.1 Geography

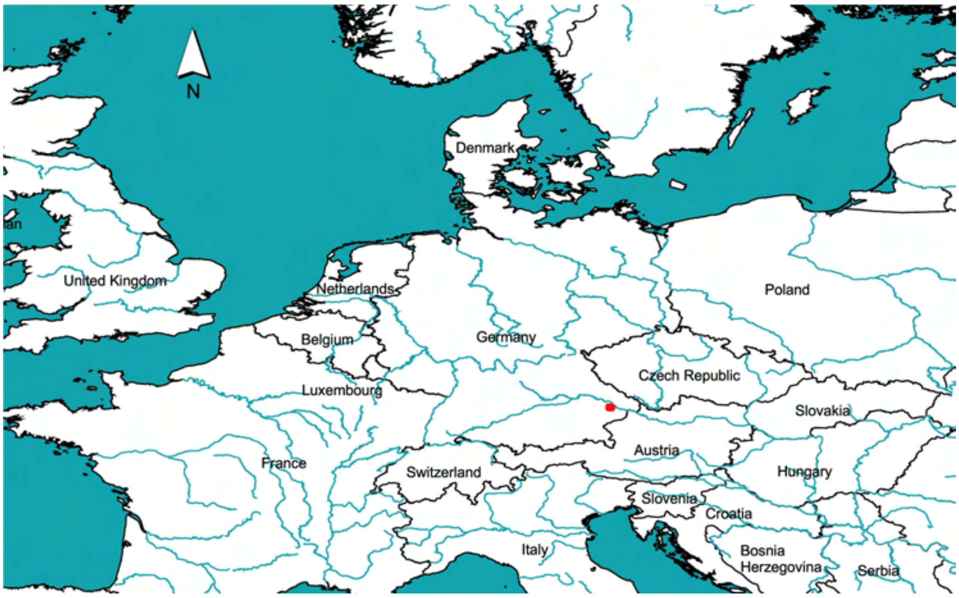


Figure 4.1: Countries and streams in Europe. (Red dot: location of the project area)

The Herzogbach catchment is located in southern Bavaria (Germany) (Figures 4.1 and 4.2). The main river reach has a length of about 20 km and a catchment size of 72.1 km^2 (53.9 km^2 above Osterhofen). It flows from west to east through a hilly landscape. The Herzogbach and all its tributaries originate in the southern hilly landscape. The areas in the upper reaches have a rural structure with about 80% agriculture and 5% forestry. Settlements are mainly located in the flat depressions along the rivulets. The lower reach passes through the city of Osterhofen, where in the past major floods have caused severe damage. The Herzogbach ends in the floodplain of the Danube and has its outlet into the Danube near the city of Vilshofen at the Danube.

The outlet is located at an altitude of 306m above sea level in the Danube valley, whereas the highest points are located in the tertiary hilly landscape in the south east of the catchment at an altitude between 400 and 410 m above sealevel.

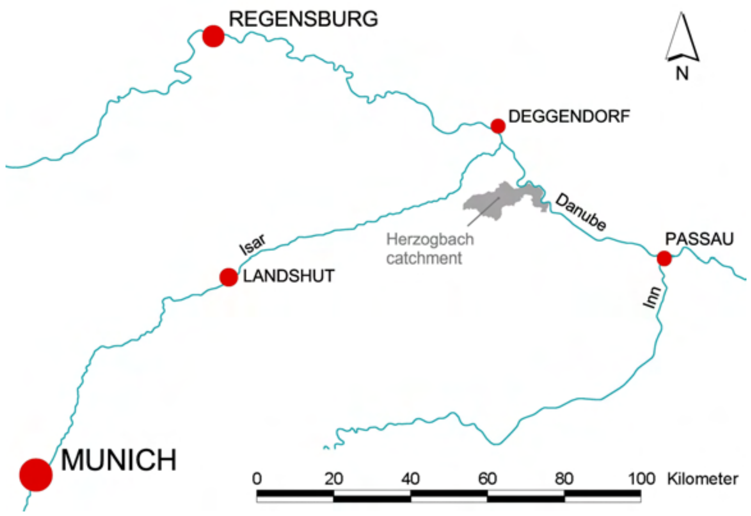


Figure 4.2: The northern part of the Danube catchment in Bavaria. (grey area: location of the project area)

The quality of the river is influenced especially by non point sources in the rural areas. Fertilizers, soil erosion after heavy rainfalls and erosion of the river bank are the major reasons for the bad water quality and sediments. Three water treatment facilities with a capacity of about 4,000 units, one unit equal to the effluent of one inhabitant, clean the water for almost 96% of the residents in the catchment.

The flood situation is dominated by two major human influences:

1. agricultural land use close to the bank, combined in most cases with river training to gain more arable land and

2. settlements close to the river in combination with a loss of retention volume.

The Herzogbach catchment is located in a geologically interesting area (Figure 4.3). It is mainly part of the Molasse Basin in Central Europe. This basin reaches from the Swiss Molasse Basin around Lake Bodensee towards the Viennes basin and is a debris basin north of the Alps (Henningsen & Katzung 1992, Liedtke & Marcinek 2002, p.150). The springs of the Herzogbach are located in the Tertiary Hilly Landscape in the south of the catchment. Steep slopes are characteristic for this region. The reaches are steep and elongated, but

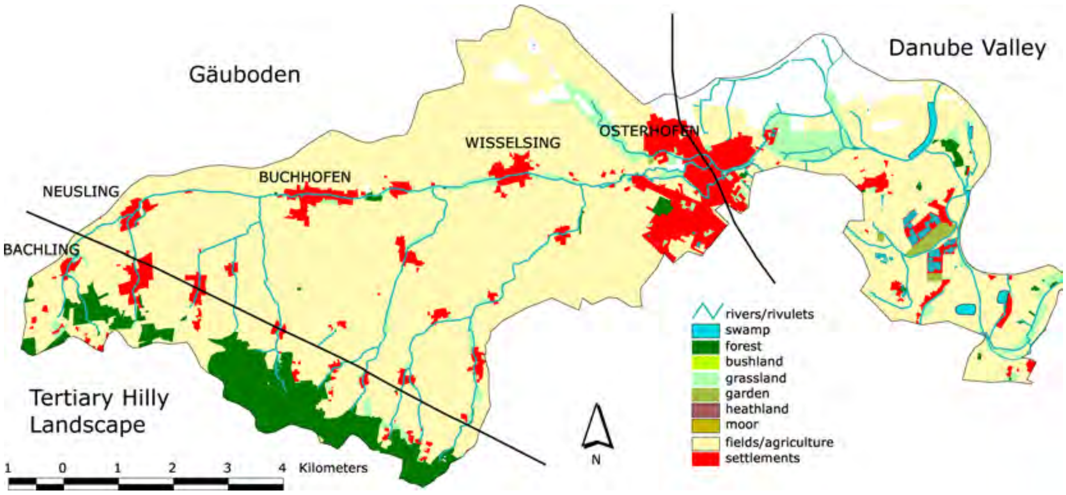


Figure 4.3: The Herzogbach catchment and its land use.

because of the catchment size, at this part still small. The main river reach is part of the Gäuboden or Dungau, a flat quarternary landscape with fertile loess soils. The outlet to the Danube is part of the Danube valley. At the border between Dungau and the Danube valley, in the city center of Osterhofen, the Herzogbach breaks through loessy hills, forming a steep valley which stands in contrast to the flat river reach it forms before and afterwards. Since the end of the last ice age, about 10,000 years ago, the landscape has been formed mainly by water and wind erosion and the river systems.

4.1.2 History of land use

Archeological evidence of human activities can be dated to 50,000 BC. The first settlements and farming have been dated to the 6th millennium BC. At this time, agriculture developed and was transferred from Asia via the Balkans to Central Europe. The area of the Gäuboden was preferred because of the fertile soils and the hydrological conditions with a dense net of rivulets. The predominant oak and mixed forests provided wood for buildings and fire, and were cleared to establish the first settlements and fields (Bayer-Niemaier 2004, p. 11).

The first period of land use intensification took place at the end of the first millenium AD, when monasteries started to clear wide areas and adopted new farming techniques. In 1004 AD, the monastery of Osterhofen was founded on a hill top next to the Herzogbach. The nearby settlement and market developed quickly, and by 1378 the market of Osterhofen was shifted to the hill top on the other side of the Herzogbach. The former market and location of the monastery is now known as Altenmarkt, which can be translated as "old market" (Halser 2006, p. 1 et sqq.).

Both developments are of relevance in relation to the river system in the area. The city of Osterhofen is unusual for a medieval city because it has no city walls. In old chronicles and pictures from the 18th century, Osterhofen is shown surrounded by lakes. Also, the Herzogbach was blocked to develop a lake which was filled with debris in the late 18th century. The lake was a defense measure, but also provided water and was used by the nearby monastery growing fish and for a mill at the outlet at the city (Halser 2006, p. 1 et sqq.). Field and street names like "Seewiesen" (lake meadow) and "Georgensee" (Lake George), now a settled and a recreational area, still refer to this history. The existence of two urban areas on two hills next to a rivulet led to the development of new settlements in the valley and the flood plain in-between. Old maps prove that this process started after 1820 AD (Figure 4.4).

Land use followed the geomorphology except on the flood plains. The top of the tertiary hilly landscape in the south of the catchment is still mainly used for forestry. Rough winds, different climatic conditions because of the altitude and thinner loess levels in this region make farming only possible in the small valleys between the hills. The open plains of the Gäuboden provide better conditions for farming because of the fertile soils and larger field units. Also, the microclimate of this flat area is more suited to agriculture.

Until the late 19th century, agriculture was dominated by the three-field crop rotation (Herbert & Maidl 2005, p.277). Like Herbert & Maidl (2005, p.277) in their introduction about the development in the area point out, "der Strukturwandel in der Landwirtschaft ist in der zweiten Hälfte des 20. Jahrhunderts so tiefgreifend gewesen wie in keinem Zeitabschnitt zuvor." [the structural changes in agriculture in the second half of the 20th century were more radical than any previous period].

The changes in the agricultural production followed new technological developments and scientific findings. The implementation of new fertilizers caused a change from the old crop rotation scheme to a rotational cropping system. The mechanisation of agriculture led to land reallocation projects, increasing the size of fields. New harvesting techniques, the development of pesticides and of new crops also influenced the types of plants used in the local agriculture. Maize, beet, vegetables and wheat are now the dominant crops - superseding clover and crop types like rye and oats (Herbert & Maidl 2005, p. 278 et sqq.).

The changes also led to a focus on agriculture, which replaced previous livestock farming (Herbert & Maidl 2005, p. 295 et sqq.). Meadows and pastures were converted to fields (Figure 4.6). Field names and local names still refer to the old functions of areas and land strips. Especially in the flood plains of rivers and rivulets, old names like "Speckwiese" (bacon meadow), "Doblwiesn" (ravine meadow) or "Puttinger Bach Wiesn" (Putting rivulet meadow) have remained, and indicate the former use of these wet areas or wetlands (Maidl 2004, p. 113). This opened space for settlement development on the former meadows in the flood plain. Other important landscape structures were lost during this development such as bushes, hedges, boundary ridges and wetlands.

These changes are shown on old land register maps (Figures 4.4 to 4.7). Surveying started in Bavaria in 1808 AD as a basis for the new land tax system (www.geodaten.bayern.de). The first maps, at a scale of 1:2,500 for the project area, date to the year 1820 AD. A comparison of old and current maps show that the changes have been dramatic.

Changes did not only take place in the landscape. Also the characteristics of settlements and cities changed. The city Osterhofen shows these developments very clearly (Figures 4.4 and 4.5). In former times, the settlements occupied the edges of the river valleys to avoid flood damages and reserved the open spaces for agriculture. Because of the fertility of the loess soils, the settlement development was forced towards the valleys and the flood plains. The loss of livestock farming and the availability of former meadows in the river valleys, as well as the intensification of agriculture on the flat fertile plains, have been the main drivers for this development.

The village of Linzing (Figure 4.7) is the only settlement in the catchment that has preserved its character over the years. There are no significant changes from 1820 to today. The rivulet flows through a valley mainly used as meadow and pasture. The buildings and farmhouses are located at the embankment - away from the flood plain and wet areas.

Figure 4.4: Historic land register map of Osterhofen and Altenmarkt in the year 1820 AD. The agricultural area between both cities is the Herzogbach valley. At the south-east corner of Osterhofen a mill channel is located. The hachures in the map indicate that the flood plain in the centre of the river valley was used as meadow and pasture

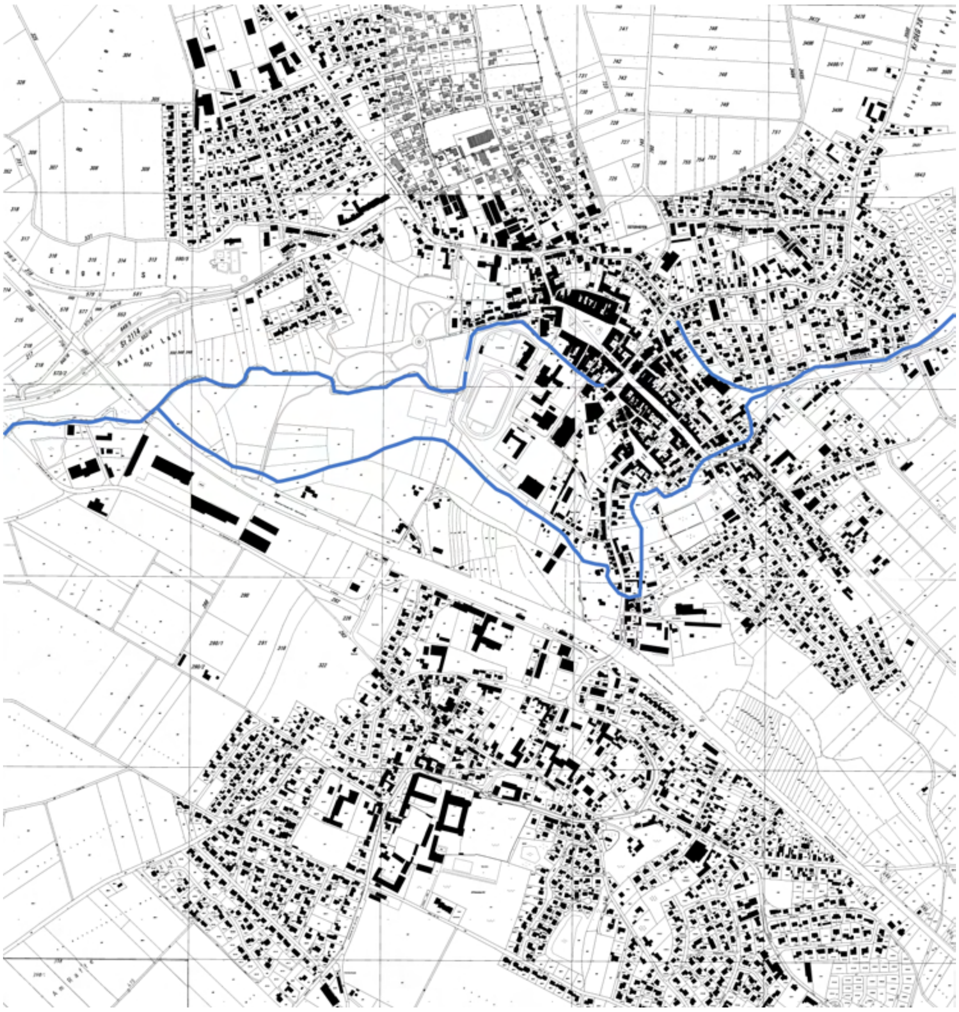
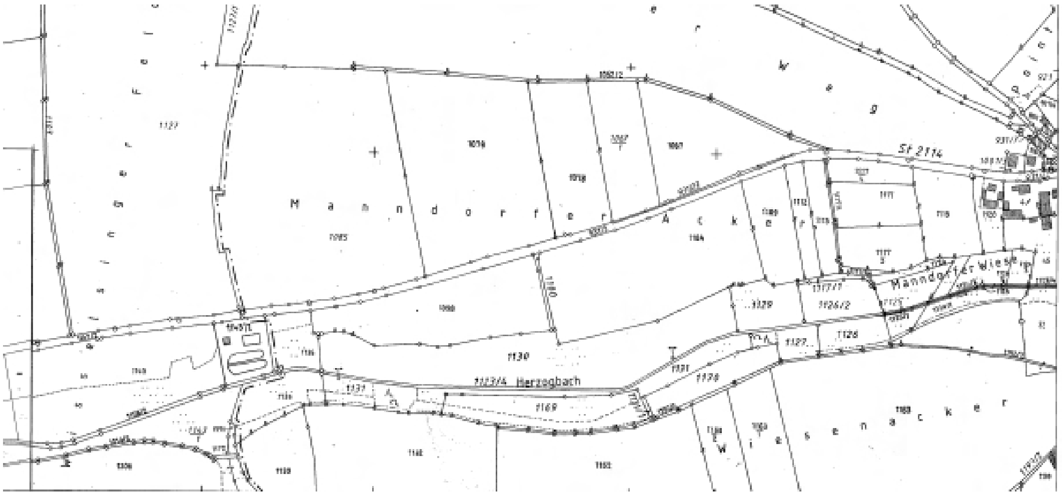


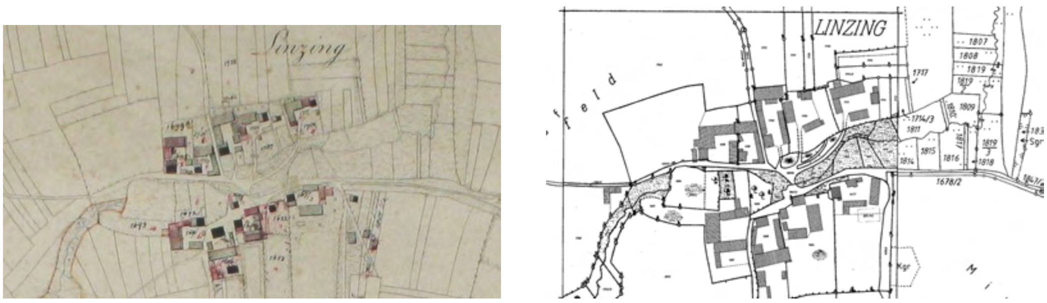
Figure 4.5: Land register map of Osterhofen and Altenmarkt from the year 2000 AD.

(a) 1820 AD



(b) 2000 AD

Figure 4.6: Historic and actual land register map of an agrarian area west of Wisselsing



(a) 1820 AD (b) 2000 AD

Figure 4.7: The village Linzing

4.1.3 Climate

The study site is located in Central Europe (Figure 4.1). It has a temperate humid continental climate. In the Köppen climate classification, it is classified as temperate climate Cf with significant precipitation in all seasons (Malberg 1997). The annual average precipitation is 850 mm, in winter between November and February also falling as snow (Figures 4.8 and4.9). In 2005, the maximum precipitation (2 day sum) was 38 mm (Figure 4.10). The precipitation pattern ranges from 5.2 mm (half-yearly event, 5 minutes duration) to 110 mm (100 year event, 72 hours duration) (Table 4.2).

During the mapping and surveying work in the study area, there were some experiences with the local climate. Although the difference in elevation between the peaks in the south of the catchment and the main flat areas of the Gäuboden are minor, in winter snow lasted much longer in the hills than in the flatter regions. It was even noted that precipitation fell as snow in the hills, but as rain in the flatter regions.

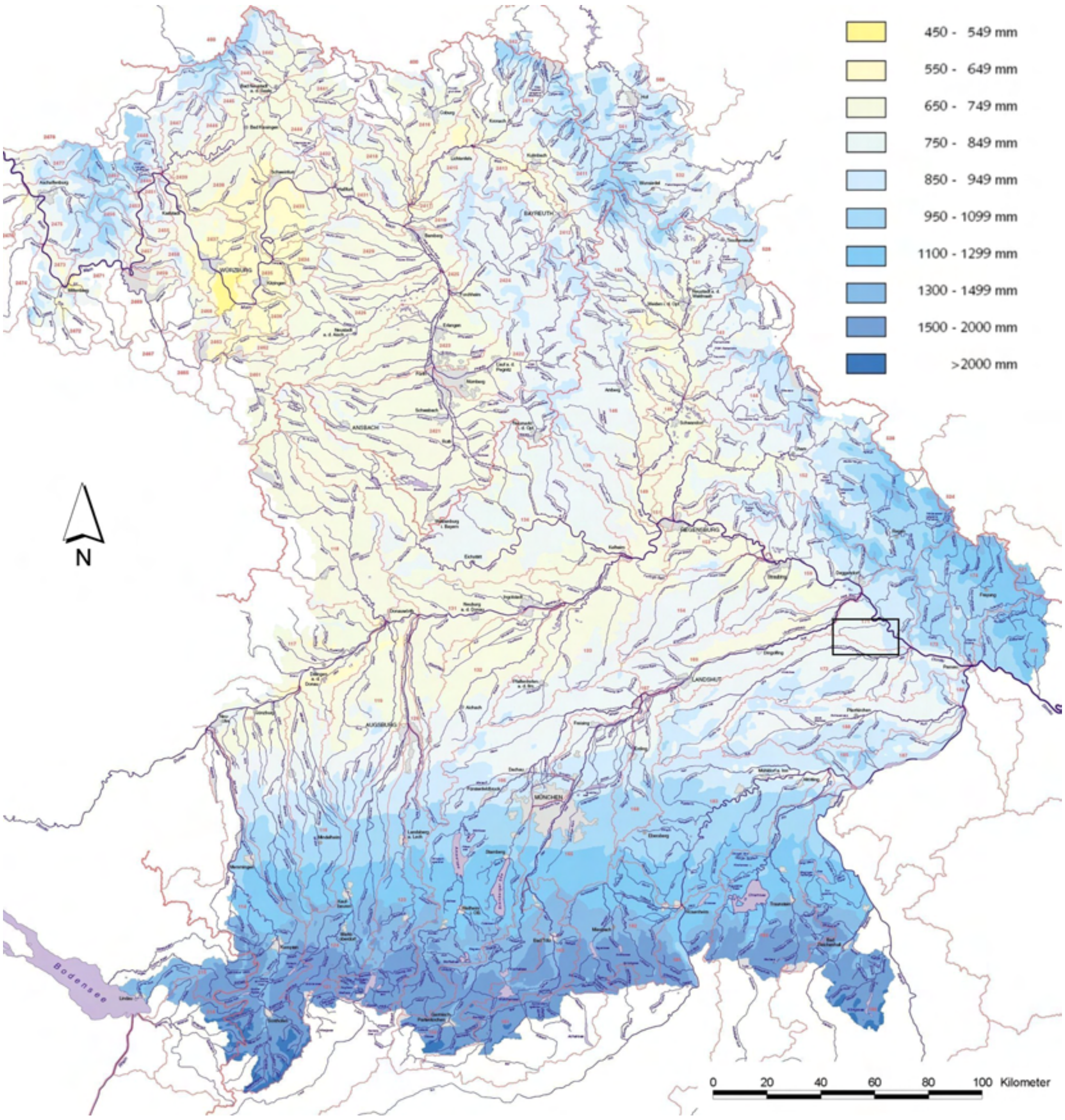
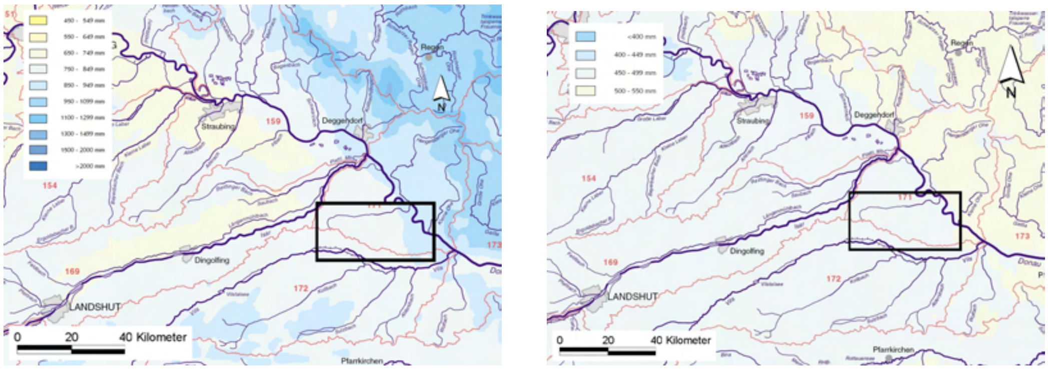


Figure 4.8: Average annual precipitation in Bavaria. The black rectangle indicates the location of the project area, after Bayerisches Landesamt für Umwelt (2007*b*)



(a) Precipiation (b) Evaporation

Figure 4.9: Average annual precipitation and evaporation. The black rectangle indicates the location of the project area, after Bayerisches Landesamt für Umwelt (2007*b*)

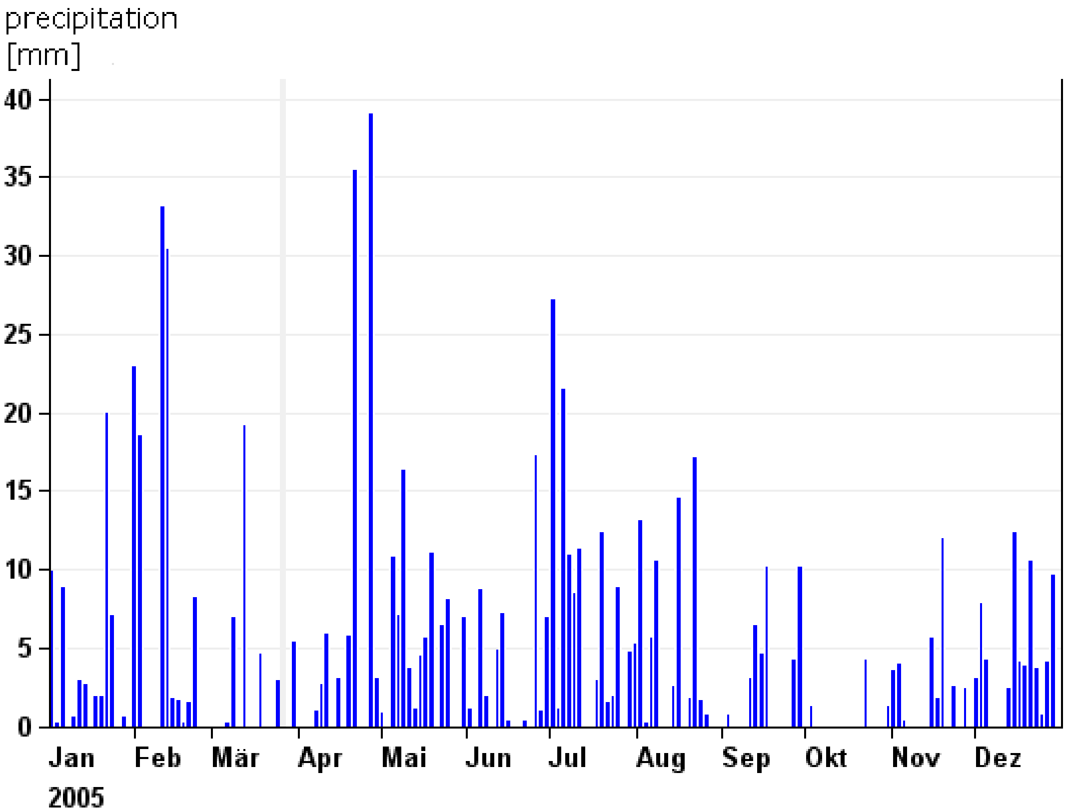


Figure 4.10: Precipitation in 2005 as 2 day sums in mm at the station Moos, 5 km north east of Osterhofen, after Bayerisches Landesamt für Umwelt (2007*a*)

4.2 Modelling approach

4.2.1 Hydrologic modelling

For the Herzogbach catchment no continuous hydrological recordings are available. Only citizens living in or next to the flood plain have a distinct knowledge of average water levels and the history of extreme events. A one year time series for base flow and distinct meteorological events was available to allow a correlation between run-off and precipitation (Slesiona 2005) and to calibrate the model. In addition, flood marks at bridges are available and were used for calibration. A catchment model was necessary to first indentify the hydrological behaviour of the catchment in its current state and derive the run-off of distinct design events. It was calibrated with the available data for the scenario of the status quo. In the second step, it was useful to simulate alternative scenarios for land use and river structure to see the differences in discharge peaks and varying volumes of flood waves.

Because of the different scales of observation in this study, ranging from a small scale catchment (1.5 km^2) as a segment of the main catchment up to the observation of the full catchment (50 km^2), the suggestions of Bergström & Graham (1998) were followed to use a conceptual model. A conceptual modelling approach is used because it is more insensitive to scales.

The computer model used for this study is a conceptual deterministic river basin model to simulate precipitation-run-off processes in small and medium sized catchments. "Deterministische konzeptionelle Flussgebietsmodell für den Abfluß setzen sich nach dem Baukastenprinzip aus Verfahren zur Simulation verschiedener Teilprozesse zusammen." [Deterministic conceptual river basin models for discharge simulation are modular systems to simulate different processes.] (Maniak 1993, p. 361). The applied model consists of three elements:

- A regionalisation approach to calculate losses from evapotranspiration and infiltration, and derive a flood wave as a hydrograph for each sub-basin,
- a flood routing approach to estimate the superposition of flood waves from sub-basins, and simulate the detention of the river reach and flood plain,
- a reservoir routing approach to check the efficiency of detention measures.

The first landscape model was developed to simulate the status quo for land use and river structure of the catchment (Table 4.1 Scen. A). The model was then modified to simulate different scenarios. The first change was a modification of land cover to simulate a catchment similar or close to the natural status (Table 4.1 Scen. B). A mixture of forest and meadow with an emphasis on dense primeval forest would be a realistic natural landscape. An analysis of historic maps showed that the change in forested areas has been minor over a 200 year period. An assumption was made because redevelopment of wide areas into forest would be unrealistic and there is uncertainty about the exact historical distribution of land cover. Areas covered with trees remained as forests in the model. Agricultural sites and sealed areas were transformed into meadow and fallow. This is a conservative assumption, because dense forest would have higher detention capacity than meadows.

A separate and new scenario was derived as a modification of the river structure in addition to a redeveloped land cover (Table 4.1 Scen. C). Old maps from the early 1820'is showed very well which modifications of the river structure took place over the years. In the 18th century, the rivers showed a natural meandering structure with a wide meadow flood plain. The current situation shows degraded structures using artificial profiles and stretched flow lines. A comparison of historic and actual maps provided the necessary data to modify the river structure in the model and to adapt it to a historic and natural situation. The analysis showed that a natural river system would have been at least 1.2 and up to 1.5 times longer than today. The elongation depends very much on the location of the river section, the severity of human intervention and the steepness and geology of the landscape. But the historical maps include the first human alterations to the river structure, making it very difficult to reconstruct the original status. Therefore, for all sections, an elongation of 20% was assumed. This assumption was checked by comparing historic and current maps. No data about historical profiles of the rivulet are available. No representative natural sections of the river system remain in the whole catchment to allow an assumption for each profile type. Renaturalized river sections show that the natural profile would not be deep, but would have lower and flatter embankments. Unfortunately, these sections have been rebuilt, but they are not old enough to be interpreted as a natural stream. Therefore, the measured profiles of the current situation have been used for the historical scenario as well.

A further scenario was derived by analysing the effects of intensive land use and the effect

Scenario	Land use	River	Reservoirs
A	status quo	status quo	no
A1	status quo	status quo	existing
B	Pasture and forest	status quo	no
C	Pasture and forest	natural	no
C1	Pasture and forest	natural	existing
D	status quo and intermediate crops	status quo	no

Table 4.1: Scenarios for land use, river structure and reservoirs used for hydrological modelling

of sustainable agricultural techniques (Table 4.1 Scen. D) on run-off. The main agricultural crops are maize, beets, corn and vegetables. For this situation the consequent use of intermediate cropping or direct cropping was assumed. Changes of land use in the river valleys, leading to a renaturalisation of the river structures, have not been taken into account for this scenario.

The reduced detention capacity of the catchment due to land use will lead to increased flood waves with higher peaks and bigger run-off volumes. These increases are quantified by checking the efficiency of detention structures and comparing the lost detention in the catchment with available and potential artificial detention. Therefore, existing, planned and potential reservoir locations were integrated as a last step in the methodology (Table 4.1 Scen. A1 and C1).

The applied IHW modelling software is standard in Germany. It can use a combination of different modelling approaches.

The regionalisation approach of Lutz (Ihringer 2002) for small and medium size catchments in Southern and Central Germany was used in this project. It allows the development of regional hydrographs in cases where no water level or run-off recordings exist. The hydrograph is defined by a peak value and the time required to reach this peak, which are functions of the catchment. Rainfall data was sourced from the KOSTRA Atlas data of the German Weather Service (DWD Deutscher Wetter Dienst) as statistical rainfall data. For flood routing, the Kalinin-Miljukow approach was used, to route the flood wave and take detention effects of the river structure into account. Reservoir routing was then used to calculate the effectiveness and efficiency of existing and planned detention reservoirs under different scenarios.

The catchment of the Herzogbach was divided into subcatchments based on the relief. For this, the available DEM (digital elevation model) in a raster 50 x 50 m was used. The divides were precisely defined, taking into account the influences of anthropogenic structures like streets and railway dams. Settlements, detention reservoirs and junctions were used to set the size of each sub-basin to delineate a regular structure to meet the needs of later evaluation. Forty sub-catchments were defined through this optimization process (Figure 4.11). Two are located downstream of Osterhofen and are of no relevance for this study. Nintey-one calculation nodes were set along the river reaches representing calculation points for sub-catchments, river reaches, reservoirs, junctions or as information nodes for certain influx or outflux situations (Figure 4.12). The calculation was run using minute intervals for 10,000 time steps (166 hours).

The model produced the run-off data at each node and for every time step structured for each individual return period of precipitation and each duration of precipitation. Individual information that can be derived from that ensemble of flood waves of different probability and duration include the maximum flood for each return period, peak, volume, shape and extent of each individual flood wave. For detention reservoirs the model provides in addition influx and discharge curves at the outlet, water levels and related volumes.

Statistical data from measurements are necessary to calibrate models. “Fehlen diese Messungen oder erreichen sie nur einen Umfang, der eine gesicherte Aussage nicht mehr zuläßt, müssen die Bemessungsgrößen mit regionalen Analysen abgeschätzt werden.” [Are the measurements missing or do they have an extent that will not allow a trusted conclusion; design values must be reevaluated with other regional analysis.] (Maniak 1993, p. 282).

For the calibration of the model, no long term series of data from gauging stations were available. Therefore, the results of the hydrological model was processed in a hydrodynamic 2D streamflow model, which delivered the corresponding water levels and flood plains for characteristic and specified areas in the settlements. These data were compared with information obtained from citizens, flood marks of past events and regular (annual or biannual) flooding and measurements performed by another study. This approach does not allow a perfect calibration, but it is the only suitable approach for most small catchments where no gauging data are available.

No weather station is located in the Herzogbach catchment . There is a metering station in Moos, 5 km north east of Osterhofen, which records the precipitation (Figure 4.10). Other stations are located in the direct neighbourhood of the catchments. Records of these stations are regularly evaluated by the German Weather Service (DWD Deutscher Wetterdienst). Results of the statistical analysis are published in the Kostra Atlas for Germany. The area of Germany is therefore subdivided into regular raster cells with a size of 71.5 km^2 per cell. For each cell, statistical precipitation volumes for rain events with durations from 5 minutes up to 72 hours and defined recurrence intervals are given. Average precipitation ranges from 5.2 mm (5 min/ 0.5 yearly) to 110 mm (72 h/ 100 year) (Table 4.2) (Deutscher Wetterdienst 2005)

For modelling purposes, the return periods 1, 2, 5, 10, 20, 50 and 100 years and the durations 15, 30, 45, 60, 90 minutes, 2, 4, 6, 9, 12, 18, 24, 48 and 72 hours were selected. The evaluation of the resulting flood waves at each node of the model will show the rainfall duration for each return period, which is responsible for the maximum flood. The wide range of return periods from 1- 100 years was chosen, because flood damages will be derived as a flood damage function over this period. Therefore, a number of sampling points were necessary.

For Germany Lutz, (Ihringer 2002) developed a regionalisation approach for areal retention that fulfills the requirements for small and medium size catchments (Ihringer 2002):

$$
\begin{aligned}
N_{eff} &= N_{eff,u} + N_{eff,s} \\
N_{eff,u} &= \Big[(N - A_V) * c - c/a * (1 - e^{-a(N-A_V)}\Big] * \frac{A_E - A_{E,s}}{AE} \\
N_{eff,s} &= (N - A'_V * \Psi_s * fracA_{E,s}A_E \\
a &= C_a * e^{-C_2/wz} * e^{-C_3/q_B} * e^{-C_4 * T_D}
\end{aligned}
$$

N : Precipitation $[mm]$

N_{eff}: Effective precipitation $[mm]$

$N_{eff,u}$: Effective precipitation of unsealed areas $[mm]$

N_{eff} : Effective precipitation of sealed areas $[mm]$

R	0.5		1.0		2.0		5.0		10		20		50		100	
D	hN	rN	hN	rN	hN	rN	hN	rN	hN	rN	hN	rN	hN	rN	hN	rN
5.0 min	5.2	172.7	6.8	225.1	8.3	277.5	10.4	346.7	12.0	399.1	13.5	451.5	15.6	520.8	17.2	573.2
10.0 min	6.4	105.9	8.5	141.9	10.7	177.9	13.5	225.4	15.7	261.3	17.8	297.3	20.7	344.8	22.8	380.8
15.0 min	7.2	79.5	9.8	108.3	12.3	137.2	15.8	175.3	18.4	204.2	21.0	233.0	24.4	271.2	27.0	300.0
20.0 min	7.8	64.8	10.7	89.5	13.7	114.1	17.6	146.8	20.6	171.4	23.5	196.1	27.4	228.7	30.4	253.4
30.0 min	8.7	48.5	12.3	68.3	15.9	88.1	20.6	114.3	24.1	134.1	27.7	153.9	32.4	180.0	36.0	199.8
45.0 min	9.8	36.3	14.1	52.1	18.4	68.0	24.0	89.0	28.3	104.9	32.6	120.8	38.3	141.8	42.6	157.7
60.0 min	10.6	29.5	15.5	43.1	20.4	56.6	26.9	74.6	31.8	88.2	36.6	101.8	43.1	119.7	48.0	133.3
90.0 min	12.5	23.2	17.4	32.3	22.4	41.4	28.8	53.4	33.7	62.5	38.6	71.6	45.1	83.6	50.0	92.6
2.0 h	14.1	19.5	19.0	26.4	23.9	33.2	30.4	42.2	35.3	49.0	40.2	55.8	46.7	64.9	51.6	71.7
3.0 h	16.4	15.2	21.4	19.8	26.3	24.3	32.8	30.4	37.7	34.9	42.6	39.5	49.2	45.5	54.1	50.1
4.0 h	18.3	12.7	23.2	16.1	28.2	19.6	34.7	24.1	39.6	27.5	44.5	30.9	51.1	35.5	56.0	38.9
6.0 h	21.2	9.8	26.1	12.1	31.1	14.4	37.6	17.4	42.6	19.7	47.5	22.0	54.1	25.0	59.0	27.3
9.0 h	24.5	7.6	29.4	9.1	34.4	10.6	40.9	12.6	45.9	14.2	50.9	15.7	57.4	17.7	62.4	19.2
12.0 h	27.0	6.3	32.0	7.4	37.0	8.6	43.5	10.1	48.5	11.2	53.5	12.4	60.0	13.9	65.0	15.0
18.0 h	28.3	4.4	34.8	5.4	41.2	6.4	49.7	7.7	56.1	8.7	62.6	9.7	71.1	11.0	77.5	12.0
24.0 h	29.6	3.4	37.5	4.3	45.4	5.3	55.8	6.5	63.8	7.4	71.7	8.3	82.1	9.5	90.0	10.4
48.0 h	36.7	2.1	45.0	2.6	53.3	3.1	64.2	3.7	72.5	4.2	80.8	4.7	91.7	5.3	100.0	5.8
72.0 h	46.7	1.8	55.0	2.1	63.3	2.4	74.2	2.9	82.5	3.2	90.8	3.5	101.7	3.9	110.0	4.2

Table 4.2: Precipitation pattern for the catchment, rN - Duration of precipitation in l/s*ha, hN - precipitation level in mm, R - recurrence in years, D- duration in minutes or hours, after (Deutscher Wetterdienst 2005)

A_V : Initial losses on unsealed areas $[mm]$

A'_V : Initial losses on sealed areas $[mm]$

c : Maximum run-off coefficient $[-]$

A_E : Catchment area $[km^2]$

$A_{E,s}$: Sealed catchment area $[km^2]$

Ψ_E : Run-off coefficient for sealed areas $[-]$

a : Event coefficient $[1/mm]$

WZ : Number of the week

q_B : Discharge per unit area $[\frac{l}{s*km^2}]$

T_D : Duration of precipitation $[h]$

$C_1 - C_4$: Area specific parameters $[-]$

Run-off coefficient c and initial losses A (Table 4.3) are similar to those of the SCS-CN values (Bedient & Huber 2002). Auerswald (2002) developed new SCS-CN values for the use of intermediate crops. The new CN values of Auerswald were transformed to c values in the Lutz approach for the simulation of the scenario D (Table 4.1 Scen. D). Auerswald does not make any comments on initial losses. It could be assumed that they would increase as an effect of this sustainable farming technique. For modelling purposes, the regular values of the parameter initial losses A_V for agricultural areas of the Lutz approach were used. Soil types and geology are quite homogeneous in the whole catchment. Due to the rural structure for settlements, an amount of 35% sealed surface per estate was assumed. This value was compared with measurements on aerial photos.

Each catchment develops a characteristic form of its flood wave depending on its form, geomorphology and land cover. This process of transformation of precipitation into a flood wave at the outlet of the catchment is described by the hydrograph as a function (Bedient & Huber 2002, p.85 et. seq.). The regionalisation approach by Lutz for the Unit Hydrograph describes the hydrograph with the parameters t_A for time of increase till the peak and u_{max} for the peak value (Ihringer 2002):

Soil Type	A	B	C	D
Land use	Maximum run-off coefficient $[-]$			
Forrest	0.17	0.48	0.62	0.70
Maize	0.62	0.75	0.84	0.88
Corn	0.54	0.70	0.80	0.85
Pasture	0.10	0.46	0.63	0.72
	Initial losses $[mm]$			
Agricultural areas	7.0	4.0	2.0	1.5
Forrest areas	8.0	5.0	3.0	2.5
Sealed areas	1.0			

Table 4.3: Run-off coefficient and initial losses (Ihringer 2002)

$$t_A = P_1 * (\frac{L * L_C}{l_g^{1.5}})^{0.26} * e^{-0.016*U} * e^{0.004*W}$$

t_A : Time for the increase of the hydrograph $[h]$

P_1 : Catchment parameter

L : Length of the main river branch $[km]$

L_C : Length of the branch from the junction to the centroid of the catchment $[km]$

l_g : Medium steepness of the main river branch $[-]$

U : Percentage of the catchment with settled areas [%]

W : Percentage of the catchment with forrests [%]

$$u_{max} = 0.612 * t_A^{-0.991}$$

Based on available GIS data, like land register maps, land use maps and geological data, the parameters for the Lutz approach (Tables A.1, A.2 and A.3) were defined and calculated for the status quo. The detailed definition of individual catchment characteristics was of importance for the later changes to land cover and landscape structure made in the scenarios B, C and D (Table 4.1).

On a meso and macro scale, no models are available to evaluate the effects of drainage, field size and field structure, and ditches. It is also difficult to estimate these changes, because very little data about the changes in these structures are available. Therefore, small scale structures were ignored. It can be assumed that the loss of these structures reduces natural detention and increases run-off, and therefore increases volume and peak of floods. It can be expected that undoing these structural changes in the landscape, e.g. modelled through a modified parametrisation of the catchment, would decrease run-off even more. Hence, it can be stated that the applied approach, ignoring these structures in the scenarios B-D underestimates the effect of land use changes.

Flood routing

Channel routing

For the flood routing, two approaches have been used:

- Translation approach as a travel time calculation of the flood wave in the channel (Ihringer 2002)
- Kalinin-Miljukov approach for river bed and flood plain (Patt 2001)

The translation approach is a simplified calculation of the travel time of the flood wave. For each section of the river or rivulet, the travel time is calculated using the Mannings equation. Storage effects of the river bed or flood plain, or differentiated speeds in the river bed and flood, are not taken into account. This approach is very efficient for small rivulets - especially for channelized sections where effects of the flood plain have no main impact on detention and run-off velocity. Therefore, this approach was used for rivulets and smaller reaches.

With the Kalinin-Miljukov approach, the flood routing is simulated using data of the channel geometry. The approach is based on the idea that a river system represents a linear reservoir. Therefore, a river section is subdivided into n subsections with the length L_C.

Using surveyed profiles of the channel, for each section the steady flow discharge function can be calculated using the Manning-Strickler equation. For each subsection, the detention coefficient k can be derived as the first derivation of the discharge function of the section (Ihringer 2002).

In the hydrological simulation, the input flood wave will be routed through each subsection. Each section will be evaluated based on the discharge volume, whether the routing will take into account only the river bed or river bed and flood plain.

The Kalinin-Miljukov approach was used to calculate the flood routing in the main river reach. The translation approach was used for the smaller sub-branches and to calibrate the Kalinin-Miljukov approach for the status quo scenario of the river systems. The assumption of a simplified travel time for the flood wave in a geometrically simplified channel fits very well with this river system. Most sections of the main river reach and also the branches in agricultural sub-catchments have been modified and are mainly trapezoidal in profile.

For each characteristic section of the main river reach, profiles were measured using a NavStarGPS System together with Earth bound reference stations (differential GPS), and the factors n and k were derived for the status quo. These data were used for the calculation of the scenarios A, B and D (Table 4.1). Because no historic profile data was available, for scenario C the profiles were used as well - only the length of each section was elongated following an evaluation of historical maps. Also, this simplification means that the current hydraulically optimal profiles were used for the historic situation, resulting in an underestimation of detention potential of natural river structures.

Pond routing

A large detention reservoir is located in the catchment for the protection of Wisselsing. It has a capacity of 56,000 m^3 and was planned to hold back a 20 year flood event. For the river basin management plan for the Herzogbach catchment (Dorner, Spachinger, Lenz & Metzka 2005*b*), the whole catchment was scanned for locations for potential detention structures. Over 30 locations were identified delineating potential sites for dams based on the conditions:

- Valley with natural potential for water storage,
- river valley with a narrowing to position a dam.

But only three new dams could provide an efficient protection level (Table 4.4) regarding the criteria:

- sufficient storage capacity calculated based on a digital elevation model,
- no villages in the backwater of the dam,
- significant reduction of a flood (reduction of the peak of a 10 year flood event).

Nr	Protected city	Volume	Node	Status
P1	Bachling		2	Planned
P2	Bachling		4	Planned
P3	Buchhofen		14	Planned
P4	Wisselsing, Osterhofen	56,000 m^3	52	Existing

Table 4.4: Existing and potential detention reservoirs in the Herzogbach catchment

For the evaluation of their efficiency under different catchment situations, it is necessary to integrate them into the model. Small reservoirs, like those in the Herzogbach catchment are normally uncontrolled. This means that a fixed orifice controls the run-off. If the run-off exceeds the capacity, a spillway (e.g. as an overflow section of the dam) discharges the excess water. In the model, reservoirs are represented by the standard reservoir formula (Ihringer 2002)

$$dS/dt = Q_z(t) - Q_a(t)$$

dS/dt: change of reservoir volume S over time t

$Q_z(t)$: Influx over time

$Q_a(t)$: outflow over time

solved numerically

$$\frac{S_{i+1} - S_i}{\Delta t} = \frac{Q_{Z,i+1} + Q_{Z,i}}{2} - \frac{Q_{A,i+1} + Q_{A,i}}{2}$$

dS/dt: change of reservoir volume S over time t

$Q_z(t)$: Influx over time

$Q_a(t)$: outflow over time

Outflow is calculated for a pipe (diameter, roughness) as regular outlet, depending on water level and resulting pressure. The spillway is modelled as a weir (length, weir-coefficient). Form and volume of each reservoir are represented by six water levels and corresponding volumes.

The efficiency was evaluated in the scenarios A1 and C1 (Table 4.1) for each individual location. Because the existing dam at Wisselsing was planned using a simplified hydrological model, the control strategy was evaluated and optimized using the improved data from the new model.

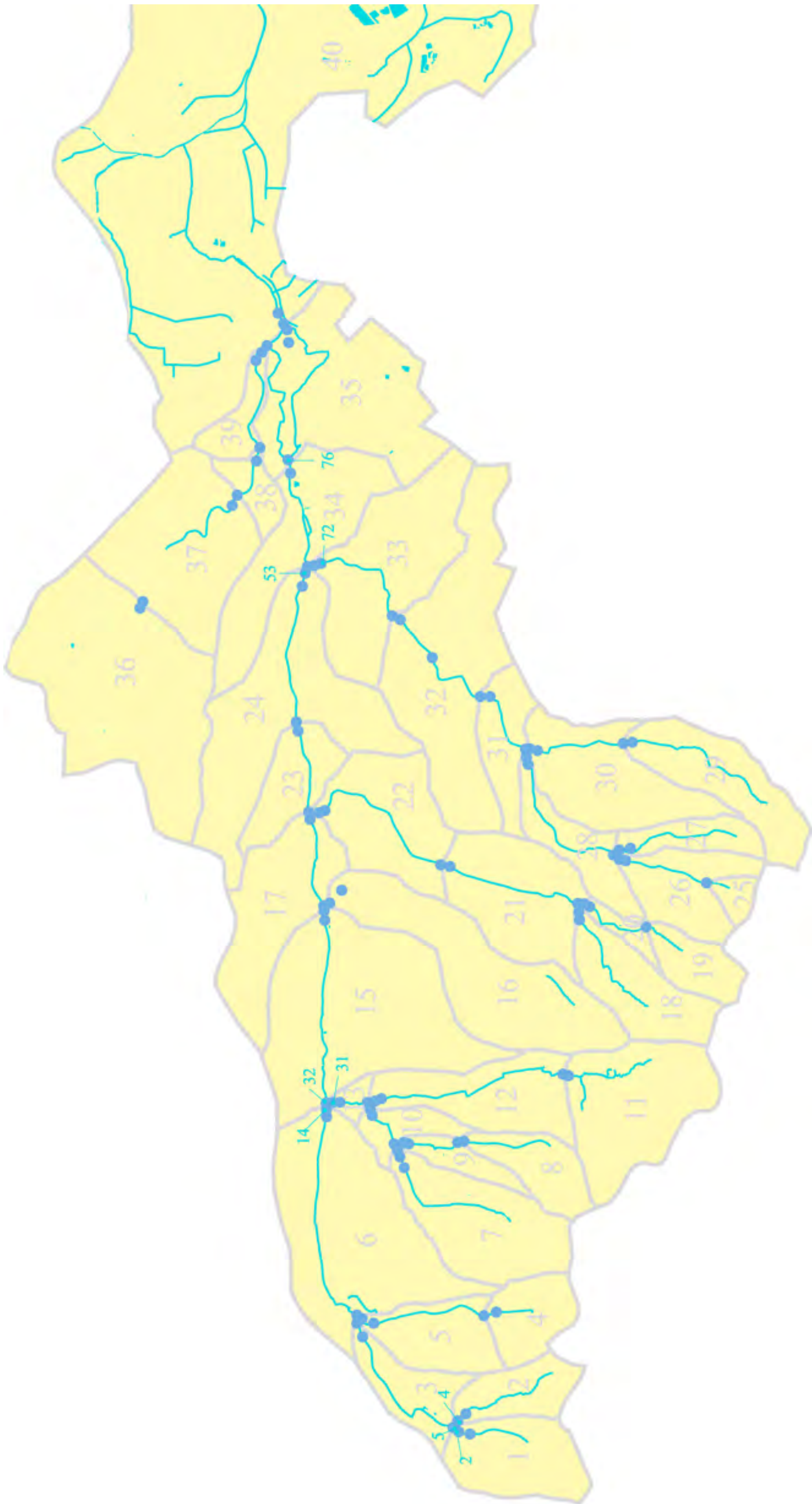


Figure 4.11: Map of the Herzogbach catchment and its division into sub-catchments

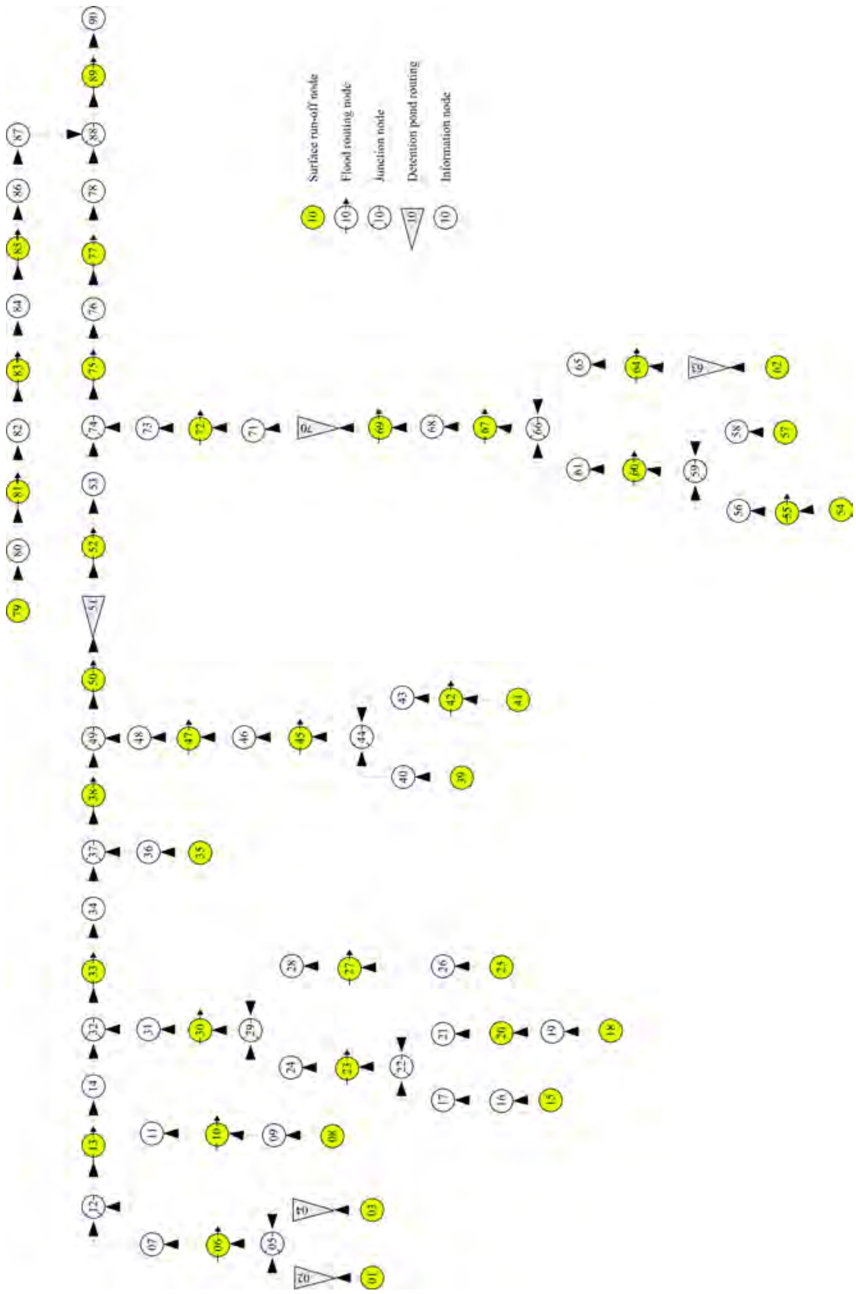


Figure 4.12: Structure of the hydrological model of the Herzogbach catchment

4.2.2 Hydrodynamic modelling

In the presented case study, a relatively small river channel (1-3m) is situated in a wide flood plain. Regarding the results and suggestions of Horritt & Bates (2002), a 2D model may produce far better results than a 1D modelling approach, because 2D models can better handle these complex situations.

In Bavaria, the SMS - HydroAS-2D software package (Nujic 2006) is a standard system used for 2D hydrodynamic flood routing. It is based on the SMS - Surface Water Modelling System developed by the Environmental Modeling Research Laboratory at Brigham Young University. It includes a pre- and a postprocessor for two- and three-dimensional finite elements and finite difference models. HydroAS-2D is a 2D stream-flow and water level calculation package. It is based on the Finite Volume Method.

The two dimensional stream flow equation is derived through the integration of the three dimensional continuity equation, the Reynolds- and Navier-Stokes equations for incompressible fluids over water depth and using the assumption of a hydrostatic pressure distribution. It includes algorithms to solve complex situations like weirs, pipes or other intersecting buildings.

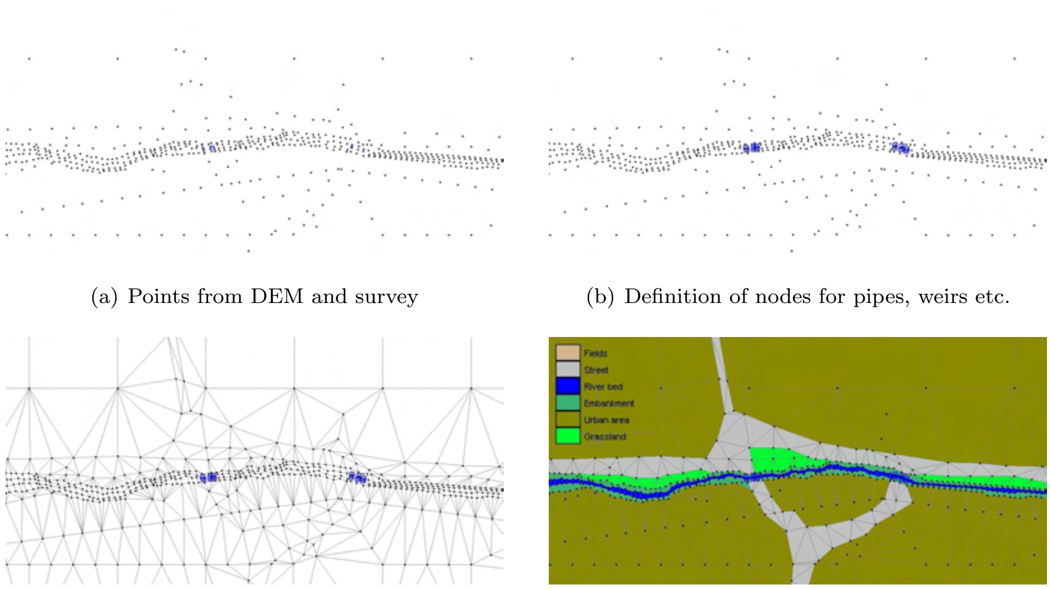
The 2D stream flow equation can be written as a vector (Nujic 2006):

$$\frac{\partial w}{\partial t} + \frac{\partial f}{\partial x} + \frac{\partial g}{\partial y} + s = 0$$

The HydroAS-2D model can solve steady and unsteady flow problems. It requires characteristic points (nodes and vertex) in and at the river to be defined. The nodes are then connected by arcs to denote characteristic areas as triangles or rectangles, such as the bank and the river channel. A linear net was developed in combination with other measured points in the area, and boundary conditions are defined for the influx and the efflux. Each polygon is assigned a friction factor based on the Mannings equation. The model can calculate stream flow conditions including velocity, water depth and the local direction of stream flow.

The net is based on the DEM (DGM25) for Bavaria at a scale of 1:25,000. Raster points are located in a 50m x 50m grid. This data was used to model flat areas of the flood plain.

The land register map was used to set additional points for edges of buildings and streets to densify the net and set marks for the integration of friction factors. Surveys precisely defined settled areas, the rivulet and its embankment. Height notations and dimensions were taken at relevant buildings along or intersecting the water body, like weirs, pipes and bridges. Cross sections of the rivulet were measured each 20 to 50 meters, (floodplain, top and bottom of the embankment and streambed). Measurements were performed using NAVSTAR GPS in combination with terrestrial and virtual reference stations (SAPOS Service of the National Surveying Authority) for differential GPS (DGPS) surveys.



(a) Points from DEM and survey

(b) Definition of nodes for pipes, weirs etc.

(c) Selection of elements

(d) Definition of materials and friction factors

Figure 4.13: Development of the hydrodynamic model from DEM, land register map and measured points

From these individual points, a combined rectangular and triangular mesh was derived. In the SMS modelling software, relevant hydraulic coefficients and height notations were added for special hydraulic situations, like discharge under water pressure in pipes or at bridges and the dimensions of weirs. The friction coefficient (Manning-Strickler) was assigned for each element of the mesh. The definition of the coefficient was based on a mapping of the floodplain and embankments.

The simulation was run in the unsteady flow mode. The influx was increased until the peak of the event. Peak levels resulted from the hydrologic model described, in Hydrological Modelling. The peak level influx remained until the end of the simulation. This form of simulation results in all the affected areas being filled. The model simulated a time period of 5.5 hours and was subdivided by time steps of 500 seconds. Simulations were performed for 1, 2, 5, 10, 20, 50 and 100 year flood events and the hydrologic scenarios A, B, C and D (Table 4.1).

The use of a constant peak influx results in a filling of all relevant flood plains. This methodology is a standard throughout Bavaria for the assessment of flood plains. It is a necessary process for the legal determination of flood plains. It leads to an overestimation of the flood plain, but compensates for the inaccuracies of the elevation model, frictions or the jamming of structures. From an engineering point of view, this method is conservative; for example, for the design of protection works. With respect to the resulting assessment of potential damages, this could lead to an overestimation of damages and must be taken into account in the later analysis of model results. A simulation with flood waves instead of peaks would result in reduced flood damages, because effects of jammed structures and other uncertainties can not be easily simulated. This step was integrated because in small catchments, the blocking of important structures in the river channel has a high probability. It changes run-off characteristics and increases water levels and the extent of the flood plain, but can't be exactly predicted. The models were calibrated using real event data from mappings, pictures, flood marks on buildings and interviews with affected land owners.

For the whole catchment, five models for the villages of Bachling, Neusling, Buchhofen, Wisselsing and Osterhofen were prepared. Three of them were selected for the study: Bachling, Buchhofen and Osterhofen. In Neusling the profile of the rivulet was tremendously extended during the last years. The analysis of the status quo shows that a 100 year flood event could occur without harm to buildings or infrastructure. The situation of Wisselsing is identical to Buchhofen. The three selected villages represent different sections of the river system (headwater, middle section, lower reach) and different structures and settlement sizes. These are described in detail in the Analysis and Results Chapter.

The hydrodynamic model delivers, as output data sets:

- extent of the flood plain,

- the flow velocity,
- flow depth and
- shear stress at the riverbed.

Results of the simulations are calculated and saved for each individual time step and each node. Using the SMS modelling software, the maximum flow depth at each node was selected and the extent of the flood plain and relevant water levels were calculated and interpolated from these nodes.

The flow depth was evaluated for different water levels corresponding to the height and consequent damage to different floors in a building:

- flood plain - indicating all affected areas
- 0.01 - 0.10 m - basements
- 0.01 - 0.8 m - functional buildings affected
- 0.1 - 0.8 m - first floor of residential buildings
- 0.8 - 1.5 m - total damage to first floors of functional and residential buildings

4.2.3 Damage assessment

In the project area, land use will affect flood characteristics in two different ways:

1. Flood peaks will increase, because of higher surface run-off, loss of detention in the flood plain and the superposition of flood waves from different branches.
2. The total volume of a flood wave will increase and the shape will differ due to a loss of detention in the catchment and flood plain.

This will result in bigger flood plains and more affected objects. Costs for protection measures in cities will rise, due to higher elevations of levees and dams. Also, the costs of flood detention measures will increase, because of bigger volumes or because the efficiency of existing protection buildings is lowered. Therefore, the study concentrates on two types of manifestation of externalities:

1. By how much will flood damages increase due to higher flood peaks and extended flood plains?
2. How do shape and volume of flood waves affect the efficiency of detention structures?

In the project area, no important infrastructure (highways, pipelines, railways, telecom,...) will be affected. Mainly farm and residential buildings, and almost no businesses, are located in the flood plain. Therefore, the majority of damages will result from direct damages, to buildings and furniture. Direct intangible, but also indirect damages are difficult to assess and quantify. All potential damages in these categories will be described. Only the effects on buildings and furniture will be economically quantified (direct tangible costs). As modelling results will show later on farm land is not significantly affected due to river training.

The rivulets of the test catchment are located on flat land, and show low flow velocities. Therefore, only the extent of the flood plain and the water level is important for the estimation of damages to buildings. The standing period will be less than one day. The transport of debris depends very much on the period of the year and erosion on agricultural sites. The intensifying effect of sediments is ignored for calculating the damages to buildings or infrastructure, but will be picked up for a qualitative evaluation of externalities and internalisation strategies. Therefore, damages to buildings calculated in this study depend on water level and flow velocity. "f, f diff,and v or their ranges may be estimated by hydrodynamic models and a reasonable level of predictability at useful spatial and temporal scales can be achieved with such models [...] This predictability leads to information helpful for estimating medium to large-scale damage patterns in a flood event." (Kelman & Spence 2004, p. 305)

Flood damages can be estimated as the damages per event of a specified discharge, overlaying of flooded areas (result of 2D stream flow model for a defined discharge), and the land use established in an area - for example as described in GIS datasets like land register maps or topographic maps. The extent of the flood plain determines the size of an affected area and the number of buildings. The water level, as the main factor for the intensity of the event, determines the level of water in the building and therefore the number of affected floors, building structures and furniture. The extent of the flood plain depends mainly on the peak discharge of the flood wave and is statistically a function of the probability of the event. The likelihood of an event or a flood of a certain recurrence interval can be deduced from the hydrologic model results.

For a cost comparison a special time frame is needed. In general, for flood protection works, this timeframe is set at 80-100 years (Länderarbeitsgemeinschaft Wasser 2005) - equal to the lifetime of protection works. In Germany, a protection level for a 100 year event is desired as the result of protection works. Therefore, the given period was chosen to be 100 years. During this time period, a specific flood event with a specific discharge occurs with a certain likelihood. This means that the probability of a flood event must be taken into account if damages of different events or different discharge scenarios are evaluated, because low probability, high loss events would be compared with high probability, low loss events.

In this study, the other cost parameter to assess the externalities of land use is the efficiency of technical detention structures in the catchment. It mainly relies on the size of available or potential detention structures and the shape, volume and peak of the flood wave. The hydrological model delivers these hydrologic input parameters and allows a comparison of the efficiency of different control structures. It can also be used to assess the extra detention volume necessary to compensate for increased flood volumes. The costs per cubic metre of detention range between 10 to 50 Euros for small and medium sized detention ponds (Dorner, Spachinger, Lenz & Metzka 2005*b*). For this study, an average value of 30 Euros per cubic meter was assumed for the reservoirs analysed. (Table 4.4)

Existing detention structures were mapped and potential structures surveyed as input parameters for the hydrologic model. An optimal control strategy for each hydrologic scenario (Table 4.1) was calculated iteratively and the achieved detention effects (reduction of the flood peak) in the downstream village or city were compared.

In the three villages of Bachling, Buchhofen and Osterhofen, the affected buildings were identified by overlaying the land register map on the results of the hydrodynamic model. In the next step, affected buildings were mapped to identify the type of building and its use. Two main types were differentiated:

1. detached houses as the predominant form of residential houses in a rural area,
2. functional buildings - especially garages and barns.

The superposition of water levels per event and the building type makes it possible to estimate the type and extent of damage for each building and to sum these for a flood event in a village.

It was assumed that the basement of a residential house will be affected if the water level is between 0.01 and 0.1 m above ground (Dorner, Spachinger & Metzka 2007). This will cause full renovation costs and total damage to all furniture on this floor. Also, the first floor of a functional building will be affected. First floors of all buildings, structures and furniture have medium damages at water levels between 0.1 and 0.8 m. Between 0.8 and 2.1 m, complete damage of all furniture and full renovation costs for the whole floor were expected. In the project area, water levels above 2.1 m above ground level can not be expected, as the results of the hydrodynamic model results show later in this thesis. There is a lead time of more than 2 hours between rain event and resulting flood, damages to cars or persons were not taken into account.

In the damage estimation, differentiations were made between costs for the renovation of buildings and furniture. In flood action plans in North-Rhine-Westphalia NRW (Germany), the average value of furniture per household was calculated on the basis of estimates of insurance companies at 46,000 Euros (price basis 2001) (Staatliches Umweltamt Hagen 2002). Assuming a 2% inflation rate, the average furniture for the year 2006 would have a total value of 50,000 Euros and is in line with the concept and damage functions on a community level derived by Kleist et al. (2006).

In NRW, the GDP per capita in 2005 was 26,968 Euros. In the project area GDP per capita is 28,321 Euros and at a comparable level. Therefore, the data seem to be transferable to the project area.

Depth-damage curves can be used to estimate potential damage to objects (Kelman & Spence 2004, p. 297). They indicate the extent of damage caused in relation to intensity of flood (water level, flow velocity). Meyer (2001) estimates the damages to furniture in percentage of the total asset value depending on water level. For water levels of 0.0 to 0.1 m

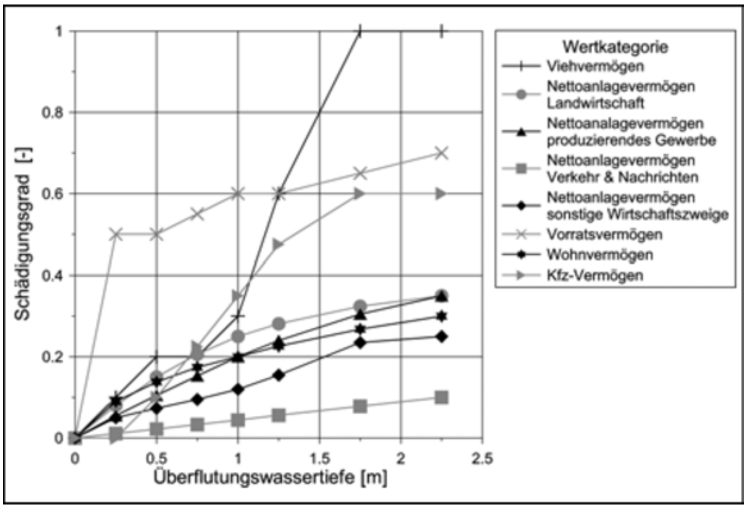


Figure 4.14: Damage functions for different types of property in relation to water level after (Meyer & Mai 2004) Legend: value of cattle, net asset of farmers, net asset of producers, net asset of infrastructure and IT, net asset of other businesses, stock value, housing asset, automobile assets

he assumes damages between 0% and 2%, applied in the basement. Between 0.1 and 0.8m, the damages rise up to 8% and are between 8% and 23% for water levels between 0.8 and 2.1 meter. Following this approach, for cost estimates, the damages to furniture were categorized using ranges of water levels like mentioned previously in this study. The percentage damage to furniture was assumed at 2% of total costs be building for water levels between 0.0 and 0.1m, 4% between 0.1 and 0.8m (first floor and basement) and 10% above 0.8m (Table 4.5). The basis of these assumed damages is the average value of furniture of 50,000 Euros per household ((Meyer & Mai 2004, Kleist et al. 2006),Stua-Hagen-Kosten-200).

Floor	Water level	Damage	Percent.
Basement	0.0 - 0.1 m	1,000 Euro	2%
First floor	0.1 - 0.8 m	1,000 Euro	2%
Funct. building (low)	0.8 - 2.1 m	4,000 Euro	8%

Table 4.5: Average damages to furniture

Also, renovation costs were estimated for various water levels in the basement and first floor. Costs were assumed based on clean up and the drying of brickwork and painting for basements, as well as additional costs of floor coverings and hangings for the first floor, which would be affected following the entrance of water (Table 4.6) derived from interviews with building companies experienced in the renovation of flood damages.

Floor	Costs
Basement	1,000 Euros
First floor	5,000 Euros
Funct. building (low)	1,000 Euros
Funct. building (high)	3,000 Euros

Table 4.6: Renovation costs for affected structures of buildings

A comparison interval of 100 years was selected in this thesis. This represents the standard design level for flood protection works. It is also the technical design period and depreciation period for technical structures like dams and levees (Worreschk 2000, Länderarbeitsgemeinschaft Wasser - LAWA 1998).

4.3 Analysis and results

Results are presented and analyzed for three distinct sections of the Herzogbach. They represent three characteristic sizes of sub-catchments and three different types of residential areas. Bachling, in the upper catchment, is a small village with farm estates and single family houses, and is affected by a comparatively small sub-catchment. Buchhofen, in the middle section, is a larger settlement. At this point of the catchment, effects of the superposition of floods from different branches could occur. Osterhofen, in the tail waters and not far from the outlet, is affected by the whole catchment. It represents a city in an urban environment.

4.3.1 Upper catchment

Hydrology

Bachling is a typical small village in the steeper upper part of the catchment (Tertiary Hilly Landscape). In the hydrologic model, only one sub-catchment (A 1 - represented by node 1, see also Figures 4.11 and 4.12) is of relevance for the run-off and flood development in the

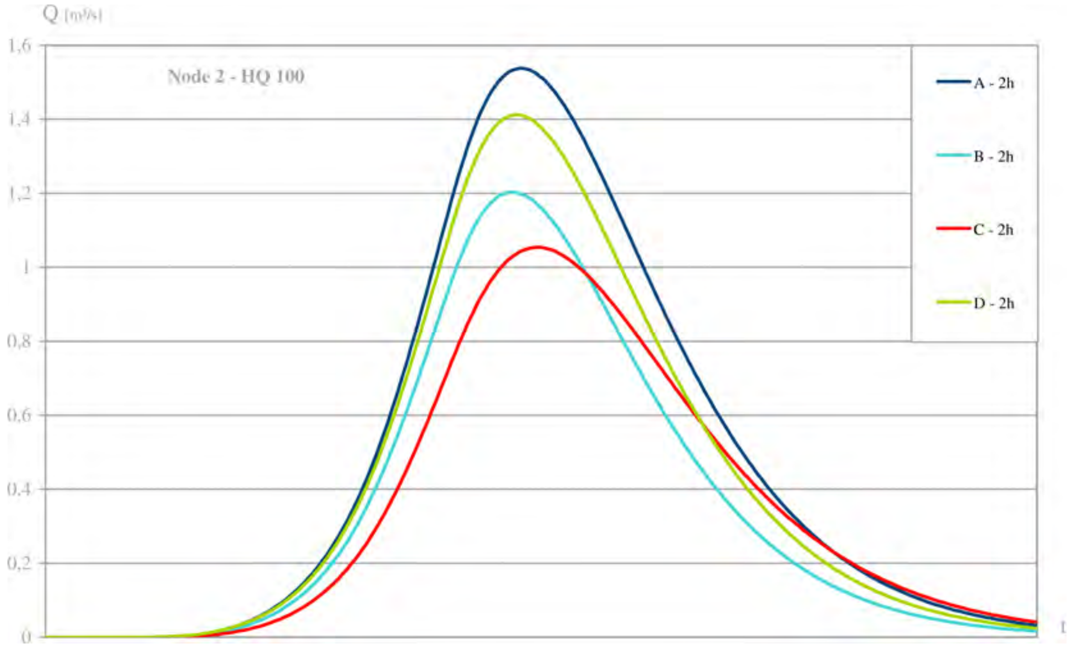


Figure 4.15: Flood waves for a 100 year flood event in Bachling for the scenarios A, B, C and D

settlement. It has a size of 1.2 km^2. A second sub-catchment (A 2 - node 3) has its influx in the centre of the village, but is not of relevance for flood hazards. 72% of the catchment consists of fields - mainly used for root crops and vegetables without intermediate crops (result of inspections in summer and early autumn 2004 and 2005). 15% of the catchment is covered by forest, 12% by grassland and less than 1% is sealed and impervious area. The rivulet is straight with a deep river bed between 1 and 1.4 m below the natural surface. Within the village, the river bed lies between 1.2 and 1.4 m below the level of the streets or the courts. This section is only represented by the regionalisation approach and not a flood routing approach because of the short length of the rivulet in this sub-catchment. This partially limits the precision of results for river elongation and renaturalisation.

The peak flow of 1.5 m^3/s for a 100 year flood event is mainly influenced by land use in the status quo scenario (Scenario A) (Figure 4.15). The catchment with natural land cover results in a simulated peak flow of 1.2 m^3/s, while a natural river structure only causes an additional decrease of 0.1 m^3/s to 1.1 m^3/s. The insertion of intermediate crops (Scenario D) causes a decrease of only 0.1 m^3/s to 1.4 m^3/s in comparison to Scenario A.

In contrast to the results at other model nodes, these minor reductions can be explained by the steepness of slopes and the river bed. On the other hand, the changes in river structure and land use have a significant impact on the shape of the flood wave. Land use increased the volume of the 100 year flood wave by 0.005 Mm^3 to 0.019 Mm^3 (Scenario A). The use of intermediate crops decreases the volume by 0.002 Mm^3 to 0.019 Mm^3 (Scenario D). In addition, a flattened wave would result from a renaturalisation (Scenario C) and decrease the volume necessary for flood detention.

Detention pond P2 (Table 4.4) is located in sub-catchment A2 and has no significant effect on the flood. Pond 1 has a maximum available volume of 6,600 m^3. Damages in the village start with a discharge of 0.6 m^3/s. For scenario A, a volume of 3,900 m^3 would be necessary to mitigate a flood wave of 1.5 m^3/s to 0.6 m^3/s. For scenario B, the same reduction could be achieved with a storage capacity of 2,000 m^3. In scenario C, a volume of 1,800 m^3 would be necessary. Assuming average building costs for detention volume of 30 $Euro/m^3$, this will increase building costs from 54,000 Euros for scenario C to 60,000 Euros for scenario B and 117,000 Euros for scenario A. Splitting up these costs per hectare of farmland means, in this catchment 580 $Euros/ha$ for scenario B for 86 ha of farmland in this sub-catchment causing this extra runoff. For scenario A, the extra costs of detention in contrast to scenario C are 730 $Euros/ha$. The difference of buildings costs of 6,000 Euros between scenario B and C would represent the extra costs to compensate for the effects of river training. For a channel length of 1.1 km in this particular sub-catchment, this means extra costs of 5.45 $Euro/m$ of channel.

Although the application of intermediate crops does not show a significant change of flood peaks, it is an important issue for flood protection. Because the settlement is located at the bottom of the hill, the incline of the rivulet is already reduced, resulting in deposition of sediments. Interviews with adjacent owners showed that annual or biannual cleanings are necessary to remove sediments blocking up to 50% of pipes and outlet diameters. The main source of sediments is erosion from agricultural sites. Studies showed that the use of intermediate crops would reduce erosion by more than 50% in this particular sub-catchment (Spachinger et al. 2005).

Hydraulics

In the upper section at the inlet of the rivulet to the village, the river structure is blocked by two piped sections. These two pipes cause backwater (fill a depression) where a farm estate is located. In the following section, different bridges and pipes intersect the channel of the rivulet. But in contrast to the first intersection, the pipes have larger and constant diameters, the river channel is deeper and estates are located on the higher bank of the rivulet.

As mentioned previously in the analysis of the hydrologic behaviour, land use and river structure did not show large impacts on flood peaks for this particular sub-catchment. The effects on the extent of the flood plain, also shown on the maps, are therefore minor. The maps indicate that a changed land use and river structure (Scenario C) would reduce the flood hazard to zero (Figure A.26) up to a 10 year flood event. For larger events, these changes would reduce, but could not avoid, resulting flood damages (Figure 4.16). It must be taken into account that these flood plains are the result of a hydrodynamic model using a constant influx as a steady flow simulation. This means that the shape and volume of a flood wave is not accounted for. Using the unsteady flow mode for the simulation would result in a smaller area flooded.

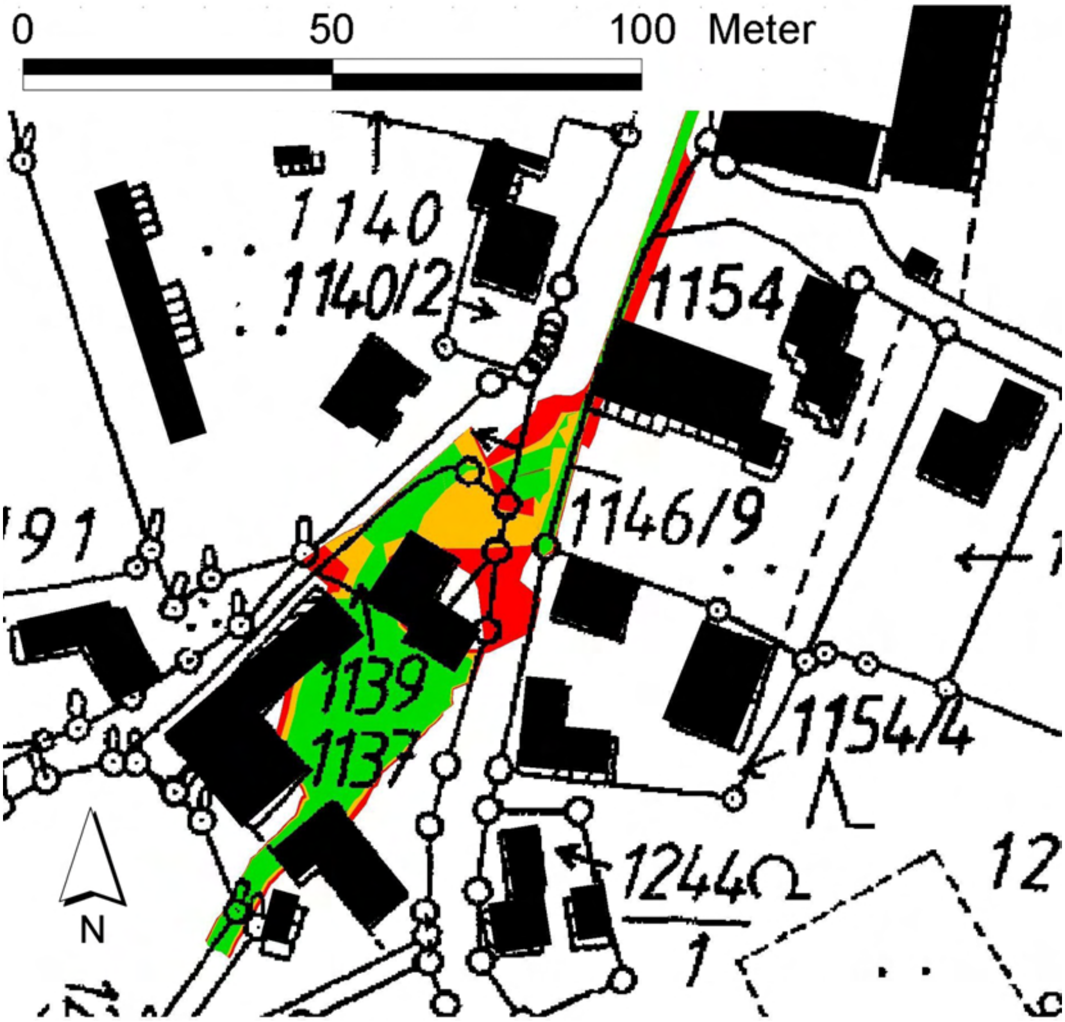


Figure 4.16: Extent of the 100 year flood in Bachling for the scenarios A (red), B (yellow) and C (green). Buildings and borders of property are indicated in black.

Damages

Only one farm estate and homestead with three buildings is located on the flood plain. Water levels in this area are below 2 meters. Only the basement of the homestead and first floor of functional buildings and the homestead are affected. The buildings are located in a depression. Backwater from the piped section fills the depression. An intersecting building also blocks the surface run-off and causes the filling of the depression. The assessment of flood related costs is possible for the different scenarios, but difficult because only one object blocking the discharge is simulated.

The situation in Bachling is characteristic for the situation in the area, and for German villages in general. Already small run-off can result in the first damages. This is a result of dense building patterns in Germany on the one hand and the development of settlements towards the valleys on the other.

As expected, low probability, high loss events cause the highest damages per event (Figures 4.17, 4.18 and 4.19) for all hydrological scenarios. Comparing them on an annual basis shows that the small events are responsible for the majority of damages accumulated over a 100 year period (Figure 4.20). This shows that even minor detention effects, will reduce the intensity or even avoid small damages and contribute enormously to the reduction of total flood damages.

Although the effects of land use and river structure are minor from a hydrological point of view, the economic impacts are significant. The accumulated damages over a certain period (100 years) show the significant costs resulting from high probability, low loss events (Figure 4.20). Time acts as leverage and the addition of individual damages over time results in high costs also exceeding those of a low probability, high risk event.

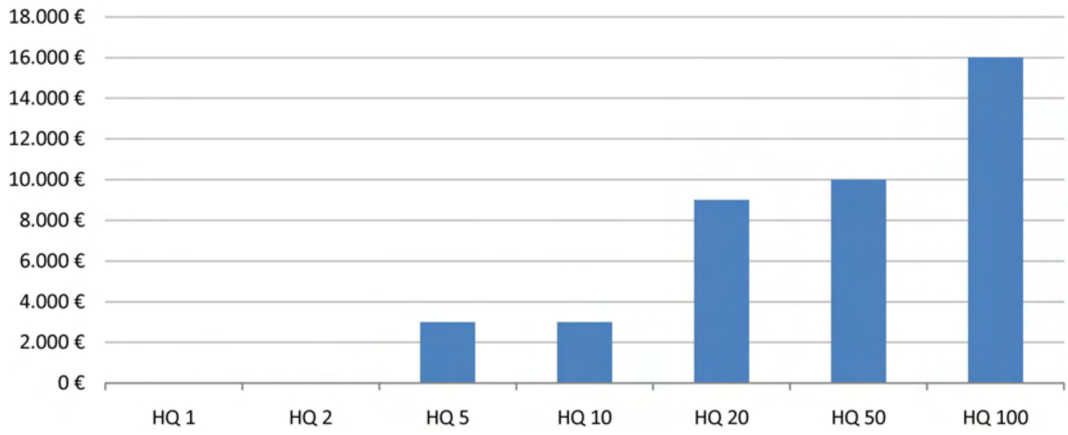


Figure 4.17: Flood damages per event for scenario A

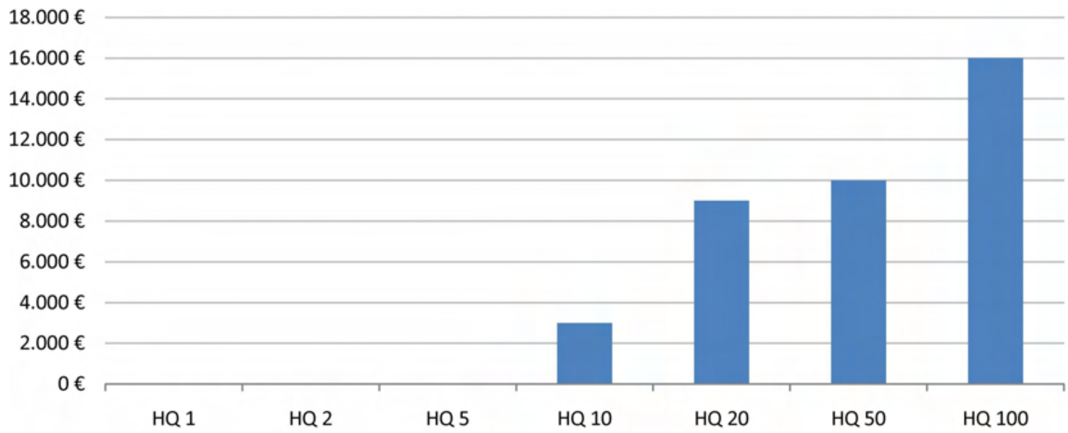


Figure 4.18: Flood damages per event for scenario B

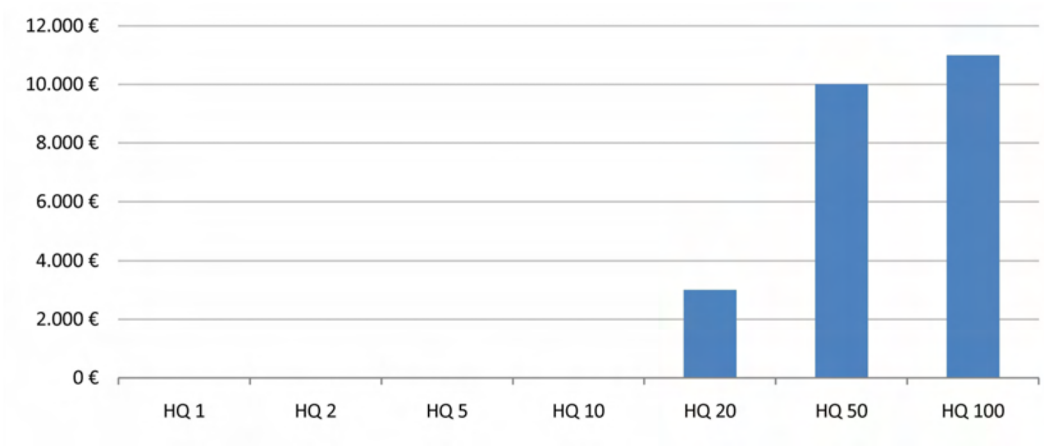


Figure 4.19: Flood damages per event for scenario C

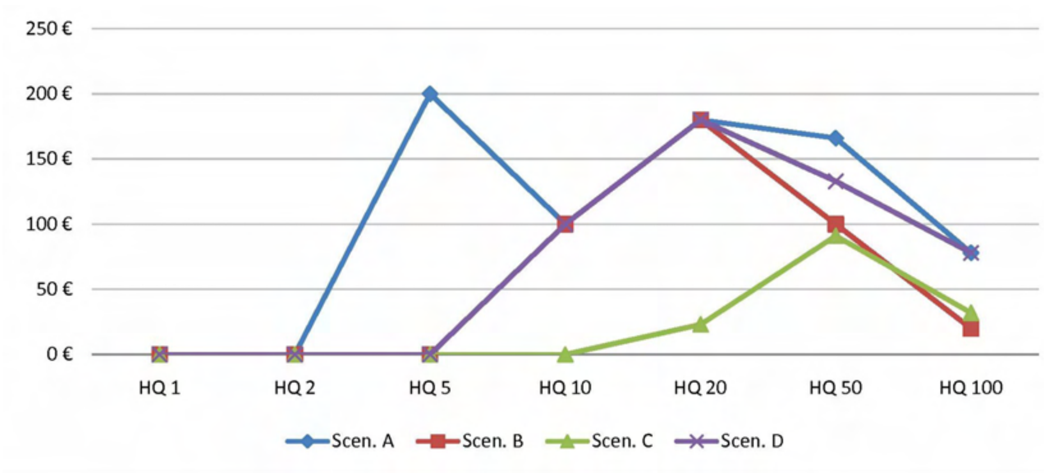


Figure 4.20: Flood damages in Bachling as a flood damages function, showing the annual damages per event over a 100 year period

4.3.2 Middle section

Hydrology

Buchhofen is a settlement in the small Herzogbach valley in the centre of the catchment. It developed first along the valley axis, but in recent years also towards the flood plain. At this point (node 32), the catchment is very symmetric and two major branches of the Herzogbach are joining just before Buchhofen.

Detention reservoir P3 at node 14 (Table 4.4), with a calculated volume of 4,000 m^3, shows no effect as an individual basin. Also, in combination with the reservoirs P1 and P3, no significant change in flood peaks can be achieved. In this area the landscape is too flat to provide sufficient detention volume. Maximum water levels in a reservoir that could be achieved are between 1.0 and 1.5 meters, and result in long dam structures.

At this point of the catchment (14 km^2), agriculture (69%) is the predominant form of land use, followed by forestry (17%) and grassland (13 %). Sealed and impervious areas are below 3 % of the size of the relevant catchment.

Land use, as well as river training, shows a significant impact on the shape and peak of the flood wave. River training increased run off by 3 m^3/s (scenario C) to 13 m^3/s (scenario B), while land use increased the peak by an additional 4 m^3/s to 16 m^3/s (scenario A) (Figure 4.21).

The time shift between the peaks of scenario A and C is visible (Figure 4.32), but not significant in respect to damages. Flood routing and the modification of the river reaches do not play a crucial role. This can be explained in terms of the short sections upstream and the equal length of river section, which means that run-off results in equal travel times of the flood wave from each tributary.

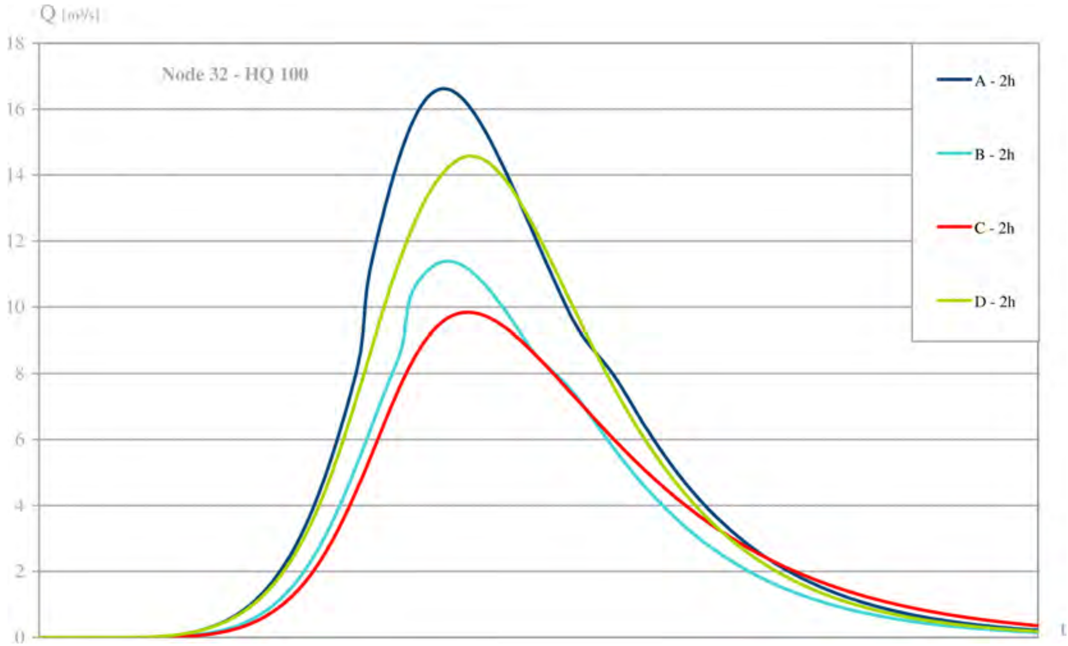


Figure 4.21: Flood waves for a 100 year flood event in Buchhofen.

Hydraulics

In Buchofen, the river is straight and should therefore provide an optimized situation to discharge a flood. But at several positions it is intersected by bridges, which in most cases act as barriers for discharge of larger floods. This is due to the fact that the infrastructural development took place at only one side of the rivulet, and estates on the other side are connected via bridges and cable ducts.

The impacts of land use and river training can not be explicitly shown for larger flood events as shown in figure 4.22. The differences between the scenarios A, B and C are minor for a 50 and also 100 year flood event. The volume of a larger flood wave is of more importance than the peak, because of backwater effects from bridges and other structures in the flow channel, as well as the wide flood plain in the valley. Scenarios B and C have a higher impact on the extent of small floods. The discharge capacity of intersecting buildings is often very small. A reduction of flood peaks therefore reduces or avoids backwater and resulting flooding. This can be seen especially in the eastern part of the village for a 5 (Fig. A.35) and 10 year flood event (Fig. A.36).

Figure 4.22: Extent of the 100 year flood in Buchhofen for the scenarios A (red), B (yellow) and C (green). Buildings and borders of property are indicated in black.

Damages

Buchhofen is a rural village, but also the centre of an independent municipality. It provides services like a city hall, restaurants and shops. Fortunately, main businesses and municipal infrastructure are located in the older parts of the village along the valley hillsides. The flood plain is mainly occupied by residential areas and farm estates. Unfortunately, the whole village is oriented along the Herzogbach valley. The number of bridges and other intersecting buildings increases the danger from backwater effects and the number of buildings located in the river valley increase the total damage costs.

The distribution of affected building base areas (Figure 4.23) shows that land use and river training affects mainly small and common floods events. But the distribution of affected buildings is also a result of the geomorphology of the flood plain, the distribution of buildings in the flood plain and intersecting buildings. In Buchhofen, backwater processes are mainly responsible for flooding. Once the discharge limit of an intersecting building is reached, it results in a filling of the valley respective the flood plain. The wide valley situation results in extensive flooding. Due to the high number of bridges and pipes in Buchhofen and their restricted diameters, flooding is increased. The form of the valley also restricts the amount of buildings affected to those at the bottom of the valley.

Buchhofen shows very well the increasing effect of high probability, low loss events. Small flood events cause the majority of damages calculated over a 100 year period (Fig. 4.24).

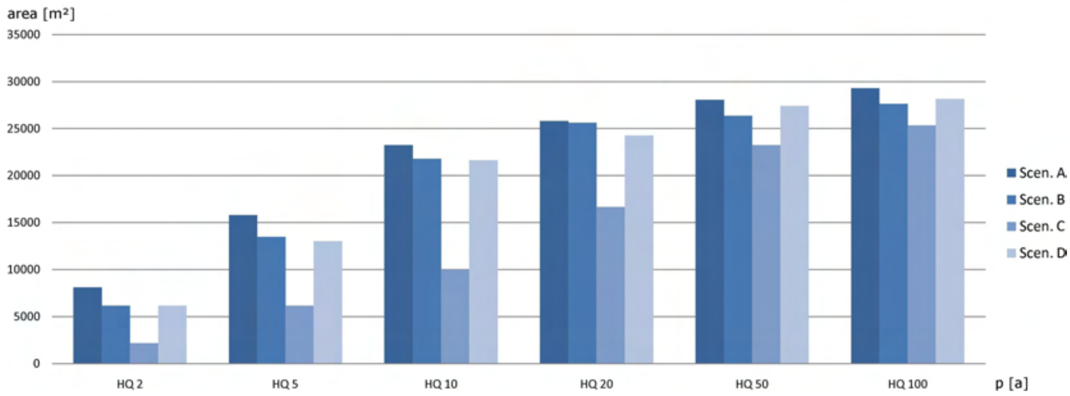


Figure 4.23: Affected base area of buildings in Buchhofen

Although natural detention only has a minimal effect on larger flood events and resulting damages, it can reduce the total accumulated damages.

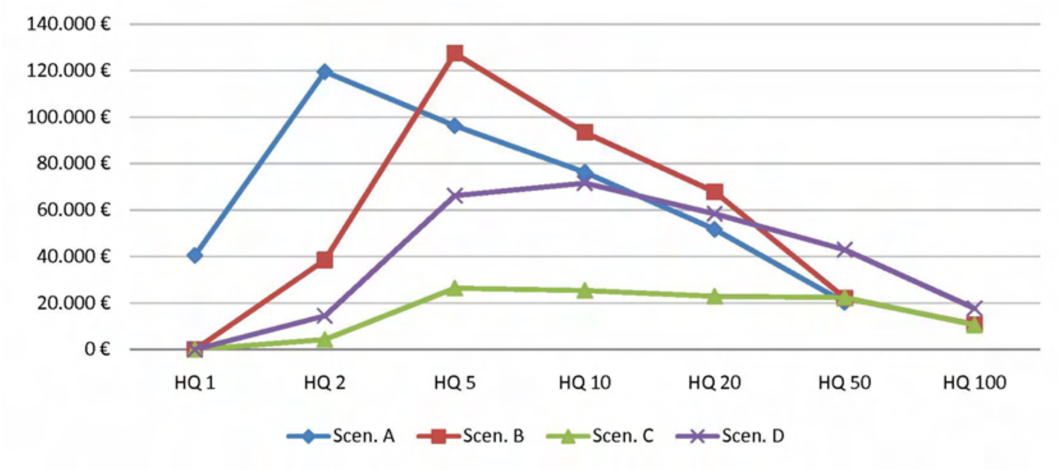


Figure 4.24: Flood damages in Buchhofen as a flood damages function, showing the annual damages per event over a 100 year period

4.3.3 Tailwater

Hydrology

Different sub-branches of the Herzogbach and its tributaries meet in the city of Osterhofen. The main tributary is the Herzogbach, with a length of 20 km. The catchment has a total size of 42 km^2, and land use is dominated by agriculture (75%) - followed by grassland (13 %), forests (10 %) and sealed and impervious areas (2 %). Effects of surface sealing and urban development in Osterhofen do not affect the run-off situation of the Herzogbach, because the sewer network transfers most of the sewage and storm water run-off directly towards the Danube. At node 76 (inlet to Osterhofen), the different scenarios show the possible impacts of land use and other forms of human activities on a flood wave. Human land use increased the natural flood wave (Scenario B) of 27 m^3/s by 9 m^3/s to 38 m^3/s (Scenario A). River training especially shows a significant impact at this point of the catchment. A natural flood plain would reduce the peak of 29 m^3/s by 10 m^3/s to 19 m^3/s (Scenario C).

Of interest is the delay of the flood wave of Scenario C (natural flood plain) in contrast to Scenario A (status quo). The asymmetric shape of the catchment causes different travel times for the flood wave from different branches. The reduction of the flood peak in Scenario C at node 76 Osterhofen can be explained partially by avoidance of superposition of flood

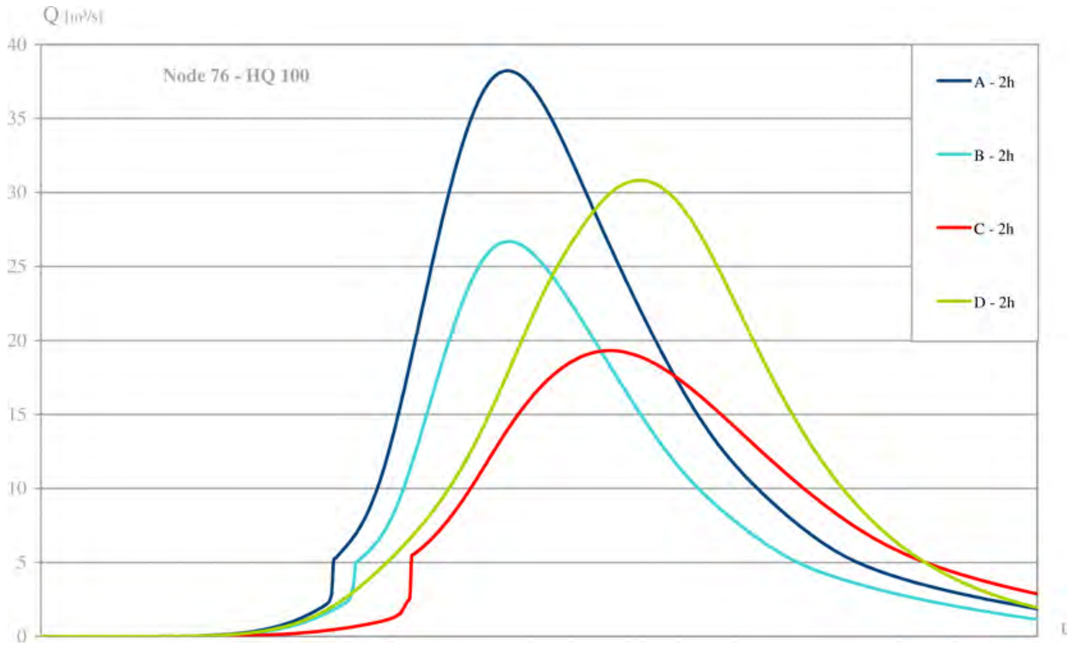


Figure 4.25: Flood waves for a 100 year flood event in Osterhofen

waves. Figure 4.26 shows how the flood waves of Scenarios A and C develop. At node 32 (Buchhofen), a delay of the flood wave from Scenario C can be identified. The development of the shape of the total catchment supports this effect. Because of a renaturalized river bed and flood plain, a flood wave from the long main branch has a significantly longer travel time than the short and even steeper side branch.

The surface and river structure influence the total volume of the flood wave, which is important for the control of a flood by detention. But also the separation of two flood waves from two different branches can help to improve the attenuation effect. This effect is mainly due to channel structures. Figure 4.27 shows how land use influences the discharge volume and detaining effect. The flood volume of Scenario A (status quo) 0.4 Mm^3 differs significantly from the 0.36 Mm^3 from Scenario B (grassland and forest).

Lost detention volume can be compensated for by artificial structures. The necessary volume depends on the peak and shape of the flood wave, but also on the location of the reservoir in the catchment and the form and extent of the dam structure and reservoir body. Technical detention always implies costs for building these structures. Depending on the shape and

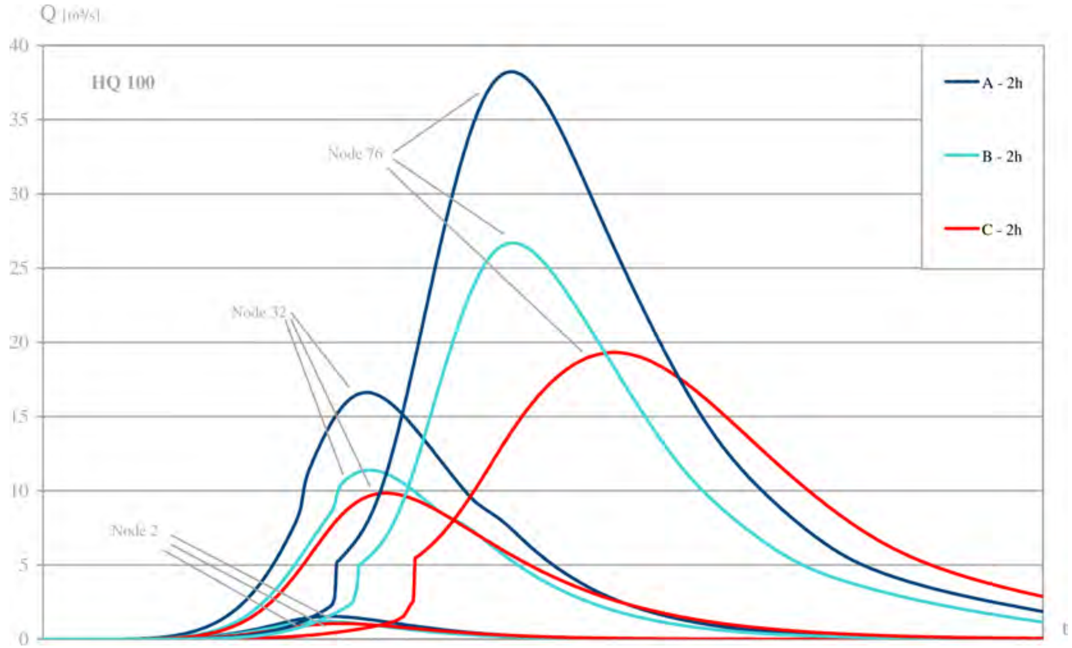


Figure 4.26: Flood waves for a 100 year flood for scenarios A, B, C at the nodes 2, 32 and 76

profile of the river valley, the form and volume of the necessary dam varies - and hence the costs as well. Three types of detention reservoirs can be distinguished for run-off control:

1. uncontrolled: a fixed outlet (pipe, fixed weir) regulates the outflow depending on water level and pressure
2. controlled with fixed run-off: the level of the control mechanism will determine the maximum outflow. Therefore, the mechanism must be moved manually or automatically depending on the water level in the reservoir
3. controlled with a flexible control strategy: depending on the influx and development of the flood wave, the control mechanism will be opened or closed to maximize the efficiency of the detention volume.

Type 1 is standard for small catchments and small reservoirs. It has the lowest building cost and is easy to maintain and handle. Types 2 and 3 need advanced technical equipment, and type 3 additional input data about the discharge in the headwater. They are only used for bigger detention structures, because of the costs and the need for qualified personel to decide about the control strategy. A type 1 reservoir is located just upstream of Osterhofen. It provides a total detention volume of 56,000 m^3. It offers protection against a 20 year flood event for the village Wisselsing just 3 kilometers upstream of Osterhofen, but not for Osterhofen. It decreases the peak of a 10 year flood event in Osterhofen by 8 m^3/s to 10 m^3/s (Fig. 4.27). Using an optimized control strategy, the detention volume would result in a maximum peak of about 5 m^3/s in Scenario C (Fig. 4.27).

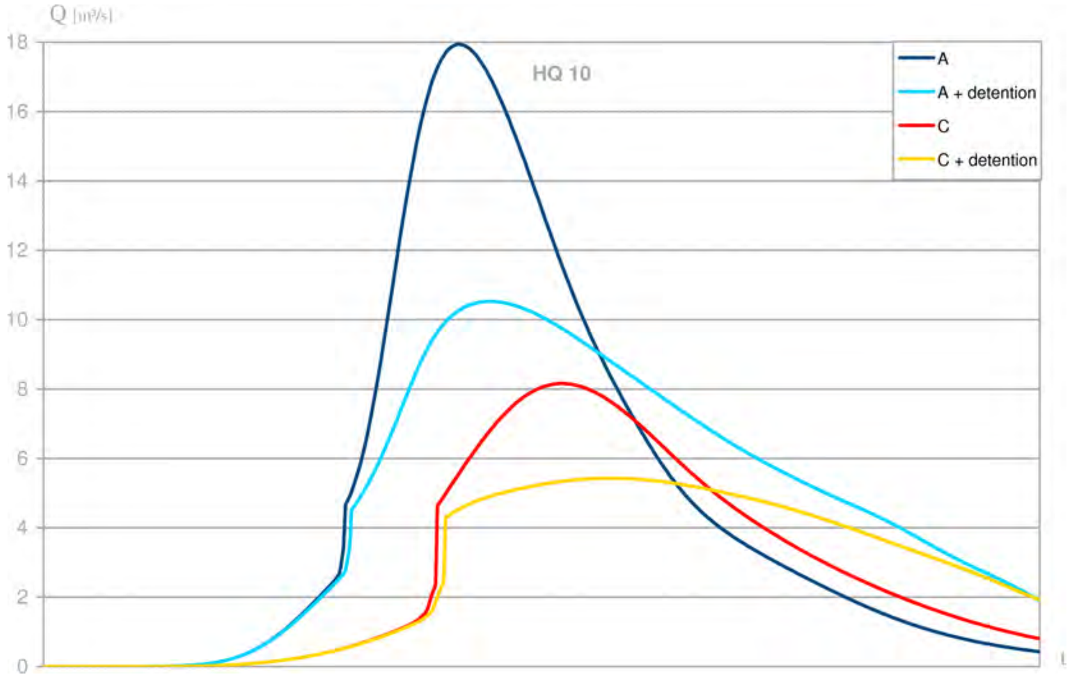


Figure 4.27: Detention of a HQ10 for the Scenarios A and C at the Node 76

The current reservoir is not built to protect Wisselsing against a flood more rare than a 20 year flood event. The effects of the reservoir for the protection of Osterhofen are negligible. In the hydrologic model, the control strategy was modified and an optimized outlet unit was applied. For Scenario A the reservoir results in only a reduction of 8 m^3/s to 30 m^3/s at the node 76 in Osterhofen. For Scenario C the reservoir could reduce the peak down to 12 m^3/s. However, an assessment of possible locations for new detention structures showed that the existing dam at Wisselsing is the only available location (Dorner, Spachinger, Lenz & Metzka 2005*b*). All other potential positions upstream of Osterhofen are either too small or do not show a significant effect on flood detention. This is the result of either size or the distance between the reservoir and protected area. Increasing the existing structure is not possible because the backwater would cause damage in an upstream village. The shapes of the flood waves from Scenarios A and C show that an immense detention volume would be necessary to achieve an equivalent detention effect to the natural flood plain. In this case study, a realistic estimation of the necessary total reservoir volume is not possible because the existing dam already represents the largest structure possible in the given landscape, and structures can not be used to simulate the total lost detention volume.

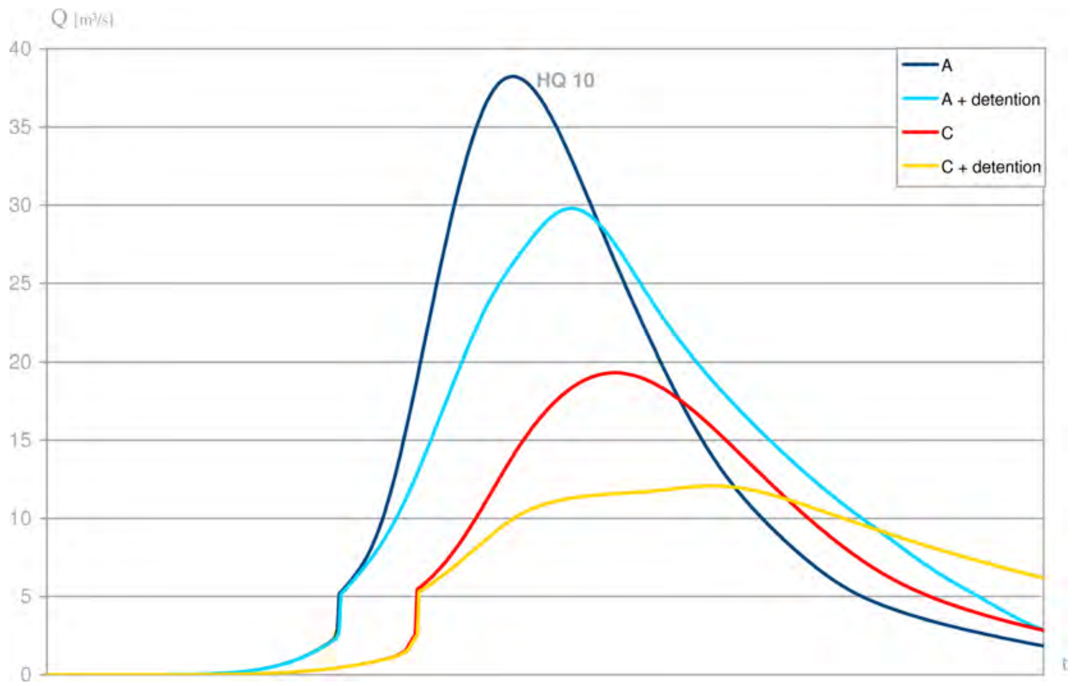


Figure 4.28: Detention of a HQ100 for the Scenarios A and C at the Node 76

Hydraulics

Upstream of Osterhofen at an old weir, the Herzogbach splits into two rivulets: the former mill channel heads directly towards the city centre, is built partially as a diked channel and partially as a hillside channel. It passes several depressions. The main river channel flows through several residential areas and cuts through the higher Danube bank to the Danube valley. Especially in the flat section of the Danube valley, the rivulet passes through several new residential areas which restrict the river channel and floodplain. In this area, the channel of the rivulet is broad and has a flat embankment.

For Osterhofen, the hydrodynamic model results show that the old weir in the west of Osterhofen (splitting discharge of the Herzogbach to the mill channel in the north and the main river bed in the south) would fail during a larger flood event. This results in additional flooding of a depression near to the city centre.

There are three reasons for flooding in Osterhofen:

1. The mill channel is built as a hillside channel above an artificial depression. The overtopping of the river bank results in a filling of this depression.
2. Backwater effects from the small valley through the Danube bank and bridges at the main rivulet.
3. Flat river bed, low banks and a wide flood plain in the Danube valley.

The flood plain in Osterhofen can be subdivided in three sections:

1. The western part in the head water is a wide flood plain. The flow splits to the mill channel and the natural river bed. The stream fills on the one side the natural open flood plain, and on the other side the artificial depression south of the city centre when the flood overtops the shoulder of the mill channel dam.
2. The section towards the small valley in the higher Danube embankment results in backwater effects from two intersecting bridges.
3. It is followed by a wide flood plain in the Danube valley, where the rivulet has a flat river bed and embankments. The topping of the embankment results in wide flooding.

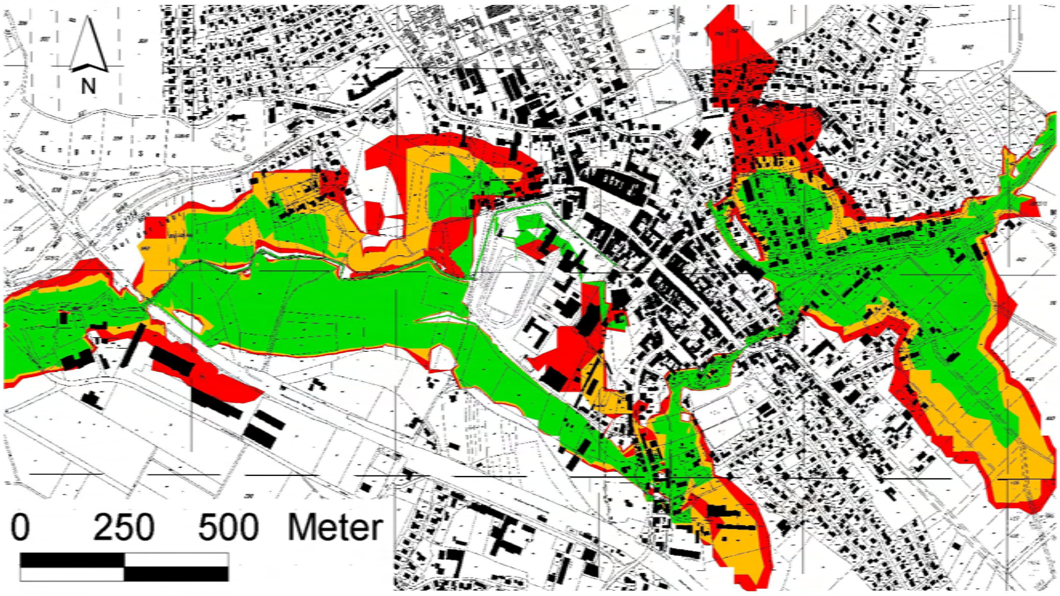


Figure 4.29: Extent of the 100 year flood in Osterhofen for the scenarios A (red), B (yellow) and C (green). Buildings and borders of property are indicated in black.

Damages

The wide flood plain in the lower system (section 3) contributes to the majority of damages in scenario A. Flooding results from an overtopping of the embankment and an inundation of the wide open flood plain. Therefore, also minor reductions of the flood peaks in scenarios B and C could contribute to a reduction of affected buildings and damages, because overtopping of protecting landscape structures can be avoided (Figure 4.23). In contrast to this, backwater effects in the middle section and the natural restriction of the valley result in a very constant extent of the flood plain in these areas and, therefore, a minor reduction of damages in Scenarios B and C.

In Osterhofen, the simulation overestimates the number of total damages because of the flooding of wide areas due to the constant inflow situation in the hydrodynamic model. This happens in all four Scenarios A to D. The relation of damages between two scenarios gives a qualitative impression of the externality. Osterhofen also provides an impression as to which impact river structure and the super positioning of flood waves from different branches can have on the damages. River training contributes to the majority of damages

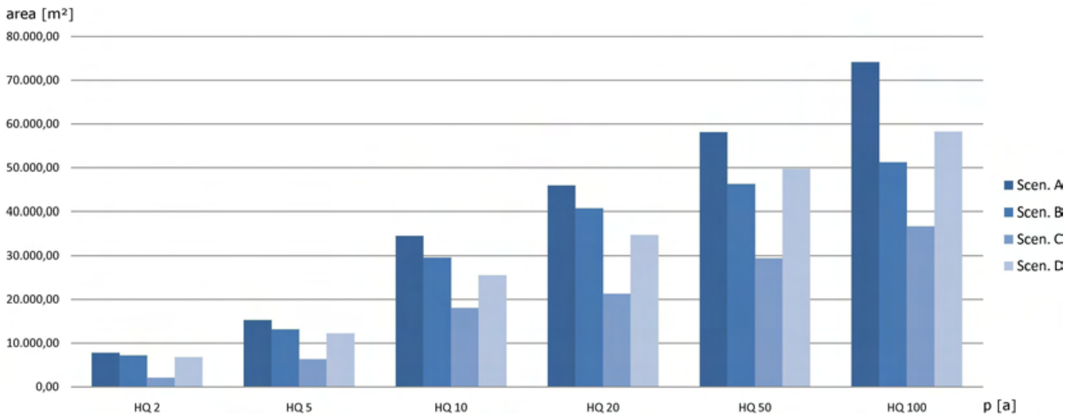


Figure 4.30: Affected base area of buildings in Osterhofen

(Scenario C minus Scenario A) and hence the main part of the externalities in Osterhofen.

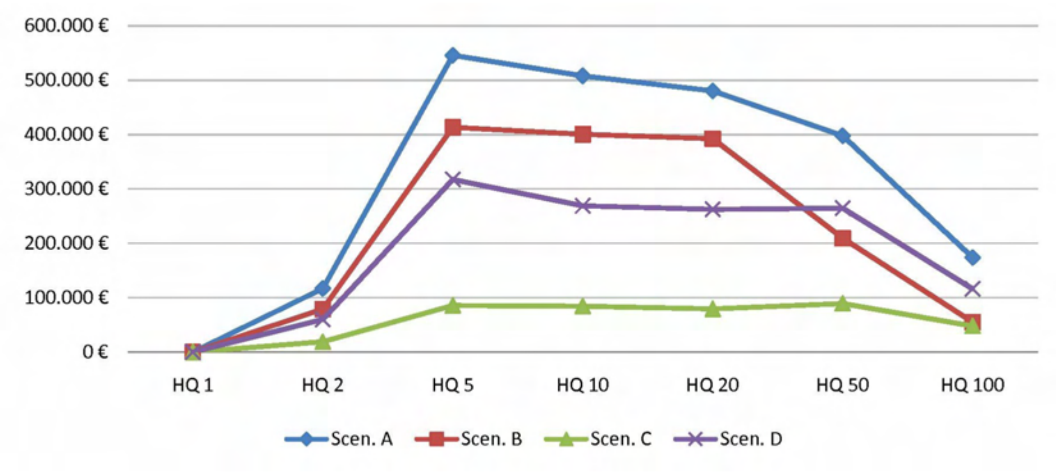


Figure 4.31: Flood damages in Osterhofen as a flood damages function, showing the annual damages per event over a 100 year period

4.3.4 Evaluation on a catchment scale

The increase of flood peaks is due to different effects.

- Reduced retention capacity of the land cover, especially during spring and autumn after the crop harvest and before seeding (expressed by the c values of the regionalisation approach in the hydrological analysis).
- Reduced retention capacity of the river bed and especially the flood plain (expressed by a prolongation of river reaches in the Kalinin-Miljukov approach, but also in the factors l and l_c in the regionalisation approach).
- Increased speed of the flood wave in the river system and super positioning of flood waves from different branches.

A comparison on a catchment scale shows that there is no general quantitative dependency between land use, river training and run-off. Too many different geomorphologic parameters influence the run-off behaviour of the catchment. From a quantitative point of view, river training as well as land use influences the peak and the detention-relevant volume of a flood wave. The effects of river training depend on the length of affected river sections. The length of modified areas in different sub-catchments and the irregular length of different branches also play a crucial role.

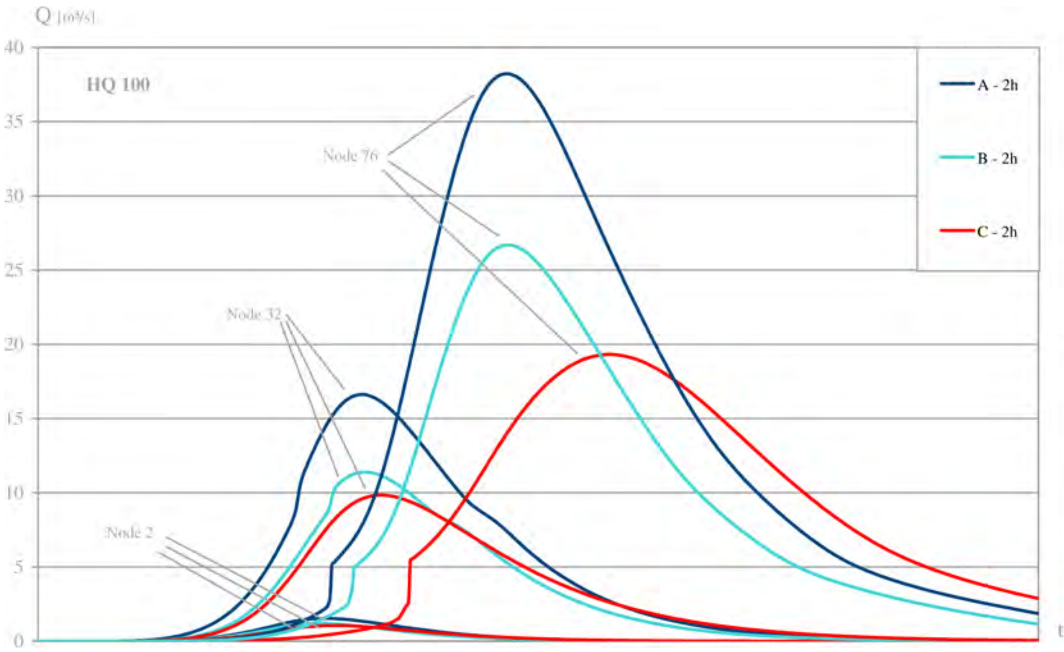


Figure 4.32: Development of the flood waves for the Scen A (Status Quo) and the natural status Scen C

The last factor depends very much on the shape of the catchment and the different branches of the river system. If we assume regular precipitation in the whole catchment, a proportional elongation of both branches would mean a proportionally longer travel time for the flood wave in the longer rivulet. Normally, the rising limb of a flood wave is steeper than the falling one, so an equalisation would lead to a significant decrease of the peak.

The comparison of Figures A.8, A.14 and A.20 show that land use especially influences the peak and volume of a flood wave (Scen A vs. Scen B). The changes in the river morphology influenced the peak, but also the speed of the flood wave and therefore the superposition of two waves at a junction. This can be seen very clearly if we compare Figures 4.33 and 4.34. For the status quo (scenario A), the run-off leads to a nearly perfect superposition of the flood waves from different sub-catchments (Flows of nodes 2 and 4 result in a peak in node 5, 14 and 31 in the peak at node 32, 53 and 72 in the peak at node 76). The channel structure influenced the run-off speed and as a result, the superposition of peaks at the junctions of

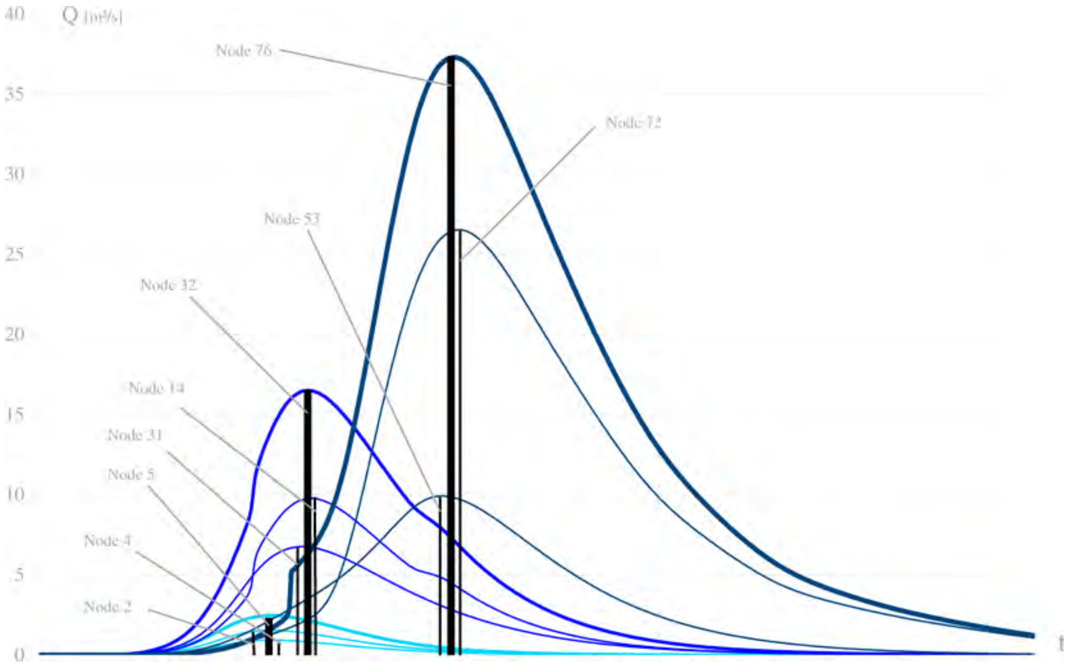


Figure 4.33: The superposition of two branches (Nodes (2,4)(14,31)(53,72)) leads to the wave in the main branch (Nodes 5,14,32) for the Scen A

two branches. This can be explained with respect to the irregular shape of the catchment. Especially towards the outlet, the longer branches coming from the upper or western part of the catchment result in longer travel times than the shorter southern tributaries.

Two factors are of interest for the evaluation of floods - the peak of a flood wave and the extent/duration and volume of a wave. The peaks are relevant for the extent of the flood wave in the flood plain, damages and the necessary elevation of measures for flood defense along the river, like dikes and walls. The volume and shape of a wave affects the efficiency of detention measures.

The analysis showed that land use and river morphology influence both peak and shape. Therefore, three measures can be identified to quantify the externality on a catchment scale:

- The flood damages of Scenario A (status quo) minus those of Scenario C (natural situation of catchment and river).
- The costs for flood protection works for Scenario A minus those of Scenario C.

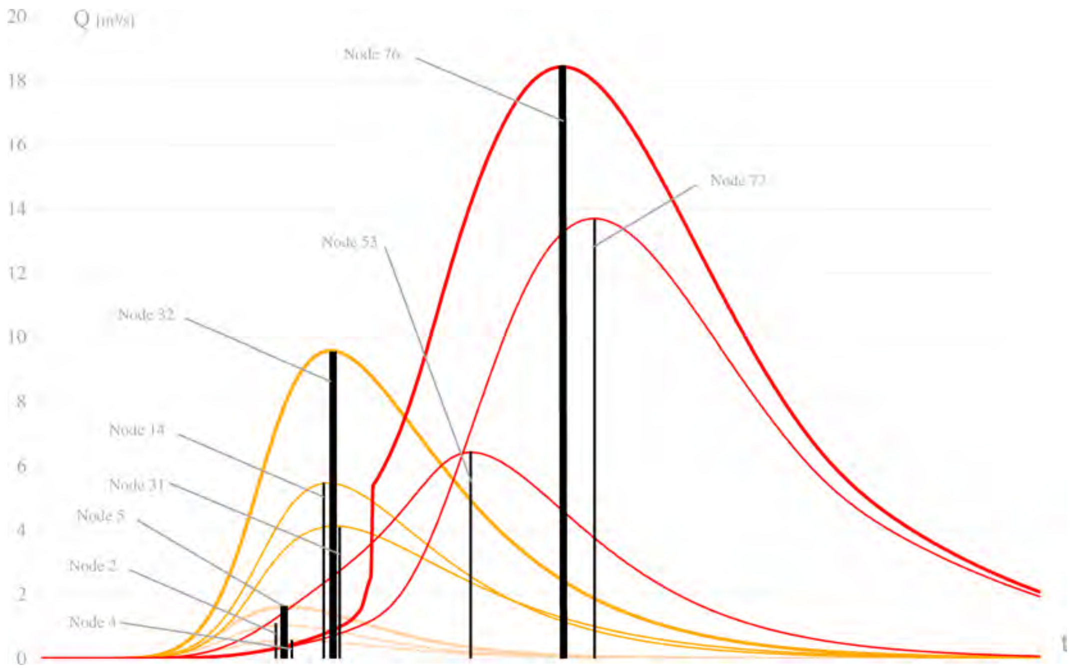


Figure 4.34: The superposition of two branches (Nodes (2,4)(14,31)(53,72)) leads to the wave in the main branch (Nodes 5,14,32) for the Scen C

- The costs for detention reservoirs for Scenario A minus those of Scenario C.

It is not always possible to quantify the externality with all three measures: in the Herzogbach catchment, no location for larger detention works are available. Therefore, it is impossible to quantify the extent and costs of these structures. In larger cities, major supra-regional infrastructure can also be affected. In such a case, it would be difficult to calculate the total damages resulting from indirect and intangible damages.

At rivulets and smaller rivers, no significant flood protection systems are available. Here especially, land use and river training seem to have a higher relevance for flood development. The study showed that smaller events are influenced by land use and river training and contribute to the majority of damages. “Neben den sehr seltenen Katastrophen-HW sind jedoch die häufiger auftretenden HW geringerer Größe von Interesse, da sie meist den Hauptbeitrag zur Schadenssumme für längere Zeitabschnitte liefern. [Besides the rare disaster floods, more common floods of a smaller extent are of interest, because they provide the main contribution to the total damage over a longer period.]” (Dyck 1995, p. 430). The study shows that land use and river training can significantly contribute to flood damages in small catchments and indicate that an internalisation strategy could aid to increase the level of flood protection, reduce the effects from land use or redraw negative developments.

Model results showed that in some areas of the catchment, a higher level of flood protection was achieved for agricultural areas than for settlements. While trained rivulets in the agricultural section are not interrupted by bridges or piped sections, in settlements these common structures cause backwater effects resulting in the flooding of used areas. Externalities are responsible for over 50% of damage costs (Fig. 4.35) in the assessed villages. The accumulated costs of high probability, low loss events contribute to the majority of damages. The results of Scenario D show that small measures like the implementation of intermediate crops or direct cropping could significantly reduce the extent of flooding and consequently, flood damage costs. But the main impacts result from modifications to the river channel for all three evaluated villages. As a consequence, the conclusion can be drawn that river renaturalisation provides a suitable tool to reduce flood-related costs.

Out of a list of over 30 hotspots in the whole catchment, three settlements have been evaluated. Bachling, Buchhofen and Osterhofen represent three typical forms and sizes of urban areas in a rural landscape. Remaining hotspots, mainly small villages or single farm estates, show similar damage potential and floodplain characteristics to the villages of Bachling and Buchhofen. This means that only in the catchment of the Herzogbach can a significant part of all flood damages be called externalities.

Only damages from flooding from the river system have been taken into account. The effects of storm water run-off, such as surface run-off from sealed urban areas, and related damages have not been evaluated. On the one hand, they are more difficult to identify, and on the other hand the impacts of land use and landscape structures cannot be directly assessed. The amount of run-off and its probability are difficult to model. As well, the flow paths in the landscape and their impact on buildings and damages can only be guessed. But as already mentioned, for the general effect of small landscape structures, it can be assumed that the same relations as found for larger impacts exist.

Differences between results of land use scenario A and scenario B show that land use does not only alter run-off and as a consequence peaks and volumes of flood waves in the lower reaches of a catchment. The analysis of flood damages as well as the evaluation of technical detention measures showed that there are significant transfers of costs from the head waters to the lower reaches of the catchment as a result of these alterations to landscape and land cover. Land use increases flood peaks and volumes resulting either in higher damages downstream or in higher costs for flood detention. These higher costs can be estimated by analyzing the difference between run-off from a pristine catchment and a catchment with the current land use and the difference of resulting damage or mitigation costs. These costdifferentials are the results of land use in the upper catchment and are therefore externalities of land use.

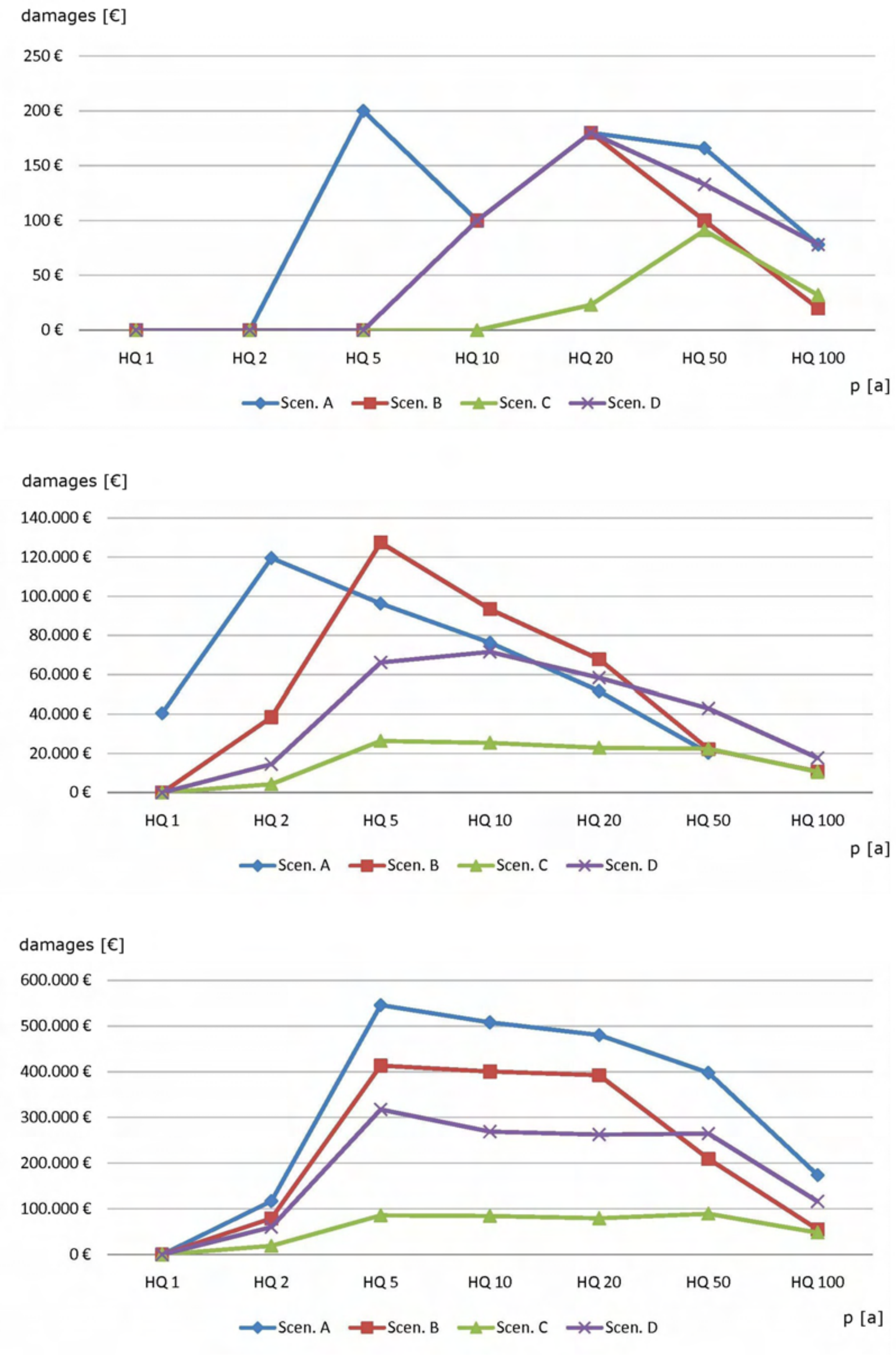


Figure 4.35: Flood damage functions of Bachling, Buchhofen and Osterhofen

Chapter 5

Discussion

5.1 Critical review of the methodology

The presented methodology to identify and quantify hydrological externalities of land use combines approaches and sub-methodologies of three different fields and disciplines:

- Quantitative hydrology,
- hydraulics and flood modelling, and
- flood damage estimation.

This results in several interfaces between the different models, as well as the requirement to use stable but simplified approaches from the different disciplines. Each transfer of data from one model type to another can result in a loss of precision and involves simplifications.

One of the major problems is the calibration of models. The hydrologic model, in combination with the hydrodynamic model, should provide sound results. Past experiences of engineering projects with the same combination of models in other catchments, and the possibility to compare measured data with model results, showed that a precision of 5 to 10 cm for water levels can be achieved. Experiences from these projects were transferred to the presented study. With regards to the historical data available, it is impossible to calibrate the historical and/or alternative land use and landscape scenarios. This implies that model results of alternative land use scenarios can only show a tendency of flood development under the estimated determining factors.

There is always a compromise between the precision of a model structure and the availability of precise input data. Models, like those used in this project, always reduce the complexity of reality and express real processes as formulas using aggregated parameters as input. Especially in small catchments, statistical data to calibrate a model is often missing as is the historical data required to model alternative scenarios. Different types of hydrologic models, such as physical models, could be used to better represent the different processes (DVWK 1999). But the details of modelling are also bound to more detailed data and modelling efforts. Under today's conditions, data gathering and model building on a catchment scale would exceed the work load for practical studies and a broader application of the suggested methodology. Precise models, which can physically simulate complex processes such as infiltration, evapotranspiration and surface run-off are only available on a micro scale. The processes are usually too complex to be modelled on a catchment scale. Hence, results presented in this thesis can give only an indication of how human interactions changed run-off and flood behaviour of the catchment. The historic data necessary to evaluate a previous condition is difficult to gain and interpret. In this study, the lack of river profiles made it difficult to accurately simulate the discharge behaviour of the river channel for historic conditions. Therefore, the model results must be interpreted carefully. The assessment of impacts of individual measures or the assignment of individual responsibilities to land owners is impossible. The methodolgy can assess the accumulated impacts of all activities in a catchment influencing run-off and flood development. The used methodology represents a compromise between precision of modelling and manageability and data gathering and processing and will provide a conservative estimate of the externality.

At the moment, medium and large scale hydrological river basin models are not able to deal with the problems of detailed rural structures like trenches, drains and field structures or data gathering would exceed the possibilities of a study. There exists too little experience and statistical data to quantify the effects of these structures and assume their effect on parameters used in catchment modelling on a meso scale. In the presented study it would also be problematic to estimate the relevant parameters for different historic scenarios because of a lack of measured and mapped data. It can be assumed that natural structures like depressions and boundary ridges would have an additional detaining effect - whereas technical elements, like drains and trenches will increase and accelerate run-off.

Therefore, the assessment of the spatial impacts of human actions in the flood plain and river basin have been excluded from this study:

- Natural depressions,
- boundary ridges,
- drainages,
- trenches,
- sewers,
- field size and structure.

For the historic situation and alternative land use scenarios, only two parameters were altered in the hydrological model:

- Distribution of land use represented by the average run-off coefficient for each sub-catchment (CN value) in the regionalisation approach.
- Length of the river channel in the flood routing and regionalisation approach.

Further modifications of other parameters like channel roughness, profile of intersections etc. were avoided because of the absence of detailed data. Hence, alternative scenarios for land use were calculated conservatively and will tend to underestimate the effect of natural landscape and river structures.

The Kalinin-Miljukov approach for flood routing proved to be a feasible and effective way of quantifying channel run-off. Problems encountered were related to the detailed modelling of the river channel and flood plain, and were due to the lack of historic data of river profiles. The adopted approach of modifying the length of river channels restricts the analytical possibilities for previous channel conditions. It underestimates the detaining effect of natural rivulet structures. An elongation leads to a reduction of flow velocities and to increased water level. It can be assumed that natural profiles would have a flatter channel and wider floodplain. This would result in earlier flooding of the floodplain and additional detention. No historic information about river profiles can be found. They are entirely modified in the current state. Renaturalised sections are not old enough to have achieved equilibrium. Future projects would benefit from the simulation of hydromorphological processes in addition to the hydraulics.

The hydrologic and hydrodynamic model results for the status quo should show a realistic picture of the current status. The other results show the minimum effect natural river structures or land cover would have. They represent maximum peaks, volumes, discharge and extent of flood plains which can be expected under the assumed basic conditions for historic scenarios or land use alternatives.

In the hydrodynamic model, the results of the different hydrological scenarios can be transposed very well. For all scenarios, the same landscape model was used, which means that no additional assumptions regarding channel structure or roughness have been made. The same applies to the calculation of flood damages.

It can be assumed that a flood under historical landscape conditions would be smaller and lower than estimated in this study, due to the following constraints:

- Small scale landscape structures, such as hedges and ditches would decrease surface run-off and flow velocity.
- In addition, they would result in increased infiltration, interflow and groundwater flow, reducing the peak flow and accumulation of flood waves from different sub-catchments.
- Natural rivers would show higher river beds and lower and flatter embankments, resulting in increased detention of the flood plain.
- Densely overgrown embankments would additionally reduce flow velocity and increase the extent of the natural flood plain.

For the economic analysis of flood damages or mitigation costs only direct tangible damages to buildings and furniture were considered. This approach provides robust data but underestimates the total costs of floods. In the current case costs or damages from other categories can be ignored because they either do not appear (e.g. interruption of production because, interruption of infrastructure as well as damages to larger infrastructure, diseases) or are negligible from the perspective of risk (e.g. diseases, loss of life). The results of the damage estimation are conservative and underestimate the total damages. Under different economic and hydrological conditions a different choice of cost categories could be more preferable.

In general, the suggested methodology can be used very well to evaluate natural detention in the catchment from an economic and technical point of view, because it indicates very well whether changes of landscape structures resulted in significant externalities. In the sample catchment, this approach showed to be technically feasible. The comparison of different land use and river scenarios evidenced significant changes in the flood behaviour of the catchment. Because classical planning often ignores "non-technical" measures of flood mitigation the approach to couple hydrologic and hydraulic modelling, economic analysis and a scenario analysis, should become the basis for future planning. Other models like erosion and diffuse pollution, sediment transport or morphology models could be integrated as well to estimate the effects of human impacts in these areas.

5.2 Research outcomes

The selected test catchment shows significant changes in land use and landscape structures. Historical maps indicate that in 1820, agriculture was already the dominant form of land use and land cover in this area. The past 200 years did not show a significant increase of agricultural areas on a catchment scale, but a change of landscape structures, agricultural emphasis and agricultural practices. This resulted in a loss of natural flood plains, natural detention structures and a concentration of run-off supporting crops and farming practices. In parallel, residential areas developed towards the flood plain.

This intensification of land use had significant effects on surface run-off, discharge and the accumulation of flood peaks from different branches of the catchment at junctions of the river system.

The results of the hydrologic model show three effects of human interventions for the test catchment when the different hydrological scenarios are compared:

1. Reduced land cover increases surface run-off and therefore flood peaks and total flood volumes.
2. Natural river structures increase the flow time of flood waves from several branches and can reduce the probability of the super positioning of flood waves.
3. Natural flood plains store large amounts of water. In combination with decoupled flood waves, this can reduce flood peaks.

Different effects can be seen at different points of the catchment. While in the small catchments (Node 2) the effect of the river structure is lowest, the reduction or increase of flood peaks can be traced back to the routing effect and the super positioning of flood waves from different river segments close to the outlet of the catchment (node 76). In very small catchments, the effect of land use on run-off and peak flow is highest for small events with a high probability. In larger catchments, the impact of river structures should be of larger importance.

The effects of land sealing have not been taken into account individually, because their impacts are well understood. The distribution of land use types clearly shows that in this catchment, the main impacts are due to agricultural land use. The city of Osterhofen could have significant effects on the downstream situation, because it has a major storm water system. However, its outlet flows directly to the Danube and so no effects can be found in the tail water of the Herzogbach. The effects of sealed areas in combination with storm water systems on run-off and flood detention in small catchments have already been proven by others (Umweltbundesamt 2001, Croke et al. 2004, Thurston et al. 2003). Therefore, this factor was ignored in this thesis. The consequences of sealing and storm-water run-off from settled areas have a similar effect on the development of externalities and need to be separately assessed in the future in a similar way. Storm water run-off in sewer systems can lead to additional inefficiencies and partial externalities if the costs for infrastructure investments and maintenance are not proportionally shared between causers.

As a result of the further hydrodynamic analysis, it can be concluded that changes in surface run-off and discharge also have significant impacts on the development of floods in

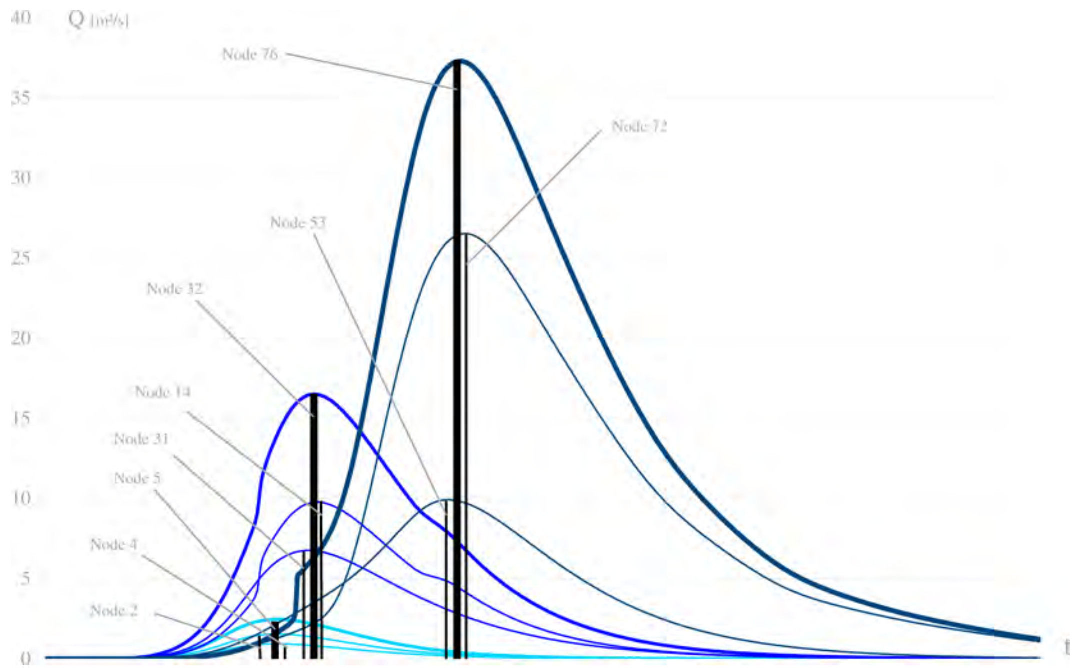
Probability	Scen. A	Scen. B.	Scen. C	Scen. D
HQ1	0.2	0.2	0.1	0.2
HQ2	0.3	0.3	0.2	0.3
HQ5	0.5	0.5	0.4	0.5
HQ10	0.7	0.7	0.5	0.7
HQ20	1.0	0.9	0.7	0.9
HQ50	1.3	1.2	0.9	1.2
HQ100	1.5	1.2	1.1	1.4

Table 5.1: Run-off at Node 2, peak values in m^3/s

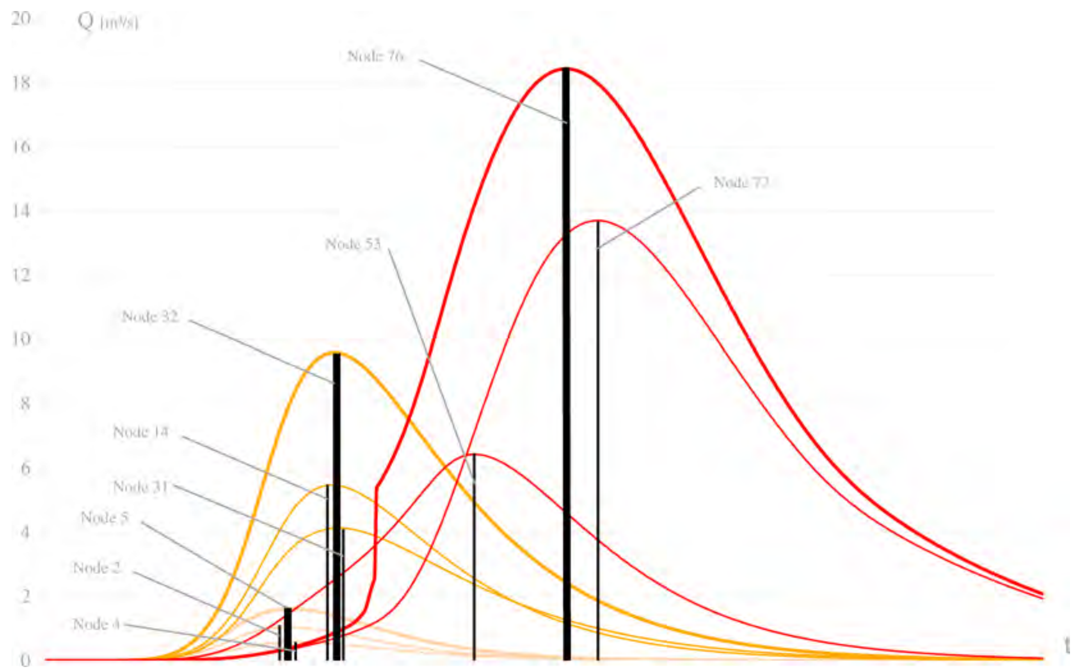
residential areas. In all three residential areas analysed in this case study, significant impacts can be stated. Together with discharge, water levels and the extent of the flood increase. The significant increase in run-off of high probability hydrological events results in more frequent flooding of residential areas. Although these physically small events only cause minor damages, the accumulation of these small damages over time are responsible for the majority of total losses.

This is of relevance for the further economic considerations. Hydrologically, the effects of natural detention in small catchments for a small but frequent event should be, in general, large. The effect should reduce with the increasing intensity of the events. This is supported by the results of the case study (Table 5.1). If under intensive land use small but frequent events are responsible for the majority of damages, then land use change results in significant externalities.

In small catchments, high probability, low loss events, which are mainly affected by land use change from a hydrological perspective, contribute most to the accumulated damages over time. In larger catchments, the river structure contributes most to peak flow and shape of the flood wave. River training and the optimisation of river profiles reduced the detention capacity of the flood plains and increased the flow velocity of flood waves from individual branches. In the worst case, increased individual flood waves from different branches tend to superpose at junctions as an effect of these alterations. Especially at Osterhofen, close to the outlet this effect is significant. The flows of two branches (nodes 53 and 72) superpose at node 76 for Scenario A and result in a significant increase (Figures 5.1(a) and 5.1(b)).



(a) Scenario A



(b) Scenario C

Figure 5.1: Superpositioning of flood waves from different branches for Scenarios A and C

All these effects of land use change are reflected in the economic impacts represented by damage or mitigation costs. The amount of the externality was estimated comparing the status quo scenario (Scenario A) with the historic land use (Scenario C). The difference of costs of these scenarios indicates the amount of the costs which are transferred from the head water to downstream riparians, because they are the result of land use.

From a range of possible methodologies (Umweltbundesamt 2007) two options were used to calculate the externality in the case of land use and floods:

- Costs of damages,
- substitutional approach.

To monetise these impacts, three methods with regard to land use and flood were identified:

- Comparison of flood damages (direct and tangible damages),
- costs for technical detention to reduce peak flow,
- costs for technical flood protection.

In the presented case study, only the first and second options showed to be feasible approaches. Even the estimation of costs for detention can not be generally applied. Technical flood protection would have been a technically feasible alternative in all three villages. Economically, however, it is highly inefficient and difficult to plan and calculate. The high number of intersecting buildings and the location of the villages extended along the axis of the rivulet would have resulted in enormous planning and building costs. The estimation of costs for technical flood detention is restricted by the availability of suitable locations for dams, resulting in significant detention volumes.

The calculation of flood damages in residential areas is the only approach which could be generally applied to all villages. In all three cases, the intensification of land use and modification of the river structure resulted in significantly increased damages. The time interval of 100 years was used to monetise costs over time, because the 100 year flood event represents the design event for the planning of flood protection works. Because of the strong increase of damages for low loss, high probability events in contrast to the low probability, high loss events the calculation period for the accumulation of damages is not of so much importance. A shorter or longer time frame would only weaken or increase this effect.

An analysis in the development of land use, for example on historic maps, shows that not one individual measure contributes to the total effect, but the accumulation of different activities ranging from the change of farming practices on individual sites over land consolidation projects to land use to urban development planning. With regard to the time frame in which these developments took place, not only a spatial component, but also an inter temporal effect must be acknowledged. Because of the probabilities of hydrological events between one in five to one in one hundred years, and on the other hand the time frame of 50 years during which the land use changes occurred, these externalities have not only a spatial but also an inter temporal character. Damages did not occur during the period of land use change and modification of river systems, but effects accumulate with the amount and extent of changes and over time. The first reactions of the hydrological system to the changes can become visible years and decades after the alterations have been implemented.

5.3 Relation to scientific and economic theory

The hydrological aspect of these findings is supported by other works for several catchments (Auerswald 2002, Bormann et al. 1999, Croke et al. 2004, Lammersen et al. 2002), but can not generally be transferred to each catchment (O'Connell et al. 2006) from a hydrological point of view.

In literature, the statement is found that the effects of spatial measures such as infiltration or intermediate crops are overestimated (O'Connell et al. 2006). Authors refer to the restricted detention volume resulting only in a protection against high probability, low loss events. Indeed the detaining effects of natural structures like higher evapotranspiration, increased infiltration and spatial detention in depressions are limited in contrast to sealed areas or farmland. Many authors refer to large basins and concentrate on low probability, high loss events (100 year flood as the main design event for flood protection works). The situation in small and medium sized catchments is different. For small catchments, short meteorologic events are of relevance. However, for large river basins where long rain events with low and medium rain intensity but a high precipitation volume are responsible for severe floods, the effects resulting from land cover and structure seem to be insignificant.

Umweltbundesamt (2007, p. 41) defines the potential costs resulting from externalities or their internalisation as

1. Damage reduction costs
    - direct costs (renovation and reconstitution)
    - indirect costs (adaptation or avoidance)
    - costs of prevention
2. Costs of uncompensated environmental and health damages
    - costs of additional measures to reduce damages
    - costs of uncompensatable damages

Compensation costs as a possible alternative or extension are also included in the methodology of the Umweltbundesamt. In flood protection studies, the cost comparison method (Länderarbeitsgemeinschaft Wasser - LAWA 1998, Länderarbeitsgemeinschaft Wasser 2005, Schmidtke 1981) is used to assess the efficiency of a flood protection project or different scenarios against the status quo without flood protection. Flood damages and building costs are weighed against each other for a defined period (100 years in Germany). The scenario with the most efficient outcome is chosen. If the building costs exceed the potential reduction of flood damages, the project can be dropped. If we assume that land use and other human impacts increase floods, actual studies would misinterpret externalities. Instead of seeing building costs partially as a compensation for land use change in upstream areas, they are calculated against flood damages and included in the costs of protection scenarios, which means accounting them on the side of the affected party. This way of calculation violates the "polluter pays principle".

The cost comparison method gains more importance as a way to allocate state money for flood protection works. In most cases, the local community is involved in these projects and as a beneficiary it pays parts of the planning and building costs. Disregarding the externality part of flood damages or protection costs distorts the results of cost comparison studies and burdens the downstream communities with almost the full costs of externalities. The state grants land users the full right to export their social costs. Only in some cases, (e.g. separate waste water fee for storm water run-off from sealed areas) (Kraemer et al. 2003) was this principle reversed in the past.

Disregarding the polluters pays principle results in two forms of inefficiencies. Upstream, there are no incentives to enforce the redevelopment of land use or river structures. Users can follow their established usage rights, or, as farmers, they are eventually subsidised and they fully export their costs in the form of increased flood damages or flood protection costs as externalities. Downstream flood mitigation projects are financed by riparians and subsidised to reduce damages and compensate the effects of upstream activities.

Therefore, an extension of the approach of tradable permits (Thurston et al. 2003) could provide a suitable solution to handle these externalities. In relation to other studies a reduction of surface run-off through auctions could also reduce the effects of erosion and diffuse pollution (Cason et al. 2003, Lewis, Barham & Zimmerer 2008).

Bargaining (Cansier 1996, Mankiw 2003) about the optimum, as suggested by Coase (1960), does not take place. One reason could be transaction costs (large and inhomogenous group of actors) which are too large. At the moment, the state grants the land users the right to "emit" the water from their surfaces. Downstream riparian users would have to compensate upstream users or bear the costs (damages, mitigation) as they do now.

The case of land use and hydrological externalities is not only a case of spatial externalities. Because of the irregularity of flood events and the changing intensity, land use affects down stream riparians later. Modifications of hydrologically relevant structures can show their effects years after their implementation. Damages accumulate over time. These externalities have also a temporal character. The second temporal effect is the accumulation of effects in different parts of the catchment over time. While the evaluation of individual and small alterations do not show a significant effect, the accumulation of several projects in a catchment can become a problem for downstream riparians.

Although floods were identified as major threats to our society and economy (Merz 2006, MunichRE 2003, Patt 2001) and the effects of land use on run-off are understood (Auerswald 2002, Bismuth et al. 1998, Bormann et al. 1999, Debene 2006, DVWK 1999, Lammersen et al. 2002, Niehoff et al. 2002), no attempts have been made to internalise the costs of flood damages or mitigation costs. This may be a result of the complex process from land use in the catchment, the transmission of this effect through surface flow and channel routing, the effects of river training on travel time and accumulation of flood waves resulting in an externality in the lower catchment. In contrast to other forms of water born or water bound externalities described in literature, such as extractions and irrigation (Bella et al. 1996, Dinar & Subrahmanian 1997, Holden & Thobani 1996, Johansson et al. 2002, Qdaisa & Al Nassayl 2001, Ward & Pulido-Velazquez n.d.) or pollution (Kraemer et al. 2003, Lewis et al. 2008, Spachinger et al. 2005, Wang 2001), quantitative hydrological externalities are possibly more difficult to identify and quantify. While the "emission" of extra surface run-off due to altered surface conditions can not directly be called "pollution", it is difficult to economically relate land use to flood damages and apply instruments to regulate or internalise the externality. In contrast to scarcity, in the current case, water is not the good. Land and land use are the producing and affected factor - or good - and water is only the vector.

5.4 Research objectives

The main objective of the study was to identify the flood-related externalities caused by land use - especially agriculture and different land management instruments such as land consolidation and river training. Statistical data, for example of past flood events, can not be used because the available duration of records is too short. The only way to identify the impacts of land use on flood damages or mitigation costs is to use a combination of hydrologic and hydrodynamic models. In addition, methods of cost estimation for flood damages or mitigation projects must be used to economically measure the impacts. A set of scenarios must be developed to describe different conditions of land use and the river system.

The thesis aimed to provide guidance for the questions:

- What are the causes of external effects and misallocations?
- What are the economic costs of external effects or misallocation of rights in river systems, and how can they be derived from technical and environmental data?

- Based on which environmental parameters can steering mechanisms be implemented technically?

The chosen methodology in this thesis agrees with the approach suggested by the German Federal Environmental Agency (Umweltbundesamt 2007, p. 53) to analyse and evaluate externalities and focuses on the first four steps:

1. Definition of objectives,
2. definition of the subject of analysis and the boundaries of the system,
3. description of impacts,
4. description of cause-effect relations,
5. allocation of economic benefit and cost categories,
6. economic interpretation of resulting changes in benefits,
7. interpretation and comparison of damages with internalised costs.

In a catchment, the development of a flood depends on the main parameters:

- Precipitation,
- geology,
- geomorphology (and consequently the catchment structure),
- land cover,
- river structure.

The human impacts on land cover and river structure are mainly related to land use and other actions like river training and land consolidation. Hydrologic and hydrodynamic models can describe the main physical cause-effect relations within the boundaries defined by the catchment. Depending on the type of hydrologic model, the different parameters for land cover, catchment structure and river system can be simulated. The evaluation of small landscape structures on a catchment scale is generally problematic because of missing landscape data of past situations, missing parameters in catchment models and the necessary large amount of work to collect the required detailed data on a catchment scale.

The results of the case study show that high probability, low loss events have a high relevance for flood damages in small catchments, because technical flood protection is not available. These high probability events can be influenced by non-technical measures of flood detention in the catchment and floodplain, but also by alterations of land use and landscape structures.

As a consequence of the study, it can be stated that increased run-off as a result of land use must be economically seen as emissions in the same way as pollution is seen. Increased damages or costs for flood defense are therefore negative externalities. The increase of costs is a consequence of land use resulting in increased run-off. The transfer of costs can be identified by subtracting the costs resulting from run-off from a pristine catchement from those of a catchment under the current state of land use. Applying the polluter pays principles means that land users must either reduce their level of "emission" or compensate the cost.

The interaction of high probability, low loss events with the effects of land use has a leveraging effect. In rural areas small rainfall events result in damages to buildings or infrastructure. The Herzogbach case study shows clearly that the accumulated damages of these high probability, low loss events are responsible for the majority of costs over time.

If land use and other human impacts increase floods, classical methodologies for flood mitigation underestimate the effect of non-technical measures (for example the renaturalisation of trained sections of river systems). Focusing on technical measures, renaturation and natural detention are ignored in a technical analysis. Economic analysis, for example cost benefit analysis, also does not value the benefit of these measures. River renaturalisation and natural detention are interpreted as a costs, which means they are on the wrong side of the equation. If we apply the polluter pays principle and have to interpret missing natural detention as an emission, then it represents a benefit in the analysis.

Also, the state subsidies for flood mitigation projects must be calculated using the compensation effect for upstream externalities and social welfare, for example resulting from increased production. This results in different forms of inefficiencies. In most studies of flood mitigation concepts, natural measures are ignored. As a consequence, technical measures are favoured and subsidised. The externalities caused by artificial river structures or missing natural detention are ignored and compensated through technical measures subsidised by the state and financed by the downstream riparian community. This contradicts the polluter pays principle, or in this case, better named the causer pays principle. The altered catchment results in increased run-off. If emission is not only defined as the emission of a hazardous substance, but each form of emission of dangerous physical or chemical effects having an impact on the environment from a technical point of view, this increase of floods due to land use can be called an emission. In addition, other forms of state subsidised projects such as land clearance and reallocation, agriculture in general, as well as urban development, can still increase the level of emission and hence externalities.

The results of this study can not be directly transferred to other catchments or be upscaled to bigger river systems. Each catchment has its characteristics, and the human impacts on the Herzogbach basin seem to be more severe than in other basins because of the large amount of modified river sections and the intensity of land use. One big issue is the effect of river training and diking to protect land use in the flood plain of bigger rivers that is widely discussed. While environmentalists say that the loss of natural detention causes higher flood waves, some engineers mention the low effect that these restricted, uncontrolled detention volumes have on the enormous volumes of floods. In bigger river systems, effects of river training, levees and the superposition of flood waves due to technical intervention maybe relevant. If actual studies show a significant decrease in flood peaks, there will be further need to evaluate the economic consequences. These can also be referred to as unidirectional externalities.

The evaluation shows that there is an inter-temporal as well as a spatial dimension. The results of land consolidation, river training and intensive farming practices cause higher and more intensive floods in downstream areas. Because of the temporal variation of precipitation and the low probability of flood events, damages can occur years or decades after the human impact. Another time factor is the accumulating effect of different measures. While an individual action such as the training of a short river section will have a minor or negligible effect, the accumulation of different impacts can significantly change the run-off regime and discharge behaviour of a catchment or river section.

Floods restrict land owners from adequately using their property. The owners must either take into account the damages to property and work or avoid or reduce vulnerable uses. In general human land use and its consequences for river structure and within the flood plain can impact other parties in the downstream section in a lot of ways. This study confirms that factors related to land use, like river degradation as a consequence of land clearance, also cause problems. The increase of floods caused by activities in the upper catchment decreases the usage value of land property or increases the damages. The human-induced part of flood damages must be separated from natural flood development. Otherwise, externalities resulting from land use would be ignored, or additional externalities could arise from newly planned measures.

A major finding of this study is that the flood damages of the situation with an upstream intervention, less the damages without an intervention, can be used to quantify the externality. Another alternative would be the estimation and difference of mitigation costs for both scenarios. As a consequence, different instruments can be used to internalise the costs, or steer and control the impacts of land use.

With regards to the objectives of the thesis, it can be summarized that:

- Flood damages can be partially externalities of upstream land use. Because land use and changes to land use were, and still are, generally granted without respect to run-off relevant considerations. The polluter pays principle is neglected with regard to this special form of quantitative "emission".
- The externalities can be estimated as the average damages of floods of the status quo of land use minus those damages resulting from floods from a pristine catchment. A combination of hydrologic and hydrodynamic models, together with methods to estimate flood damages, can be used. Other methods, like substitutional approaches, only provide a weak estimate of the extent of the externality, and are bound to certain conditions in the catchment.
- Hence, hydrologic run-off coefficients can be used to describe the impact of land cover and could be the basis for the application of steering instruments, such as regulations, run-off certificates, taxes or other concepts to steer or internalise the costs.

5.5 Impacts on policy making

The effects of changes to the hydrological parameters have been shown and evaluated above. In the following subsection, an overview is given showing the points at which an internalisation and avoidance strategy could start - based on these parameters as indicators and handles. It is discussed which future developments are of relevance for the development or reduction of negative externalities with regard to floods and how this must be interpreted taking into account the legal situation in Germany and in some cases in Europe.

Land clearance and land consolidation have been mainly responsible for the hydrological effects investigated in this project. We know that different political and societal interests have caused these developments, for example the need for food, and independence of food production after World War II and during the Cold War. But further significant developments can also be expected in the future. The expansion of cities parallels the increasing need for agricultural land. Land is a restricted resource, and land use optimization will still be a major topic in the future. The conflicting interests of food production and renewable energies will increase the demand for arable land and result in an intensification of agriculture. Already these conflicting interests clash. World wide land clearance and consolidation are going on. In Germany, it is progressing with a restricted intensity and includes measures of nature conservation and habitat development. But often, run-off detaining actions are ignored in this process. The results of this project seem to make it necessary to check the efficiency of this state subsidised instrument. The case study showed that the accumulation of different developments in the catchment results in negative externalities like increasing flood damages.

Land use change is a process on a catchment scale that happens over generations and establishes usage rights. This means that future usage right allocation and land use planning must be more foresighted. A problem for project evaluation is caused by the spatial and inter-temporal effects of human impacts. In the Herzogbach catchment, land use changes and the modification of rural structures is a result of several land clearance projects over the past 100 years. The results of this study show that significant hydrological consequences and externalities do not result from any one project. They are the consequences of an accumulation of different activities and projects over time. Therefore, the assessment of hydro engineering works, land use planning and urban development must be extended in the future and take into account inter-temporal, accumulating and supra-regional effects.

It is impossible to make individual riparian land owners directly responsible for the impacts on river structures. As part of land clearance projects, parcels of land are reorganised on a larger scale. Structures such as boundary ridges and the shapes of fields are rearranged, and ownership is reallocated to achieve an optimised structure and ownership situation. In the past negative effects on a supra regional level have not been taken into account. Land clearance projects of the 60'is and 70'is as a subsidised measure and policy instrument had negative impacts on run-off and floods. As a result, it can be stated that the tools for individual project assessment failed.

Mitigating or reducing the negative impacts of current activities is an important objective of flood risk management. The internalisation of externalities in the water sector is not only for environmental protection, but also, from a resource point of view, an economic necessity. The project results show clearly that land use can cause significant externalities in a catchment. This indicates that there can be a need for internalisation instruments in the field of land use and its impacts on flood development in some catchments. The study describes which relevant factors and parameters can be used as success indicators or handles of an internalisation strategy. Urban development and land sealing impacted the run-off situation, as well as agriculture. Therefore, different instruments and approaches are described to internalise the external costs of land use in Germany and other developed countries.

In general, instruments for an internalisation or to reduce or restrict externalities can be divided into:

- Command and control strategies,
- legal regulations and definition of limits (e.g. emission standards),
- taxes, fees and subsidies to set incentives,
- voluntary self-limitation and bargaining (Coase theorem).

Different approaches can be used to control and steer the effects of land use on run-off and flood development:

- Operational instruments, like land clearance projects to allocate land property and land usage rights to optimise land use from a run-off perspective,
- integration of run-off relevant parameters in existing legal instruments or sectoral policies, like farming subsidies or urban land use planning,
- development of new instruments, like run-off certificates or run-off permissions.

Wallacher's (1999) approach to integrate natural sciences, engineering, economics, ethics, theological, social and political sciences in the development of a water management framework goes far beyond most ideas mentioned in literature. Before such a holistic approach can be started, a lot of interfaces between the individual disciplines must be assessed. An approach similar to that described in this thesis fills the gap between environmental sciences and economics.

Bernauer (2002) gives more integrated countries which are already bound by other contracts or trade exchange a better chance of being cooperative in their basin management. This also means that these countries have better legal and administrative basis on which to handle externalities within their borders. To avoid the additional transaction costs of an internalisation strategy, existing instruments can be used to influence the behaviour or regain the costs. In Germany, a lot of regulations and instruments are used in environmental politics - but also different sectors of planning and governance that could be used to implement water related objectives with regard to externalities. Evaluating actual policies shows a lot of areas, where an internalisation strategy could be implemented by changing regulations or governmental instruments. The use of regulative instruments to internalise externalities of land use is bound to certain framing conditions:

- Existence of a land register to assign and get information about property rights,
- distinct land usage rights,
- land use planning as a planning and control instrument.

The knowledge of property rights like ownership (cadaster or land register), and especially usage rights, is the main basis to installing control instruments for land use. Because land provides different environmental functions in different parts of the catchments, it is necessary to have planning and to use the right systems - either to deny special forms of use or to grant them. Regular market policies to control land use and its distribution would ignore environmental and morphological functions (Nicholas 1999).

> Despite regulations also incentive and market based mechanisms could be applied. Thurston et al. (2003) suggests a system of tradable run-off permits to internalize and steer the run-off from impervious areas. But also he emphasizes the necessity of framing conditions to apply a certificate based approach: "Since property rights at the parcel level are well delineated, runoff information at the parcel level makes allowance trading a technically feasible management alternative. Making the standard assumption that property owners facing explicit costs for managing runoff from their properties will be cost minimisers, we can predict the effects of changes in allowance prices and land use" (Thurston et al. 2003, p. 411)

This means that a strong legal and administrative basis must be available to establish, for example, a market to trade run-off permissions, but also to apply regulations.

Holden & Thobani (1996) provide the following suggestions for the implementation of water markets, which can be taken as guidelines for the implementation of other policies as well:

1. Stakeholder participation,
2. establishment of rules for the initial allocation of rights,
3. setting up and strengthening water user associations,
4. protection against monopolies.

The policy making process must respect the existence of different reasons and interests held by stakeholders in the development of policies. The stakeholders' views represent ecological as well as technical criteria such as cost recovery, redistribution of income or economical development (Dinar & Subrahmanian 1997, p. vii). Controlling the impacts of an internalisation strategy relies on the available forecast of behaviour, as mentioned above.

The choice of instruments may depend on the existing legal framework. In developed countries, a strong legal basis exists and is enforced. This offers the possibility to use the full bandwidth of instruments. Through land use planning and the allocation of land usage rights, land use can directly be controlled. But also existing agricultural subsidies or fees for waste water discharge can be used to influence user behaviour. Last but not least, state driven or subsidised land clearance or land consolidation projects can also be influenced.

For Germany, a set of solutions to internalise the costs of surface run-off or set incentives to draw back existing mis-developments could contain:

- Adding new criteria to the cross compliance catalogue for farming subsidies to enforce the use of sustainable farming techniques like intermediate crops or direct cropping,
- implementing a separate waste water fee for sewage and storm water run-off to enforce local detention and infiltration techniques instead of piped run-off,
- integrating river development and the building of small scale detention structures like grassed water ways in land consolidation and allocation projects.

In the project area, different instruments could be applied as an adaptation of existing regulations to decrease the impact of land use, internalise the costs of flood protection and set incentives to change inefficient techniques.

One possibility to influence the majority of surfaces in the catchment would be a change in agricultural practices and plot structures. In European agriculture, the conditions defined by the cross compliance requirements of European subsidies could be used to define best practice that includes retaining effects. At the moment, criteria for livestock breeding and the use of fertilzers are the ones mainly defined. The reduction of erosion is an abstract objective defined in this regulation. A clarification of best practices for the reduction of erosion and surface run-off would bring benefits for both objectives. Run-off, but also erosion, are mainly influenced by physical structures. The use of intermediate crops or direct cropping would reduce erosion as well as run-off. This could provide additional benefits for water quality and the reduction of maintenance costs for river structures.

Existent field structures also lead to a loss of flood plains and natural river structures. Environmental and water management criteria for state subsidised land consolidation projects would have a controlling effect. For these types of measures, a cost-benefit analysis and impact assessment would help to define the need for action. State subsidies could then be bound to positive externalities regarding run-off and floods resulting from the project.

Next to regulations or the modification of existing subsidies also more market oriented approaches could be used to such as splitted waste water fees or their extension as run-off certificates.

In Germany, the standard fee for waste water is based on the metered fresh-water consumption of a household or consumer. Waste water is charged equivalent to the consumed fresh-water to compensate the costs for sewer-system and waste water treatment. Some cities applied a new type of fee that also includes the equivalent costs resulting from storm water run-off from sealed areas. The separate waste water fee splits the costs for waste water services into the two parts:

1. Waste-water and
2. storm-water.

Waste-water is still calculated by the fresh water equivalent. In addition, a fee is charged based on the extent of sealed areas connected by the consumer to the sewer-system. The main idea behind this fee separation was to set an incentive either to unseal areas or install measures to infiltrate storm water or retain it in ponds or reservoirs. The fast growth of some urban areas and total sealed areas offered only two possibilities: either to improve the existing infrastructure and substitute smaller pipes, reduce the effects resulting from sealed areas (e.g. infiltration) or reduce the extent of sealed areas.

In some parts of Germany, this instrument is still not implemented. Because of its dense population, Germany has a high percentage of sealed surfaces. The general consequences of sealing on surface run-off and flood development have been mentioned above and have been shown by different authors (Umweltbundesamt 2001, Niehoff et al. 2002).

Separate waste water fees can be used to reduce or regain infrastructural costs. However, they can also be implemented to reduce surface run-off by setting an incentive for unsealing and regaining the costs of externalities. The system of separate waste water fees could be extended to all surfaces in the catchment. "One criterion that might be widely acceptable as a basis for the initial distribution of allowance endowments could be the runoff volume that would exist if the land were in its original, pristine condition, ..." (Thurston et al. 2003, p. 412). The separate fee could be applied on a catchment scale. Hydrological run-off coefficients could be used to estimate the effects of different use types and surface structures. In combination with the size of a land parcel, this approach would allow water emissions rights to be assigned. In contrast to a separate waste water fee, a certificate market would also allow an upper limit of water emissions to be set on a catchment scale.

In general, run-off permissions/certificates as a special form of emission rights could be used to control the total water emissions in a catchment. Allowances could be based on the size of the parcel and the hydrologic run-off coefficient and use type. On a municipality level, these allowances could be traded between land owners. On a catchment scale, different municipalities could use this system to avoid upstream-downstream effects between communities.

"Renaturation, alternative agricultural methods and similar sustainable techniques provide additional positive effects like a reduction of surface erosion on agricultural sites or reduced bed and embankment erosion. To solve or reduce the effects of floods in all areas protection can only be financed, if solutions solve different problems. The mentioned techniques help to reduce erosion, sediment delivery and better the water quality. From the economic point of view the theory of externalities supports these implementations to partially compensate the negative effects of land use." (Dorner, Spachinger & Metzka 2005, p. 30)

As we have seen on the sample of water-related land use externalities, the economic valuation of externalities needs a broader scientific and environmental understanding of human actions and environmental reactions. Especially the impacts of actions over different scales must still be developed. While the demonstrated effects of land use and river development on flood behaviour can be stated for general in smaller catchments, their dependencies in bigger catchments or international river basins is not always clear. Another aspect is the individual characteristic of each river basin, and for bigger basins, even changing conditions within the basin.

Most measures to reduce externalities or internalise the costs on a local scale in a small catchment, would lead to no negative reaction on a larger scale. It can be assumed that reduced surface run-off, increased natural detention in the catchment and the flood plain of rivulets would also have positive effects in larger areas, as they would lead to for example improved water quality and reduction of sediments. As a consequence, it can be stated that there is a need to set up new or modify existing instruments to either reduce human impacts or partially internalise these costs.

As we have seen above, not only the direct use of water, but also the side effects of other human actions affect water and water bodies indirectly. The effects of both direct and indirect actions must be taken into account when valuing the use of water and strengthening its protection. "The changes in land use and the human impacts to soil have also consequences for the hydrological cycle. Sealing, compaction and missing natural cover reduce the infiltration and retention capacity of our landscape. Rivers and rivulets have been straightened to improve land use in the flood plains. The peaks of flood waves in small catchments increased and in parallel settlements in the flood plain developed and the potential damage grew. The use of technical measures of flood control may work along streams or for areas with high vulnerability. But due to financial and technical aspects the high standards of flood control can't be established in all areas based on these techniques. Sustainable land use on agricultural sites and in settlements can help to amend surface run-off and reduce flood risks especially in small catchments." (Dorner, Spachinger & Metzka 2005, p. 27)

In relation to water, Wallacher (1999, p. 165) states: "Diese Ressourcen werden in der Produktion als Faktoren eingesetzt, deren Ertrag gemessen wird, ohne sie als Kapital zu bewerten. Die Erträge werden privatisiert, während soziale und ökologische Kosten des Naturgebrauchs externalisiert werden, d.h. die gesamte menschliche Gemeinschaft belasten. Wenn diese als Kapital bewertet würden, käme deren Schonung schon aus ökonomischen Gründen eine wichtige Bedeutung zu." [These resources are used as factors for production, whose revenues are measured without valuing them (the resources) as capital. Revenues are privatised, whereas social and ecological costs are externalised, stressing the whole human society. Valuing them as capital, would make their protection of importance from an economic perspective.]. But he even goes beyond the level of an internalisation strategy and asks for an ethical discussion of the value of water and normative societal regulations to restrict the misuse.

Existing systems of usage rights and use structures established over the last decades, resulted in externalities and societal inefficiencies. Often, land owners and land users refer to grown, established and granted rights. Applying the polluter pays principle to the water sector means that in small catchments, but also larger areas, land users would have to compensate either flood damages or the costs of flood protection works. It is unrealistic to avoid all forms of "emissions". It must also be weighed between different and often conflicting societal interests. For example:

1. Growth of energy crops as renewable resources vs. reduction of erosion.
2. Intensification of agriculture for food production vs. renaturalisation of sites and development of filter strips.
3. Urban and infrastructural development vs. unsealing and infiltration.

Leaving the scale of small catchments behind, problems resulting from unidirectional externalities can be found in international river basins as well. In regions where water is scarce, the effects of upstream-downstream externalities, like water retention for irrigation and hydro-power, have already been addressed. In Europe, different forms of water-related externalities can also cause problems on a catchment scale. Major engineering works in upstream areas, the Danube for example, reduce the bed-load and cause erosion in downstream areas. The nutrient transport from upstream agricultural areas to the Danube delta and Black Sea endangers fishery and habitats. Also, the flood increasing effect of levees and river corrections is in this discussion.

Sadoff & Grey (2002) show that co-operation in international river basins can bring four types of benefits to all participants in the common management process:

1. Ecological benefits to the river,
2. production benefits from the river due to improved and more efficient management of common resources,
3. reduction of political tensions because of the river, and

4. economic or social benefits beyond the river, as co-operation along the river can have a catalytic function for other forms of cooperation.

But it means that upstream countries and municipalities, but also individual land users, have to accept restrictions on land use and other forms of impacts on the water bodies to reduce externalities in downstream areas. Also, upstream countries can "profit" because actions will result in reduced externalities within their country.

In addition, the conclusion must be drawn that a system of static or permanent land property and usage rights reduces the ability of a society under land use pressure to react to risks and developments. Land and soil provide different functions, as shown in this project from a hydrological perspective. From an economic point of view, land, soil and their functions can be seen as a scarce resource. The optimization of land use and, therefore, the optimised allocation of land must be an objective of future policies. A rejecting attitude of individuals or groups of individuals and the disregard of negative societal impact can inhibit necessary developments. Land property rights restrict the ability of a society to react in the short-term on mis-developments in the distribution of land use. The social responsibility of property must be transferred also to land use and usage rights. The first approaches to land use optimization can be seen in the irrigation water allocation projects using tradable water abstraction allowances. To avoid over-abstraction and especially regional over-abstraction, for example in infertile upper catchments, water markets have been established. These markets can, firstly, restrict the total amount of abstracted irrigation water and, secondly, have a steering function to enable more productive areas or producers to bid and pay for the resource.

Chapter 6

Conclusions

6.1 The externality problem

More than 2,000 years of human land use altered our landscape. During the past 50 years urban development, land consolidation and land clearance, as well as river training and hydraulic engineering works, significantly modified the catchments and influenced the hydrological behaviour of our catchments. Due to the situation of our river systems linking different land users from upstream to downstream, upstream alterations can have negative impacts on downstream users. From an economic perspective, these influences can be seen as externalities of upstream land use.

These externalities can be negative and are worth analysing from an economic viewpoint for different reasons because:

- The costs of human actions are not integrated into the economic equation of the producer, but assigned over time to other people.
- Externalities may have inter-temporal effects. The negative effects can be delayed and occur as economic costs to future generations.
- Minor externalities of different individual polluters or causers can accumulate over time and on a catchment scale.

As a working hypothesis, it was assumed that the extent of flood damages is influenced by land use in the upstream areas. Therefore, flood damages would be a function of hydrological parameters such as surface characteristics, catchment and river structure, and land use. Anthropogenic impacts in the upper catchment could result in negative economic effects, such as increased flood damages or additional costs for flood protection, which can be seen as externalities of upstream land use.

The main questions, that follow are:

1. Can externalities, for example flood damages, be directly linked to land use and human-induced changes to hydrology and river morphology, and so quantified using hydrological models?
2. Can externalities be assigned to identified causers or polluters, or at least alternatively be made a requirement to specified user groups?
3. Can natural effects of flood development be split from anthropogenic ones?
4. Are the external costs significant and worth analysing?

The hypothesis addressed in this project was that land use in the upper catchment can have significant negative impacts in the lower catchment, which must be seen as negative externalities of land use. A key question to be answered was how these externalities can be quantified and which scientific parameters of land use (for the description of hydrological systems) can be used to draw conclusions about the economic effects of changes to this system.

6.2 Modelling approach, findings and contributions to the field of research

The presented thesis is one of the first research projects assessing externalities related to land use and flood development. Individual authors already indicated in the past that land use and other human impacts could alter the hydrological behaviour of a catchment. While the effects of land use on hydrology have sufficiently been proven, the externality effect was only stated (Thurston et al. 2003). This thesis presents for the first time an integrated methodology that allows an estimate of the existence and extent of flood related externalities of land use and other anthropogenic impacts on landscape.

The hypothesis addressed in this project was that land use from a hydrological perspective results in significant external effects. The development of a conceptual framework based on technical and ecological parameters, as well as the idea of a hydrological scenario analysis used in this study, was a necessary first step to identify the mechanisms of land use and externalities and provide the necessary handles for an internalisation strategy.

An internalisation strategy as well as the identification of externalities, needs measurable parameters to define a behavioural change as an objective or impacts as a cause and to quantify the resulting welfare or externalities. Therefore, different techno-environmental parameters were identified:

- Type of land use and land cover,
- changes in the landscape. Especially small structures such as boundary ridges, drains and depressions,
- changes of the river structure (sinuosity, elevation of floodplain, buildings like levees).

Depending on the type of landscape and land use, also other factors such as structure of the sewage system and intersecting buildings like weirs or dams can have additional effects.

To estimate the extent and amount of the externality, it was necessary to develop a concept for a hydrological scenario analysis. The parameters can be used to hydrologically simulate different scenarios of land use, which can be compared from a technical and economic point of view. This scenario analysis is the key to identifying the extent and amount of the externality. The hydrological status quo is compared to different alternatives of land use, river structure and flood protection. Two general economic concepts to measure the externality can be used and were applied to this hydrological problem:

- Comparison of damage functions and
- costs for compensation through technical flood protection.

Parameters to technically quantify the extent of an externality or to measure the technical impact of the internalisation strategy are:

- Change in peaks of the flood wave [m^3/s] (hydrologic parameter),
- change of volume of the flood wave [m^3] (hydrologic)
- delay of individual flood waves and avoided super positioning [h] resulting in a reduction of peaks [m^3/s] (hydrologic),
- changes in the water level [cm] (hydrodynamic),
- changes in the extent of the flood plain [m^2] (hydrodynamic),
- changes of flow path and flow velocity [m/s] (hydrodynamic),
- changes of the affected areas by type (building, farmland, ...) [m^2] (hydrodynamic).

To achieve this, it was necessary to couple a hydrodynamic model with the hydrological model to calculate the effects of different hydrological scenarios in the flood plain.

As the final step, the externality (or the effect of the internalisation strategy), must be quantified in financial terms. For this, relevant cost or damage functions affected by floods were identified as:

- Changed flood damages: difficult to assess, because indirect and intangible damages must be estimated and will cause extensive work if larger areas are surveyed.
- Changed costs for technical detention: in combination with hydrological models easy to assess, if areas for potential detention structures are available.
- Changed in situ protection costs: difficult to estimate, because it causes high planning efforts for different planning scenarios.

Using this approach the transfer of costs from upstream land users to downstream riparians can be assessed comparing two land use scenarios from a hydrological and hydrodynamic perspective. Subtracting the resulting damage or cost functions for flood damages or mitigation costs indicates the amount of the resulting externality. Comparing the scenario of the current land use with a pristine catchment indicates amount of the externality.

The case study showed that land use can have a significant impact from an economic point of view and result in externalities for downstream riparian land owners and users. With regards to the geomorphology, land use structure and other parameters, not all suggested methods can be applied to estimate the amount of the externality. The calculation of flood damages was restricted to direct tangible damages in the case study. Technical detention to compensate the effect of land use can only be used if sufficient storage capacity is available at suitable locations in the catchment. Also, the comparison with measures of technical flood protection is restricted by the availability of technically feasible solutions.

The estimation of hydrologically relevant land use externalities can only be achieved using integrated modelling approaches. Because of the long term measurements necessary to quantify the outcomes, only hydrologic and hydrodynamic models can provide data of the potential impacts and compare different scenarios of land use and landscape. The methodology applied in the study can also be used to control the impacts of internalisation policies and forecast environmental outcomes. Impacts of policies on behaviour and practices would be necessary as input data. To control the outcomes, either different scenarios of development can be assumed or results from economic, or social models could be used. Market-based internalisation strategies could be especially evaluated through this coupling of models.

The study indicates that the external effects of human actions on other parties using a catchment and a river system are significant and should be managed. The extent of external effects shown for the quantitative hydrology of the catchment indicates that internalisation of external costs or regulation is necessary and could provide a contribution to flood risk management on a catchment scale. The necessary next step for externalities - options for regulation, internalisation and transaction costs must be weighed against each other and be compared with other economic and social impacts of such an approach.

6.3 Implications for future policies

Different impacts in the past have led to the development of externalities in river basins. "The most significant human interventions in the hydrological cycle have been made over the last decades." (Scheidleder et al. 1996, p. 5). Actions to avoid externalities in the future, therefore, must start at different levels:

- Scenario analysis for projects to estimate supra-regional and accumulative effects related of runoff and floods,
- impact assessment of new policies affecting land use,
- better integration of environmental objectives in land use planning and land clearance projects,
- assessment of natural detention in flood mitigation studies.

In general, the following technical and environmental counter measures could be applied to reduce the hydrological impacts of land use:

- Application of sustainable farming techniques such as direct cropping or intermediate crops (Auerswald 2002),
- renaturalisation of run-off relevant landscape structures like ditches for example into grassed waterways (Fiener & Auerswald 2003),
- methods for local rain water detention and infiltration in urban storm water management (Sieker & Klein 1998),
- renaturation of river sections and
- redevelopment of the natural flood plain (Umweltbundesamt 2001).

Of course, these suggested instruments can only achieve a significant result if they are applied on a large scale that is representative of the catchment. The effectiveness depends very much on the local climatic and hydrologic conditions and the size and structure of the catchment, as mentioned above.

Land consolidation and land clearance have been identified as major reasons for the negative changes in the landscape that are causing externalities. In Germany for example, these instruments were established as state driven and legally based processes for land use optimisation, and can also provide the solution. To re-establish natural landscape structures and re-organise the floodplain on a larger scale, it is necessary to reallocate land and land use, as well as to acquire areas for these structures. Land consolidation can be an instrument to achieve this. Hence, instruments for an economic assessment of the status quo and an evaluation of land use externalities must be necessary preconditions before a project of land consolidation can start.

Today's technical assessment practices still focus mainly on the local effects of a measure. The accumulation of effects because of a set of measures in the same catchment, are not quantified. Classical cost-benefit analysis of individual measures tends to underestimate the externality effect, because they often only take into account the effects of a local measure on a local scale. As a consequence, cumulative effects are not assessed.

Therefore, it is necessary to develop assessment tools that include general tendencies, which could lead to the accumulation of effects. An individual activity has not only to be reviewed using the status quo of the surrounding, but also future scenarios, trends and potential or intended activities in the area of interest. For assessments in river basin management, the hydrologic catchment would provide the spatial frame for such an analysis.

But on a political level, new assessment instruments are also necessary. Umweltbundesamt (2007, p. 8) sees economic assessment as an important instrument to develop sustainable solutions in the future and avoid or reduce externalities. The subsidies for renewable energies provide a current example of this. In areas around the test catchment, environmental policies tend to foster and subsidise the implementation of biomass energy and influence agricultural practices. As a consequence, subsidised biomass production increases the cultivation of maize and influences surface run-off and soil erosion - with all its negative impacts for flood development and water quality. But also other policy fields, such as agricultural policies in general, urban development, land programmes and plans and building codes, can influence run-off relevant parameters. In addition to technical impact assessments policy results assessments are necessary to evaluate the general environmental impacts of political decisions.

“ Die Bauwerke in und an den Flüssen - insbesondere die Staubauwerke - und jede Landnutzung in potentiellen Überschwemmungsgebieten schließen stets ein Hochwasserrisiko ein. Es ist nach technischen und ökonomischen, ökologischen, sozialen und letztlich politischen Gesichtspunkten zu entscheiden, welches HW-Risiko akzeptiert werden kann.” [Buildings in and at rivers - especially detaining structures - and land use in potential flood plains always include a flood risk. From a technical, economic, ecological, social and finally political stand point, it is necessary to decide which flood risk can be accepted.] (Dyck 1995, p. 430). This also includes the evaluation of competing land uses and its upstream-downstream relations. Past river training in rural areas intended to make farmland available and protect crops against floods. As a consequence, downstream riparians have to bear the extra costs for flood protection or damages.

But not only land users or land owners have to rethink their activities with regard to externalities. Also in engineering practice, a rethinking of established concepts for flood protection is necessary.

Future projects must take river renaturalisations and spatial measures into account as part of a long term mitigation strategy. For this, (external) costs and benefits must be assessed as a part of a cost-comparison and cost-benefit study. The used methodology could be generally applied to identify the costs of land use and river training. In addition, other benefits resulting from spatial measures - such as reduced erosion and ground water recharge - should be taken into account as additional benefits.

In flood mitigation projects, measures in the catchment such as changes of land use, small detention structures, etc., are often not evaluated. Samples from Bavaria show that either the effect of these spatial measures is underestimated and not taken into account, or planners are not able to quantify either the effect of spatial measures (Dorner, Spachinger, Lenz & Metzka 2005*a*) or compare their efficiency to technical buildings like reservoirs or levees.

Taking the results of this study, spatial measures in particular should be assessed because of the double dividend. The negative effects caused by river training and land clearance in past years could be compensated. As a second benefit, the costs for technical flood protection infrastructure could be saved or reduced. In addition, other side effects like erosion reduction and better water quality increase the benefit.

The avoidance of flood-related externalities can also carry additional benefits because of erosion protection, reduction of diffuse pollution, reduced infrastructural costs for sewage infrastructure, protection or extension of habitats or reduced maintenance costs for technical structures.

In the Herzogbach catchment the transfer of costs from land users in the upper catchment to riparians downstream showed to be significant. Therefore further actions must be evaluated from an economic or social perspective either

- to regulate land use and reduce the externality,
- compensate the costs and damages e.g. through governmental transfers,
- subsidize the use of detaining agricultural techniques and renaturalisation,
- or use market oriented approaches to establish "emission´´ levels e.g. through the trading of certificates.

In the test catchment regulations could establish easily first results. Scenario D shows that a change in land use practices would result in a significant reduction of flood peaks and costs. This could be achieved e.g. by defining standards for sustainable farming. A second approach would be the use of established subsidy programmes for land reallocation and river development to establish new structures or re-establish natural detention structures in the landscape. A third approach would be a system of tradable run-off permissions on a catchment scale. The compensation of costs represents the current approach, where flood damages are partially and costs for technical flood protection on a community level are fully subsidized by the state. The current approach must be seen very critical. In smaller catchments this approach often fails if two or more communities situated in the same catchment can not agree to build jointly a protection systems, which is often the only effective approach for flood protection. This results in additional costs or the flood protection project is dropped. As mentioned above this approach is also critical regarding the current approach used in cost benefit analysis because technical solutions are preferred in contrast to natural detention. The individual use of one of the other three alternative approaches would result in the reduction or partial avoidance of externalities, but not in a balanced and comprehensive internalisation. While land use in relation to land cover and river training both contribute to the problem only a combination of different approaches would result in a balanced internalisation strategy.

From a technical point of view and based on the findings of the case study a suitable solution would be the regulation of agricultural practices (use of intermediate crops) in combination with subsidies for river renaturalisation in the first step. This would quickly achieve first results without large preparations or administration. Both relevant factors (river training and land cover) resulting in externalities would be covered. To achieve a full reduction of externalities or a compensation of remaining external costs a system of run-off certificates based on run-off coefficients for different land covers would be an adequate second step to provide a long term perspective. Revenues of the certificate trading could be used to compensate remaining external costs.

6.4 Opportunities for future research

The results of the study show clearly that there is a need for further research in the field of water-related economics. Three major fields need to be covered to gain a better understanding of environmental processes and economic effects:

1. How, and up to which extent, do changes in the landscape - like shapes of fields and boundary ridges - affect run-off (on a catchment scale)?
2. Which other types of water related externalities like erosion and diffuse pollution arise as a result of human activities in the catchment?
3. How would water-related internalisation strategies affect other sectoral policies?
4. Did the benefits of past land clearance projects cover the costs of resulting externalities, and how will this problem be handled in the future?

Besides the quantitative side of surface and channel run-off, other related processes are also of interest and need to be assessed. Erosion and diffuse pollution both depend on precipitation and land use. Both affect water quality and, therefore, may reduce the welfare of downstream riparians. Also, hydro power, although a carbon dioxide neutral form of energy production, has ecological impacts. Power plants and their technical infrastructure, like weirs and reservoirs, block the bed load and can increase erosive processes in the downstream water courses. As a barrier for fish migration, they affect the quality of habitats and upstream areas. From a water management perspective, there is a strong need to quantify ecological and economic dependencies on a catchment scale. Economic studies are mainly focused on administrative borders. Applying methods and instruments of environmental economics to the water sector means using the relevant physical and environmental borders of rivers and their catchment.

Also other economic questions in relation to water seem to be unsolved. In technical and environmental literature, water is always referred to as a public good. But depending on the section within the hydrologic cycle, the good's character can change from public to private. Precipitation on a land parcel makes water a private good for the owner of the parcel. He may exclude others through detention measures while the use of the resource is rivaled for example for irrigation and as potable water. For the development of internalisation and control instruments, a better understanding of the physical character of water is needed to assess its economic implications.

Flood protection is often referred to as a public good. From an economic point of view, flood protection measures are, in most cases, a public investment. But the good character depends on the type of protected uses and areas. If levees protect residential areas, they are a private good or club good, because only land owners in the protected area benefit from the protection effect. Only in the case of major public infrastructures protected through levees, or valleys protected through large reservoirs, the status as a public good seems to be a given. The argument for flood defense measures is to make valuable areas available for more intensive uses. But ongoing state subsidies for flood protection works could lead to misallocation of land use and set the wrong incentives. People building on cheap land in a protected former flood plain are subsidised by the state.

In general new methodologies for project assessment are necessary. To avoid future externalities, resulting from hydro-engineering projects, rural and urban development, as well as other forms of land use, the effects of these measures need to be quantified in technical and economic terms. Environmental and technical models are needed to simulate different scenarios and make predictions about the impacts. Cost-benefit and cost-comparison studies must be extended and externalities be taken into account. This means that environmental, physical and economic methods and knowledge must be combined to establish new combined and integrated management and evaluation instruments to deal with oft mentioned water crises and to protect the water resource.

The thesis argues that the effects of land use often cause water crisis in a catchment. It is equally true that they represent a crisis in land use. Through the hydrological cycle, water and land are closely bound together. Every action will show its effects downstream. The presented effects of land use on water bodies are only one segment of an integrated river basin assessment. Consequences of surface sealing, farming, land clearance and hydraulic engineering on groundwater recharge and quality, surface water quality, erosion and sediment delivery, river morphology, bed load and habitat conditions have not been within the scope of this study. In most of these cases, environmental and scientific cause-effect chains are well understood. Like in the case of flood development and economic analysis of floods, the missing link is the relation between the human intervention and resulting economic consequences from an environmental economic perspective.

To solve land, soil and water problems, it is also necessary to deal with the economic activities behind the use of resources and the interaction of temporal and spatial externalities. In the water sector, future scientific effort is needed to assess the effects of land use and hydraulic engineering works on erosion and sediment management, soil degradation, bed load management and water quality.

There is a need for further studies - for example a cost-benefit analysis of the land consolidation instrument - first to assess its economic benefit, and second, to improve the whole structure and make it more efficient from a social point of view.

The presented methodology provides an approach to identify and quantify land use externalities from a quantitative hydrological perspective. From an economic point of view, the project stalls where a cost-benefit analysis would be necessary to weigh benefits of land use against the described impacts or compare the status quo with different internalisation strategies. For a better understanding of the local situation and the implications for policy making, the results open the field for research in economics, politics and social sciences to reflect and study the cause-effect relations from their perspective. It will be necessary in the future to investigate different strategies of internalisation of the economic costs of human actions in a catchment. Internalisation strategies could provide significant assistance towards preventing environmental degradation and the prevention or mitigation of flood damages.

The broad application of environmental techniques and changes in farming practices on a national level also requires a review of current policies and an evaluation of impacts in other sectors - including an economic impact assessment and cost-benefit-analysis. This would go beyond the scope of this thesis and needs to be evaluated by other disciplines, such as economics, agricultural sciences and political sciences.

In general, it can be stated that there is a need for further studies in the field of "hydro-economics" with regard to flood economics. Physical aspects of water-related externalities are not well described in literature, except for the problem of water scarcity and rival water use. The economic understanding of the resource water is very little. Most hydrological processes and use types known to be of economic relevance are technically well understood, but have rarely been monitored and highlighted from an economic point of view. The protection of our water resources is not only an environmental, but also an economic task. Hydro-economics, as a combination of environmental and engineering knowledge with economics, could provide the right instruments to increase the environmental and economic efficiency of our activities.

Results of the project ILUP - Integrated Land Use Planning and River Basins Management (Dorner, Spachinger & Metzka 2008) and other research in the field of river basin management (Cason et al. 2003, Wang 2001, Moss 2004), indicate that also other problems need to be reviewed from an environmental economics-perspective. The problems in quantitative hydrology referred to in this work are not the only externality situation in a catchment resulting from land use. Water quality, erosion and sediments are additional points that need to be analysed. Rivalry in the river system between different stakeholder groups such as fisheries, tourism and the recreation industry, as well as farming, require an integrated environmental, technical and economic evaluation of activities and their impacts.

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Appendix A

Appendices

A.1 Principles of hydrology

Water exists in three different phases on our planet: ice, liquid water and vapour, in lakes, rivers, the sea, as groundwater, glacier or snow cover, moist air, precipitation and clouds. The phase changes depending on the location of the water in the hydrological cycle. "The hydrologic cycle describes the movement of water in all its states of aggregation from precipitation, over, evapo-transpiration, infiltration, surface run-off, from the surface over the rivers to the sea. Human actions like agriculture, settlements, infrastructure influence this cycle and increase, especially in small catchments, the flood peaks. The development of floods is highly dependant on surface structures, soil type and land cover. In densely settled areas the percentage of sealed surface is the important factor. In rural regions the type of fruits and plant cover influences mainly the run-off." (Dorner, Spachinger & Metzka 2005, p. 27) Water is transformed by weather processes or using the energy of the sun. It is transported and stored in each of these phases.

Within a river catchment the hydrological process can be written in the form

$$N = A + V + -\Delta S$$

N: Average height of precipitation

A: Average run-off

V: Evaporation

ΔS: Storage in or release from the catchment

Annual water balance of the German Federal Republic between 1931 and 1960 N = 837 mm, V = 519 mm, A = 318 mm (Maniak 1993, p. 2).

The hydrological cycle starts with evaporation of water e.g. at the open sea, but also over humid continental areas. As water dust it is transported as clouds. Under certain conditions it condensates and starts to rain. Depending on the local climate a lot or most of the precipitation already gets lost as evaporation. It covers the surface of plants and trees or the soil, where it mainly gets lost as vapor through evaporation. Also plants loose water in form of transpiration. These combined losses of evaporation and transpiration, mainly depending on land cover and plants, are called evapotranspiration.

Other parts of the precipitation infiltrate into the soil. There it either runs-off in the upper layer as the so called interflow or infiltrates to deeper zones, where it fills the groundwater layers. Ground water is an important storage, and influenced by water transport through different layers, by capilarity and along the decline. This transport is called ground water run-off.

The excess water that does not evaporate or infiltrate is stored in natural depressions or builds the surface run-off. Surface run-off later unions with ground water run-off and interflow in rivulets and rivers.

Snow and ice is a special form of precipitation, which in a first step builds a natural storage as snow cover or glaciers. In addition it can also store big amounts of precipitation in its porous structure. In contrast it can also release big amounts of water during the melting period in spring and early summer.

All these processes and the individual amount of water getting lost or remaining in each step, depends on the local situation. Main factor is the local climate, which does not only influence the amount of precipitation, but also of evaporation. Infiltration rate, interflow and ground water very much depend on the geology, soil types and soil structure. Land cover, especially size and types of plants, layers of the local plant colonies and effects of roots on the soil structure very much influence the detention and losses ranging from transpiration via evaporation to infiltration.

“The average annual precipitation in Bavaria is 940 mm. About 530 mm evaporate again and only 410 mm are relevant for the earth bound water cycle as infiltration or surface run-off. Evaporation and transpiration are highly dependent on land structure and land cover. Infiltration is influenced by soil type and compaction. But also land cover influences infiltration because of breaking the energy of falling raindrops and preventing silting and plugging of pores and micropores. Surface flow, interflow and ground water flow are the main soil bound processes of water transport. Surface flow is influenced by land structures like gullies, depressions, that also provide detention capacity, but also by land cover, because dense vegetation and root penetration influence the flow velocity. Therefore the earth bound part of the hydrologic cycle can be said to be a complex system with deep interrelations between soil, plants and morphological structures.” (Dorner, Spachinger & Metzka 2005, p. 27)

In our times especially this factor was influenced by human activities. In Central Europe land clearance started in the roman period and reached its peak in mideaval times. Large forrest areas got lost and were transformed to arable land. Big land reallocation projects started in the early 20ies century AD. Farm and field structures were resized to fit the needs of a new mechanised agriculture. Large sites were drained, rivers restructured to optimize field structures and sizes. Since the 1950ies the spreading of urban areas, sealing for infrastructure and industrial areas is a new trend. All these developments decreased the land cover and, therefore, the available surface for evaporation and detention on the wide spread surface. Sealed surfaces reduce the infiltration capacity nearly to zero.

A.2 Principles of economics

> “Most goods in our economy are allocated by markets, where buyers pay for what they receive and sellers are paid for what they provide. Prices provide the necessary signals for these goods to guide the decisions of both buyers and sellers.” (Mankiw 2003, p. 223)

Demand and supply determine prices in a market. If the price of a good rises, the demand falls, when the price falls, the demand rises. The basic assumptions for a theoretic market are: it is a perfectly competitive market with a lot of buyers and sellers, so no individual can influence the price using his market power. Outcomes of market actions only affect participants of that market. All costs of goods or services are included in the price calculation of the seller. On such a market supply and demand are closely bound together, because they and their balance define the prices for goods available on the market.

The demand depends on the willingness to pay for a good. This potential price expresses the value consumers or purchasers allot the good. Factors that influence the willingness to pay are the income, prices of related goods, substitutes - alternatives or complements - the number of buyers, expectations about the future and especially the will or necessity to own the good. The demand on a market is a sumfunction of the demands of all individuals in a market. The higher the price for a good is, the lower the demand will be, because only individuals are able to pay the price or all individuals are only willing to buy a small amount of the good. The cheaper the good becomes the higher demand will be.

"The quantity supplied of any good or service is the amount that sellers are willing and able to sell." (Mankiw 2003, p. 71). Supply can also be described as a function. The supply side depends on the possibility to produce a number of this good for a certain price. The economy of scales normaly allows to produce more of the good for a cheaper price, while the production of a small number of this good or individualised productions causes high costs per product.

Depending on the market (product, persons, ...) different types of linear, quadratic or more complex mathematical functions describe this supply and demand as a curve. The intersection of these curves of supply and demand is the market price. A number of consumers or investors are willing to pay a price for a certain amount of this good, while another number of producers/factores is willing to offer this amount for the same price. For this single point, the so called equilibrium price and equilibrium quantity, the market is in balance.

The supply function very much depends on the cost function for the production of the good, while the cost function depends on other market prices for the production factors like resources, labour, capital, ground and knowledge and in addition the bargain. If we reduce the price for one factor also the price for the produced good on the market should fall.

If we in contrast now presume that manufacturers use one resource without paying for it a lower market price establishes. A bigger amount of the good can then be sold on the market and will be produced. "When goods are available for free of charge, however, the market forces that normally allocate resources in our economy are absent." (Mankiw 2003, p. 223).

In economies markets have the function to allocate resources. Labour, goods, money and natural resources are allocated by markets.

> "In any economic system, scarce resources have to be allocated among competing uses. Market economies harness the forces of supply and demand to serve that end. ... prices in turn are the signals that guide the allocation of resources" (Mankiw 2003, p. 84)

Prices set an important signal, because they indicate how important a resource is. "Thus, in market economies, prices are the mechanism for rationing scarce resources" (Mankiw 2003, p. 84). Those consumers who need the resource most have the highest willingess to pay. The allocation of goods and resources normally garantuees, that all economic costs are included in the market price. Because the supplier would only produce and sell a good, if he could regain all his costs.

The market allocation maximizes the total surplus of buyers and sellers. Macroeconomic theory measures the efficiency of a society by welfare. The optimum allocation of resources is said follow the Pareto principle. It says that a situation is optimal if no actor can optimise his welfare without reducing the welfare of another actor.

Two factors can change this efficiency. If not all economic costs, like assumed above, are included in the development of the supply situation on the market, inefficiencies can arise. Also government policies can influence the market situation. Taxes, regulations or price ceilings either influence demand or supply curve and move it, so the equilibrium changes. Normally this is a side effect of governmental actions, because their intended effect is to gain money for public purposes or restrict market forces e.g. through social policies. Instruments like taxes and regulations can also be used directly to control a market and regulate market inefficiencies.

A.3 Catchment parameters

Nodes	N1	N3	N6	N8	N10	N13	N15	N18	N20	N23	N25	N27	N30	N33	N35
Subcatchment	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A15	A16
Catchment parameters															
Catchment area A_E (km²)	1,177	0,700	0,753	0,730	0,933	3,186	1,699	0,728	0,358	0,403	1,940	1,387	0,144	3,547	2,454
Elevation at the outlet (above sealevel)	361	361	341	367	341	330	338	344	338	333	358	333	330	325	325
Elevation at the catchment boundry (above sealevel)	409	410	361	399	367	361	408	417	344	338	402	358	333	330	393
Length of rivulet from outlet to the catchment boundry L (km)	1,707	1,71	1,905	0,994	1,542	2,534	2,492	1,84	0,761	0,586	1,788	2	0,472	2,198	4,848
Length of rivulet to the cetroid of the catchment L_c (km)	0,886	0,876	1,198	0,473	0,866	1,58	1,402	1,159	0,66	0,586	1,788	1,174	0,253	1,077	2,106
Slope of the rivulet J_G (-)	0,028	0,029	0,010	0,032	0,017	0,012	0,028	0,040	0,008	0,009	0,025	0,011	0,006	0,002	0,014
Forrest (km²)	0,176	0,272	0,000	0,246	0,010	0,000	0,055	0,066	0,000	0,000	1,667	0,026	0,000	0,000	0,005
Grassland (km²)	0,118	0,070	0,075	0,073	0,093	0,319	0,170	0,073	0,036	0,040	0,194	0,139	0,014	0,355	0,245
Fields (km²)	0,843	0,318	0,604	0,365	0,610	2,671	1,320	0,585	0,299	0,363	0,069	1,219	0,130	2,863	2,178
Built-up area (km²)	0,040	0,040	0,074	0,046	0,220	0,196	0,154	0,004	0,023	0,000	0,010	0,003	0,000	0,329	0,026
Percentage of sealed areas (%)	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%
Total sealed area (km²)	0,014	0,014	0,026	0,016	0,077	0,069	0,054	0,001	0,008	0,000	0,004	0,001	0,000	0,115	0,009
Month	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Base flow per area q_B (l/skm²)	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5
Base flow Q_B (l/s)	14	8	9	8	11	37	20	8	4	5	22	16	2	41	28
Percentage of settled areas (%)	3,4%	5,7%	9,8%	6,3%	23,6%	6,2%	9,1%	0,5%	6,4%	0,0%	0,5%	0,2%	0,0%	9,3%	1,1%
Run-off coefficient c and initial loss A_v (Lutz)															
Forrest															
Soil type (A, B, C, D)	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B
Percentage of area (%)	15,0%	38,8%	0,0%	33,7%	1,1%	0,0%	3,2%	9,1%	0,0%	0,0%	85,9%	1,9%	0,0%	0,0%	0,2%
Coefficient c	0,48	0,48	0,48	0,48	0,48	0,48	0,48	0,48	0,48	0,48	0,48	0,48	0,48	0,48	0,48
Initial losses A_v (mm)	5,0	5,0	5,0	5,0	5,0	5,0	5,0	5,0	5,0	5,0	5,0	5,0	5,0	5,0	5,0
Grassland															
Soil type (A, B, C, D)	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B
Percentage of area (%)	12,2%	13,7%	16,4%	14,1%	25,3%	14,0%	15,9%	10,4%	14,2%	10,0%	10,3%	10,1%	10,0%	16,0%	10,7%
Coefficient c	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50
Initial losses A_v (mm)	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0
Fields															
Soil type (A, B, C, D)	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B
Percentage of area (%)	71,6%	45,5%	80,2%	50,0%	65,3%	83,8%	77,7%	80,4%	83,6%	90,0%	3,6%	87,9%	90,0%	80,7%	88,7%
Coefficient c	0,71	0,71	0,71	0,71	0,71	0,71	0,71	0,71	0,71	0,71	0,71	0,71	0,71	0,71	0,71
Initial losses A_v (mm)	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0
Sealed area															
Soil type (A, B, C, D)	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B
Percentage of area (%)	1,2%	2,0%	3,4%	2,2%	8,3%	2,2%	3,2%	0,2%	2,2%	0,0%	0,2%	0,1%	0,0%	3,2%	0,4%
Coefficient c	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Initial losses A_v (mm)	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0
Medium run-of coefficient c	0,65	0,59	0,67	0,60	0,65	0,68	0,67	0,67	0,68	0,69	0,49	0,68	0,69	0,68	0,69
Medium initial losses A_v (mm)	4,2	4,4	4,0	4,3	4,0	4,0	4,0	4,1	4,0	4,0	4,9	4,0	4,0	4,0	4,0
Catchment coefficient (Lutz)															
Parameter C1	0,020	0,020	0,020	0,020	0,037	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020
Parameter C2	4,22	3,58	4,62	3,72	4,59	4,62	4,53	4,38	4,62	4,62	2,36	4,57	4,62	4,62	4,61
Parameter C3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Parameter C4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unit Hydrograph coefficient (Lutz)															
P1	0,17	0,22	0,27	0,27	0,27	0,27	0,22	0,27	0,27	0,27	0,27	0,27	0,27	0,27	0,27

Figure A.1: Catchment parameters: Input parameters for the hydrologic model for the status quo of land use and river structure (node 1- 35, subcatchments A1 - A16)

Nodes	N38	N39	N41	N42	N45	N47	N50	N52	N54	N55	N57	N60	N62	N64	N67
Subcatchment	A17	A18	A19	A20	A21	A22	A23	A24	A25	A26	A27	A28	A29	A30	A31
Catchment parameters															
Catchment area A_E (km²)	1,709	1,150	0,558	0,207	1,677	1,599	0,819	2,925	0,187	0,975	0,521	0,788	1,326	1,643	0,734
Elevation at the outlet (above sealevel)	322	347	362	347	334	323	321	318	371	345	345	334	341	334	330
Elevation at the catchment boundry (above sealevel)	325	408	415	362	347	334	323	321	407	371	411	345	417	341	334
Length of rivulet from outlet to the catchment boundry L (km)	1,083	2,259	1,21	0,924	1,621	1,897	1,011	1,749	0,54	1,115	1,866	1,795	2,562	1,115	0,877
Length of rivulet to the cetroid of the catchment L_c (km)	1,083	1,371	0,67	0,602	0,922	1,204	0,781	0,833	0,337	0,977	0,932	1,391	1,347	1,15	0,714
Slope of the rivulet J_G (-)	0,003	0,027	0,044	0,016	0,008	0,006	0,002	0,002	0,067	0,023	0,035	0,006	0,030	0,006	0,005
Forrest (km²)	0,000	0,450	0,328	0,000	0,000	0,000	0,000	0,000	0,107	0,258	0,050	0,000	0,377	0,000	0,000
Grassland (km²)	0,171	0,115	0,056	0,021	0,168	0,160	0,082	0,293	0,019	0,098	0,052	0,079	0,133	0,164	0,073
Fields (km²)	1,467	0,554	0,174	0,154	1,499	1,341	0,737	2,347	0,052	0,584	0,395	0,667	0,793	1,404	0,615
Built-up area (km²)	0,071	0,031	0,000	0,032	0,010	0,098	0,000	0,286	0,009	0,036	0,024	0,042	0,023	0,075	0,046
Percentage of sealed areas (%)	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%
Total sealed area (km²)	0,025	0,011	0,000	0,011	0,004	0,034	0,000	0,100	0,003	0,013	0,008	0,015	0,008	0,026	0,016
Month	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
Base flow per area q_B (l/skm²)	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5
Base flow Q_B (l/s)	20	13	6	2	19	18	9	34	2	11	6	9	15	19	8
Percentage of settled areas (%)	4,2%	2,7%	0,0%	15,5%	0,6%	6,1%	0,0%	9,8%	4,8%	3,7%	4,6%	5,3%	1,7%	4,6%	6,3%
Run-off coefficient c and initial loss A_v (Lutz)															
Forrest															
Soil type (A, B, C, D)	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B
Percentage of area (%)	0,0%	39,1%	58,8%	0,0%	0,0%	0,0%	0,0%	0,0%	57,2%	26,5%	9,6%	0,0%	28,4%	0,0%	0,0%
Coefficient c	0,48	0,48	0,48	0,48	0,48	0,48	0,48	0,48	0,48	0,48	0,48	0,48	0,48	0,48	0,48
Initial losses A_v (mm)	5,0	5,0	5,0	5,0	5,0	5,0	5,0	5,0	5,0	5,0	5,0	5,0	5,0	5,0	5,0
Grassland															
Soil type (A, B, C, D)	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B
Percentage of area (%)	12,7%	11,8%	10,0%	20,0%	10,4%	14,0%	10,0%	16,4%	13,1%	12,4%	13,0%	13,5%	11,1%	13,0%	14,1%
Coefficient c	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50
Initial losses A_v (mm)	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0
Fields															
Soil type (A, B, C, D)	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B
Percentage of area (%)	85,8%	48,2%	31,2%	74,5%	89,4%	83,9%	90,0%	80,2%	28,0%	59,8%	75,8%	84,7%	59,8%	85,4%	83,7%
Coefficient c	0,71	0,71	0,71	0,71	0,71	0,71	0,71	0,71	0,71	0,71	0,71	0,71	0,71	0,71	0,71
Initial losses A_v (mm)	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0
Sealed area															
Soil type (A, B, C, D)	B	B	B	B	B	B	B	B	B	B	B	B	B	B	B
Percentage of area (%)	1,5%	0,9%	0,0%	5,4%	0,2%	2,1%	0,0%	3,4%	1,7%	1,3%	1,6%	1,9%	0,6%	1,6%	2,2%
Coefficient c	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00	1,00
Initial losses A_v (mm)	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0
Medium run-of coefficient c	0,68	0,59	0,55	0,67	0,69	0,68	0,69	0,67	0,55	0,62	0,66	0,68	0,62	0,68	0,68
Medium initial losses A_v (mm)	4,0	4,4	4,6	4,0	4,0	4,0	4,0	4,0	4,6	4,3	4,1	4,0	4,3	4,0	4,0
Catchment coefficient (Lutz)															
Parameter C1	0,020	0,020	0,020	0,028	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020	0,020
Parameter C2	4,62	3,59	3,08	4,62	4,62	4,62	4,62	4,62	3,10	3,92	4,36	4,62	3,87	4,62	4,62
Parameter C3	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
Parameter C4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Unit Hydrograph coefficient (Lutz)															
P1	0,27	0,27	0,27	0,27	0,27	0,27	0,27	0,27	0,27	0,27	0,27	0,27	0,27	0,27	0,27

Figure A.2: Catchment parameters: Input parameters for the hydrologic model for the status quo of land use and river structure (node 38- 67, subcatchments A17 - A31

Nodes	N69	N72	N75	N77	N81	N83	N85	N89	N91	N92
Subcatchment	A32	A33	A34	A35	A37	A38	A39	A40	A41	Total
Catchment parameters										
Catchment area A_E (km²)	3,088	2,244	1,851	2,737	2,324	0,363	0,427	15,951	2,313	72,165
Elevation at the outlet (above sealevel)	325	318	316	311	314	314	311	305	305	305
Elevation at the catchment boundry (above sealevel)	330	325	318	316	316	314	314	311	305	417
Length of rivulet from outlet to the catchment boundry L (km)	1,451	1,427	1,3	2,157	2,2	0,618	1,268	6,777	1,274	28
Length of rivulet to the cetroid of the catchment L_c (km)	0,589	0,877	0,622	1,054	1,246	0,513	1,041	3,2	0,6	14
Slope of the rivulet J_G (-)	0,003	0,005	0,002	0,002	0,001	0,000	0,002	0,001	0,000	0,004
Forrest (km²)	0,000	0,017	0,000	0,079	0,000	0,000	0,000	0,200	0,007	4,406
Grassland (km²)	0,309	0,224	0,185	0,274	0,232	0,036	0,043	1,595	0,231	7,217
Fields (km²)	2,779	1,961	1,583	1,093	2,089	0,326	0,062	13,064	1,997	55,660
Built-up area (km²)	0,000	0,042	0,083	1,291	0,003	0,001	0,322	1,092	0,078	4,883
Percentage of sealed areas (%)	35%	35%	35%	35%	35%	35%	35%	35%	35%	35%
Total sealed area (km²)	0,000	0,015	0,029	0,452	0,001	0,000	0,113	0,382	0,027	1,709
Month	5	5	5	5	5	5	5	5	5	5
Base flow per area q_B (l/skm²)	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5	11,5
Base flow Q_B (l/s)	36	26	21	31	27	4	5	183	27	830
Percentage of settled areas (%)	0,0%	1,9%	4,5%	47,2%	0,1%	0,3%	75,4%	6,8%	3,4%	6,8%
Run-off coefficient c and initial loss A_v (Lutz)										
Forrest										
Soil type (A, B, C, D)	B	B	B	B	B	B	B	B	B	B
Percentage of area (%)	0,0%	0,8%	0,0%	2,9%	0,0%	0,0%	0,0%	1,3%	0,3%	6,1%
Coefficient c	0,48	0,48	0,48	0,48	0,48	0,48	0,48	0,48	0,48	0,48
Initial losses A_v (mm)	5,0	5,0	5,0	5,0	5,0	5,0	5,0	5,0	5,0	5,0
Grassland										
Soil type (A, B, C, D)	B	B	B	B	B	B	B	B	B	B
Percentage of area (%)	10,0%	11,2%	12,9%	40,7%	10,1%	10,2%	59,0%	14,4%	12,2%	14,4%
Coefficient c	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50	0,50
Initial losses A_v (mm)	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0
Fields										
Soil type (A, B, C, D)	B	B	B	B	B	B	B	B	B	B
Percentage of area (%)	90,0%	87,4%	85,5%	39,9%	89,9%	89,7%	14,6%	81,9%	86,3%	77,1%
Coefficient c	0,71	0,71	0,71	0,71	0,71	0,71	0,71	0,71	0,71	0,71
Initial losses A_v (mm)	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0
Sealed area										
Soil type (A, B, C, D)	B	B	B	B	B	B	B	B	B	B
Percentage of area (%)	0,0%	0,7%	1,6%	16,5%	0,0%	0,1%	26,4%	2,4%	1,2%	2,4%
Coefficient c	1,00	1,00	2,00	3,00	5,00	6,00	7,00	8,00	9,00	10,00
Initial losses A_v (mm)	1,0	1,0	2,0	3,0	5,0	6,0	7,0	8,0	9,0	10,0
Medium run-of coefficient c	0,69	0,68	0,68	0,60	0,69	0,69	0,54	0,68	0,68	0,66
Medium initial losses A_v (mm)	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,0	4,1
Catchment coefficient (Lutz)										
Parameter C1	0,020	0,020	0,020	0,052	0,020	0,020	0,063	0,020	0,020	0,020
Parameter C2	4,62	4,60	4,62	4,53	4,62	4,62	4,62	4,59	4,61	4,46
Parameter C3	2	2	2	2	2	2	2	2	2	2
Parameter C4	0	0	0	0	0	0	0	0	0	0
Unit Hydrograph coefficient (Lutz)										
P1	0,27	0,27	1,27	2,27	4,27	5,27	6,27	7,27	8,27	0,27

Figure A.3: Catchment parameters: Input parameters for the hydrologic model for the status quo of land use and river structure (node 69- 92, subcatchment A32 - A41 and total catchment

A.4 Hydrologic model results

The following figures are the graphic representation of the hydrologic model results. For node 2 - inlet to Bachling, node 32 inlet to Buchhofen and node 76 inlet to Osterhofen.

Bachling - Node 2

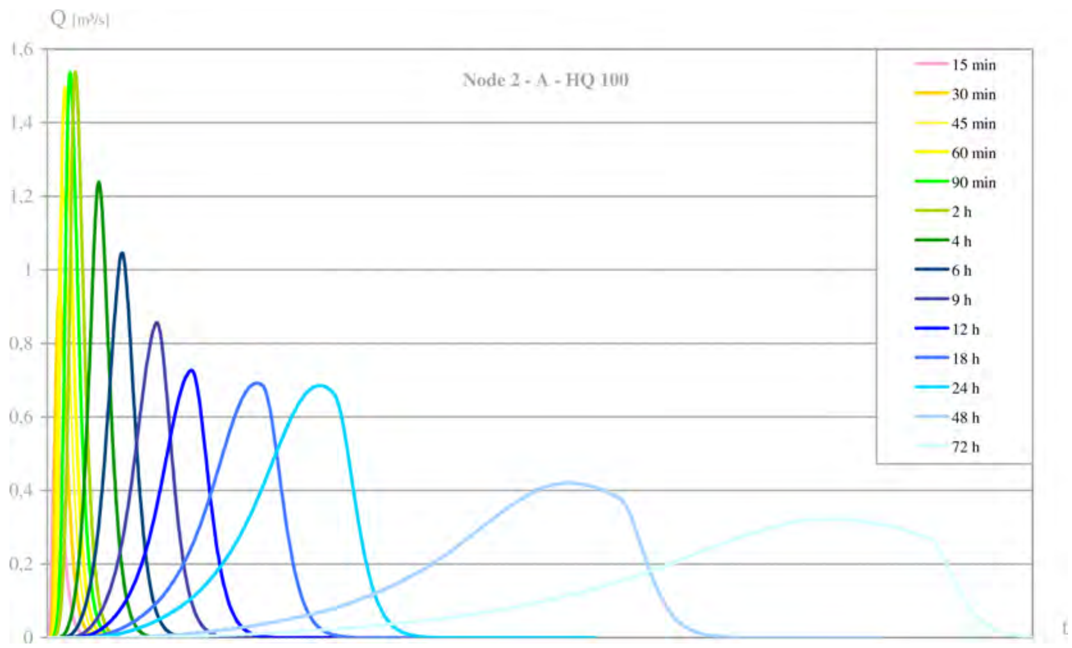

Figure A.4: 100 year floods for different precipitation patterns for scenario A at node 2

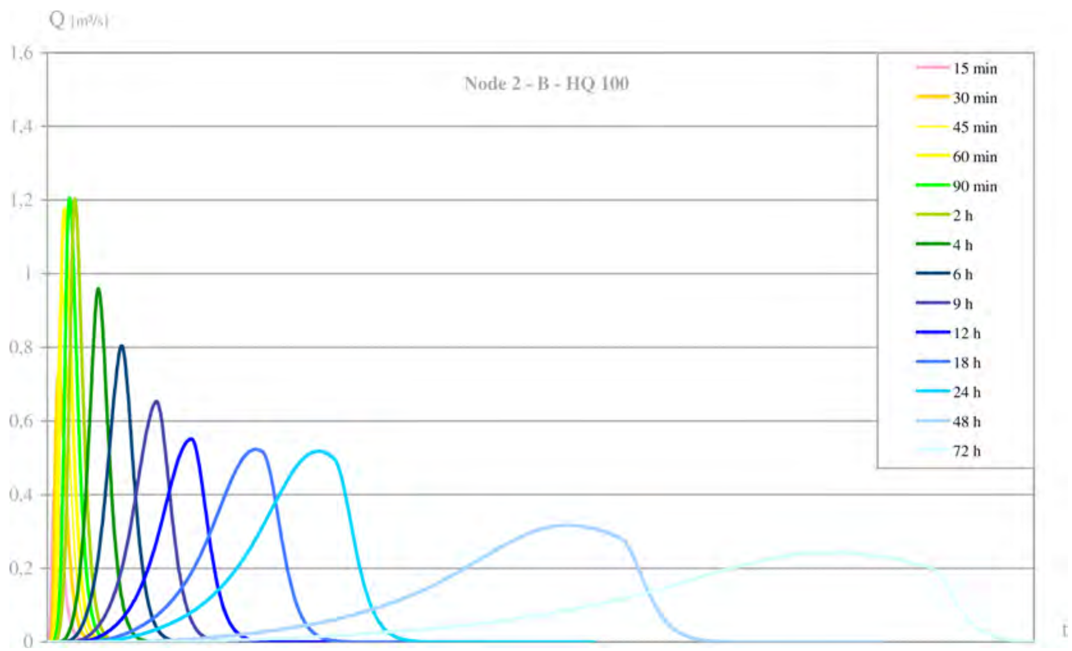

Figure A.5: 100 year floods for different precipitation patterns for scenario B at node 2

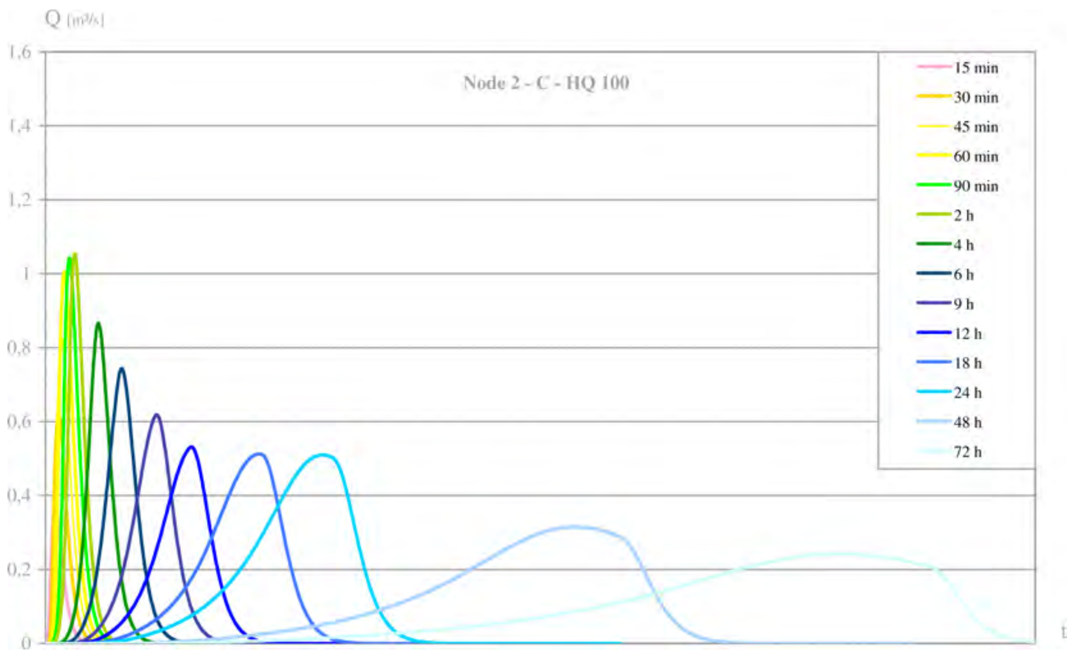

Figure A.6: 100 year floods for different precipitation patterns for scenario C at node 2

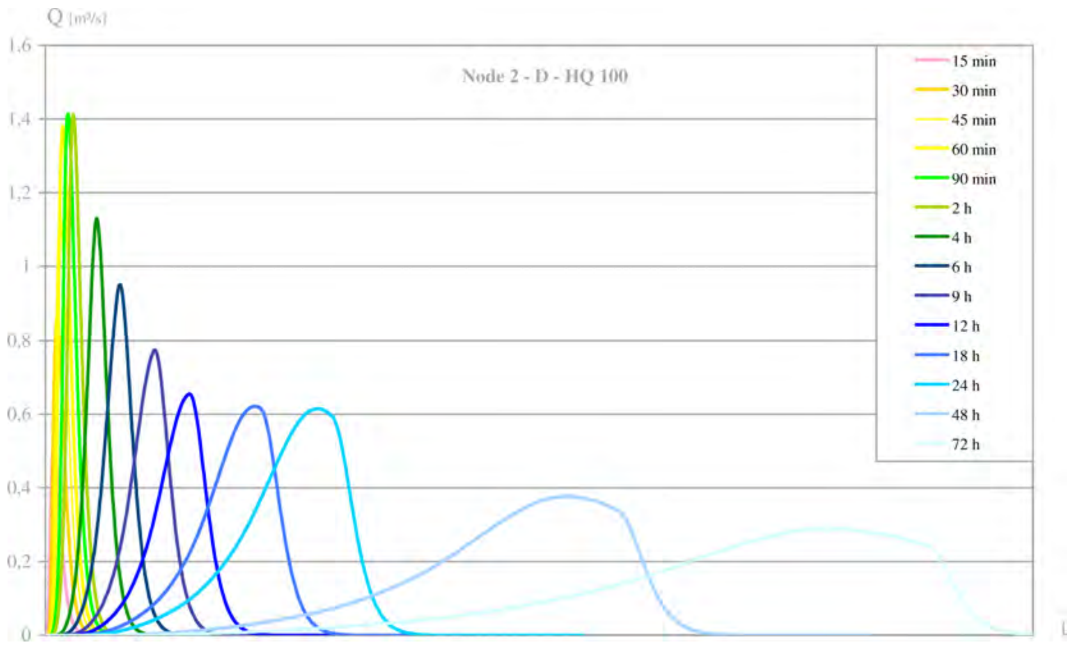

Figure A.7: 100 year floods for different precipitation patterns for scenario D at node 2

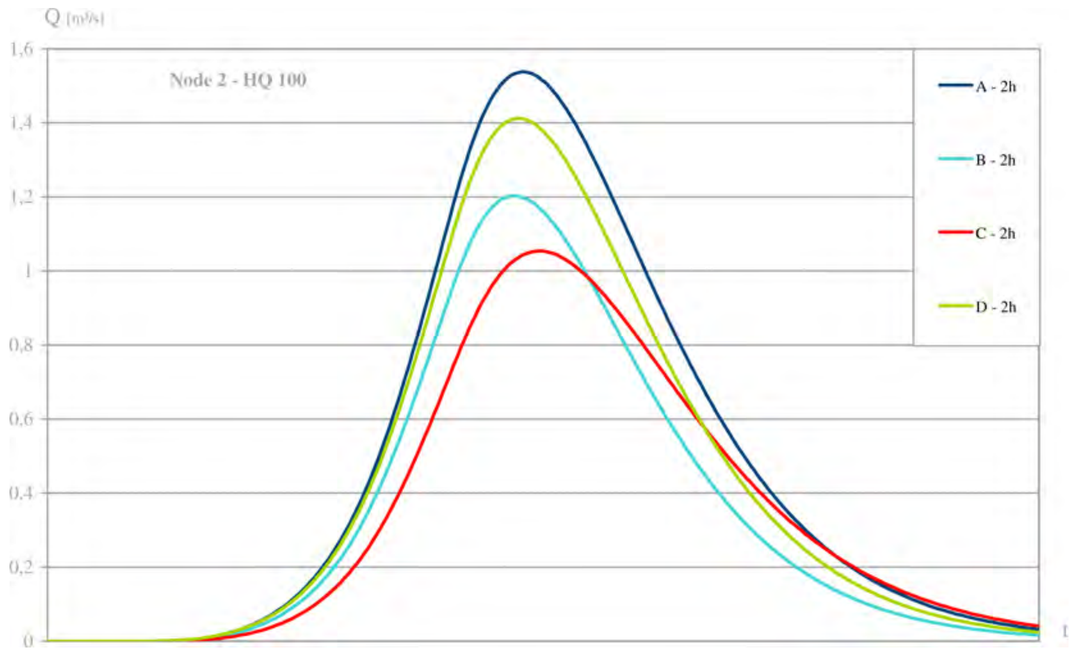

Figure A.8: Maximum 100 year flood wave at node 2 resulting from a 2h precipitation

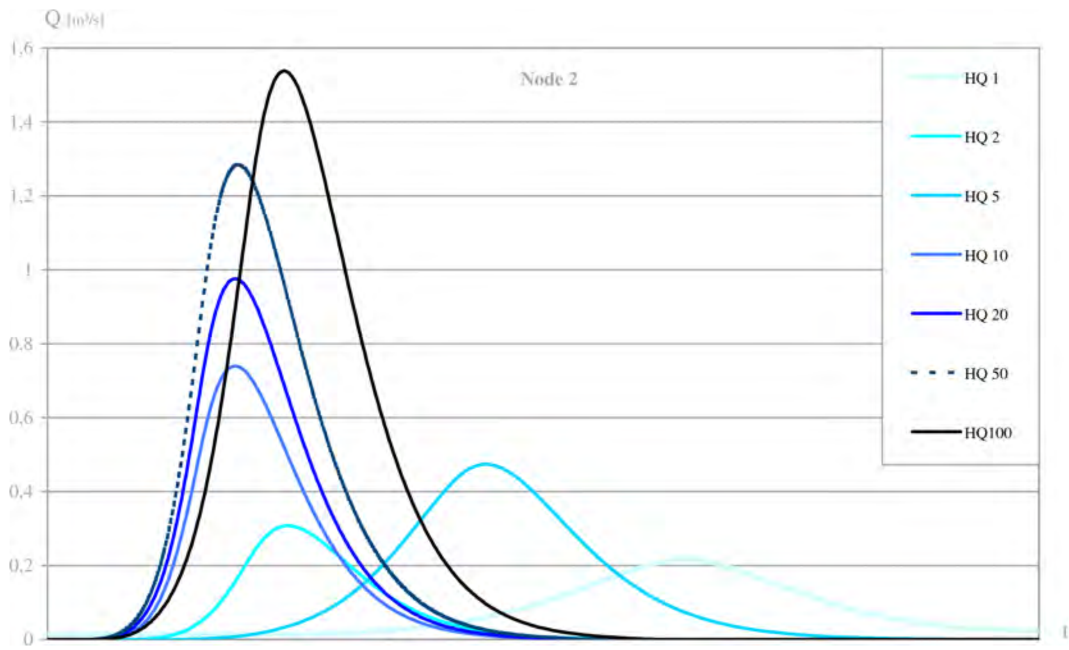

Figure A.9: Maximum flood waves at node 2 for the different probabilities for hydrological scenario A

Buchhofen - Node 32

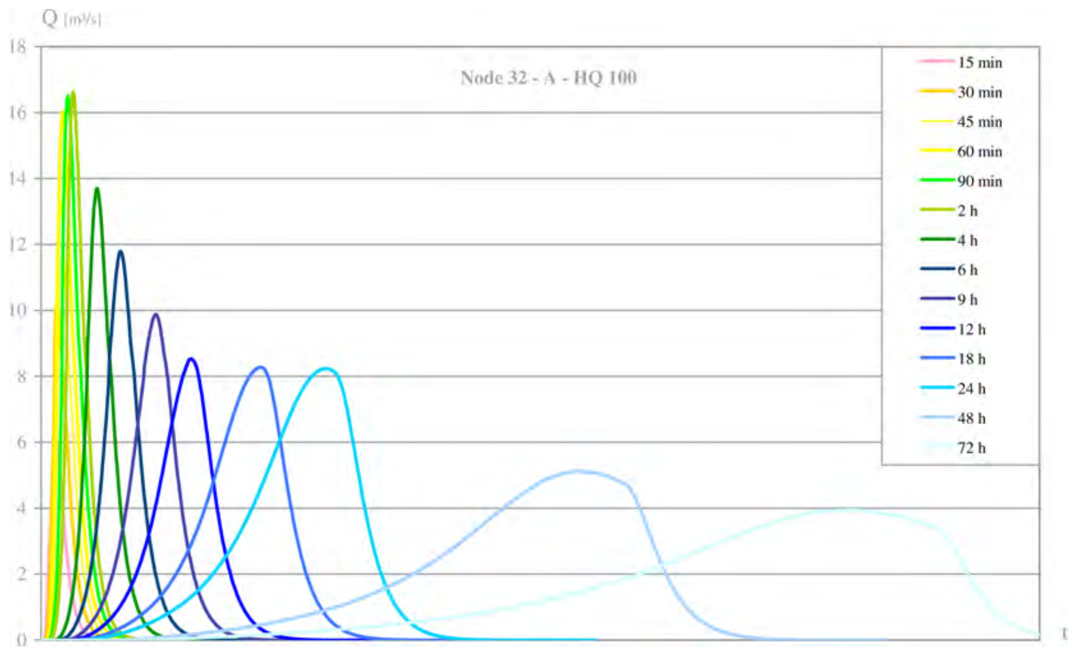

Figure A.10: 100 year floods for different precipitation patterns for scenario A at node 32

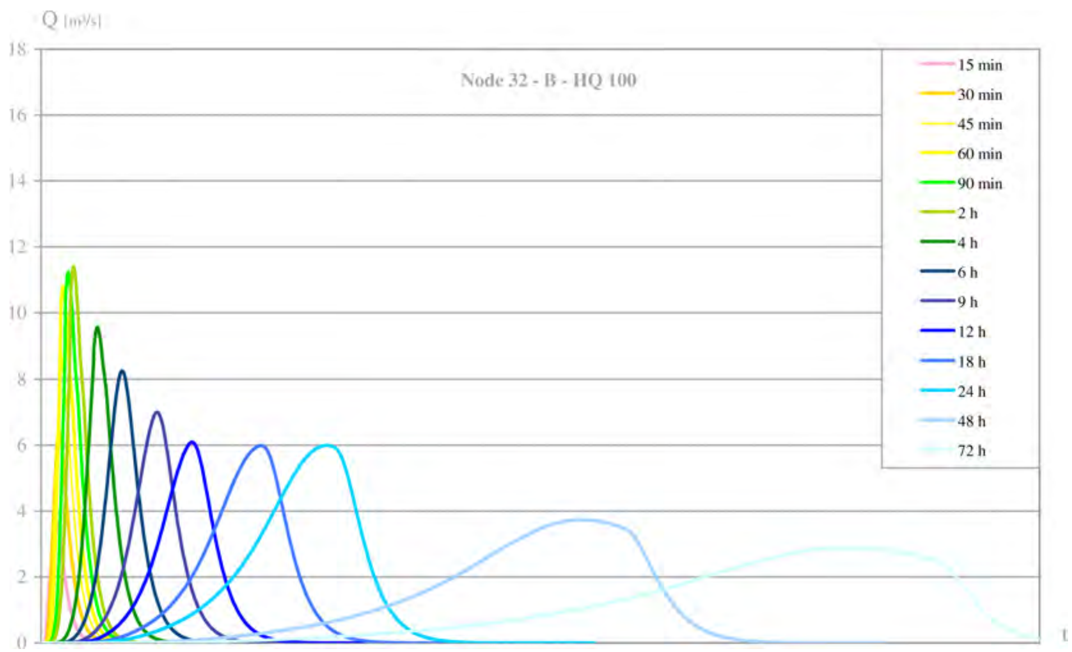

Figure A.11: 100 year floods for different precipitation patterns for scenario B at node 32

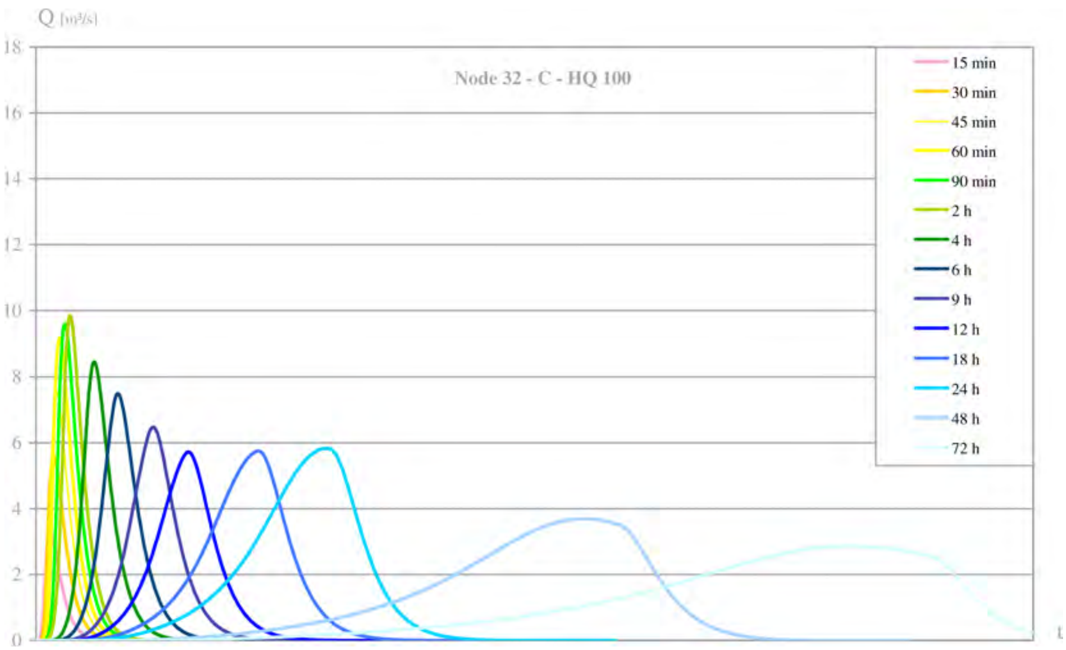

Figure A.12: 100 year floods for different precipitation patterns for scenario C at node 32

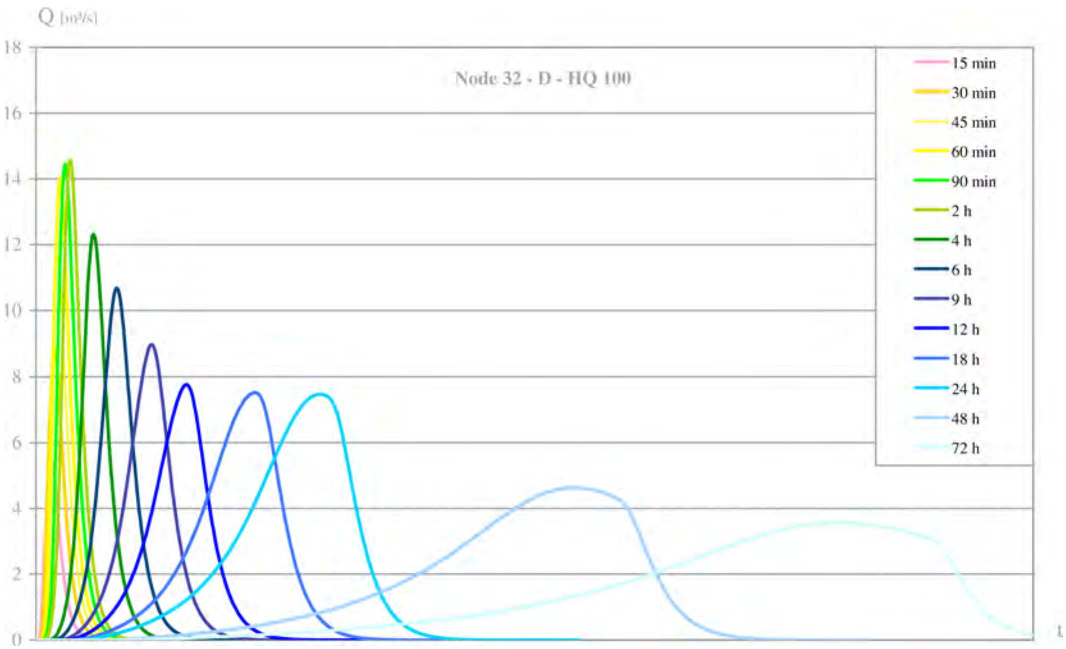

Figure A.13: 100 year floods for different precipitation patterns for scenario D at node 32

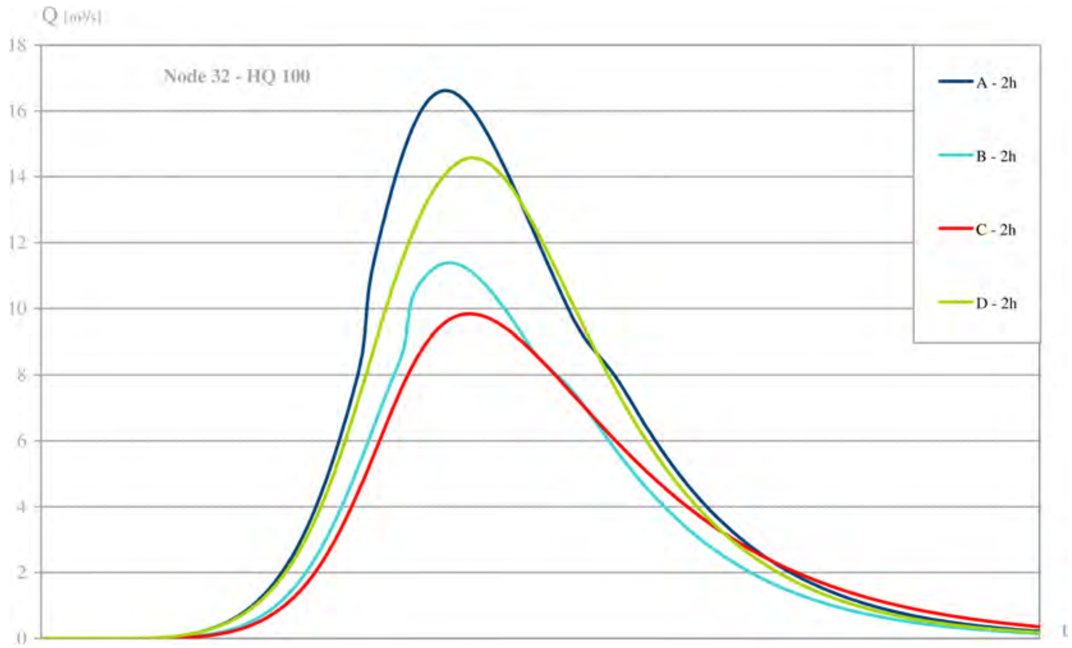

Figure A.14: Maximum 100 year flood wave at node 32 resulting from a 2h precipitation

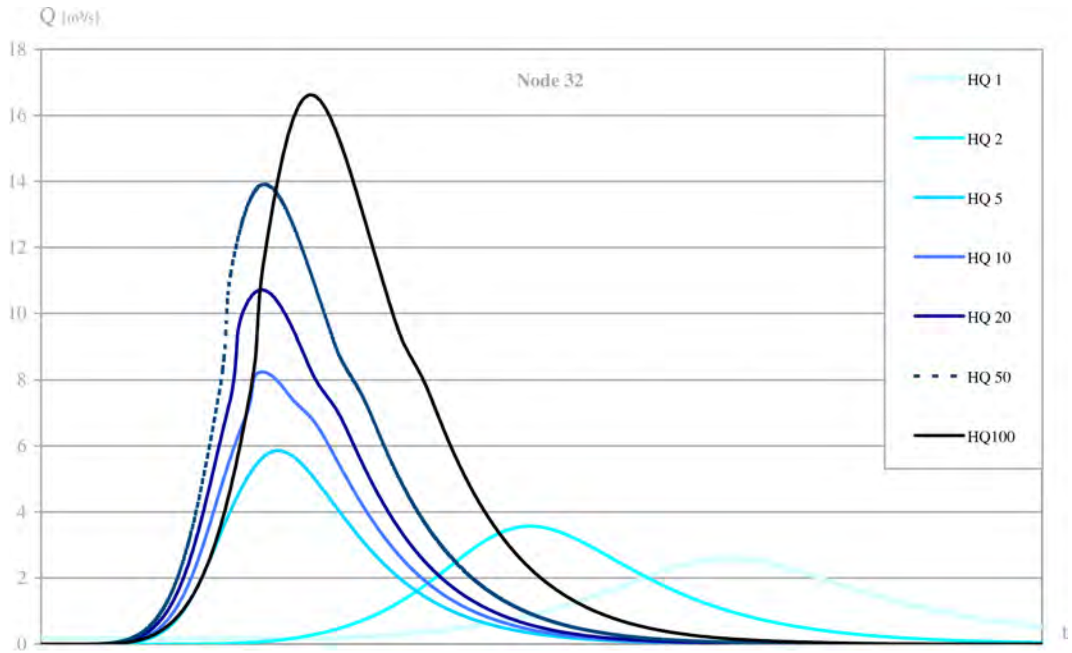

Figure A.15: Maximum flood waves at Node 32 for the different probabilities for hydrological scenario A

Osterhofen - Node 76

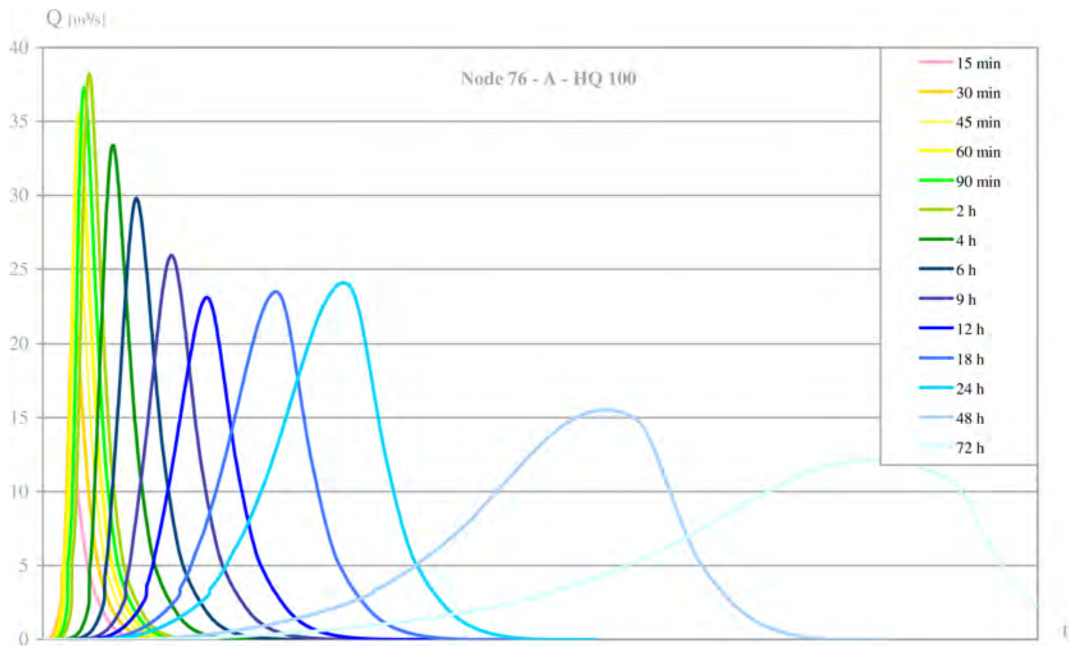

Figure A.16: 100 year floods for different precipitation patterns for scenario A at node 76

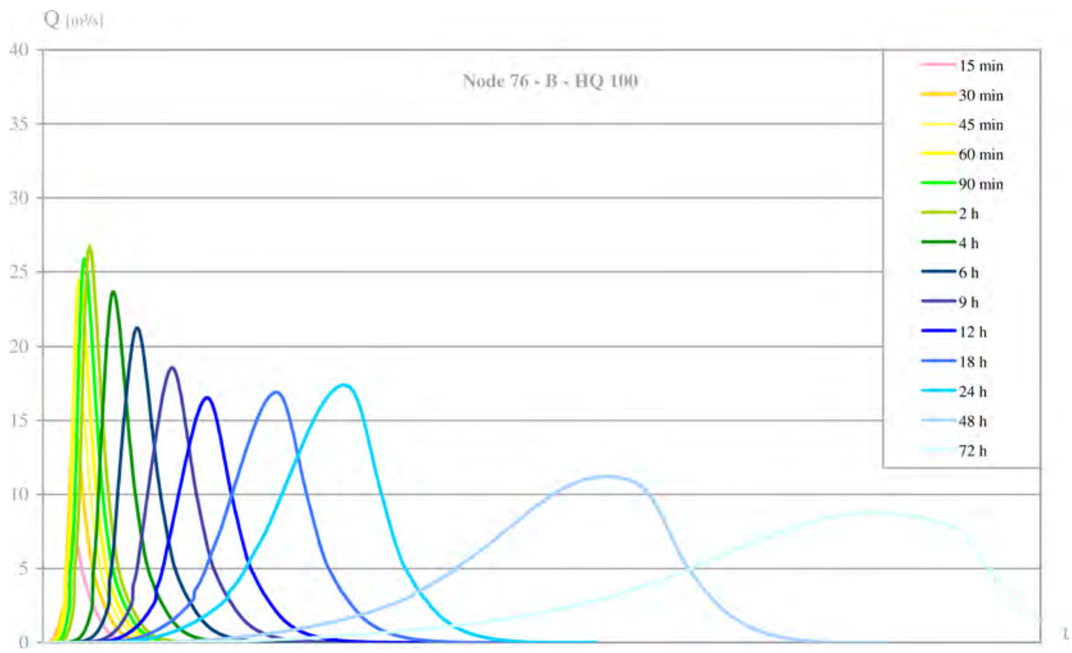

Figure A.17: 100 year floods for different precipitation patterns for scenario B at node 76

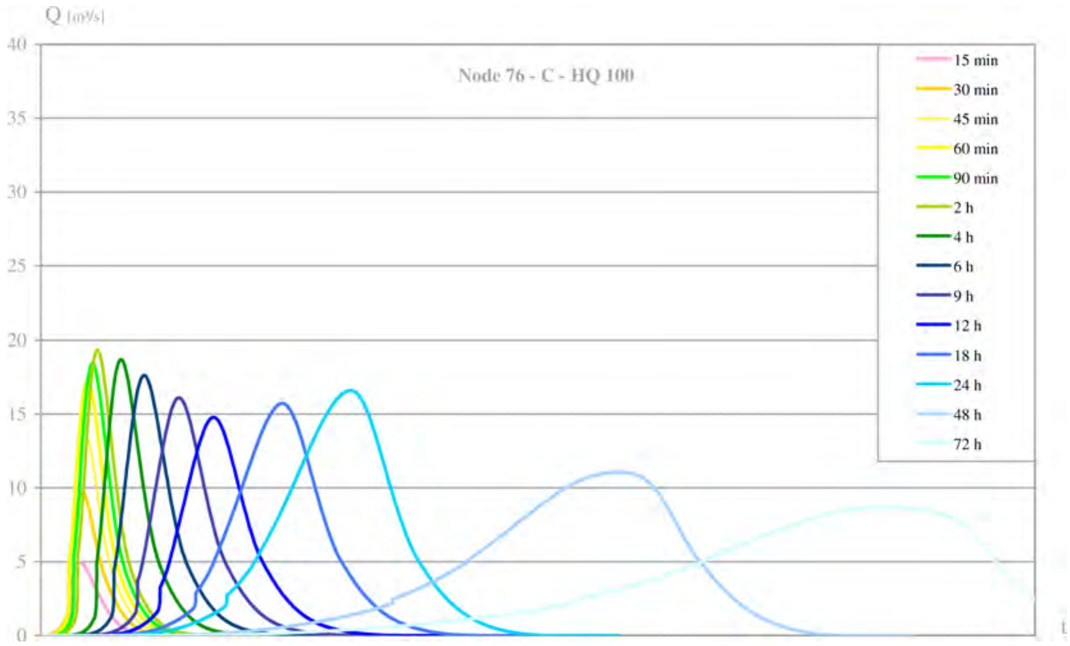

Figure A.18: 100 year floods for different precipitation patterns for scenario C at node 76

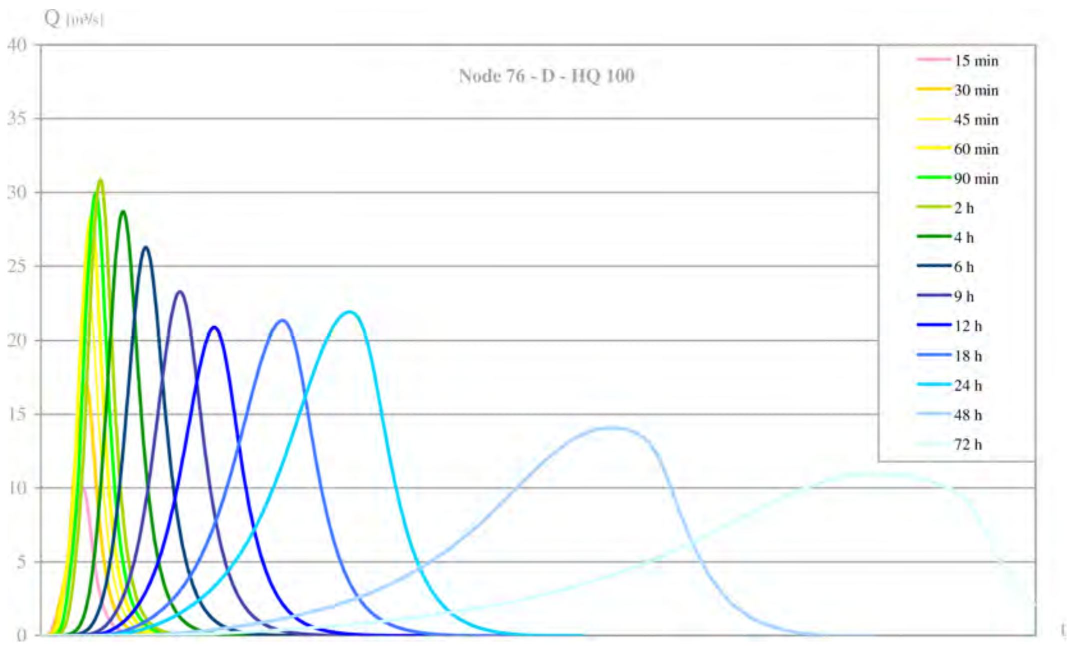

Figure A.19: 100 year floods for different precipitation patterns for scenario D at node 76

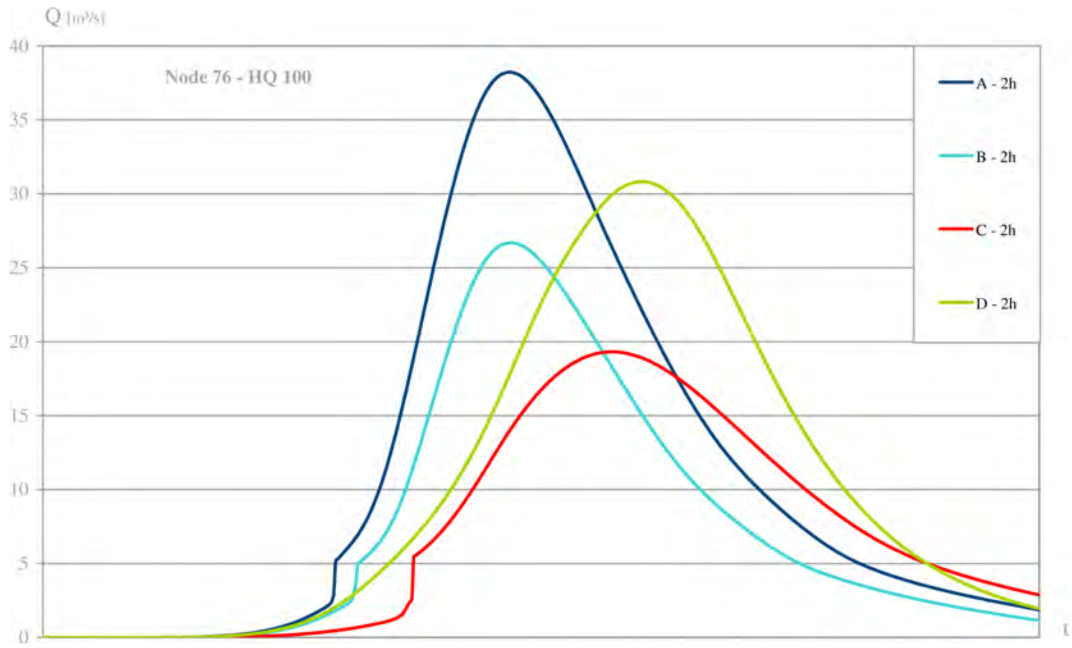

Figure A.20: Maximum 100 year flood wave at node 76 resulting from a 2h precipitation

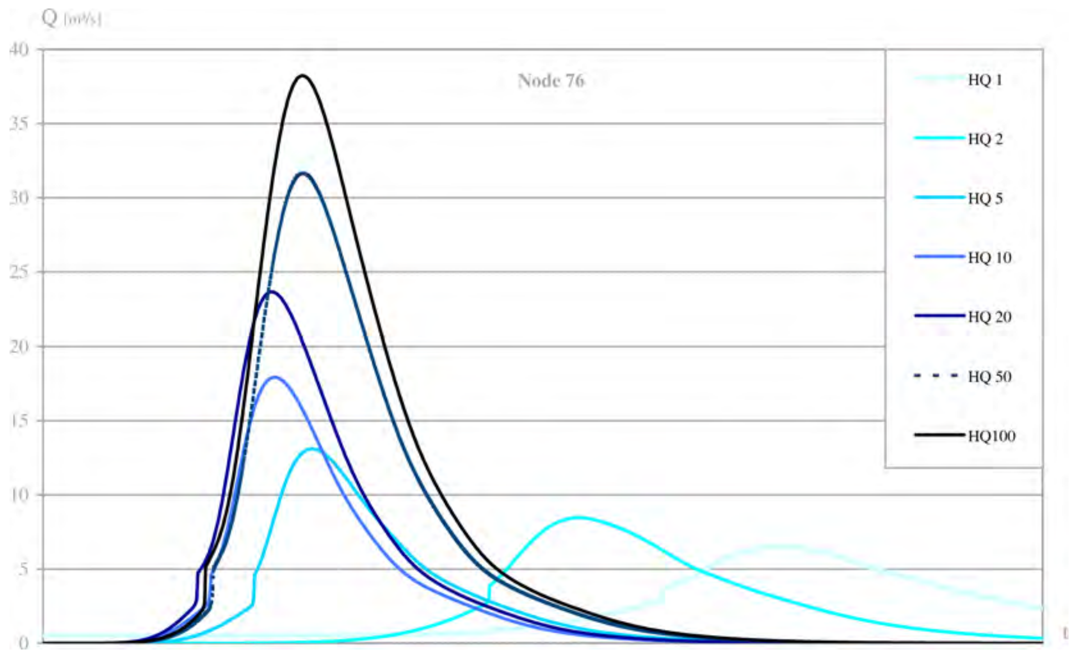

Figure A.21: Maximum flood waves at node 76 for the different probabilities for hydrological scenarios A

A.5 Hydrodynamic model results

The following figures are graphic representations of hydrodynamic simulations. They show the extent and in some cases the water depth of floodings of different probabilities. Different levels of blue indicate increasing water depth with increasing darkness in levels of 0.01 - 0.10 m, 0.1 - 0.8 m, 0.1 - 0.8 m, 0.8 - 2.1 m.

Bachling

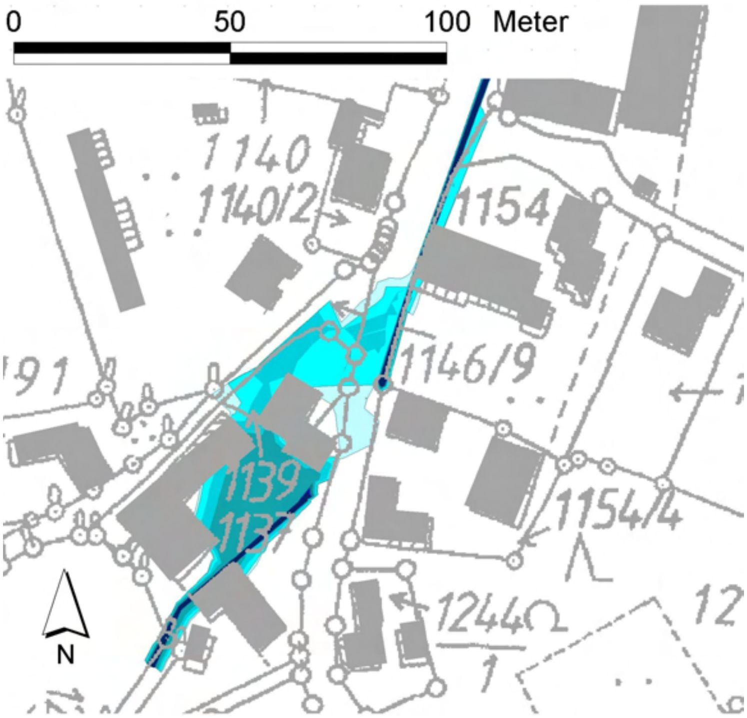

Figure A.22: Flood plain in Bachling for the scenario A for a 100 year flood event. Buildings and borders of property are indicated in black.

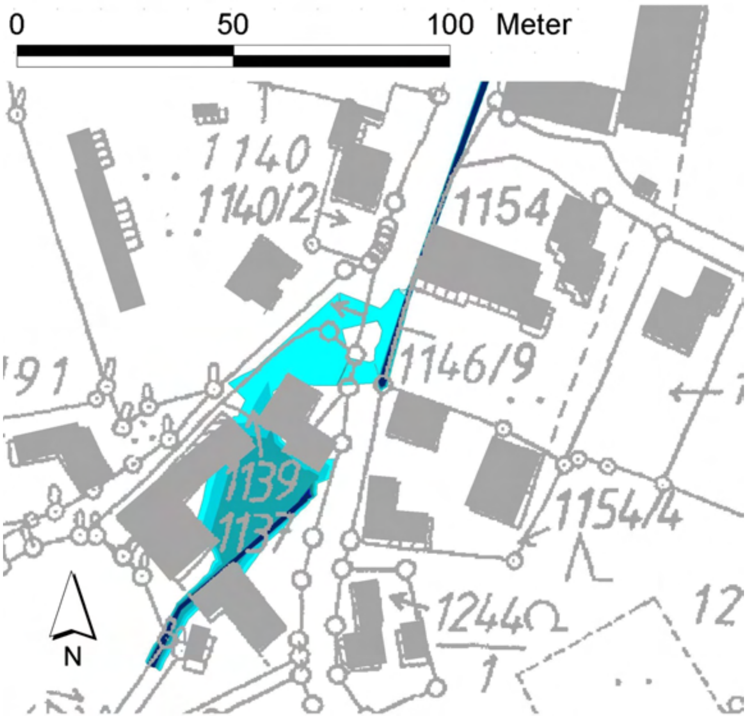

Figure A.23: Flood plain in Bachling for the scenario B for a 100 year flood event. Buildings and borders of property are indicated in black.

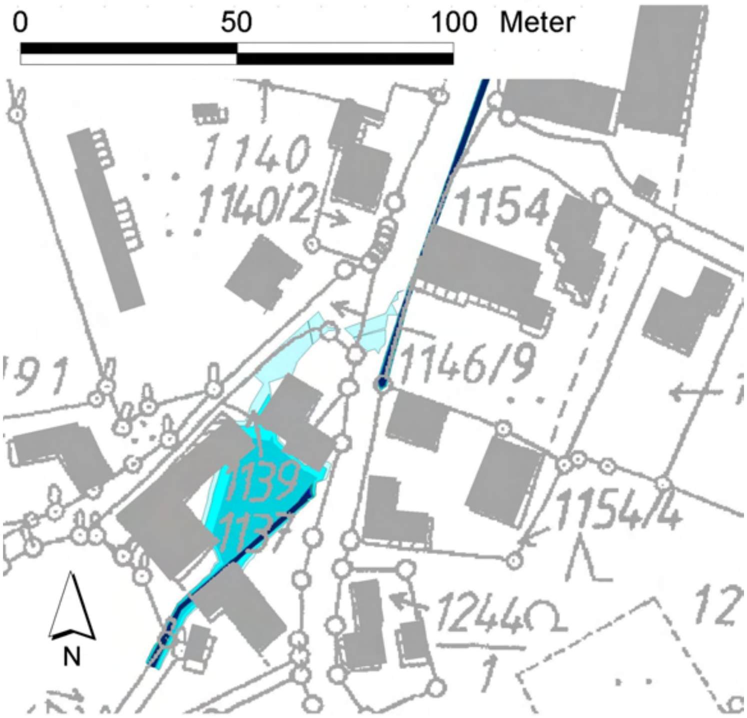

Figure A.24: Flood plain in Bachling for the scenario C for a 100 year flood event. Buildings and borders of property are indicated in black.

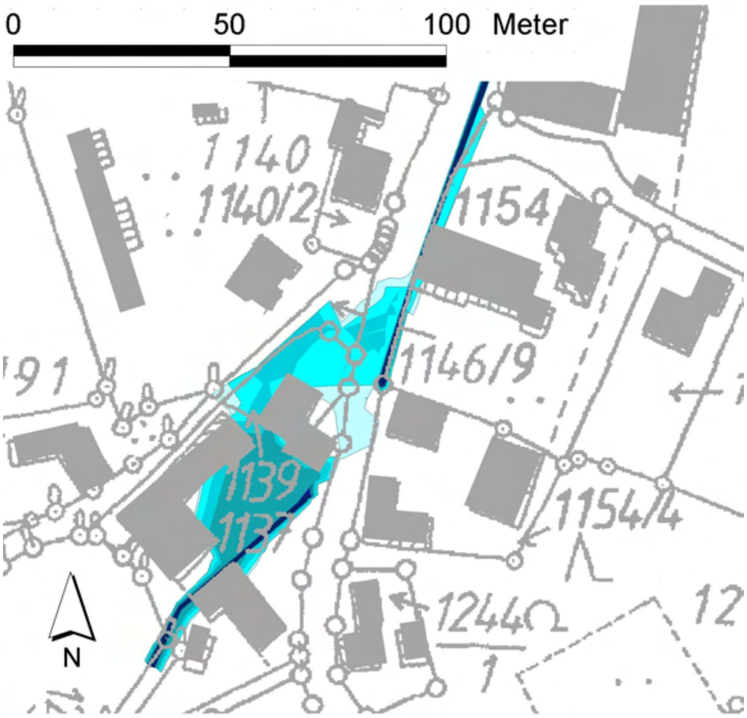

Figure A.25: Flood plain in Bachling for the scenario D for a 100 year flood event. Buildings and borders of property are indicated in black.

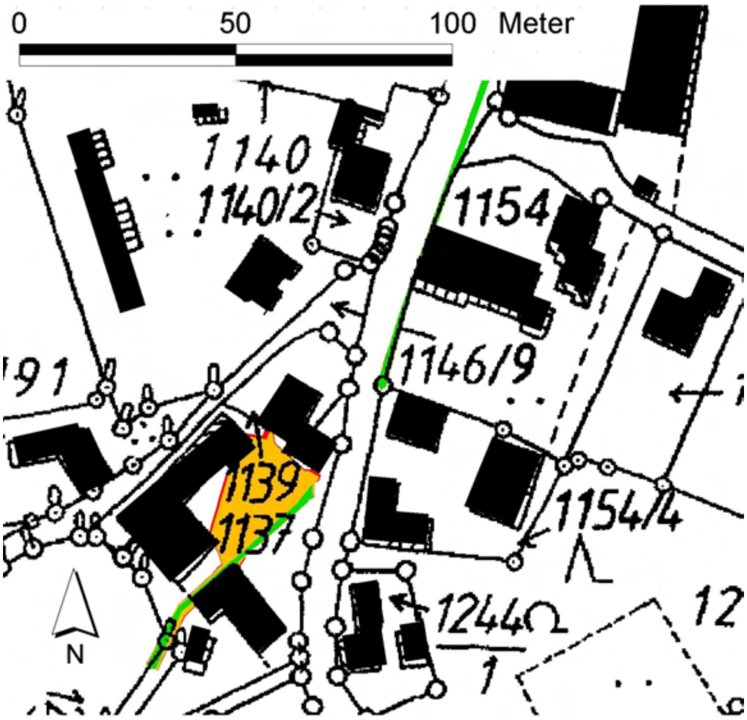

Figure A.26: Flood plain in Bachling: Comparison of the scenarios A (red), B (yellow) and C (green) for 10 year flood event. Buildings and borders of property are indicated in black.

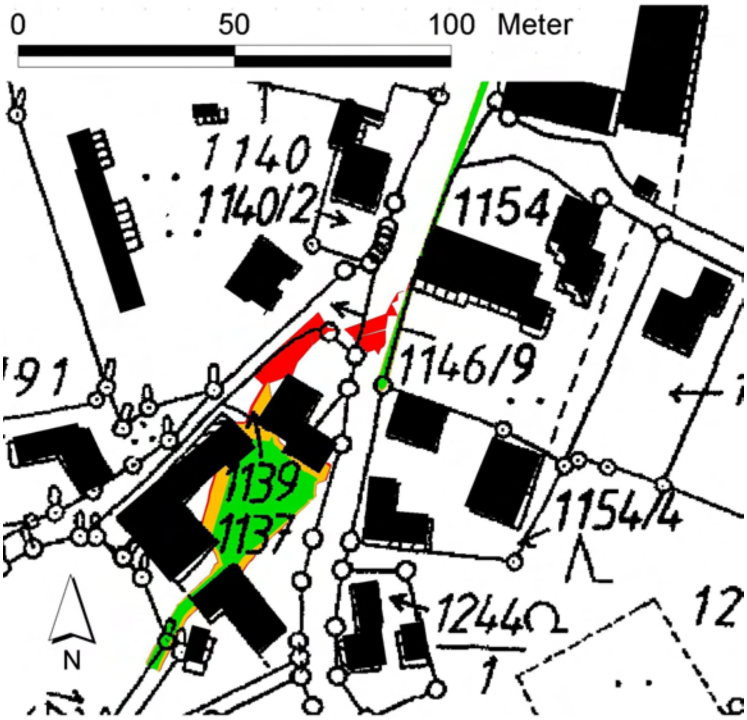

Figure A.27: Flood plain in Bachling: Comparison of the scenarios A (red), B (yellow) and C (green) for 20 year flood event. Buildings and borders of property are indicated in black.

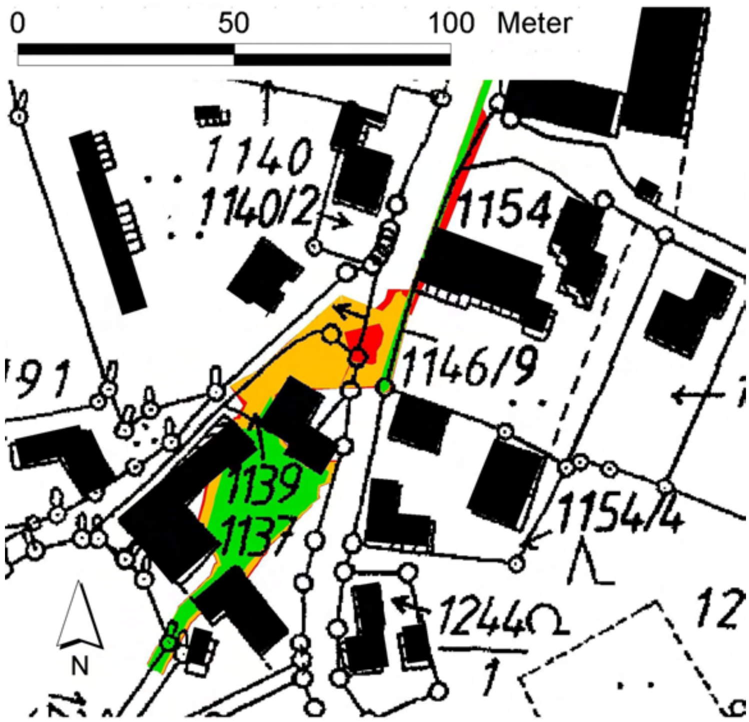

Figure A.28: Flood plain in Bachling: Comparison of the scenarios A (red), B (yellow) and C (green) for 50 year flood event. Buildings and borders of property are indicated in black.

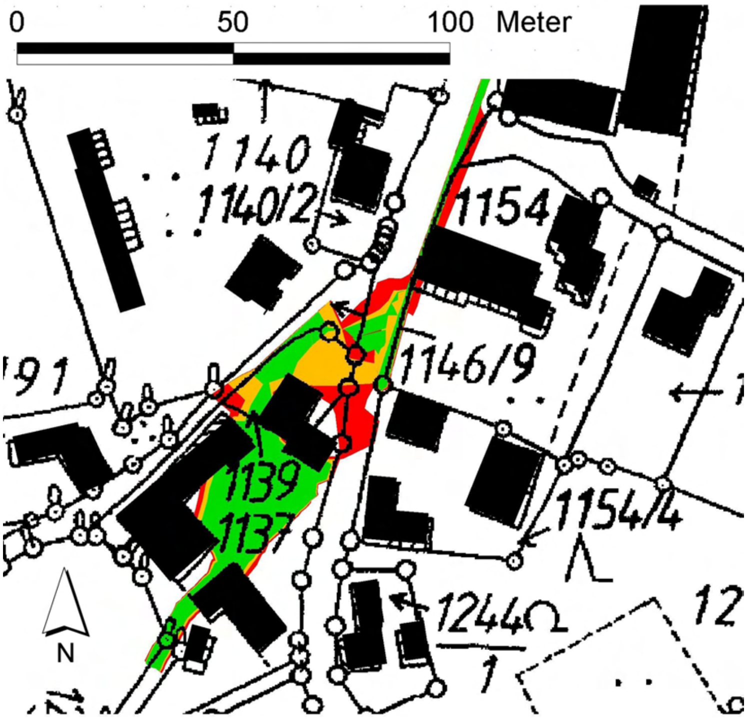

Figure A.29: Flood plain in Bachling: Comparison of the scenarios A (red), B (yellow) and C (green) for 100 year flood event. Buildings and borders of property are indicated in black.

Buchhofen

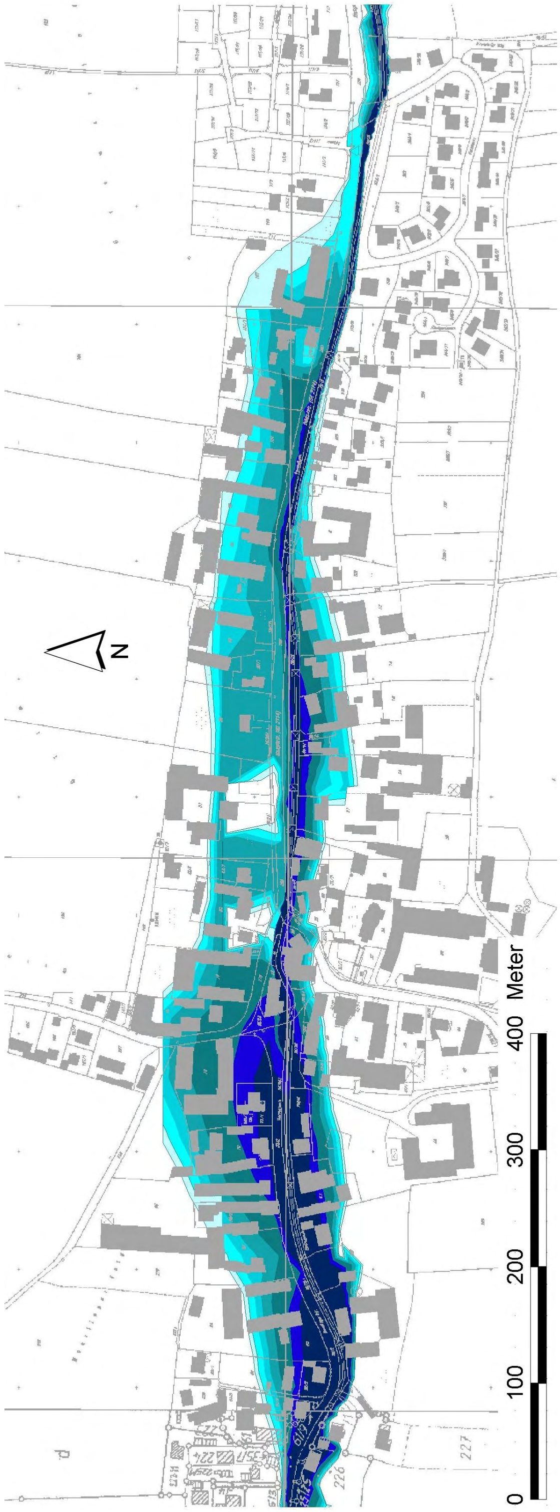

Figure A.30: Flood plain in Buchhofen for the scenario A for a 100 year flood event. Buildings and borders of property are indicated in black.

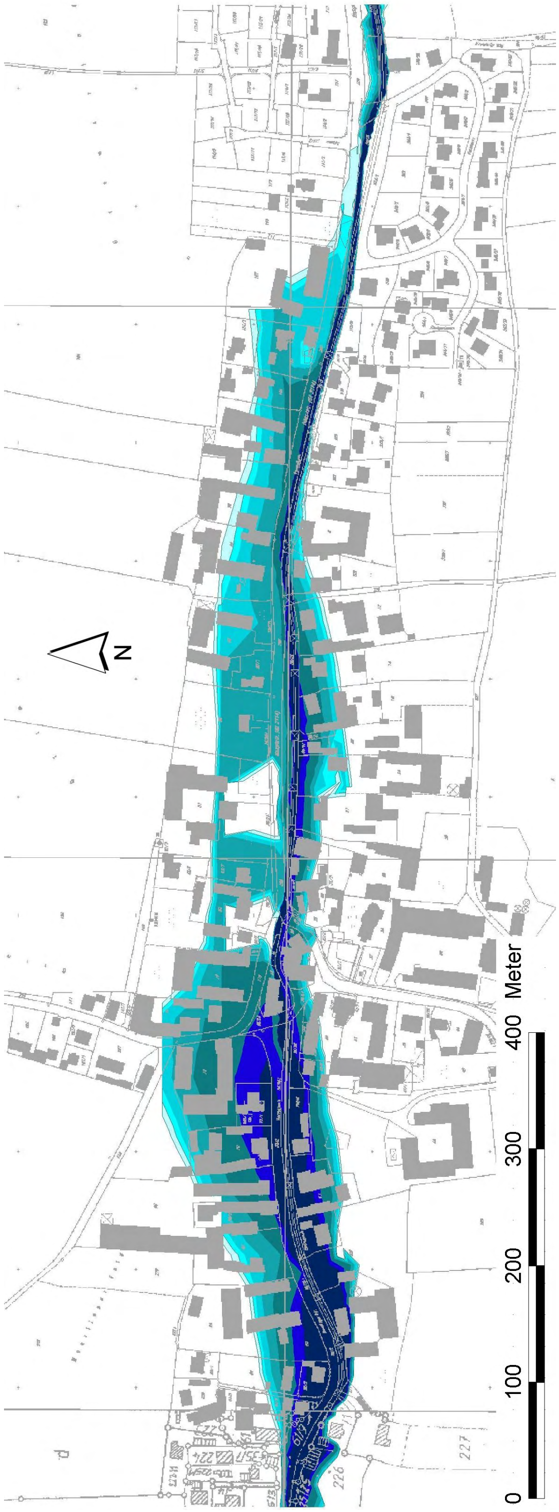

Figure A.31: Flood plain in Buchhofen for the scenario B for a 100 year flood event. Buildings and borders of property are indicated in black.

Figure A.32: Flood plain in Buchhofen for the scenario C for a 100 year flood event. Buildings and borders of property are indicated in black.

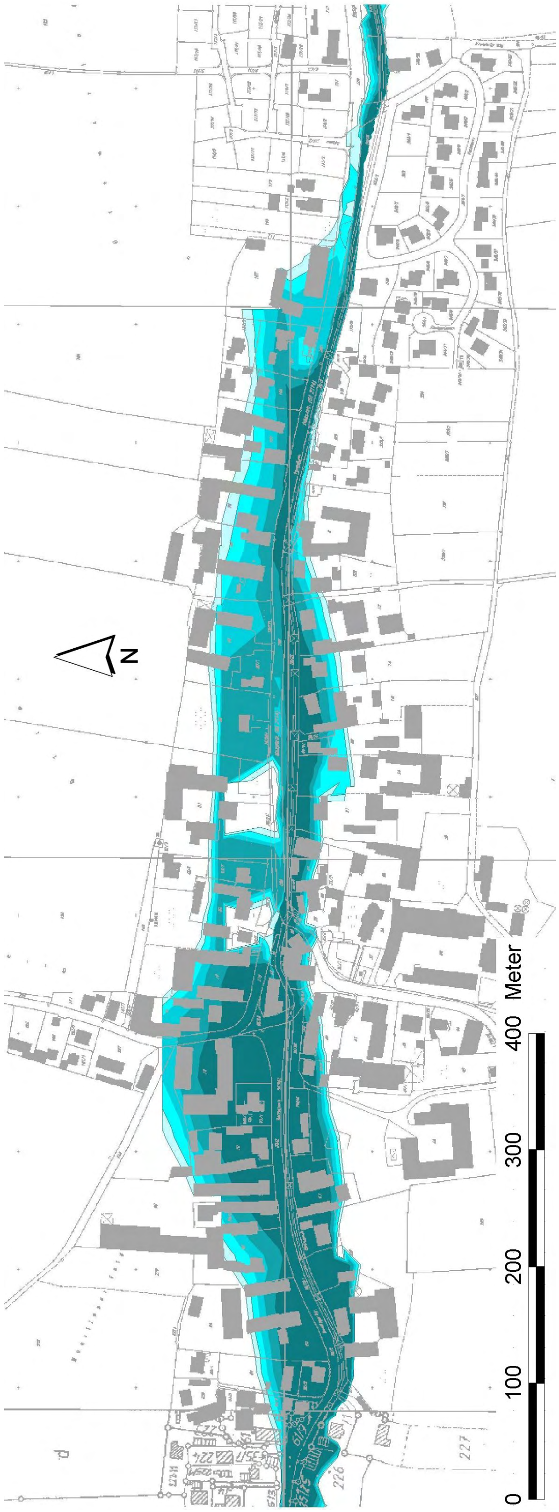

Figure A.33: Flood plain in Buchhofen for the scenario D for a 100 year flood event. Buildings and borders of property are indicated in black.

Figure A.34: Flood plain in Buchhofen: Comparison of the scenarios A (red), B (yellow) and C (green) for 2 year flood event. Buildings and borders of property are indicated in black.

Figure A.35: Flood plain in Buchhofen: Comparison of the scenarios A (red), B (yellow) and C (green) for 5 year flood event. Buildings and borders of property are indicated in black.

Figure A.36: Flood plain in Buchhofen: Comparison of the scenarios A (red), B (yellow) and C (green)C for 10 year flood event. Buildings and borders of property are indicated in black.

Figure A.37: Flood plain in Buchhofen: Comparison of the scenarios A (red), B (yellow) and C (green) for 20 year flood event. Buildings and borders of property are indicated in black.

Figure A.38: Flood plain in Buchhofen: Comparison of the scenarios A (red), B (yellow) and C (green) for 50 year flood event. Buildings and borders of property are indicated in black.

Figure A.39: Flood plain in Buchhofen: Comparison of the scenarios A (red), B (yellow) and C (green) for 100 year flood event. Buildings and borders of property are indicated in black.

Osterhofen

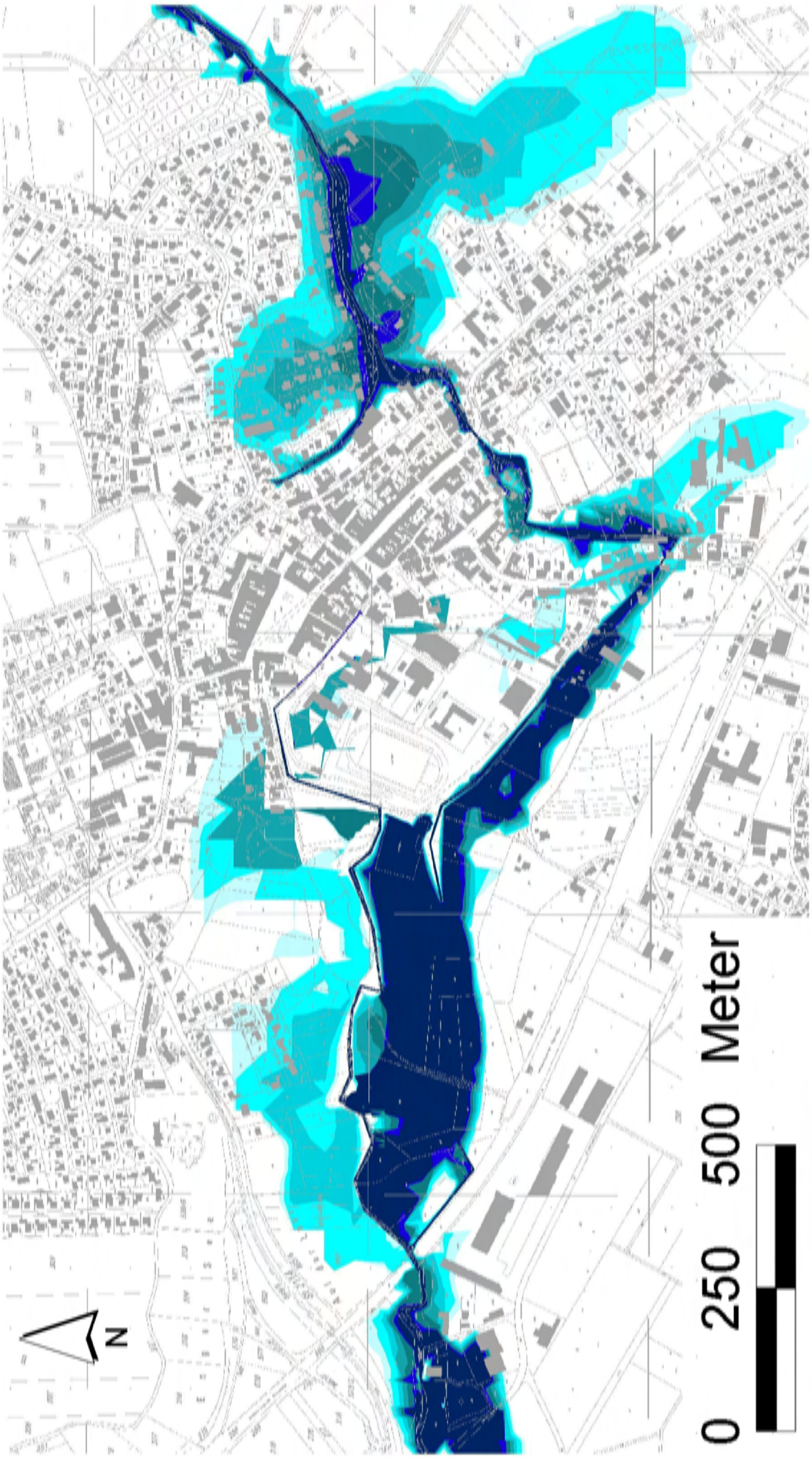

Figure A.40: Flood plain in Osterhofen for the scenario A for a 100 year flood event. Buildings and borders of property are indicated in black.

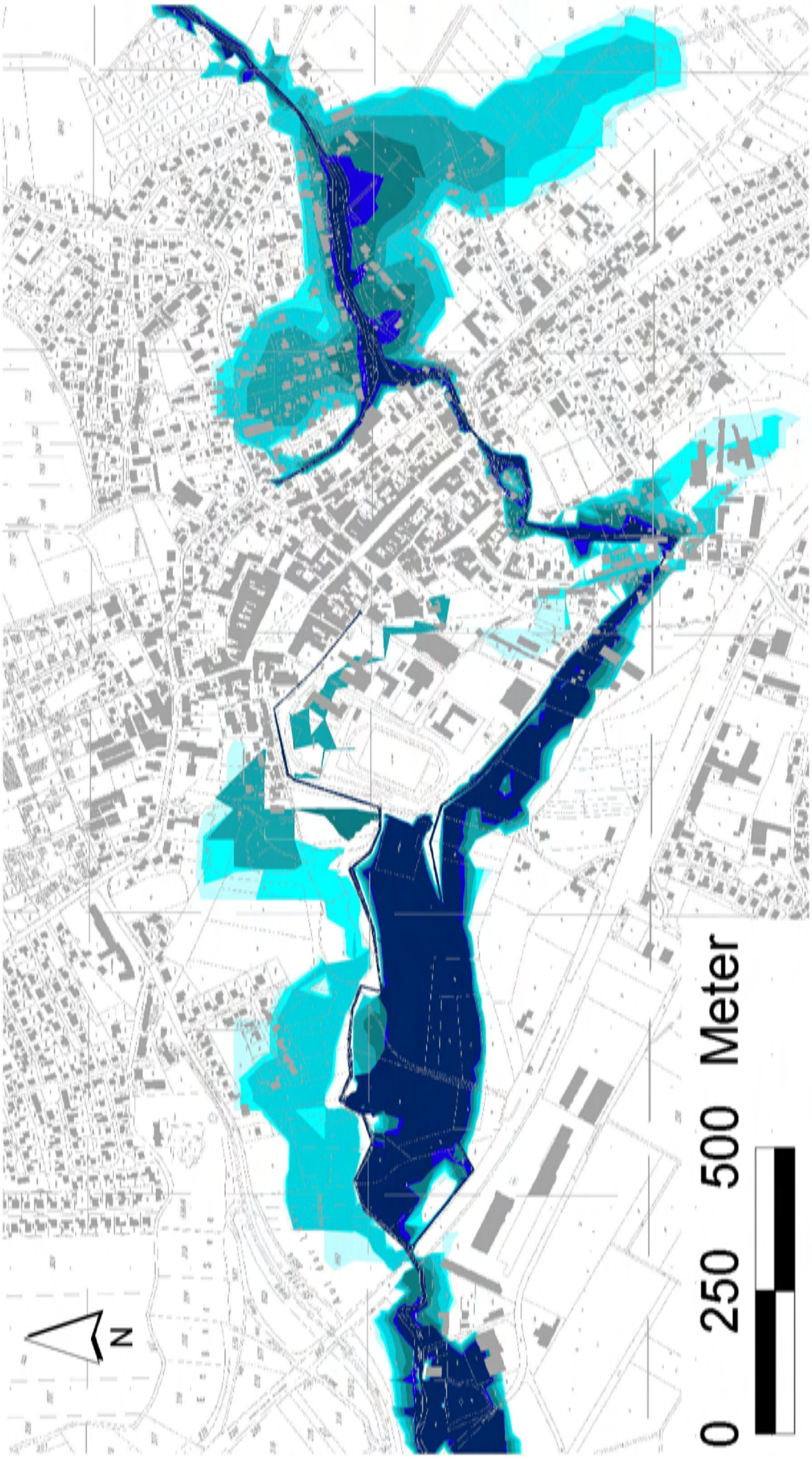

Figure A.41: Flood plain in Osterhofen for the scenario B for a 100 year flood event. Buildings and borders of property are indicated in black.

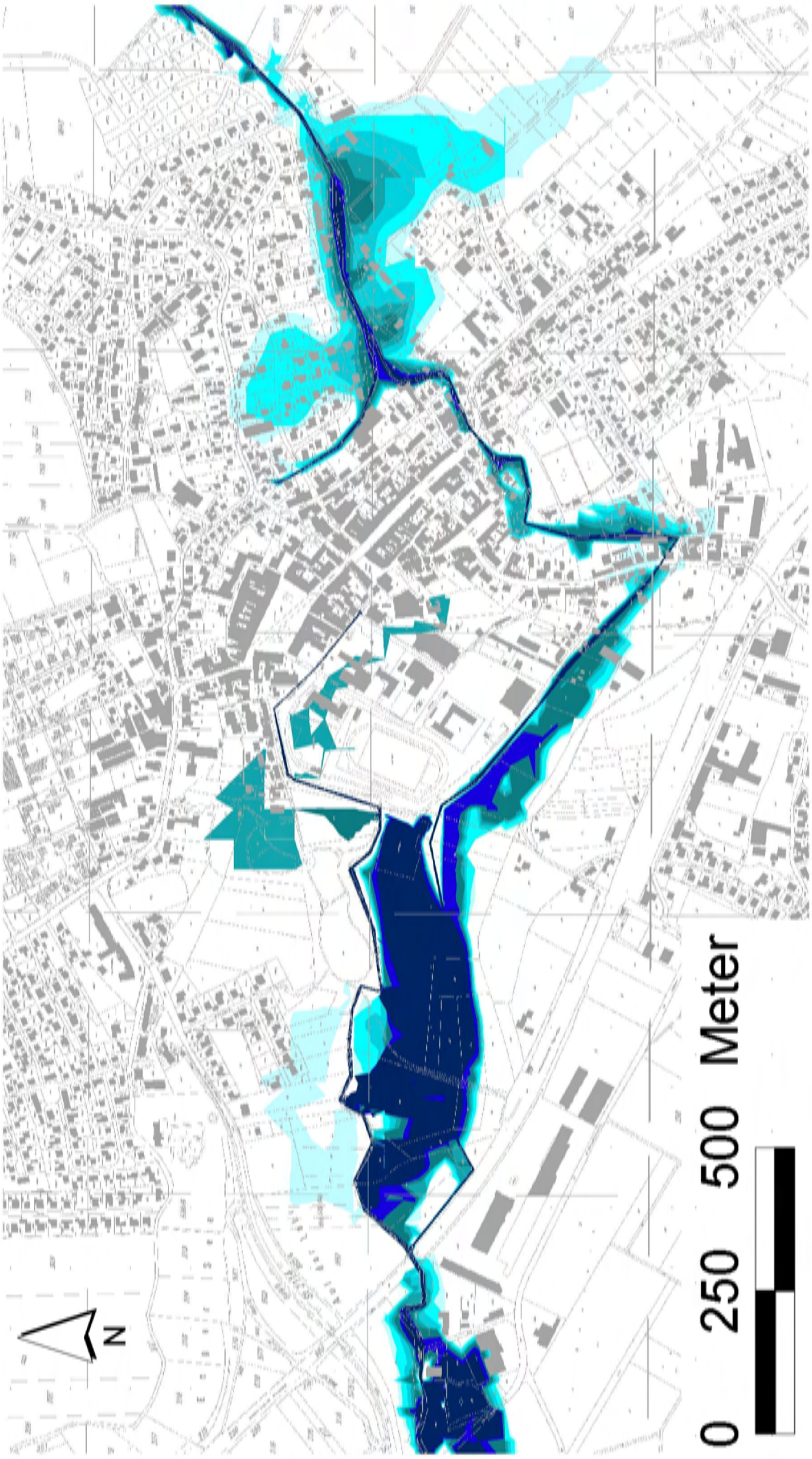

Figure A.42: Flood plain in Osterhofen for the scenario C for a 100 year flood event. Buildings and borders of property are indicated in black.

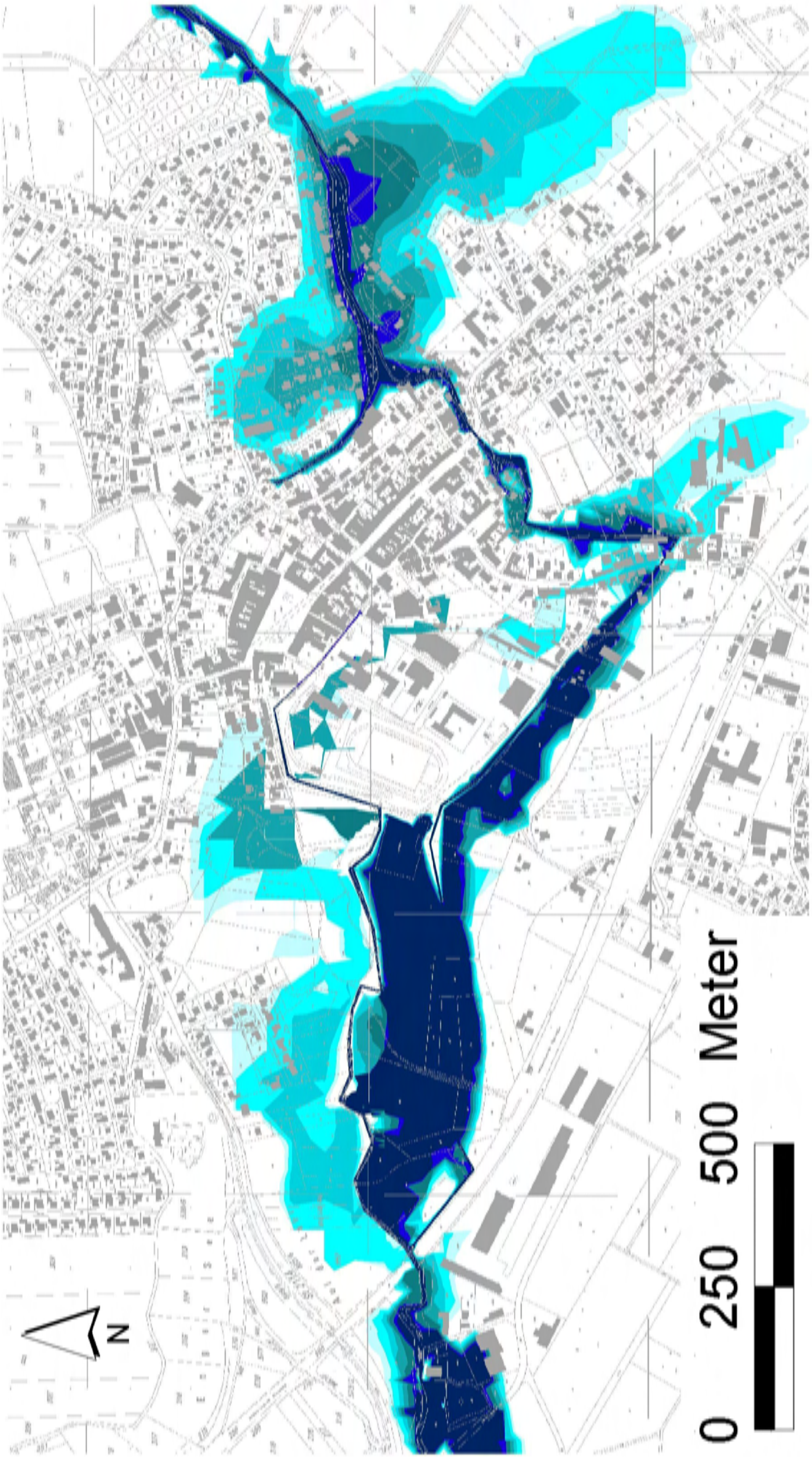

Figure A.43: Flood plain in Osterhofen for the scenario D for a 100 year flood event. Buildings and borders of property are indicated in black.

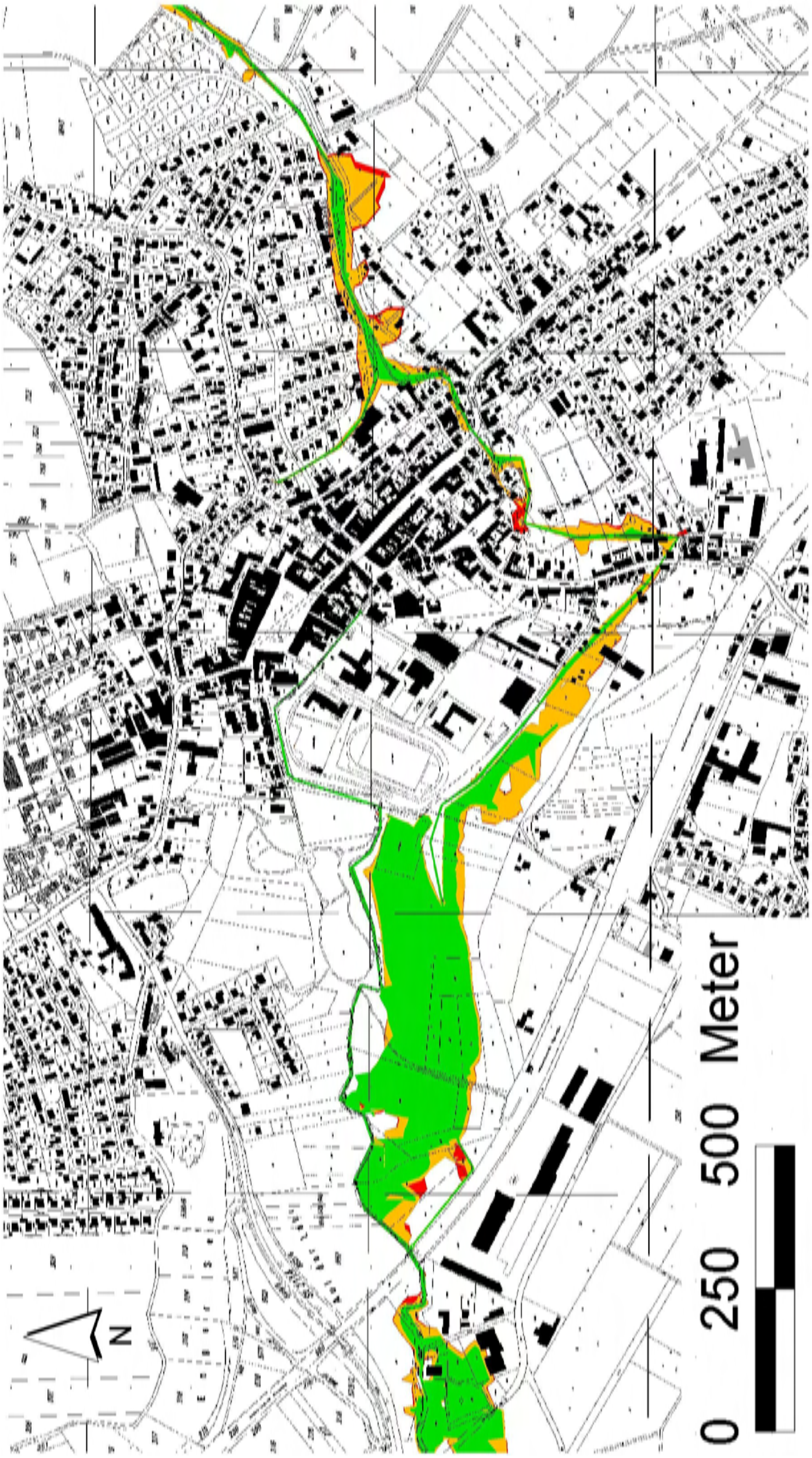

Figure A.44: Flood plain in Osterhofen: Comparison of the scenarios A (red), B (yellow) and C (green) for 2 year flood event. Buildings and borders of property are indicated in black.

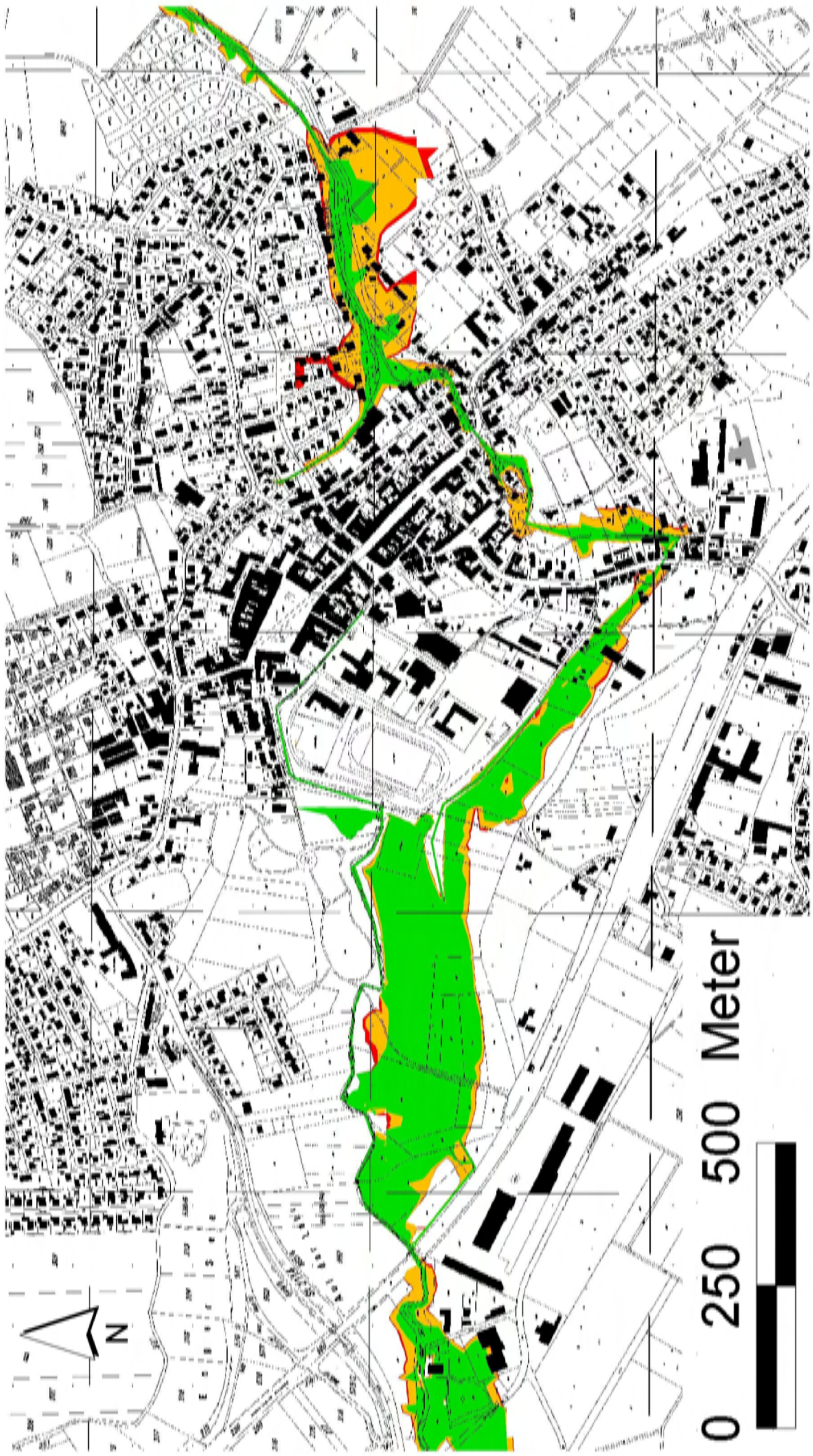

Figure A.45: Flood plain in Osterhofen: Comparison of the scenarios A (red), B (yellow) and C (green) for 5 year flood event. Buildings and borders of property are indicated in black.

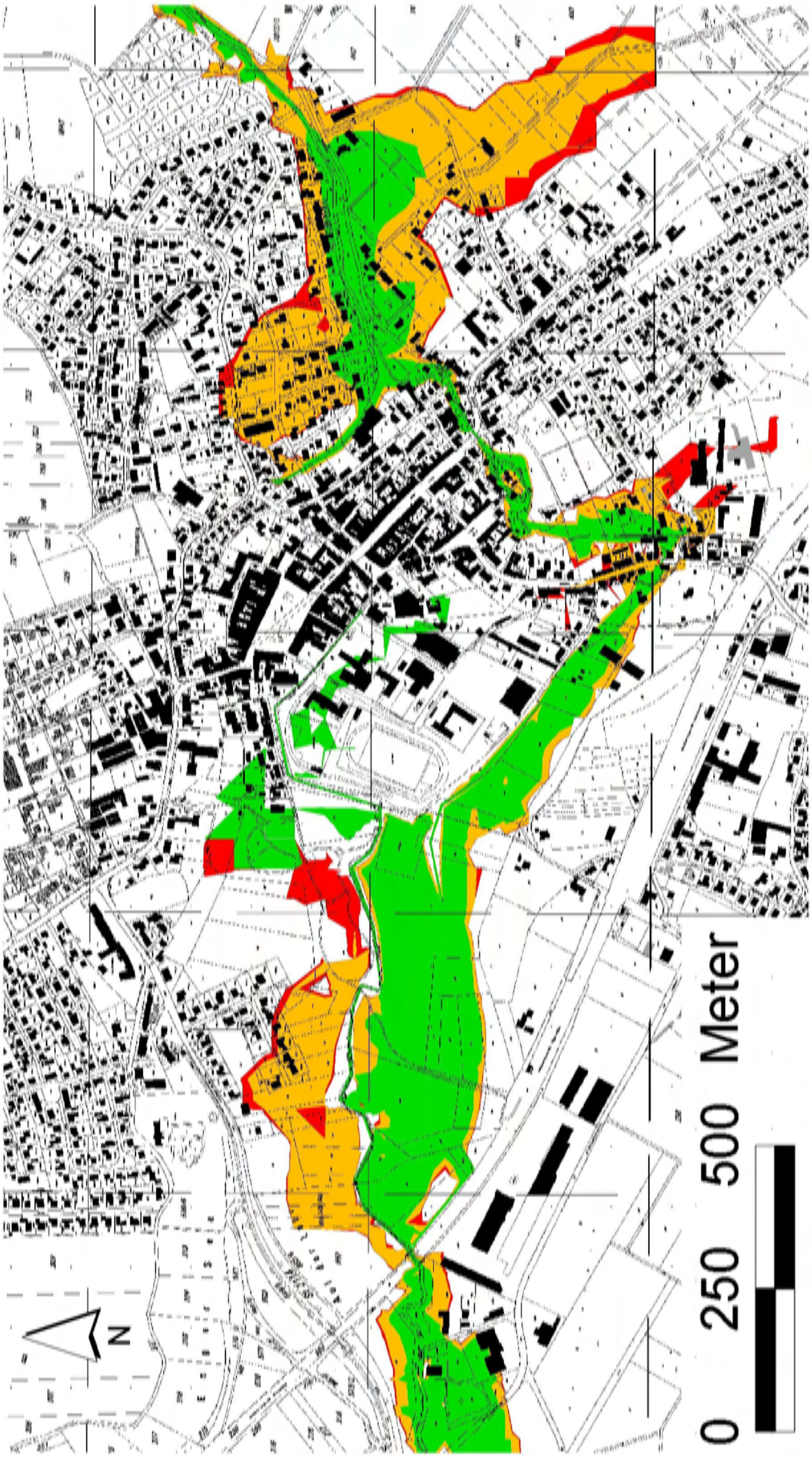

Figure A.46: Flood plain in Osterhofen: Comparison of the scenarios A (red), B (yellow) and C (green) for 20 year flood event. Buildings and borders of property are indicated in black.

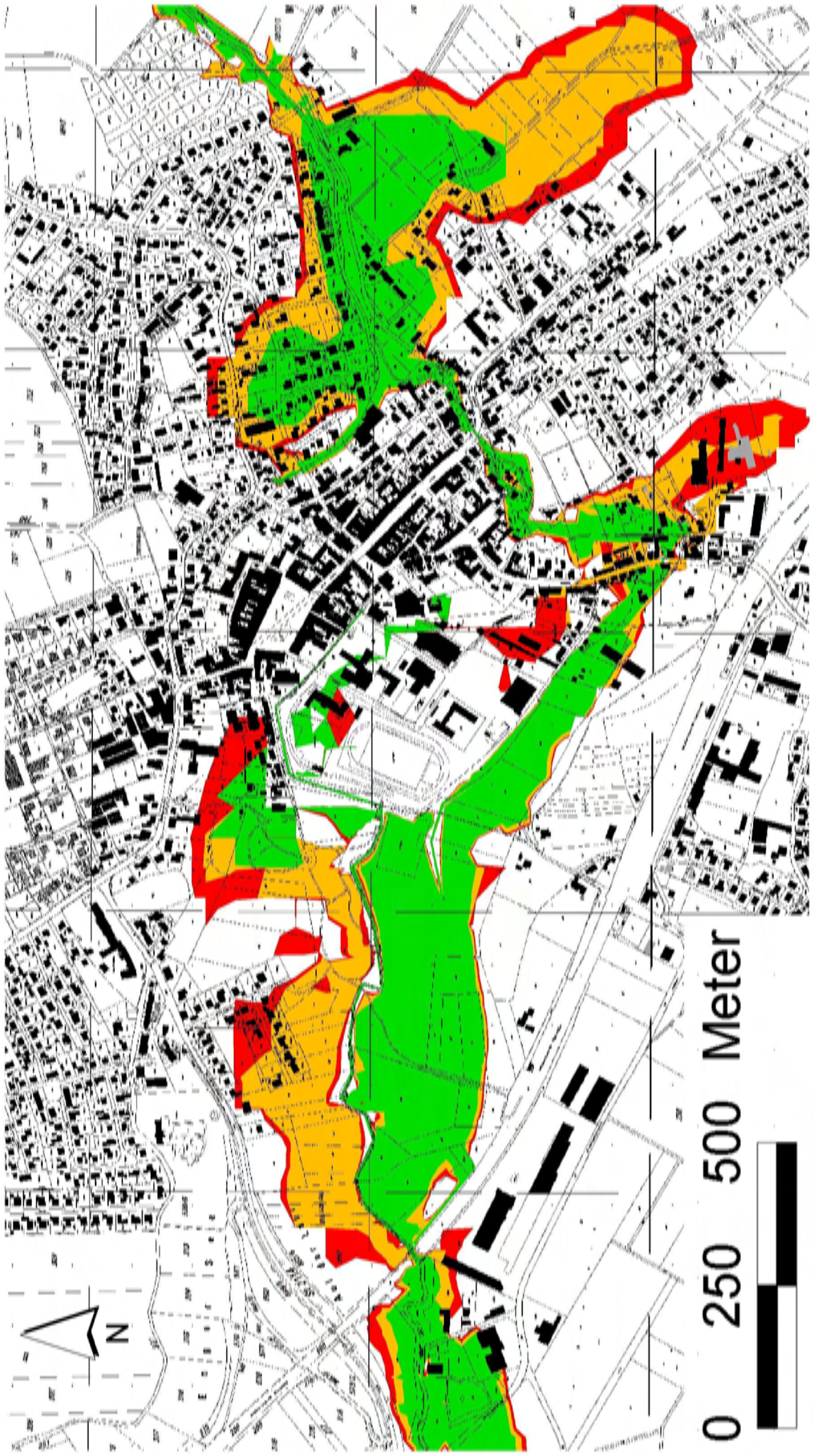

Figure A.47: Flood plain in Osterhofen: Comparison of the scenarios A (red), B (yellow) and C (green) for 50 year flood event. Buildings and borders of property are indicated in black.

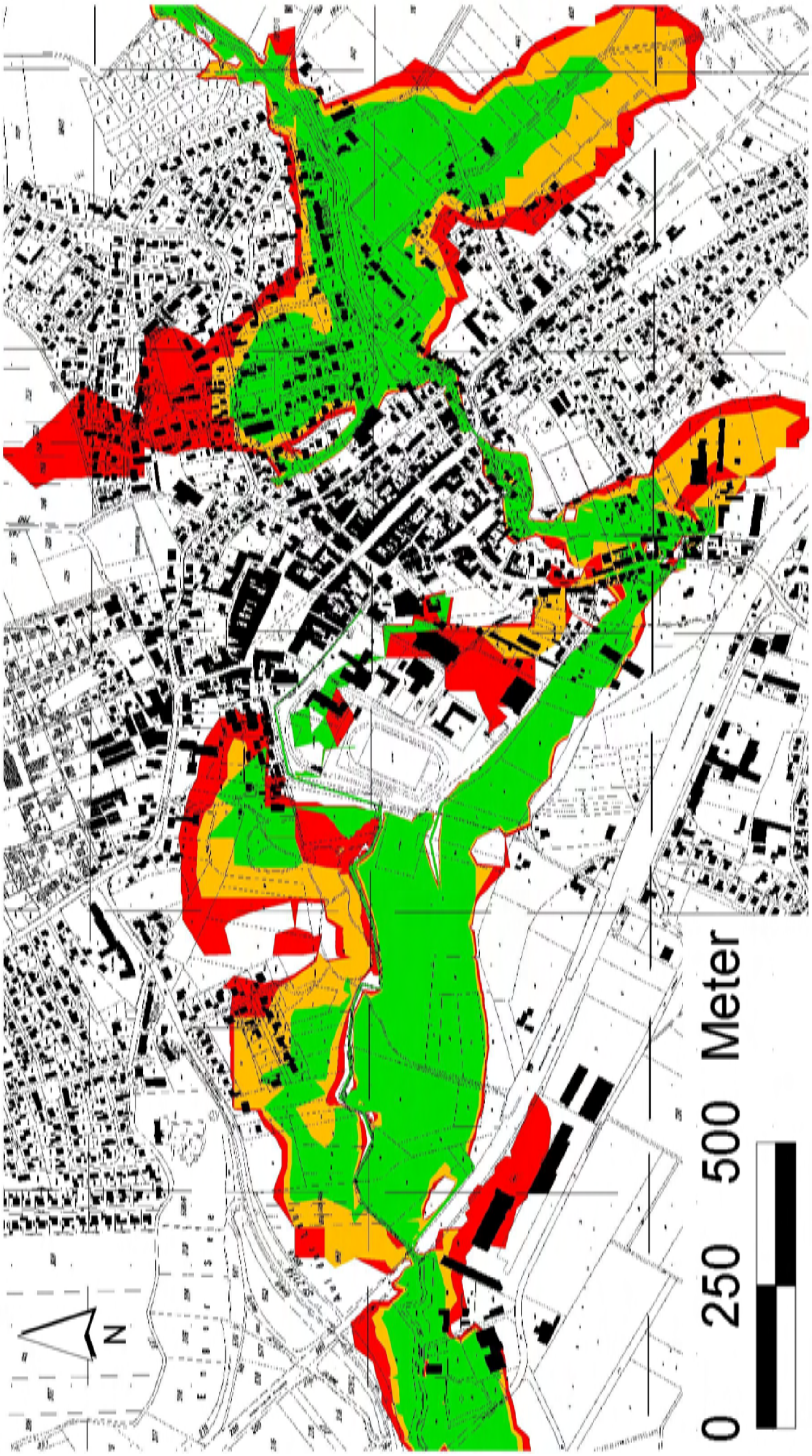

Figure A.48: Flood plain in Osterhofen: Comparison of the scenarios A (red), B (yellow) and C (green) for 100 year flood event. Buildings and borders of property are indicated in black.

A.6 Flood damage functions

The tables and figures are the results of mapping of buildings and the resulting damage estimations based on standard water depth - damage functions for detached houses and functional farm buildings.

Table:	Flood damages based on affected buildings and water depth.
Beamchart:	Damages per flood event for floods with a 1, 2, 5, 10, 20, 50 and 100 year recurrence interval.
Graphs:	Damage function of cumulated damages over a 100 year period as damages per year and event.

Table A.1: Overview of the presentation of flood damages as tables and charts

Bachling

Bachling Scen. A								
event	dis-charge in m³/s	residential house			other structures		Total costs per event	costs in €/a
		Base-ment	First floor					
			low	high	low	high		
HQ 1	0,4						0 €	0 €
HQ 2	0,5						0 €	0 €
HQ 5	0,9	1			1		3.000 €	200 €
HQ 10	1,2	1			1		3.000 €	100 €
HQ 20	1,6	1	1		1		9.000 €	180 €
HQ 50	2,1	1	1		2		10.000 €	166 €
HQ 100	2,5	1		1	2	1	16.000 €	78 €
								724 €

Tab.: Calculation of flood damages for Buchhofen

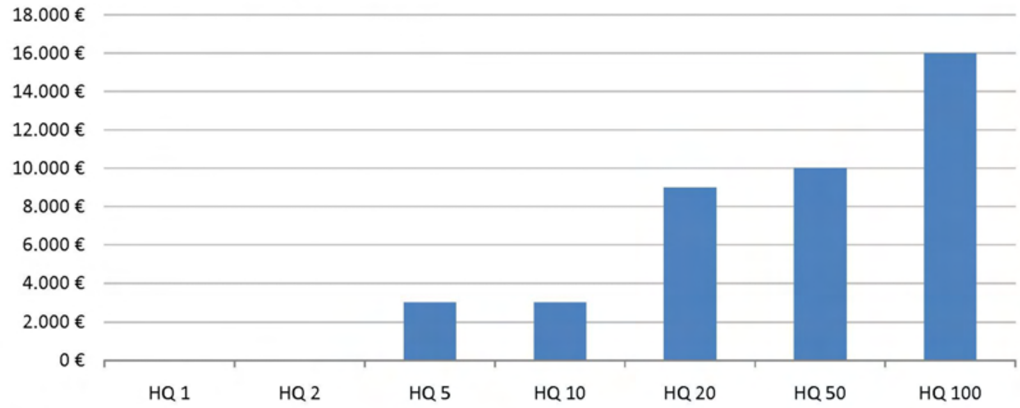

Fig.: Total costs per event

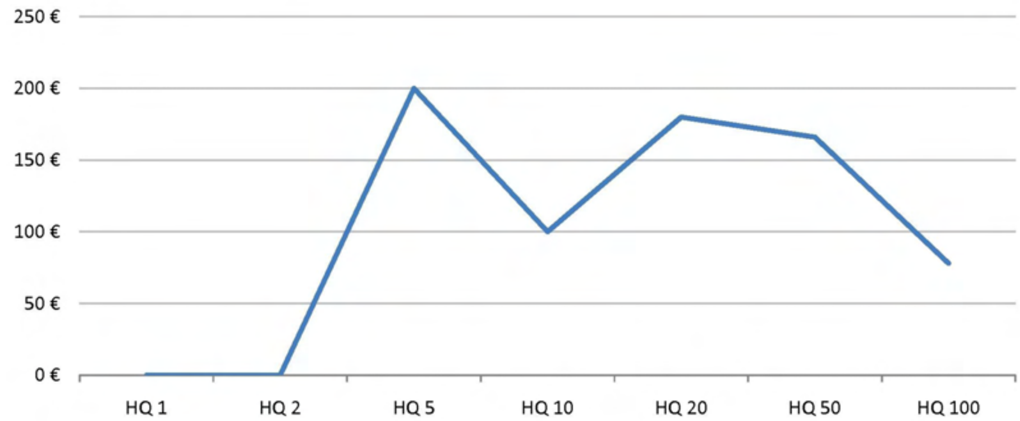

Fig.: Flood damage function

Figure A.49: Flood damages and damage function for Bachling scenario A

Bachling Scen. B								
event	dis-charge in m³/s	residential house			other structures		Total costs per event	costs in €/a
		Base-ment	First floor					
			low	high	low	high		
HQ 1	0,3						0 €	0 €
HQ 2	0,5						0 €	0 €
HQ 5	0,8						0 €	0 €
HQ 10	1,1	1			1		3.000 €	100 €
HQ 20	1,5	1	1		1		9.000 €	180 €
HQ 50	1,8	1	1		2		10.000 €	100 €
HQ 100	1,9	1		1	2	1	16.000 €	20 €
								400 €

Tab.: Calculation of flood damages for Buchhofen

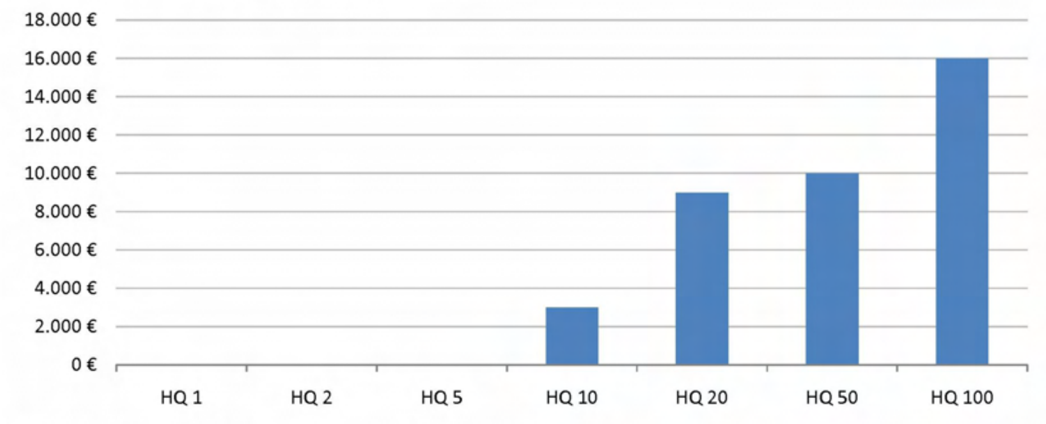

Fig.: Total costs per event

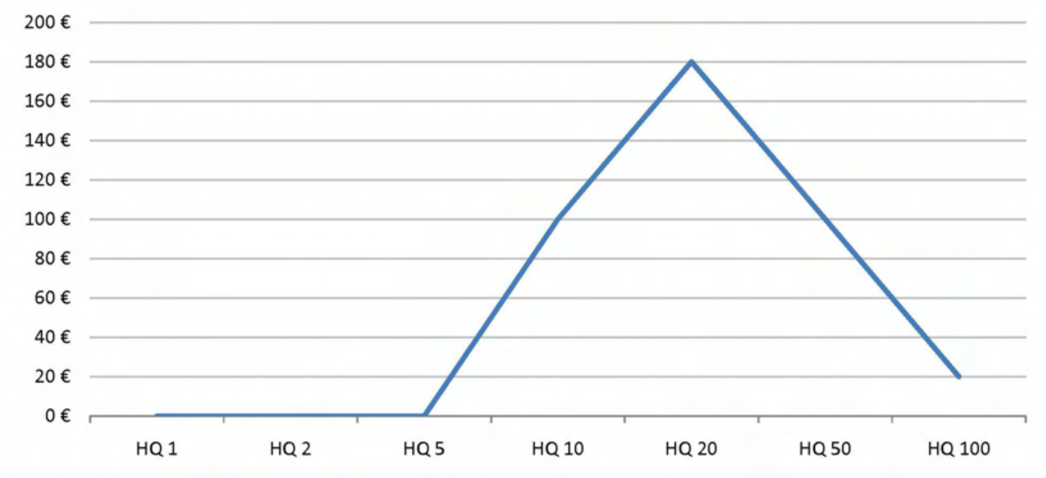

Fig.: Flood damage function

Figure A.50: Flood damages and damage function for Bachling Scenario B

Bachling Scen. C								
event	dis-charge in m³/s	residential house			other structures		Total costs per event	costs in €/a
		Base-ment	First floor					
			low	high	low	high		
HQ 1	0,2						0 €	0 €
HQ 2	0,3						0 €	0 €
HQ 5	0,5						0 €	0 €
HQ 10	0,8						0 €	0 €
HQ 20	1	1			1		3.000 €	23 €
HQ 50	1,4	1	1		2		10.000 €	91 €
HQ 100	1,6	1	1		3		11.000 €	32 €
								146 €

Tab.: Calculation of flood damages for Buchhofen

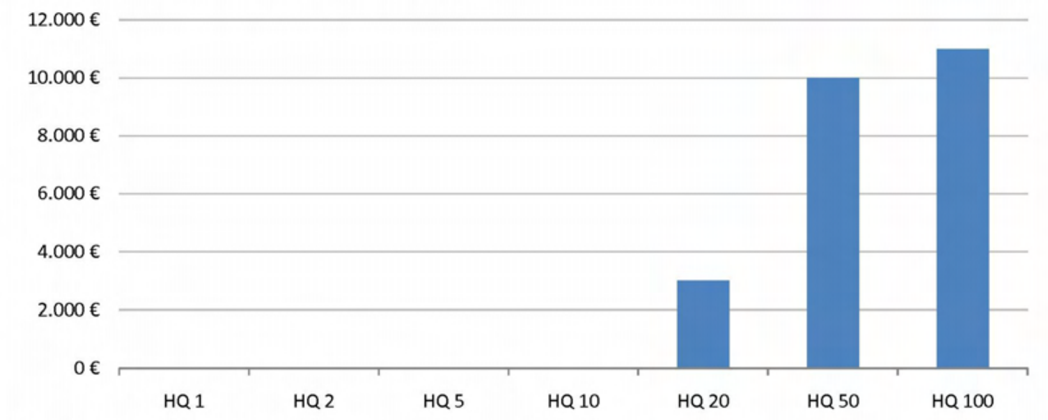

Fig.: Total costs per event

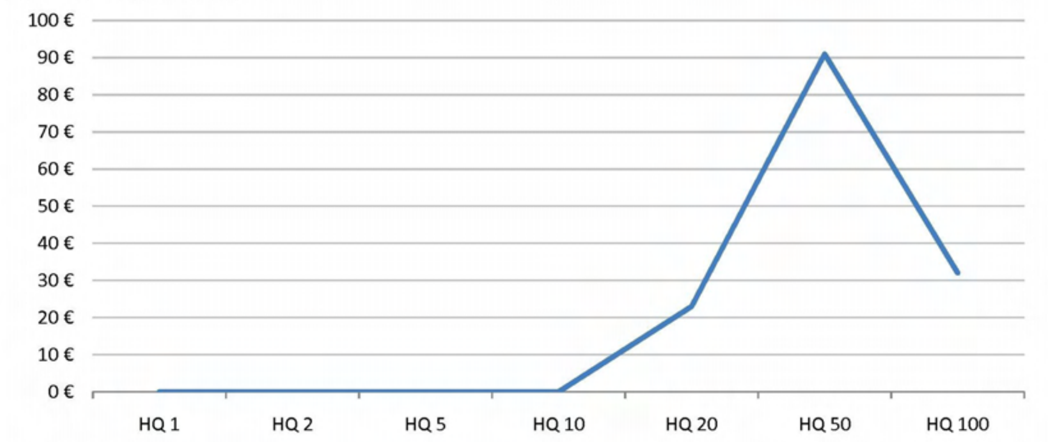

Fig.: Flood damage function

Figure A.51: Flood damages and damage function for Bachling Scenario C

Bachling Scen. D								
event	dis-charge in m³/s	residential house			other structures		Total costs per event	costs in €/a
		Base-ment	First floor					
			low	high	low	high		
HQ 1	0,3						0 €	0 €
HQ 2	0,5						0 €	0 €
HQ 5	0,8						0 €	0 €
HQ 10	1,1	1			1		3.000 €	100 €
HQ 20	1,5	1	1		1		9.000 €	180 €
HQ 50	1,9	1	1		2		10.000 €	133 €
HQ 100	2,3	1		1	2	1	16.000 €	78 €
								491 €

Tab.: Calculation of flood damages for Buchhofen

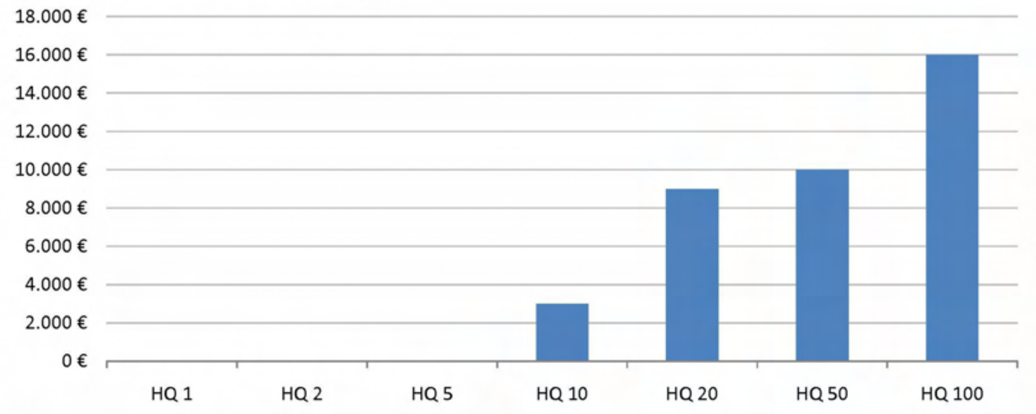

Fig.: Total costs per event

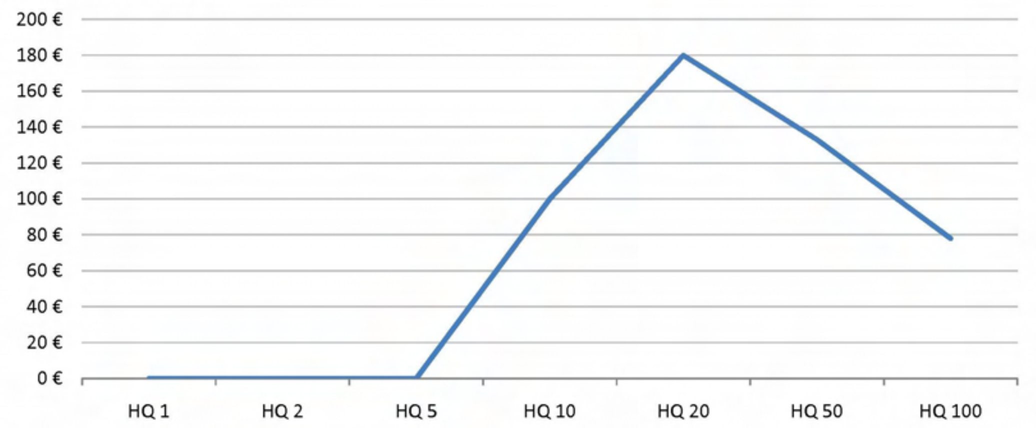

Fig.: Flood damage function

Figure A.52: Flood damages and damage function for Bachling Scenario D

Buchhofen

Buchhofen Scen. A								
event	dis-charge in m³/s	residential house			other structures		Total costs per event	costs in €/a
		Base-ment	First floor					
			low	high	low	high		
HQ 1	2,6						0 €	0 €
HQ 2	3,6	11	10		26		108.000 €	40.500 €
HQ 5	5,9	23	17		41		189.000 €	119.500 €
HQ 10	8,2	37	29	5	49	9	369.000 €	96.300 €
HQ 20	10,7	42	34	8	58	9	445.000 €	76.300 €
HQ 50	13,9	44	32	9	60	19	478.000 €	51.700 €
HQ 100	16,6	46	35	11	62	20	523.000 €	20.300 €
								404.600 €

Tab.: Calculation of flood damages for Buchhofen

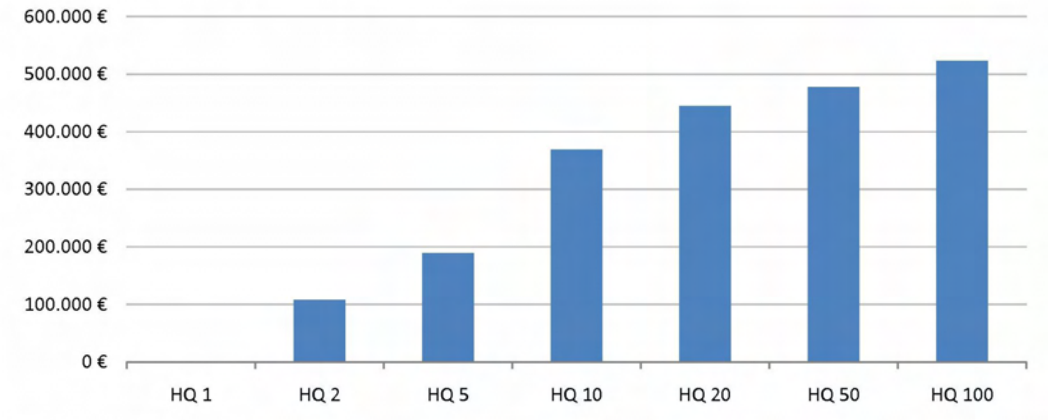

Fig.: Total costs per event

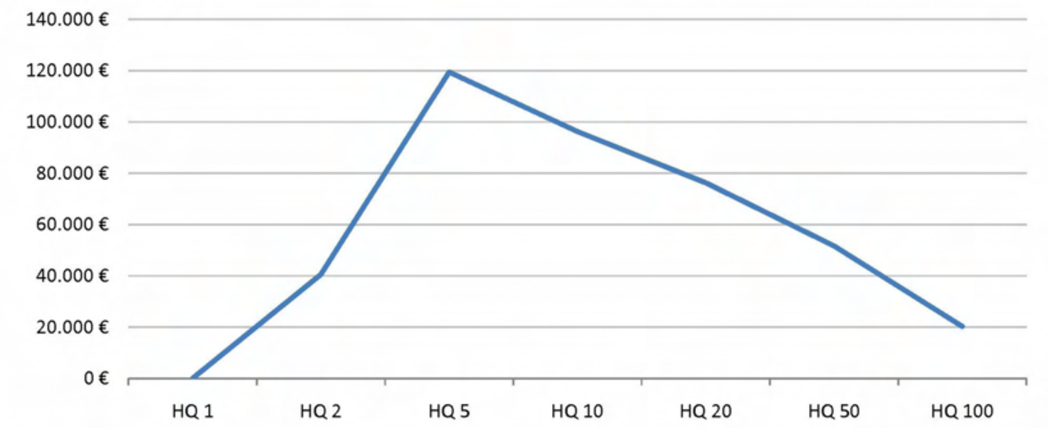

Fig.: Flood damage function

Figure A.53: Flood damages and damage function for Buchhofen Scenario A

Buchhofen Scen. B								
event	dis-charge in m³/s	residential house			other structures		Total costs per event	costs in €/a
		Base-ment	First floor					
			low	high	low	high		
HQ 1	2,4						0 €	0 €
HQ 2	3,3	11	9	1	17	4	114.000 €	38.500 €
HQ 5	5,5	20	15	4	30	7	217.000 €	127.400 €
HQ 10	7,7	35	25	6	45	10	349.000 €	93.400 €
HQ 20	10	42	33	7	53	13	437.000 €	67.800 €
HQ 50	11,4	43	35	8	53	16	469.000 €	22.200 €
HQ 100	12,9	44	35	9	58	18	491.000 €	10.800 €
								360.100 €

Tab.: Calculation of flood damages for Buchhofen

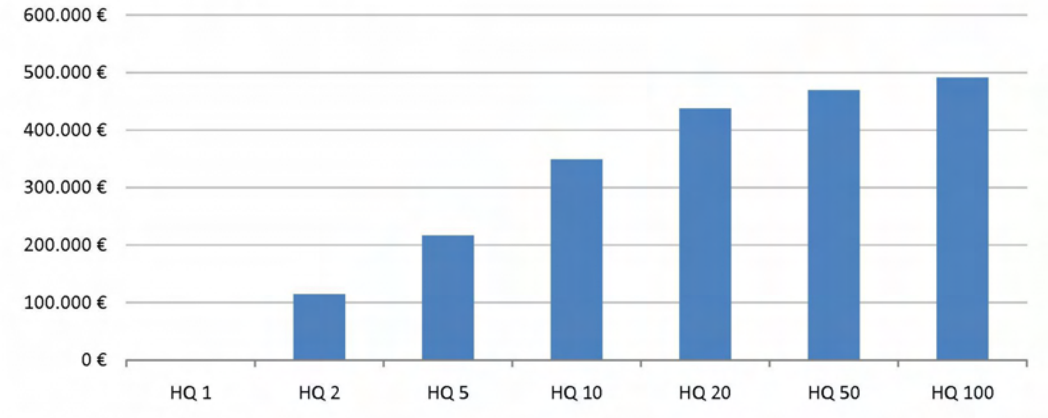

Fig.: Total costs per event

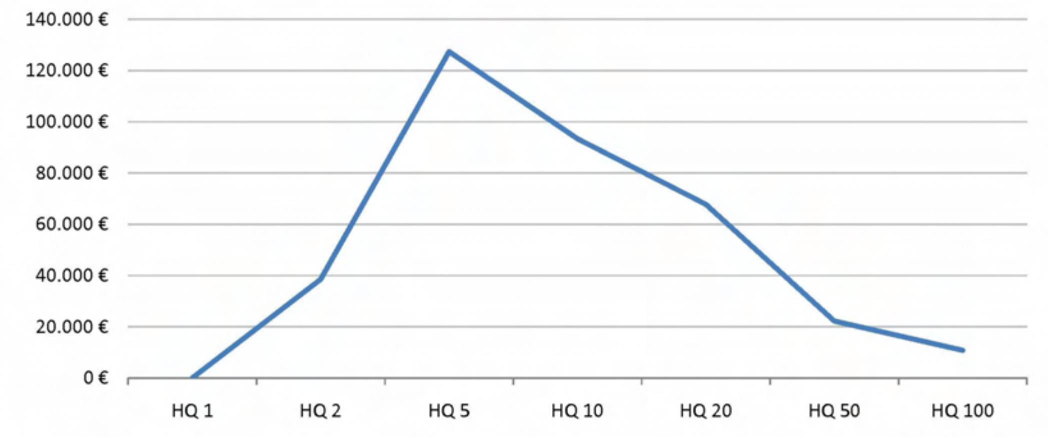

Fig.: Flood damage function

Figure A.54: Flood damages and damage function for Buchhofen Scenario B

Buchhofen Scen. C								
event	dis-charge in m³/s	residential house			other structures		Total costs per event	costs in €/a
		Base-ment	First floor					
			low	high	low	high		
HQ 1	1,4						0 €	0 €
HQ 2	2	5			9		19.000 €	4.300 €
HQ 5	3,3	11	9		21		97.000 €	26.400 €
HQ 10	4,6	14	11	3	27	5	163.000 €	25.400 €
HQ 20	6,1	24	17	4	37	7	244.000 €	22.900 €
HQ 50	8,1	37	29	8	49	9	396.000 €	22.400 €
HQ 100	9,8	41	33	7	53	12	432.000 €	10.600 €
								112.000 €

Tab.: Calculation of flood damages for Buchhofen

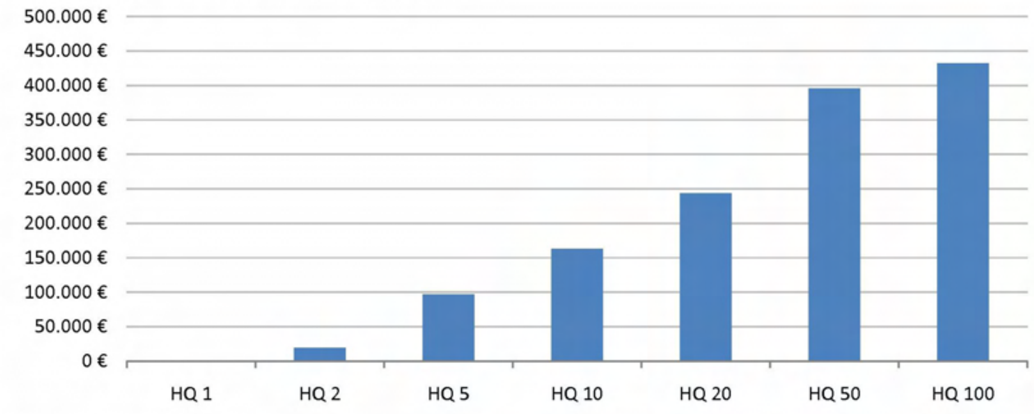

Fig.: Total costs per event

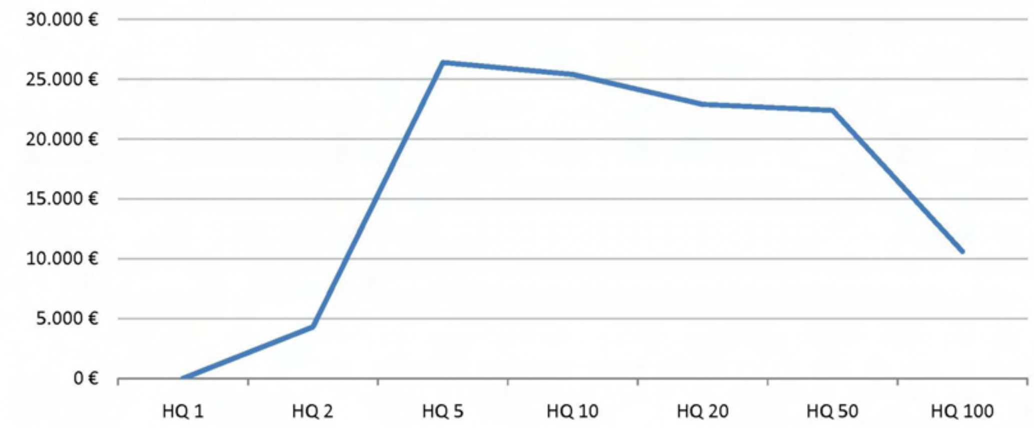

Fig.: Flood damage function

Figure A.55: Flood damages and damage function for Buchhofen Scenario C

Buchhofen Scen. D								
event	dis-charge in m³/s	residential house			other structures		Total costs per event	costs in €/a
		Base-ment	First floor					
			low	high	low	high		
HQ 1	2,4						0 €	0 €
HQ 2	3,3	11			21		43.000 €	14.500 €
HQ 5	5,2	18	14		36		156.000 €	66.200 €
HQ 10	7,2	34	23	4	55	8	321.000 €	71.600 €
HQ 20	9,3	40	32	7	61	8	420.000 €	58.400 €
HQ 50	12,1	44	30	9	54	18	457.000 €	43.000 €
HQ 100	14,6	44	32	10	61	19	488.000 €	17.700 €
								271.400 €

Tab.: Calculation of flood damages for Buchhofen

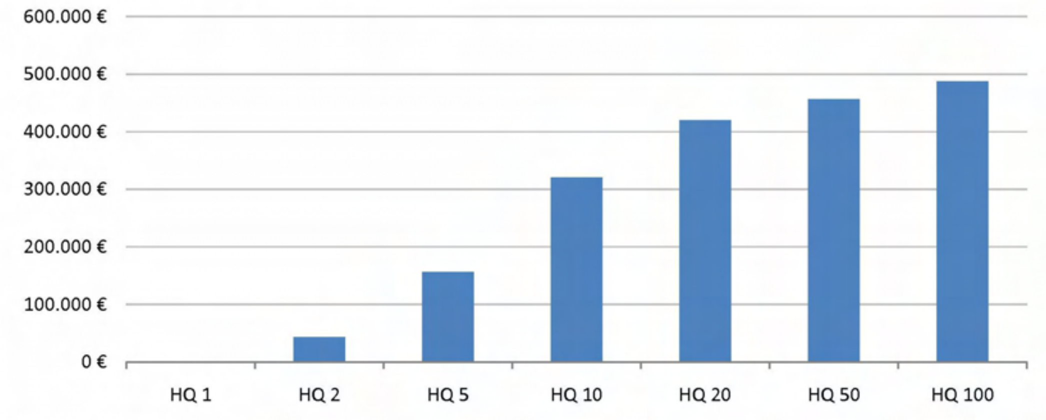

Fig.: Total costs per event

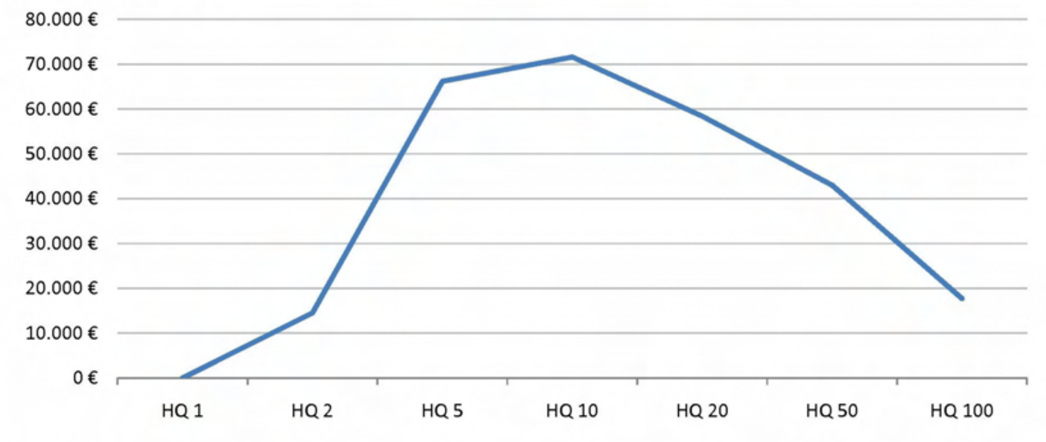

Fig.: Flood damage function

Figure A.56: Flood damages and damage function for Buchhofen Scenario D

Osterhofen

Osterhofen Scen. A								
event	dis-charge in m³/s	residential house			other structures		Total costs per event	costs in €/a
		Base-ment	First floor					
			low	high	low	high		
HQ 1	6,5						0 €	0 €
HQ 2	8,5	25	16		10		156.000 €	117.000 €
HQ 5	13,1	57	44	12	18	6	522.000 €	545.800 €
HQ 10	17,9	102	75	18	43	10	889.000 €	508.000 €
HQ 20	23,7	142	115	25	75	15	1.319.000 €	480.200 €
HQ 50	31,6	174	135	31	74	16	1.559.000 €	397.900 €
HQ 100	38,2	245	159	39	85	24	1.952.000 €	173.800 €
								2.222.700 €

Tab.: Calculation of flood damages for Buchhofen

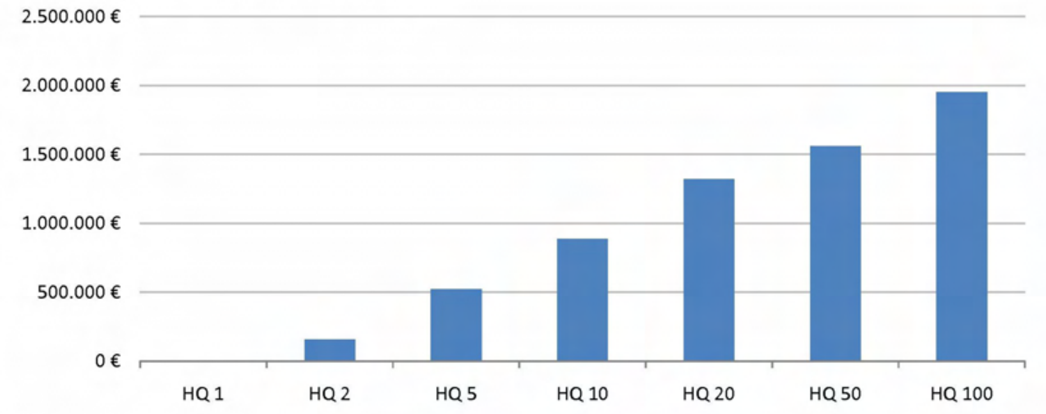

Fig.: Total costs per event

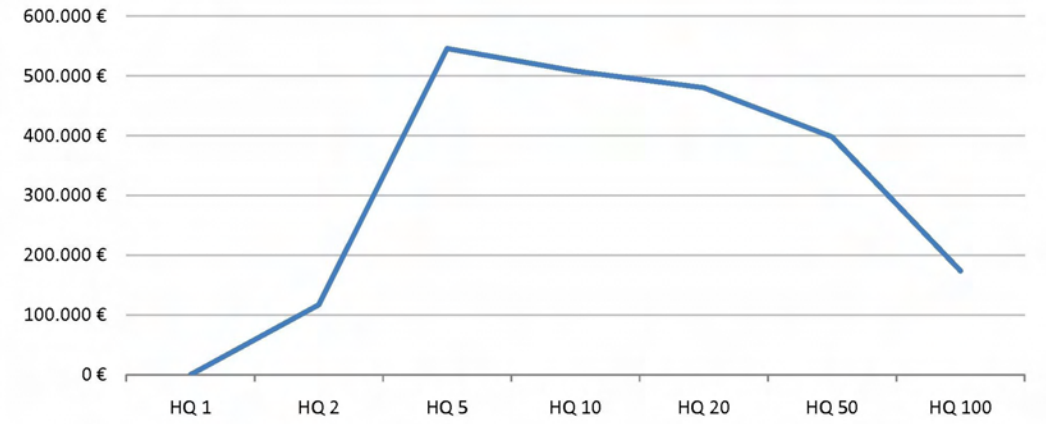

Fig.: Flood damage function

Figure A.57: Flood damages and damage function for Osterhofen Scenario A

Osterhofen Scen. B								
event	dis-charge in m³/s	residential house			other structures		Total costs per event	costs in €/a
		Base-ment	First floor					
			low	high	low	high		
HQ 1	6,1						0 €	0 €
HQ 2	7,8	21	12		10		124.000 €	79.100 €
HQ 5	12,2	44	34	10	16	5	413.000 €	413.500 €
HQ 10	16,6	89	71	15	35	9	801.000 €	400.600 €
HQ 20	21,9	134	105	21	45	14	1.174.000 €	392.500 €
HQ 50	26,7	144	117	25	61	15	1.321.000 €	209.600 €
HQ 100	29,4	159	120	27	70	15	1.396.000 €	55.000 €
								1.550.300 €

Tab.: Calculation of flood damages for Buchhofen

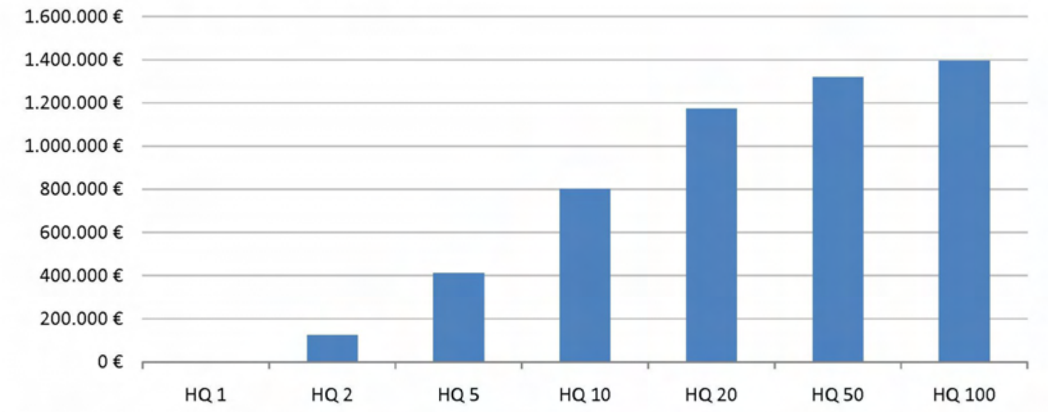

Fig.: Total costs per event

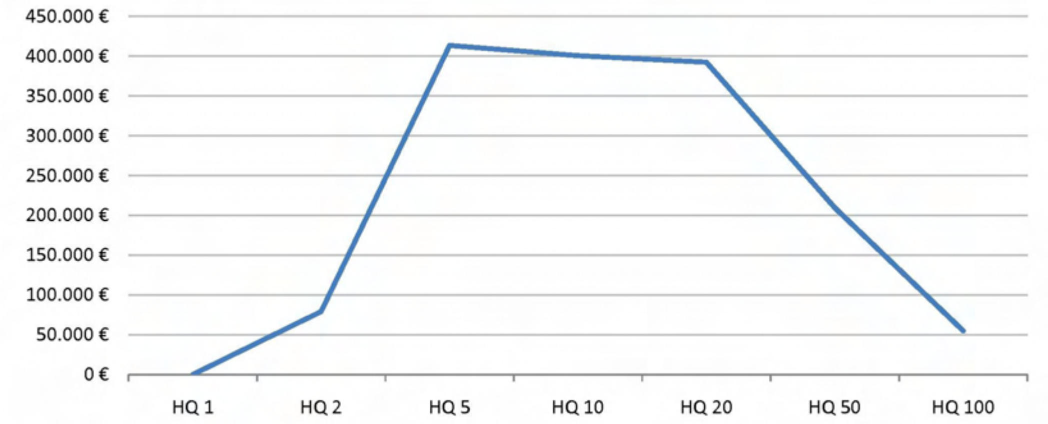

Fig.: Flood damage function

Figure A.58: Flood damages and damage function for Osterhofen Scenario B

Osterhofen Scen. C								
event	dis-charge in m³/s	residential house			other structures		Total costs per event	costs in €/a
		Base-ment	First floor					
			low	high	low	high		
HQ 1	3,4						0 €	0 €
HQ 2	4,7	9	3		3		39.000 €	19.000 €
HQ 5	7	16	7	9	10	3	174.000 €	85.700 €
HQ 10	9,1	38	29	9	21	3	361.000 €	84.300 €
HQ 20	11,7	48	38	10	24	5	453.000 €	79.400 €
HQ 50	15,8	88	70	15	34	9	792.000 €	89.300 €
HQ 100	19,3	123	93	17	42	13	1.038.000 €	48.000 €
								405.700 €

Tab.: Calculation of flood damages for Buchhofen

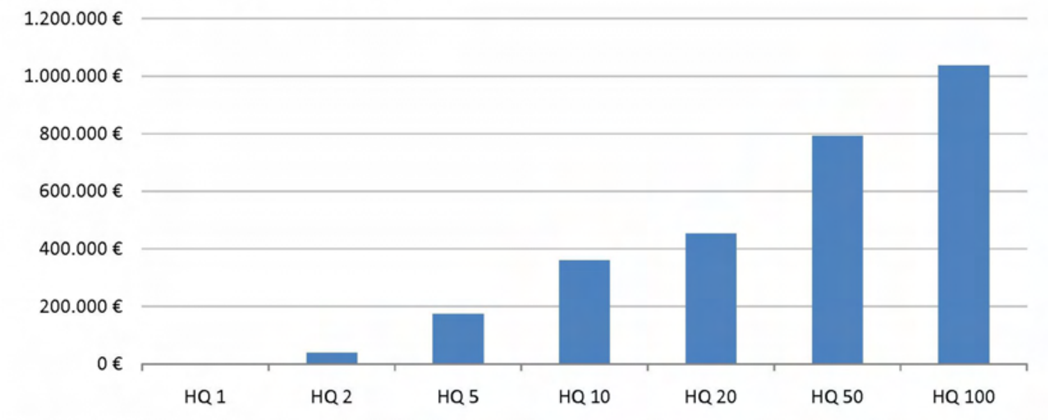

Fig.: Total costs per event

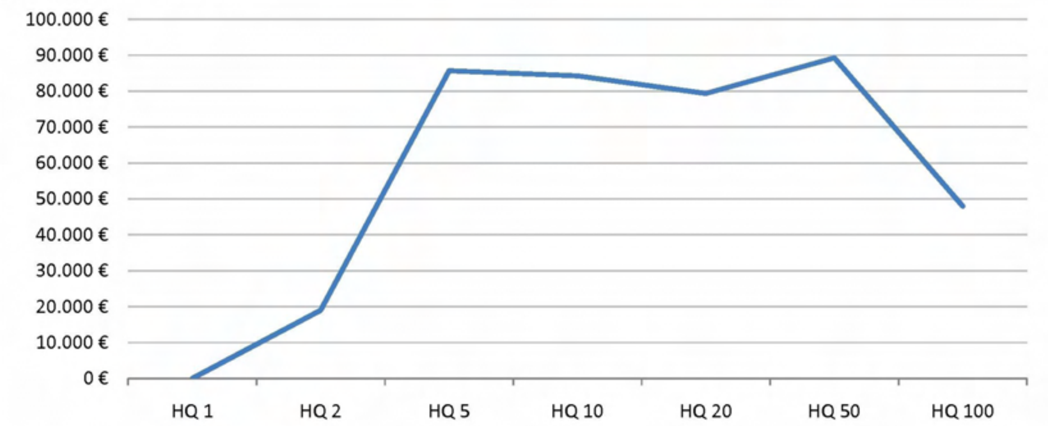

Fig.: Flood damage function

Figure A.59: Flood damages and damage function for Osterhofen Scenario C

Osterhofen Scen. D								
event	dis-charge in m³/s	residential house			other structures		Total costs per event	costs in €/a
		Base-ment	First floor					
			low	high	low	high		
HQ 1	6						0 €	0 €
HQ 2	7,6	18	9		10		100.000 €	60.000 €
HQ 5	11,3	43	31	10	13	5	390.000 €	317.300 €
HQ 10	14,7	72	55	15	28	9	664.000 €	268.800 €
HQ 20	19	114	86	16	40	12	964.000 €	262.500 €
HQ 50	25,5	151	119	26	66	15	1.361.000 €	264.500 €
HQ 100	30,8	175	135	31	74	16	1.561.000 €	116.100 €
								1.289.200 €

Tab.: Calculation of flood damages for Buchhofen

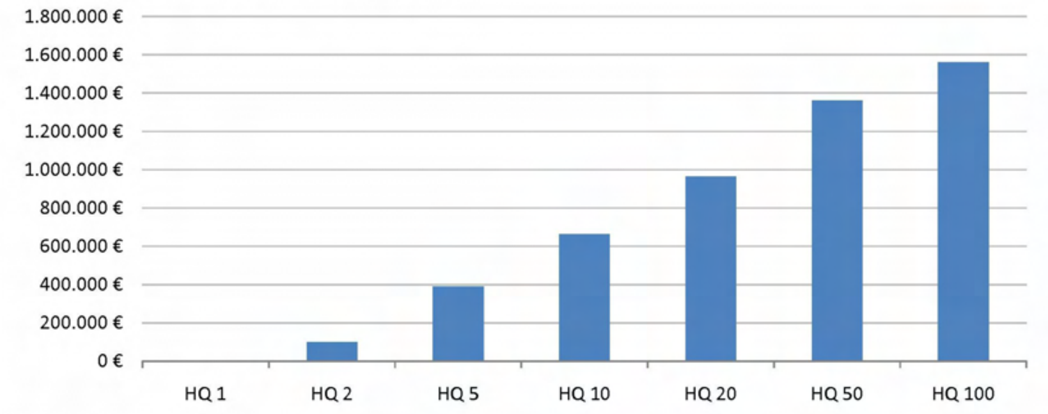

Fig.: Total costs per event

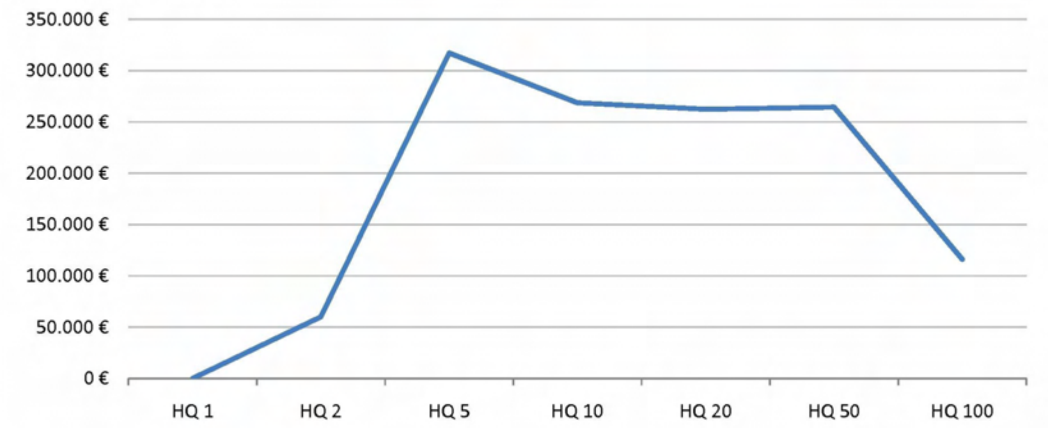

Fig.: Flood damage function

Figure A.60: Flood damages and damage function for Osterhofen Scenario D